Evaluation of Natural Green Infrastructure for Watershed Planning in the City of Atlanta

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ABSTRACT

Preservation of greenspace can provide a wide range of environmental, social, and economic benefits to the urban environment. The importance of green spaces such as urban forests, wetlands, and greenways is increasing because of the expansion of urban land. The City of Atlanta is committed to a resilient and sustainable future for its citizens. As a result, city leadership is embracing a more holistic approach to protecting water quality and watershed health, supplementing traditional gray infrastructure systems with innovative green infrastructure (GI) solutions to manage stormwater at its source. Atlanta's Department of Watershed Management (DWM) has a history of greenspace acquisition as a means to safeguard the City's waterways from the impacts of stormwater, creating a network of "natural green infrastructure (GI)." DWM has recently completed Watershed Improvement Plans (WIPs) to identify and prioritize engineered green infrastructure opportunities throughout the city. In an effort to expand the incorporation of natural GI into this watershed planning process, DWM has subsequently developed a Preservation Toolset which includes: a Preservation Evaluation Tool used to assign an evaluation score to a particular area of preservation or restoration interest, and a watershed model used to understand the water quality benefits provided by natural GI and the City's tree canopy.

KEYWORDS

Green Infrastructure, Watershed Planning, Preservation, Runoff Reduction, i-Tree Hydro, Urban Forests

INTRODUCTION

Atlanta is known as the city in the forest, with nearly 50% of its land area covered in trees (Giarrusso and Smith 2014), but a recent report from the U.S. Forest Service shows Georgia is leading the nation in tree loss (Nowak and Greenfield 2018). Between 2009 and 2014, Georgia lost an average of 18,000 acres of urban tree cover per year, and rapid urban development is likely the largest driver within the City limits. The Atlanta metro area has a population of over 5.8 million people and, according to U.S. Census estimates, saw the third highest population gain of any metro area in the country between 2016 and 2017 (U.S. Census Bureau 2018). Metro Atlanta is expected to grow by nearly fifty percent over the next two decades, with the City itself tripling its population during that time period [from 465,000 to 1.2 million], reflecting a national trend of re-urbanization (ARC 2016). The Atlanta City Design (COA 2017) states that "between July 2016 and July 2017, the city of Atlanta permitted more than $4 billion in construction: more than any other 12 months in the city's history."

Increasing development goes hand in hand with an increase in impervious areas, which prevents infiltration of rainfall and generates stormwater runoff that is known to have adverse impacts on water quality, aquatic habitat, and physical hydrologic processes (Grimm et al. 2008). The loss of green spaces such as urban forests and wetlands also means a loss of critical ecosystem services. In addition to naturally filtering pollutants from stormwater runoff and mitigating sedimentation, erosion, and flooding, forested green spaces provide benefits such as keeping cities cool and improving air quality (Nowak et al 2007).

To combat the impacts of urbanization, the City of Atlanta is advancing the use of green infrastructure to address flooding and water quality concerns, while providing added environmental, economic, and social benefits (CNT 2010). Broadly stated, green infrastructure (GI) is a collection of natural lands, working landscapes, open spaces, street trees, and engineered practices that provides benefits to human populations, including improving air and water quality, mitigating climate extremes, supporting biodiversity, and enhancing public health and well-being. Applied in stormwater management, GI reduces the volume of polluted runoff entering our streams and pipe systems by conserving or replicating the natural drainage systems of undeveloped land. Guided by its Green Infrastructure Strategic Action Plan (COA 2017a), the City of Atlanta’s Department of Watershed Management (DWM) is implementing GI across city departments at a broad range of scales to strengthen the resiliency of Atlanta’s watersheds and communities in the face of rapid growth and climate change. Efforts fall into two categories: 1) incorporating engineered green infrastructure systems such as rain gardens, green roofs, permeable pavement, and cisterns in streetscapes, parks, and new private development; and 2) preserving and restoring a network of healthy forests, wetlands, and riparian buffers, collectively known as “natural green infrastructure.”

Benefits of Natural Green Infrastructure

Natural green infrastructure systems are an important and highly efficient contributor to water quality and watershed health. They also support biodiversity, improve air quality, and mitigate climate change and extreme heat. These combined ecosystem services can provide a significant economic value to communities (LIDC 2015), while also enhancing overall quality of life.

Intact, structurally diverse urban forests substantially reduce runoff rates and volumes through the combined effects of canopy interception, evapotranspiration, and improved infiltration (Berland et al 2017, CWP 2017). Natural GI slows and filters runoff, trapping sediments and pollutants before they reach waterways and allowing groundwater to recharge (Nowak et al. 2007). American Forests (2003) completed an analysis for Mecklenburg County, North Carolina that estimated that the existing tree canopy with 49 percent coverage reduced runoff by 11.3 million cubic meters (398 million cubic feet). In a similar study performed for Montgomery, Alabama, the existing tree canopy at 34 percent coverage provided 6.5 million cubic meters (227 million cubic feet) of runoff reduction (American Forest 2004). The value of the runoff reduction provided was estimated at $797 million for Mecklenburg County and $454 million for Montgomery.

Natural green infrastructure is a cost-effective investment. Nowak et al (2007) estimated that trees in Atlanta provide over 1,500 metric tons of pollution removal annually at a value of over $8 million dollars. In Prince George’s County, Maryland, the county’s forest and tree canopy improves air quality by removing more than 5,100 metric tons of air pollutants per year and absorbing 211,000 metric tons of carbon – services respectively worth $21 million and $16.6 million annually (LIDC 2015). The U.S. Forest Service examined the benefits and cost of trees in the Piedmont area of the United States and found that net annual benefits provided per tree ranged from $31 to $112 per year (USDA 2006). Also, proximity to greenspace and tree coverage can enhance property values. In Atlanta, homes with trees cost 5-20 percent higher than those without (Georgia Forestry Commission 2018).

In addition, green spaces have been shown to promote recreation and add value to communities. The EPA EnviroAtlas cites several studies demonstrating the positive correlation between green spaces and recreation (EPA 2018). People who live close to green space visit them more frequently and thus increase their time spent in physical activity, both at the green space itself and walking or biking to the area instead of driving.

Program Background

DWM presently owns and manages 1,900+ acres of permanently protected Greenway and Greenspace properties. The majority of these lands (±160 properties) were purchased in fee simple or via easement between 2001 and 2007 under the City of Atlanta's Greenway Acquisition Project, in accordance with the 1998 Combined Sewer Overflow (CSO) Consent Decree, to preserve streamside buffers that protect water quality and reduce erosion. Others were acquired for flood mitigation or infrastructure projects. DWM's Greenway management staff currently monitors and oversees maintenance of all the properties in the existing inventory.

Recently, DWM has completed Watershed Improvement Plans (WIPs) for all ten of the City's watershed planning units. The goal of the plans is to improve water quality, biotic integrity, and habitat of streams and watersheds. The WIPs assess watershed conditions and identify the most cost-effective stormwater management projects by modeling cumulative impacts on water quality and evaluating associated environmental, social, and economic criteria. Projects are also weighted based on factors affecting implementation feasibility, such as land control. Presently, the WIPs focus on opportunities for engineered green infrastructure (GI) practices as well as stream restoration projects and new or retrofit stormwater control measures that will help attain water quality standards, providing a multi-year road map of projects for DWM's green infrastructure program.

Moving forward, DWM's natural green infrastructure program will capitalize on both of these efforts. DWM is looking to strategically expand and improve its Natural GI network through land preservation and ecosystem restoration opportunities and natural resource management techniques that are cost-effective and have measurable value. As such, DWM needs a framework for identifying, evaluating, and prioritizing potential natural GI, in the same manner as it does for engineered stormwater practices. By quantifying the co-benefits of forest preservation and restoration, DWM can track the contribution of these measures toward meeting the goals of its green infrastructure program.

To attain this objective, DWM decided to expand the focus of the WIPs to examine the watershed protection value of forested land and evaluate strategic opportunities to expand its network of greenspaces that will support and enhance existing gray and green infrastructure investments and minimize financial and management burdens. DWM developed a Preservation Toolset by applying an approach similar to that used in the WIPs to assess the individual value and cumulative benefits of potential projects.

METHODOLOGY

DWM's Watershed Improvement Plans (WIPs) employ a two-part methodology to evaluate the benefits of engineered GI, consisting of: 1. Individual project assessment, and 2. Watershed level assessment. In the first, each identified project is assigned a project evaluation score based on the summation of eight weighted scoring criteria with a maximum score of 50. The second assessment consists of a planning-level water quality model that examines the benefits provided to the entire watershed by implementing various groupings of projects. As a result, all projects in the WIPs have an individual evaluation score and are also included in overall watershed modeling to understand the cumulative benefits of all identified projects.

DWM has developed a Preservation Toolset that implements a similar two-pronged assessment methodology with a focus on greenspace acquisition or restoration. The Preservation Toolset includes:

1. The Preservation Evaluation Tool
2. i-Tree Hydro Watershed Model

The first component of the Preservation Toolset is the Preservation Evaluation Tool which is a methodology for quantifying the relative value of acquiring an area of interest for protection and/or restoration. The second component of the Toolset uses a hydrology model called i-Tree Hydro to evaluate the benefits provided by natural GI in the South River Watershed, one of the City's ten watershed planning units.

Preservation Evaluation Tool

The goal of the evaluation methodology is to provide the City with an objective way to measure and compare areas of interest for preservation and reforestation of urban areas. The evaluation focuses primarily on water quality protection, while also taking into consideration management costs and efforts. The first step in the development of the evaluation methodology was a literature review. Due to the large amount of material on this topic the literature review was not comprehensive but included a wide range of academic and agency articles along with a review of many existing methods for assessing preservation benefits.

Several studies reviewed examined the relationship between water quality and watershed characteristics (Coles et al 2010, Goetz et al. 2003, Matteo et al 2006, Riva-Murry et al. 2010, and USGS 2003). The parameter most prevalent across these and other studies and tools reviewed was impervious cover; however, other parameters that also aligned with the preservation evaluation assessment included tree coverage, riparian buffers, and forest patch size and configuration metrics. The literature review provided a scientific basis to develop a tool for evaluation of potential preservation parcel(s) with a focus on water quality benefits.

Through the literature review and team discussions, evaluation criteria were selected, and point values and weighting factors assigned for each. The evaluation scoring was divided into six primary parameters (Table 1) and six additional considerations (Table 2). The six primary parameters have a total maximum score of 50 and the six additional consideration include physical features and practical factors that may increase the total score to 60. The primary parameters focus on water quality benefits provided by preservation of the parcel of interest while the additional considerations include co-benefits derived from the protection of sensitive areas such as steep slopes, wetlands, and floodplains, as well as financial criteria such as cost sharing potential, maintenance needs, and proximity to other DWM property.

Table 1. Primary Parameters for Preservation Evaluation

Parameter	Score				Weighting Factor	Score Range
	0	**1**	**3**	**5**		
Impervious Cover	>20% of parcel(s) size	10-20% of parcel(s) size	5-10% of parcel(s) size	<5% of parcel(s) size	**2**	**0-10**
% Tree cover in riparian buffer	No 75-foot stream buffer on parcel(s)	<33% tree coverage within the 75-foot buffer	33-66% tree coverage within the 75-foot buffer	>66% tree coverage within the 75-foot buffer	**0.75**	**0-3.75**
% Tree cover	Less than 25% forested cover on parcel(s)	25-50% tree cover	50-75% tree cover	>75% tree cover	**2.25**	**0-11.25**
Distance to stream	Closest stream >1,000 feet away	Closest stream 500-1,000 feet away	Closest stream 200-500 feet away	Closest stream ≤200 feet away	**1**	**0-5**
Location in the watershed	Parcel(s) size <1% of upstream watershed area	Parcel(s) size 1-5% of upstream watershed area	Parcel(s) size 5-10% of upstream watershed area	Parcel(s) size >10% of upstream watershed area	**2**	**0-10**
Forest patch size	no-small forest patch (0-25% size quartile)	small-medium forest patch (25-50% size quartile)	medium-large forest patch (50-75% size quartile)	large forest patch (75-100% - size quartile)	**2**	**0-10**
				Total Score		**0-50**

Table 2. Additional Considerations for Preservation Evaluation

		Score Adjustment		
100-yr FEMA floodplain on the parcel(s)?		**Yes = +1**		**No = +0**
Wetlands on the parcel(s)?		**Yes = +1**		**No = +0**
Parcel(s) average slope ≥12%?		**Yes = +1**		**No = +0**
Cost-sharing opportunity with another partner?		**Yes = +1**		**No = +0**
Maintenance needs: Low/High		**Low = +1**		**High = +0**
	Adjacent	**< 0.15 miles away**	**0.15-0.25 miles away**	**>0.25 miles away**
Distance from parcel(s) to existing park or greenspace.	+5	+3	+1	+0

The Preservation Evaluation Tool consists of two components: an Excel interface and a GIS interface. These two components are used in conjunction with one another to calculate a preservation evaluation score for selected parcel(s) or area(s) of interest. The GIS interface is used to perform spatial analysis (Figure 1) and includes the city-wide spatial datasets needed for the assessment. The Excel interface (Figure 2) is used to document and compile the results of the analysis and assign a preservation evaluation score. A parcel can be evaluated based on its existing condition, i.e., for preservation value, *or* based on a proposed restored condition.

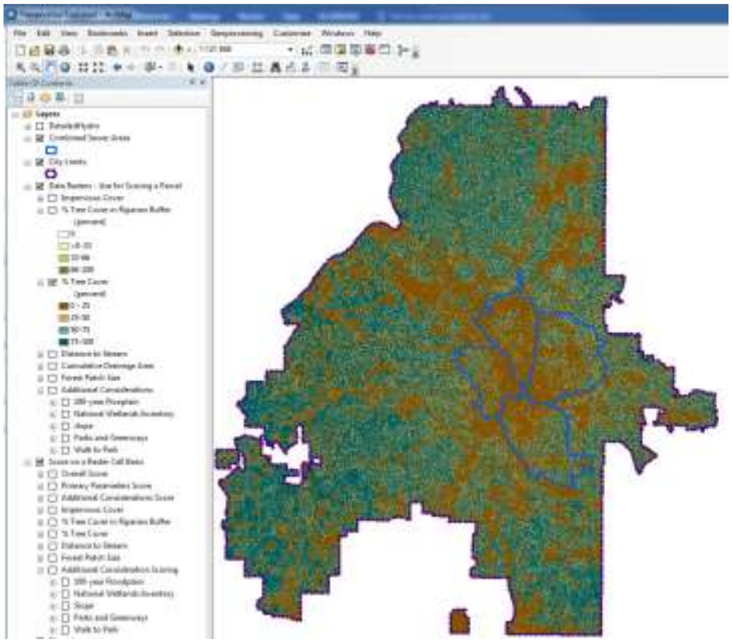


Figure 1. GIS Interface of the Preservation Evaluation Tool

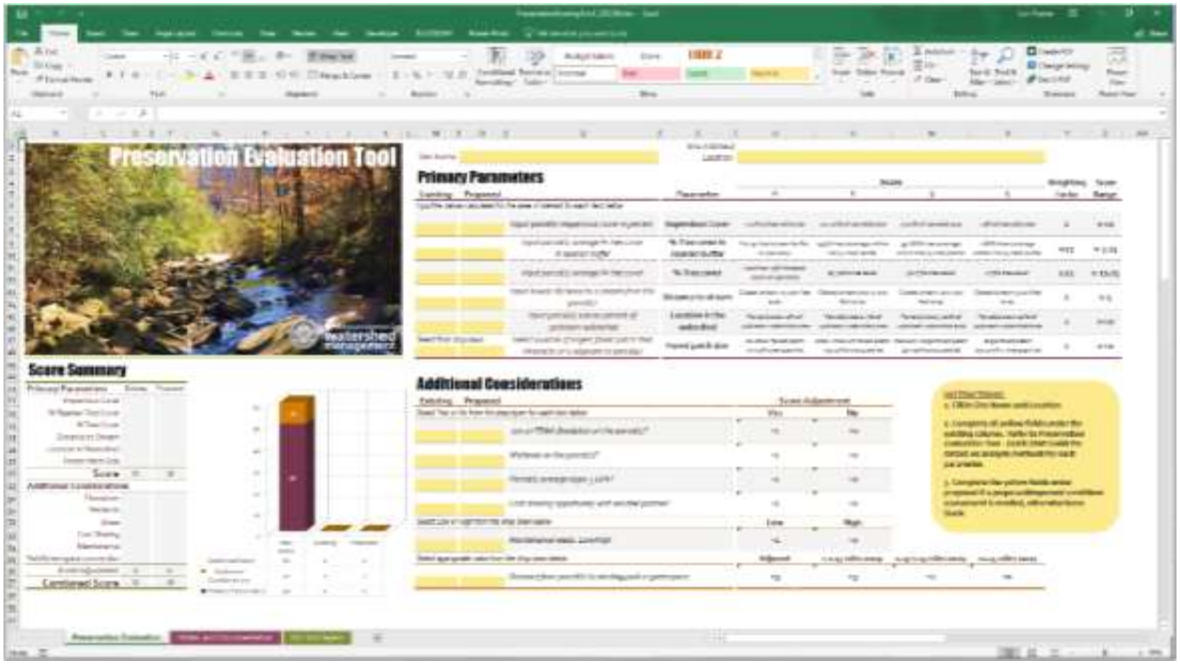
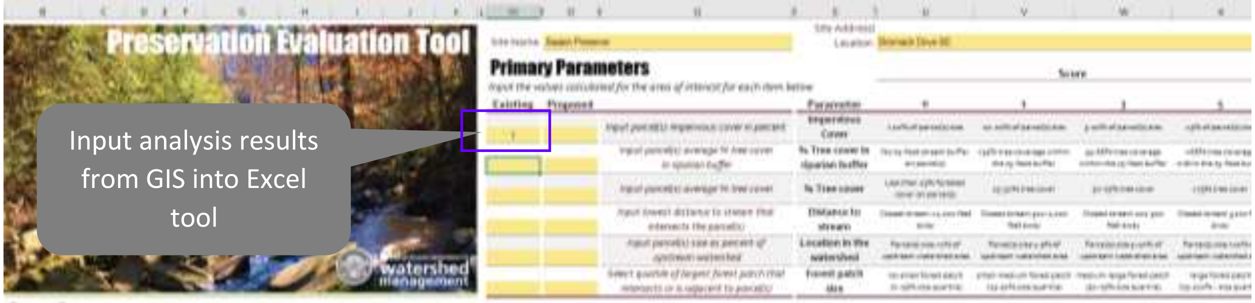


Figure 2. Excel Interface of the Preservation Evaluation Tool

The user begins the analysis process by generating a single polygon for the area to be evaluated. This polygon is used in the GIS interface to determine the inputs for each of the Primary Parameters and Additional Considerations. Both the GIS and Excel interfaces are set up in the same order with Primary Parameters followed by Additional Consideration. The user starts at the first Primary Parameter and works downward to the last Additional Consideration. Each of these inputs requires a spatial analysis function using the data provided in the GIS interface. The specific analysis methods used in GIS are detailed in the Preservation Evaluation Tool Users Guide (BC 2019). As the analysis is completed in GIS, the appropriate input is added to the Excel Interface (Figure 3).



Input analysis results from GIS into Excel tool

Figure 3. Add GIS Analysis Results to Excel Interface.

The user may develop an evaluation score for the existing site conditions or a score for both the existing conditions and a proposed (improved/restored) condition. As shown in Figure 3, there is one column of input for the existing condition and one for the proposed. The proposed condition is based on hypothetical improvements to the site, e.g., reforestation. Some Primary Parameters, such as distance to the stream, would remain unchanged between existing and proposed conditions. However, other parameters such as impervious cover and tree cover may change for the proposed conditions. The user may document the basis for the proposed conditions inputs in the Notes and Documentation tab of the Excel Interface.

As the parameter inputs are completed, the Excel Tool automatically calculates the Preservation Evaluation Score for the project using the score range and weighting factors outlined in Tables 1 and 2. The resulting score is shown in tabular and graphical form on the lower left side of the Excel Interface.

i-Tree Hydro Watershed Model

The second component of the Preservation Toolset is the development of a watershed level model to understand the benefits provided by natural GI. Since modeling the entire city at once would be a significant initial undertaking, a demonstration watershed was selected. For this analysis the South River, one of the city's ten (10) watershed planning units, was selected as the demonstration watershed (Figure 4). Based on the results of this analysis similar watershed models may be developed for the remaining watershed planning units.

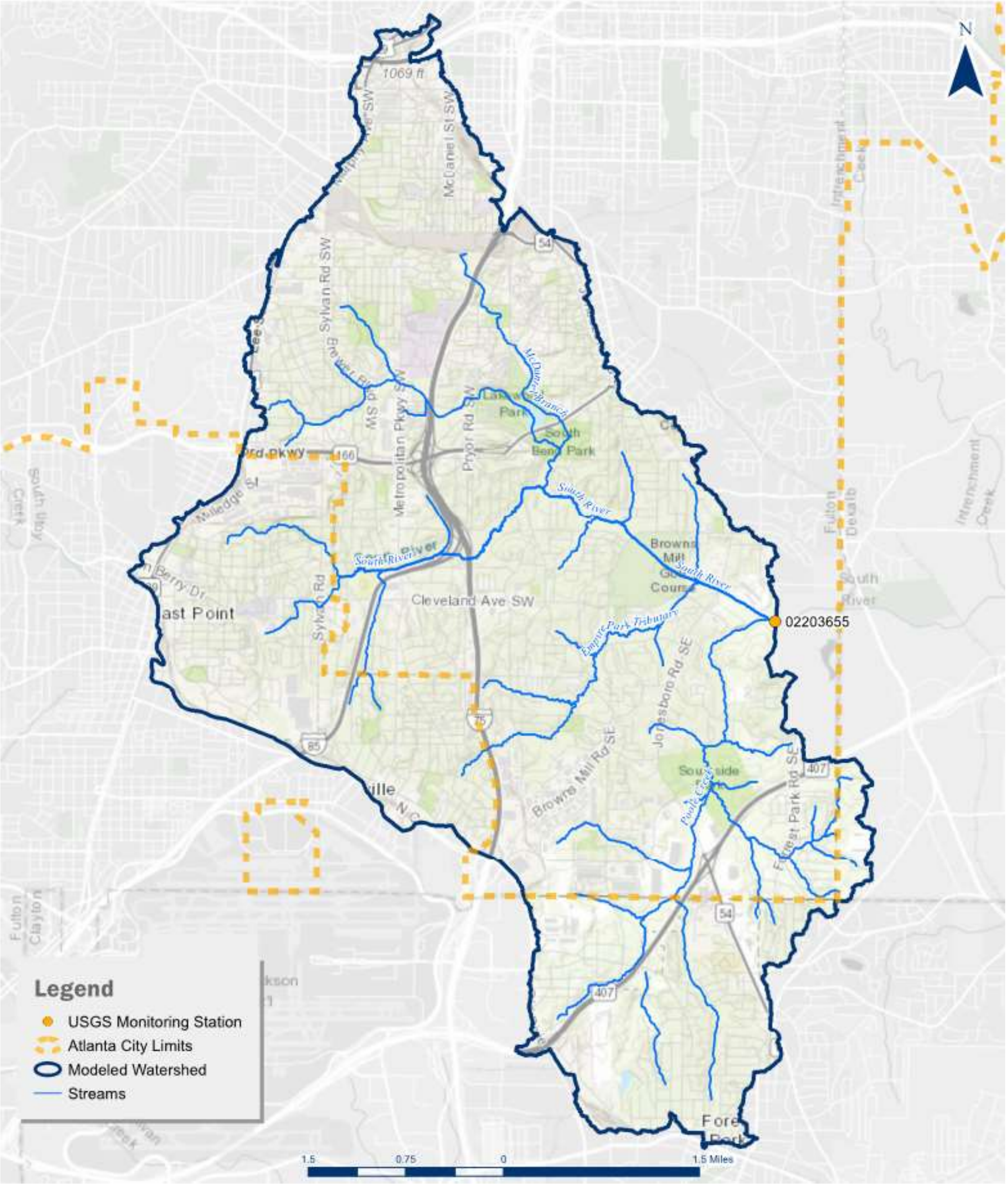


Figure 4. Modeled Watershed

The watershed level assessment of natural GI employs the i-Tree Hydro model, which was developed by the U. S. Department of Agriculture (USDA). It is a semi-distributed watershed model with a water-balance based analysis that includes specific parameterization of trees and vegetation. The model includes both water quantity and quality. For this analysis, three scenarios were examined to better understand the benefits of natural GI in the demonstration watershed:

- Scenario 1 Runoff Reduction Goal - total additional tree canopy coverage needed to meet target runoff reduction volumes.
- Scenario 2 Existing Greenspace Benefits - benefits provided by greenspaces already owned by the City in terms of runoff reduction.
- Scenario 3 Benefits of Existing Tree Canopy - avoided runoff provided by overall existing tree cover, i.e., potential impacts from loss of tree canopy and conversion to impervious surfaces.

The modeled watershed starts at the headwaters of South River and continues downstream to the USGS station 02203655 which covers 59.8 square kilometers (23.1 square miles) with 40.9 square kilometers (15.8 square miles) within the city limits (Figure 4). USGS Station 02203655 is located on South River near Forrest Park Road. Hourly flow data along some water quality data are collected at this site. Eight years of data (2005-2012) from this USGS station were used to calibrate and validate the model. In order to best represent an overall average condition, six years of data (2005-2010) were used for the baseline conditions and scenario analysis. While this time frame includes some dry and wet years, the six-year average was deemed the best representation of typical conditions. The calibrated model serves as the basis for comparison to understand watershed changes as a result of scenario implementation.

Model Development

i-Tree Hydro is one model in a series of models and tools developed by the USFS that are used to manage, understand, and analyze water quality, financial, and other benefits provided by trees. The tools are public domain and may be downloaded at www.itreetools.org. For this analysis, i-Tree Hydro version 5 was used. The i-Tree model works in a systematic manner starting with Step 1 and continuing to Step 5. Steps 1 through 3 are for model input parameters. Step 4 is only used if alternate or proposed scenarios are considered and may be skipped if these scenarios are not a part of the analysis. Step 5 runs the model.

Digital Elevation Model/Topographic Index

The watershed for the i-Tree Hydro model may be represented by a digital elevation model (DEM) or a topographic index (TI). The i-Tree Hydro model contains pre-loaded TIs that were developed from 30-meter DEMs (USDA 2016). However, the City of Atlanta's (COA) more detailed surface data was used for the model.

The DEM for the modeled watershed was developed from a DEM provided by COA combined with multiple DEMs downloaded from the National Map Viewer USGS website. The National Map is the National Elevation Dataset. The downloaded DEM has a 1/9 arc-second resolution (approximately 3 meters [m]). COA has a 0.6 m (2-foot) grid cell size and these more refined data were used for the portion of the modeled watershed within the city limits. The USGS data was used for modeled portions of the watershed outside of the city limits (portions of Fulton, DeKalb, and Clayton Counties). All source DEMs were re-sampled, or simplified, into a 6.1 m (20-foot) DEM, which match the grid cell size used for the Preservation Evaluation Tool.

The i-tree Hydro model requires that the DEM be clipped to the watershed boundary, projected into Universal Transverse Mercator (UTM) coordinate zone in meters, and converted to ASCII format.

The watershed boundary was developed using the Hydrology tool box in the Spatial Analysis Tools for ArcGIS with the USGS station 02203655 as the pour point (watershed outlet). This watershed boundary was used to extract the DEM for just the modeled watershed. This DEM was projected into UTM Zone 17N and converted to ASCII format to use in the i-Tree Hydro model.

Project Location

The project location information is completed by selecting the project location from a series of drop-down input boxes. The following were selected for this model:

- Nation: United States of America
- State: Georgia
- County: DeKalb
- City: Atlanta

It should be noted that DeKalb must be selected as the county. If Fulton is selected as the county, then Atlanta does not appear as an option in the city list.

Basic Watershed Characteristics

The inputs for basic watershed characteristics include and are derived as described below:

- Watershed Land Area (km^2) = 59.8
- Percent Tree Cover = 50.6
- Tree Leaf Area Index = 4.51
- Percent Evergreen Tree Cover = 33.9
- Percent Evergreen Shrub Cover = 26.6
- Start Date – 1/1/05 for calibration; 1/1/09 for validation
- End Date – 12/30/08 for calibration; 12/30/12 for validation

The watershed area was determined from the watershed boundary developed as part of extracting the DEM of the modeled watershed. The area of the watershed boundary is 23.1 square miles or 59.8 square kilometers.

The Georgia Forestry Commission assisted with the parameterization of the i-Tree Hydro model by using primarily i-Tree Canopy and i-Tree Eco to estimate several watershed parameters. The estimated percent tree cover is 50.6 percent. The tree leaf area index of 4.51 was estimated by the Forest Commission using 51 i-Tree Eco plots. The percent evergreen shrub and tree covered were also estimated by the Forest Commission.

The preprocessed data for stream flow and weather were split in two with the first half of the data being used for calibration (1/1/05 – 12/30/08) and the second half used for verification (1/1/09 – 12/30/12).

Observed Streamflow Data

i-Tree Hydro may be used to develop a model with or without calibration. However, if the model is calibrated, hourly stream data is required. Developing a dataset for this input can be quite time consuming since stream flow data may have occasional data gaps. As a result, the i-Tree Hydro team developed preprocessed hourly stream flow data from 1/1/2005 through 12/30/2012 for many USGS stations in the United States and this data is included with the model. For the observed stream flow data input, the preprocessed data for USGS station 02203655 was selected. This station includes a majority of the South River watershed within the city limits (Figure 4). This station is located a short distance upstream of where the city limits intersect the South River.

Weather Station Data

The required inputs for weather data include wind direction and speed, cloud ceiling, sky cover, temperature, dewpoint, altimeter setting, pressure, and hourly precipitation (USDA 2016). Similar to the stream flow data, the i-Tree Hydro team has developed preprocessed files of weather data. These data were obtained from the National Oceanic and Atmospheric Administration’s National Climate Data Center. The preprocessed weather data for Atlanta Municipal weather station ID 722190-13874 was selected for the modeled watershed.

Land Cover Parameters

The inputs for Step 2) Land Cover Parameters consist of surface cover types, cover type beneath trees, leaf area index, and directly connected impervious area (DCIA) (Table 3). The parameters were determined, as noted previously, by the Georgia Forestry Commission and verified based on available GIS data.

Table 3. Land Cover Parameters

Parameter	Model Input
Tree Cover (%)	50.6
Shrub Cover (%)	4.9
Herbaceous Cover (%)	14.1
Water Cover (%)	0.4
Impervious Cover (%)	27.6
Soil Cover (%)	2.4
Impervious Under Tree Canopy (%)	15.2
DCIA (%)	15.6
Shrub Leaf Area Index	2.2
Herbaceous Leaf Area Index	1.6

Hydrological Parameters

The hydrological parameters for the model include the soil, vegetation, and water conditions for the modeled watershed. Several of these parameters may be modified during model calibration. Table 4 includes a listing of the initial, auto-calibration, and manual calibration parameters used for this model. The number of decimal places shown in the table reflect that used by the model are not necessarily indicative of the accuracy of the parameters

Table 4. Hydrological Parameters

Parameter	Initial	Auto-calibration	Manual Calibration
Annual Average Flow of Project Area (cms)	0.53	0.6237	0.6237
Soil Type	Sandy Loam	Blended Texture	Blended Texture
Wetting Front Suction (m)	0.1110	0.3511	0.3511
Wetted Moisture Content (m)	0.2060	0.1000	0.1000
Surface Hydraulic Conductivity (cm/h)	1.0900	1.1701	1.1701
Depth of Root Zone (m)	0.05	0.0529	0.0529
Initial Soil Saturation Condition (%)	50	47.2606	47.2606
Leaf Transition Period (days)	28	28	28
Leaf on Day (day of year 1-365)	75	75	75
Leaf off Day (day of year 1-365)	311	311	311
Tree Bark Area Index	1.7	1.7	1.7
Shrub Bark Area Index	0.5	0.5	0.5
Leaf Storage (mm)	0.2	0.2	0.2
Pervious Depression Storage (mm)	1.0	1.1717	6.0
Impervious Depression Storage (mm)	2.5	2.7820	7.5
Scale Parameter of Power Function	2	2	2
Scale Parameter of Soil Transmissivity	0.023	0.0364	0.065
Transmissivity at Saturation (m^2/h)	0.13	0.0106	0.05
Unsaturated Zone Time Delay (h)	10	10	10
Soil Macropore Percentage (%)	0.0000001	0.0000001377	0.0000001377
Sub Surface Flow Routing: B (h)	1.0	0.9462	100
Time Constant for Surface Flow: Alpha (h)	1.0	0.3907	80
Time Constant for Surface Flow: Beta (h)	2.0	0.9577	10
Watershed area where rainfall rate can exceed infiltration rate (%)	65.0	65.0	50

Some of the initial model values were estimated based on watershed information referenced from the USGS and USDA. These include average annual flow and soil type. USGS average annual flow data for gage station 02203655 (modeled watershed outlet) for the years 2005-2008 were used for the initial estimate of the annual average flow.

The soil type was determined based summation of soil classifications for the modeled watershed that were obtained from the USDA National Resource Conservation Service (Web Soil Survey) GIS data. The most prevalent soil type in the model watershed is sandy loam (51 percent) which was selected for the initial soil type. However, large areas with soil classifications of Urban Land and Udorthents are also present in the watershed.

When the soil type is selected in the model, the values for the wetting front suction, wetted moisture content, and surface hydraulic conductivity are automatically filled in by the program based on the soil type selection.

For the remainder of the parameters listed in Table 4 the default values provided in the model were initially used. Table 4 also includes the parameter values from the auto-calibration and additional manual calibration that was performed.

Calibration and Validation

The i-Tree Hydro model may be calibrated in order to provide results that more closely match observed conditions. Calibration was performed for this analysis. Once the calibration was complete, the model was validated using another time period data set to determine how well the model performs using data other than that to which it was calibrated.

As previously described, preprocessed streamflow data are available from 1/1/2005 through 12/30/2012. This data was divided into two segments with the first half of the data (1/1/2005–12/30/2008) being used for the calibration and the second segment (1/1/2009–12/30/2012) used for the validation.

For this analysis the calibration and validation evaluation are based on comparison of 1) the stream discharge (modeled versus observed) and 2) the total volume of runoff (modeled versus observed). To understand the performance of the model discharge as compared to the observed stream discharge, two coefficients were used to assess the predictive capabilities of the model: Nash-Sutcliff efficiency (NSE) (Nash and Sutcliffe 1970) and Volumetric Efficiency (VE) (Criss and Winston 2008). The values for the NSE range from negative infinity to 1. A result of 1 means that the model exactly matches the observed data. One shortcoming often noted about the NSE is that it gives more weight to high flow values. In an effort to address this issue, Criss and Winston (2008) proposed the use of VE which uses the absolute value of the difference instead of squaring the difference of observed and modeled values in the coefficient calculation. Once again, a 1 value for the VE would mean that the model results exactly match the observed data. Lastly the total volume of runoff was compared using model output to perform the comparison. The model performance results using the initial input parameters (Table 4) are listed in Table 5.

Table 5. Model Performance Evaluation

Model	NSE	VE	Volume Difference
Initial Base Run	-13.18	-0.35	26% higher than observed
Auto-calibration	-1.66	0.08	20% lower than observed
Manual Calibration	0.34	0.40	0% difference
Validation	0.53	0.29	1% higher than observed

The i-Tree Hydro model includes an automated calibration option that uses the Parameter Estimation (PEST) routines to calibrate the model to observed discharge (Wang et al 2008). The auto-calibrated parameters were then used to complete a model run and the model performance results for this run are listed in Table 5. Both the NSE and VE are closer to 1 after the auto-calibration and the volume difference is less.

Manual model calibration builds on top of the auto-calibration and includes adjusting the hydrologic parameters in a systematic manner so that the model discharges more closely simulate observed discharges. The i-Tree User's Guide provides a range of acceptable values along with the default value for each of the hydrological parameters. Manual adjustments to parameters were made but did not go beyond the ranges established in the User's Guide. The manual calibration was an iterative process in which a single parameter was adjusted, the results evaluated, and then a different value of the same parameter or for another parameter was adjusted. For each of these adjustments the model performance evaluation factors were calculated. In addition, the results of each calibration run were graphed and reviewed to understand how modification to an input parameter affected the model discharge. Table 5 shows the resulting NSE and VE values following manual calibration along with the volume difference. Both flow assessment coefficients are closer to 1 and the volume difference decreased to zero percent.

To evaluate the calibration, a validation of the calibrated input parameters was performed. For the validation, the second range of flow and weather data (1/1/09 – 12/30/2012) were used along with the manually calibrated hydrologic parameters. The resulting performance evaluation factors for this model run are listed in Table 5. The evaluation metrics are comparable to the manual calibration, with the NSE being higher, the VE lower and the volume difference increase to one percent.

Scenario Analysis

Once an acceptable calibrated model was developed, i-Tree Hydro model was used to examine three different scenarios for the project area. These scenarios use the manually calibrated model as the starting point.

The time period used for establishing the baseline conditions and for conducting the scenario analysis is different than that used for calibration. The model time period for the scenario analysis is selected to represent an average precipitation condition. To determine an average precipitation condition, the entire time range and subsets to the time range of available model input were analyzed and compared to the long-term precipitation data available. Model precipitation input is available from 2005-2012.

The Atlanta airport records of precipitation have been maintained since the late 1920s and the average annual precipitation for the time period 1929-2018 is 49.37 inches (SERCC 2019). Years 2005-2010 were selected as the time frame for the scenario analysis. While this time frame includes some dry and wet years, the overall average is 49.29 inches. This is close to the overall average of the period of record for this station and was deemed the best representation of an overall average condition given the data set available

Baseline Conditions

The manually calibrated model using the 2005-2010 time frame serves as the baseline conditions for the scenario analysis. The resulting model performance evaluation factors for the baseline conditions model are listed in Table 6. The performance evaluation factors are very close to those calculated during manual calibration. Therefore, it was decided that the parameters developed during calibration are appropriate for the selected time frame and the scenario analysis.

Table 6 Baseline Model Performance Evaluation

Model	NSE	VE	Volume Difference
Baseline Conditions	0.45	0.39	3% higher than observed

Scenario 1 – Runoff Reduction Goal

The COA Green Infrastructure Strategic Action Plan has a goal to use GI to reduce runoff by 85l million liters (ML) (225 million gallons (MG)) on an annual basis (COA 2017a). Based on the analysis performed as part of the GI Strategic Action Plan, the COA generates about 2,419 ML (640 MG) of runoff from a single 2.5-cm (1-inch) storm. The goal of the Strategic Action Plan is to reduce the runoff by 1 percent for each 2.5-cm (1-inch) storm. This is equivalent to an annual reduction of 851 ML (225 MG) for the entire city.

To perform the analysis for this scenario, the portion of the runoff reduction goal that should be allocated to the modeled watershed was determined. The runoff reduction volume equation from the Georgia Stormwater Manual (AECOM et al. 2016) was used to calculate the amount of runoff generated from the portion of modeled watershed within the city limits for a 2.5 cm (1-inch) storm event. This area covers 40.9 square kilometers (15.8 square miles) with an average impervious cover of 35.5 percent resulting in a calculated runoff of 383.3 ML (101.4 MG) for a 2.5 cm (1-inch) storm event. This is approximately 16 percent of the entire city's 2.5 cm (1-inch storm) event. Sixteen percent of the annual goal of 851 ML (225 MG) runoff reduction equates to 134.9 ML (35.7 MG).

Scenario 1 examines modifications that may be made within the modeled watershed to reach the goal of an annual reduction of 134.9 ML (35.7 MG). For Scenarios 1a – 1c, a layered approach was taken in which one modification was made for the first scenario (Scenario 1a) and then another modification was added to the first scenario to develop the second (Scenario 1b) and so on. For Scenario 1a, the amount of tree coverage on the city-owned property was increased from 39.9 percent to 65.0 percent. It was assumed that the additional trees would be planted to have 15 percent impervious area under tree canopy similar to the rest of the modeled watershed. Scenario 1b adds to Scenario 1a. It includes the increase of tree coverage on the city-owned property from 39.9 percent to 65.0 percent and it also adds the increase of the tree coverage to city school properties from the existing tree coverage of 23 percent to 40 percent. For Scenario 1c, the additional reduction of the DCIA was examined. In addition to the increased tree cover on city-owned parks and school properties, the amount of DCIA was systematically reduced in the model and the results examined.

Through the analysis performed in Scenarios 1a and 1b, it was determined that additional tree coverage for the city properties (parks and schools) was not sufficient to reach the runoff reduction goal. As a result, Scenario 1d examined the amount of additional tree coverage on a watershed-wide basis that would be needed to meet the runoff reduction goal for this watershed. The tree cover amount was increased on an incremental basis, the impervious cover was adjusted to maintain the existing percent impervious cover under tree canopy, water cover was not adjusted, and the remaining cover types were adjusted proportionally. The model was re-run until the results indicated the goal was achieved.

Scenario 2 – Existing Greenspace Benefits

The South River modeled area has 12 existing greenway properties totaling 25.1 hectares (62 acres). The greenway properties cover 0.4 percent of the modeled watershed. In addition to greenways, the City has a range of parks, gardens, and conservation areas. Within the South River modeled area, there are 31 of these areas totaling approximately 326.2 hectares (806 acres). This represents 5.5 percent of the modeled watershed. Combined, the greenways and parks cover 5.9 percent of the modeled watershed.

Scenario 2 includes two evaluations (2a and 2b), one that examines the benefits provided by the existing greenways and one evaluating the benefits of all greenspaces (greenways and parks). For both scenarios, an alternative case was added to the i-Tree model which represents the watershed land surface cover if the greenspaces were developed; this provides an evaluation of their existing land cover benefit. It was assumed that the greenspaces would develop in a manner similar to the rest of the watershed or, specifically, the portion of the project area within the city limits. The average percent impervious for the portion of the study area within the city limits with the greenspace removed was calculated to be 37.8 percent; thus the developed greenspaces were assumed to also have a total of 37.8 percent impervious surface. The increase in impervious was taken from the tree cover and the ratio of the other cover types remained the same.

Scenario 3 – Benefits of Existing Tree Canopy

The conversion of tree coverage to impervious surface can have a significant impact on runoff volumes for a watershed. This scenario examines the benefits provided by the existing tree canopy by systematically replacing the tree cover with impervious cover. This scenario does not take into account the City’s post development stormwater ordinance requirements but simply looks at the impacts of the conversion of tree canopy to impervious cover.

The existing impervious cover for the modeled watershed is estimated as 27.6 percent with the portion within the city limits having 35.5 percent impervious cover. In this scenario, the impervious cover within city limits is increased and the land cover outside the city limits remains the same. The total impervious cover within the city limits was incrementally increased to 40, 45, 50, 55, and 60 percent. The increase was capped at 60 percent because increases beyond this are unlikely for a watershed area this size; the city's most developed watersheds do not exceed 50 percent cumulative impervious.

The increase in impervious acreage was added to the modeled watershed impervious cover and subtracted from the tree cover. The revised percentage of land cover was calculated for the modeled watershed. For typical development, the modification of watershed land cover includes a mix of cover type as opposed to the direct conversion of tree coverage to impervious cover. However, for simplicity and to better understand the relationship between the two variables, tree coverage was converted to impervious and the shrub, herbaceous, water, and soil cover percentages were not modified

RESULTS

Preservation Evaluation Tool

As part of the development of the Preservation Evaluation Tool, three sites were scored using the tool, including two existing preservation sites along with a potential site. For each of these sites, only the existing conditions were evaluated. In addition, several more sites have been scored since the draft tool was developed. An example of a completed preservation evaluation for a selected parcel is shown in Figure 5. The Figure includes (at top) images of the following GIS raster data inputs: a. aerial map of parcel boundary showing existing DWM greenways, b. % impervious, c. % tree cover in riparian buffer, d. % tree cover, e. distance from stream, f. cumulative drainage area, g. forest patch size (quartile), h. 100-year floodplain, i. wetlands, j. slope; and (bottom) the Excel interface with scoring matrix.

These evaluations gave insight into the practical application of the tool along with some shortcomings of the data set. Since several of the inputs are based on the stream GIS layer, locations where the stream is not shown in the GIS or is shown incorrectly will impact the score of a project. As a result, the User's Guide for the tool was updated to include a process to account for these situations.

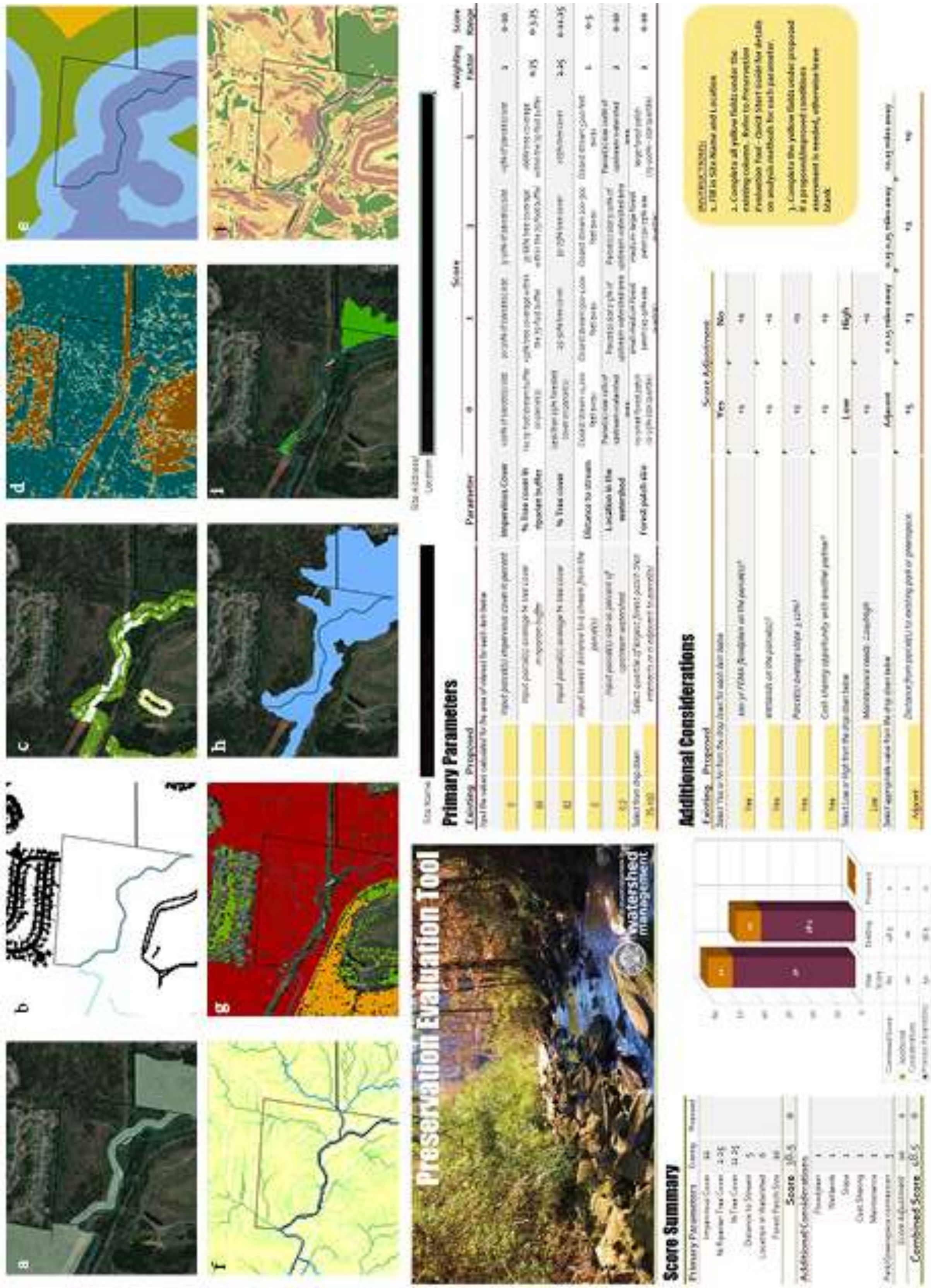


Figure 5. Example of a Completed Preservation Evaluation

iTree Hydro Watershed Model

Results of the three modeled scenarios are summarized in Table 7. A positive sign in front of the results equate to an increase in average annual runoff volume as compared to the baseline conditions model while a negative indicates a decrease in average annual runoff volume for the modeled watershed.

Scenario 1 – Runoff Reduction Goal

The Green Infrastructure Strategic Action Plan sets a goal to reduce runoff by 851 ML (225 MG) on an annual basis (COA 2017a). The proportion of this goal for the modeled section of the South River watershed is 134.9 ML (35.7 MG), based on the amount of runoff it generates from a 1-inch storm in proportion to the total runoff generated citywide (16%). Scenario 1 examines modifications that may be made within the modeled watershed to reach the goal of an annual reduction of 134.9 ML (35.7 MG). For Scenarios 1a – 1c a layered approach was taken in which one modification was made for the first scenario (Scenario 1a) and then another modification was added to the first scenario to develop the second (Scenario 1b) and so on in order to reach the desired runoff reduction goal. Scenario 1d is a separate standalone analysis. The results of each scenario are shown in Table 7.

For Scenario 1a, the amount of tree coverage on the city-owned property was increased from 39.9 percent to 65.0 percent, an increase of 121 hectares (300 ac.). Since the runoff reduction goal was not achieved, the next scenario, 1b, includes the changes made in 1a along with an increase in tree cover on City schools from 23.0 to 40.0 percent, which is an increase of almost 50 acres. Since the goal was not achieved by adding tree coverage to these city properties, Scenario 1c added a reduction in directly connected impervious area (DCIA) to previous scenario 1b. It was determined that the overall watershed DCIA would need to be reduced from 52 percent to 51 percent to achieve the runoff reduction goal. This is equivalent to disconnecting 20 acres of impervious area on city properties.

Through the analysis performed in Scenarios 1a and 1b, it was determined that adding tree coverage on city properties alone was not sufficient to reach the runoff reduction goal. As a result, Scenario 1d examined the amount of additional tree coverage on a watershed wide basis that would be needed to meet the runoff reduction goal. The tree cover amount was increased on an incremental basis. The final iteration of the model included an addition of 2,250 acres of tree canopy to the watershed which would result in meeting the runoff reduction goal.

Scenario 2 – Existing Greenspace Benefits

This scenario includes two components, one that examines the benefits provided by the existing DWM greenways and one that looks at the benefits of all greenspaces (greenways plus parks). For both, the model was modified to represent the watershed land surface cover if the greenspaces were developed. It was assumed that the greenspaces would develop in a manner similar to the rest of the watershed; specifically, the area within the city limits. Developing existing greenspaces increased runoff volumes for the watershed, as shown in Table 7.

Scenario 3 – Benefits of Existing Tree Canopy

Scenario 3 examines the benefits provided by the existing tree canopy by systematically replacing the tree cover with impervious cover. The existing impervious cover for the modeled watershed is estimated as 27.6 percent with the portion within the city limits having 35.5 percent impervious cover. In this scenario the impervious cover within city limits was incrementally increased and the land cover outside the city limits remained the same. Increased runoff resulting from the increases in impervious surface cover are shown in Table 7.

Table 7. Scenario Results for the South River Watershed

Scenario	Average Annual Runoff Volume Change	Percent change from Baseline	Percent of Runoff Reduction Goal
	ML (MG)	(%)	(%)
Scenario 1 – Runoff Reduction Goal			
1a – Additional tree coverage; City Property (65%)	-17.8 (-4.7)	-0.1	13
1b – Additional tree coverage; City property (65%) + City schools (40%)	-32.5 (-8.6)	-0.2	24
1c – Additional tree coverage; City property (65%) + City Schools (40%) + decrease DCIA (20 ac)	-139.1 (-36.8)	-0.9	103
1d – Tree Coverage Percent to Reach Goal	-138.7 (-36.7)	-0.9	103
Scenario 2 – Existing Greenspace Benefits			
2a - Greenways	+24.2 (+6.4)	+0.2	-
2b – Greenspace	+302.4 (+80.0)	+2.0	-
Scenario 3 – Runoff Benefits of Existing Tree Canopy			
40% City Impervious	+936 (+247.5)	+6.2	-
45% City Impervious	+1,930 (+510.6)	+12.9	-
50% City Impervious	+2,939 (+777.6)	+19.6	-
55% City Impervious	+3,949 (+1,044.8)	+26.4	-
60% City Impervious	+4,976 (+1,316.3)	+33.2	-

DISCUSSION AND CONCLUSION

DWM has developed the Preservation Toolset to provide an objective framework for incorporating natural GI into the watershed improvement planning process, on both a parcel-by-parcel basis and at the watershed scale. The Preservation Evaluation Tool, a multi-criteria spatial analysis of weighted parameters that impact water quality, along with additional management considerations, can be applied across the City and to date has been used to evaluate several parcels of interest. The tool is meant to guide DWM decision-making to achieve the "biggest bang for the buck" for watershed protection and to evaluate and compare acquisition opportunities on an as-needed basis. In the near term, DWM plans to use the tool to evaluate potential acquisitions related to specific funding programs, primarily external sources such as the Tree Trust Fund established under the City of Atlanta's Tree Ordinance. In the longer term, it can be used to pinpoint hot spots of preservation interest that would strategically expand DWM's existing Natural GI network and identify funding, as well as to prioritize areas for restoration in coordination with multiple local stakeholders.

As noted previously, the development of a watershed model for the entire city would be a significant undertaking. As a result, the South River was selected as a demonstration watershed for this analysis. The i-Tree Hydro model was used to simulate the South River watershed and quantify the benefits of natural GI, particularly tree canopy preservation. The model also shows how increasing tree canopy can meet the GI Strategic Action Plan runoff reduction goals. The modeling demonstrates that increasing tree canopy can reduce stormwater runoff, while reducing tree cover increases stormwater runoff volumes. In Scenario 1, the addition of trees on both city and school properties provided up to 24% of the runoff reduction goal for the South River watershed; disconnecting an additional 20 acres of impervious surfaces would meet the runoff reduction goal. Scenario 2 examined the benefits provided by existing greenways and greenspaces (greenways plus parks). If these areas were developed, the modeled runoff increased by 0.2 percent (24.2 ML or 6.4 MG) for the greenways and 2.0 percent (302.4 ML or 80.0 MG) for greenspaces. The existing benefit provided by the greenspaces is more than two times the runoff reduction goal, emphasizing the importance of these natural GI assets in attaining GI Action Plan goals. Lastly, Scenario 3 examined the increase in runoff as a result of converting tree coverage in the watershed to impervious surfaces. The amount of runoff increased from 6.2 percent (936 ML or 247.6 MG) to 33.2 percent (4,976 ML or 1,613.3 MG), showing a significant change if measures were not taken to provide runoff reduction as development occurs.

Based on the findings of this initial watershed analysis DWM is considering the development of models for additional watersheds with a significant acreage of protected and unprotected greenspaces and/or where substantial restoration opportunities exist. These models will help DWM quantify the benefits provided by natural GI and aid in developing strategies for incorporating natural GI into the watershed protection program. In general, the Preservation Toolset provides a standard and objective method to evaluate the City of Atlanta's natural green infrastructure and a quantifiable way to estimate the stormwater benefits it provides.

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