GIS and Green Infrastructure: Case Study in the Alley Creek Watershed and Sewershed, Queens, New York

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Introduction

In urban settings, stormwater runoff (precipitation flow over streets, parking lots, and roofs) finds its way into waterbodies in two ways: 1) municipal separate sewer systems (MS4s) and 2) combined sewer systems. MS4s collect sewage and stormwater in two separate pipes and only treat sewage before discharging.[1] Combined sewer systems collect and treat both sewage and stormwater into one pipe. Combined sewer overflows (CSOs) occur during periods of heavy rainfall, when runoff exceeds treatment capacity and untreated excess sewage and stormwater are discharged into the nearest receiving waterbody.[2] This untreated stormwater runoff from CSOs and MS4s causes water quality problems. Runoff from impervious surfaces can have a high velocity and entrain pollutants. For example, runoff flowing over roads can pick up oil and grease from cars. Redirecting flow away from sewer and storm drains and treating runoff through green infrastructure (GI) is one way of improving water quality.

In compliance with New York State's requirements to reduce CSOs, the NYC Department of Environmental Protection (NYCDEP) and the NYC Department of Parks and Recreation (NYCDPR) are building GI across NYC.[3] Efficacy of GI performance can be dependent on various factors, including location. This paper demonstrates how to use spatial analytics, specifically Geographic Information Systems (GIS), to identify GI locations in public lands within the Alley Creek watershed and sewershed (Study Area, see Figure 1) in Queens, New York. Of the various types of GI, NYCDPR is most interested, of the various types of GI, in rain gardens.

Figure 1. Study Area and public lands within

Rain gardens catch and detain runoff and allow for infiltration, evapotranspiration, and filtration.[4] Infiltration is the process by which water seeps into the ground – it slows down runoff velocity, diverts runoff away from the drains, and treats runoff through

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[1] http://water.epa.gov/polwaste/npdes/stormwater/Municipal-Separate-Storm-Sewer-System-MS4-Main-Page.cfm
[2] http://water.epa.gov/polwaste/npdes/cso/
[3] http://www.nyc.gov/html/dep/html/stormwater/nyc_green_infrastructure_plan.shtml
[4] http://www.phillywatersheds.org/what_were_doing/green_infrastructure/tools

pollutant removal.[5] Evapotranspiration (ET) is the process by which plant roots uptake water and transpire it through their leaves.[6] ET reduces the runoff flowing into the sewer systems by moving water into the atmosphere. Plant material and soils filter out pollutants in runoff through absorption, microbial degradation, and other processes.[7] Rain gardens are composed of flood-tolerant plants in the center and drought-tolerant plants on the outer edges growing on permeable soils.[8] This ensures infiltration and evapotranspiration in wet and dry seasons. Using plants with a wide range of inundation tolerances also ensures that rain gardens will stay vegetated and functional. Figure 2 shows how stormwater can be diverted and contained in rain gardens.

Figure 2. Rain garden

Placing rain gardens in the appropriate locations maximizes these benefits. This paper uses a two-tier method for choosing locations: biophysical and programmatic. Biophysical variables can include surface type, depth to groundwater, and the presence of bedrock. These variables determine whether locations are physically suitable to rain garden placement. Programmatic variables depend on the regional, management, regulatory, and political context. These can range from design objectives to management priorities. These variables were selected based on fieldwork, collaboration with local and regional stakeholders, and input from the Natural Resources Group (NRG) housed within NYCDPR.

This paper presents a set of GIS methods for identifying and prioritizing locations for rain garden placement within public lands in the Study Area (Figure 1). A customized GIS model was created to show locations that meet both biophysical and programmatic criteria. Locations that meet biophysical criteria are then ranked by priority depending on how many programmatic criteria were met. This research provides NRG and NYCDPR with a tool that can allow for a systematic and clear way to manage stormwater by using GIS for rain garden site selection.

Objectives

The objectives of this work are to:

1. Create an automated approach to selecting optimal rain garden locations for stormwater management within the Study Area; and
2. Understand the limitations of and the extent to which this process can be automated and replicated for use outside the Study Area.

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[5] http://stormwater.pca.state.mn.us/index.php/Overview_for_Infiltration_trench
[6] http://www.phillywatersheds.org/what_were_doing/green_infrastructure/tools
[7] http://www.pca.state.mn.us/index.php/view-document.html?gid=7733
[8] http://cfpub.epa.gov/npstbx/files/MassAudubonRGBrochure.pdf

Methodology

First, all biophysical and programmatic variables are determined. These are described below. Regionally specific variables chosen for the Study Area are described below.

Biophysical Variables:

1. Surface type: All land within the Study Area is not suitable for GI construction. Lands with existing uses cannot be built upon and are excluded from analysis. 'Buildable' lands are all public lands within the Study Area. The following types of land are designated 'non-buildable' and will be removed:
    - Programmed land: lands with existing uses (e.g. buildings, basketball courts, drinking fountains, etc.)
    - Roads
    - Open water
    - Marshland
    - Habitat
    - Canopy
2. Flow from impervious surfaces (IS): Putting rain gardens in locations where there is runoff from IS will reduce CSOs and improve water quality through infiltration and detention storage. For this reason, only locations that receive flow from IS are considered.

Programmatic Variables:

1. Impervious surfaces runoff threshold: Capturing higher volumes of runoff means more stormwater can be treated. Areas that are draining runoff from impervious surfaces larger than 50 square feet will be prioritized.
2. Depth to groundwater: High groundwater tables may result in pooling of water and poor infiltration reducing rain garden effectiveness. New York State's 2010 Stormwater Management Design Manual requires that there be at least a 3-foot separation between the bottom of GI and seasonally high groundwater levels.[9] High groundwater levels can mean poor infiltration and drainage. Within the Study Area, the water table has been increasing since the 1980s thought to be due, in part, to increased flooding around Oakland Lake. For this reason, areas where the groundwater table is higher than 10 feet from the surface are excluded.
3. Proximity to IS: Proximity to IS will reduce the construction work and time required to reroute and divert water from storm and sewer drains to rain gardens. Areas that are within 100 feet of IS will be prioritized.
4. Slope: Steeper slopes increase the work and time required to construct rain gardens. Areas at 5% grade or lower (2.8624 degrees) will be prioritized over steeper areas.
5. Discharge to *Phragmitesmites australis* (phragmites): Phragmites is a common invasive wetland reed that provides water quality improvement treatment.[10] Because runoff discharging to

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[9] New York State Stormwater Management Design Manual (2010), Chapter 5, pp. 5-76 – 5-85. http://www.dec.ny.gov/docs/water_pdf/swdm2010chptr5.pdf

[10] Muelman, A., Beekman, J., & J. Verhoeven (2002). Nutrient Retention and Nutrient-Use Efficiency in *Phragmitesmites Australis* Stands After Wasterwater Application. *Wetlands* (22), 712-721.

phragmites already receives treatment, areas where runoff is not discharging to phragmites will be prioritized.

6. Drainage type: NYC Department of Environmental Protection (NYCDEP) is required under a 2005 Order on Consent to reduce CSOs. In 2011, the CSO Consent Order was modified to include green infrastructure strategies.[11] Thus, CSO drainage areas will be prioritized over MS4 and direct drainage areas.
7. Land ownership: NYCDPR-owned land will be prioritized over land owned by other government agencies.

Second, using the ModelBuilder tool in ArcGIS, a model was created to select locations in a two-part process. In Part 1, all rain garden locations that meet biophysical variables are identified, i.e. only lands that can be built on. These are referred to as 'buildable' lands while all locations that do not meet biophysical variables are discarded as 'non-buildable' lands. Locations must meet both biophysical variables to be considered 'buildable'. In Part 2, locations identified in Part 1 are ranked into high-, medium-, and low-priority sites. Locations that meet the most number of programmatic criteria are considered high-priority and locations that meet fewer programmatic criteria are ranked lower in priority.

Model

Part 1 categorizes all lands into 'buildable' and 'non-buildable'.

Step	Description	Data layer Inputs	Output
1	Identify all buildable parkland ('Build grid') and non-buildable, non-impervious lands ('Non-build grid'). Convert to raster, if necessary (Use Polygon to Raster tool, set cell size to '1').	• Build grid: Park • Non-build grid: Programmed land, roads, open water, marshland, habitat, and canopy	All inputs converted to raster file format
2	Remove the Non-build grid from the Build grid		
2.1	Give the Non-build grid pixels all values of '0' (Use Reclassify tool).	• Output from Step 1	Non-build grid pixels are given a 'non-build' value of '0'
2.2	Give the Build grid pixels all values of '1' (Use Reclassify tool).	• Output from Step 1	Build grid pixels are given a 'build' value of '1'
3	Determine which remaining Build grid pixels are draining runoff from impervious surfaces (IS)		
3.1	Give IS grid all values of '1' (use Reclassify tool).	• IS grid • DEM grid	IS grid with simulated rainfall of 1 unit on each pixel (IS-rainfall)
3.2	Calculate flow direction on DEM (Use Flow Direction tool). Using the output	• Output from Step 3.1	Grid showing where all the runoff from IS

[11] http://www.dec.ny.gov/chemical/77733.html

	from flow direction and weighting the IS-rainfall grid, calculate flow accumulation (Use Flow Accumulation tool).		drains (IS flow acc)
3.3	Multiply the Build grid pixels with the IS flow acc (Use Raster Calculator).	• Output from Step 2.2 • Output from Step 3.2	Grid showing how much IS runoff flows to Build grid pixels
4	Add the Build and Non-build grids together (Use Cell Statistics tool with minimum function).	• Output from Step 2 to 3	One grid showing all the pixels that can and cannot be built on

PART 1 OUTPUT: A grid showing all pixels that meet the biophysical variables (Figure 3).

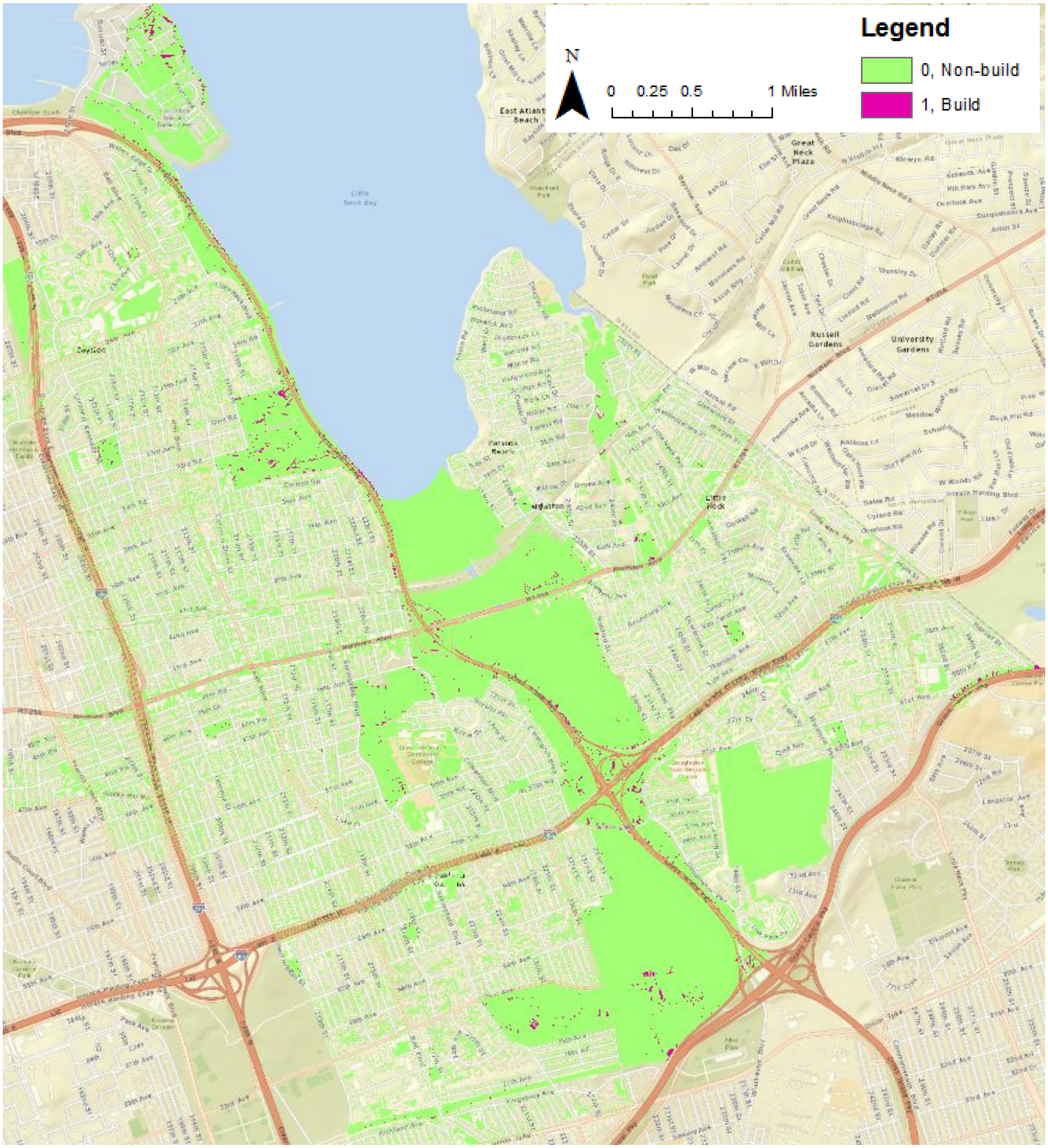


Figure 3. Map showing results of running model Part 1

Part 2 ranks all 'buildable' lands into 'high-, medium-, and low-priority' sites depending on the number of programmatic criteria met.

Step	Description	Data layer Inputs	Output
5	Determine priority based on programmatic criteria. Convert all files to raster, if necessary (Use Polygon to Raster tool, set cell size to '1').	N/A	All inputs converted to raster file format
5.1	Take output from Step 3.3 (Build grid with runoff values from IS). Give all pixels with a value of 50 or more a value of '2' and all others a value of '1' (Use Reclassify tool).	• Output from Step 3.3	Areas that drain runoff from IS larger than 50 square feet are given priority
5.2	Find distances of Build grid pixels from IS (Use Buffer tool). Give all pixels that are within 100 feet away from IS a value of '2' and all others a value of '1' (Use Reclassify tool).	• Output from Step 2.2	All pixels within a 100 feet of impervious surfaces are given priority
5.3	Calculate slope using the DEM (Use Slope tool set to degrees). Give all pixels with a slope of 2.8642 degrees (5% grade) or less a value of '2' and all others a value of '1' (Use Reclassify tool).	• Output from Step 1	All pixels with a slope of 5% grade or less are given priority
5.4	Give all non-phragmites pixels a value of '2' and all others a value of '1' (Use Reclassify tool).	• DEM	All pixels that do not flow to phragmites are given priority
5.5	Give all CSO pixels a value of '2' and all MS4 pixels a value of '1' (Use Reclassify tool).	• CSO grid • MS4 grid	All CSO pixels are given priority
5.6	Give all NYCDPR-owned pixels a value of '2' and all other state-owned pixels a value of '1' (Use Reclassify tool).	• Park owned grid • Non-park owned grid	All NYCDPR-owned pixels are given priority
5.7	Give all pixels with groundwater depth at 10 feet or below a value of '2' and all others a value of '1' (Use Reclassify tool).	• GW grid	All pixels where GW is deeper than 10 feet are given priority
6	Add all prioritization grids together (Use Cell Statistics with sum function).	• Output from Step 5.1 through 5.7	Grid showing prioritization scores of each pixel, ranging from 14 to 1.
7	Multiply Build grid with the sum of all the prioritization grids (Use Raster Calculator).	• Output from Step 2.2 • Output from Step 6	Final output

PART 2 OUTPUT: A grid where all pixels that can be built on are ranked by how many programmatic criteria are met (Figure 4).

Results

Selected sites were divided into short-term and long-term possibilities. Results are shown in the map below; running the model yielded the following high-priority, medium-priority, and low-priority sites (Figure 4). Rain garden construction in high-priority sites will happen over the short-term (1-2 years) and over the long-term (3-5 years) for medium- and low-priority sites.

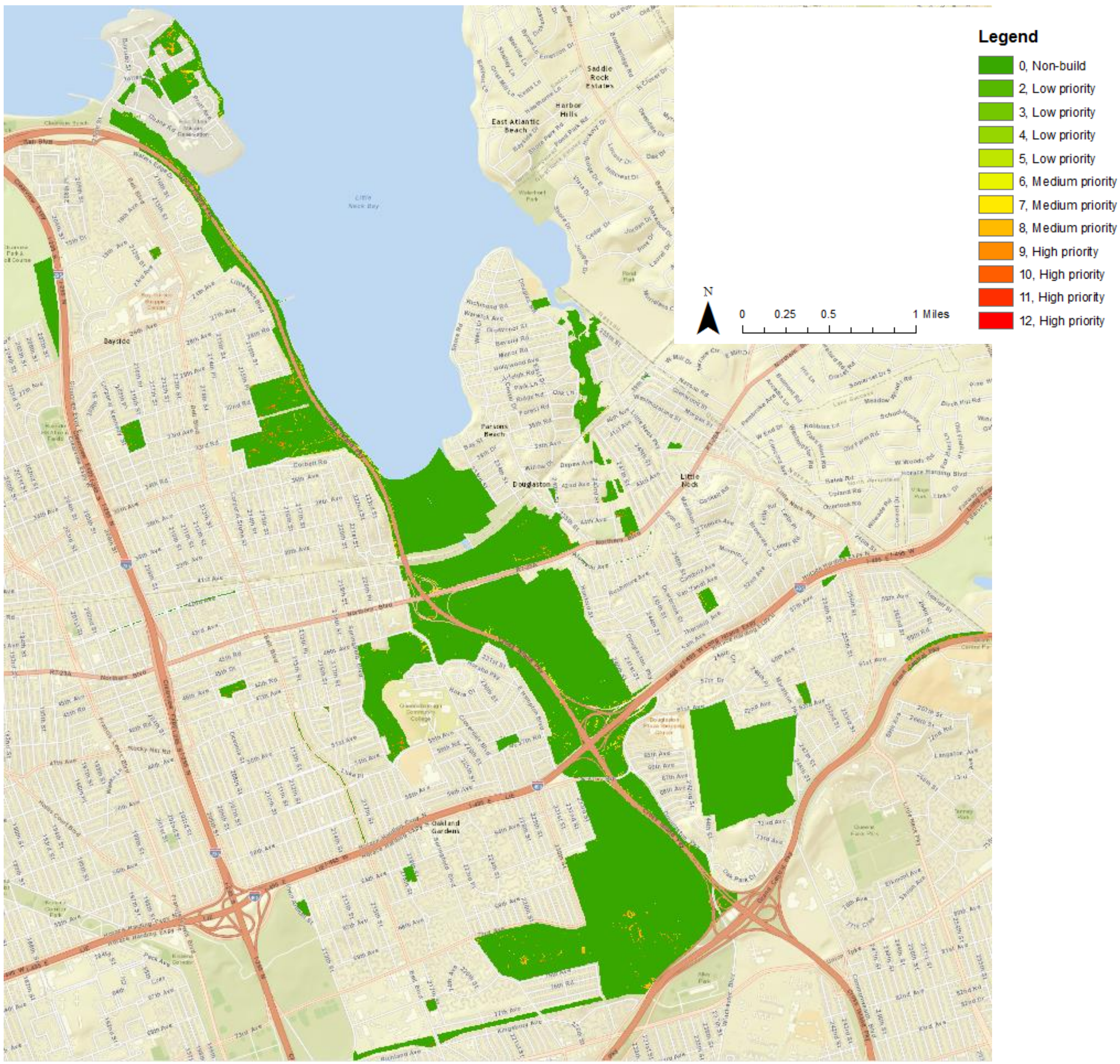


Figure 4. Map showing the final output

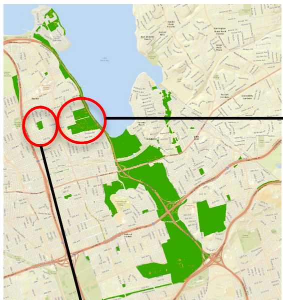


Figure 5. Zoomed-in view of model results showing medium to high-priority sites at John Golden and Crocheron Park

Figure 6. Zoomed-in view of model results showing medium to high-priority sites at Kennedy Playground.

Figures 5 and 6 show a zoomed-in view of the selected model results and overlaid them on Google Earth imagery. In Kennedy Playground (Figure 6), the red areas – which indicate high priority sites – are along the streets. Placing rain gardens here would capture runoff flowing from these streets making these locations ideal. Similarly, in Figure 5, the red areas are next to the parking lot and tennis courts and streets surrounding the park. Rain gardens in these areas will capture runoff from these impervious surfaces.

Discussion

Model Reproducibility Outside the Study Area

One of the objectives of this research is to see how a city might automate the selection of optimal rain garden locations. For the Study Area, this model is entirely automated, except for selecting the current model inputs (See Appendix for more detail about data preparation). Once the user has selected the appropriate inputs and runs the tool, the model will produce a map, identifying high-priority, medium-priority, and low-priority sites.

Another objective is to see how the model could operate beyond the Study Area, including the rest of New York City. Because biophysical and programmatic variables can change from region to region, the model will require some manual desktop work from the user to change the inputs accordingly. The advantage of creating a model is that additional inputs and steps to analyze them can easily be added and removed, as necessary, to make it specific to the region in question. For example, soils play a significant role in determining infiltration (e.g. clay soils are less permeable than loam soils). Soils were not considered as a biophysical variable in this protocol because of insufficient data. Once this data becomes available, soil should be considered a prioritization variable. With this model, soils can be added as a prioritization variable into Part 2 of the model – lands with loamy soils will have higher priority than lands with clay soils. Existing model variables that do not apply to the region of interest can also be easily taken out. If the user wants to treat MS4 and CSO drainage areas similarly, those inputs and associated functions can be deleted without affecting the rest of the model. Or the user may decide to prioritize MS4 drainage areas over CSOs. This will require manual work to update the prioritization numbering scheme outlined in the protocol.

Building a model allows locating optimal rain garden locations to be automated within the Study Area and achieves Objective 1. As variables to select rain garden locations may change from region to region, some user input will be required to adjust the model accordingly. Despite the need for additional input, the ability to operate the model outside the Study Area achieves Objective 2.

Limitations

There were several significant omissions within this research. First, the model does not consider repurposing lands that may serve as ideal potential rain garden locations. For example, a basketball court at the edge of a park may have proved to be the best site for a rain garden and could have been retrofitted. By removing all such “programmed” land, this protocol overlooks the potential that any of these lands can be retrofitted for stormwater management. A finer-scale analysis that creates subcategories of programmed land into surfaces that can and cannot be retrofitted can increase the land that is available for GI.

Second, the model does not consider soils as a site selection variable because the soil profile dataset did not provide enough information to meaningfully categorize the Study Area by infiltration capacity. The model should be updated to include soil as a selection variable once the data becomes available.

Figure 7. LiDAR data overlaid over Google Earth imagery

Third, the IS layer is incomplete and does not include all IS within the Study Area. The source data is the 2010 Light Detection and Ranging (LiDAR) data showing landcover. Figure 5 shows that IS within the LiDAR dataset (in red), when overlaid with a basemap from Google Earth, does not cover the entire extent of the existing IS, particularly roads.

Step 3 of the protocol calculates whether any buildable areas drain runoff from IS. Not having all the existing IS included in the LiDAR dataset means that not all IS flow is accounted for. Because the purpose of this model is to understand where GI should be placed to treat runoff from impervious area, having a dataset that includes all impervious surfaces is crucial. As Figure 7 shows, there are more impervious surfaces within the Study Area than were used for the runoff analysis. Using a complete dataset would have resulted in identifying more sites that received runoff from IS and, thus, making them eligible for building rain gardens.

Fourth, the model always assumes some amount of water treatment from phragmites. However, the actual amount of water quality improvement is likely dependent on several factors: detention duration, location, time of year, local hydrological conditions, and species-species interactions. Thus, the assumption made in this paper is site-specific to the Study Area. To use the model outside the Study Area, users must decide if the assumption that phragmites provides water quality treatment is applicable to their location. Users will have to decide whether to include phragmites either as a programmatic variable or to leave it out of the model entirely.

Fifth, social variables such as community willingness, public awareness, etc. are not included. These factors are harder to evaluate, but not impossible– for example, if a majority of survey respondents answered positively about community willingness, this could be added to the model. However, this type of social data can be much more complicated and nuanced than biophysical data and may not lend itself to a model-type analysis. The user must determine whether the inclusion of social data in the model will provide useful and meaningful results.

Sixth, the model cannot account for how much infrastructure retrofit or new construction would be needed to redirect impervious surface flow to the identified rain garden locations. This analysis would have to be done for each individual location manually. To identify infrastructure needs, a second-tier analysis of supplemental fieldwork and assessments at model-selected sites would be necessary.

Finally, the model does not indicate which variables were and were not met. For the Part 1 output, the model cannot distinguish between whether a pixel was non-build because of conflicting land uses or because it did not receive IS flow. Similarly for the Part 2 output, the model cannot identify whether a pixel is low priority because it had high slope or because it had phragmites.

This model presents a 'first-tier' analysis in choosing rain garden sites. Although there are limitations this approach and all identified locations should be subject to further analysis through fieldwork, using the model approach significantly decreases manual user input.

Role of Field Assessments

Field assessments should still be an essential part of choosing sites. Visual inspections should be used to confirm model results. For example, one field visit revealed that a flower garden with a rock border had been constructed at the edge of the park. The gentleman that had built the garden was present and spoke about his love of the park, his desire to take care of it, the need for stormwater management in the area, and supported the idea of rain gardens. Another field visit to [specific site] revealed that nearby residents had set up a memorial to a solider. These observations would never be picked up by the model but present valuable and supplemental information in choosing sites. In the first example, there is a contact that can be tapped into for rain garden maintenance. Interviews can be conducted at the second site with neighbors to see if they would be amenable to constructing a rain garden in their place of their existing memorial.

Of course, on-the-ground conditions can change all the time, but data layers do not. Because data layers used for the model represent a snapshot in time, fieldwork is essential to corroborate the accuracy model results.

Beyond Rain Gardens

Currently, model results only show the best locations for rain gardens. Over time, NYCDPR may want to implement other GI strategies within or outside of the Study Area. Riparian buffers, vegetated swales, and tree pits have similar requirements as rain gardens. For example, the New York State Stormwater Management Design Manual recommends that riparian buffers be built on areas with slopes less than 6% and vegetated swales be built on locations with a slope between 0.5 to 4% grade. The methodology presented in this paper uses a slope constraint of 5% grade. Thus, with slight adjustments, the model can be used to identify optimal locations for riparian buffers, vegetated swales, and tree pits.

Other GI strategies such as green roofs and downspout disconnections have different feasibility requirements. The variables for identifying locations will have to be adjusted accordingly. The user must decide if these changes to the current model will still result in suitable locations or if a different model should be created.

Additional Considerations

The current model and the results reflect the programmatic criteria that NYCDPR has for building rain gardens within the Study Area. Criteria are balanced between those that focus solely on providing the maximum amount of stormwater treatment with those that do not. For example, the criterion of 'impervious surfaces threshold' is only concerned with stormwater management objectives. But, the criterion of 'slope' is not – the focus here is on reducing construction work and time. There may be areas that have steeper slopes that can treat larger volumes of stormwater that are being pushed down in priority because of the 'slope' programmatic criterion. Similarly, lands that are owned by other government agencies such as the Department of Transportation (DOT) are moved down in priority because of the additional work and time required for inter-agency collaboration even though there may be some low-priority DOT lands that can treat larger volumes of stormwater than some other high-priority NYCDPR owned lands.

Where you want to place rain gardens may change depending on the purpose of the protocol. Programmatic criteria may change from region to region. They can change over time as well, including within NYCDPR. The following examples show how the protocol can be adjusted and changed to reflect different purposes:

1. Stormwater management objectives

   Although the current programmatic criteria reflect an optimal and realistic priority ranking of rain garden sites within the Study Area, these are not necessarily the sites that treat the largest volumes of stormwater. The model and protocol created for this research can be adjusted so that the results show all areas where stormwater can be treated, regardless of whether the slope is too steep or the land is owned by DOT, etc. This adjustment would require for Part 2 of the protocol, the prioritization part, to be eliminated. By simply running Part 1 of the protocol, the model results will show all areas where rain gardens can be physically placed that are also draining runoff from impervious surfaces. The results could be ranked by areas that are draining the largest to smallest amount of IS runoff; areas that are draining the largest volume of runoff could be considered 'high priority'.

2. Environmental co-benefit objectives

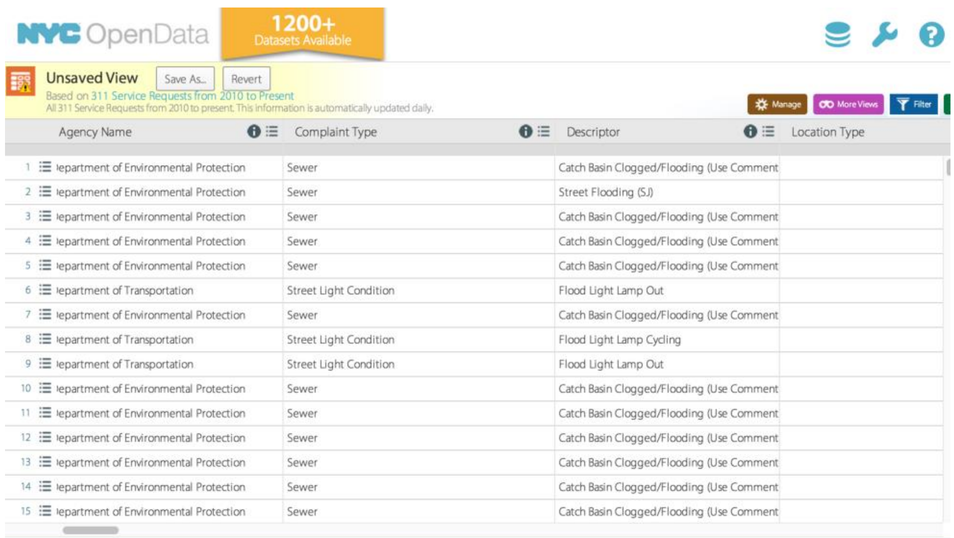
   The protocol can also be used to maximize environmental co-benefits. Programmatic criteria can be based on placing GI in areas with high visibility to increase environmental education, reducing air pollution, and alleviating the urban heat island effect. Any binary variable – e.g. slope is either steeper than 5% grade or it is not – can be used within Part 2 of the protocol. For example, in a response to alleviate the urban heat island effect – areas that have average temperatures higher than a certain degree can be considered prioritized locations for placing GI. Similarly, to increase environmental education, areas in close proximity to schools can be prioritized for placing GI. This methodology will select sites that provide both stormwater management and associated co-benefits.

3. Environmental justice objectives

The current protocol does not look at any variables that result in environmental justice. Cleveland, Ohio is under a similar Consent Order from the EPA to reduce CSOs. In fulfilling this, Cleveland is placing green infrastructure in low-income neighborhoods.[12] Research shows that street trees[13] and greenery[14] can reduce crime rates. Programmatic variables that are looking at demographics, income, and other socio-economic metrics can be designed. Selected sites through this methodology will provide stormwater management in an equitable manner.

4. Additional NYC data

Additional NYC data can be incorporated into the model. Calls made to 311, NYC's main source of government information and non-emergency services, are coded and recorded.



	Agency Name	Complaint Type	Descriptor	Location Type
1	epartment of Environmental Protection	Sewer	Catch Basin Clogged/Flooding (Use Comment	
2	epartment of Environmental Protection	Sewer	Street Flooding (SJ)	
3	epartment of Environmental Protection	Sewer	Catch Basin Clogged/Flooding (Use Comment	
4	epartment of Environmental Protection	Sewer	Catch Basin Clogged/Flooding (Use Comment	
5	epartment of Environmental Protection	Sewer	Catch Basin Clogged/Flooding (Use Comment	
6	epartment of Transportation	Street Light Condition	Flood Light Lamp Out	
7	epartment of Environmental Protection	Sewer	Catch Basin Clogged/Flooding (Use Comment	
8	epartment of Transportation	Street Light Condition	Flood Light Lamp Cycling	
9	epartment of Transportation	Street Light Condition	Flood Light Lamp Out	
10	epartment of Environmental Protection	Sewer	Catch Basin Clogged/Flooding (Use Comment	
11	epartment of Environmental Protection	Sewer	Catch Basin Clogged/Flooding (Use Comment	
12	epartment of Environmental Protection	Sewer	Catch Basin Clogged/Flooding (Use Comment	
13	epartment of Environmental Protection	Sewer	Catch Basin Clogged/Flooding (Use Comment	
14	epartment of Environmental Protection	Sewer	Catch Basin Clogged/Flooding (Use Comment	
15	epartment of Environmental Protection	Sewer	Catch Basin Clogged/Flooding (Use Comment	

Figure 8. 311 calls, logged and coded

This data is available online[15] and can be downloaded for analysis. Two categories for coding calls are 'street flooding' and 'catch basin clogged/flooding' (Figure 8). Addresses and location coordinates are recorded and, therefore, can be mapped. This can be used as a data layer/input into model as a prioritization factor, i.e. locations with known incidences of street flooding can be given higher priority over locations that do not have such incidences.

Communication across agencies must be improved. A field visit to a site at 34th Avenue and Brookside Street revealed that the NYC Department of Transportation (NYCDOT) was putting in a new water main and replacing the sidewalk. Knowing which sites are slated for construction would be helpful because NYCDPR can capitalize on this to try and include GI in the already-occurring construction.

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12 http://www.epa.gov/sciencematters/april2012/overflows.htm

13 Troy, A., Grove, J.M., & O'neil-Dunne, J. (2012). The relationship between tree canopy and crime rates across an urban-rural gradient in the greater Baltimore region. *Landscape and Urban Planning*, (106), 262-270.

14 Kuo, F.E. & Sullivan, W.C. (2001). Environment and crime in the inner city: Does vegetation reduce crime? *Environment and Behavior*, 33(3), 343-367.

15 https://nycopendata.socrata.com/data

Conclusion

This paper demonstrates that GIS can be used to automate the process of locating optimal sites for rain gardens within the Study Area. This process can also be automated, to an extent, for areas outside the Study Area. Using GIS can significantly reduce the time, effort, and manual input required for siting rain garden locations. However, users must keep in mind that the model is only the first step in analysis. Fieldwork is still essential in validating model results and for gaining additional valuable information that cannot be displayed by the model.

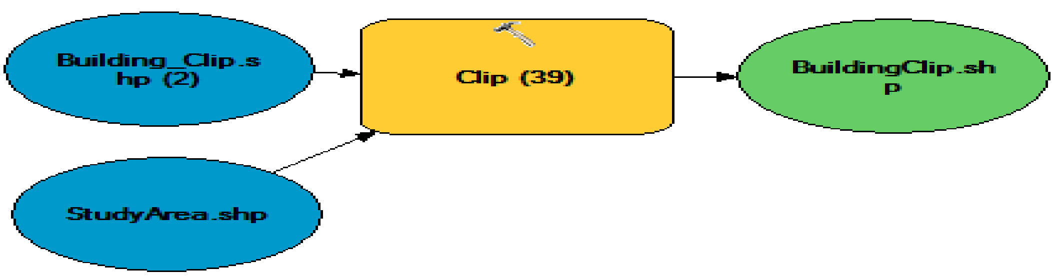
Appendix

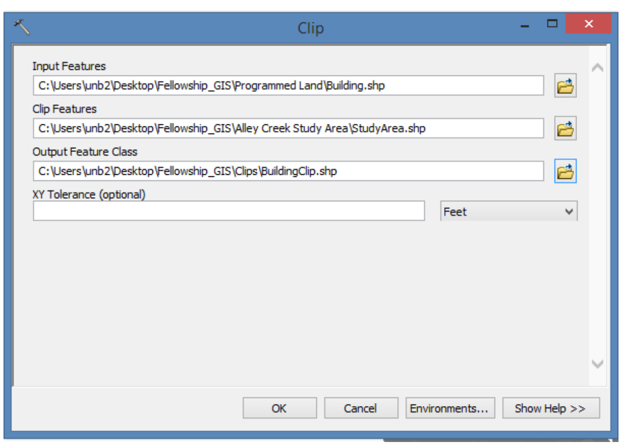
All data used in the model was provided by NYCDPR. Running the model will not result in any variations in the map regardless of who is running it. Each input in the model has been parameterized. Setting inputs as parameters means that users will be asked to upload input files before the model will run. A detailed description of how data layers were analyzed and how the model was created is described below. Each input in the model has been parameterized. Setting inputs as parameters means that users will be prompted to upload input files before the model will run.

PART 1

Step 1: Data was provided for the whole of NYC. Data layers were clipped to the region of interest, public lands within Study Area. Because impervious surfaces exist outside of public lands, these were clipped to the extent of the entire Study Area. Figure A1 shows an example where the buildings layer for all for NYC was clipped to include buildings only within public lands in the Study Area (shown in red on image on the right).

a. Use 'Clip' tool. Set file to be clipped as the 'Input feature' and the file that will be used to clip (i.e. extent of interested region) as the 'Clip feature'.





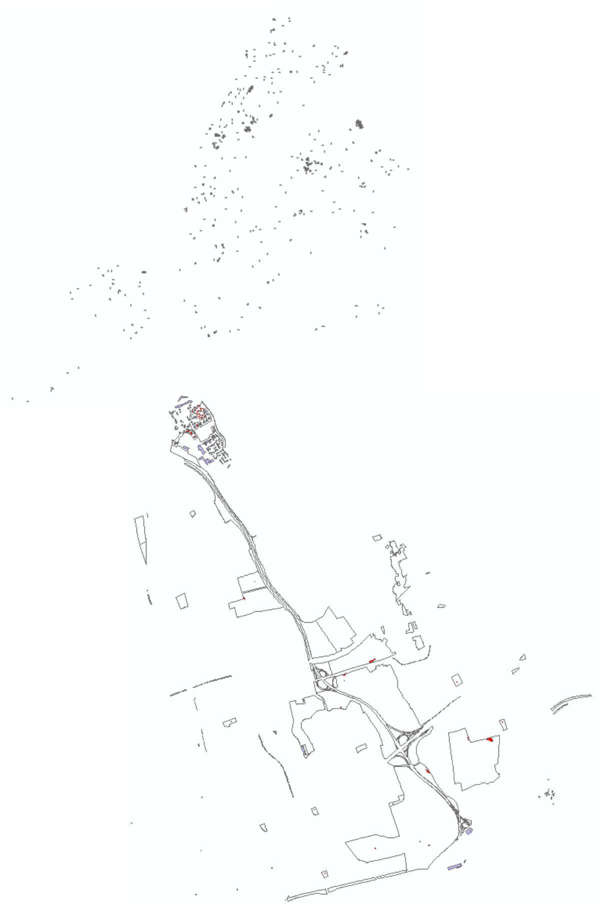


Figure A1. Building Clip

Step 2: Programmed land data was in the three different file types – points, lines, and polygons. For ease of work, data was combined into one file. Point and line files were converted to polygons. The following line features were merged together into one file and then buffered: 1) bicycle paths; and 2) paths. The following point features were merged together and then buffered: 1) access points; 2) AMPS centroids; 3) chess tables; 4) drinking fountains; 5) eateries; 6) fire hydrants; 7) flagpoles; 8) kayak canoe launches; 9) monuments; 10) paddleboat rentals; 11) park tree priorities; 12) spray showers; 13) waste receptacles; and 14) Wi-Fi hotspots. Figure A2 shows an example.

a. Use 'Merge' tool to combine files of the same file types.
b. Use 'Buffer' tool to draw 5-foot buffers around point and line features.

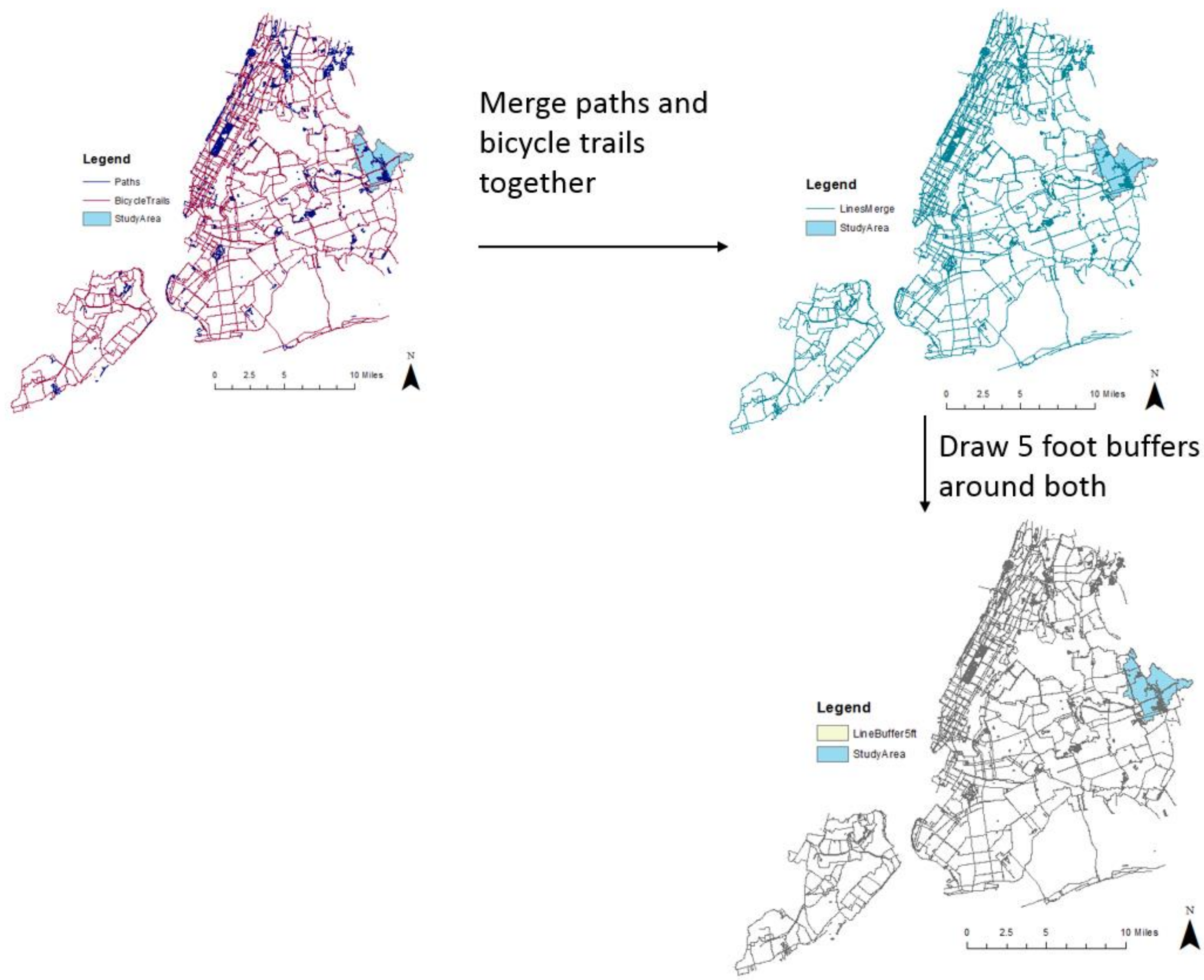


Figure A2. Combining different file types together

Step 3: Convert all files from vector to raster format.

a. Use 'Polygon to Raster' tool. Set cell size to 1 foot.

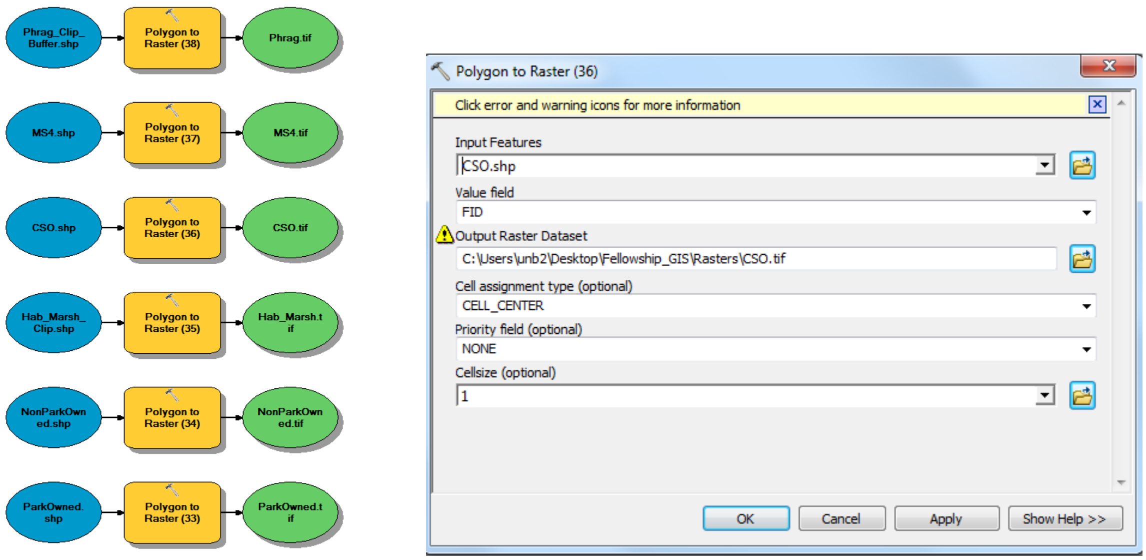


Figure A3. Converting all files from vector raster format

Step 4: Categorize all 'non-build' lands. 'Non-build' pixel are: programmed land; roads; open water; marshland, habitat, and canopy.

a. Use 'Reclassify' tool to give all 'non-build' pixels a value of '0'.

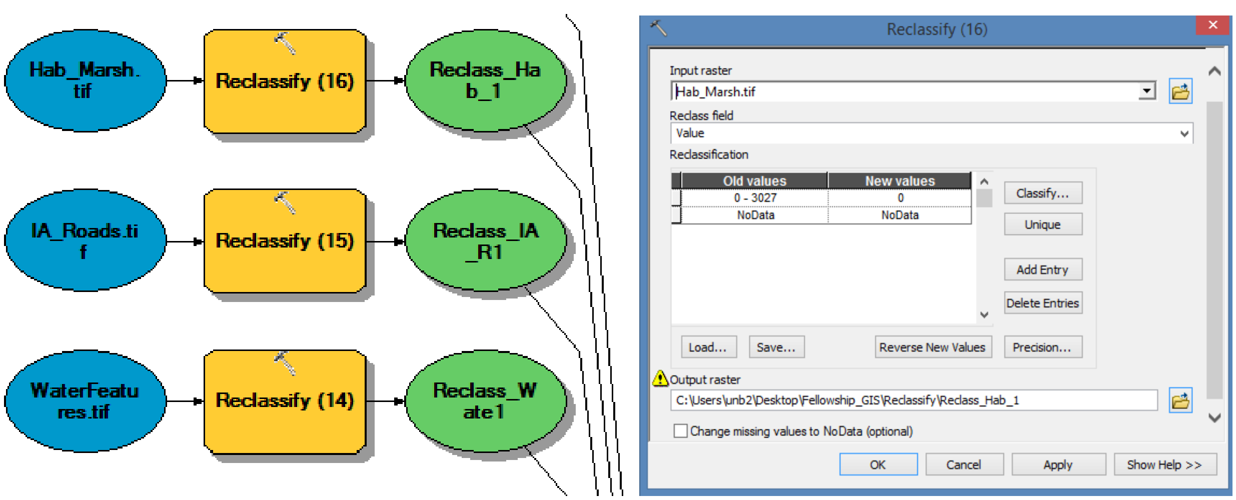


Figure A4. Categorizing all 'non-build' pixels

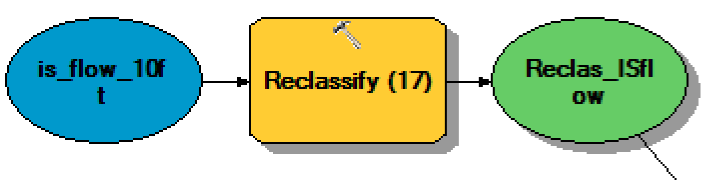
Step 5: Determine if any flow from impervious surfaces is flowing to the 'build' pixels. Since the goal of the model is stormwater management, only pixels that receive stormwater flow are identified. To isolate stormwater that is only flowing from impervious surfaces, the following steps were taken.

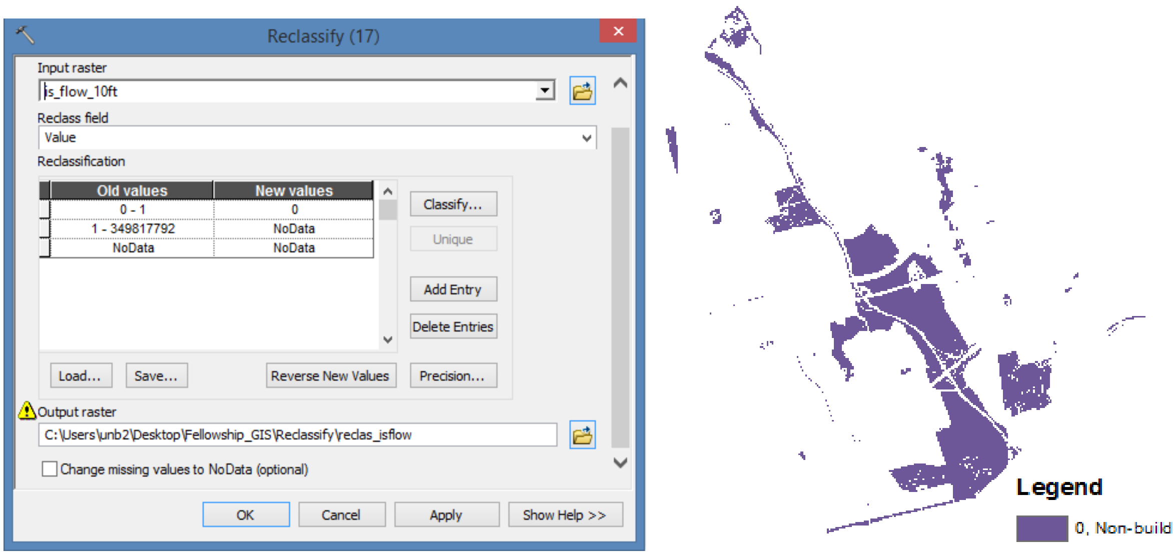
a. Use 'Flow Direction' tool using the DEM layer* as the input. This will identify in what direction stormwater that lands on each pixel will flow.
b. Use 'Reclassify' tool to give all impervious surfaces a value of '1'. The value indicates that one drop of rainfall falls onto every pixel.
c. Use 'Flow Accumulation' tool. Use the input from Step 6a for the 'Input flow direction raster' input. Use input from Step 6b for the 'Input weight raster' – weighting the impervious surface layer will isolate flow from only those surfaces. The will output a layer (IS flow acc) that shows were all flow from impervious surfaces accumulates.
d. Use 'Raster Calculator' tool to multiply the 'Build' grid with the IS flow acc layer. Pixel values indicate how many other pixels the stormwater has flown over, i.e. pixels that are located upstream. This means pixels located at the tops of hills will have low values and pixels located in valleys will have high values.

   Note: The DEM layer provided has a cell size of 1 foot. At this small scale, all bumps and ridges and contours of the surface are captured. Although such fine resolution is usually desired, the DEM layer did not prove useful for flow accumulation analysis. Flow accumulation was calculated using the 1-foot DEM and projected in ArcScene – an ArcGIS extension that allows for 3-D viewing (Figure A5). The valley running through the center of the image is Alley Creek, where all the flow accumulates. As can be seen in Figure A5, this is not the case. This is because as flow hits a bump, it stops. Because every single bump and ridge is captured, flow stops in ways that's inconsistent with what may be happening on the ground; in reality, a . To understand if this phenomenon was indeed occurring, the DEM was 'smoothed out' using 'Focal Statistics' tool with the 'average' function. This tool looks at a pixel's user-specified number of neighbors, calculates the average, and reassigns the pixel value to be the average. This averaging process will smooth out the bumps.
   'Focal Statistics' was run on the DEM, with 15 neighbors – each pixel is reassigned the mean value of the 15 neighboring pixels. Figure A6 shows flow accumulation run using this DEM and projected in ArcScene. Flow travels farther towards Alley Creek than it does in Figure A5.

Step 6: Categorize pixels that receive flow from impervious surfaces as 'build' and those that do not receive any flow from impervious surfaces as 'non-build'. Flow accumulation was calculated in Step 6 assuming 1 unit of rainfall on each pixel. So, pixels with a value higher than 1 are pixels that are receiving flow from impervious surfaces – 'build' pixels. Pixels with a value of 0 or 1 are not – 'non-build' pixels. Rain gardens will only be built on public lands. Therefore, only public lands that receive stormwater flow are identified.

a. Use 'Reclassify' tool to give 'non-build' pixels a value of '0'.



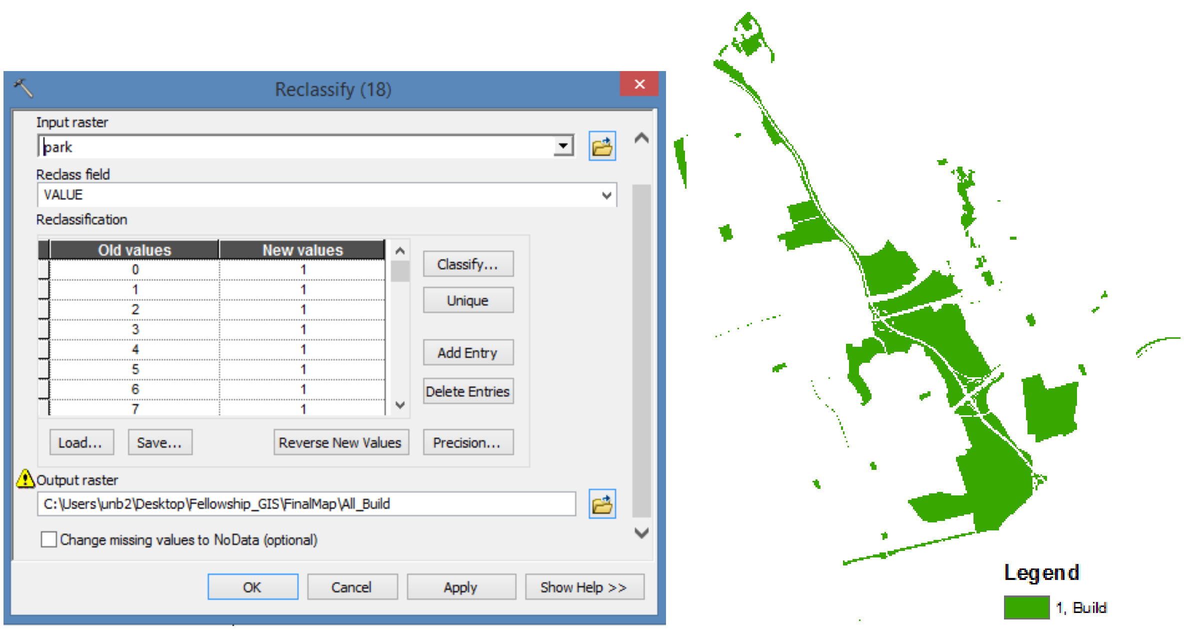


Step 7: Merge outputs from Step 3 and Step 6 together to form one 'Non-build' layer.

a. Use 'Cell Statistics' tool. Note: Because all pixel values are set to '0', choosing either the 'minimum' function or the 'maximum' function will result in the same output.

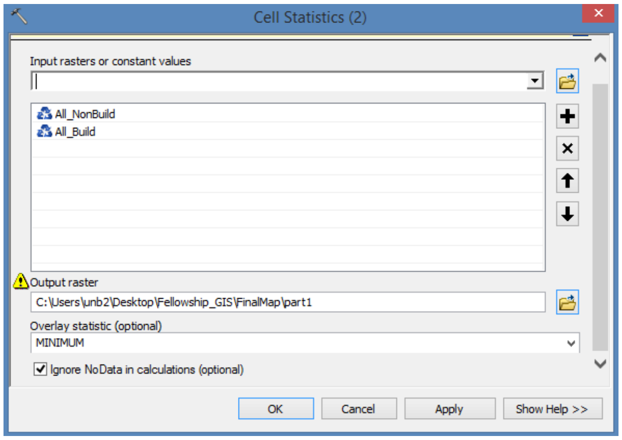
Step 8: Categorize all 'build' lands. 'Build' lands are all pixel lands within the Study Area.

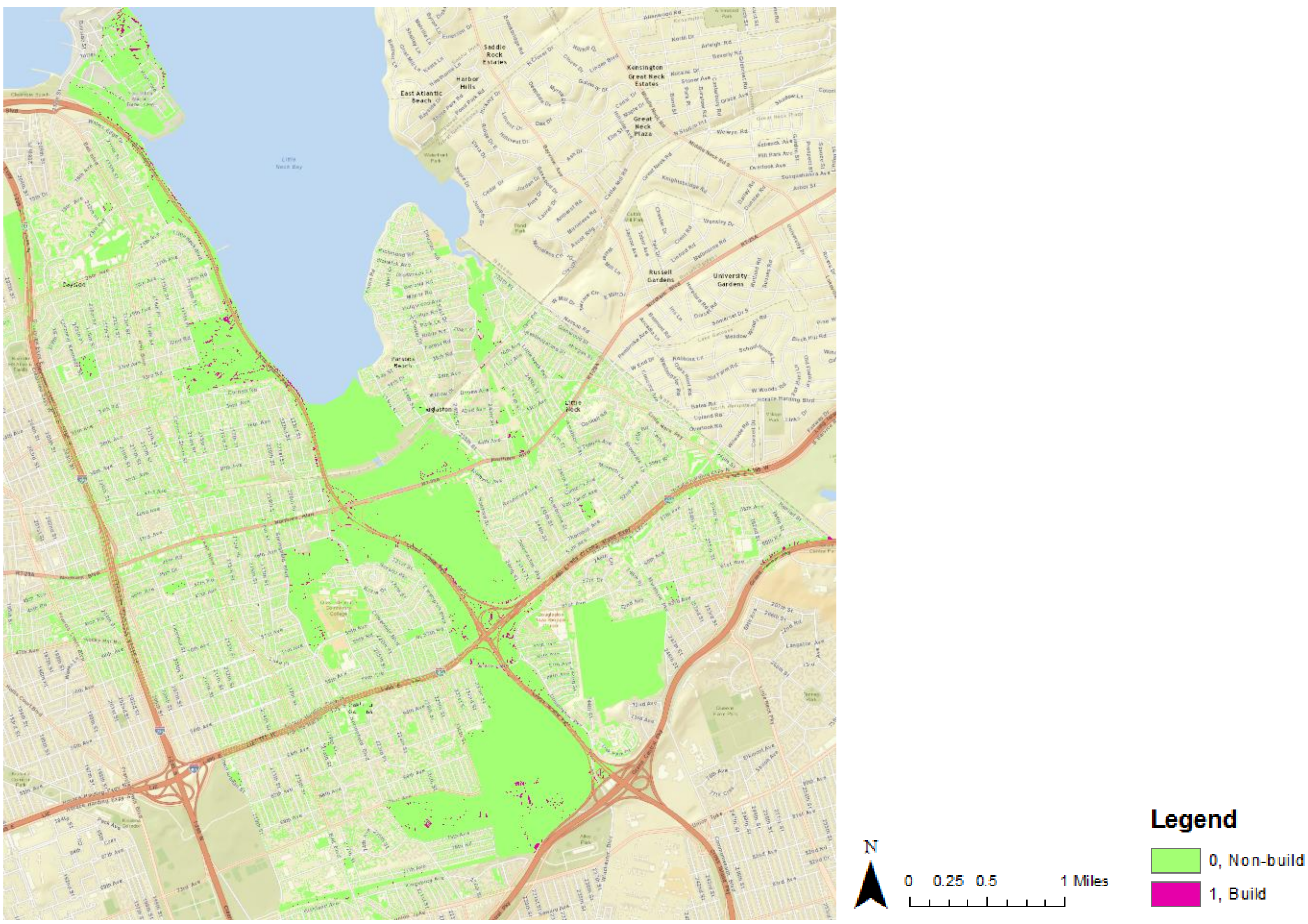
a. Use 'Reclassify' tool to give all 'build' pixels a value of '1'.



Step 9: Merge outputs from Step 7 and Step 8 to form the **final output of Part 1**.

a. Use 'Cell Statistics' tool with 'minimum' function.

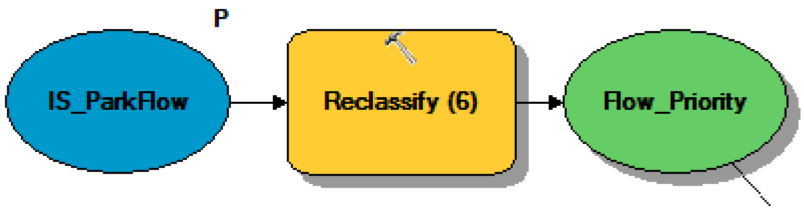


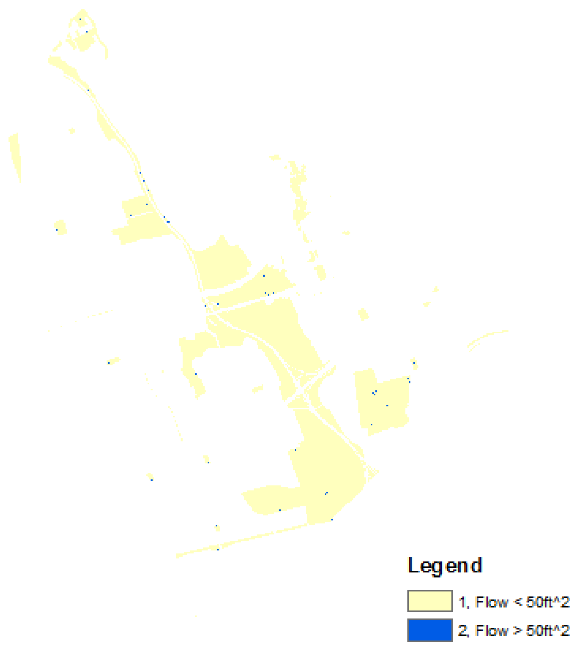


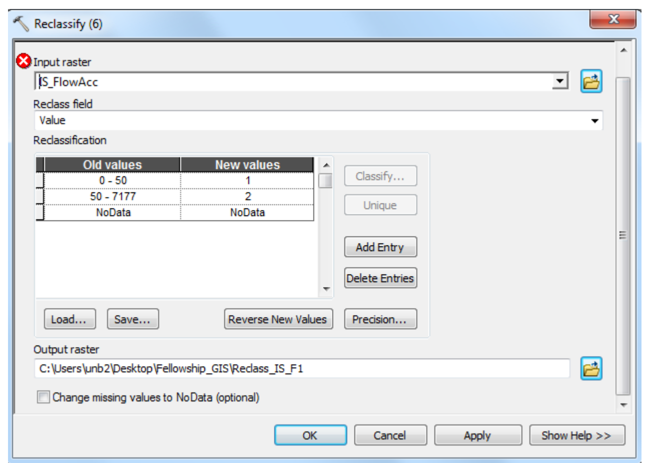
PART 2

Step 9: Categorize pixels that receive flow from impervious surfaces larger than 50 ft^2 as higher priority than pixels that do not.

Use ‘Reclassify’ tool to give pixels that receive flow from impervious surfaces larger than 50 ft^2 a value of ‘2’ and pixels that do not a value of ‘1’.

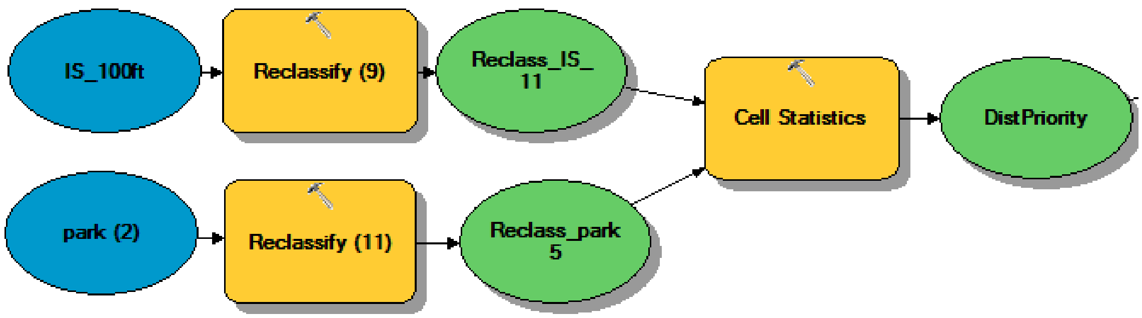


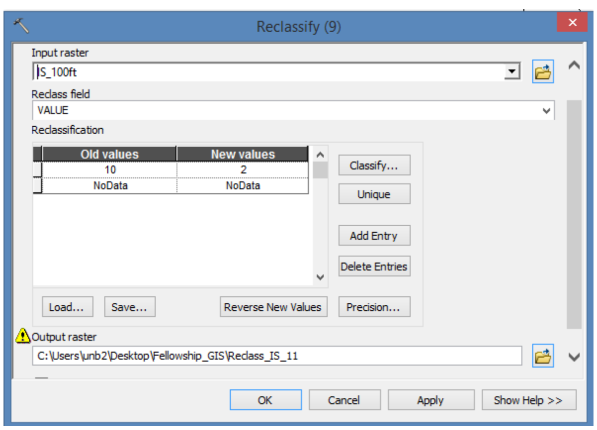


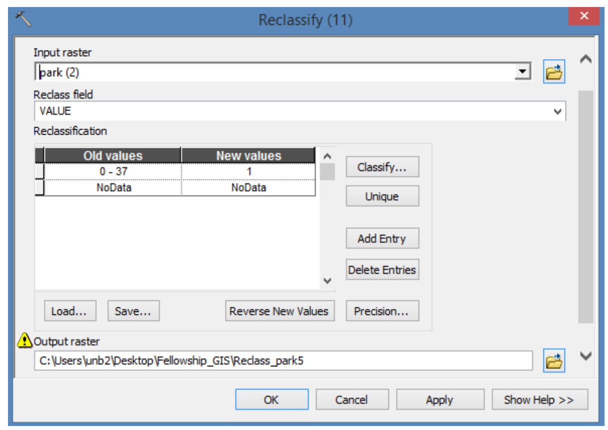


Step 10: Categorize pixels that are within 100 feet from impervious surfaces as higher priority than pixels that are not.

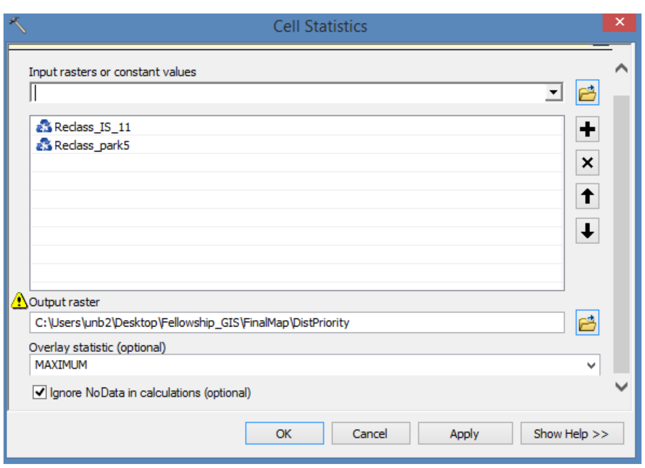
a. Use ‘Buffer’ tool to draw a 100ft. buffer on the impervious surface layer and convert to raster using ‘Polygon to Raster’ tool.
b. Use ‘Reclassify’ tool on output from Step 10a to give pixels that are within 100 feet from impervious surfaces a value of ‘2’.
c. Use ‘Reclassify’ tool to give output from Step 8a a value of ‘1’.

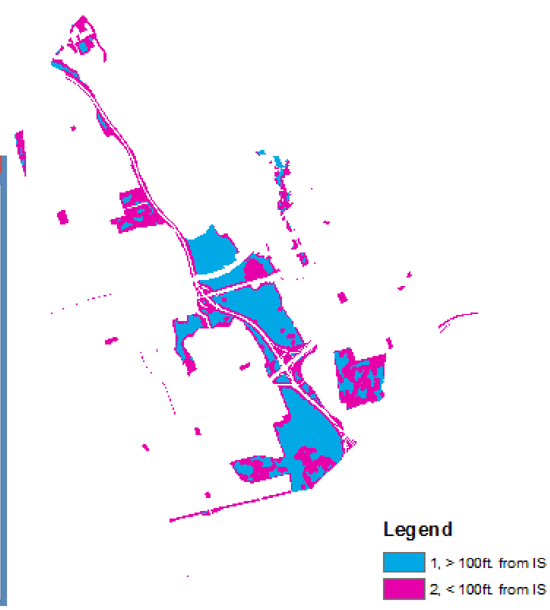






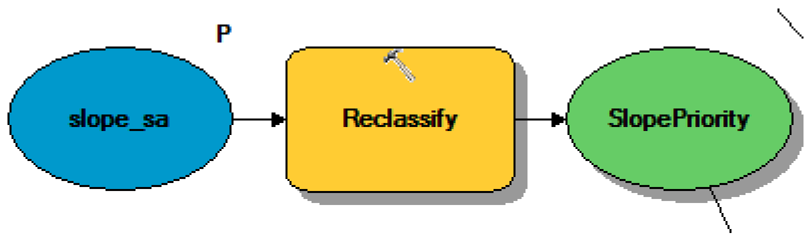
d. Use ‘Cell Statistics’ with the ‘maximum’ function to merge output from Step 10b and Step 8 into one prioritization layer.

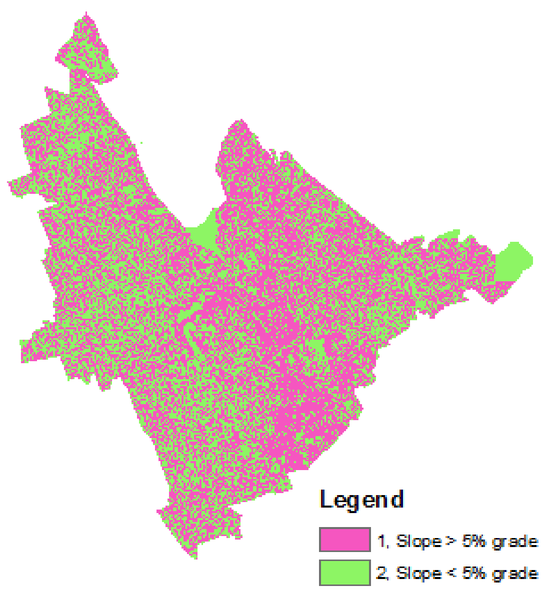


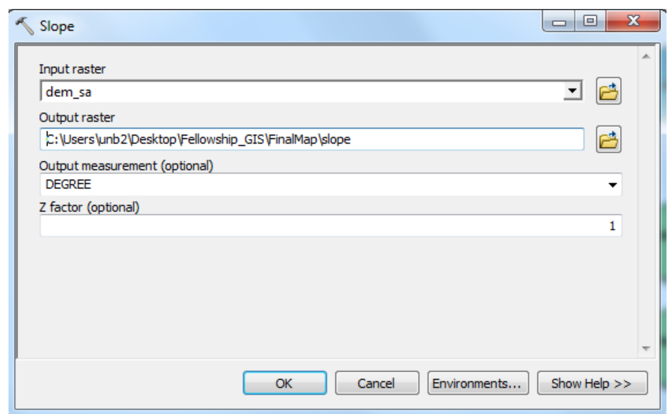


Step 11: Calculate slope and categorize all pixels that have a slope of less than 5% grade higher priority than pixels with higher slope.

- Using the DEM as the input, use 'Slope' tool.
- Use 'Reclassify' tool to give pixels that have a slope of less than 5% grade a value of '2' and all other pixels a value of '1'.

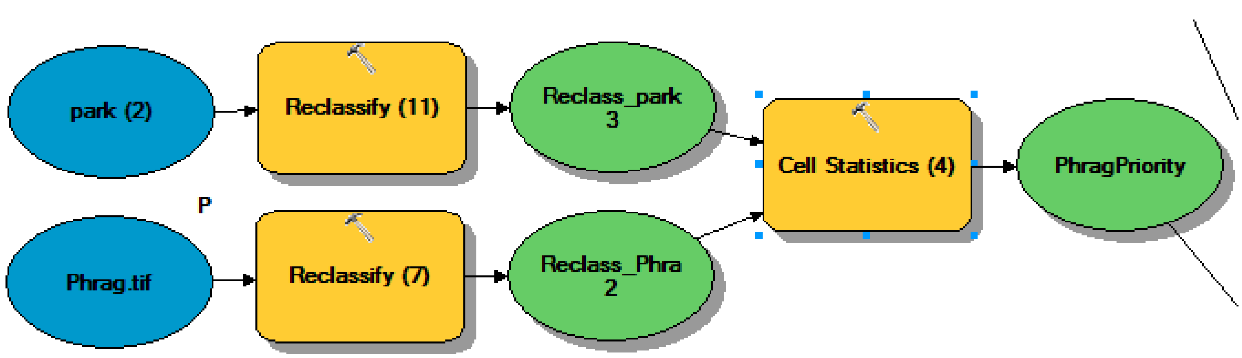


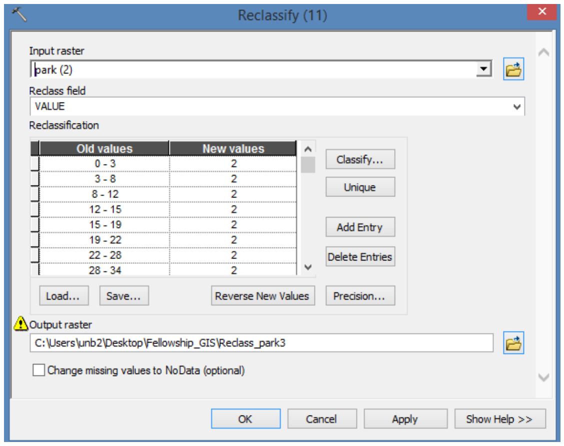


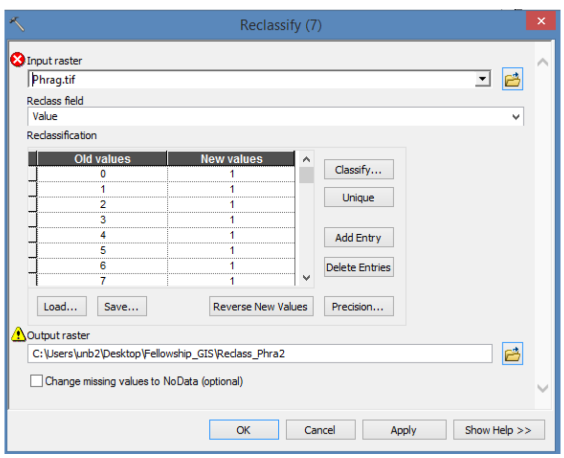


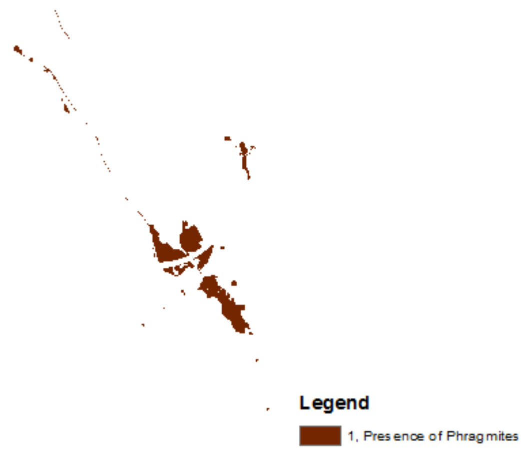
Step 12: Categorize pixels where there are no phragmites as higher priority. Areas within a 5ft. buffer (done using 'Buffer' tool) of phragmites pixels were also classified as phragmites.

a. Use 'Reclassify' tool to give output from Step 8 a value of '2'.
b. Use 'Reclassify' tool to give the phragmites layer a value of '1'.

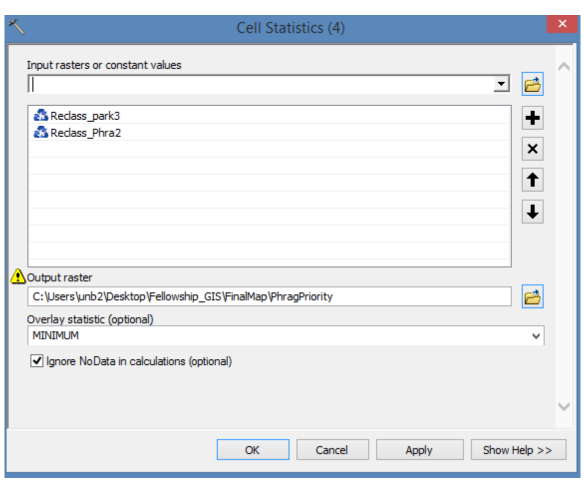






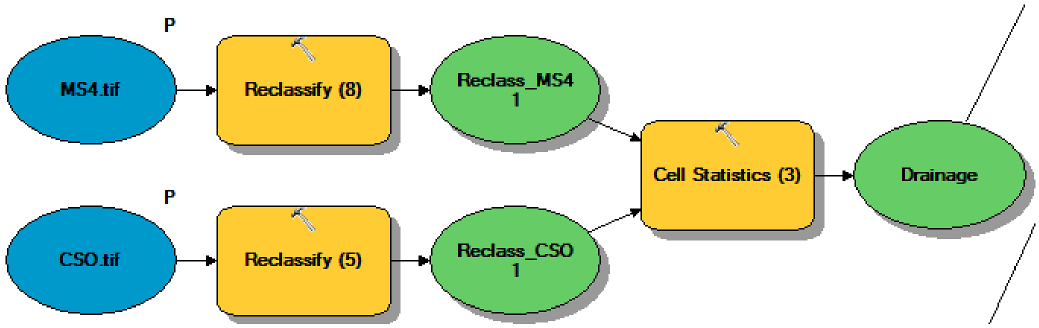


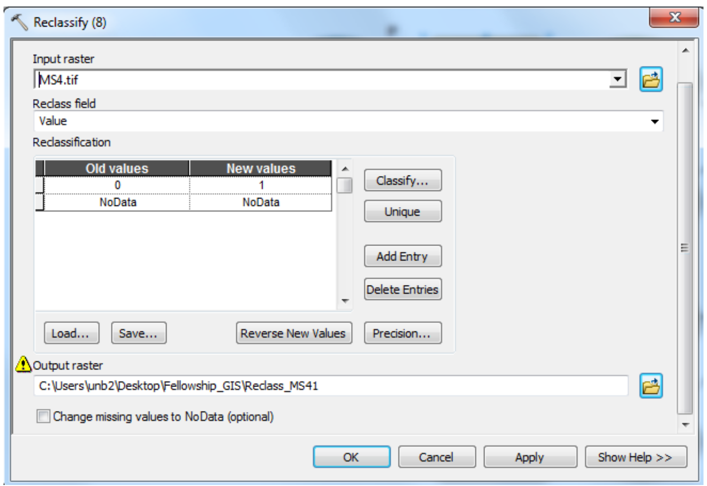
c. Use ‘Cell Statistics’ with ‘minimum’ function to merge into one prioritization layer.

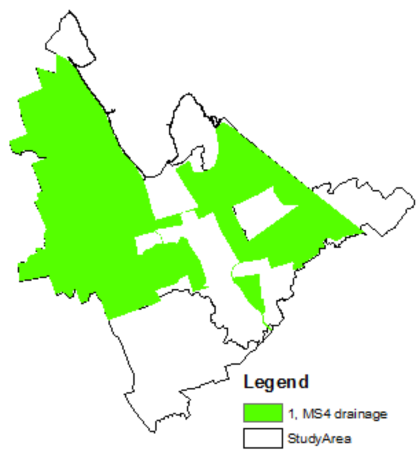


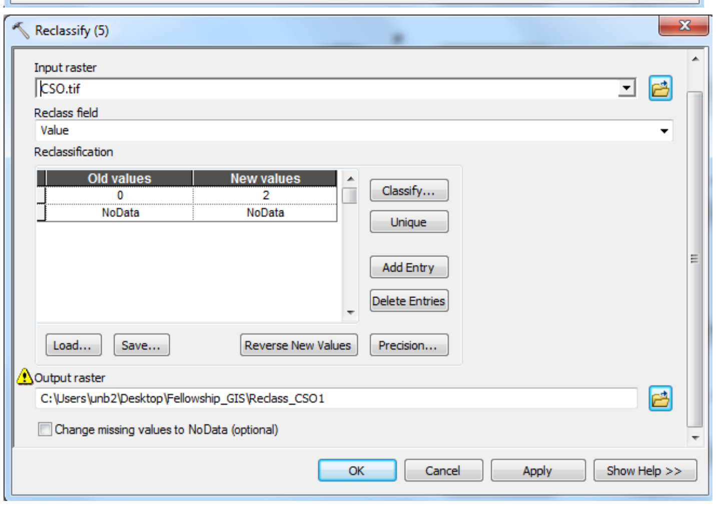
Step 13: Categorize CSO drainage areas as higher priority than MS4 drainage areas.

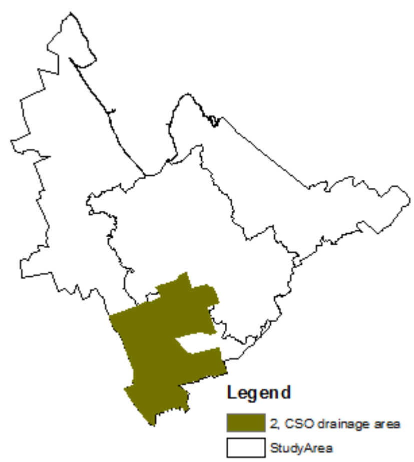
a. Use ‘Reclassify’ tool to give CSO drainage area pixels a value of ‘2’.
b. Use ‘Reclassify’ tool to give MS4 drainage area pixels a value of ‘1’.



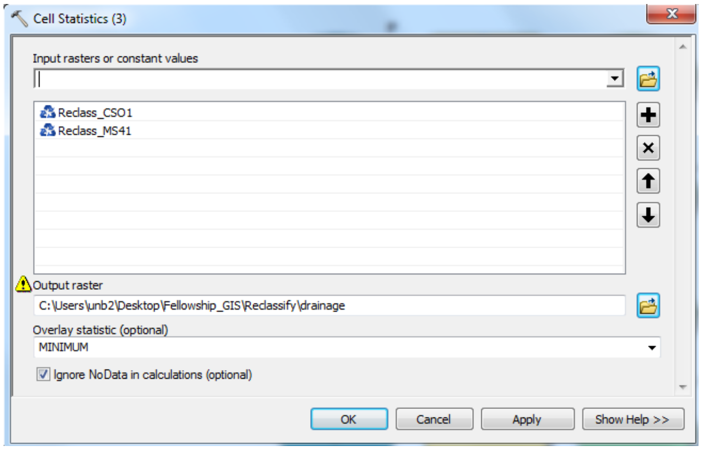


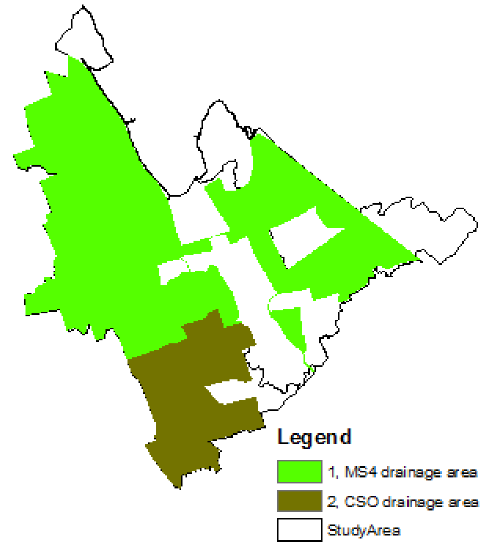






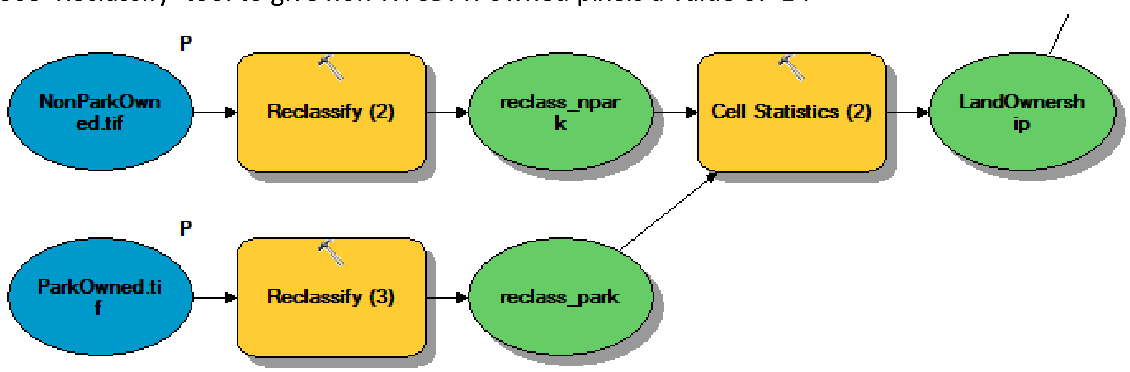
c. Use ‘Cell Statistics’ tool with ‘minimum’ function to merge into one prioritization layer.

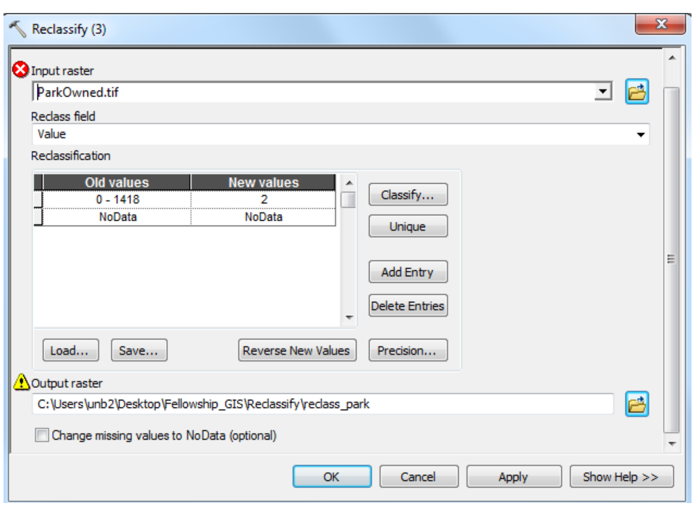


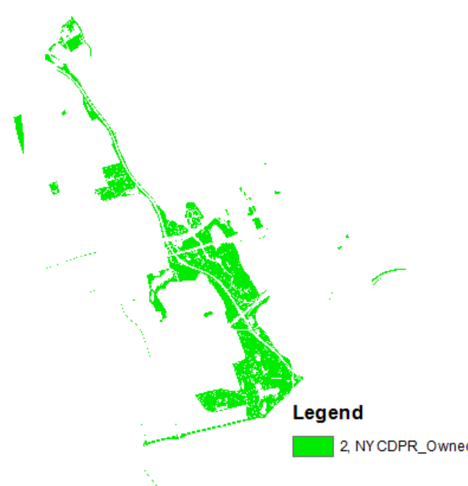


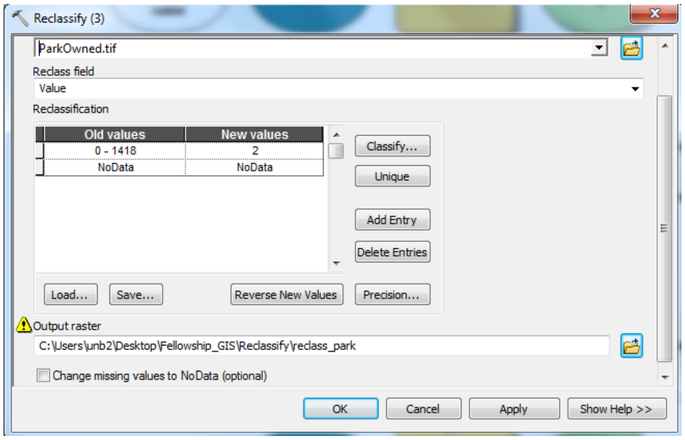
Step 14: Categorize NYCDPR-owned land as higher priority than other lands.

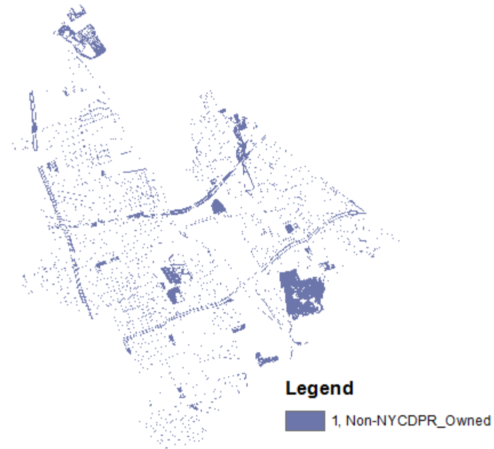
a. Use 'Reclassify' tool to give NYCDPR-owned pixels a value of '2'.
b. Use 'Reclassify' tool to give non-NYCDPR-owned pixels a value of '1'.



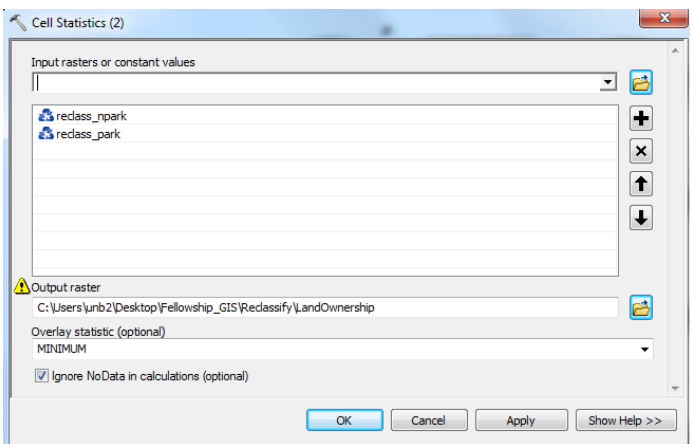


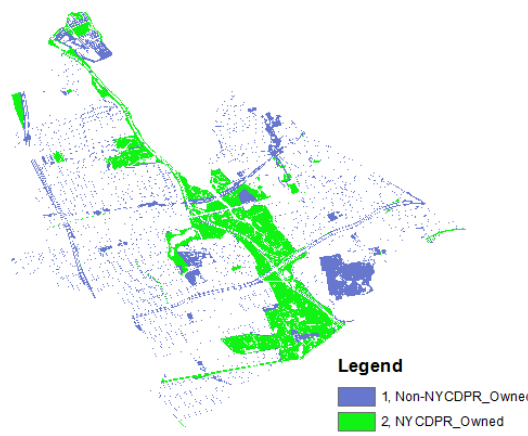






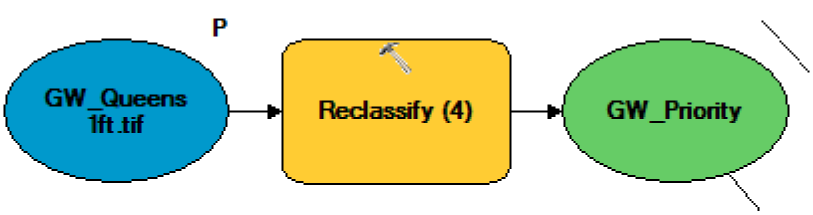
c. Use 'Cell Statistics' with the 'minimum' function to merge into one layer.

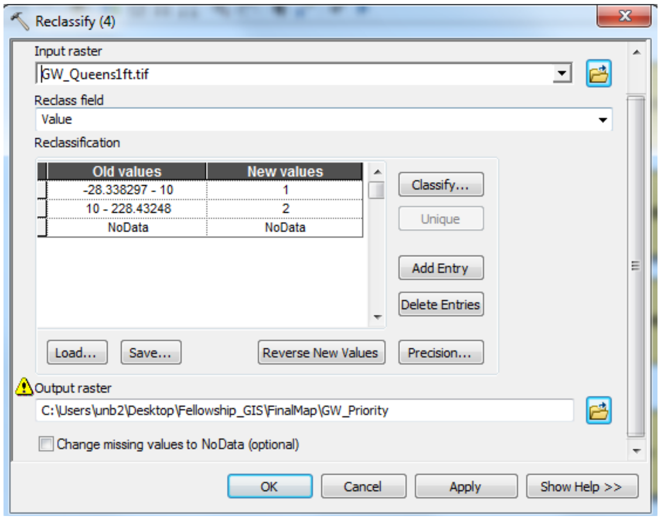


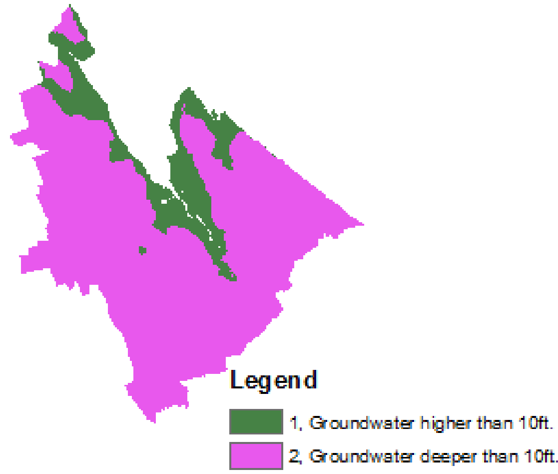


Step 15: Categorize areas where groundwater is deeper than 10 feet as higher priority.

a. Use 'Reclassify' tool to give pixels where groundwater is deeper than 10 feet a value of '2'.
b. Use 'Reclassify' tool to give pixels where groundwater is higher than 10 feet a value of '1'.

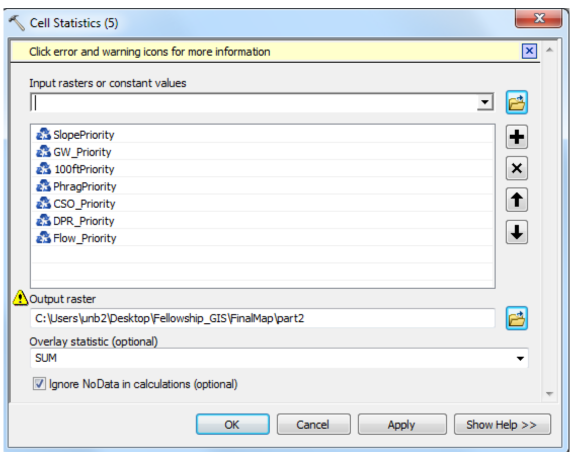


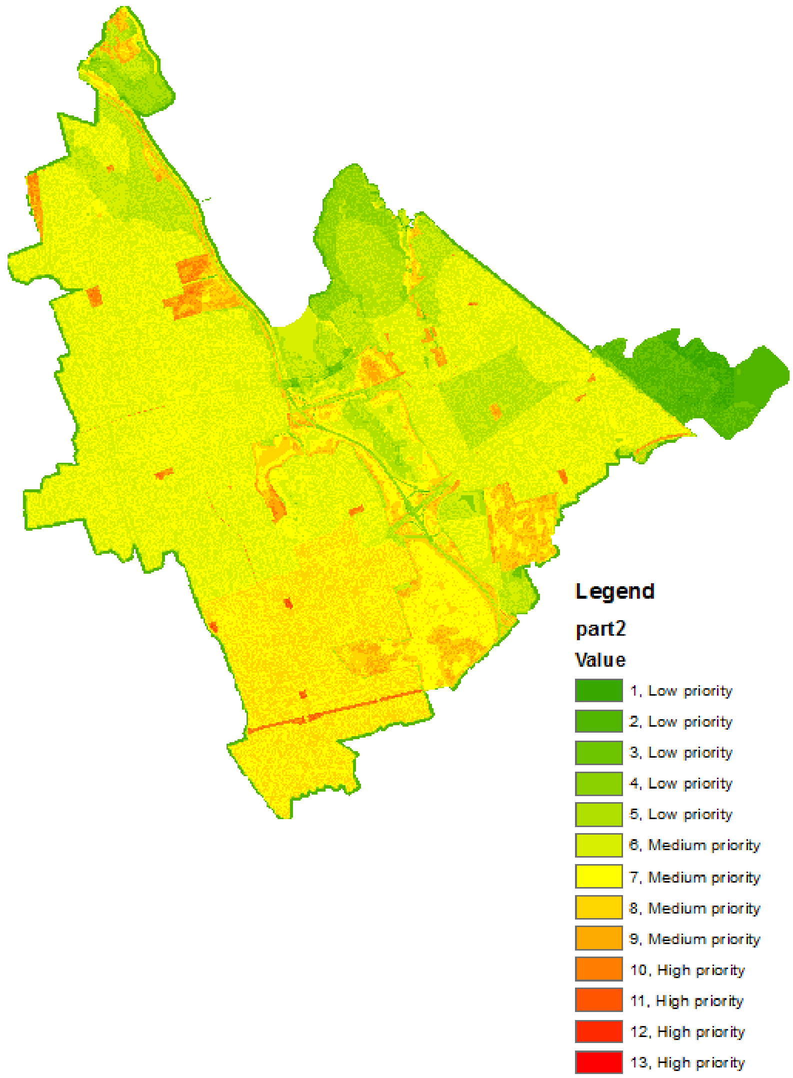




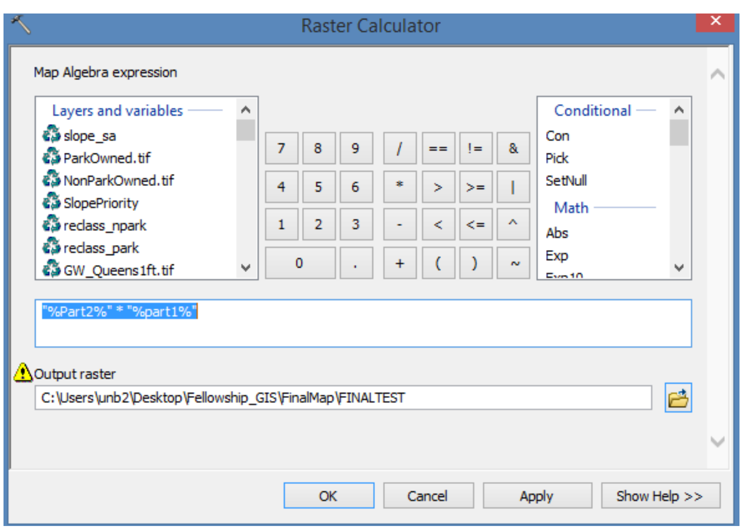
Step 16: Add all prioritization layers together to get final scores for each pixel.

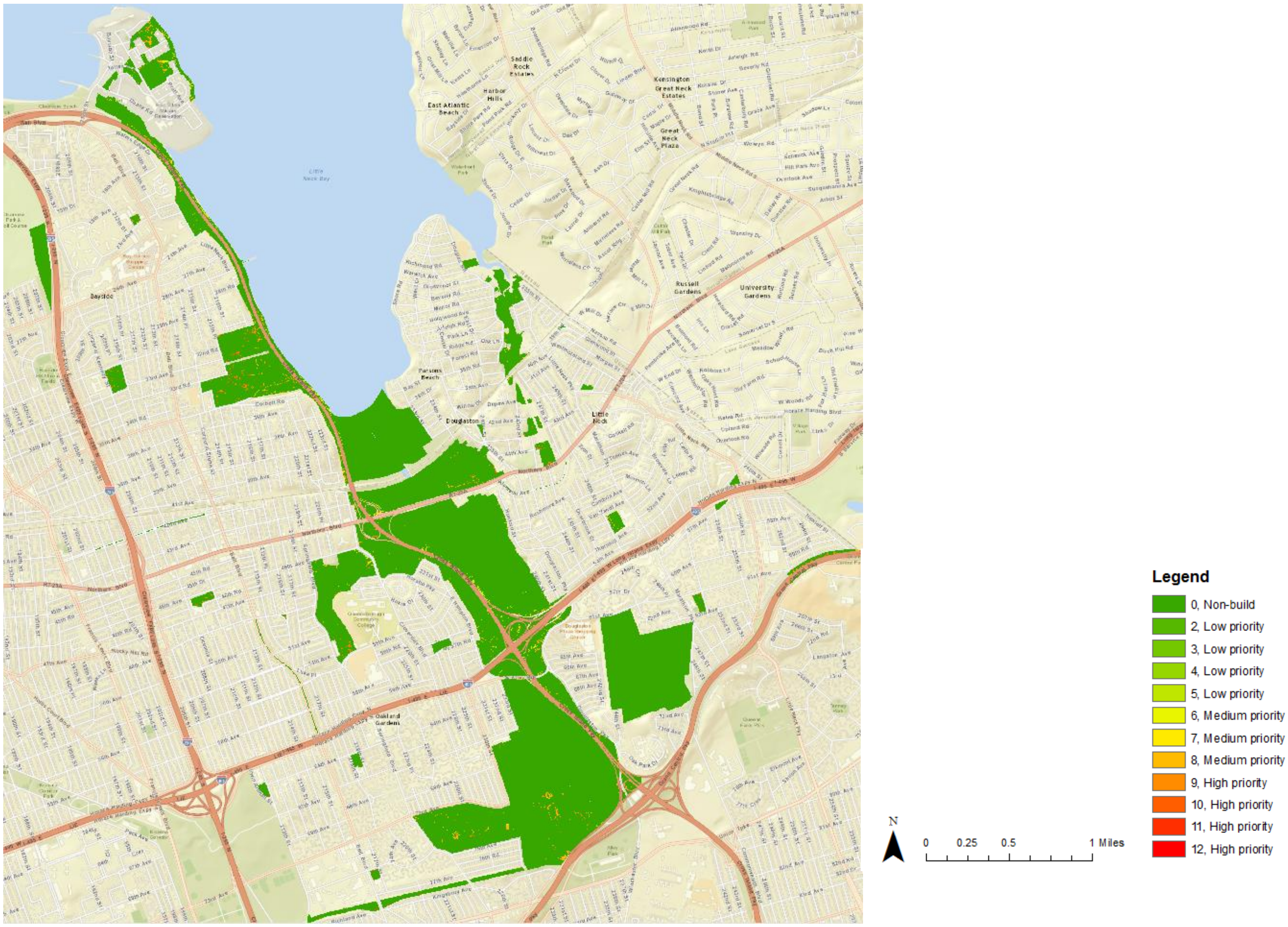
Use ‘Cell Statistics’ tool with the ‘sum’ function to add all layers together.





Step 17: Multiply the final output from Part 1 with the output from Step 16 to form the **final output from Part 2**.




Legend
0, Non-build
2, Low priority
3, Low priority
4, Low priority
5, Low priority
6, Medium priority
7, Medium priority
8, Medium priority
9, High priority
10, High priority
11, High priority
12, High priority
N
0 0.25 0.5 1 Miles