Trails Spatial Join Toolset

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Abstract

In 2014, Jefferson County Open Space (Jeffco Open Space) was given the opportunity to partner with the USGS and other local agencies to jointly purchase high resolution LiDAR terrain data of the county. With this data came the ability to perform higher resolution analysis of their park system. After identifying a lack of spatial connection of their trails and park boundary data sets, a computational toolset was created to spatially connect Jeffco Open Space's trail and park data to their newly acquired LiDAR terrain data. This toolset can be applied to all of their current parks and future land acquisitions, enabling the GIS team to better serve the organization as a whole by creating more robust park and trail data sets.

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Introduction

In 2013, Colorado was subject to a devastating flooding event which significantly impacted the greater Denver region and its watershed. As a result the USGS determined it was necessary to use Airborne LiDAR sensors to update the flood zones and flood plain mapping of this area. LiDAR is a remote sensing technique that "uses light in the form of a pulsed laser to measure ranges (variable distances) to the earth" (NOAA 2015). This Lidar data is combined with GPS information along with an inertial measuring system to measure pitch, roll and heading, in this case, for an airplane to accurately map the earth's surface. As a result of the flooding events, Jeffco Open Space was given the opportunity to purchase county-wide LiDAR data at a discounted price through a third party company. Jeffco Open Space decided to purchase data of over 80% of the county.

While still finding new uses for this data, Jeffco Open Space has been able to implement it in many ways. One example of this is an alternative analysis project of the Hall Dam in Mount Galbraith Park. For this project, Jeffco Open Space developed multiple plans to bring a recently acquired dam up to federal regulations. With this project Jeffco Open Space was able to use the newly acquired LiDAR to create one-foot contours to accompany minimal spot elevation measurements on-site. This use of the LiDAR data compared to the price of traditional survey methods saved Jeffco Open Space $10,000 from this one project alone.

As a GIS intern for this organization; one of my responsibilities is to formulate creative uses for this newly acquired data. By looking at the data sets which are currently being maintained by Jeffco Open Space, this organization will benefit by increasing the robustness of their trails and park boundary data sets. This paper outlines the process of using ERSI's ModelBuilder program to produce a computational toolset, creating a semi-automated process that spatially connects Jeffco Open Space's trails and park data sets with their high resolution, LiDAR, terrain data. This toolset will be used to connect their current and future trails and park data sets with elevation, aspect, and slope data derived from the high resolution terrain data. By using data and resources already owned by Jeffco Open Space to create this toolset, I reduced the costs required to produce these more robust data sets. While providing a semi-automated process and workflow to join these data sets together, this toolset produces the following deliverables:

Vector based deliverables – cumulative elevation gain/loss per trail segment, mean slope per trail segment, cross slope per trail segment, majority aspect per trail segment, aspect polygons for the parks, and a roughness ratio calculation for the parks and trails.

Raster based deliverables – hillshade raster image of the parks, slope raster image of the parks, and aspect raster image of the parks.

The deliverables listed above will be of great use to the natural resources, trails, and planning teams of Jeffco Open Space in regards to resource management, park development, and maintenance of their current and future parks and trails.

Background Information – Jeffco Open Space

Jeffco Open Space is a governmental organization funded by Jefferson County citizens. Jeffco Open Space was founded in 1972 after a vote from local citizens. This organization receives a ½ cent of every dollar received from sales taxes in Jefferson County. Their mission statement is “Preserve open space & parkland, Protect park & natural resources, Provide healthy nature-based experience” (Jefferson County Open Space 2015). With this mission in mind, Jeffco Open Space is a public facing organization with a wide range of functions from park maintenance and supervision to land acquisition and billing, while always providing a positive experience to all visitors. GIS is currently being used for analysis, assessment, and cartographic purposes within Jeffco Open Space and other affiliated organizations. By creating and maintaining an extensive database of all their resources and holdings, the GIS team can help facilitate this mission while providing support to other teams within the organization.

Needs Assessment

Developing and maintaining high quality data is one way Jeffco Open Space fulfills the goals outlined in their mission statement. Jeffco Open Space maintains extensive data sets ranging from land management boundaries to park assets to wildlife and vegetation data throughout the parks and surrounding areas. Among these data sets, Jeffco Open Space has a very robust trails data set which they actively maintain. This data set is extremely useful to the public sector and other organizations, as well as internally.

One aspect where the trails data set is lacking is in the vertical spatial component. Currently this data set only captures the two-dimensional layout of the trails system, and fails to account for elevation. With the newly acquired LiDAR terrain data, a toolset was needed to spatially connect the trails data set to the third-dimension of height. This toolset automates the GIS functions needed to perform the spatial analysis to connect the current trails system and/or any future trail development to the terrain data. By linking the trails and terrain data, Jeffco Open Space will have a more solid understanding of the assets they hold and maintain. One of the many ways this information can be used to benefit the organization is to create a more concise management plan for the maintenance and upkeep of their current and future trails. By identifying the slope, cross slope, and aspect of certain sections of their trails, the Jeffco Open Space's trails team can more efficiently create site specific solutions to combat and prevent unique trail maintenance needs.

Another area where Jeffco Open Space's maintained data sets could be improved is within their park boundary data. Currently Jeffco Open Space only maintains data about the area of their parks in a two-dimension planimetric basemap. While this gives a good estimate of the available area of some of their parks with lower relief, it underestimates the area of their parks with varying terrain. By looking at a list of Jeffco Open Space's 28 regional parks, roughly 82% of them have significant change in relief. By calculating the three-dimensional surface area and a roughness ratio (a calculation of surface area divided by planimetric surface) of the parks it will provide additional information to Jeffco Open Space's planners and decision makers.

Literature Review

Researchers have known for many years that planimetric calculations of area in locations with high relief underestimate the available area of that location. In figure 1, one can clearly see that the area from a planimetric calculation would not provide an accurate representation of the available space as compared to that of a surface area calculation. Many studies have been conducted on the methods for accurately calculating land surface area. Jenness (2004) conducted research on methods in deriving surface area by using Digital Elevation Models (DEMs) and raster calculations. In order to accurately represent surface area in an efficient and consistent method,

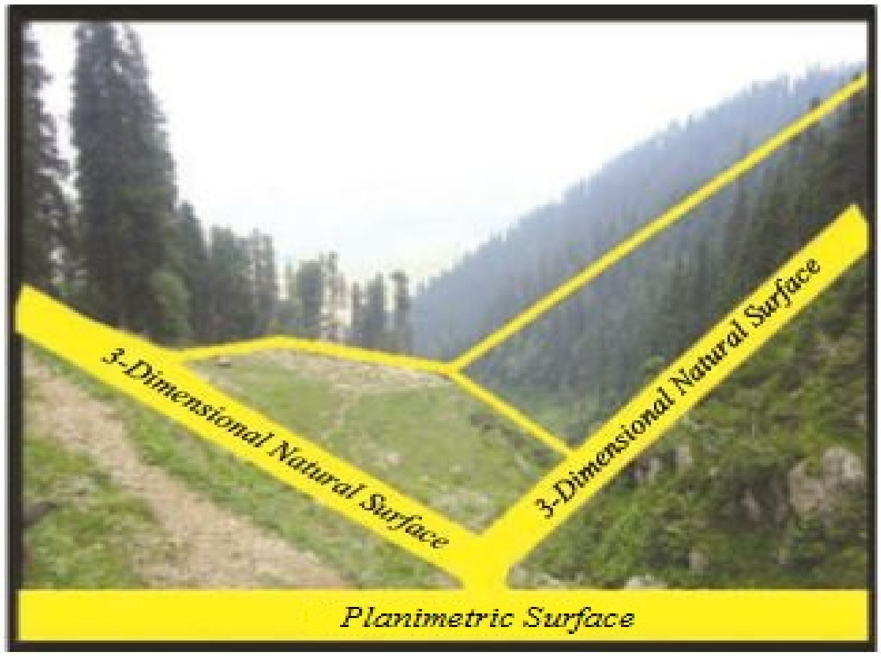

Figure 1. Difference between planimetric area and surface area. (Rashid 2010)

Jenness derives his calculations by using a central raster cell which represents elevation information and their neighboring 8 cells. This method proved to accurately represent surface area in a reliable manner in comparison to methods using Triangulated Irregular Networks (TINs).

For this study I used a combination of raster and vector calculations. Jenness point out in his 2004 study that DEMs are more widely available to the public free of charge. However with today's available technology and the scale of the study area, the construction of reliable park specific TINs are very straight forward and efficient. Using ESRI's 3D Analyst's Raster to TIN tool, TINs can be automatically created in a matter of minutes.

Another useful calculation from Jenness (2004) is the roughness ratio; a surface-area calculation derived by dividing the three-dimensional surface area by the planimetric area. This calculation provides valuable information on the ruggedness of an area's terrain. The concept of surface roughness, which dates back to studies done by Hobson (1972), plays an important role in decision making for land management organizations such as Jeffco Open Space. Previous research has been conducted on wildlife habitats and the parameters that define them. Wakelyn (1987) identified that the Rocky Mountain bighorn sheep preferred areas of high relief. Inversely, Warrick and Cypher (1998) found that kit foxes, in their study, preferred areas of low relief or ruggedness. This measurement of park roughness will be extremely useful to both the planning and natural resources teams of Jeffco Open Space.

When using planimetric area calculations instead of three-dimensional surface area calculations for planning and decision making, the values derived are potentially underestimated. An example of this can be seen in Rashid (2010), a study that was conducted in the Jammu & Kashmir State in India on the differences of three-dimensional surface area vs planimetric surface calculations. In this study, researchers used 90-meter resolution data from the Interferometric Synthetic Aperture Radar (IFSAR), collected by the Shuttle Radar Topographic Mission in 2000 (Rashid 2010), to generate a slope map used to calculate the three-dimensional surface area. This study found a nearly 34 percent difference between the planimetric and three-dimensional surface area calculation, with the planimetric calculations drastically under representing the actual available space. By using such calculations and data which underestimate the available surface area, planners and decision makers are inherently at a loss when preparing for the future.

Data and Study Area

Jeffco Open Space's LiDAR data was purchased from a remote sensing company, A Quantum Spatial Company, in 2014. Jeffco Open Space acquired this LiDAR data in a partnership with the USGS after the devastating floods of 2013. The data was collected at a nominal pulse spacing of 0.7 meters with a vertical accuracy of +/- 11.2 cm at a 95% confidence interval (Lidar data for Colorado Flood USGS 2014). A Quantum Spatial Company has preprocessed this data and produced DEM raster images which were also purchased. Figure 2 is map of the raw LiDAR data capturing the southern section of the North Table Mountain Park.

The study area for this project is the North Table Mountain Park in Jefferson County, Colorado. Figure 3 shows the park extent and surface model of North Table Mountain to provide context of the study area. North

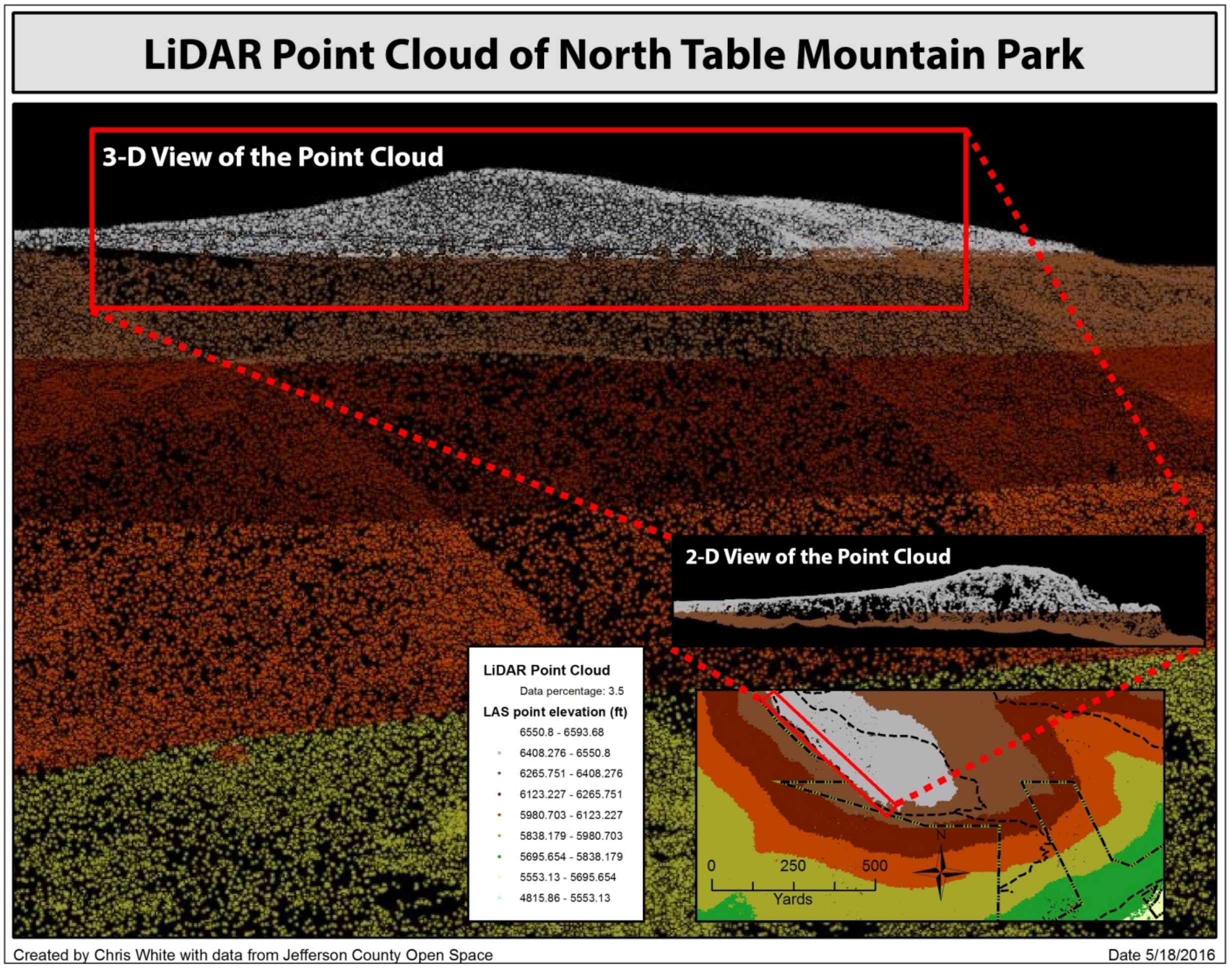

Figure 2. A map of the raw LiDAR Data.

Table Mountain Park is a 1,997 acre park located northeast of Golden, Colorado. This park has an interesting mesa top topography, which will inevitably effect the calculation of surface distance and area.

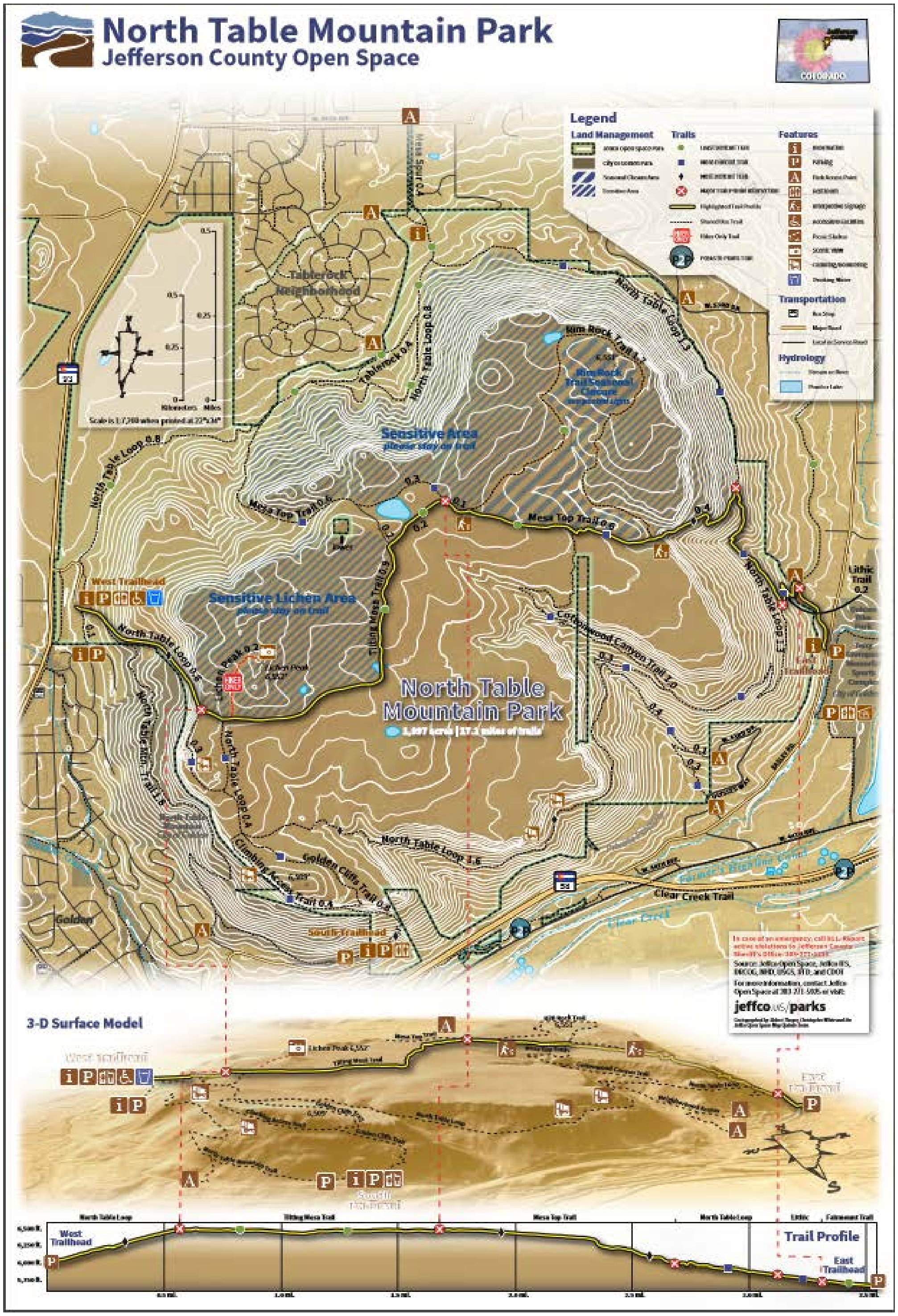

Figure 3. A map of the study area. (Thayer, White and Team 2016)

This image is also attached to this document due to size and clarity issues.

File Structure

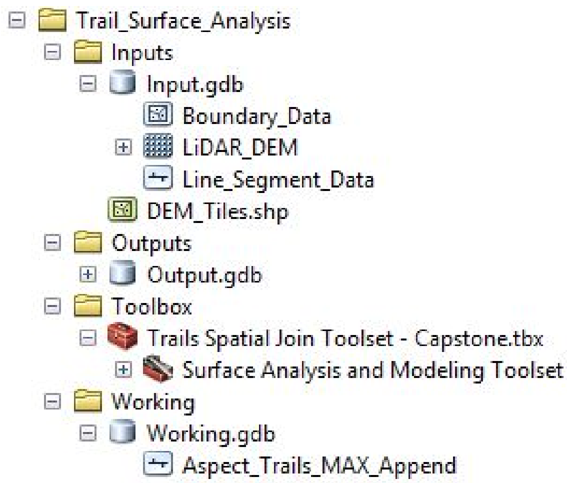

Figure 4. File Structure of Surface Analysis and Modeling Toolset

The file structure of the Trails Spatial Join Toolset, illustrated in figure 4, consists of four folders: Inputs, Outputs, Toolbox, and Working. The toolset's tools are housed in the Toolbox folder in an ESRI .tbx file, entitled Trails Spatial Join Toolset – Capstone, with the individual tools stored in an ESRI toolset entitled Surface Analysis and Modeling Toolset. The other three folders contain file geodatabases with the following names: Input.gdb, Output.gdb, and Working.gdb. These file geodatabases are individually designed to hold the corresponding data; inputs to the toolset are stored in the Input.gdb, outputs of the toolset are stored in the Output.gdb, and files associated with the working processes of the toolset are temporarily stored in the Working.gdb and deleted by the user after the completion of the toolset's data processing. There is also a blank line feature in the Working.gdb with specified fields; this will be addressed later in the Trail

Aspect Tool section. The toolset is designed to run off the user’s C: drive in order to maximize the proficiency of their computer’s processing power and speed. Another benefit of running this toolset within the designed file structure is the user will not have to adjust the tools’ environment workspaces.

Methodology

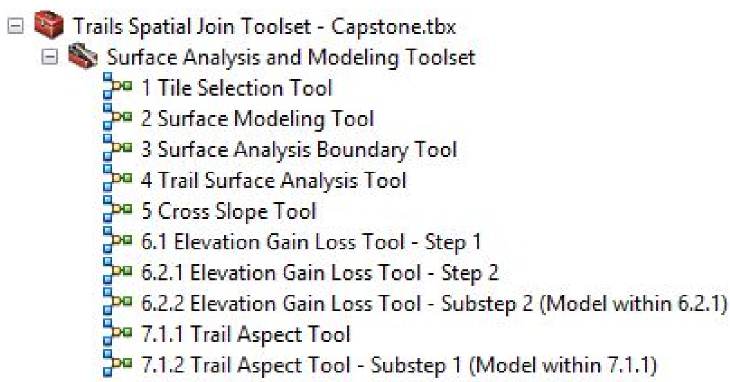

Figure 5. Surface Analysis and Modeling Toolset

The toolset is broken up into seven tools which can be seen in figure 5. Due to the complicated nature of this toolset it made computational sense to create distinct tools for each function instead of combining them all into one tool. This toolset is designed in a way that the user must run the Surface Modeling Tool (tool #2) in order to create the inputs for the sequential tools. The user can then choose which additional tools they wish to run. In the following sections, each of the toolset’s distinct tools will be examined and the methodology used will be further explained. While describing specific tools within each individual tool it should be noted that they are from the

ESRI toolset with the addition of the 3D Analyst and Spatial Analyst Extensions. For the purpose of this paper the linked processes created by ESRI's ModelBuilder will be referred to as tools and together they will be referred to as the toolset. For clarity, full page versions of the tools can be found in the appendix of the paper.

Tile Selection Tool

Description – The first tool in the toolset is used to determine which raster tiles will be used to create a mosaicked raster DEM for the study area. Jeffco Open Space's data provider created a polygon layer, in a grid format, which represents raster DEMs. This tool, illustrated below in figure 6, uses the Select tool to choose a specific polygon feature from the input feature layer. Once selected, the tool then creates a one mile buffer around the polygon and then applies a Select by Location of the buffered polygon using the intersect specification for the tiled input layer. This tool then creates an output of the selected tiles of the polygon layer from which the user can easily create a mosaic raster DEM to be used in the later steps of the toolset.

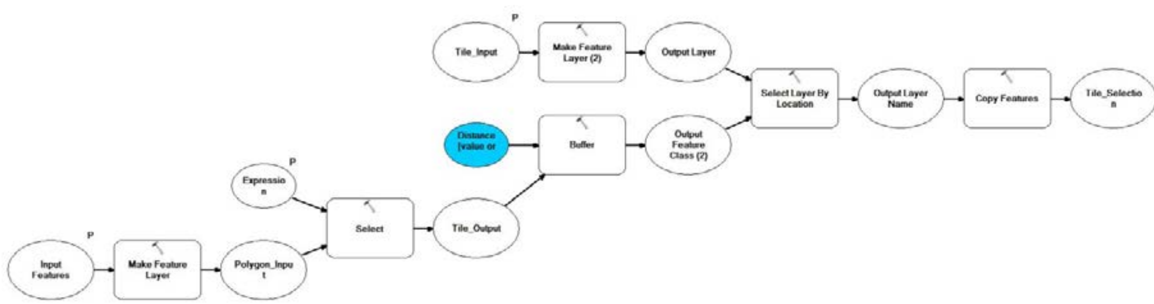

Figure 6. Tile Selection Tool Model Layout

Inputs – This tool requires a polygon boundary layer which the user wishes to analyze. In addition to the polygon boundary layer, this tool also requires a polygon layer representing the raster DEM tiles. For this study, I used Jeffco Open Space's Park Boundary polygon layer and a polygon layer of tiles representing corresponding raster DEM images created by their LiDAR data provider.

Expression - For selection purposes of the polygon boundary layer an optional SQL expression can be entered to specify an individual feature. An example from this study using the Jeffco Open Space's Park Boundary layer is "Name = 'North Table Mountain Park'". This SQL selection is dependent on the user's input data.

Outputs – This tool creates a polygon layer in the Outputs.gdb entitled "Tile_Selection". This layer will give the user a list of raster tiles they should mosaic in order to create a DEM to fully cover their study area.

Surface Modeling Tool

Description – The next tool in the toolset is used to perform surface analysis and create surface models of the study area.

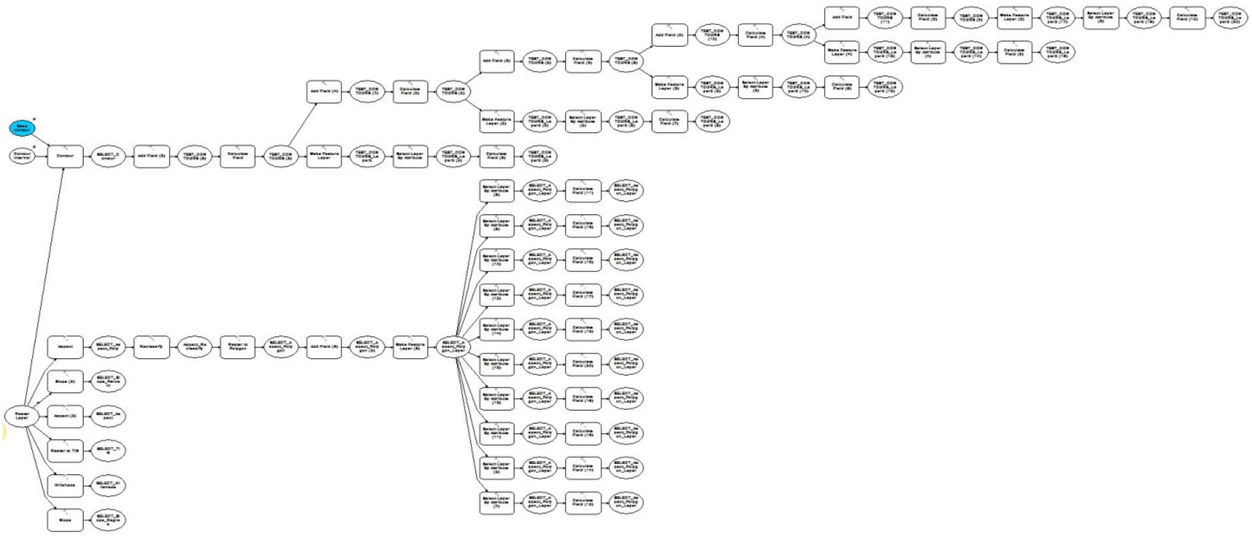

Figure 7. Surface Modeling Tool Model Layout

Figure 7 shows the tool in its entirety. This rather large tool is easily explained if broken up into three smaller sections. The first section of the tool, illustrated in figure 8, uses the DEM and Raster Surface Tools, located in the 3D Analyst Tools section of the ArcToolbox, to create seven different deliverables; a slope raster image represented in degrees, a slope raster image represented in percent, a hillshade raster image, an aspect raster image represented in degrees, an aspect polygon layer represented in cardinal directions, a TIN of the study area, and elevation contours of the study area.

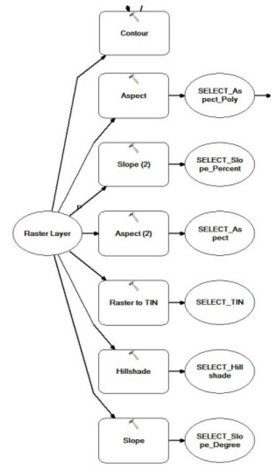

Figure 8. Surface Modeling Tool Model Layout Section 1 Outputs

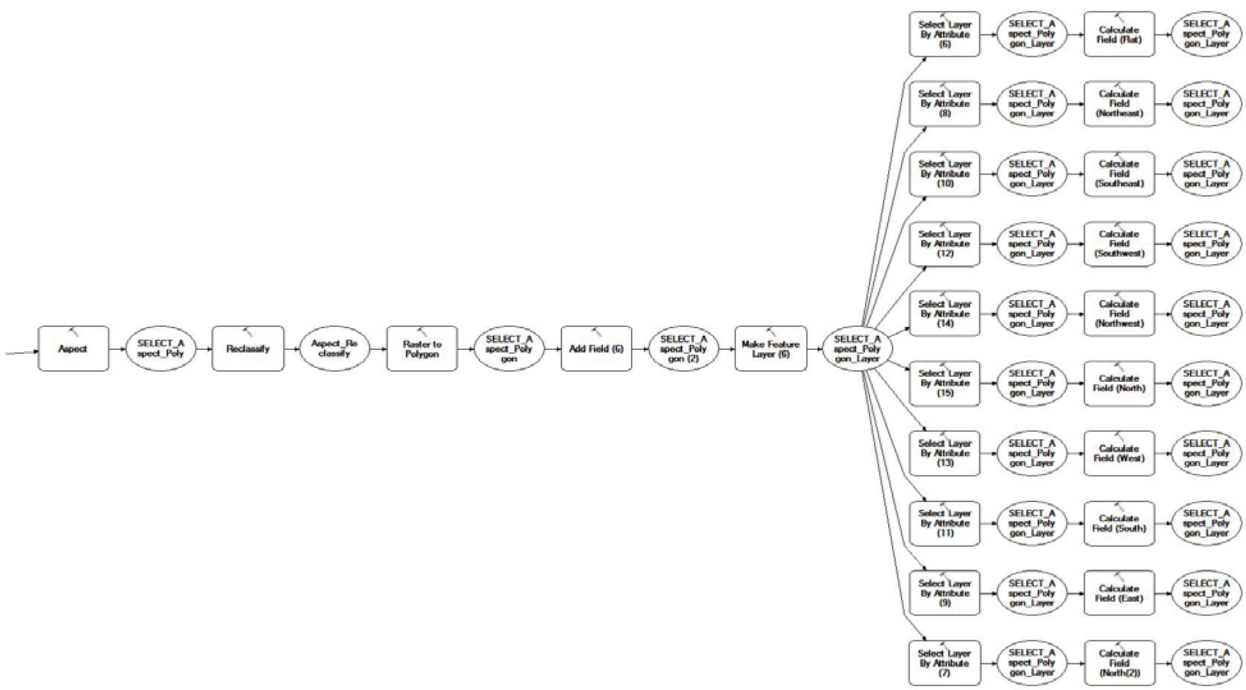

Figure 9. Surface Modeling Tool Model Layout Section 2 Aspect Raster to Vector

Figure 9 illustrates the process of converting the aspect raster image into an aspect vector polygon layer. This process begins by taking the raster image and reclassifying the degrees into a range of degrees which signify north, south, east, west, northeast, northwest, southeast, southwest, and flat (represented by an aspect of -1). This is done by converting the degree ranges into short integers which signify the cardinal directions. With these newly created short integers, the raster image is then converted into a vector layer consisting of polygons. Once this has been done, the tool then creates a new field within the polygon layer and converts the short integers into the cardinal directions they represent based on the pre-defined degree ranges.

The next section of the tool, illustrated in figure 10, takes the previously created contour lines and attributes them based on the elevation they represent. This section of the tool, using a series of add field, calculate field, selection, and a calculation of the selected feature field, identifies and attributes the contour layer based on an interval of 10 feet, 25 feet, 50 feet, 100 feet, and 200 feet. By using the SQL expression,

*mod(round(*Field*,0)*10,X)=0*

with the "*Field*" representing the field which contains the elevation data of the contour layer and "X" representing ten times the desired interval, the tool selects and attributes the contours with the desired interval data.

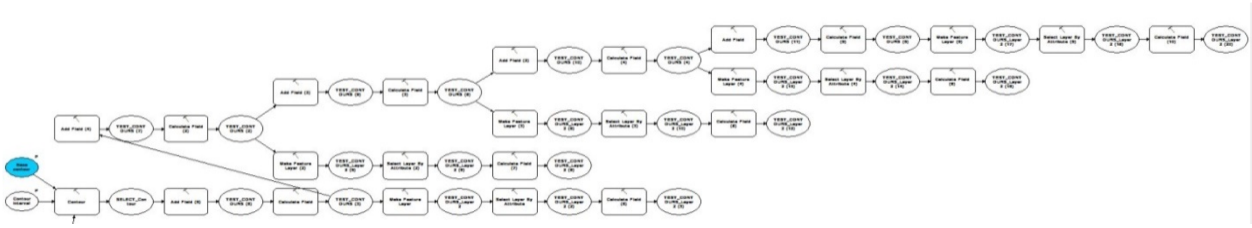

Figure 10. Surface Modeling Tool Model Layout Section 3 Contour Line Set Up

Inputs – This tool requires a DEM raster image of the study area. For this study, I used a mosaicked DEM which encompasses Jeffco Open Space's North Table Mountain Park and surrounding areas.

Specifications – For this tool there are two additional specifications which need to be input. The first specification is the base elevation level, in feet, of the input DEM per the contour interval. The second specification is the interval at which the user wishes to create the elevation contours. Due to the design of the tool, a 5 foot interval is the maximum.

Outputs – This tool creates seven different outputs which are then located in the Outputs folder. The outputs are the following; a raster aspect image entitled SELECT_Aspect, a vector aspect polygon layer entitled SELECT_Aspect_Polgyon, a vector line layer of elevation contour lines entitled SELECT_Contour, a raster hillshade image entitled SELECT_Hillshade, a raster slope image in degrees entitled SELECT_Slope_Degree, a raster slope image in percent entitled SELECT_Slope_Percent, and a TIN of the area entitled select_tin.

Surface Analysis Boundary Tool

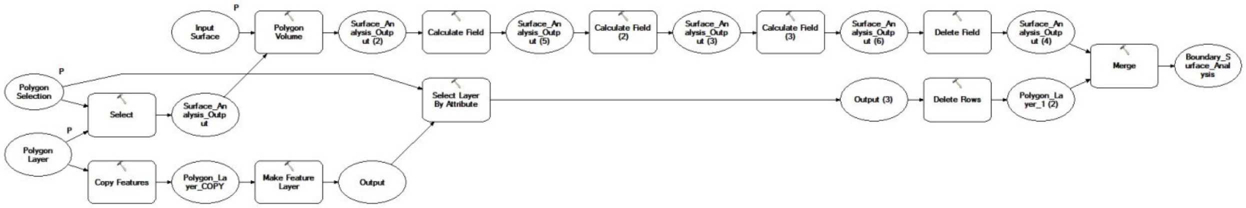

Figure 11. Surface Analysis Boundary Tool Model Layout

Description – The Surface Analysis Boundary Tool, illustrated in figure 11, uses the newly created TIN to determine the three-dimensional surface area of the desired boundary polygon. First this tool selects the desired polygon feature from the input polygon layer and uses the TIN to perform a surface analysis on it using the Polygon Volume Tool. By using simple calculations the surface data is then converted into a roughness ratio of the polygon and the surface area in square feet is converted into acres. The tool then enters the newly created surface data into the desired fields and deletes the working fields from the polygon layer. In order to maintain the integrity of the original input data, the tool creates a sister data set of the input data and locates it in the Outputs.gdb. The tool then merges the polygon with the newly calculated surface data into the sister data set. In order to not duplicate the selected data before the merge process, the selected polygon is deleted from the sister data set and then is reentered with the merge.

Inputs – This tool requires a TIN of the study area. In addition to the TIN, this tool also requires a polygon layer the user wishes to analyze. For this study, I used a TIN of the North Table Mountain Park area created earlier by this toolset from the Surface Modeling Tool and the Jeffco Open Space's Park Boundary polygon layer.

Input Layer Requirements – The input polygon layer must contain the following fields with the specified format in parentheses; Roughness_Ratio (Double), Surface_Area_Acres (Double), and Surface_Area (Double).

Expression - For selection purpose of the polygon boundary layer, an optional SQL expression can be entered to specify an individual feature. An example from this study using Jeffco Open Space's Park Boundary layer is "Name = 'North Table Mountain Park'". This SQL selection is dependent on the user's input data.

Outputs - This tool creates a polygon layer in the Outputs.gdb entitled "Boundary_Surface_Analysis". This is a duplicate of the input polygon layer with the required fields listed above calculated and attributed.

Trail Surface Analysis Tool

Description – The Trail Surface Analysis Tool, illustrated in figure 12, uses the TIN of the study area to perform multiple surface and elevation analyses on a desired line feature layer. Similar to the Surface Modeling Tool, this tool is more easily understood if looked at in smaller sections.

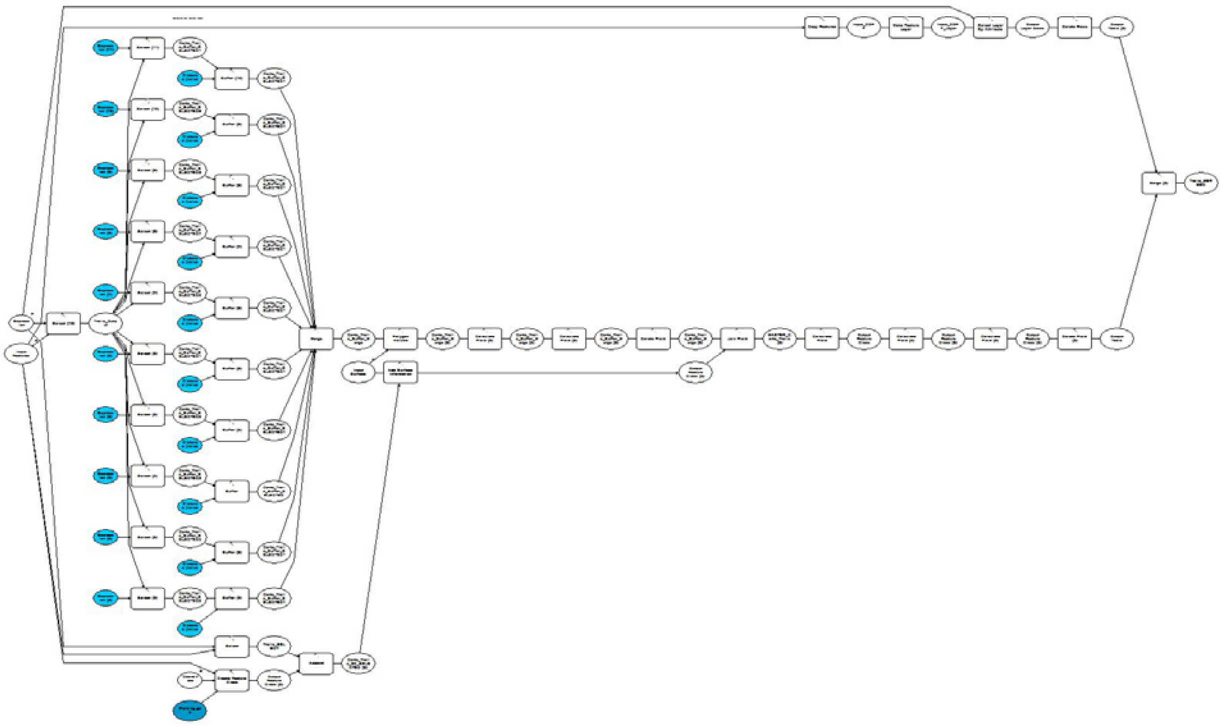

Figure 12. Trail Surface Analysis Tool Model Layout

Figure 13 illustrates the first section of the tool which converts the trail segments into polygons so a surface analysis can be performed. The tool begins by using a SQL expression to select the desired line segments for the analysis. Then by using a series of selections and buffers, the tool creates an area of impact polygon for each individual line segment using the line segments' "Trail_Width" field. It then merges all of these newly created buffer polygons back into one layer.

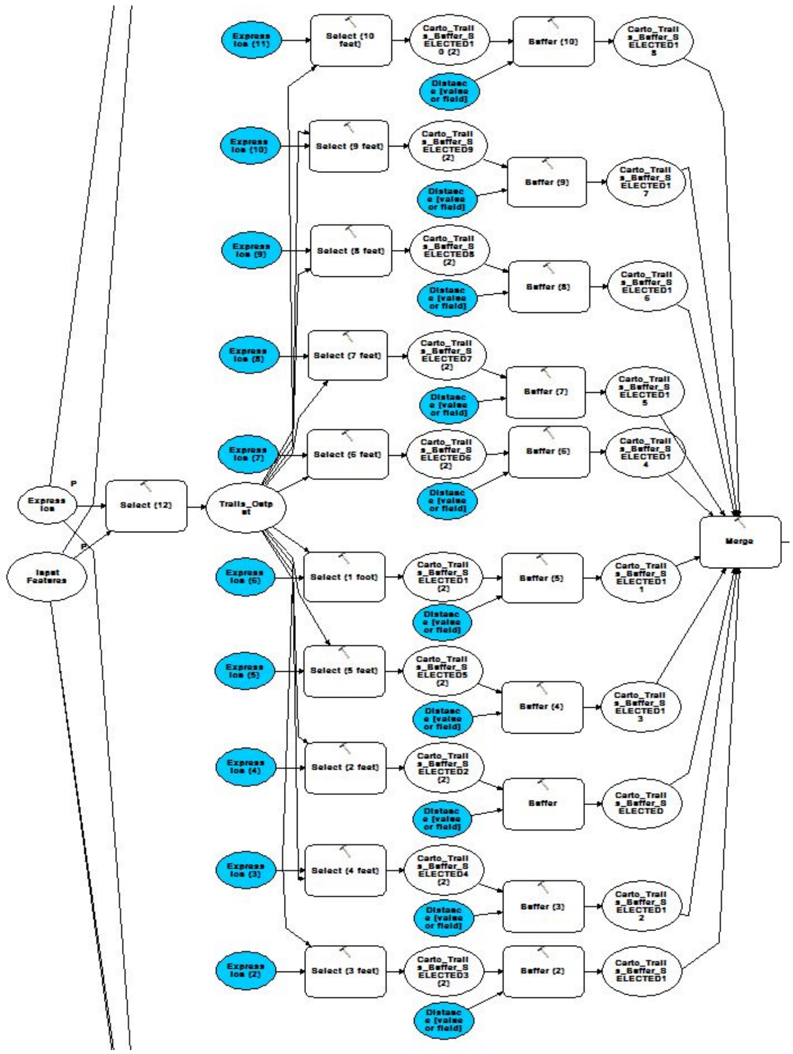

Figure 13. Trail Surface Analysis Tool Model Layout Section 1 Trail Buffer

Parallel to this buffering process, illustrated in figure 14, the tool creates a sister data set of the original line layer located in the Outputs.gdb. This is done so the original line layer is not altered during the process. After the line data is entered into this sister data set, an elevation analysis is performed using the input TIN. This elevation analysis determines the elevation minimum, maximum, and mean, as well as the three-dimensional length and the mean slope of the line segments.

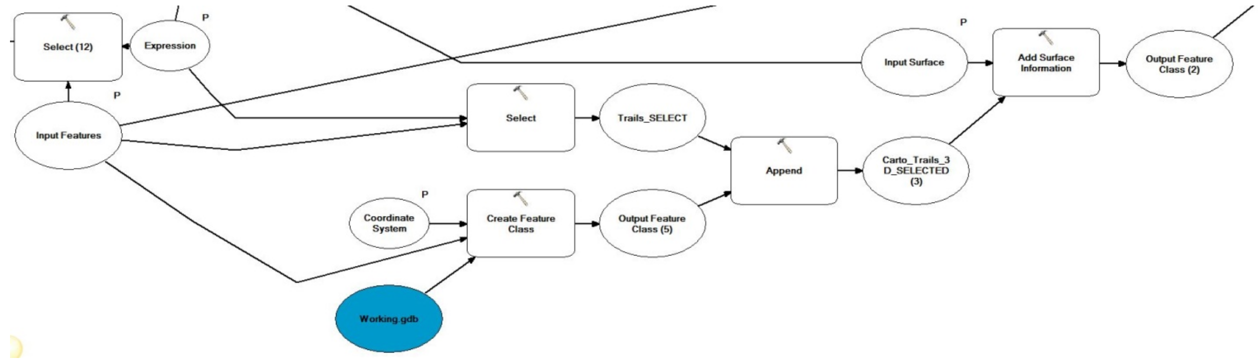

Figure 14. Trail Surface Analysis Tool Model Layout Section 2 Surface Information Input

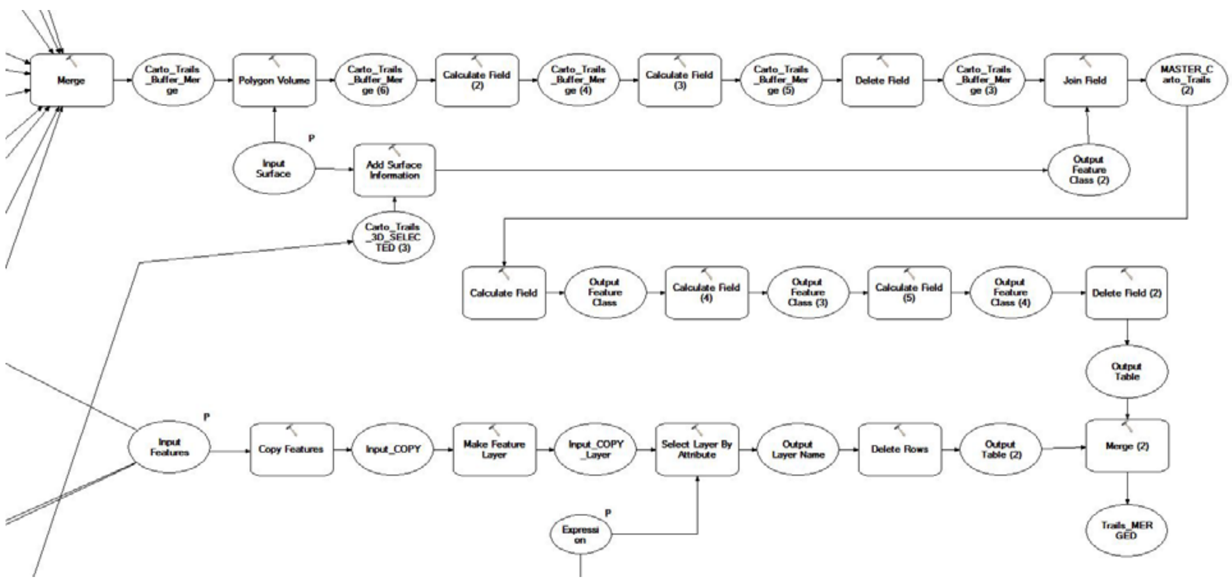

Figure 15. Trail Surface Analysis Tool Model Layout Section 3 Analysis and Join

Figure 15 illustrates how the tool then uses the newly created trail impact polygons and the TIN to perform a Polygon Volume calculation to determine the three-dimensional surface area of each trail. By using calculations similar to the Surface Analysis Boundary Tool, the tool converts the surface data into a roughness ratio of the trail polygons and converts the surface area from square feet into acres. The trail surface data is then merged into the newly created sister line data set. Similar to the Surface

Analysis Boundary Tool, the original line segment data is copied and then the selected trails are deleted to avoid duplication.

Inputs – This tool requires a TIN of the study area. In addition to the TIN, this tool also requires a line feature layer the user wishes to analyze. For this study, I used a TIN of the North Table Mountain Park area earlier created by the toolset and the Jeffco Open Space's Trail System line layer.

Input Layer Requirements - The input line layer must contain the following fields with the specified format in parentheses; Trail_Width (Short Integer), Roughness_Ratio (Double), Surface_Area_in_Acres (Double), Surface_Area (Double), and Primary_Key (Short Integer). The Primary_Key and Trail_Width fields must be attributed before the analysis is run for the tool to work properly.

Expression - For selection purpose of the line layer, an optional SQL expression can be entered to specify which individual feature the user wishes to analyze. An example from this study using Jeffco Open Space's Trail System line layer is "Park_Name = 'North Table Mountain Park'". Once again, this SQL selection is dependent on the user's input data.

Specifications – For this tool, a coordinate system for the specified area can be assigned. For this study, I used the State Plane projected coordinate system, "NAD_1983_StatePlane_Colorado_Central_FIPS_0502_Ft_US".

Outputs - This tool creates a line layer in the Outputs.gdb entitled "Trails_MERGED". This is a duplicate of the input line layer with the required fields listed above calculated and attributed.

Cross Slope Tool

Description – The Cross Slope Tool, illustrated in figure 16, uses the DEM of the study area to determine the cross slope of a line segment. This tool is designed to calculate the cross slope of a line segment at a 10 foot interval, as well as the mean cross slope of the line segment. Similar to the other tools in this toolset, it is more easily understood if looked at in segments.

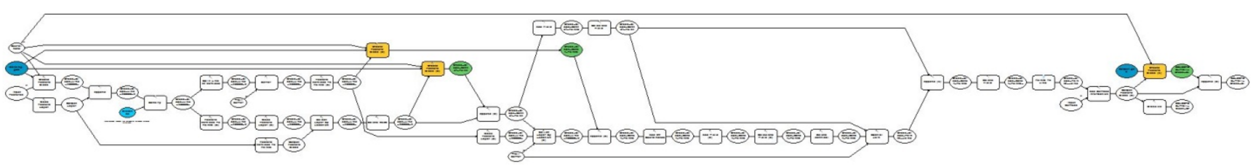

Figure 16. Cross Slope Tool Model Layout

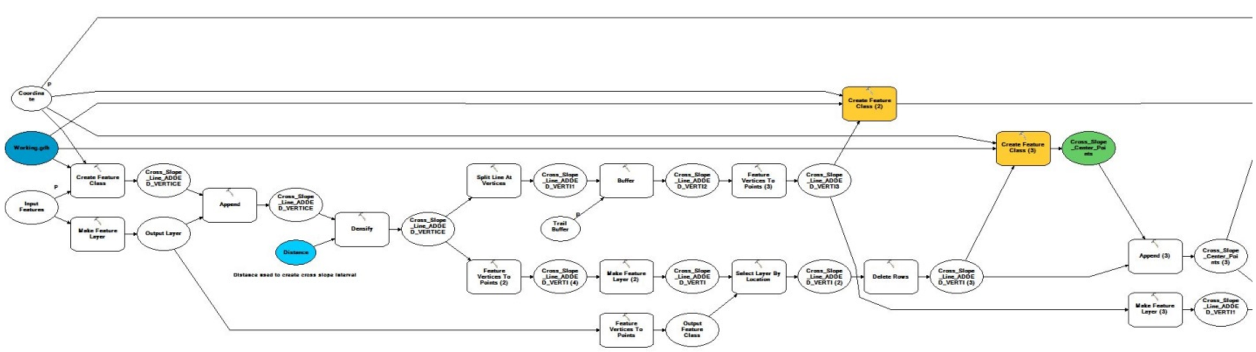

Figure 17. Cross Slope Tool Model Layout Section 1 Point Creation

Figure 17 illustrates the first section of the tool, which creates points along the line segment to perform the cross slope analysis. By using the Densify tool, it adds vertices to the line segment at a 10 foot interval. Next the tool splits the line segment up at these newly created vertices and buffers (with flat ends) the individual line segments, based on the width of the trail (the trail width is added as an input expression). It then uses the vertices of the buffers to create points perpendicular to the line segment. Parallel to this process the tool creates a point feature class and inputs the vertex points into it. The original vertex points of the line segment and newly created buffer points corresponding to the original vertices of the line segment are removed to leave only points that are perpendicular to the line.

In the next section of the tool, illustrated by figure 18, the coordinate locations of the points are used to identify and delete identical points created from the buffer vertices point process. This leaves only one point in each location. The tool then takes these points and groups them together by assigning attributes based on their location to the line's vertex points. This creates groups containing three points which are perpendicular to the line segment.

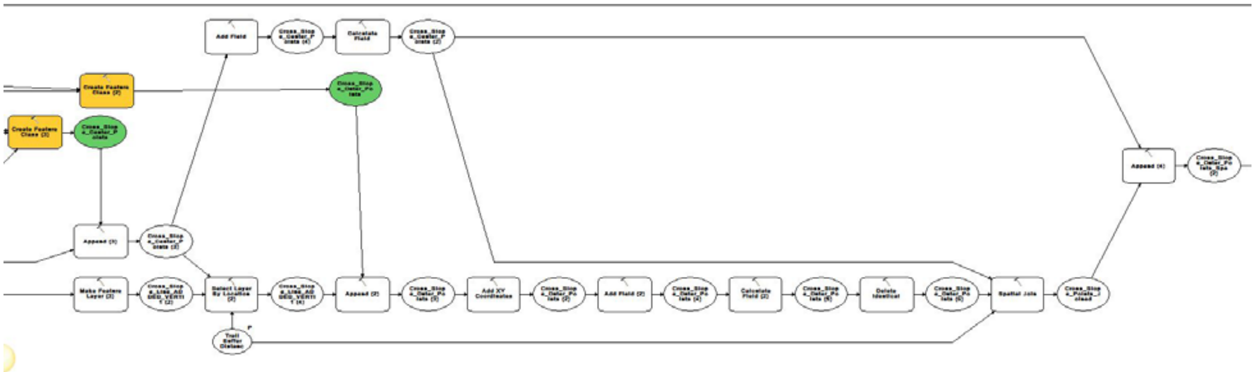

Figure 18. Cross Slope Tool Model Layout Section 2 Point Join

The final section of the tool, illustrated in Figure 19, takes the point groups and uses the Points to Line Tool to create individual line segments perpendicular to the original line. Then by using the DEM of the study area, the tool calculates the mean slope of each newly created perpendicular line segment. The tool creates two outputs; one line layer of the individual cross slope line segments and one line layer of the mean slope of all the cross slope line segments.

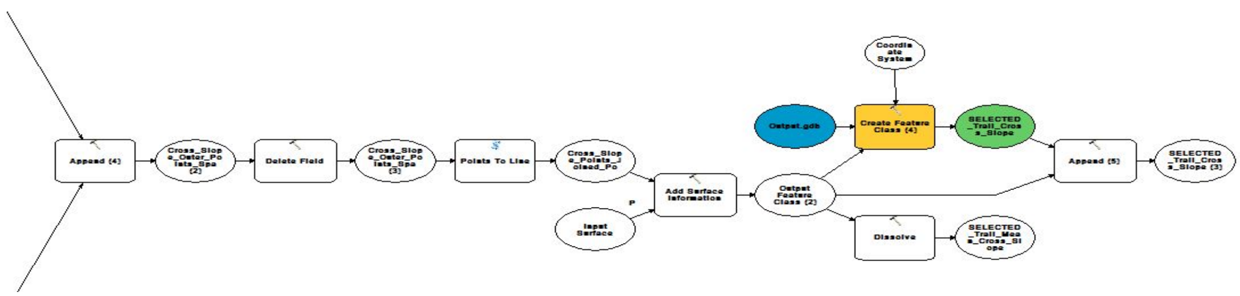

Figure 19. Cross Slope Tool Model Layout Section 3 Line Creation and Analysis

Inputs – This tool requires a DEM of the study area. In addition to the DEM, this tool also requires a line layer feature the user wishes to analyze. This line feature should consist of only one line segment for the purpose of this tool. For this study, I used the DEM of the North Table Mountain Park area and a line segment from the Jeffco Open Space’s Trail System line layer.

Input Layer Requirements - The input line layer must contain the field, Primary_Key in a short integer format. This field must be attributed before the analysis is run for the tool to work properly.

Expression – This tool requires the user to designate the trail width for the line segment they wish to analyze. This number, then divided by two for buffering process, will be used as the “Trail Buffer Distance” input of the tool. Then for analysis purposes, the user will add 1 to the trail width and use it as the “Trail Buffer Distance Plus 1” input of the tool.

Specifications – For this tool, a coordinate system for the specified area can be assigned. For this study, I used the State Plane projected coordinate system, “NAD_1983_StatePlane_Colorado_Central_FIPS_0502_Ft_US”.

Outputs - This tool creates two line layers in the Outputs.gdb entitled “SELECTED_Trail_Cross_Slope” and “SELECTED_Trail_Mean_Cross_Slope”. The first layer is an output of the individual cross slopes of the line segment at a 10 foot interval and the second layer is a mean calculation of the cross slopes of the line segment.

Elevation Gain Loss Tool

Description – The Elevation Gain Loss Tool consists of a series of tools used to calculate the cumulative elevation gain and loss over a line segment. This tool uses a DEM of the study area to calculate the difference in elevation along a line segment at an interval of two feet. Similar to other tools, it will be examined in sections.

The first section of the tool, illustrated in figure 20, uses a similar process to the previous tool and creates points along the line segment at a two foot interval. This is accomplished by using the Densify Tool and creating points at each vertex. The tool then uses the DEM to input elevation data into each of the points by using the Extract Multi Values to Points Tool. It then adds additional fields to the point data which will be used to calculate the difference between each point and record whether it is a gain or a loss compared to the previous point.

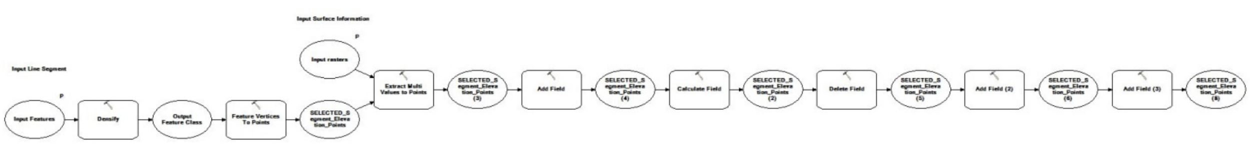

Figure 20. Elevation Gain Loss Tool Section 1 Point Creation

The next section of the tool (technically a subsection of the second step to the tool), illustrated in figure 21, uses the iteration power of ESRI's ModelBuilder to calculate the difference between each sequential point along the line segment. It then determines whether the calculated difference is a gain or a loss and attributes it as such.

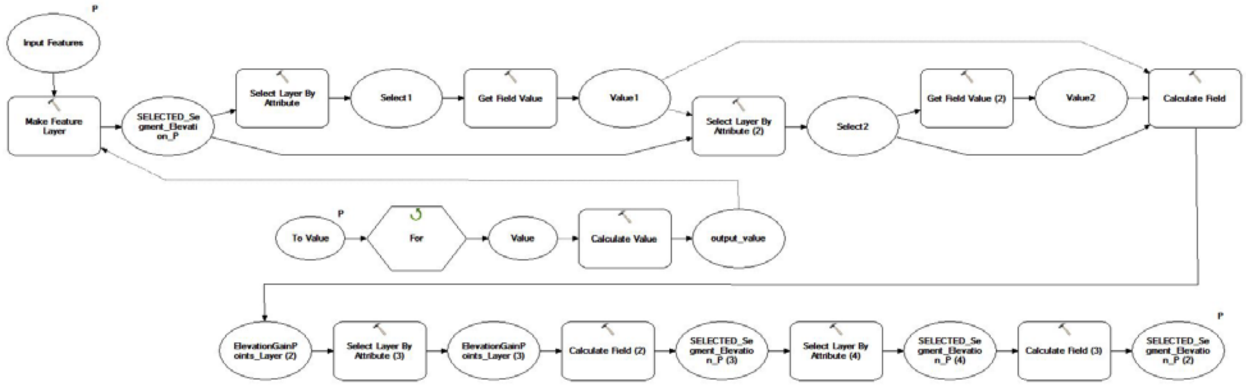

Figure 21. Elevation Gain Loss Tool Section 2 Point Elevation Difference Calculation

The final section of the tool, illustrated in figure 22, takes these calculations and dissolves them based on whether they were a gain or a loss. During the dissolve process, a sum of the elevations is recorded to determine the cumulative gain and loss. The tool then takes the original line segment layer and inputs the calculated data back into it.

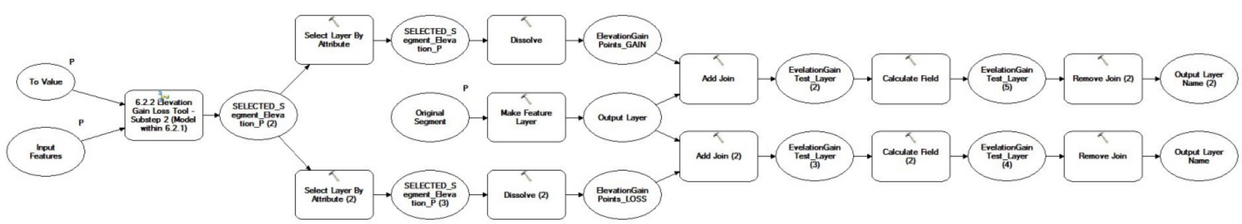

Figure 22. Elevation Gain Loss Tool Section 3 Elevation Difference Join with Trail Segments

Inputs- This tool requires a DEM of the study area. In addition to the DEM, this tool also requires a line layer feature the user wishes to analyze. For the purpose of this tool the line feature should consist of only one line segment. This tool also creates a working point layer in the Working.gdb which is then used as input for the second step of the tool. For this study, I used the DEM of the North Table Mountain Park area and a line segment from the Jeffco Open Space's Trail System line layer.

Input Layer Requirements - The input line layer must contain the following fields with the specified format in parentheses; Elevation_Gain (Double), Elevation_Loss (Double), and Primary_Key (Short Integer). The Primary_Key field must be attributed prior to the analysis.

Working- This tool creates a point layer in the Working.gdb entitled "SELECTED_Segment_Elevation_Points". This layer will be used in the second step of the tool as an input.

Expression – The second step of the tool requires the user to view the "SELECTED_Segment_Elevation_Points" created by the first step located in the Working.gdb and determine the number of points created. The user must then subtract one from the total number of points and use it as the "To Value" input of the second step of the tool.

Output – This tool will input the calculations directly into the original line layer feature.

Trail Aspect Tool

Description – The Trail Aspect Tool consists of two tools which use the aspect polygon layer created by the Surface Modeling Tool to determine the majority aspect of a line layer. The first step of the tool (which is embedded within the second step of the tool), illustrated in figure 23, uses the same processes as the Trail Surface Analysis Tool to create buffer polygons of the line segments based on their width. The tool then clips the aspect polygon data based on the line segments' buffers. From there, illustrated in figure 24, the tool uses the Spatial Join Tool to join the line segments and the clipped aspect data based on the intersection of the line buffer and the aspect polygons. It then dissolves the aspect data based on cardinal direction to determine the total amount of area per aspect direction for each line segment. The tool then uses the iteration processes of ModelBuilder to select the cardinal direction with the majority area per line segment and records this in a line feature layer within the Working.gdb, entitled "Aspect_Trails_MAX_Append".

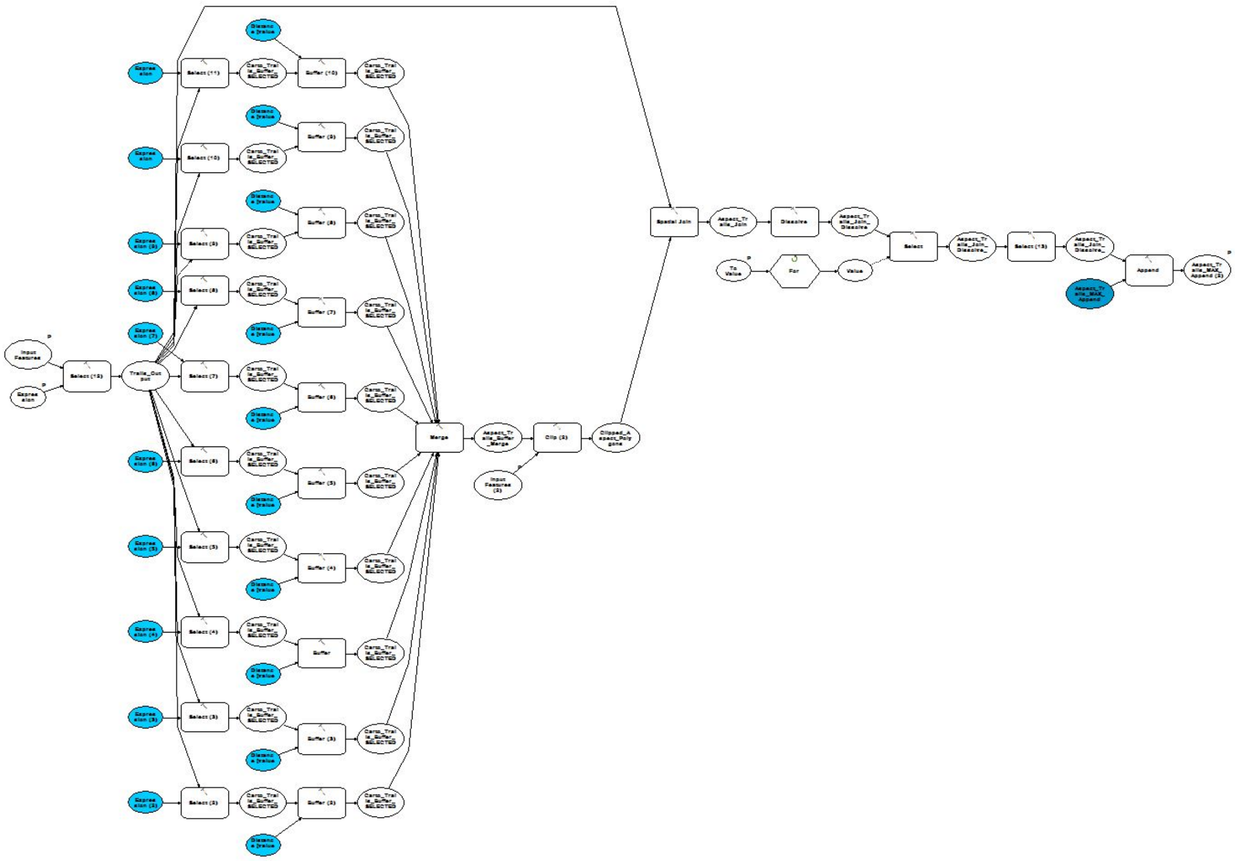

Figure 23. Trail Aspect Tool Sub Step 1 Model Layout

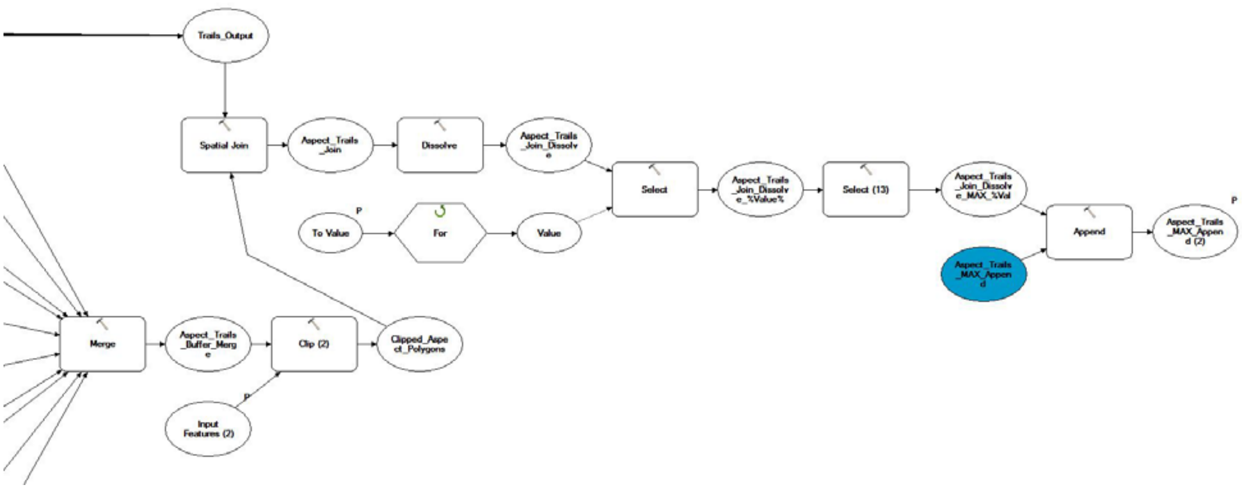

Figure 24. Trail Aspect Tool Sub Step 1 Model Layout Aspect Polygon Join and Analysis

The next step of the tool, illustrated in figure 25, embeds the previous step within itself and joins the working line layer and the original line layer together. The data from the working layer is then entered into the original layer. Once the aspect data is entered, the join between the two layers is removed.

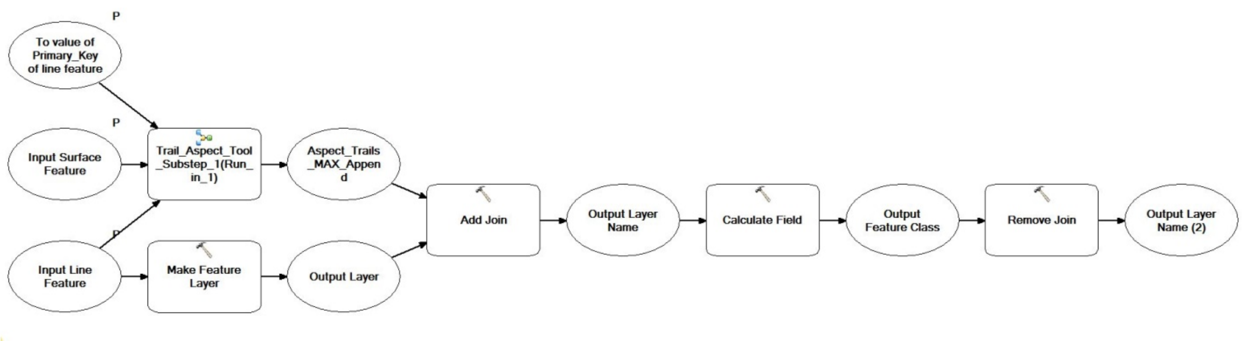

Figure 25. Trail Aspect Tool Step 1 Data Join

Inputs – This tool requires the polygon aspect layer created for the study area by the Surface Modeling Tool. In addition to this polygon layer, this tool requires a line layer feature the user wishes to analyze. For this study, I used the aspect polygon layer of the North Table Mountain Park area created earlier by this toolset from the Surface Modeling Tool and the Jeffco Open Space's Trail System line layer.

Input Layer Requirements - The input line layer must contain the following fields with the specified format in parentheses; Majority_Aspect

(Text), Trail_Width (Short Integer), and Primary_Key (Short Integer). The Trail_Width and Primary_Key fields must be attributed before the analysis is run for the tool to work properly. The Primary_Key field must be in sequential order from 1 to x (x being the total amount of line features the user wishes to analyze).

Expression – This tool requires the user to input the total number of features within the input line feature layer they used for analysis. This number should correspond to the maximum Primary_Key attribute within the line layer for the tool to run properly.

Working – This tool requires a line feature layer entitled "Aspect_Trails_MAX_Append" to be located within the Working.gdb. This line layer must contain the following fields with the specified format in parentheses; Primary_Key (Short Integer) and Aspect_Cardinal_Direction (Text). This layer should be a newly created layer with zero features within it for each repetition of this tool.

Outputs - This tool will input the majority aspect calculations directly into the original line feature layer.

Results

By creating the desired deliverables for Jeffco Open Space, which we set out to produce with this toolset, I consider this project a success. The toolset successfully achieves its goals by producing the following deliverables: cumulative elevation gain/loss per trail segment, mean slope per trail segment, cross slope per trail segment, majority aspect per trail segment, aspect polygons for the parks, and a roughness ratio calculation for the parks and trails, hillshade raster image of the parks, slope raster image of the parks, and aspect raster image of the parks. This was accomplished by using resources and technology already owned by Jeffco Open Space, therefore saving them time and resources. By creating a toolset that spatially connects their trail and park system to their high resolution LiDAR terrain data it frees up time and resources for the GIS team which can be better used to serve the organization as a whole. The file structure and toolset can be downloaded from https://github.com/cdwhite29464/DU-Capstone-Spring-2016.git.

To showcase some of the data created by this toolset, I have produced a few maps and images. Figure 26 is a three-dimensional surface model of the North Table Mountain Park using the TIN created from the toolset as the basemodel. This image was created in ArcScene to display North Table Mountain's mesa topography. The trails from the study were overlaid onto the TIN using the TIN as the base height to display their elevation in the third-dimension. Figure 27 is a map created to illustrate the Elevation Gain Loss Tool using the Lichen Peak Trail in the North Table Mountain Park.

Figure 26. Three-Dimensional Model of North Table Mountain using a TIN

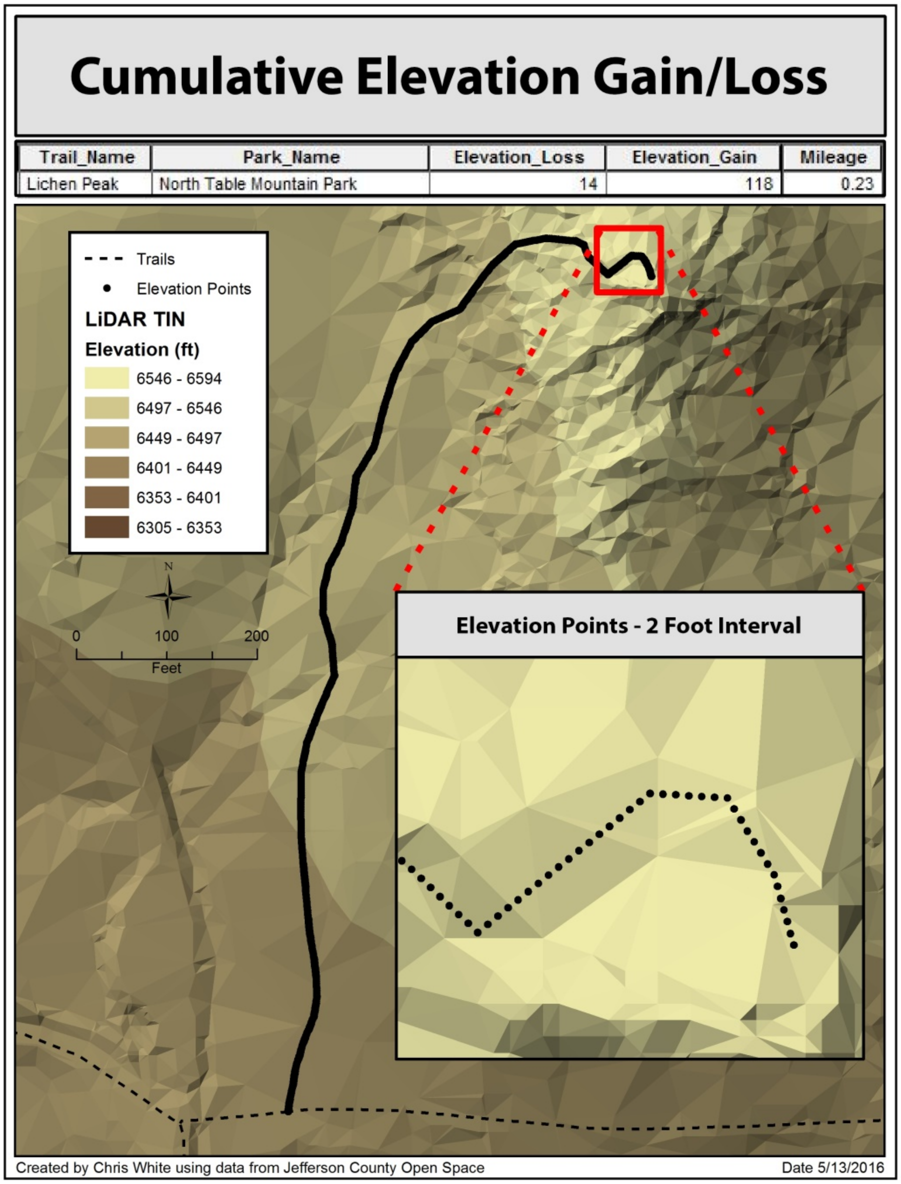

Figure 27. Cumulative Elevation Gain Loss Map of Lichen Peak Trail

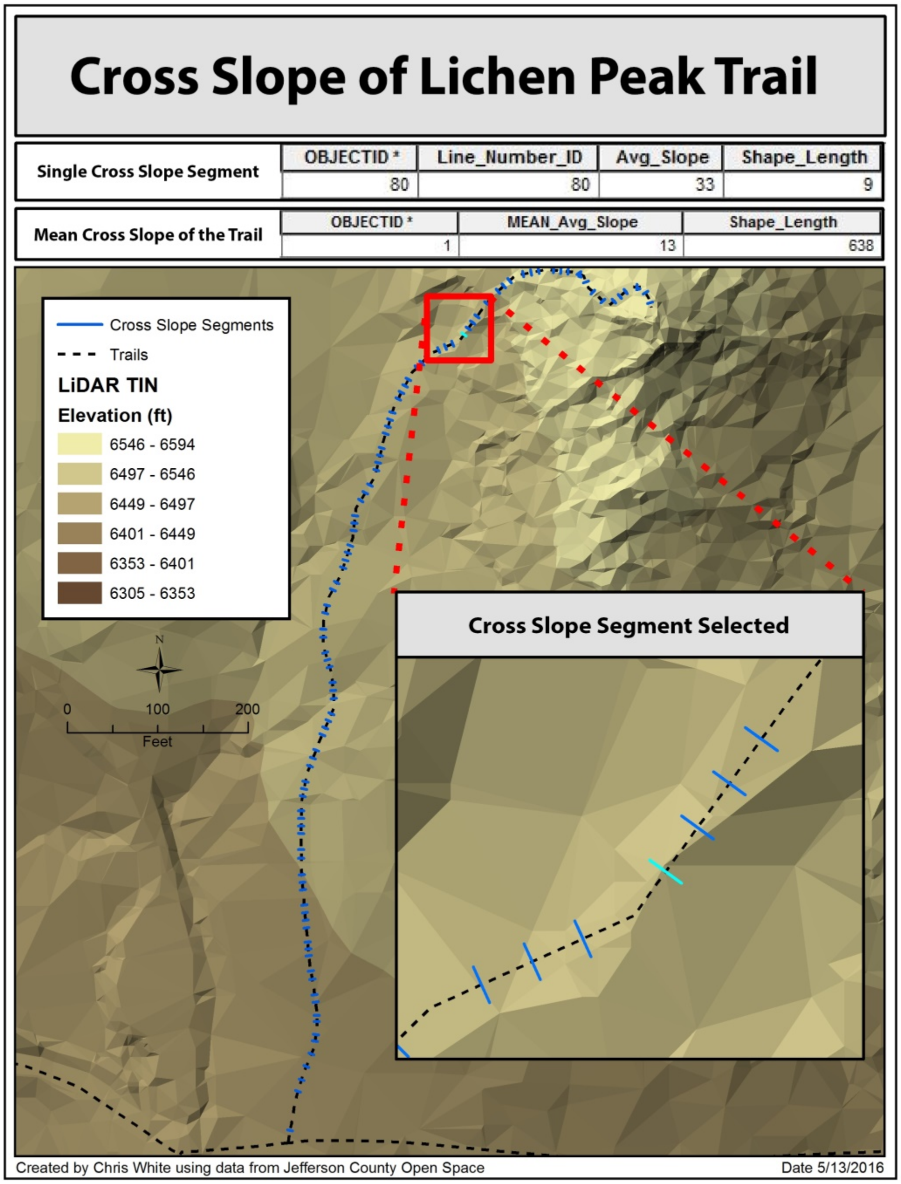

Figure 28. Cross Slope Map of Lichen Peak Trail

Figure 28 is an illustration of the process and outputs of the Cross Slope Tool. This map uses the TIN of the North Table Mountain Park as the basemap and trail data from Jeffco Open Space. Figure 29 shows the processes and outputs of the Trail Aspect Tool. Similar to the other maps, this map uses the TIN of the North Table Mountain Park, Jeffco Open Space trails data, as well as the aspect polygons created from the Surface Modeling Tool.

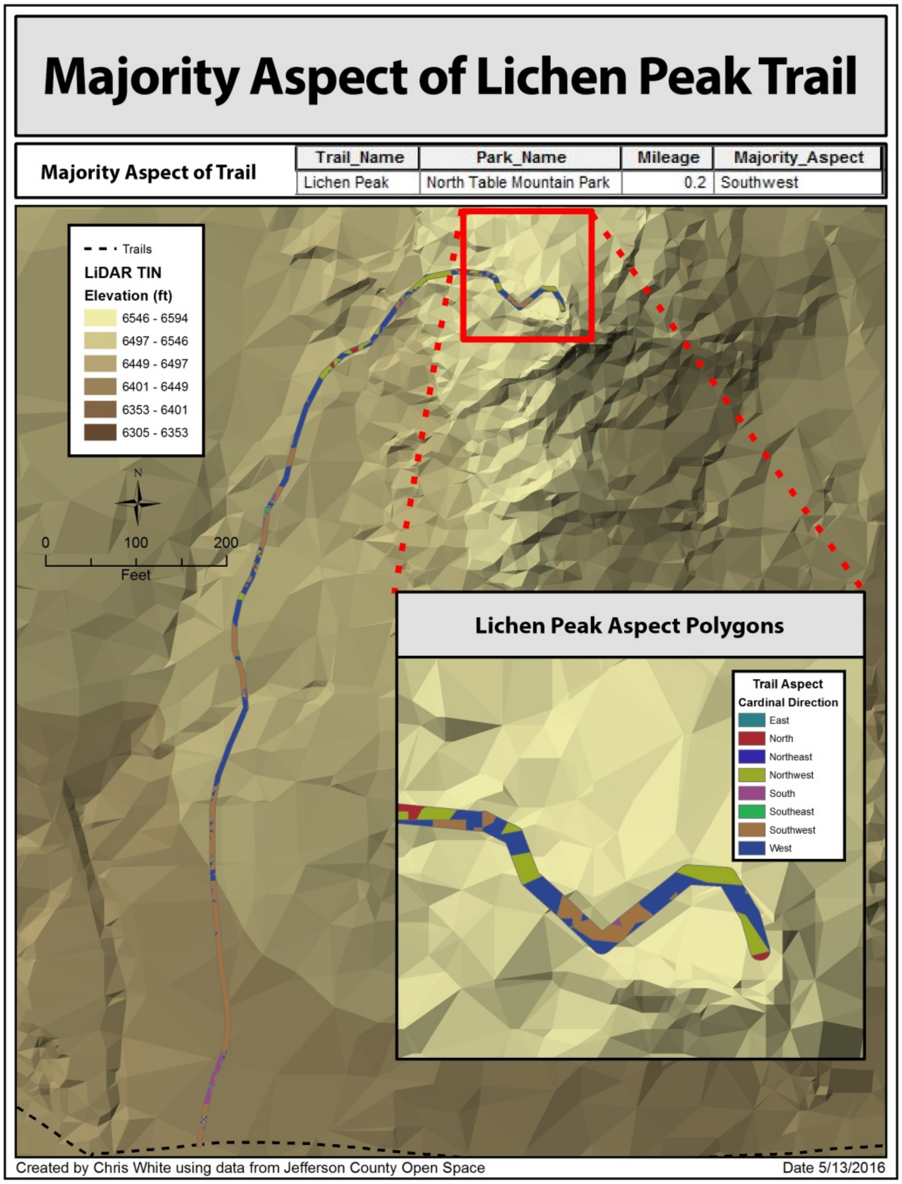

Figure 29. Majority Aspect Map of Lichen Peak Trail

Possible Errors in the Toolset

"A large proportion of total error is introduced during the processing of raw data and the subsequent modeling with and analysis from it" (Smith, Holland and Longley 2004). It is proven that errors can compound on themselves when using raw LiDAR data converted to raster format. This can be seen in the process of creating a DEM from LiDAR data. Not all points in the LiDAR data correspond with actual ground levels and for these areas extrapolation has to occur. Not all DEM processes are created equal and error can be carried deep into this toolset from the conversion of LiDAR point clouds to raster images. One must be aware of such potential errors while running this toolset.

"A decrease in horizontal accuracy will result in increased horizontal displacement, and thus elevation error of the LiDAR returns in sloped terrain." (Glenn, et al. 2011) One of the attractions to Jeffco Open Space parks are their diverse elevation ranges. This addition of slope variation may play a negative effect on the toolset's overall accuracy. While the creation of the DEMs which are being used in this study is outside of the scope of this project, it is important to understand this possible error and the effects that it might have on the pre-generated DEMs.

Discussion

While this toolset did meet all of the goals we set out to accomplish, there is room for improvement to the tools themselves. The tools were designed completely with out of the box tools native to ArcGIS with the addition of the 3D Analyst and Spatial Analyst extensions. With a stronger understanding of the Python coding language I believe that some of these tools could be streamlined more efficiently. The Elevation Gain Loss Tool in particular could benefit greatly from a custom toolset using Python code. Currently this tool can only handle one line segment at a time and dependent on the length of the segment, it can have upwards of thousands of calculations to perform. This leads to the tool taking a substantial amount of time to accomplish its desired calculations. In the future I wish to strengthen my knowledge of the Python coding language and reevaluate this toolset as a whole. Hopefully I will be able to increase its efficiency and processing times.

Further Study

In order to study the errors introduced to this toolset by change in slope, further research could be conducted by applying this toolset to other Jeffco Open Space parks with varying levels of elevation change. These further studies will have two distinct benefits in which Jeffco Open Space would acquire more derived data and, I would develop a further understanding of the errors introduced by slope during the DEM generation process and its effect on the toolset.

Once the toolset has been run on every Jeffco Open Space park, Jeffco Open Space can create a ranking system of each park's terrain based on the roughness ratio of each park. The roughness ratio for a single park does not give that much usable information to the user, however a comparison of all the roughness ratios of each park tells a great deal. By comparing the roughness ratio of the park to the park system, Jeffco Open Space will be able to accurately rank the terrain variation of all their parks. This ranking concept and process can also apply to the roughness ratio of the trail system.

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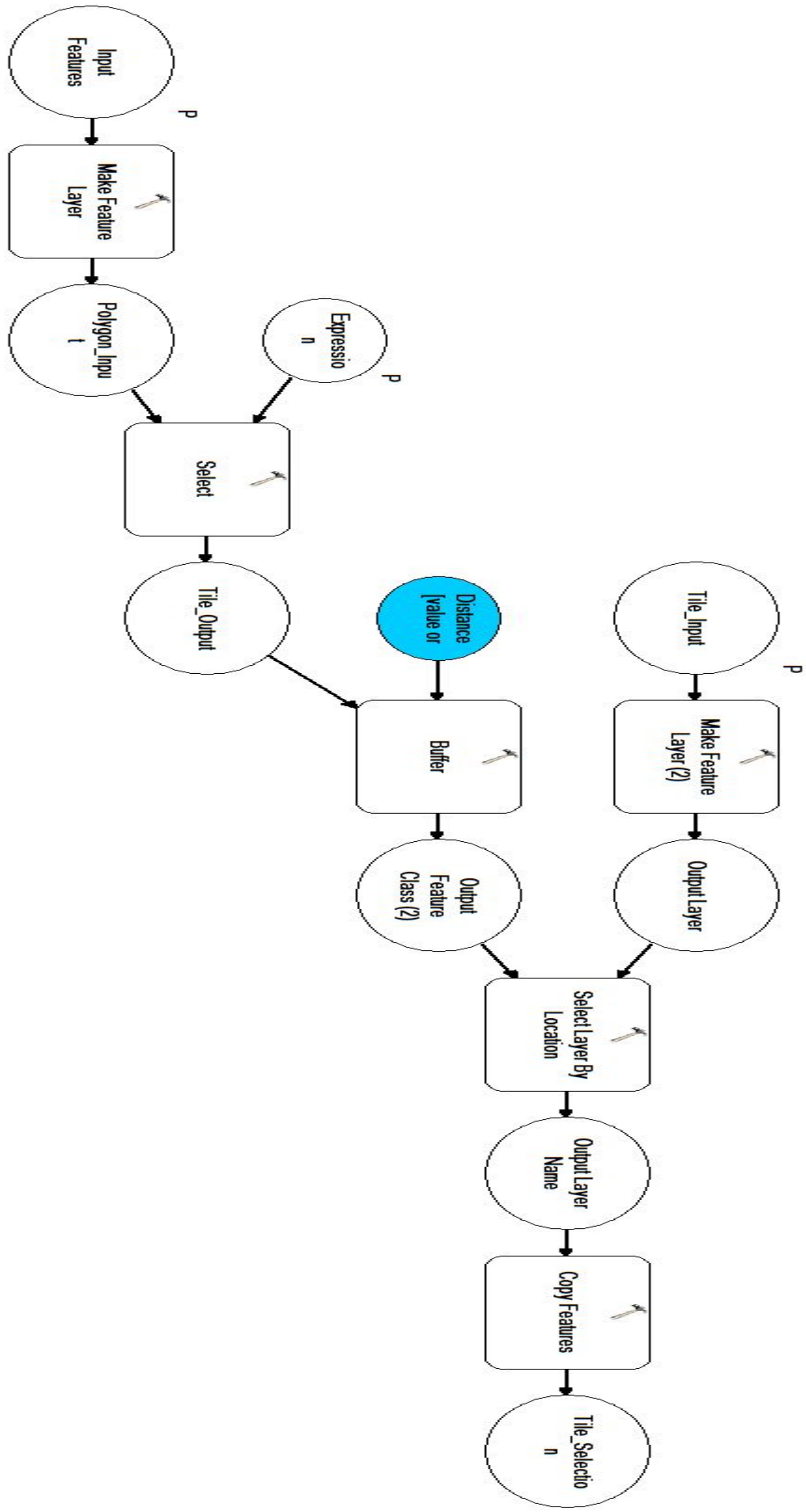
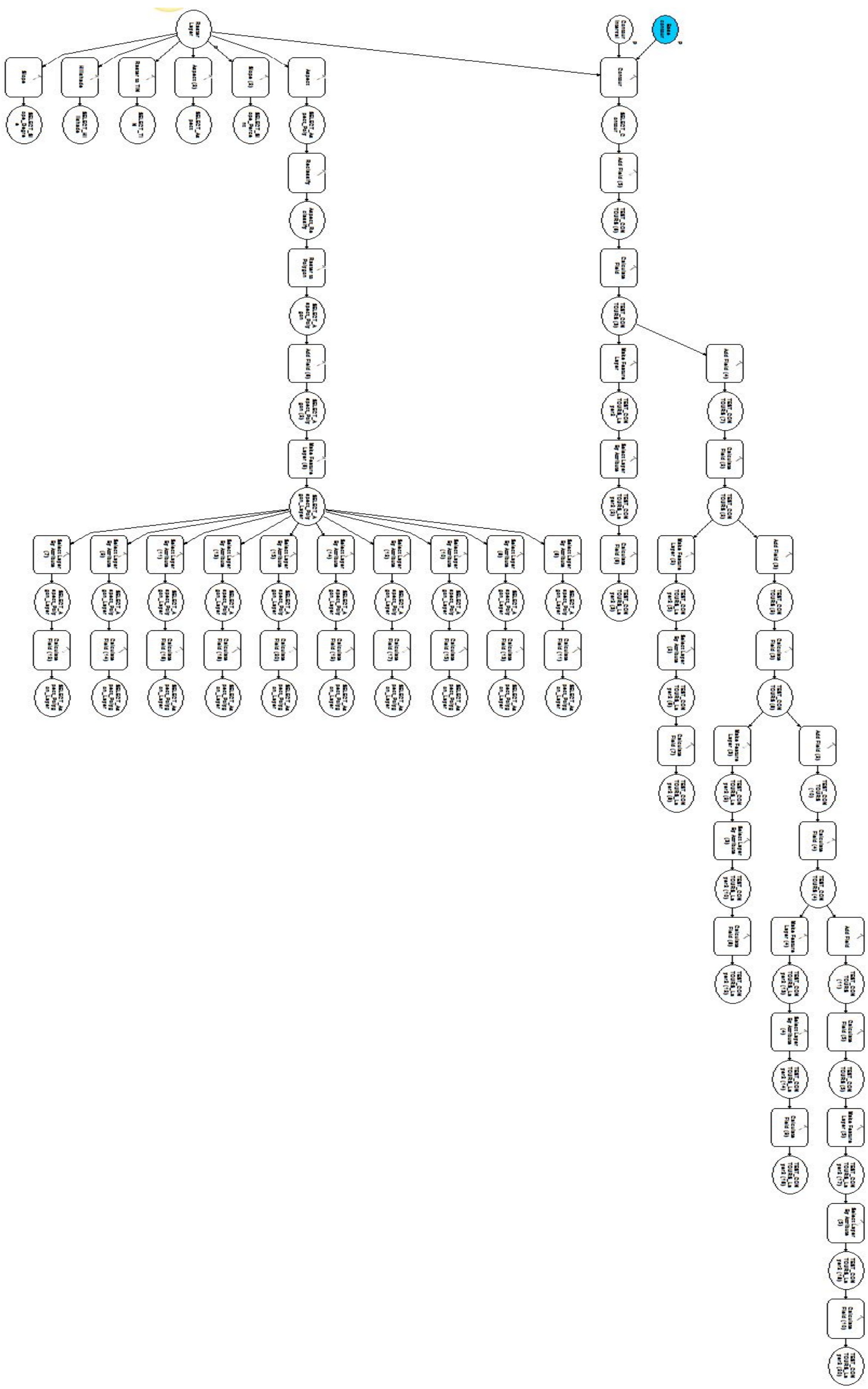
Appendix

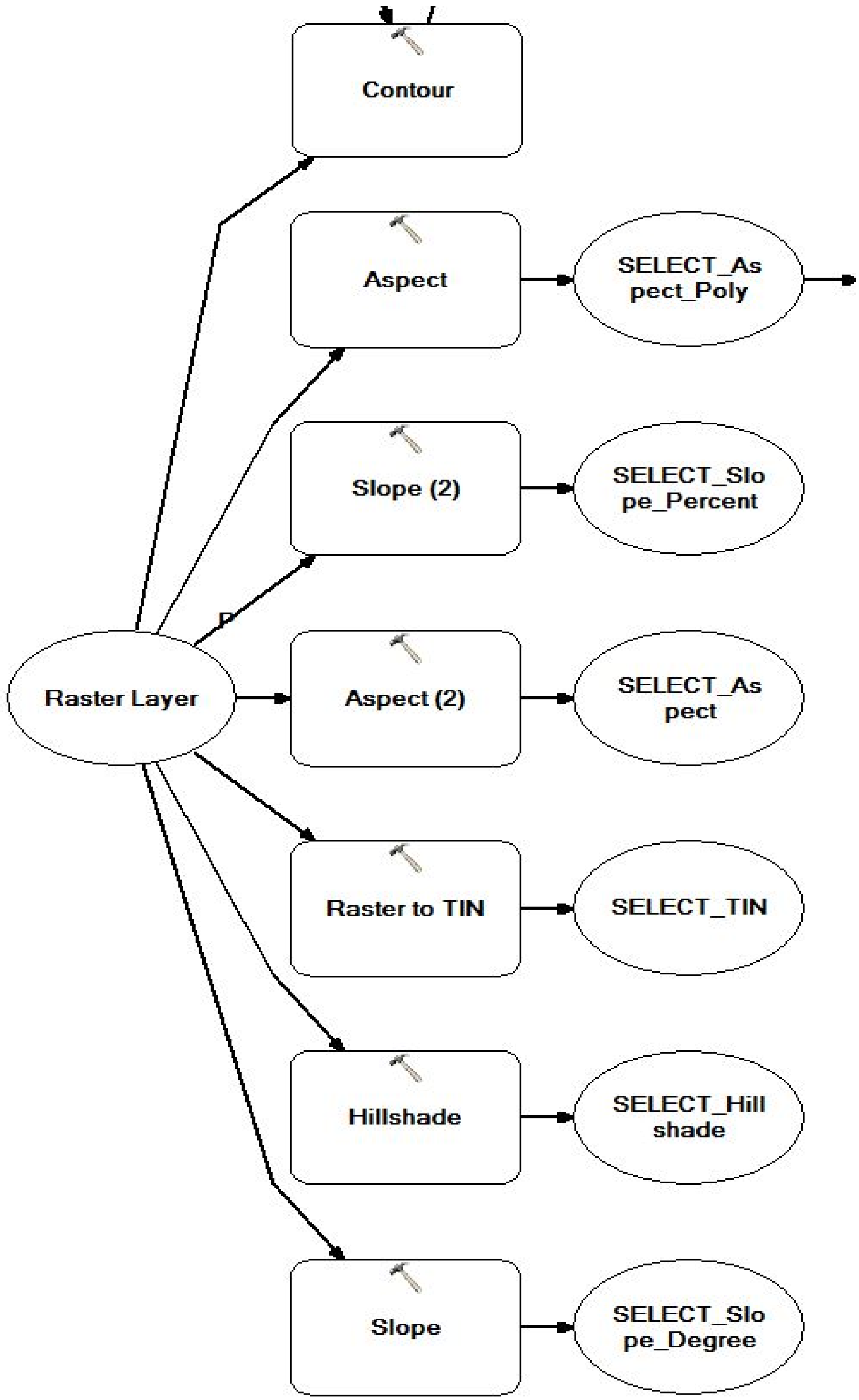
Tile Selection Tool



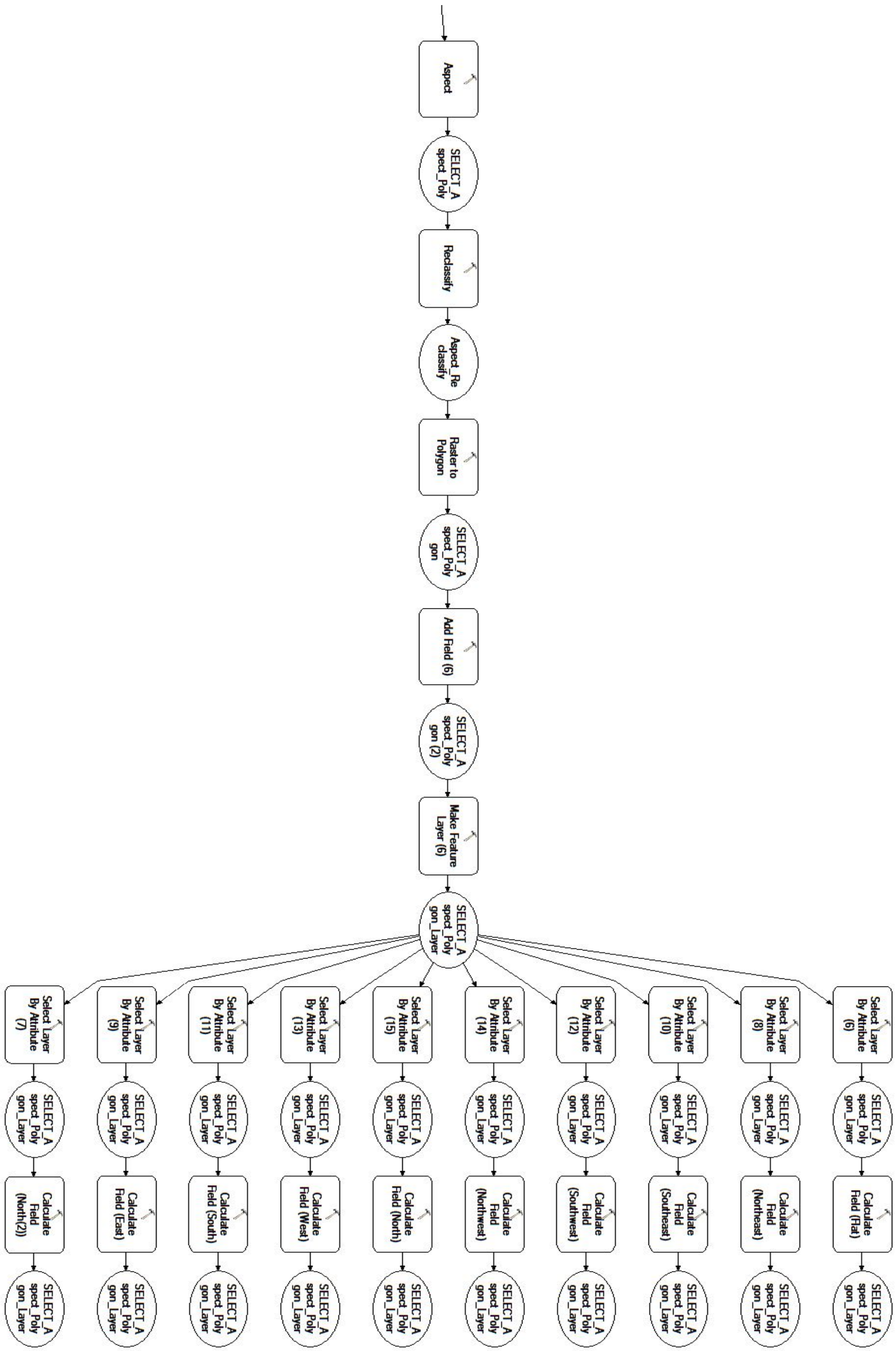
Surface Modeling Tool



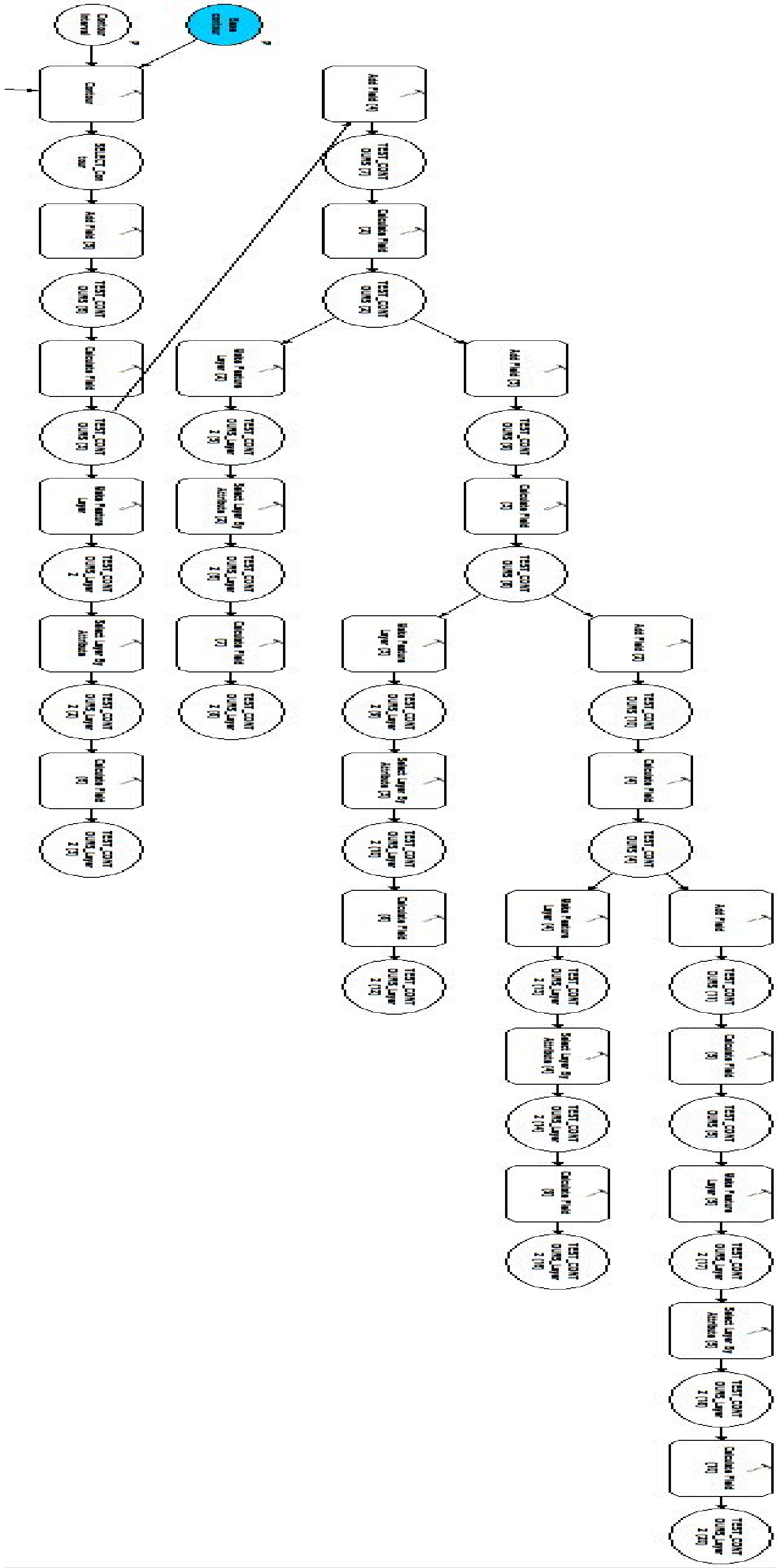
Surface Modeling Tool – Section 1



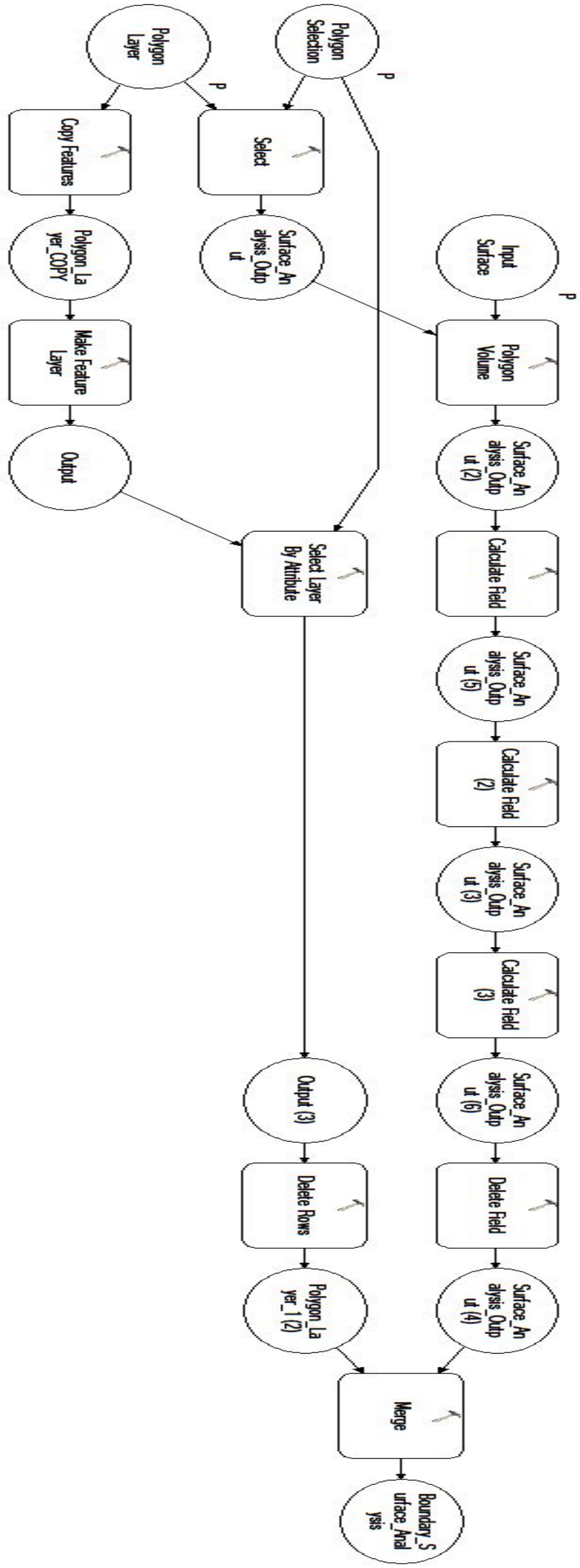
Surface Modeling Tool – Section 2



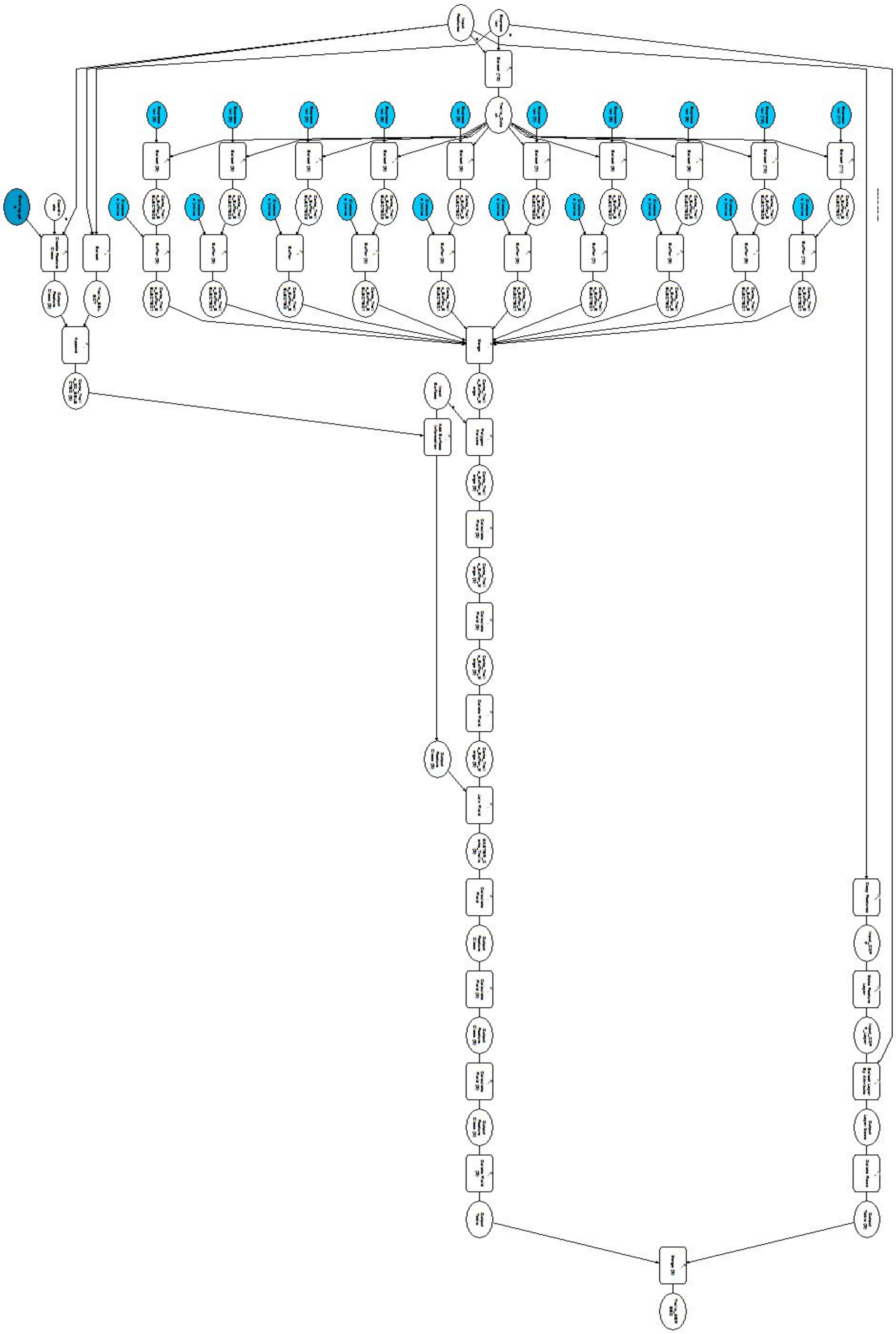
Surface Modeling Tool – Section 3



Surface Analysis Boundary Tool



Trail Surface Analysis Tool



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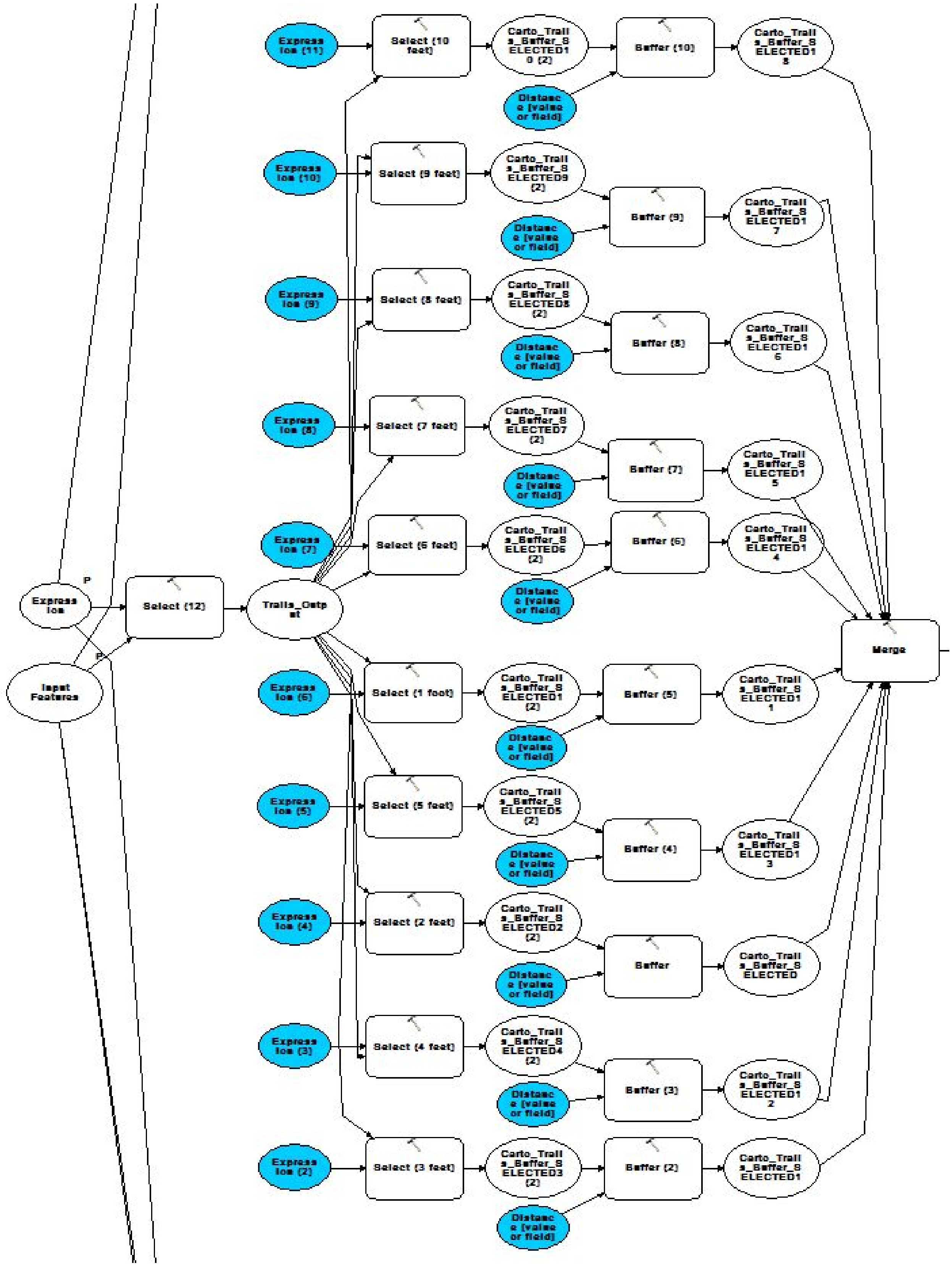

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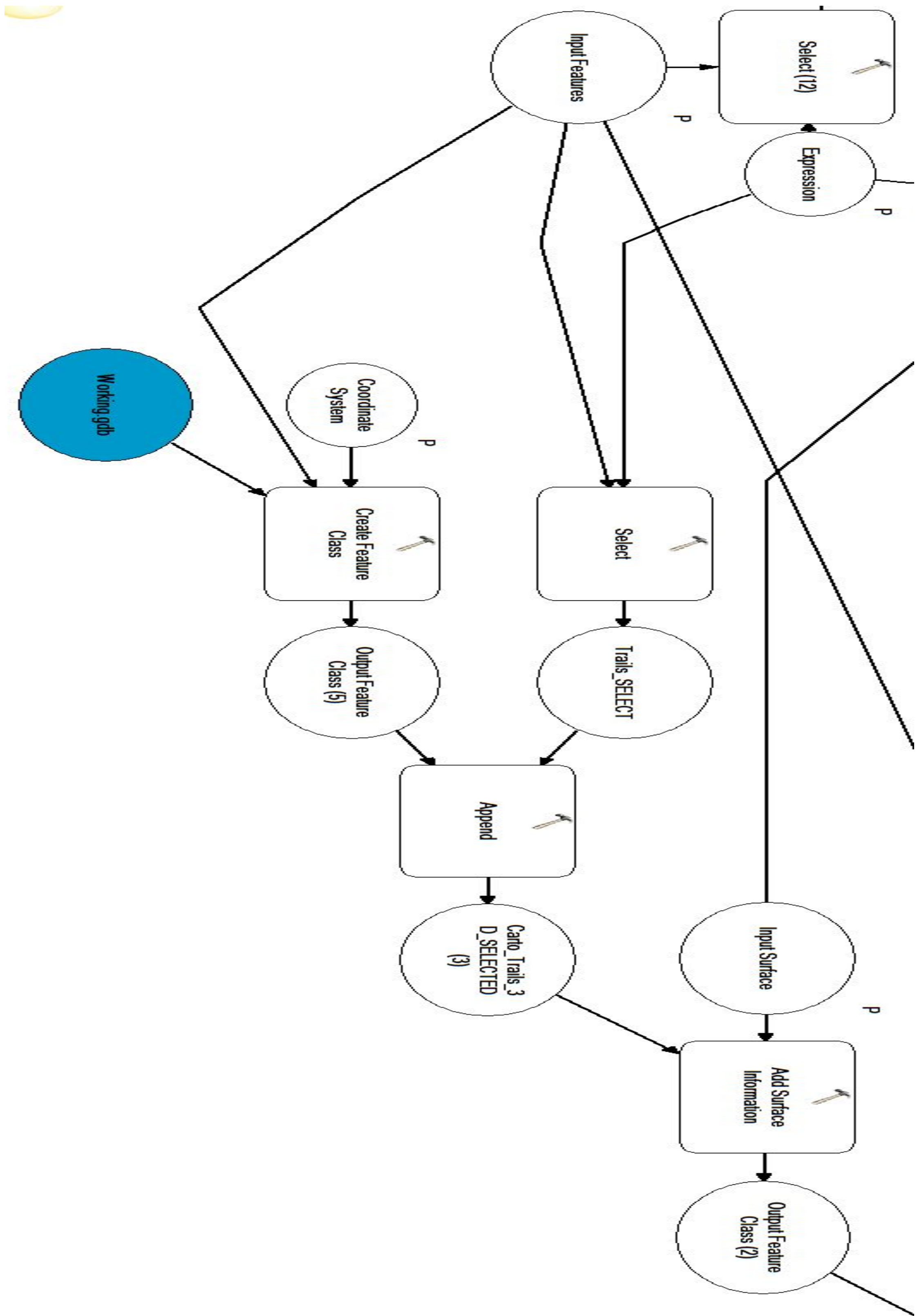

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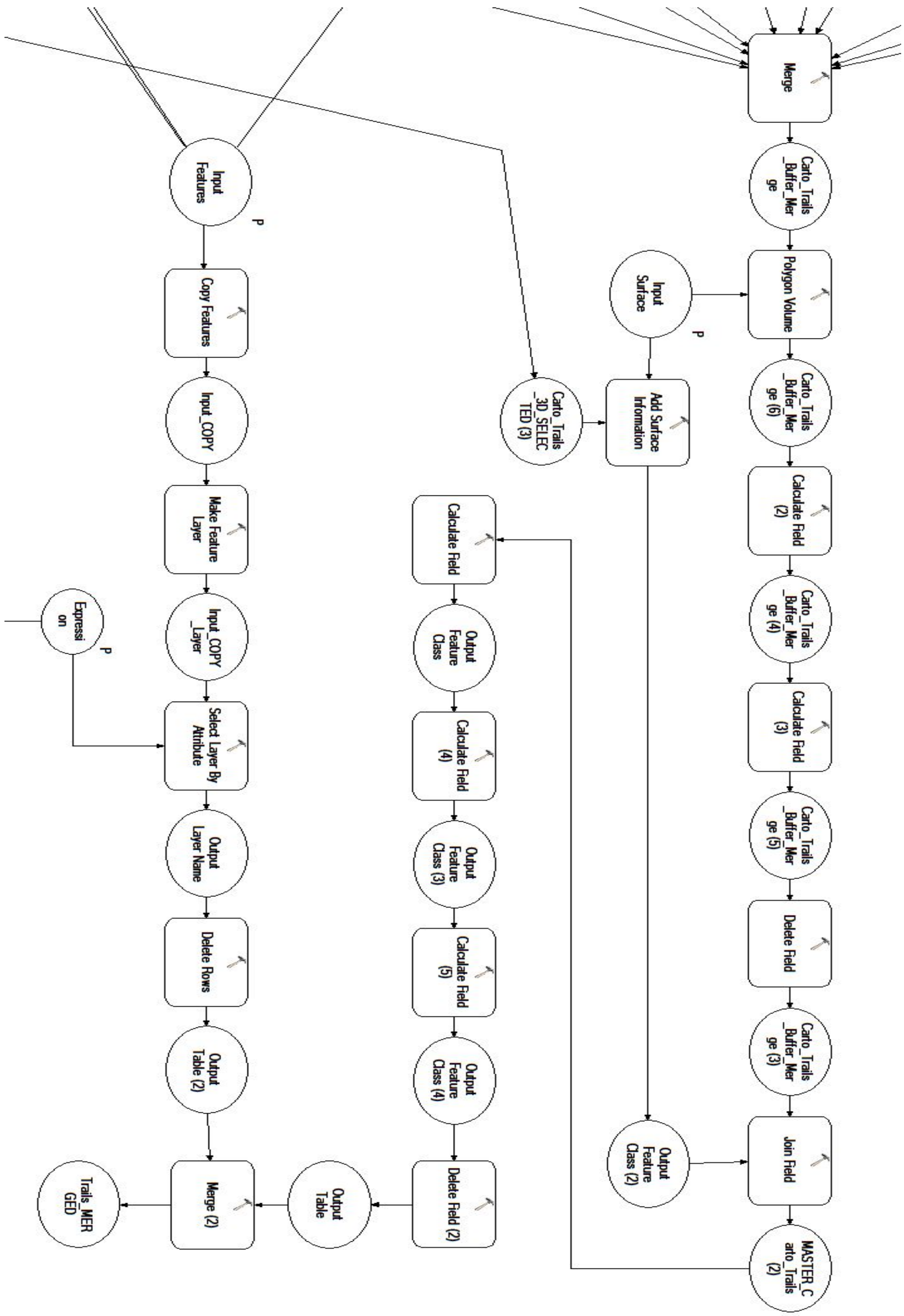
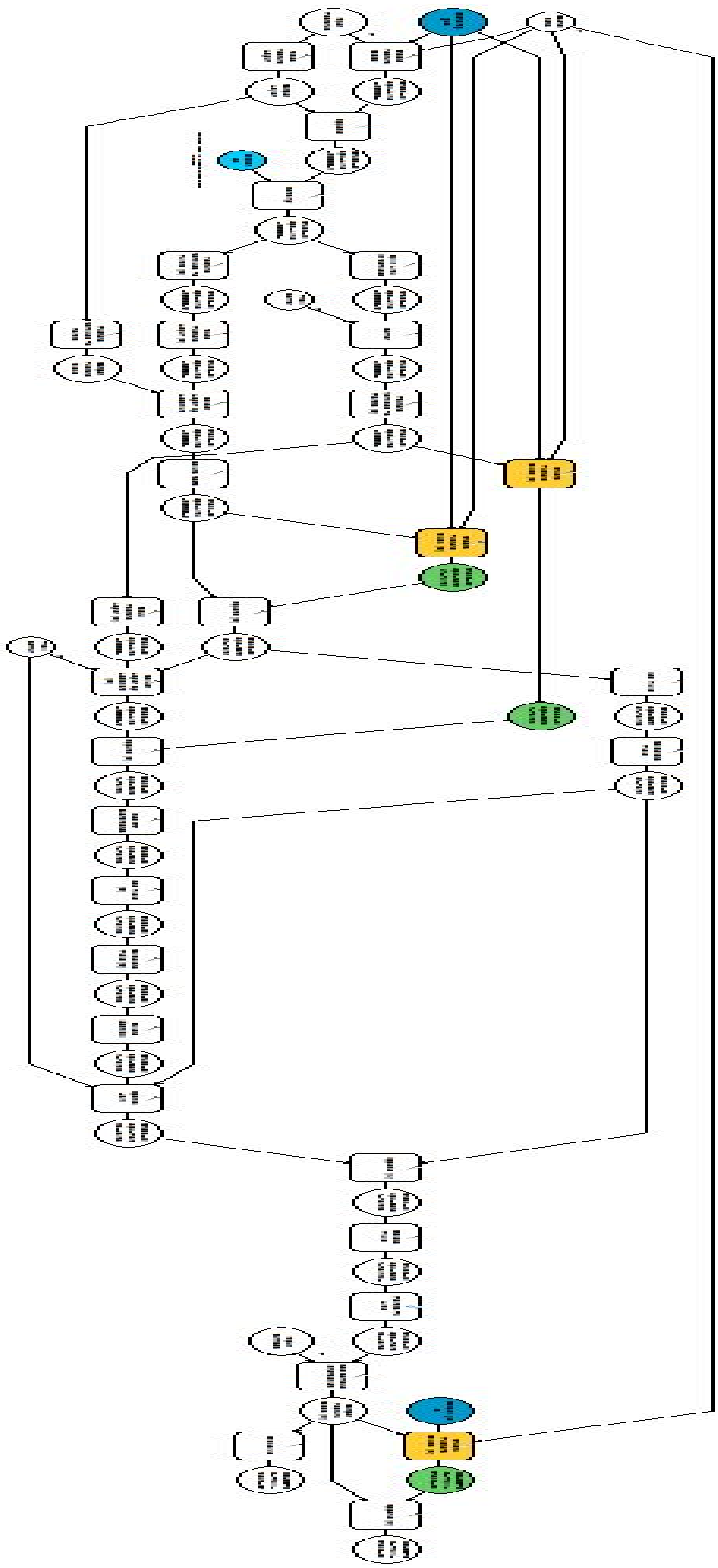
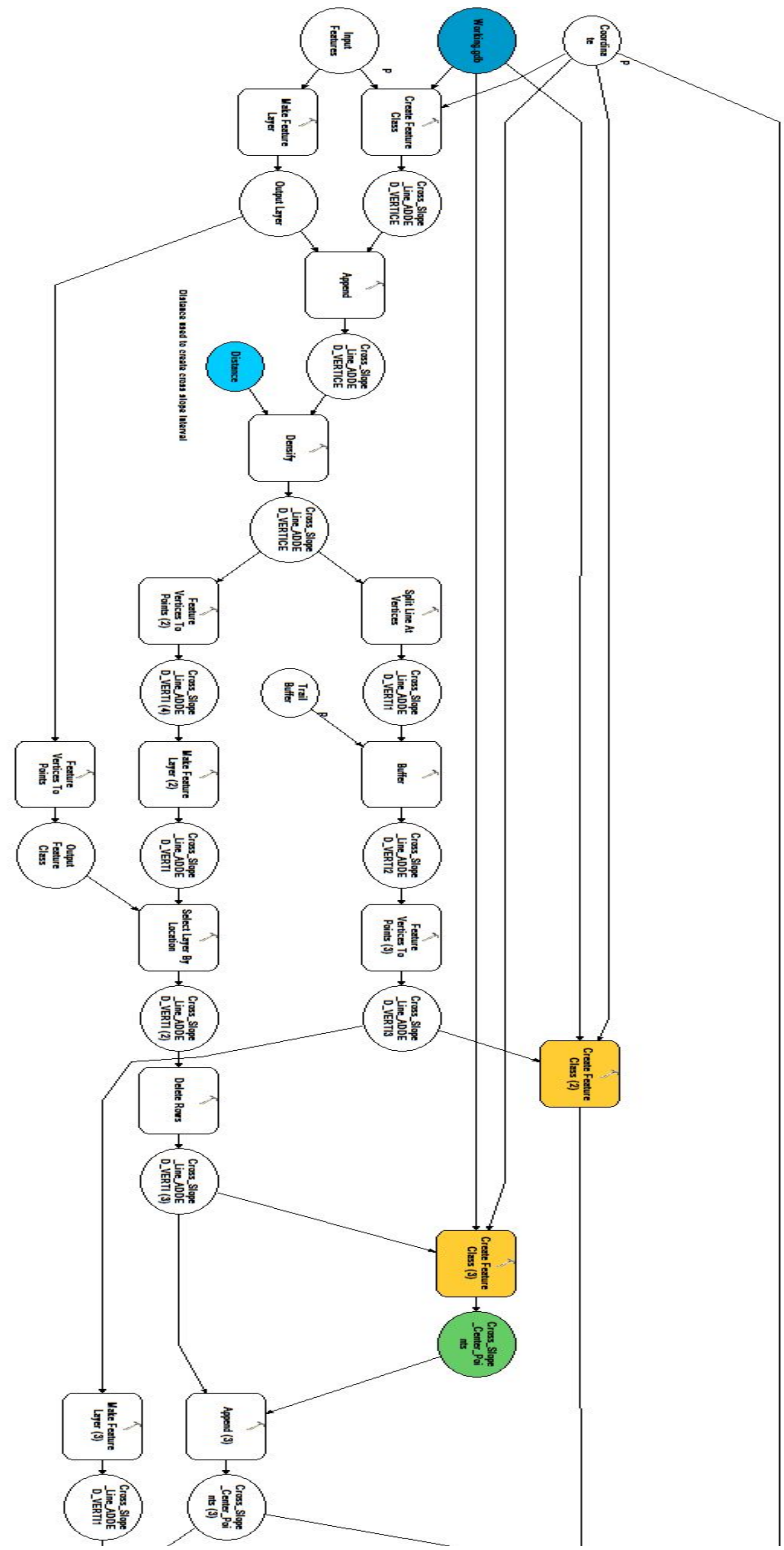


Cross Slope Tool



Cross Slope Tool – Section 1



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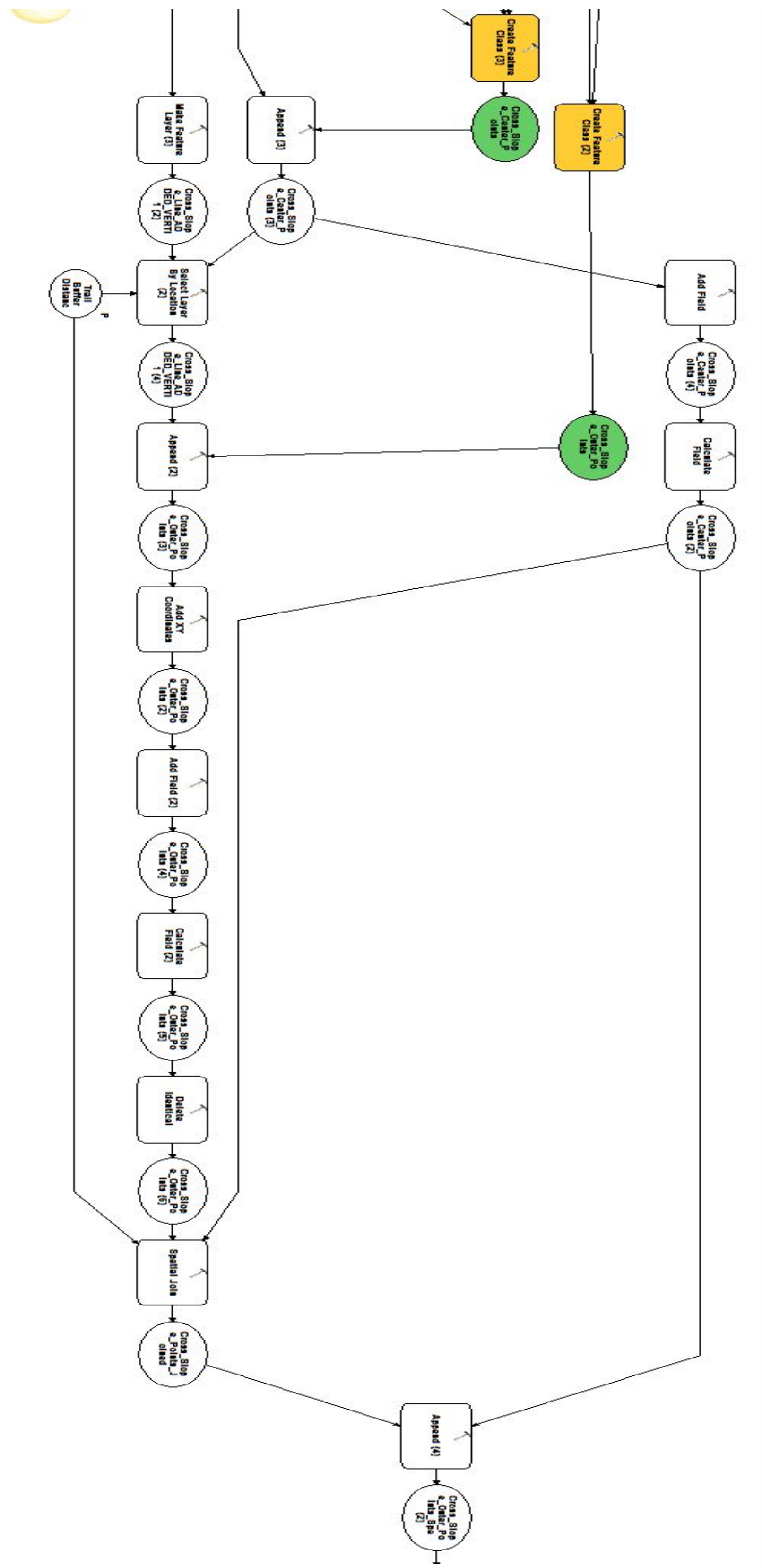

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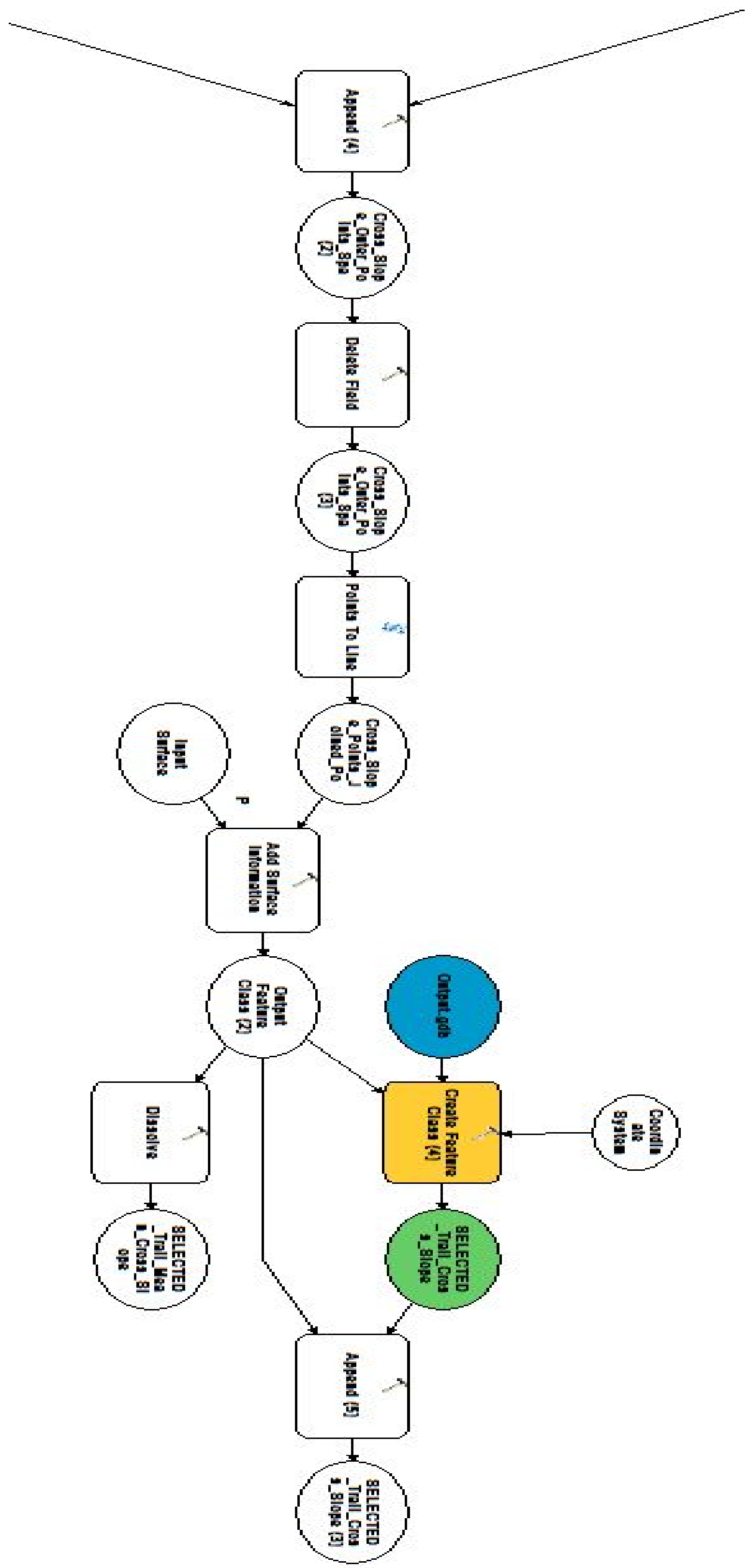
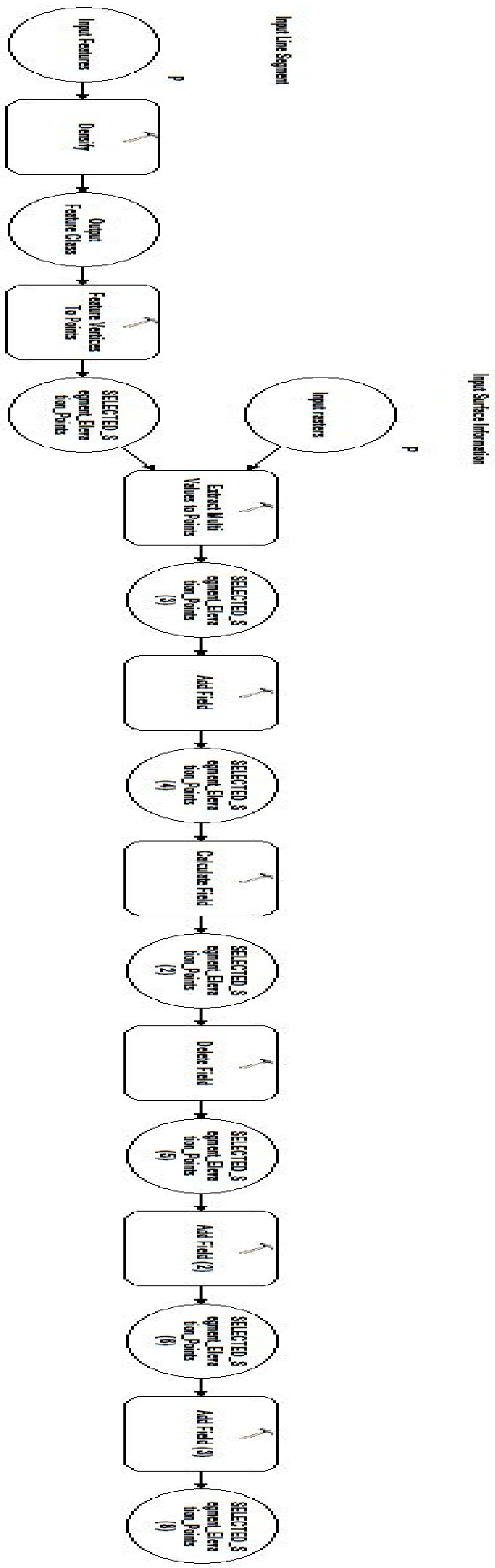


Elevation Gain Loss Tool – Section 1



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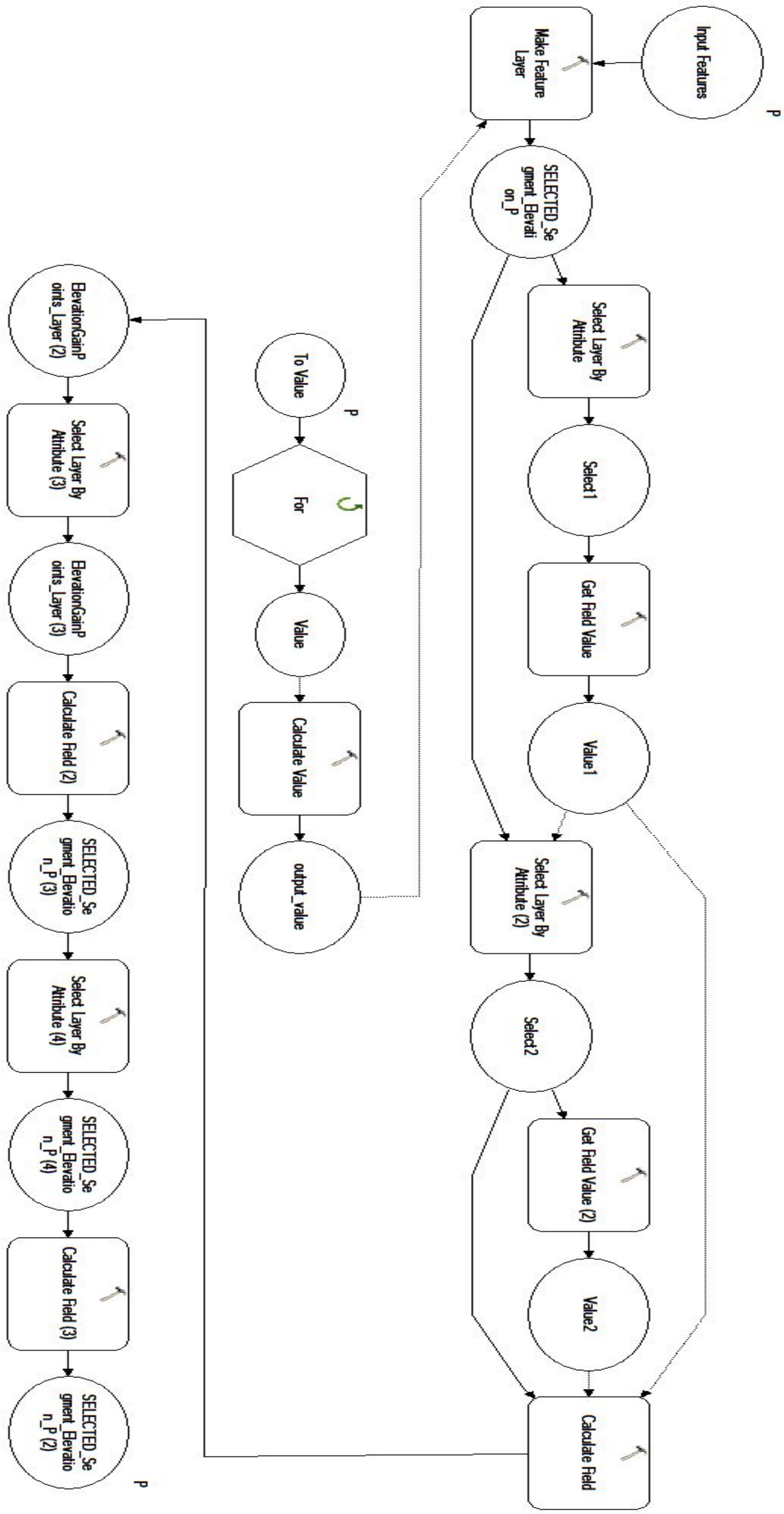

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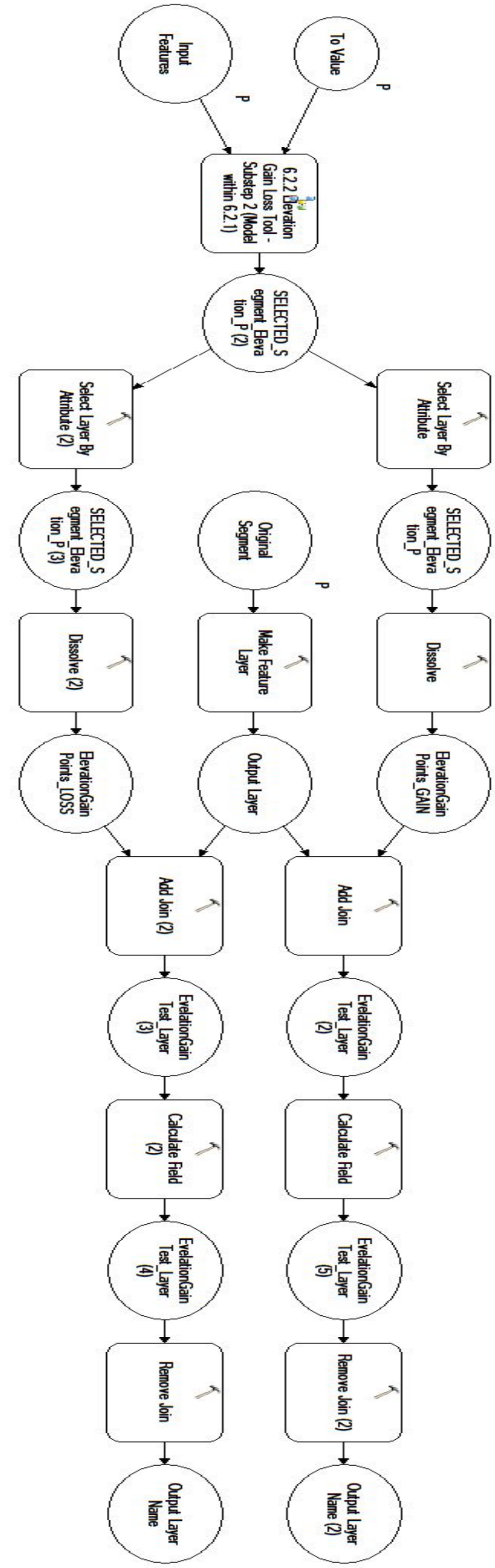
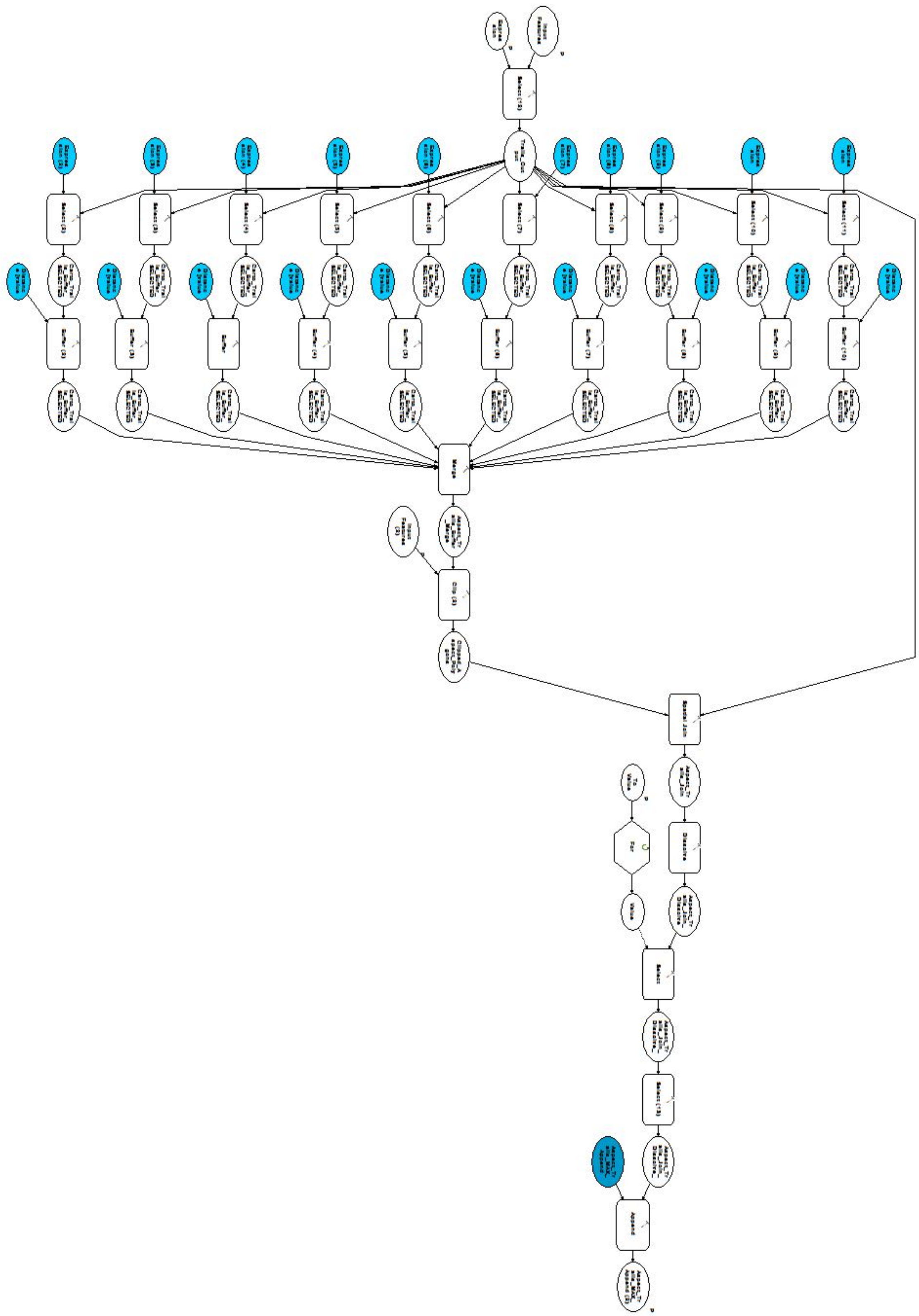


Trail Aspect Tool – Section 1



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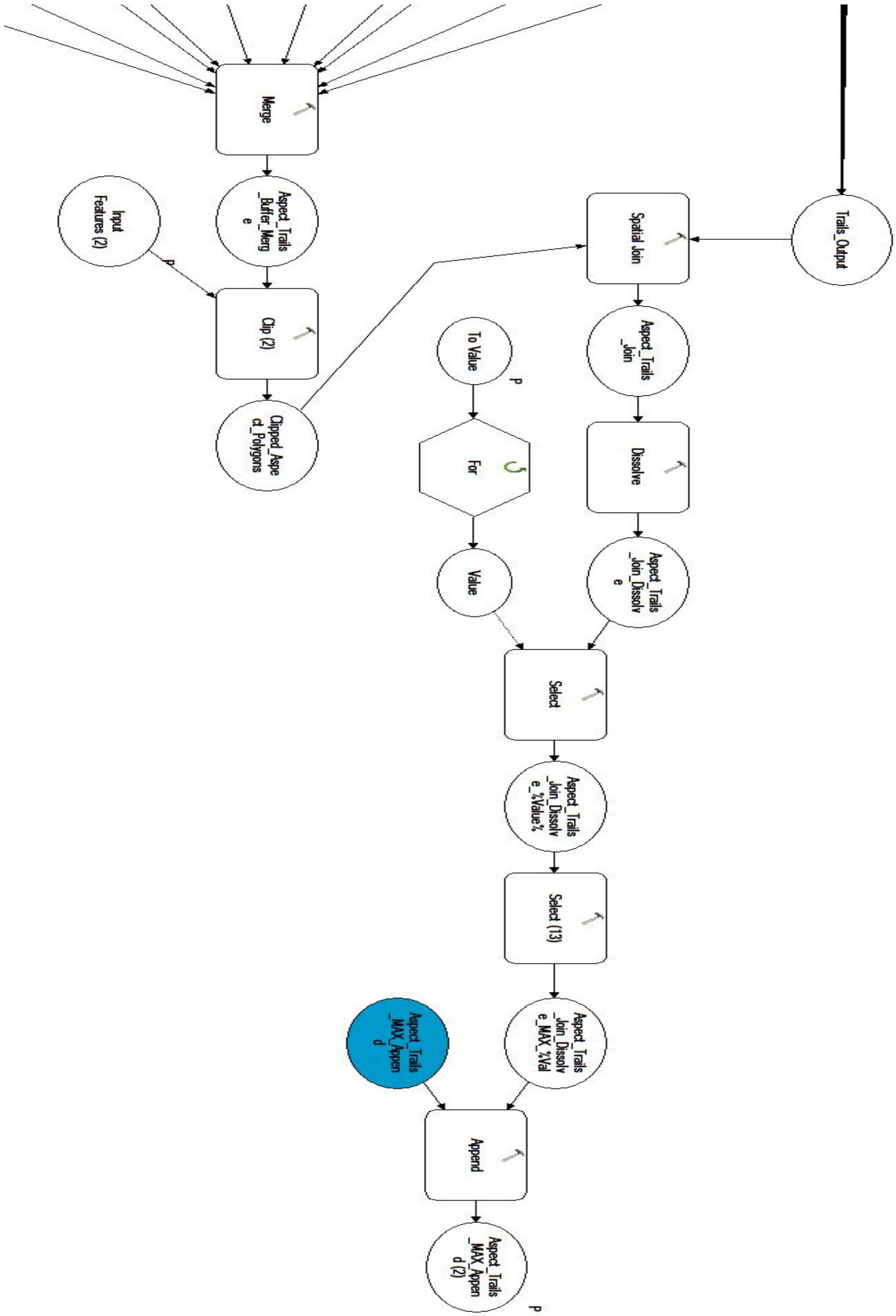

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