Developing an Automated Land Cover Classifier Using LiDAR and High Resolution Aerial Imagery

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Abstract

This project is a refinement of the process used to create a land cover as well as tree canopy density maps using modeling techniques on LiDAR LAS point cloud dataset as well as multispectral aerial photographs from the National Agriculture Imagery Program (NAIP). Using a geoprocessing model, a land cover map is created based on filtered returns from LiDAR point cloud data (LAS dataset) and high resolution multi-spectral aerial photographs for Clarion County in Pennsylvania. The newly developed model produced 7 classes instead of 5 in the original one (Added Water and Artificial Surfaces) at 10ftx10ft spatial resolution. The model was tested against areas with different sizes (townships and municipalities) which revealed an enhanced classification accuracy between 94% and 96%. Furthermore, a geoprocessing service was created in order to share the results of the land cover classification as well as the tree canopy density calculation. The service was tested and delivered in the form of a web application where users can select an area of interest and the model will produce the land cover and/or the tree canopy density results (*http://maps.clarion.edu/LandCoverExtractor*). The results can be printed in the form of a PDF (or other formats) as a final map layout with the highlighted area of interest and its corresponding legend. The interface also allows the user to download the results of an area of interest as a zipped file geodatabase for further investigation using their desktop mapping software.

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Introduction

This project expands on earlier work that created a model that extracts the land cover as well as the tree canopy density of a selected study area within the County of Clarion, PA.

In this study, methods of LiDAR point cloud data manipulation combined with supervised multi-spectral image classification are applied in order to extract both the land cover and the tree canopy density (percent coverage) of any selected municipality within Clarion County. The resulting model could be easily adjusted to accommodate the data of any other county in Pennsylvania given that the required data is prepared accordingly.

Furthermore, as a main objective of this project, the dissemination of the results through a web interface was accomplished. The design and function of the interface was planned to be user friendly and contains the capability of customizing the extraction of the land cover and the tree canopy information for a user-defined area. The results could be displayed, prepared for download, and printed using a template layout.

Methods

In the earlier model, the LAS dataset was used to extract different features using a different set of classes and returns. The tree canopy density was extracted by dividing the number of tree returns by the total number of returns within a 10ftx10ft cell area. Similarly, the structures were also extracted using their corresponding class and return numbers. Those tree as well as structure returns were combined later on with the other classified data to produce the final output for the land cover map.

Ground only data were also extracted from the LAS dataset and used as a constraining mask for the unsupervised classification of the NAIP multiband aerial photographs. Which produced 3 additional classes, namely: Grassland (e.g. open vegetation), Roads (mainly asphalt pavements), and Other Pavement Surfaces.

It is important to note that using the unsupervised classification was acceptable for only the area of interest that was used to test the model. Once this area is changed to another Municipality boundaries the results were unpredictable, the classes were arbitrarily merged and the water bodies were misclassified as structures in most cases. Besides, the accuracy assessment of this classification method for this specific selected area was 77%. This necessitated the use of a more rigorous method to identify most of the possible land cover classes that could be extracted using the given data.

Land Cover Classification

Trees and Structures Extraction

The extraction of the Trees as well as the Structures was conducted using the earlier methods. A revision of the different classes and returns of the LiDAR LAS dataset revealed that the adopted extraction method was optimal according to the given data. The same methods were also applied to calculate the tree canopy density. The model was modified to accommodate data from different areas of interest instead of the predefined study area of the previous project.

Supervised Classification of the Ground Areas

Training areas (77) were selected for a total of 15 different classes according to *Table 1*. The spectral signatures of those 15 classes were reviewed and, according to their separations, they were aggregated to 4 main classes, namely: Artificial Surfaces, Bare Ground, Grassland, and Pavement. The Shadow class was difficult to classify since it represented all of the 4 main classes, but since Clarion County is mostly rural, it was assumed that the shadows represented mostly Grassland. It was aggregated with the Grassland class.

Table 1 General and specific classes of the training polygons for the supervised classification

Category Name	Class Name	Number of Polygons
Artificial Surfaces	Artificial Turf	3
	Track Cover 1	2
	Track Cover 2	1
	Track Cover 3	2
Bare Ground	Bare Ground Bright	4
	Bare Ground Medium	7
	Bare Ground Dark	5
Grassland	Grassland 1	14
	Grassland 2	3
Pavement	Pavement 1	8
	Pavement 2	6
	Pavement 3	3
	Pavement 4	4
	Pavement 5	5
Shadow	Shadow	10

The final signature file for all class aggregation was graphed and showed a good separation in the multi-spectral aerial photo bands (1-4). Figure 1 depicts the spectral signatures of the aggregated classes. The signature file was saved and used in the general model as a reference to the supervised classification. This ensured the integrity of the classification and its uniformity when applied to any area of interest similar to Clarion County. Using the signature file for multiple smaller test area classification resulted in acceptable results overall.

Within the model, a Maximum Likelihood supervised classification was carried out using the given signature file and the resulting classified raster was prepared to be merged with the other classes (Trees, Water, and Structures).

Water Bodies Preparation

The "Water" bodies were extracted using the LiDAR derived breaklines, available from the Pennsylvania Spatial Data Access (PASDA) website, that were labeled as "Double Line Drains" and "Lakes & Ponds", the lines were carefully edited in order to ensure the closure of all area features. It was then converted to a polygon feature class.

The polygon feature class was used to prepare the Municipalities polygons for the LiDAR LAS file manipulation. Since the water classes were mainly classified as “Structures” in the class returns of the available point cloud data, the Water polygons were erased from the Municipalities areas. The resulting Municipalities (with no Water bodies) was used as a mask for the LiDAR LAS dataset manipulation. Furthermore, the water class was rasterized and added to the classification model.

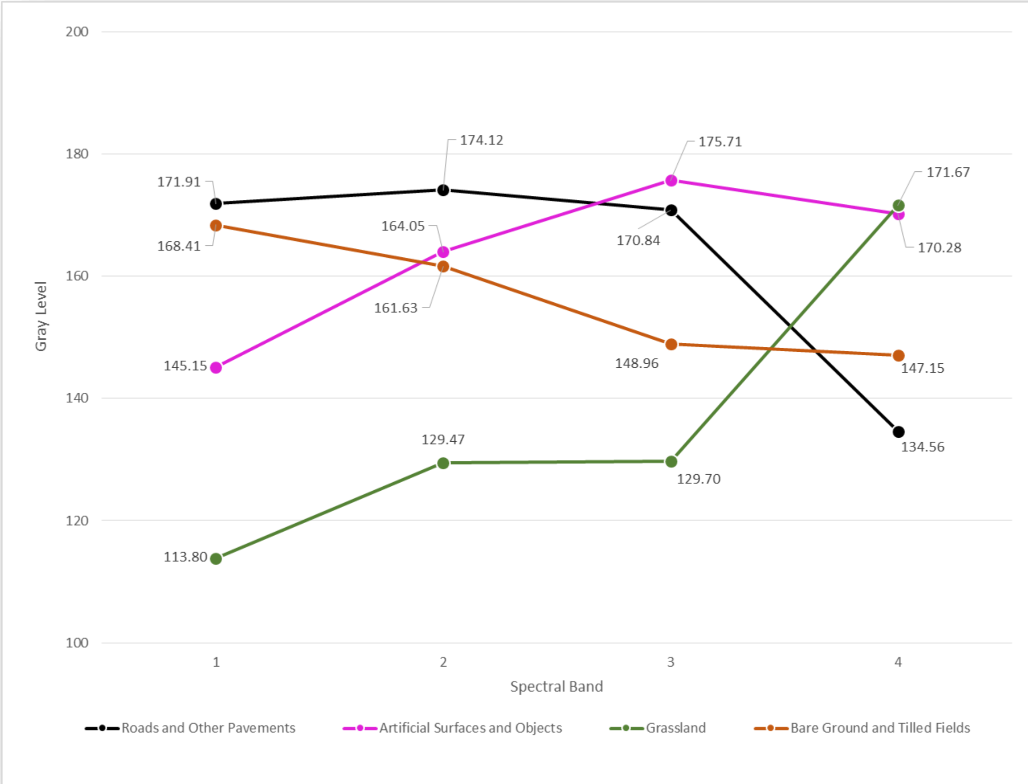


Figure 1 Line plot of the signature file of the aggregated classes

Land Cover Classification Assembly

The last step for the land cover classification was to assemble all individually produced classes in one final raster file. The Structures, Trees, Artificial Surfaces, Bare Ground, Grassland, Roads, and Water were all combined in one raster output in the model. Furthermore, the text description for each of the classes, the area in square feet, and the percent from total were calculated for each of the classes and added to the attribute table.

Table 2 Final land cover classes and their corresponding symbol and description

Class Code (Value)		Description
1		Grassland
2		Roads
3		Bare Ground
4		Structures
5		Trees
6		Artificial Surfaces
7		Water

Overall Land Cover Classification Accuracy Assessment

An overall accuracy assessment was carried out for three Municipalities: Clarion Borough, Sligo Borough, and Porter Township (Figure 2). Not all of the identified classes were present in all three municipalities. For example, Clarion Borough did have some Artificial Surfaces that were located at the stadium as well as some of the outdoors tennis courts while it was absent in both Sligo Borough and Porter Township.

300 random points were generated by the model within each of the selected municipalities and intersected with the classification result to produce the reference data to ground truth checks. All truth data checks were carried out on the original NAIP aerial photograph due to the unfeasibility of conducting ground checks within the available time and resource limits. Also, some inconsistencies existed due to the 4 years time difference between the LiDAR LAS point cloud dataset (2006) and the NAIP multi-spectral aerial photographs (2010).

Each point's ground truth information was recorded and cross tabulated against the classified data for this specific point. The resulting accuracy assessment revealed an overall producer accuracy of 94.33% for the Clarion Borough, 94.67% for Sligo Borough, and 95.67% for Porter Township (Figure 3, Figure 4, and Figure 5)

Model Refinement

The general model designated to extract the land cover as well as the tree canopy density was reviewed for possible enhancements. A few adjustments were performed in order to ensure the smooth operation and use versatility for a broader study area.

General Model Workflow Enhancements

It was necessary to use two different study area definitions for the Municipality borders, one for all Municipality polygons and the other would be excluding water polygons. This operation could be included within the model, alternatively, it was elected that this data should be pre-prepared prior to running the model (refer to the Data Requirements section below). The Municipalities feature class that excludes the water polygons was used in the LAS dataset operation for tree canopy density calculations, while the complete borders of the Municipalities feature class was used in the remaining operations of the land cover production.

Running the model as a tool, the user would be prompted to select a Municipality using a query from the attribute table (e.g. !NAME! = "Clarion_Borough"). According to this initial selection, all operations are executed within the defined borders. The attribute calculations for percentage of tree canopy from total as well as the land cover areas and percentages are all now sensitive to the selected Municipality (in the earlier model, the total number of cells of a defined area were actually embedded in the model).

The ground classifier now uses the supervised classification method explained earlier in this report, which makes use of a given signature file that would be required as part of the data necessary to run the model.

Finally, a random point generator section was added to the model in order to facilitate the accuracy assessment operation in the future. For each completed classification, 300 random points would be automatically generated, intersected with the produced raster land cover, and exported as a DBF table in the Output folder of the project. This DBF table contains the point ID as well as its corresponding classified value from the land cover raster.

Figure 2 Clarion County municipalities. The selected municipalities for the accuracy assessment are highlighted.

		Classified							
		1	2	3	4	5	6	7	
Truth	1	117 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	117
	2	0 (0%)	52 (96.3%)	0 (0%)	0 (0%)	0 (0%)	2 (3.7%)	0 (0%)	54
	3	0 (0%)	0 (0%)	8 (88.89%)	1 (11.11%)	0 (0%)	0 (0%)	0 (0%)	9
	4	0 (0%)	1 (1.92%)	2 (3.85%)	45 (86.54%)	4 (7.69%)	0 (0%)	0 (0%)	52
	5	0 (0%)	0 (0%)	2 (3.39%)	5 (8.47%)	52 (88.14%)	0 (0%)	0 (0%)	59
	6	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	2 (100%)	0 (0%)	2
	7	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	7 (100%)	7
		117	53	12	51	56	4	7	300

Figure 3 Clarion Borough transition matrix. A 94.33% overall accuracy was achieved. Each cell contains the point count as well as the percent correct from the generated random points.

		Classified							
		1	2	3	4	5	6	7	
Truth	1	136 (98.55%)	0 (0%)	2 (1.45%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	138
	2	1 (11.11%)	8 (88.89%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	9
	3	0 (0%)	1 (1.79%)	54 (96.43%)	0 (0%)	1 (1.79%)	0 (0%)	0 (0%)	56
	4	0 (0%)	0 (0%)	0 (0%)	6 (75%)	2 (25%)	0 (0%)	0 (0%)	8
	5	1 (1.16%)	0 (0%)	0 (0%)	8 (9.3%)	77 (89.53%)	0 (0%)	0 (0%)	86
	6	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0
	7	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3 (100%)	3
		138	9	56	14	80	0	3	300

Figure 4 Sligo Borough transition matrix. A 94.67% overall accuracy was achieved. Each cell contains the point count as well as the percent correct from the generated random points.

		Classified							
		1	2	3	4	5	6	7	
Truth	1	162 (96.43%)	0 (0%)	5 (2.98%)	0 (0%)	0 (0%)	1 (0.6%)	0 (0%)	168
	2	0 (0%)	5 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5
	3	0 (0%)	1 (2.08%)	47 (97.92%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	48
	4	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0
	5	0 (0%)	0 (0%)	0 (0%)	6 (7.69%)	72 (92.31%)	0 (0%)	0 (0%)	78
	6	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0
	7	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (100%)	1
		162	6	52	6	72	1	1	300

Figure 5 Porter Township transition matrix. A 95.67% overall accuracy was achieved. Each cell contains the point count as well as the percent correct from the generated random points.

Model Tool Simplification

The produced model was large and difficult to follow. Therefore, it was broken into seven (7) sub-models (model tools). The main model "Classifier and Tree Canopy Extractor" (Figure 6) was produced using all 7 model tools (Figure 12 to Figure 18).

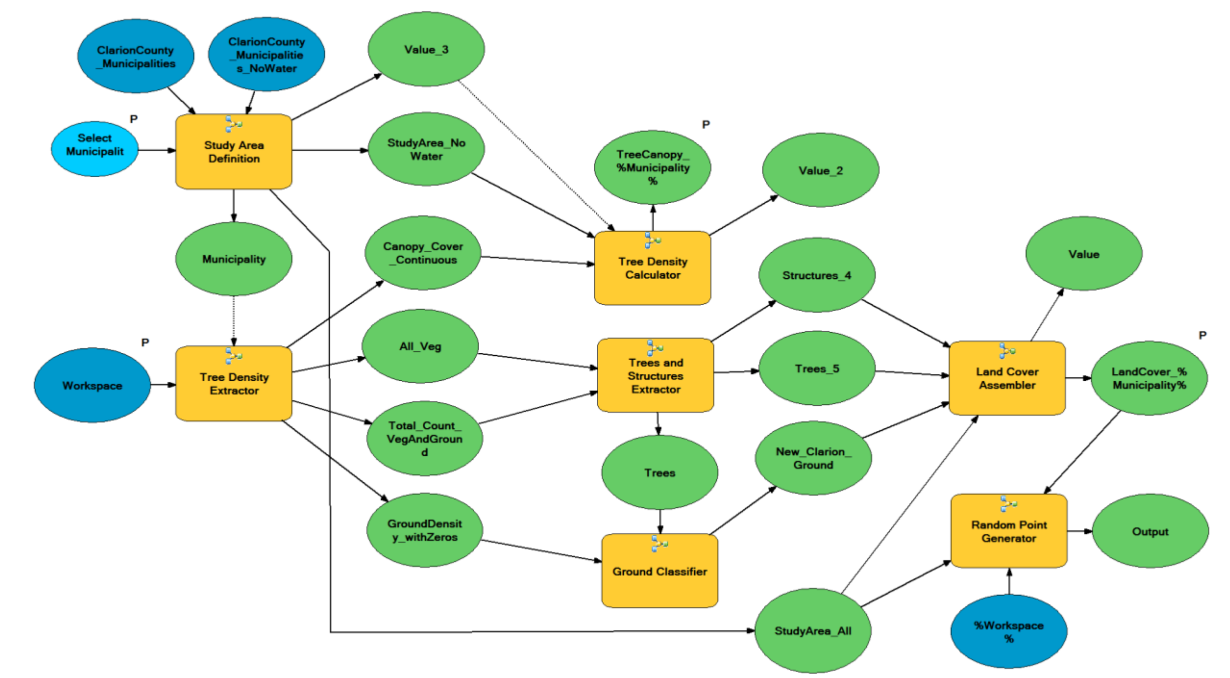


Figure 6 Main Model: Classifier and Tree Canopy Extractor

The main model, when run as a tool, prompts the user for the current workspace where the data is found, the Municipality Name using a SQL query builder, and the output name for the tree canopy as well as for the land cover rasters (Figure 7).

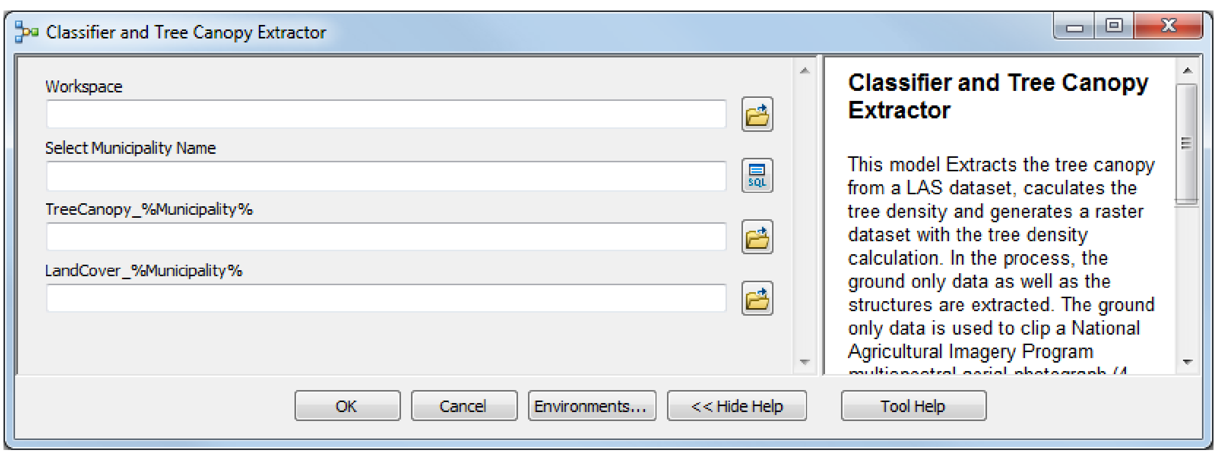


Figure 7 The main Classifier and Tree Canopy Extractor tool dialogue box

Data Requirements for the Model Tool

The model is designed to run on the Default geodatabase. The Project folder should contain the following subfolders and data:

1- **Data**

A folder containing all of the necessary data for the model to run properly. It contains:

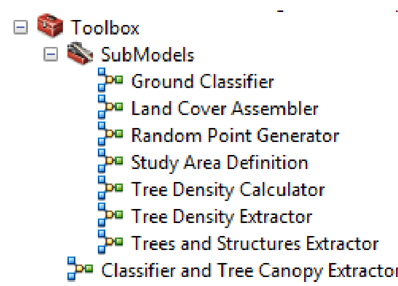
  a. **Lidar**: Folder
     - *LAS:* A folder containing all LAS files)
     - LAS dataset of the files stored in the LAS folder
  b. **NAIP**: Folder
     - *TIFF:* A folder containing all tiles of the multi-spectral NAIP aerial photographs)
     - *NAIP.gdb:* A file geodatabase that contains a raster mosaic dataset of all TIFF files)
  c. **Other**: Folder
     - *PAVIEW_OtherData.gdb:* A file geodatabase that contains the following:
       – *VectorData:* Dataset
         > *Municipalities*
         > *Municipalities_NoWater*
       – *Water_Raster:* rasterized water bodies polygons
     - *clarionnaip_signaturefile.gsg:* The signature file required by the supervised classification
     - *TreeCanopyTemplate.lyr;* A layer file containing the recommended symbology of the tree canopy density (percentages)
     - *LandCoverTemplate.lyr;* A layer file containing the recommended symbology of the land cover classes (descriptions)

2- **Output:**

A folder that would hold the generated DBF files for accuracy assessment

3- **PAVIEW.gdb**:

A geodatabase that contains a toolbox with the *Classifier and Tree Canopy Extractor* tool and a *SubModels* toolset with all 7 sub-models.



It is important to note in order for the model to handle the LAS dataset at least 3D Analyst ArcGIS Extension is required. Spatial Analyst extension would be also required to manipulate raster data (classification, reclassification, and other functions). Those extensions need to be enabled prior to running the model tools.

Land Cover and Tree Canopy Extractor Web Application

Initially, the main model and its corresponding model tools were planned to be shared online in order to be able to dynamically produce both land cover as well as tree canopy density data for a user defined area. But this idea was modified after encountering several technical issues, among which:

- The size of the data hosted at Clarion University's server would be extremely large and it would consume most of the web and data server's storage space;
- Due to the complexity of operations, the processing times measured at the local level to produce both the land cover and the tree canopy density rasters of a small-sized municipality was high (e.g. 4:08 minutes for Clarion Borough, and 3:40 minutes for Sligo Borough) and to produce the same results for a larger municipality would significantly increase the processing time (e.g. 11:50

minutes for Porter Township, second largest municipality in Clarion County after Farmington Township); and,

- Due to the complexity of the model, that was not originally designed to be shared online as a geoprocessing service, it would be time consuming and complex to be manipulated for web sharing.

Therefore, it was decided to produce a mosaicked land cover as well as tree canopy density raster datasets using the desktop model (*Classifier and Tree Canopy Extractor*) and use both of them as inputs for other geoprocessing models that clip, display, print, and export a user-defined area of interest from each.

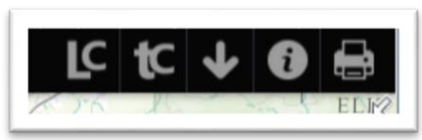
Three geoprocessing models were created on the basis that they will be shared through a geoprocessing service and that will be consumed in a web application. They were all assigned a customized geoprocessing widget in the application.

All of those geoprocessing models read from a file geodatabase and used a map service that contains the Land Cover as well as the Tree Canopy datasets as ancillary data for display and referencing purposes.

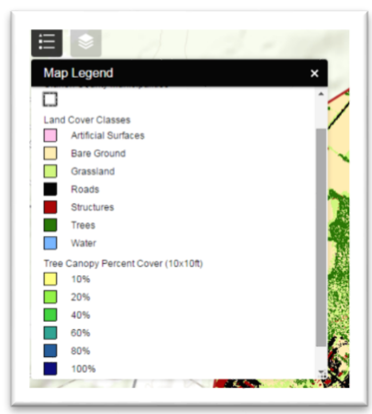
The Web Application Interface

The published web interface (http://maps.clarion.edu/LandCoverExtractor) has general widgets for changing the basemap, display the legend, and list the operational layers. All those widgets are located near the navigation bar on the top left corner of the window (Figure 8). All other application-related geoprocessing custom widgets are located at the top right corner.

From the left, **LC** is the Land Cover Extractor, **tC** is the Tree Canopy Extractor, the down arrow, is the Download Land Cover and Tree Canopy geoprocessing widget.

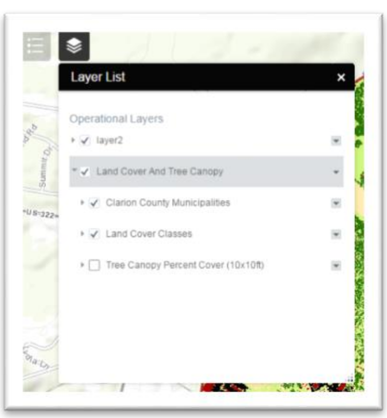


Land Cover Extractor (Geoprocessing Widget)



Similar to the Tree Canopy Extractor geoprocessing model, the Land Cover Extractor (Figure 9) clips a user-defined area of interest from the original dataset and updates the attribute table. It outputs the clipped land cover information of the desired area and displays the map.

When clicked, the Land Cover Extractor geoprocessing widget opens a sidebar with and Input tab where the user can pick a method for on-screen identifying an area of interest. Once done, the area is highlighted with a red boundary polygon. The user then clicks "Execute". Once the operation is complete, the app zooms in to the defined area of interest and displays the land cover of that area. It also automatically adds a layer on to the Layer List. This layer could be turned off to temporarily clear the display. Otherwise, the user could select the Input tab from the Land Cover Extractor widget, click Clear. Then run either the LC or tC tools to permanently update the display with the new result.



By default, the Map Legend shows the classification of both the land cover as well as the tree canopy density.

Those could be manipulated to show only the land cover classes by turning off the Tree Canopy Percent Cover (10ftx10ft) layer from the Layer list. It is a good idea to turn off the unnecessary layers prior to printing the results using the Print tool.

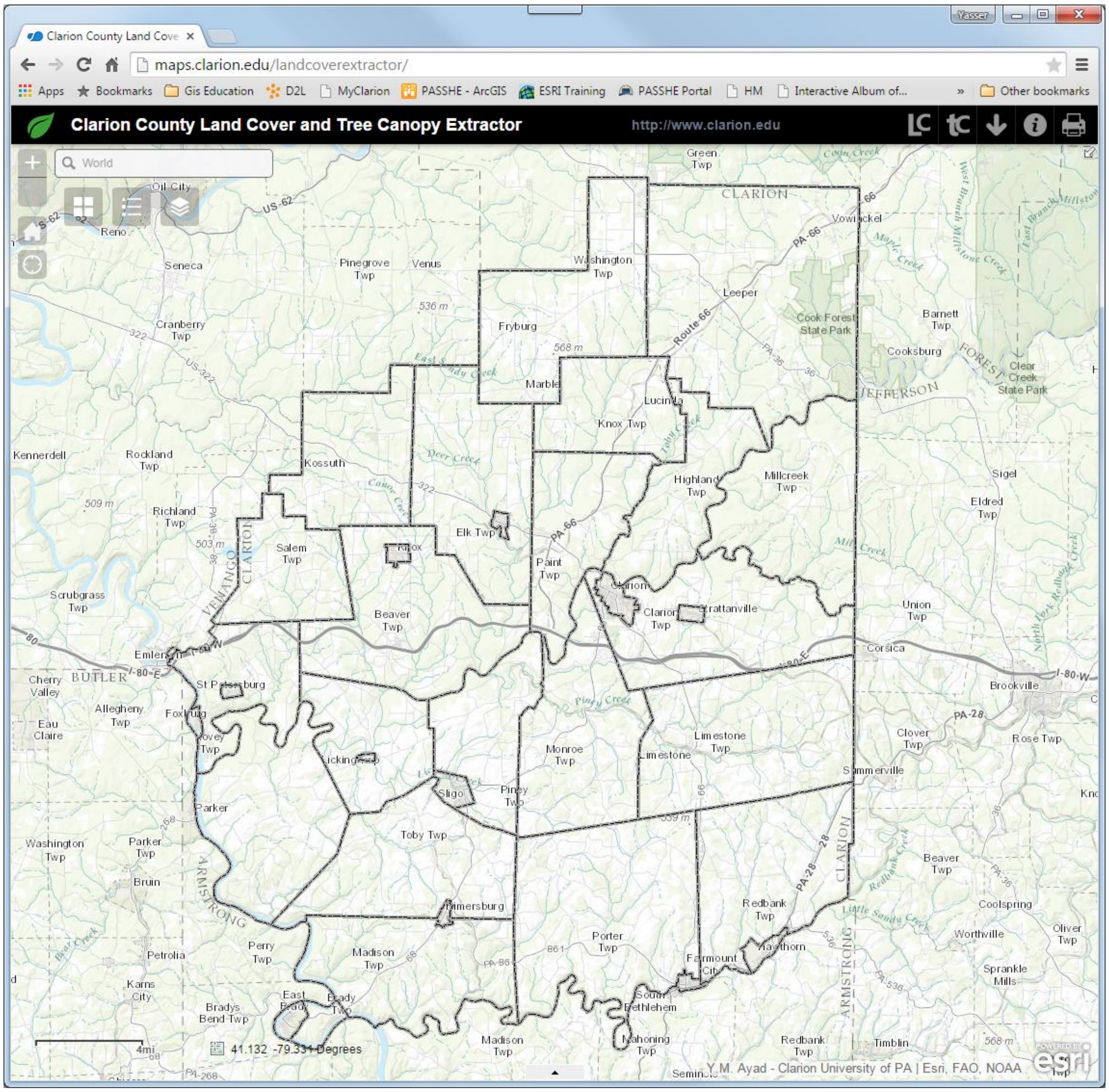


Figure 8 The Land Cover Extractor Web Application Interface

Tree Canopy Extractor (Geoprocessing Widget)

Similar to the Land Cover Extractor geoprocessing model, the Tree Canopy Extractor (Figure 10) clips a user-defined area of interest from the original dataset and updates the attribute table. It outputs the clipped Tree Canopy Density information of the desired area and displays the map.

Similar to the Land Cover Extractor interface, when clicked, the Tree Canopy Extractor geoprocessing widget opens a sidebar with and Input tab where the user can pick a method for on-screen identifying an area of interest. Once done, the area is highlighted with a red boundary polygon. The user then clicks "Execute". Once the operation is complete, the app zooms in to the defined area of interest and displays the tree canopy density percentages of that area. It also automatically adds a layer on to the Layer List. This layer could be turned off to temporarily clear the display. Otherwise, the user could select the Input tab from the Tree Canopy Extractor widget, click Clear. Then run either the LC or tC tools to permanently update the display with the new result.

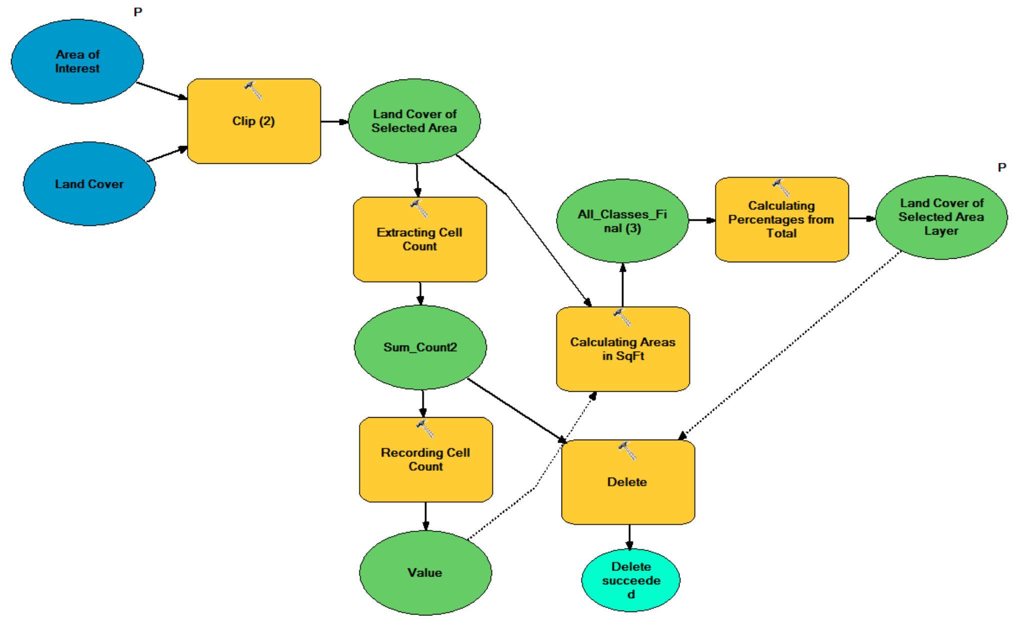


Figure 9 Web application geoprocessing model: Land Cover Extractor

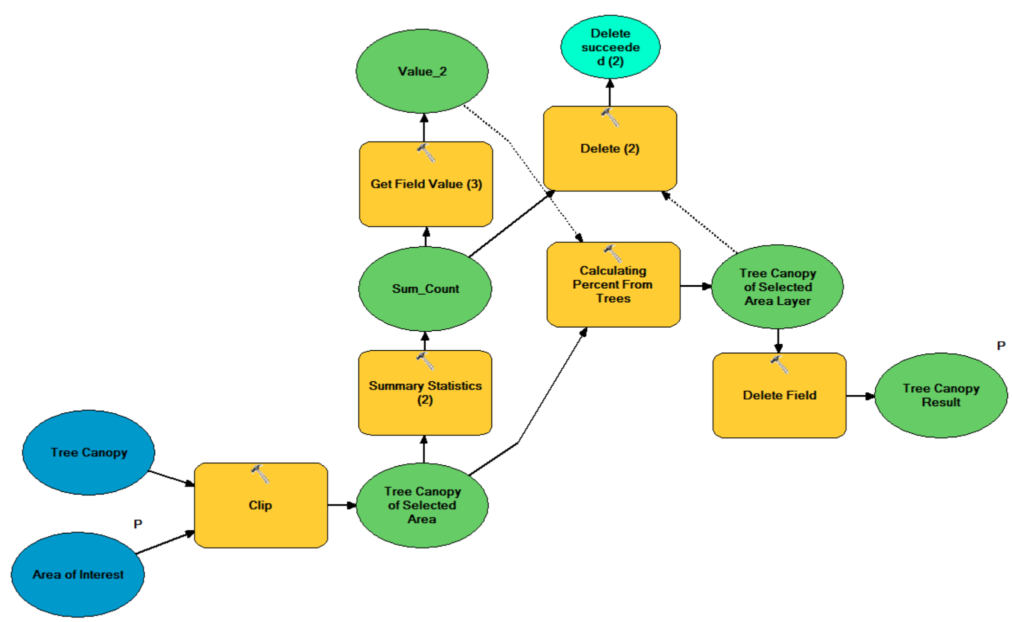


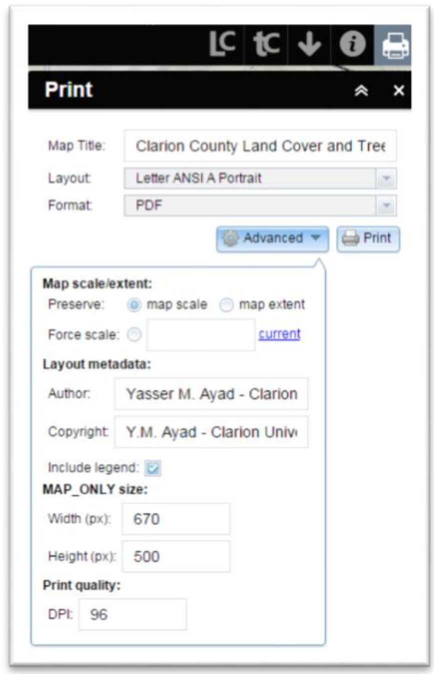
Figure 10 Web application geoprocessing model: Tree Canopy Extractor

By default, the Map Legend shows the classification of both the land cover as well as the tree canopy density. Those could be manipulated to show only the tree canopy density classes by turning off the Land Cover Classes layer from the Layer list.

It is a good idea to turn off the unnecessary layers prior to printing the results using the Print tool.

Print (Printing Tool)

The Print tool exports the result of either the Land Cover Extractor or the Tree Canopy Extractor to PDF (by default) or other image formats using a template layout for different page sizes.



The user has the option of modifying the Map Title, change the Layout (page size and orientation), and select a different file format for the output. Furthermore, the user can select the Advanced button to adjust other detailed options such as defining what to print, a scale for the print, change the Author name, include/exclude the legend (turn on or off the necessary layers from the Layer List prior to printing), define a map size if printing the Map only, and the print quality in DPI (the higher the DPI the better the resolution of the output and the larger its file size).

After clicking the submit button, an output would be generated in the desired format and a link will show to download the produced zip file.

Two sample map outputs of the Brady Township area are available in Figure 19 and Figure 20.

Download Land Cover and Tree Canopy (Geoprocessing Widget)

The Download Land Cover and Tree Canopy tool operates the same way as the LC and tC widgets, except that the results are not displayed, instead, they are saved as a zipped file geodatabase, and provides a link for its download. It gives the user the choice to select which layer to produce, either the Land Cover, Tree Canopy, or both.

About (Information)

The about button gives information about the tool, how it was built and how each of the provided data was created (land cover and tree canopy).

Future Work

This project opens the possibilities for sharing complex models with others through a packaged project folder or a web application. Many enhancements could be accomplished in order to provide either better data or better processes to produce the desired information. Following are a couple of suggestions that could be considered for future improvements.

Other Counties Consideration

Although this project was especially designed for Clarion County, similar data are available for all Pennsylvania and, therefore, the model that generates the land cover and the tree canopy as well as the web application for sharing this set of data could be both easily modified to accommodate any other county within the state. In addition, this project could be certainly applied to any other state with similar datasets, especially the LiDAR LAS point cloud files and Breaklines.

Process Enhancements

The following model enhancements could be carried out at a later stage:

- Unification of input and output coordinate systems.
- Improvement on processing speed by using In-Memory workspace for intermediate data instead of an active workspace path or a default geodatabase on disk.
- Cleaner model tool development in order to ensure a simpler and more straight-forward user interface.
- Adding a sub-tool that would use only one dataset for the Municipalities instead of two. This tool would erase the water polygons from the Municipalities and provides the output as an analysis mask for the LAS dataset manipulation.
- Provide an automated method for the creation of the transition matrix after the user input of the ground truth information.
- An updated set of data for input to the model might reveal more ways to enhance the classification process. For example, there is a 2013 multispectral NAIP aerial photographs available, they can be used to either update the land cover map or to improve on the classification process by removing some of the uncertainty of the shadows between the two dates (2010 and 2013).

Web Application Enhancements

The provided web application is basic in nature. It was developed using the Web ApppBuilder for ArcGIS, and mostly used all out of the box solutions for widgets and design templates. For a future design effort, the interface could be enhanced using custom templates for display and printing. Also, the geoprocessing widgets used in this app could be customized in a way to provide the following:

- Automatic clearing of the display and the layer list from any previous process once a new one is started; or at least provide a “Clear” button at the output level to provide the user to manually accomplish the task;
- Provide a feedback at the output level for each of the geoprocessing tasks (LC and tC) when the process is completed;
- Provide a splash screen that can be manually dismissed (or time-based) and would include information about the application, its purpose and how to navigate its components;
- Provide extended help and assistance at multiple levels at each geoprocessing task;
- Enrich the application by adding functions that would graph the output results and summarize its tables in a printable format;
- Unify the selection of the area of interest between all geoprocessing tasks instead of making the user to reenter it every time a process is run;
- Enable an option for the user to run each of the available processes using the existing boundaries of a selected Municipality in addition to the available polygon selections; and,

- Provide a user input form in order to collect suggestions on recommended enhancements of the application as well as the classification process.

Conclusions

This project demonstrated the possibilities of using process automation through the adoption of Model building techniques as well as the dissemination of the results through the deployment of a web-based application. The adopted techniques produced land cover and tree canopy density data at 10ftx10ft (≈3x3 meters) spatial resolution due to the use of LiDAR data and high resolution multispectral aerial photographs.

Using the web applications, any interested user or agency can download the available data, the data can be used and manipulated accordingly. It is hoped that the provided data would be helpful and that this project would receive input on the important issues that need to be considered in future development.

References

Chen, L., Chiang, T., and Teo, T. (?). *Fusion of LIDAR Data and High Resolution Images for Forest Canopy Modeling*. Center for Space and Remote Sensing Research, National Center University, Jhong-Li, Taiwan.

Syed, S., Dare, P. and Jones, S. (2005). *Automatic Classification of Land Cover Features with High Resolution imagery and LIDAR data: An Object-Oriented Approach*. Proceedings of SSC2005 Soatial Intelligence, Innovation and Praxis: The national biennial Conference of the Spatial Sciences Institute. September 2005. Melbourne: Spatial Sciences Institute.

Data Sources

- Pennsylvania Spatial Data Access (PASDA)
  http://www.pasda.psu.edu
- National Agricultural Imagery Prograph (NAIP)
  http://www.fsa.usda.gov/FSA/apfoapp?area=home&subject=prog&topic=nai
- Pennsylvania Department of Conservation and Natural Resources PAMAP
  http://www.dcnr.state.pa.us/topogeo/pamap/index.aspx

Acknowledgments

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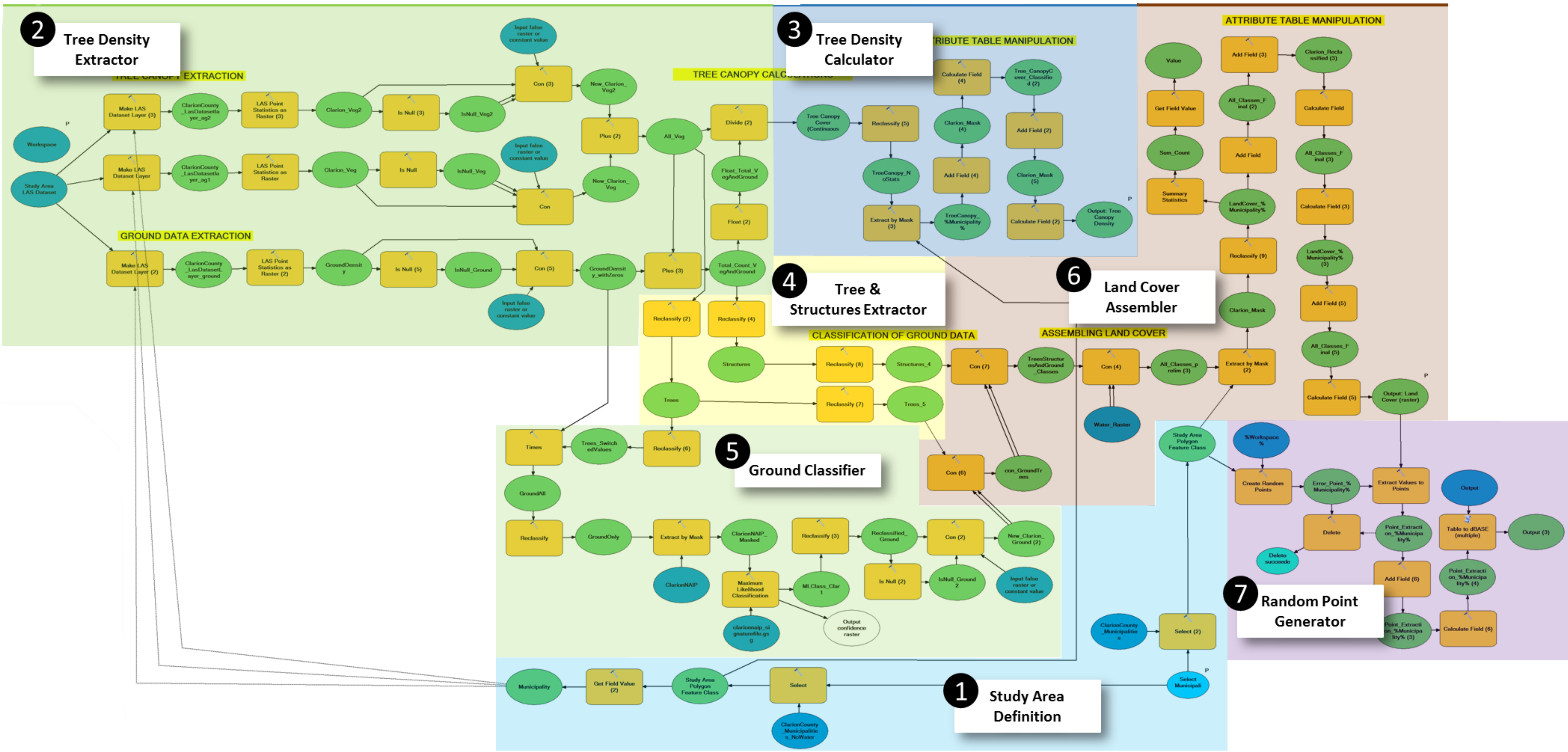

Figure 11 General model for tree canopy density and land cover calculation. It shows the main sub-models that were extracted for a simpler representation

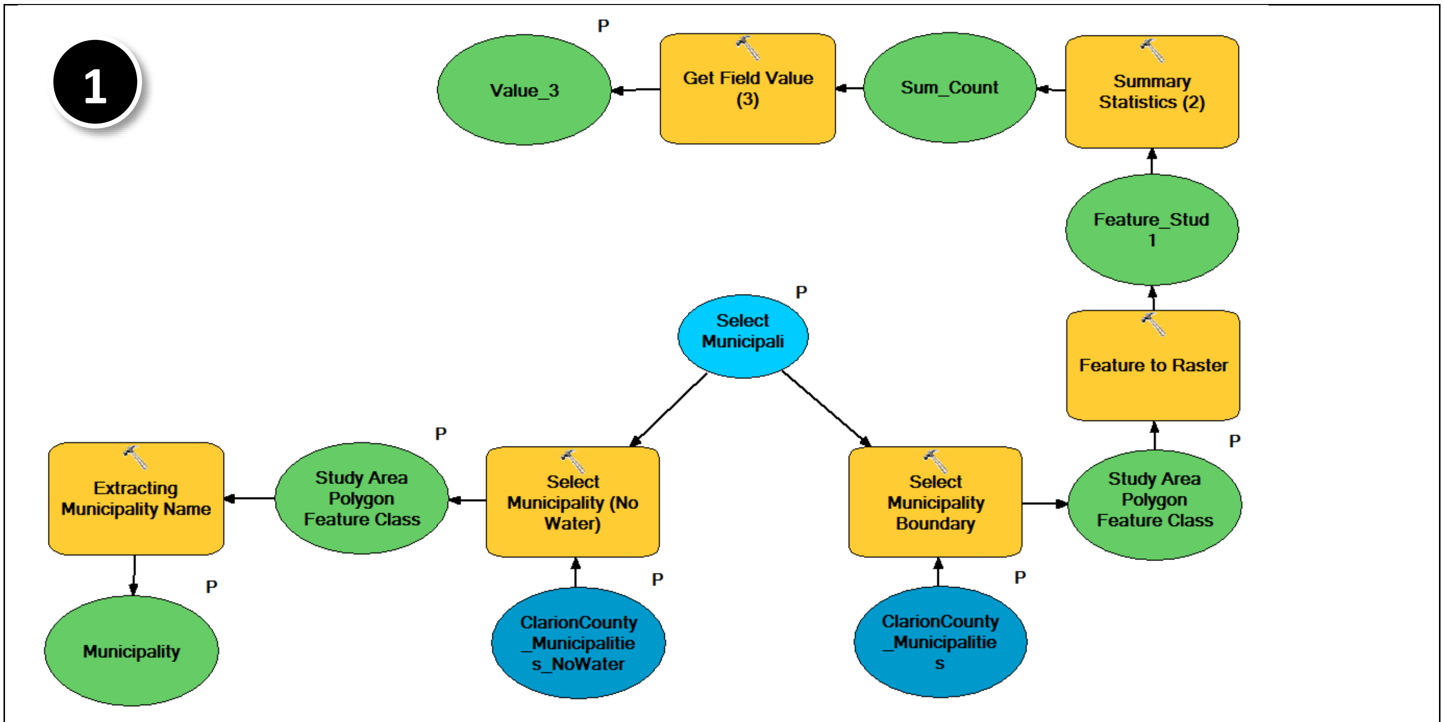

Figure 12 Sub-Model: Study Area Definition

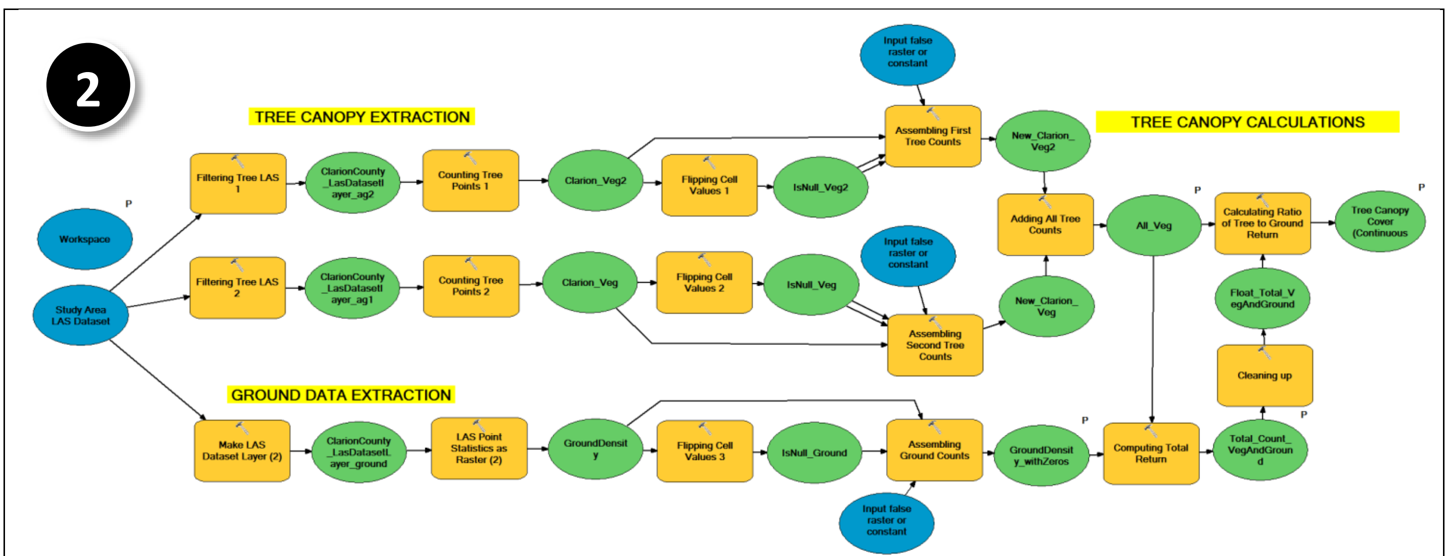

Figure 13 Sub-Model: Tree Density Extractor

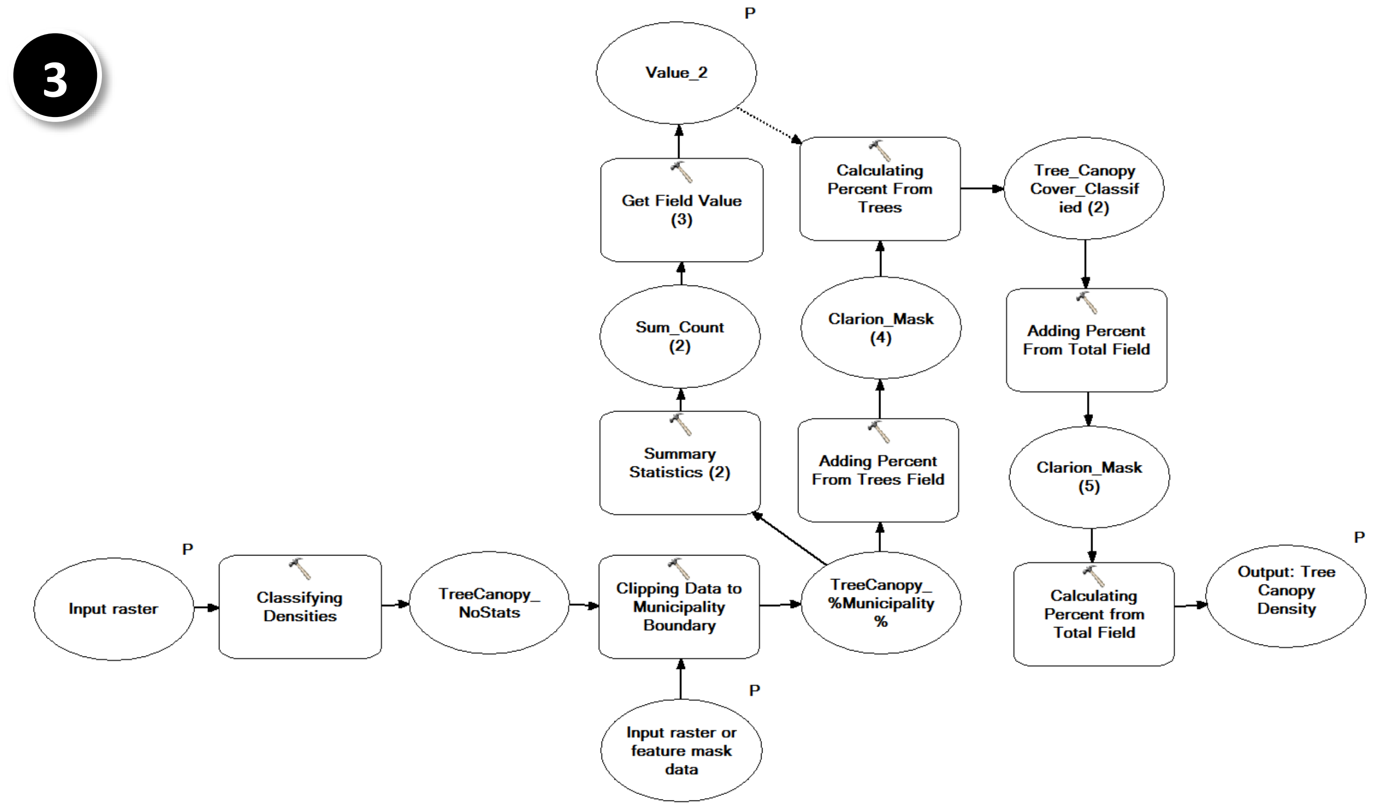

Figure 14 Sub-Model: Tree Density Calculator

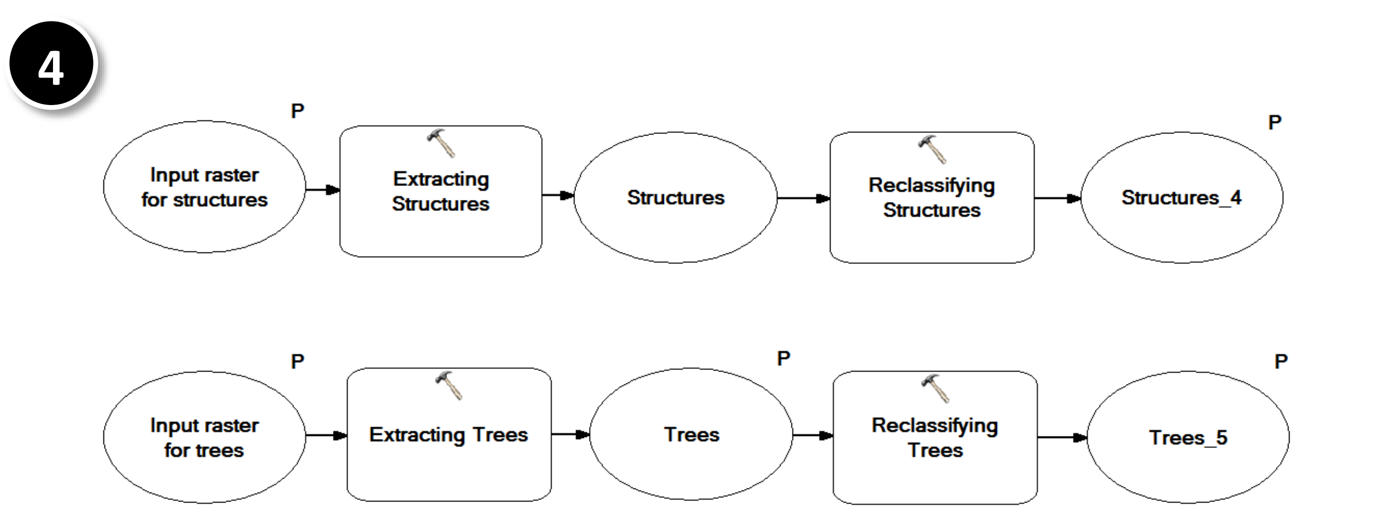

Figure 15 Sub-Model: Trees and Structures Extractor

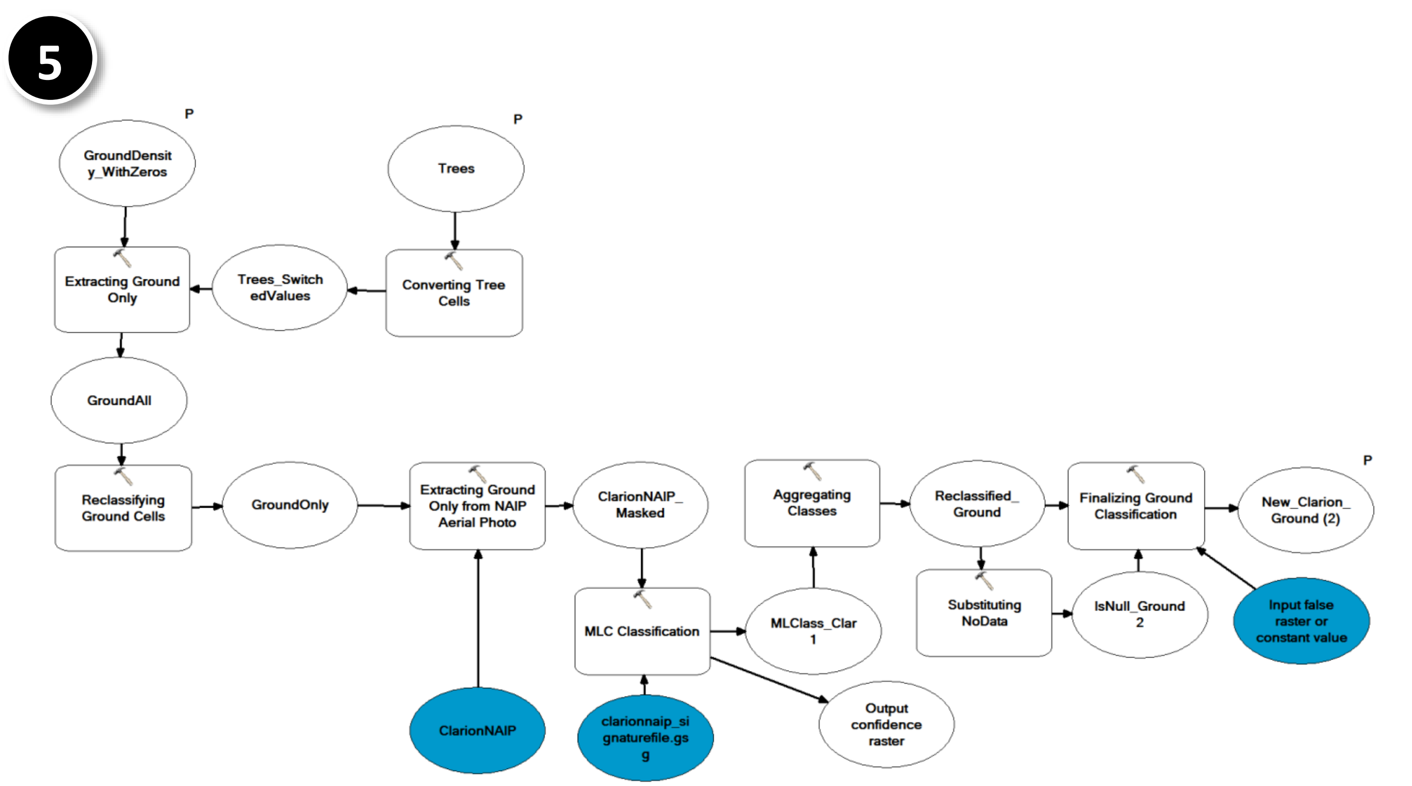

Figure 16 Sub-Model: Ground Classifier

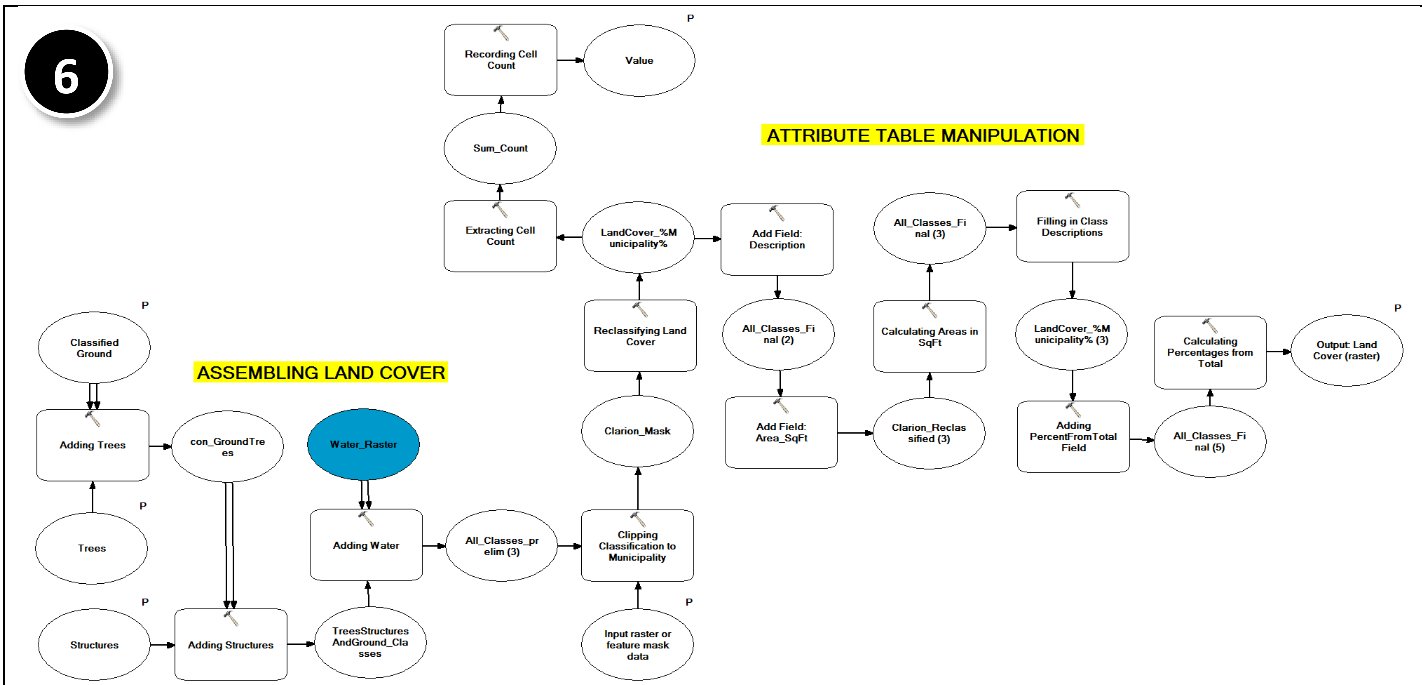

Figure 17 Sub-Model: Land Cover Assembler

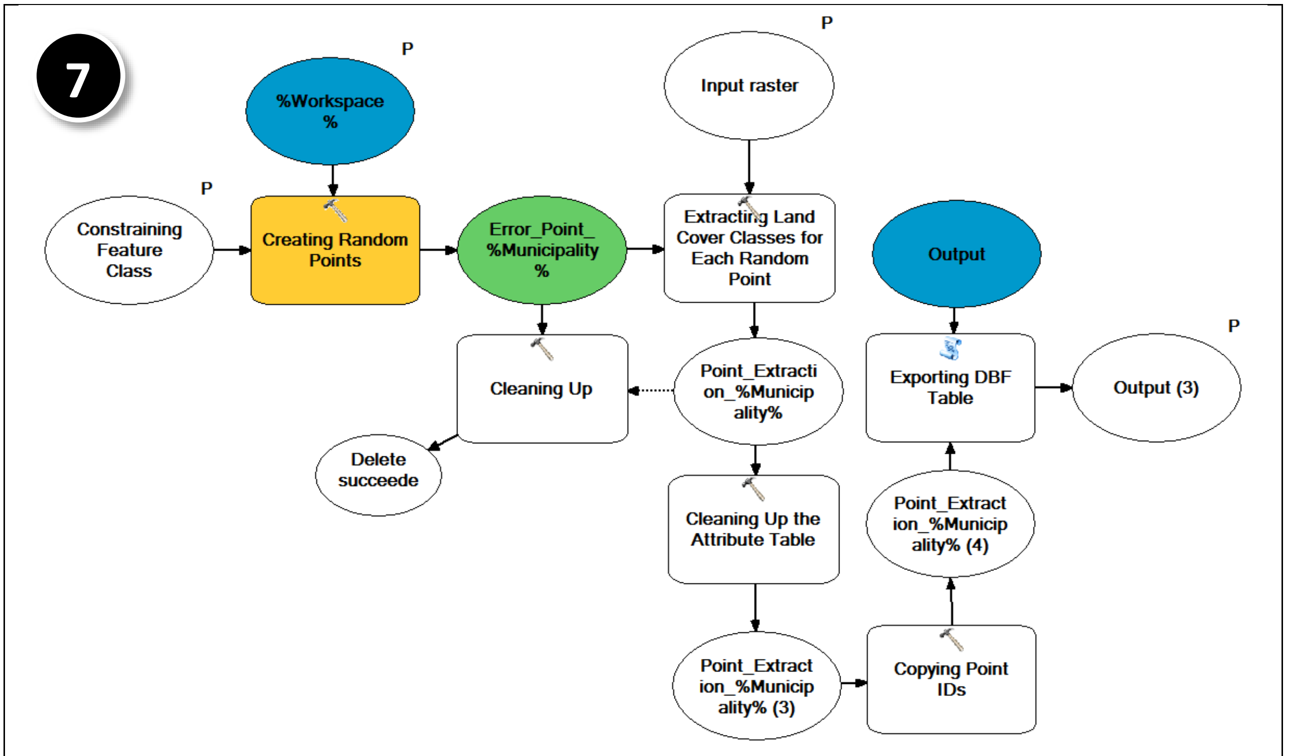

Figure 18 Sub-Model: Random Point Generator

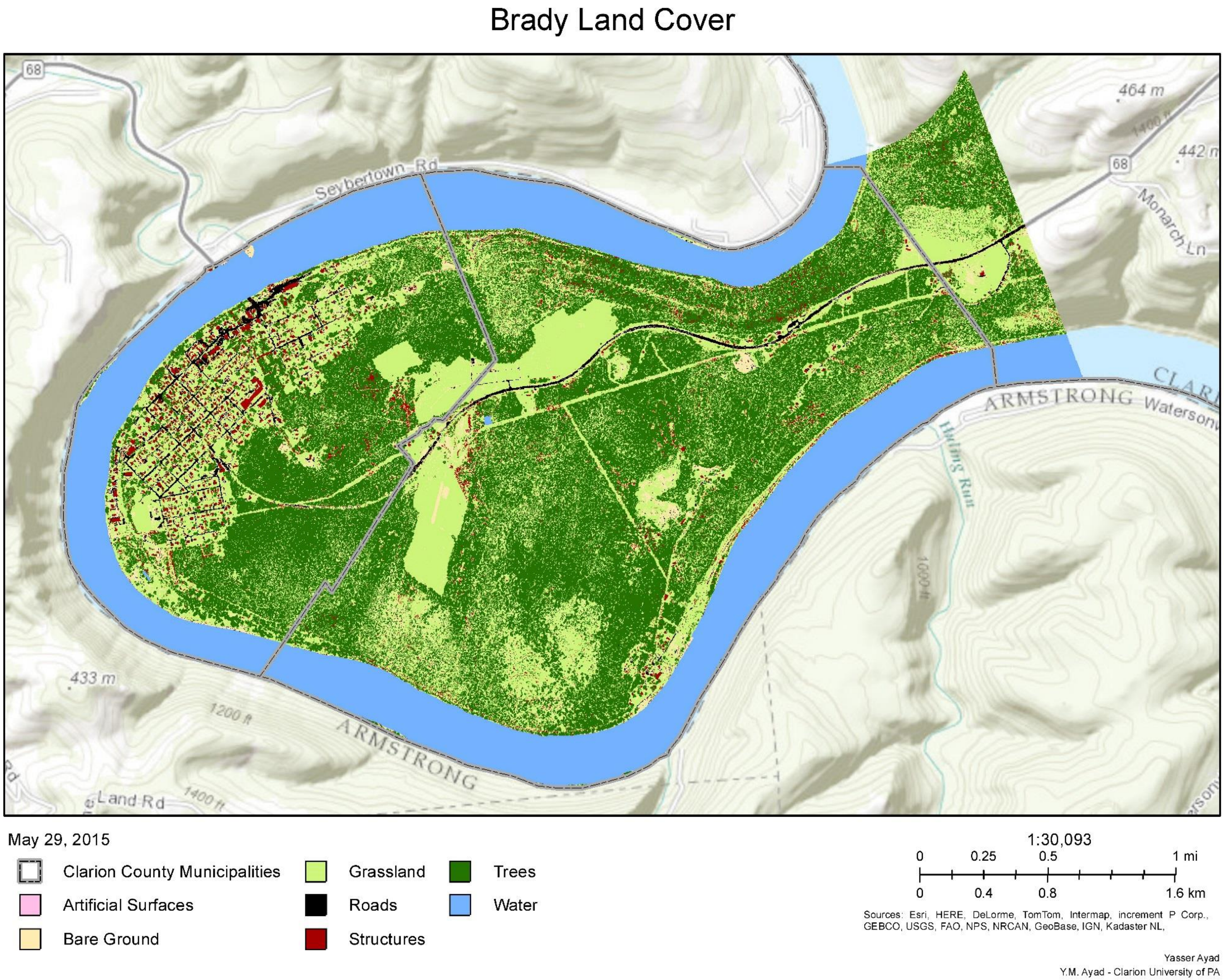

Figure 19 Sample print of the Land Cover output for the Brady Township area

Brady Tree Canopy Density

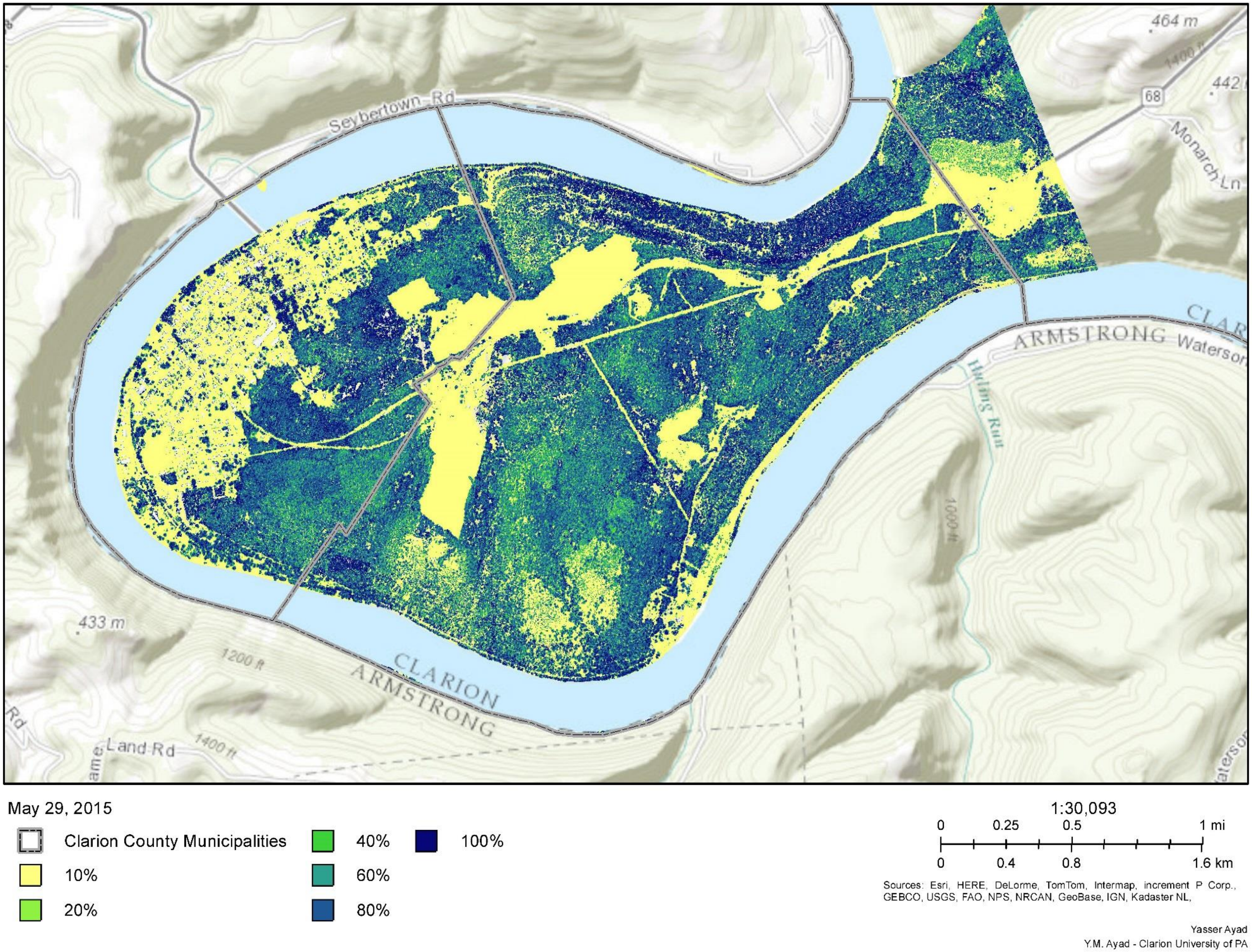

Figure 20 Sample print of the Tree Canopy Density output for the Brady Township area