Landscape Connectivity Modeling Across the Credit River Watershed

User's Guide

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1. Introduction

This document is a user manual that provides step-by-step instructions for modelling landscape connectivity across the Credit River Watershed. This is a supporting document to the report *"Evaluating Natural Heritage Connectivity in the Credit River Watershed"* by Moniem et al. (2020). The manual has two main objectives: (1) to produce a watershed-level, wall-to-wall current density map; and (2) to quantify the importance of each natural area for the maintenance of landscape connectivity across the CVC jurisdiction. This document is divided into six main sections, as follows:

1. System and Data Requirements
2. Establishing Resistance Surface
3. Creating Current Source Nodes Around Buffer Area
4. Modeling Landscape Connectivity: Wall-to-Wall Map
5. Visualizing Wall-to-Wall Current Density Map
6. Quantifying the Importance of Natural Areas: Creating Node and Connection Files
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2. System and Data Requirements

2.1. Geospatial Input Data

Three initial files are necessary as geospatial input data before any analyses can be completed:

- A shapefile of a land-cover (land-use), with land-cover types reclassified into three policy-relevant categories that describe resistance to organism movement: natural and permeable, non-natural and permeable, and non-natural and impermeable.
- A shapefile of the natural areas (polygons) within the CVC jurisdiction.
- A shapefile of the CVC jurisdiction boundary (polygon).

Please note that all initial geospatial data for this project was provided by the CVC geospatial team.

2.2. Necessary Software and Add-ins

The following software and add-ins are necessary to complete the analysis:

- Esri ArcGIS 10.X and the following associated add-ins:
    - Spatial Analyst toolbox
    - Conefor Inputs add-in (http://www.jennessent.com/arcgis/conefor_inputs.htm)
    - Linkage Mapper add-in (https://circuitscape.org/linkagemapper/)
- QGIS 3.X (https://qgis.org/en/site/forusers/download.html)
    - Buffer by Percentage add-in (https://plugins.qgis.org/plugins/BufferByPercentage/)
- Circuitscape 4.0 (https://circuitscape.org)

- Conefor 2.6 (http://www.conefor.org)

2.3. Global Environment Settings

Several environment settings can be defined in the ArcGIS global workspace before using GIS tools. In this project we used snap raster for output extent settings to ensure that grid cells of input rasters are aligned when raster tools are used. The default Coordinate System was set to NAD 83 CSRS, UTM zone 17N. The default cell size was set to 10 x 10 meters.

3. Establishing Resistance Surface

3.1. Rasterize Land-Cover (Land-Use) Vector Data

To create the resistance surface required for landscape connectivity modeling, the land-cover type (land-use) data layer needs to be transformed into a raster (this land-cover layer was provided by the CVC geospatial team as a shapefile). The land-cover type data is a vector layer that includes different categories of land-cover types and their corresponding suggested resistance values. These resistance values reflect the degree of non-naturalness of each land-cover type as a proxy of the degree to which these categories could impede or facilitate the movement of organisms in the landscape. Three different values of resistance were assigned to land-cover types based on policy-relevant categories: natural and permeable (10), non-natural but permeable (100), and non-natural an impermeable (1000). The three policy-relevant resistance categories were selected following previous work that modelled landscape connectivity across southern Ontario (Bowman and Cordes, 2015). The resulting raster layer has a single resistance value for each cell, which is derived from the resistance value assigned to each land-cover polygon map.

In ArcMap (Figure 1):

A. Import land-cover type layer (shapefile) and the CVC boundary layer (shapefile) into ArcMap.
B. Convert the land-cover type layer to raster with 10 m resolution. For this open the "Polygon to Raster" conversion tool.
C. As "Input Features" select the land-cover type layer.
D. In "Value field" select "RESISTANCE." This will tell the tool to build the new raster with the resistance values of the main land-cover type layer.
E. In the "Output Raster Dataset" select the output location and name of the new raster.
F. In "Cell assignment type (optional)" select "MAXIMUM AREA." This will tell the tool which resistance value to use when a pixel has more than two resistance values. With this option the maximum value of resistance of each pixel will be used (more conservative approach).

G. In “Cellsize (optional)” select 10. This will define the size of each pixel in map units. A cell size of 10 provides a high spatial resolution for the output raster and is an appropriate cell size for this watershed-scale analysis.

H.

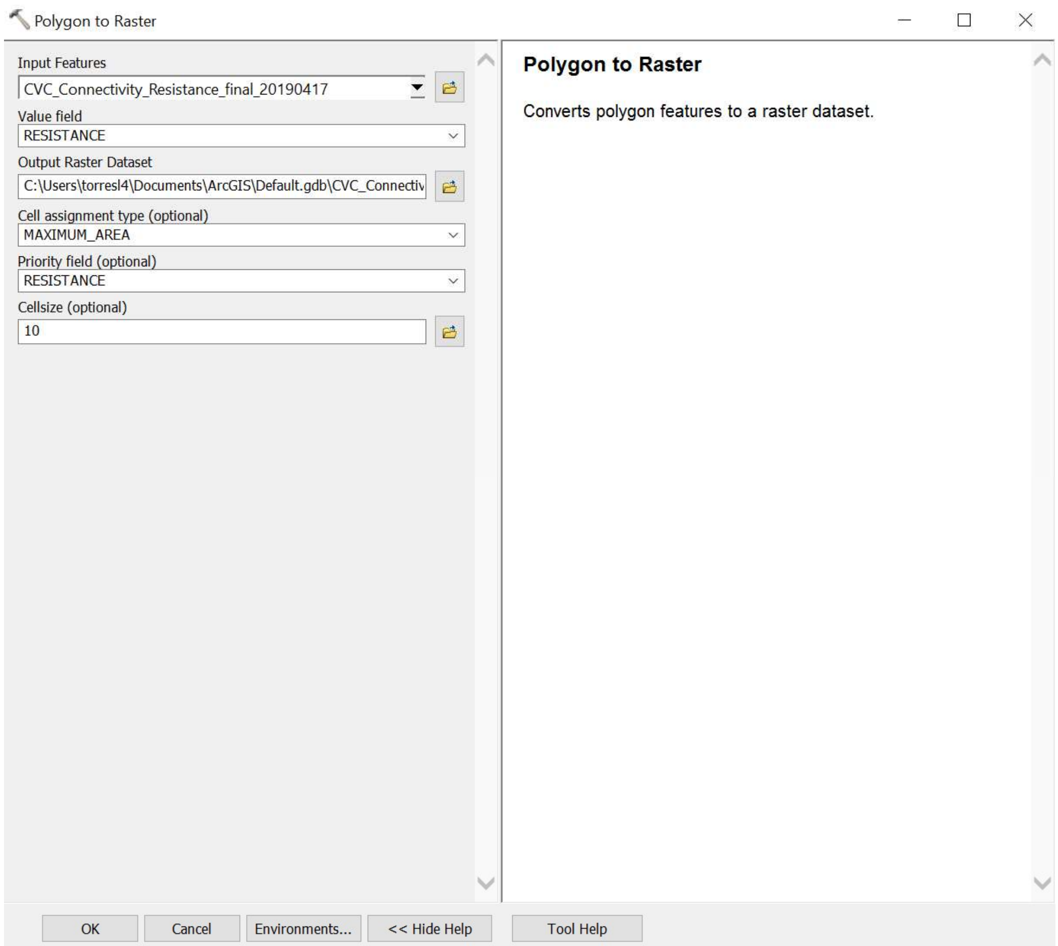

Figure 1: Steps to rasterize vector data from land-cover type layer.

I. The resulting raster will include the three policy-relevant landscape resistance categories (10, 100, 1000). Color used to represent each landcover type will vary depending on the selected symbology (Figure 2).

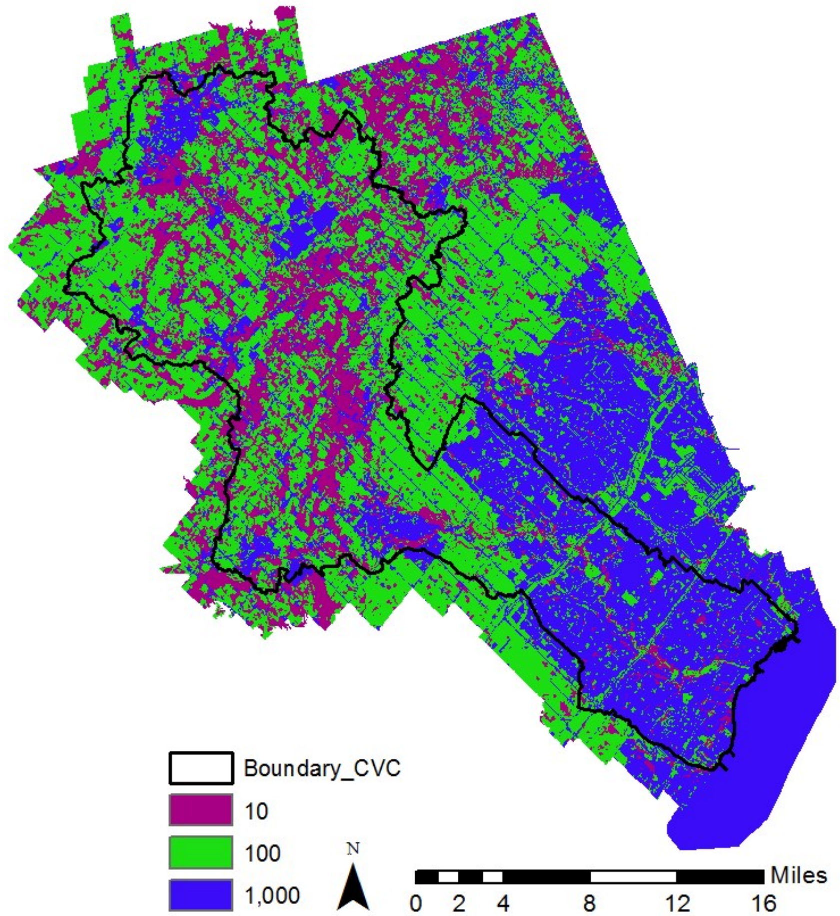

Figure 2: Raster including the three policy-relevant landscape resistance categories (10, 100, 1000).

3.2. Establish Buffer Area around the CVC Boundary Polygon

To complete the analysis for landscape connectivity modeling (compute current density map), there is a need to establish a buffer zone that is approximately 25% larger than the area of interest (CVC jurisdiction). This buffer will be used in later steps to place current source nodes. A buffer of 25% was sufficient to remove potential bias of high current flow within the study area.

In QGIS (Figure 3):

A. Import the CVC boundary layer (shapefile).
B. Install the “Buffer by Percentage” plugin. For this go to the “Plugins” menu and select “Manage and Install Plugins.” Then type “Buffer by Percentage” in the search textbox, select “Buffer by Percentage” and click “Install Plugin.”
C. To open the plugin, go to the “Processing Toolbox” and type “Buffer by Percentage.” Select “Fixed percentage buffer.”
D. In “Input Layer” select the CVC boundary layer.

E. In "Percentage" select "250.0" This will create a 25% buffer area around the CVC boundary layer.
F. In "Segments" select "5."
G. In "Buffer" select an output location and name of the new buffer. Make sure to save it as a shapefile (.shp).

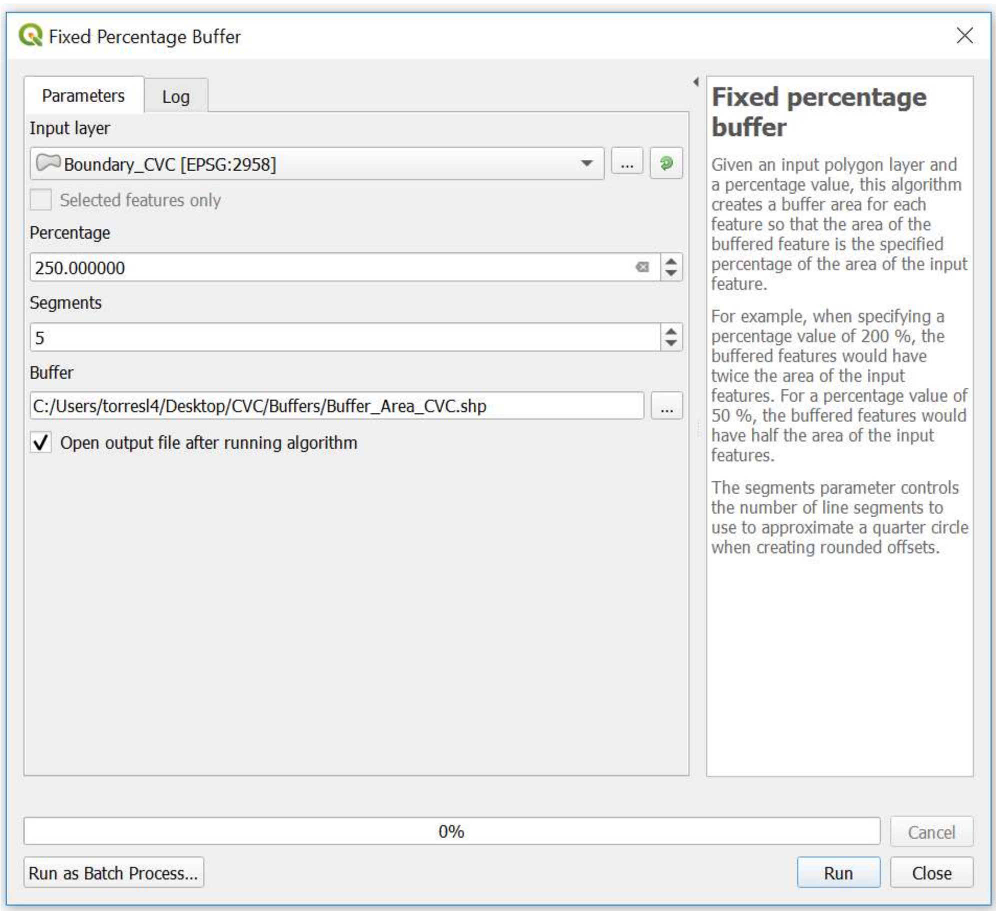

Figure 3: Establish 25% buffer area around the CVC boundary layer.

3.3. Rasterizing the Buffer Area

The newly created shapefile includes the original CVC boundary plus a 25% buffer (Figure 4). In the following steps, this shapefile will be converted to a raster (all cells will have a value of zero by default), then all cells will be assigned an 'intermediate level' of resistance (value = 100) that will fill in the gaps for cells that are outside of the rasterized land cover layer.

In ArcMap (Figure 5):

A. Import the shapefile of the 25% buffer zone created in QGIS from the previous step (Figure 3). Visualization will vary depending on the chosen symbology.

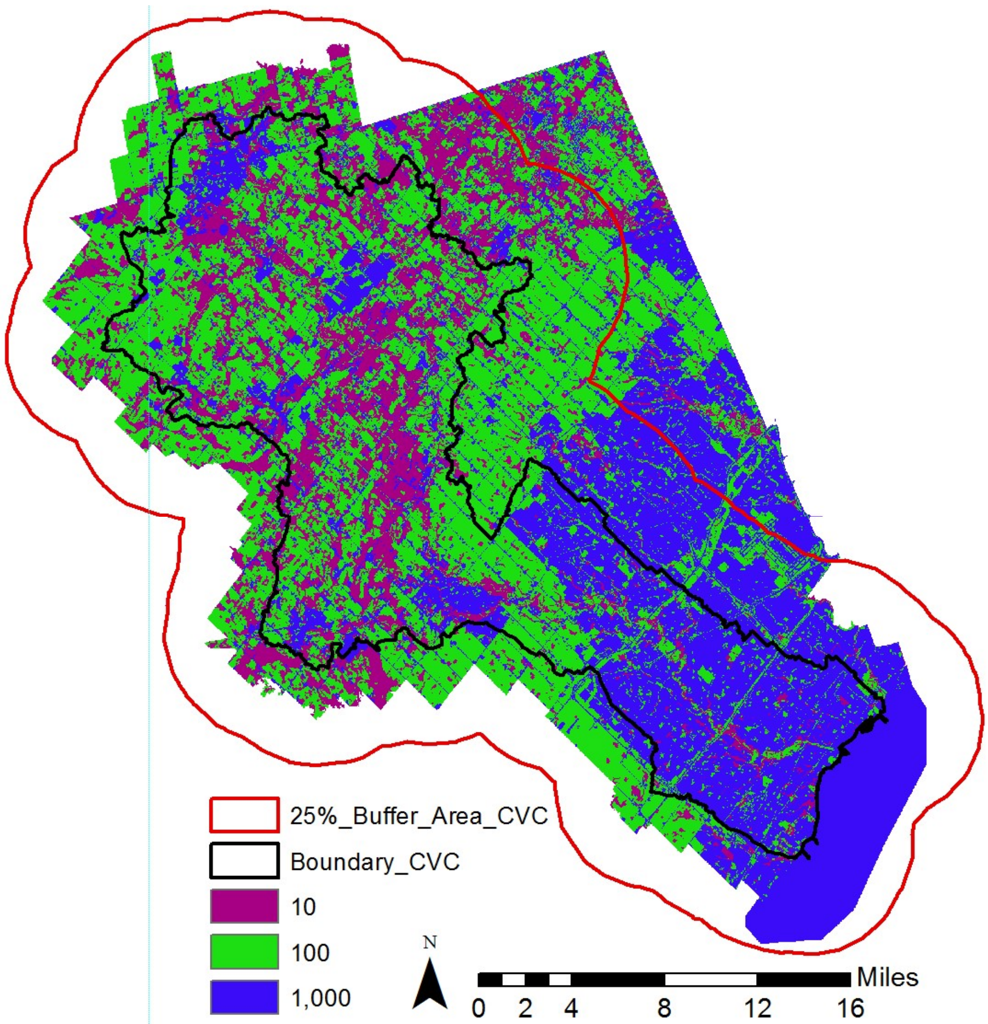

Figure 4: A Shapefile of CVC jurisdiction plus 25% buffer area is shown here as a red outline (step 3.2 G). The rasterized policy-relevant landscape resistance raster with values of 10, 100 and 100 is shown as an underlay.

B. To rasterize the buffer area, select the “Polygon to Raster” conversion tool in ArcMap.

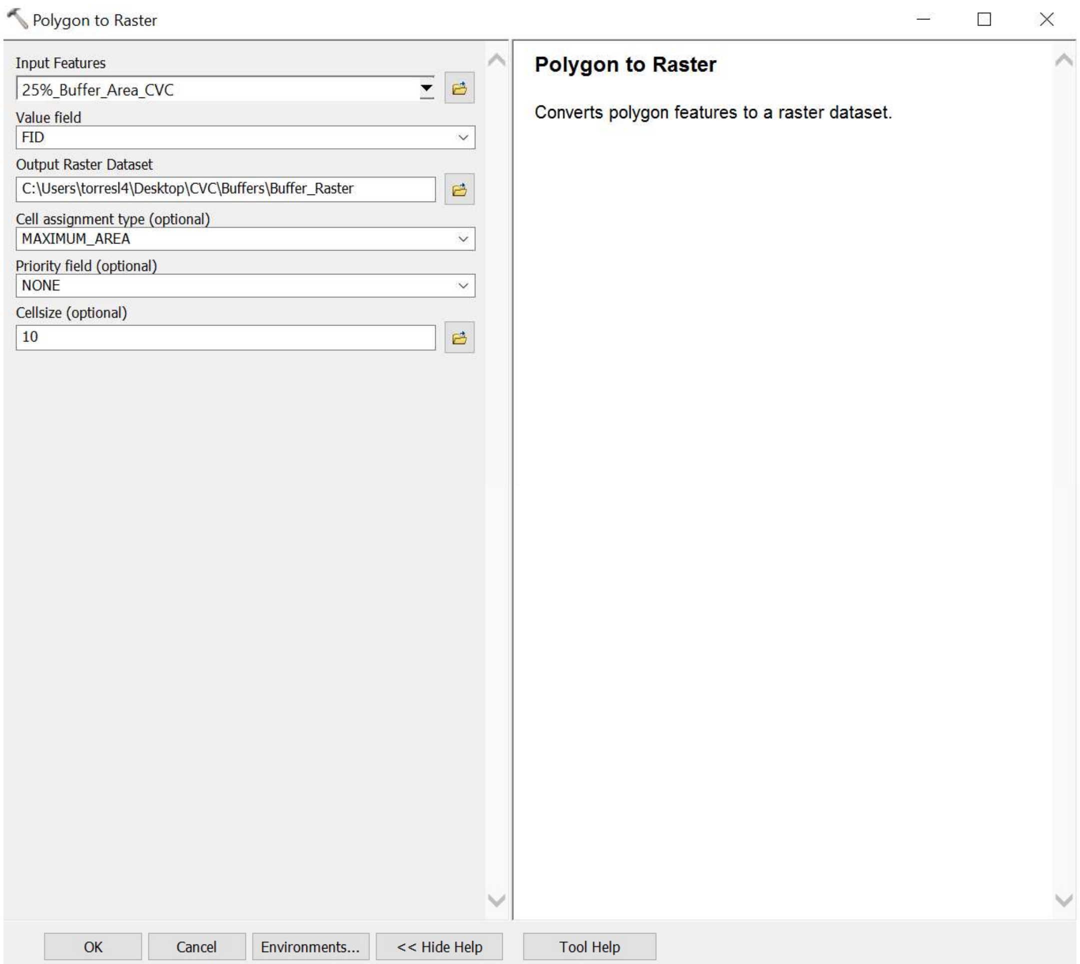

Figure 5: Rasterizing the buffer area.

C. As "Input Features" select the 25% buffer area surrounding CVC. This is the polygon that was created in QGIS (Figure 3).
D. In "Value field" select "FID." We will later assign resistance values to cells in the rasterized buffer.
E. In the "Output Raster Dataset" select the output location and name of the new raster.
F. In "Cell assignment type (optional)" select "MAXIMUM AREA."
G. In "Cellsize (optional)" select 10. This will define the spatial resolution of each cell (pixel size).
H. The resulting raster will include all the area within the 25% buffer and the CVC boundary. All pixels within the rasterized buffer area will have a value of zero (Figure 6).

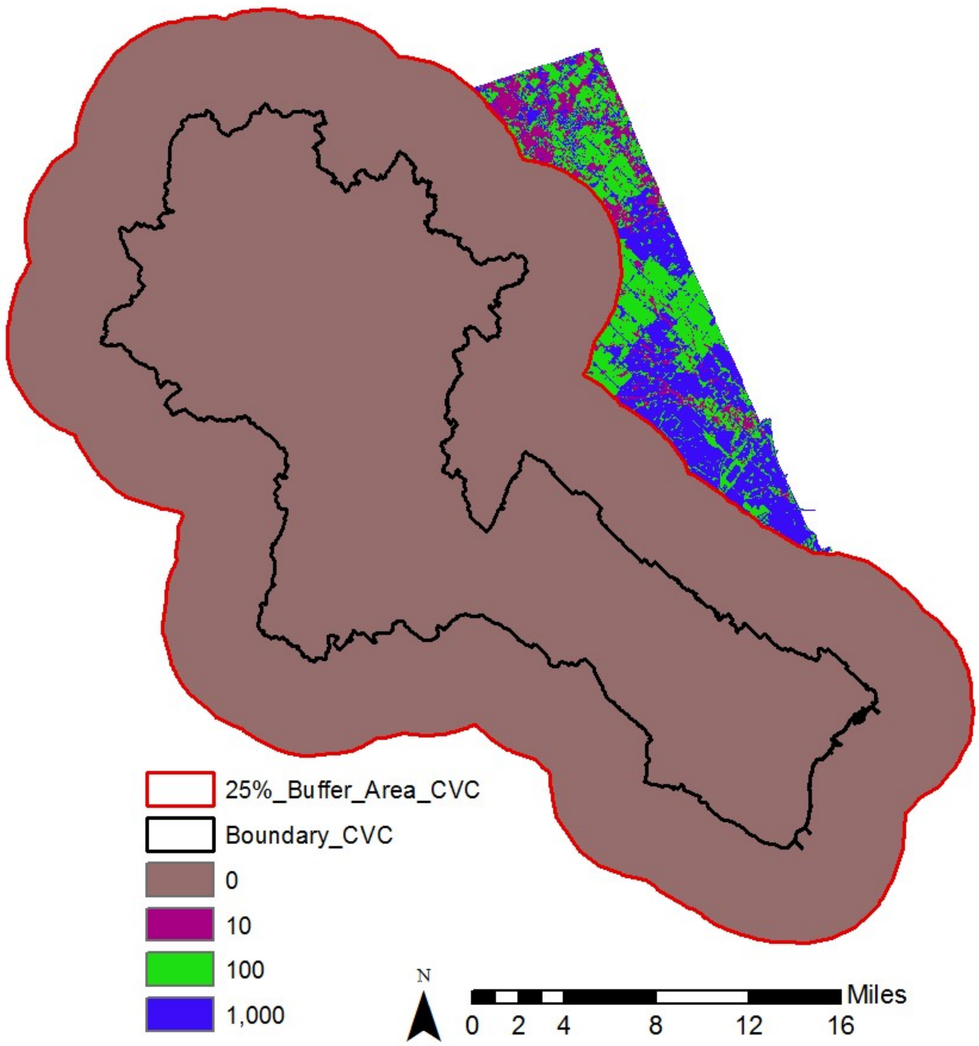

Figure 6: The Shapefile of CVC jurisdiction plus 25% buffer area after rasterization (step 3.3 H). Note that all pixels within the buffer area have a value of zero to start, and will be corrected in steps 3.3 I-K.

I. To assign resistance values to this new buffer raster, open the "Raster Calculator" in the Spatial Analyst toolbox. Note that these resistance values will not be final, as the buffer raster needs to be combined with the landcover type raster created previously (Figures 1 and 2).
J. In the "Raster Calculator" select the buffer raster layer (Figure 6) and add 100. For example, if the rasterized buffer is called "Buffer_Raster", then the expression in the calculator should be "Buffer_Raster + 100". Select a destination and name for this new rasterized buffer. Note that now all pixels in the rasterized buffer will have a value of 100 (Figure 7). We select 100 because it is the median value of resistance.

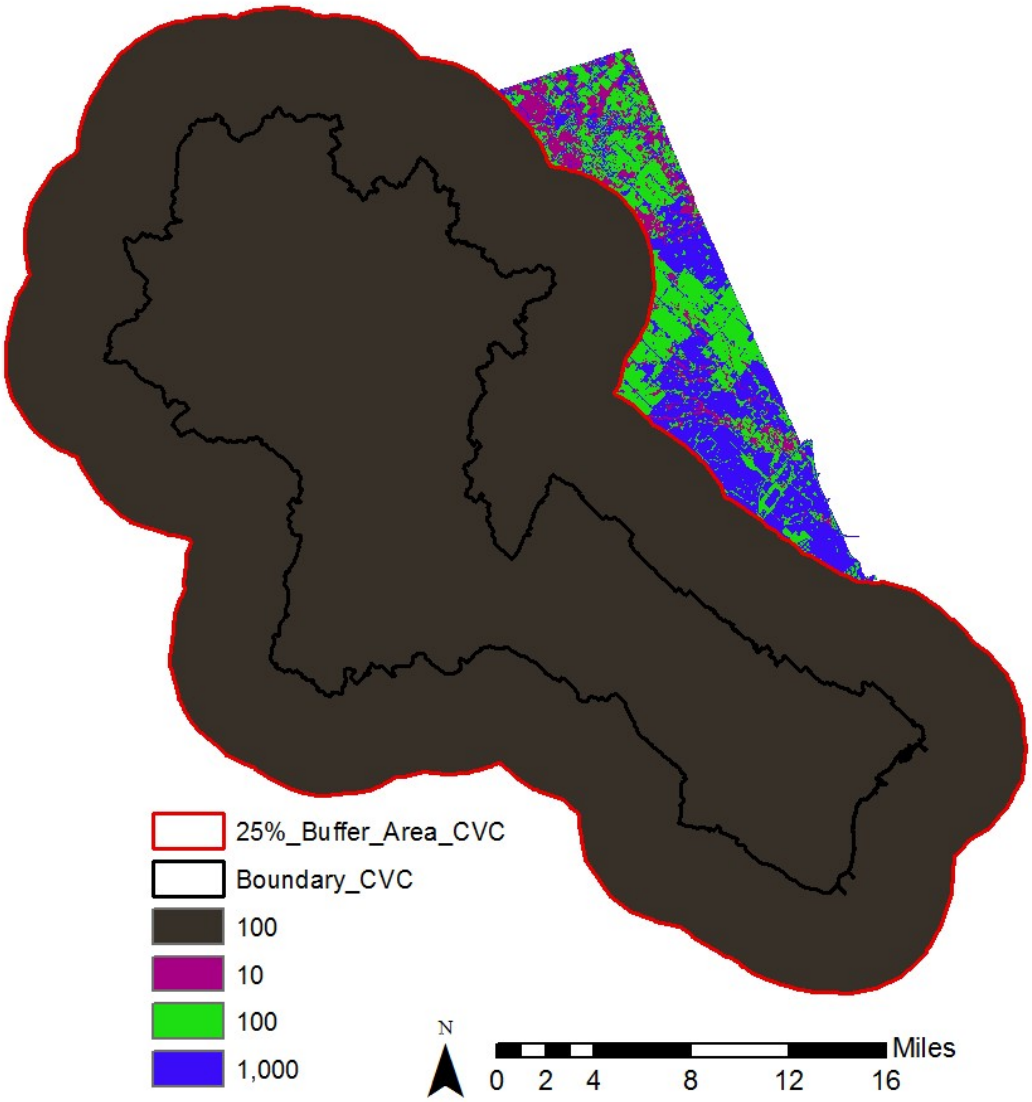

Figure 7: Rasterized buffer area. Note that all pixels within the buffer area have a value of 100.

K. Notice how all pixels within the area of the 25% buffer have a resistance value of 100 (original values were 0). Visualization may change depending on the selected symbology.

3.4. Combining Rasterized Land-Cover Types with Rasterized Buffer

To produce the resistance surface, the rasterized landcover types layer (Figure 2) needs to be combined with the rasterized buffer area layer (Figure 7). The resulting combination of these layers will result in the resistance surface. However, notice that there is quite a bit of overlap between them. Whenever these two layers overlap, pixels will take the resistance value of the rasterized landcover type layer (Figure 2).

In ArcMap (Figure 8):

A. Open the "Mosaic to New Raster" Data Management Tool.

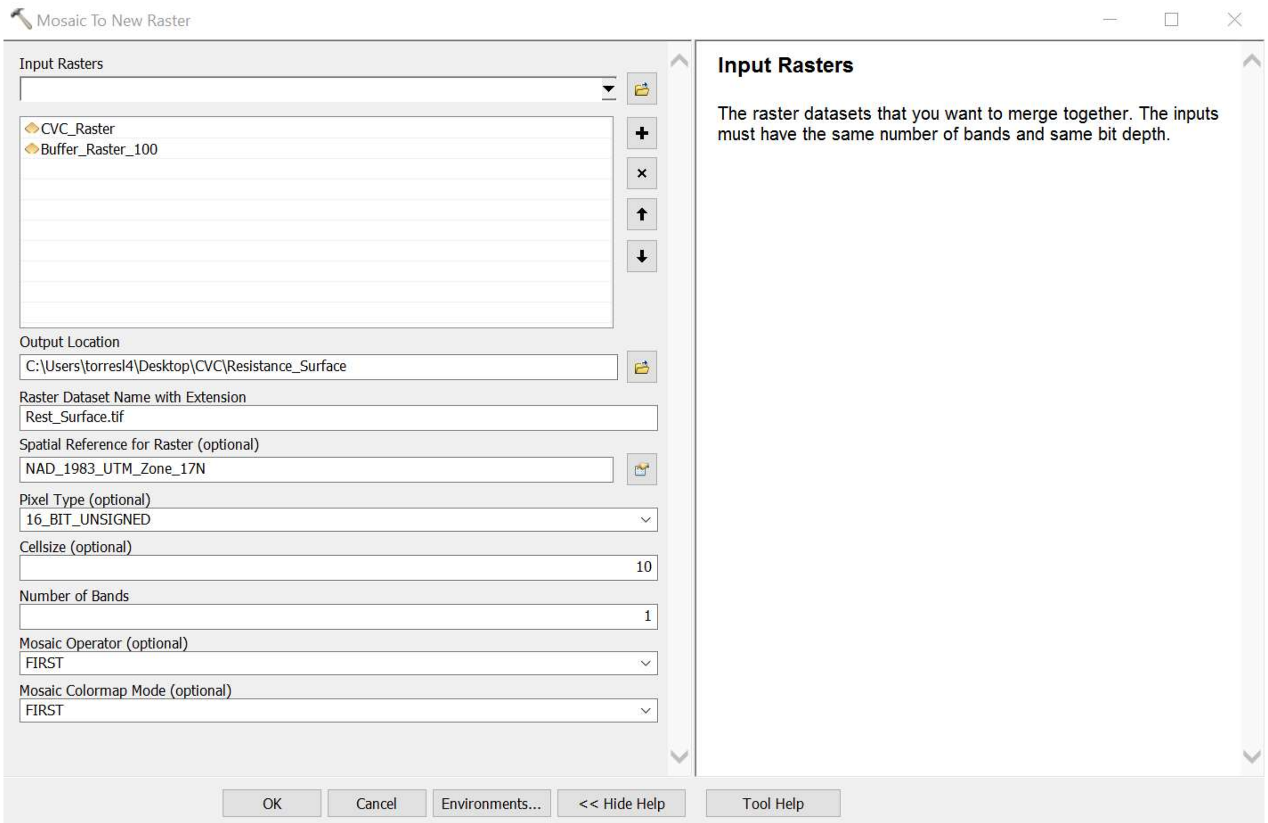

Figure 8: Combining rasterized land-cover types with rasterized buffer.

B. In “Input Rasters” select the raster layers that will be combined. Select first the landcover type raster (Figure 2) and then select the buffer raster (Figure 7). Notice that “CVC_Raster” (rasterized landcover type map) is selected before “Buffer_Raster_100” (rasterized buffer area). The order in which these layers are selected matters (i.e. cells will only be assigned values from the second input raster if there is no data available from the first input raster).

C. In “Output Location” select a directory in which the file (output raster) will be saved and name the file.

D. In “Raster Dataset Name with Extension” select a name for the new raster and include an appropriate file extension. In this case we use .tif.

E. In “Spatial Reference for Raster” select the appropriate coordinate system for the output raster. This should be the same as the coordinate system of the input rasters.

F. In “Pixel Type” select “16_BIT_UNSIGNED” (This is the amount and type of information the cell can carry).

G. Select a “Cellsize” of 10. This has to be the same Cellsize as in the input rasters.

H. Select a “Number of Bands” of 1. This has to be the same as in the input rasters.

I. In “Mosaic Operator” select “FIRST.” This will tell the tool that overlapping pixels between the input rasters will assume the value from the first input raster, in this case form the rasterized landcover type map. This is why the order of the input rasters matter. In this case, any overlapping pixels will take the value of the landcover type raster.

J. In “Mosaic Colormap Mode” select “FIRST. The color map from the first input raster will be applied to the output raster.
K. Change the “Symbology” of the resulting layer to “Classified” to visualize the resistance surface.

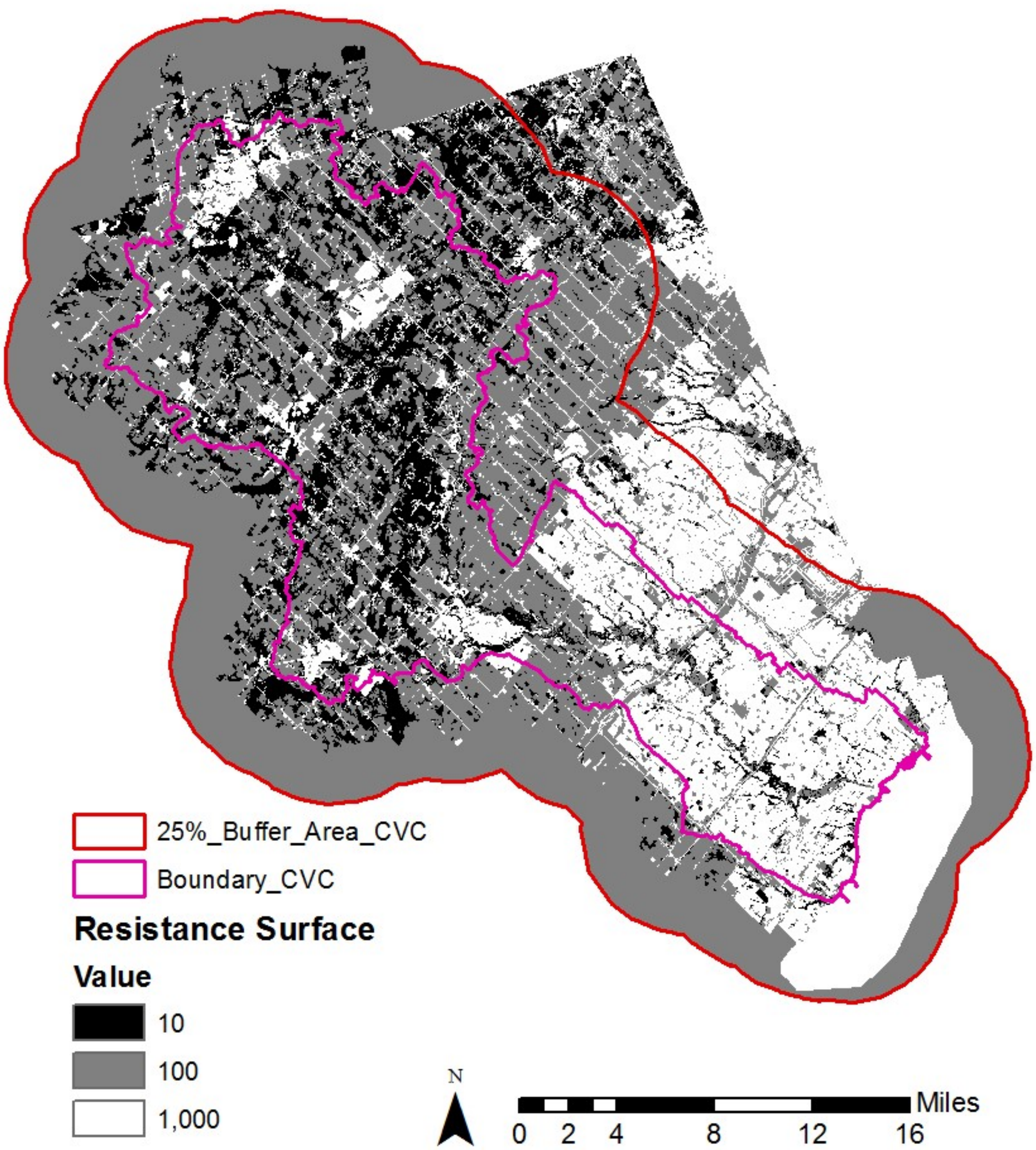

Figure 9: Resistance surface raster.

L. The resulting resistance surface (Figure 9) includes the original landcover type map, plus a 25% buffer area around the CVC boundary (each pixel has a value of 10, 100, or 1000). This raster file will be used in downstream current density modeling.

3.5. Exporting the Resistance Surface Raster as an ASCII Text File

The resistance surface raster that was previously created (Figure 9) needs to be exported as an ASCII text file. This is the file format needed as as an input in Circuitscape 4.0.

In ArcMap (Figure 10):

A. Open the “Raster to ASCII” conversion tool.

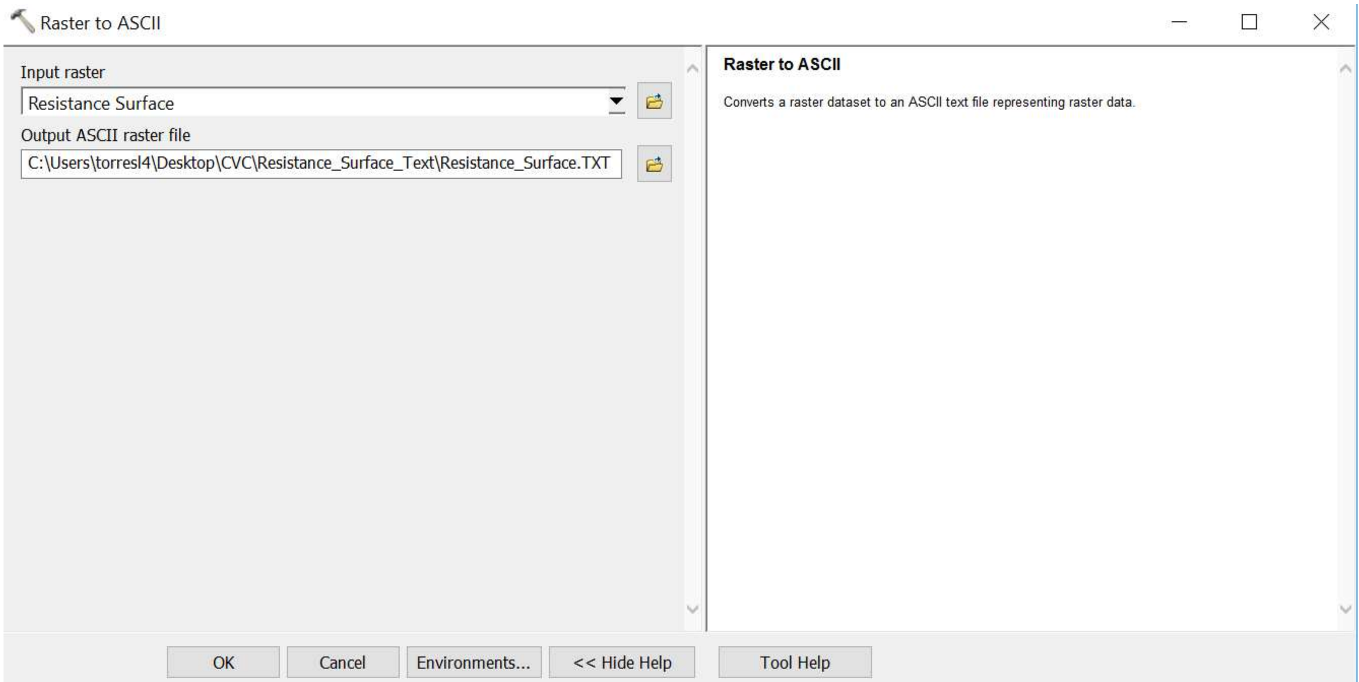

Figure 10: Exporting resistance surface raster as an ASCII text file.

B. In “Input Raster” select the resistance surface raster that was created in the last step (Figure 9).
C. In “Output ASCII raster file” select a destination and name for the text file.
D. The resulting ASCII text file will be used for input in Circuitscape 4.0.

4. Creating Current Source Nodes Around Buffer Area

To complete the wall-to-wall current density map, current source nodes will have to be placed around the buffer area surrounding the CVC boundary. These nodes will act as sources of current that will flow throughout the resistance surface to produce a current density map that models landscape connectivity.

4.1. Transform Buffer Polygon into Polyline Feature

In order to place current source nodes around the buffer area, the buffer polygon (shapefile) needs to be converted into a polyline feature. This buffer polygon was previously produced in QGIS (Figure 4).

In ArcMap (Figure 11):

A. Select “Polygon to Line” under “Data Management Tools.”

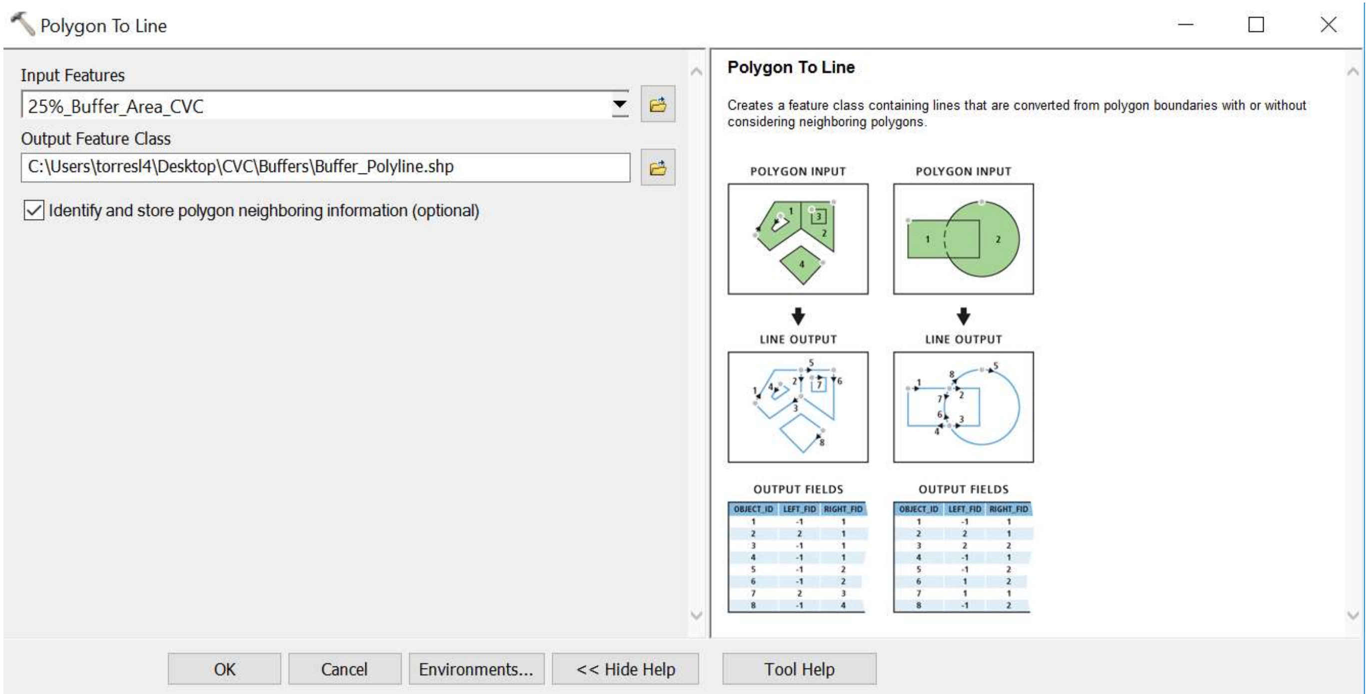

Figure 11: Transform buffer polygon into polyline feature.

B. In “Input Features” select the buffer area shapefile. This corresponds to the buffer produced in QGIS (Figure 3).
C. In “Output Feature Class’ select a destination to save the buffer polyline feature and name it.
D. Check the “Identify and store polygon neighboring information” option.

4.2. Transform Polyline Features into Spatial Points (Current Source Nodes)

We will transform the polyline feature created in the previous step (Figure 11) to spatial points (current source nodes). Current source nodes will be placed 5 km apart along the buffer polyline feature created above.

In ArcMap:

A. Select the “Generate Points Along Lines” Data Management tool.
B. In “Input Features” select the buffer polyline feature previously created (Figure 11).
C. In “Output Feature Class” select the output location and name of the output file.
D. In “Point Placement” select the “DISTANCE” option.
E. In “Distance” type “5” and select “Kilometers” as the unit of measurement.
F. Leave the “Percentage” and “Include End Points” options unfilled.

4.3. Export Spatial Points (Current Source Nodes) to Feature Class

Nodes have to be exported as a shapefile feature class.

In ArcMap (Figure 12):

A. From the layers displayed in the ArcMap panel, right click on the nodes layer created above (Transform Polyline Features into Spatial Points) and select the "Data" option and click on the "Export Data" option.

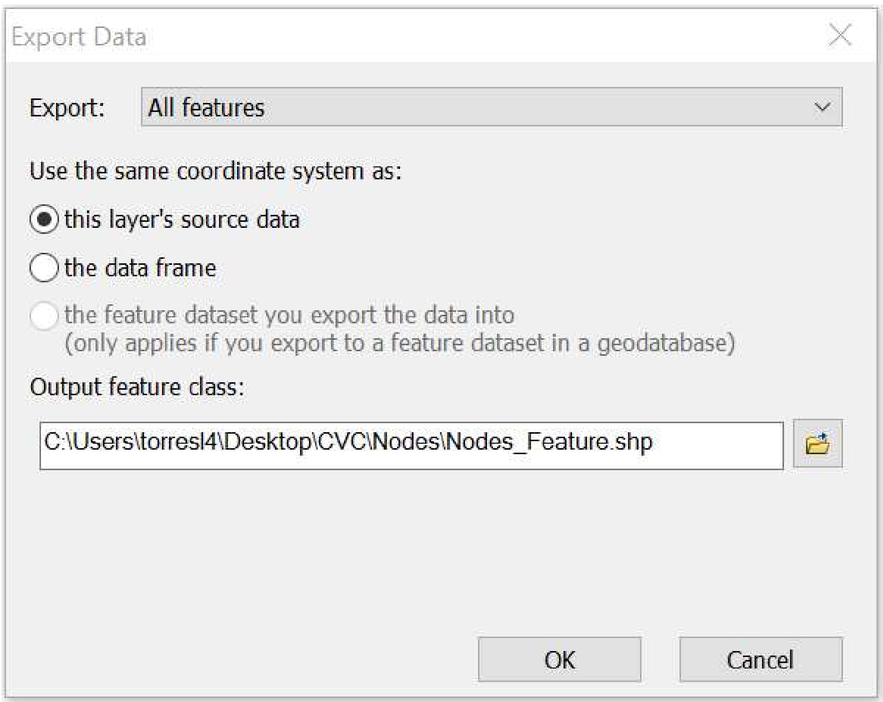

Figure 12: Export spatial points (current source nodes) to feature class.

B. Select "All features" and "this layer's source data" options to define the coordinate system.
C. Specify an output location a name for the newly created shapefile.

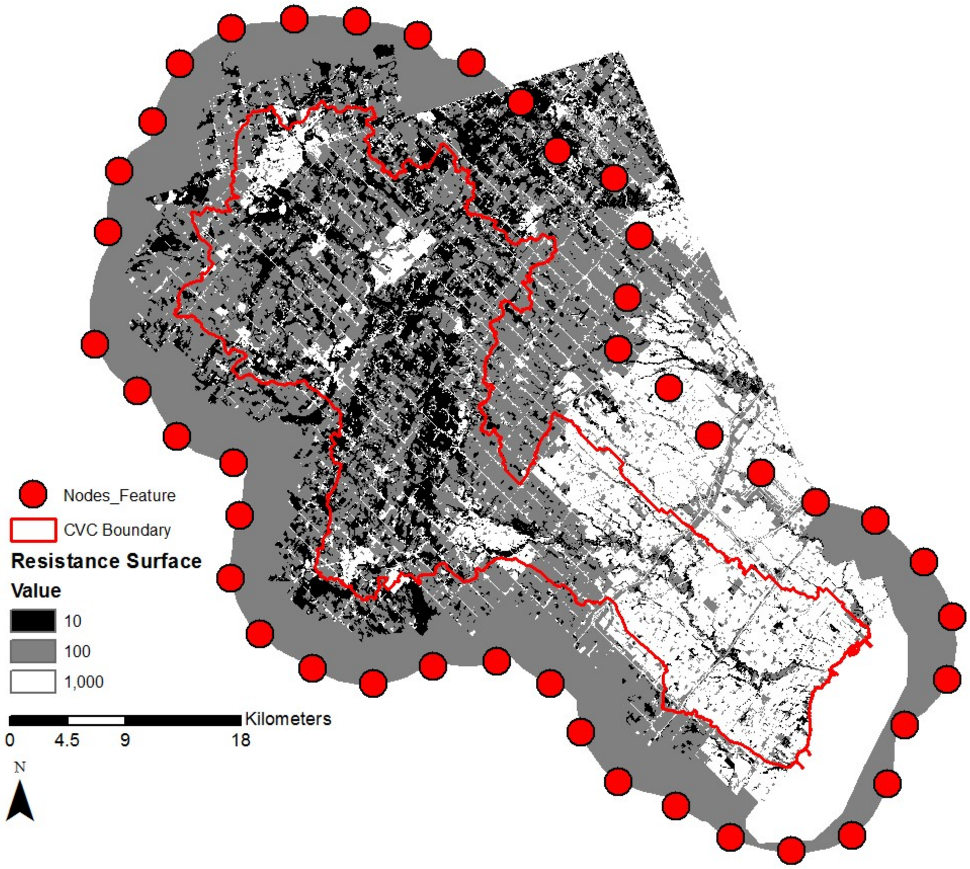

Figure 13: Spatial points (current source nodes) as a feature class

4.4. Determine Spatial Coordinates for Current Source Nodes

Connectivity modelling in Circuitscape 4.0 requires that the spatial coordinates of the nodes (UTM), (Figure 13), from which current will be generated, be specified as an input text file.

In ArcMap (Figure 14):

A. Open the “Attribute Table” of the current source nodes shapefile created in the previous step (Figure 13) and select “Add Field” to add two extra columns to the table. One will be called “X”, the other “Y”. These columns will contain the spatial coordinates for each node.
B. Right click on the newly created “X” field and select “Calculate Geometry.”

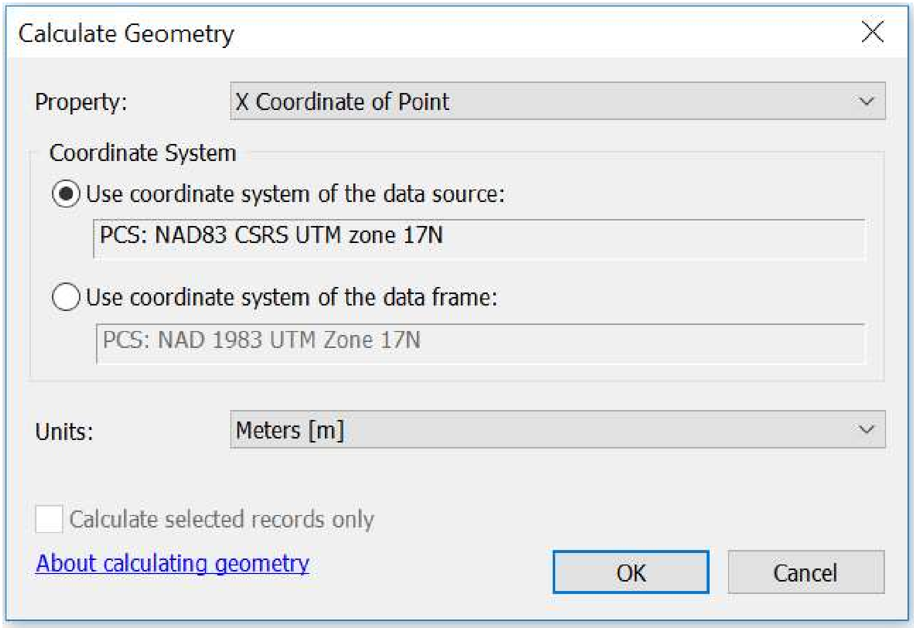

Figure 14: Spatial coordinates for current source nodes.

C. In “Property” select “X coordinate of Point” and define the “Coordinate System” by selecting “Use coordinate system of the data source.”
D. Select “Meters [m]” as “Units.”
E. Repeat this for the “Y” field, making sure you calculate “Y coordinate of Point.”

4.5. Export the Spatial Coordinates of Current Source Nodes as a Text File

The spatial coordinates of each current source node needs to be imported into Circuitscape 4.0 as a text file.

In ArcMap (Figure 15):

A. Open the “Table to Excel” conversion tool.

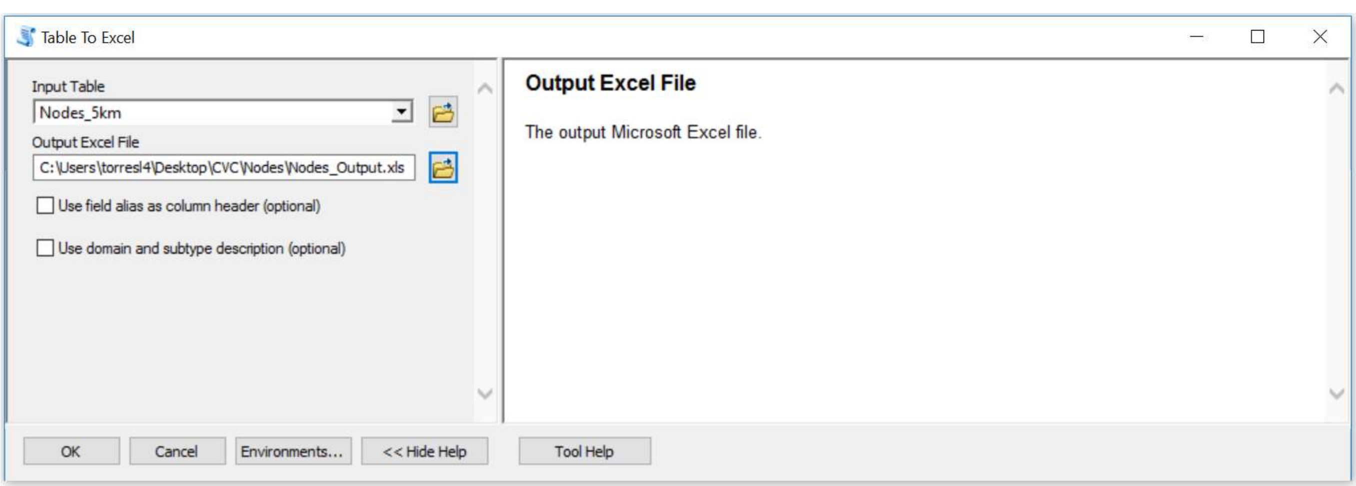

Figure 15: Export the spatial coordinates of current source nodes as text file.

B. In “Input Table” select the Nodes feature class previously created (Figure 13). This file should contain the X and Y spatial coordinate values for each node (Figure 14).
C. In “Output Excel File” select an output destination and name the file.
D. Leave “Use field alias as column header” and “Use domain and subtype description” options unchecked.
E. The resulting file will have a “.xls” extension and should only include “FID”, “X”, and “Y” columns, representing the ID and the spatial coordinates of each node, respectively (Figure 16).

	A	B	C
1	**FID**	**X**	**Y**
2	0	558265.4781	4857206.426
3	1	559074.9571	4861988.399
4	2	561732.9446	4865882.605
5	3	563882.3763	4870338.722
6	4	567914.6393	4873112.048
7	5	572745.941	4873800.38
8	6	577644.2377	4873639.63
9	7	582436.6475	4872577.781
10	8	586634.4968	4870405.118

Figure 16: spatial coordinates of current source nodes as text file

F. This file format has to be edited before it can be used in Circuitscape 4.0. Delete the first row indicating the names of each column and save as a text (tab delimited) file. This text file will be used as input for Circuitscape 4.0 (Figure 17).

0	558265.4781	4857206.426
1	559074.9571	4861988.399
2	561732.9446	4865882.605
3	563882.3763	4870338.722
4	567914.6393	4873112.048
5	572745.941	4873800.38
6	577644.2377	4873639.63
7	582436.6475	4872577.781
8	586634.4968	4870405.118

Figure 17: spatial coordinates of current source nodes as text file in correct format for use in Circuitscpae 4.0.

5. Modeling Landscape Connectivity: Wall-to-Wall Map

The Circuitscape 4.0 software will be used to compute a wall-to-wall, current density map of the Credit River Watershed. This section will explain how to install and run Circuitscape 4.0. We will be using the resistance surface and the current source nodes, both in ACSII format, as file inputs (Figures 10 and 17). Current will flow throughout the resistance surface, starting from the nodes placed around the buffer area.

5.1. Downloading and Installing Circuitscape 4.0

A. Download Circuitscape 4.0 from: https://circuitscape.org/downloads/ and install.
B. Detailed documentation and technical support for this software can be found at: https://circuitscape.org/docs/
C. Notice that we will be running Circuitscape 4.0 in its standalone, graphical user interface for Windows.

5.2. Running Circuitscape 4.0

Step 1 (Figure 18):

A. Launch the graphical user interface version of the software.
B. In the "Choose your input data type" pull-down menu, select "Raster."

Step 2 (Figure 18):

A. In the "Choose a modeling mode" menu, select "Pairwise: iterate across all pairs in focal node file."
B. In the "Input resistance data" menu browse for and select the Resistance Surface ASCII text file that was previously created (Figure 10). Make sure to leave the "Data represents conductances instead of resistances" box unchecked.
C. In the "Pairwise mode options" browse for and select the Node Spatial Coordinates text file (a.k.a ASCII file) that was previously created (Figure 17). This is the file that contains the spatial coordinates for the all the nodes that were placed (5 km apart) around the 25% buffer area.
D. In the "Output options" select a location and a base name for the output files. In the "Output maps to create" option select "Current maps."

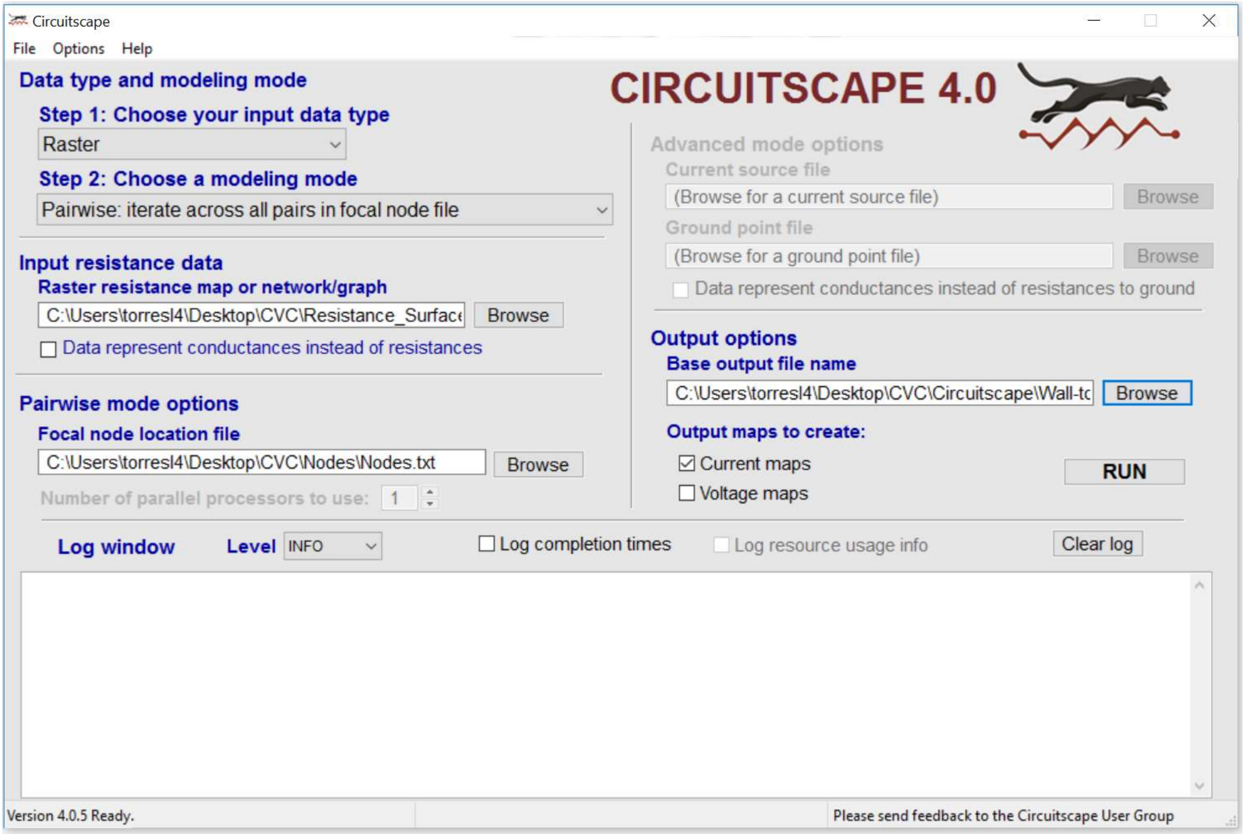

Figure 18: Running Circuitscape 4.0. Steps 1 and 2.

Step 3 (Figure 19):

A. Click on the “Options” menu and select “More setting and inputs.”
B. Make sure the “Connect raster cells to FOUR neighbors instead of EIGHT” box is unchecked (this was chosen to reduce the complexity of the network, thus reducing processing time). The resulting current density maps will be computed using the eight corners rule.
C. Make sure that the “Use average conductance instead of resistance for connections between cells” box in unchecked.
D. In the “Mapping options” select “Write cumulative & max current density maps only.”
E. Leave all other options unchecked.

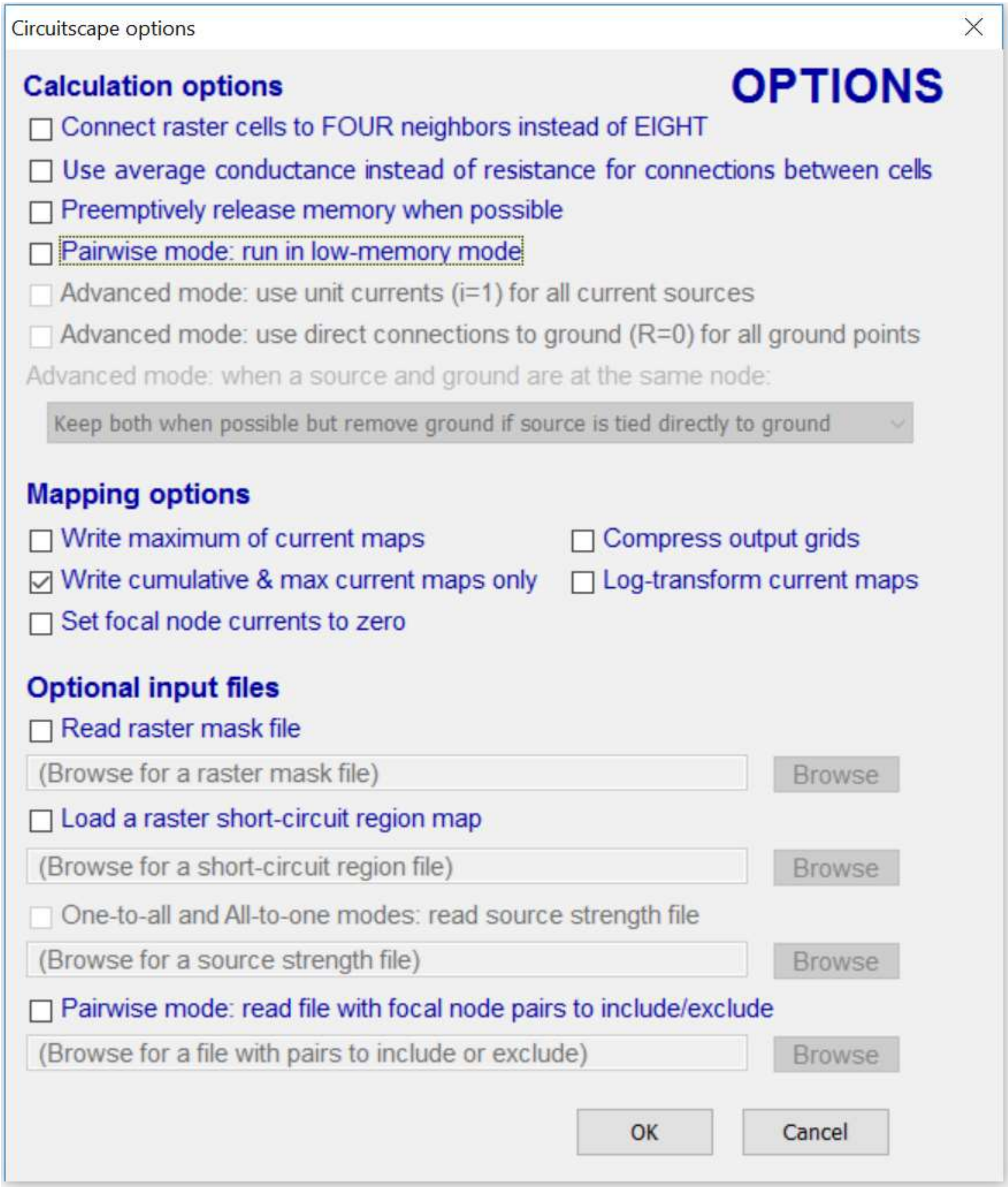

Figure 19: Running Circuitscape 4.0. Steps 1 and 2.

6. Visualizing Wall-to-Wall Current Density Map

The results from Circuitscape 4.0 can be visualized in ArcMap to as a current density map. There were two steps to visualization. First, the raw current density output values were visualized using symbology with a high contrast colour ramp (section 6.1. and 6.2.). Second, the raw current density values were transformed via standardization (z-score normalization) in order to visualize and identify highly connective corridors.

The second step is to contrast the important biodiversity highways with the background values.

6.1. General Guidelines to Visualization

A. Navigate to the folder where the Circuitscape 4.0 output was stored and import the resulting raster file into ArcMap (Figure 20). This raster should have the name that was defined in the output options of Circuitscape followed by a ".asc" extension (Figure 18).

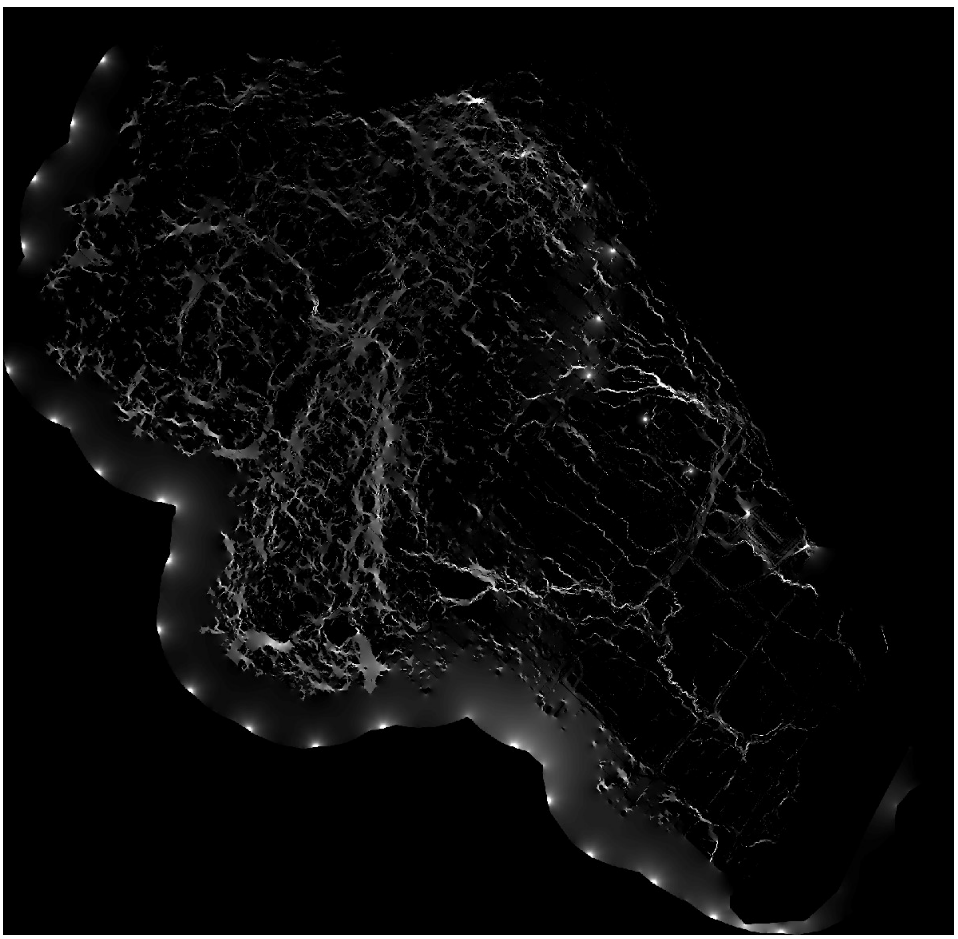

Figure 20: Wall-to-wall current density map as raw results from Circuitscape 4.0.

B. Once this layer is added to ArcMap (Figure 20), you will need to modify the symbology for effective visualization of current density. Access the "Symbology" options and select the "Stretched" option. Check the "Display Background Value" option and assign a value of "0" to remove the dark background from the current density map.

C. Select a color ramp in which pixels with high current density are represented by bright colors, while pixels with low current density are represented by cooler colors. Under the "Type" options select "Standard Deviations." (Figure 21) Modify this value to increase the contrast between areas of high and low current density (Figure 21). The resulting current density map will include the Credit River Watershed plus the 25% buffer area around it (Figure 22).

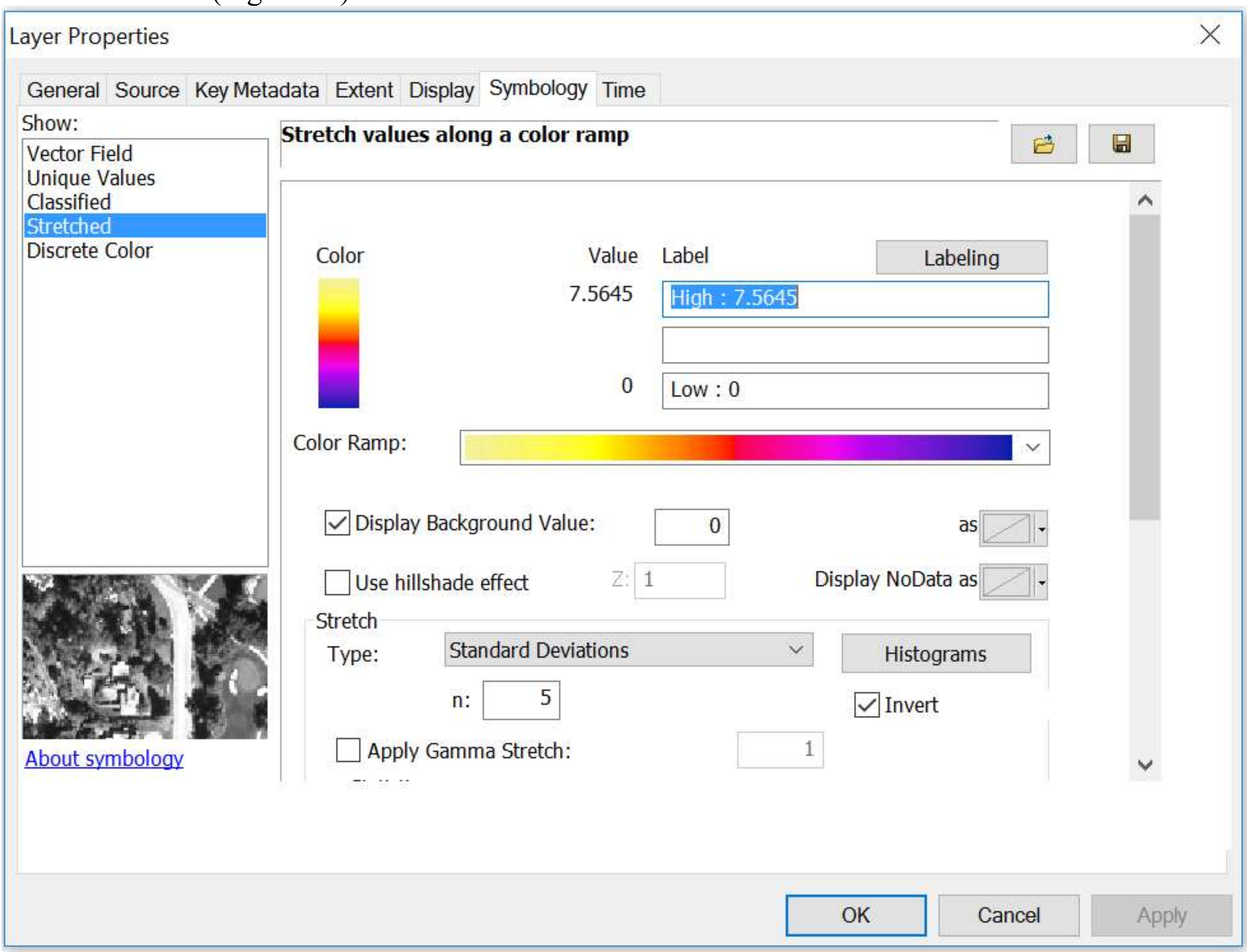

Figure 21: General guidelines to visualization of the wall-to-wall current density map.

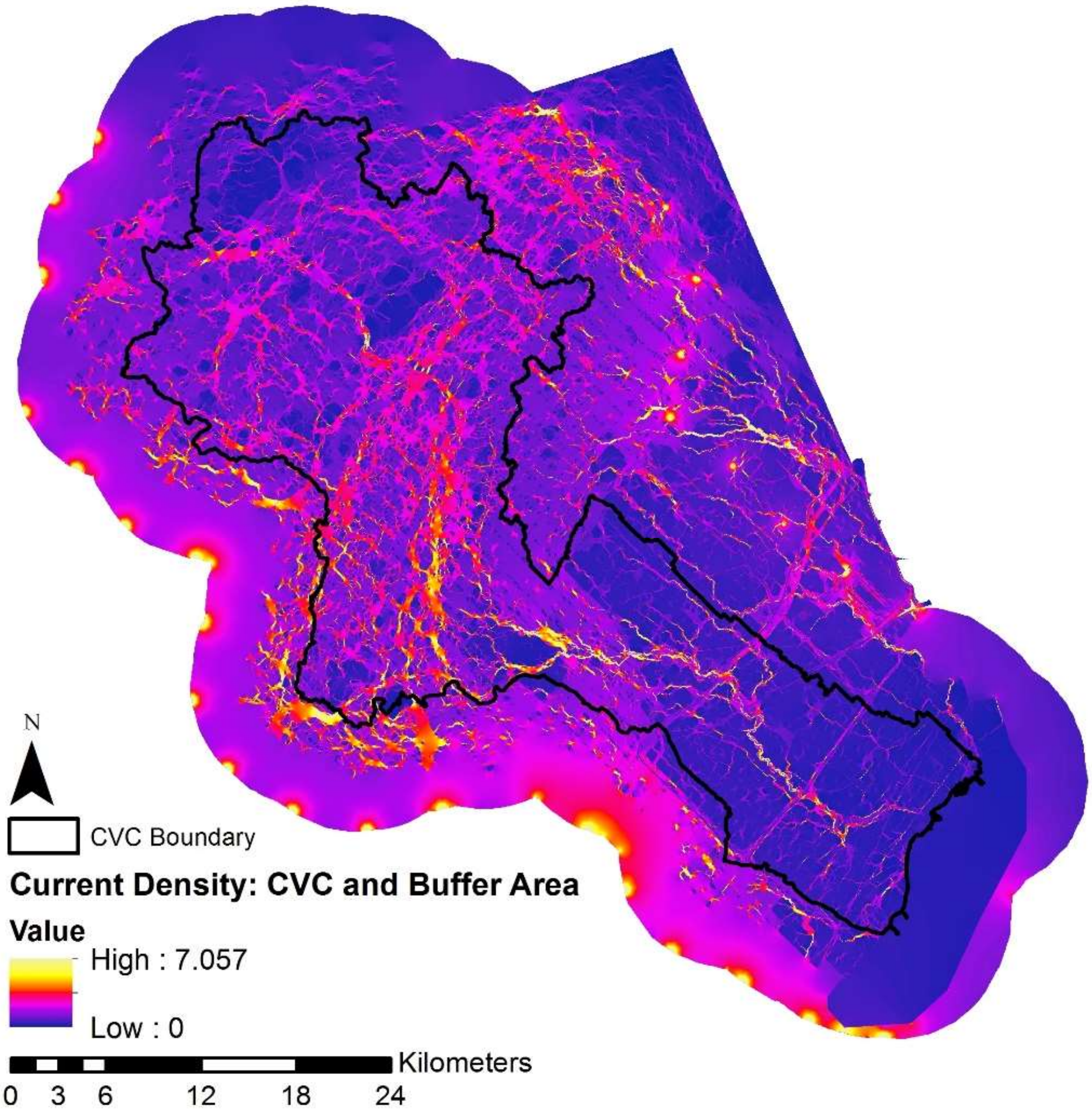

Figure 22: Wall-to-wall current density map, including 25% buffer area.

6.2. Clipping the Wall-to-Wall Current Density Map

Here we will clip the resulting current density map (Figure 22) to include only the area inside the CVC boundary. This step is done to eliminate potential bias due to high current flow from the source nodes places around the buffer area.

In ArcMap (Figure 23):

A. Open the “Extract by Mask” tool within the “Spatial Analyst” toolbox.

B. In “Input raster” select the wall-to-wall current density map produced by Circuitscape 4.0 (Figure 22).
C. In “Input raster or feature mask data” select the CVC boundary shapefile.
D. In “Output raster” select a location and name for the newly clipped current density map.

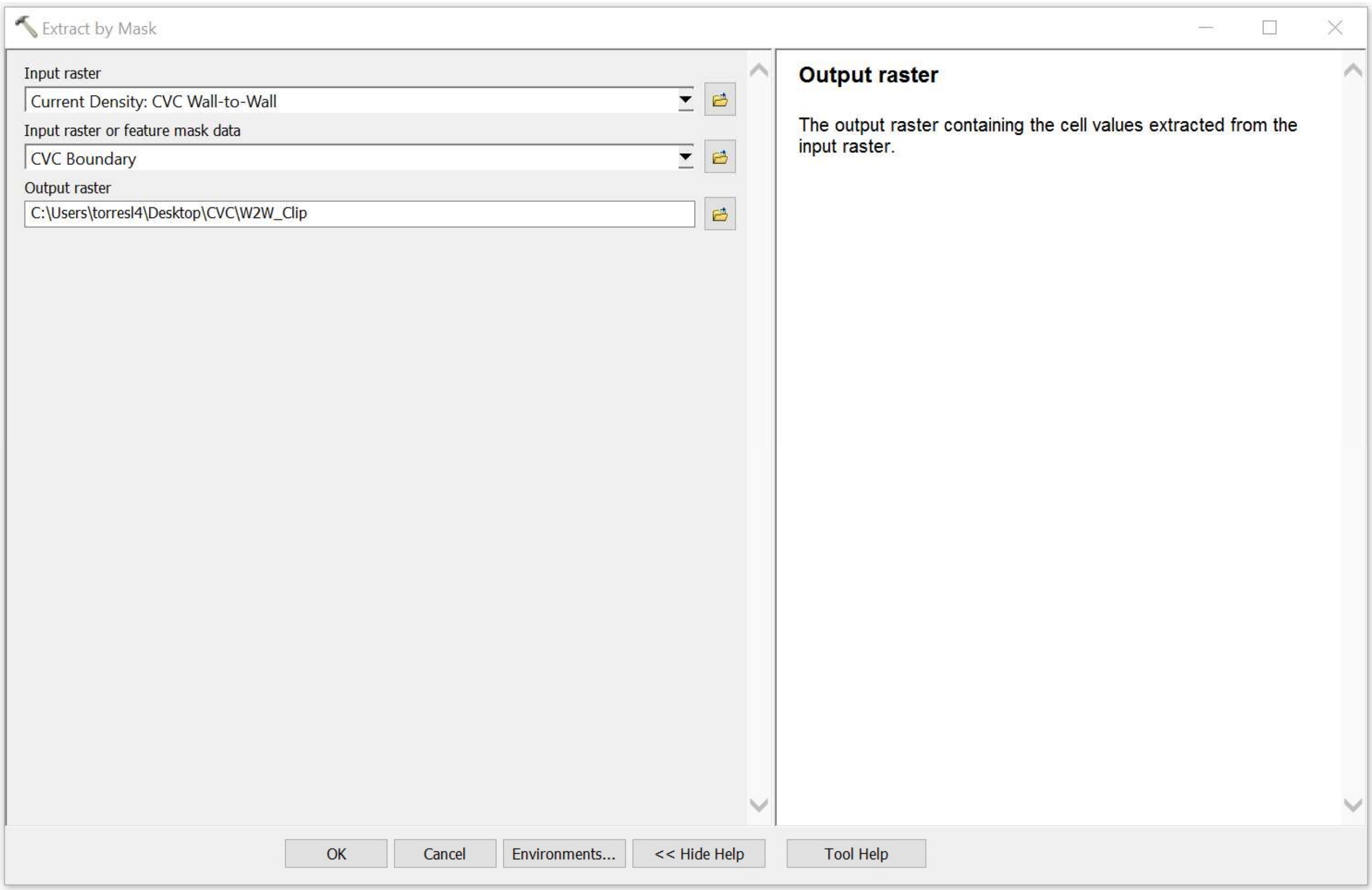

Figure 23: Clipping the wall-to-wall current density map.

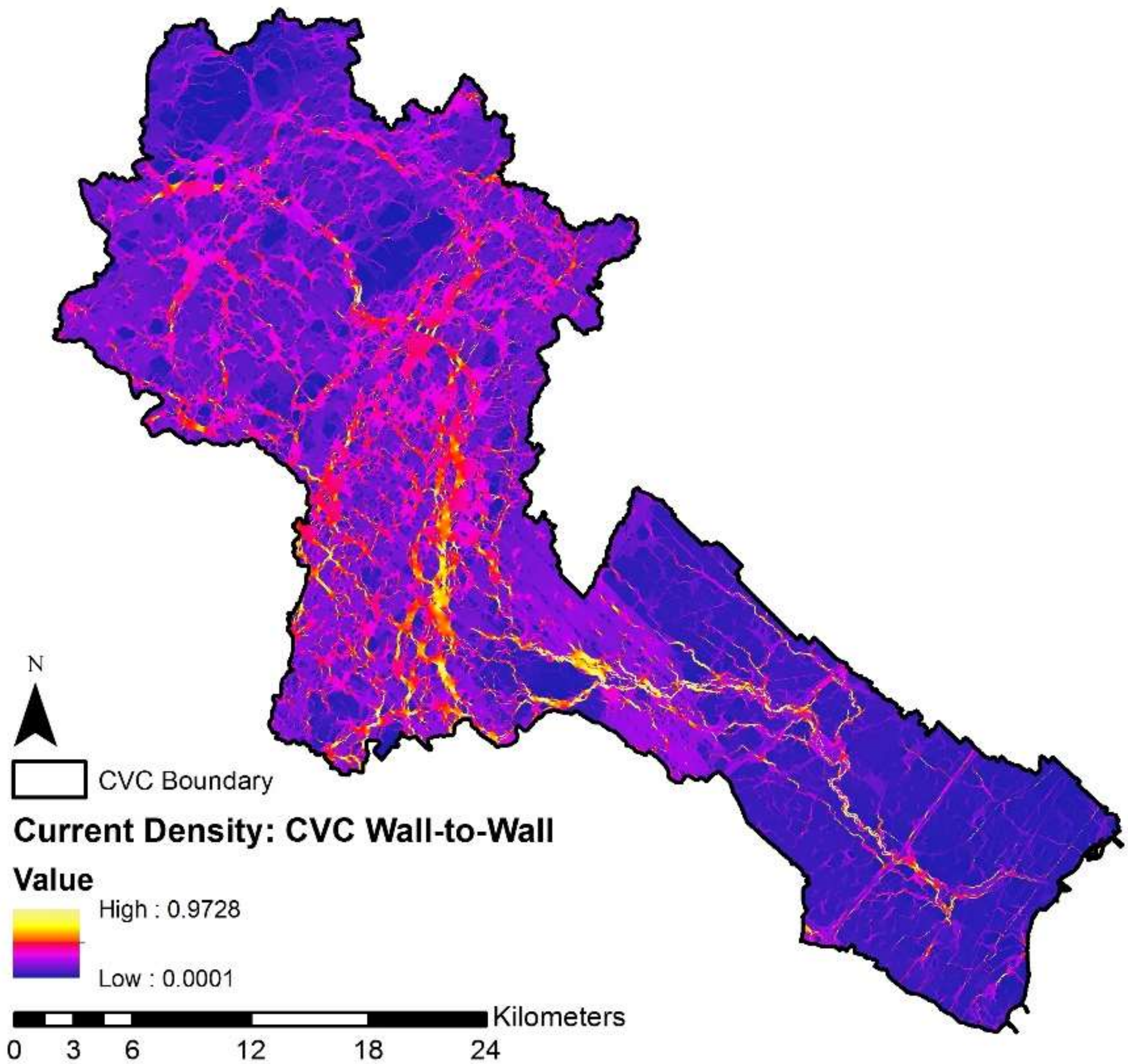

Figure 24: Clipped wall-to-wall current density map.

6.3. Standardizing the Current Density Map

Standardizing current density maps is useful in order to visualize and identify highly connective corridors or biodiversity highways – high current density pixels in contrast to low current density pixels in the background. The resulting current density values will be standardized to a mean of zero to identify pixels that are highly connective, as follows:

$$z = \frac{(x - \bar{x})}{SD}$$

Where *x* is the pixel-by-pixel cumulative current density within the Credit River Watershed (after buffer area is removed); $\bar{x}$ is the mean current density value of all pixels within the watershed; and *SD* is the standard deviation. Thus, the standardized current density map will provide current density values as z-scores. High current densities relative to the mean will be greater than zero, while values less than the current density mean will be negative. Note that modifying the value of the standard deviation threshold, will produce different standardized current density maps.

In ArcMap (Figures 25 and 26):

A. Open the "Symbology" tab in the "Layer Properties" menu for the wall-to-wall current density map previously created (Figures 23 and 24).
B. Under the "Stretched" options panel in the left-hand side, scroll down to the "Statistics" options.
C. Select "From Each Raster Dataset" and take note of or copy the mean and standard deviation reported. These values will be used to produce a standardized current density map.

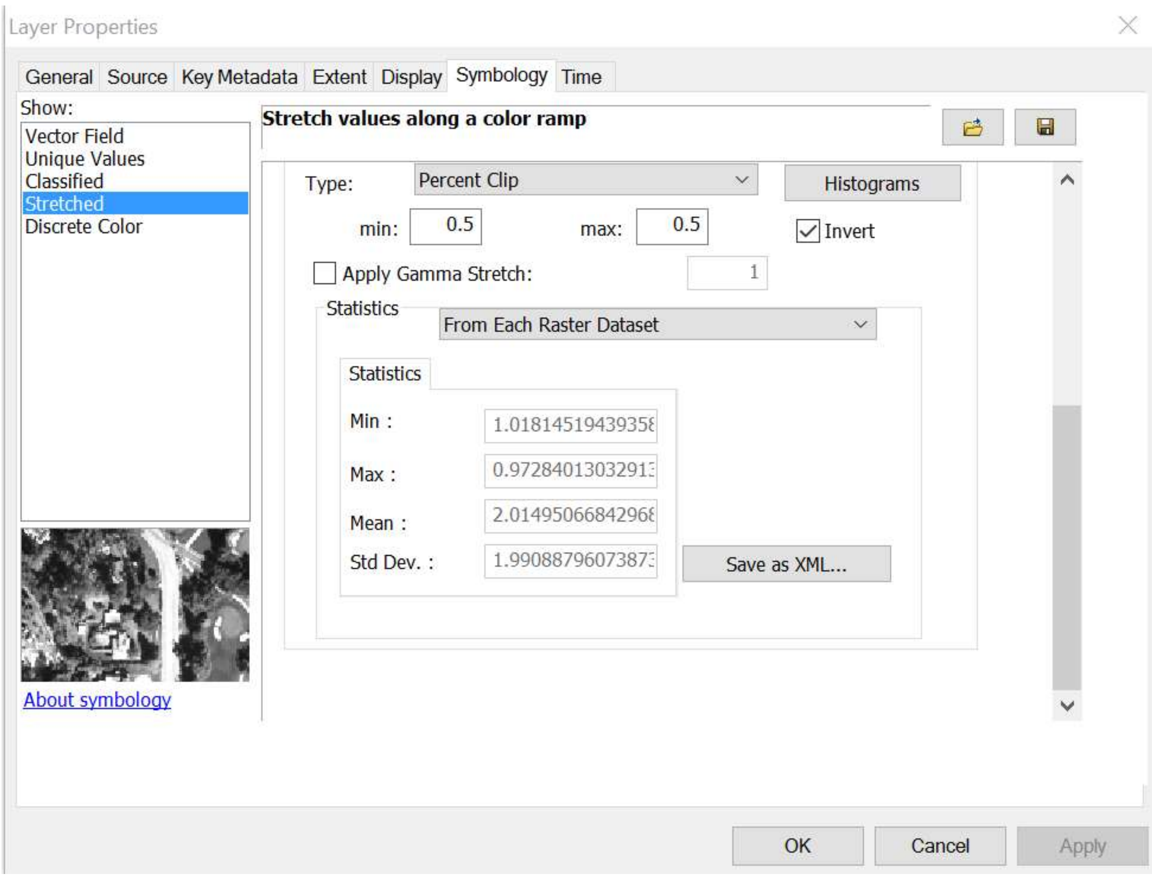

Figure 25: Standardizing current density map (mean and standard deviation).

D. With note or copy of the mean and standard deviation values (Figure 25), open the "Raster Calculator" tool.
E. In the "Raster Calculator" type in the following formula: (wall-to-wall current density map - mean) / (standard deviation). Remember that the mean and standard deviation correspond to the values reported in the "Symbology" tab for the wall-to-wall current density map (Figure 25).

F. In “Output Raster” select a destination and name the resulting standardized current density map.

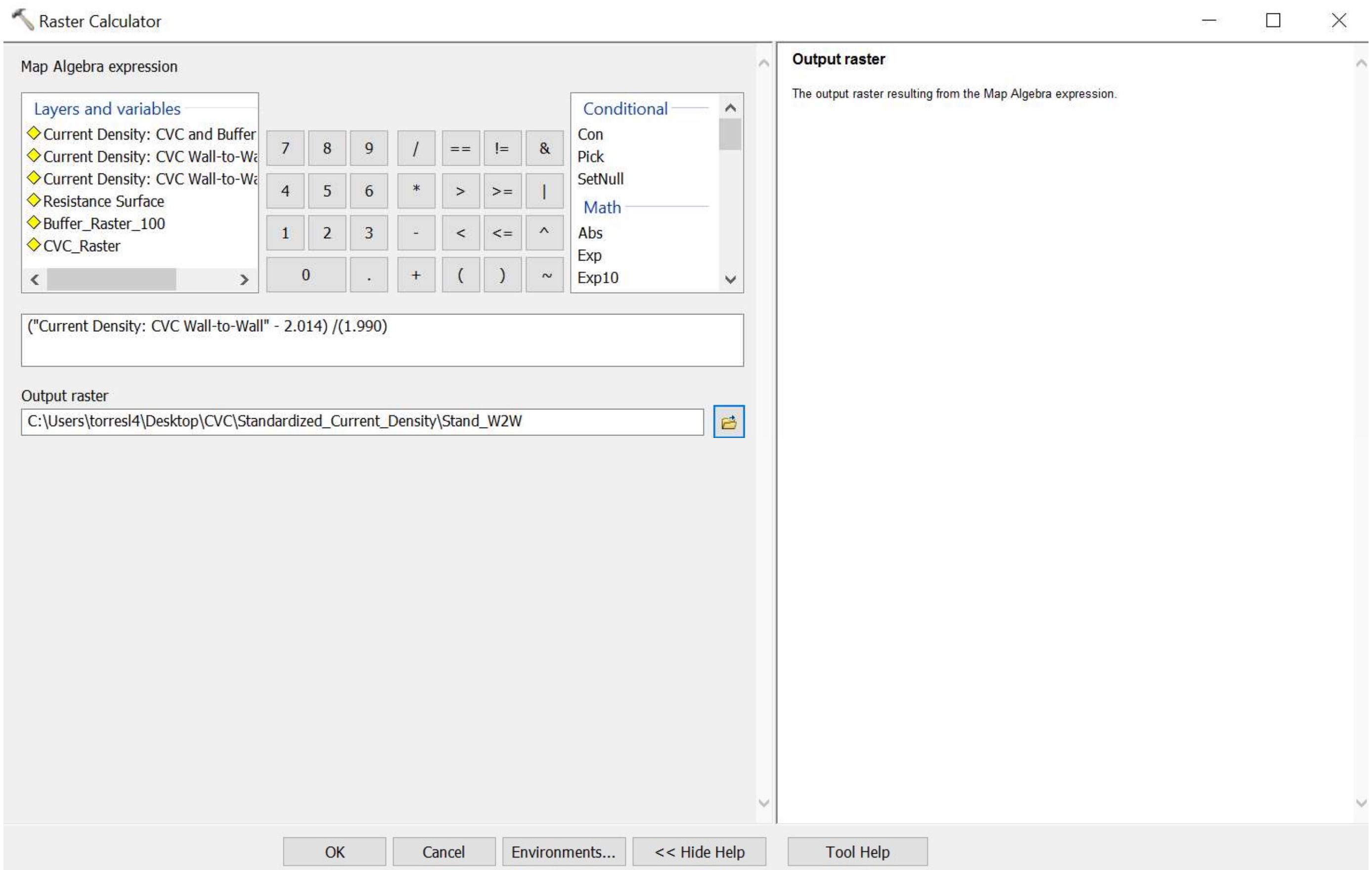

Figure 26: Standardizing current density map (raster calculator).

7. Quantifying the Importance of Natural Areas: Creating Node and Connection Files

We will use Conefor 2.6 to quantify the importance of each natural area for the maintenance of habitat connectivity. We will estimate the change in the probability of connectivity (*dPC*) for each natural area (polygon) within the Credit River Watershed, as well as their corresponding *dPCintra, dPCflux, and dPCconnector* fractions. For a detailed description of these metrics and how to calculate them please see the following:

Saura, S. and L. Rubio. 2010. A common currency for the different ways in which patches and links can contribute to habitat availability and connectivity in the landscape. Ecography. 33:523-537.

7.1. Selecting Natural Areas of Interest

The analysis will only consider natural areas (polygons) that are within or that intersect the CVC watershed boundary. The shapefile containing all the natural areas was provided by the CVC geospatial team.

In ArcMap (Figure 27):

A. Import the natural areas shapefile and the CVC watershed boundary shapefile.
B. Choose the "Select Layer by Location" tool.
C. In "Input Feature Layer" select the layer with all the natural areas in the Credit River Watershed (provided by CVC geospatial team).
D. In "Relationship" select "Intersect."
E. In "Selecting Features" select the CVC boundary shapefile.
F. Leave the rest of the options as default.

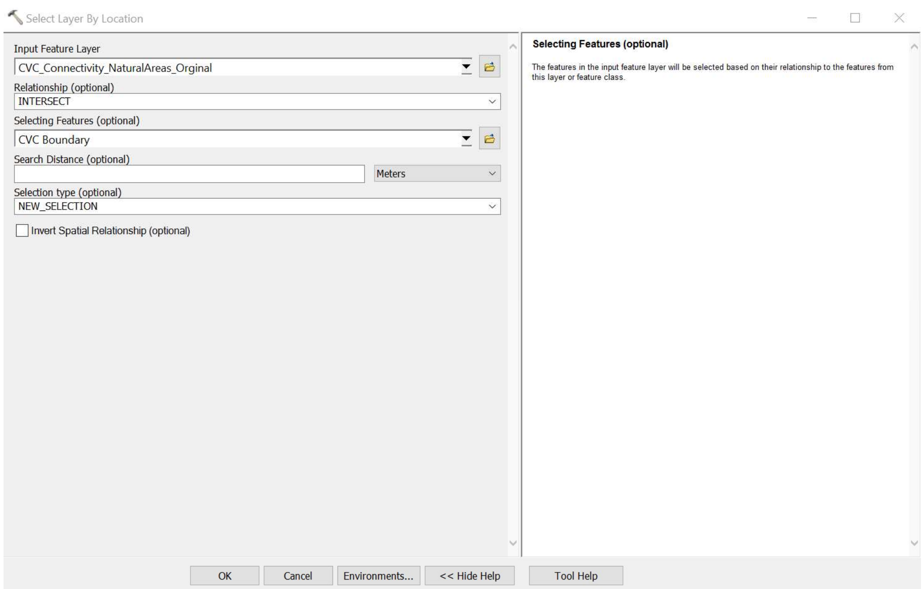

Figure 27: Selecting Natural Areas of interest.

G. This tool will select all the natural areas (polygons) that are within or that intersect the CVC boundary. These polygons will be selected in the attribute table of the natural areas shapefile (Figure 28).

Table

CVC_Connectivity_NaturalAreas_Orginal

FID	Shape *	RESISTANCE
0	Polygon	10
1	Polygon	10
2	Polygon	10
3	Polygon	10
4	Polygon	10
5	Polygon	10
6	Polygon	10
7	Polygon	10
8	Polygon	10
9	Polygon	10
10	Polygon	10
11	Polygon	10
12	Polygon	10
13	Polygon	10
14	Polygon	10
15	Polygon	10
16	Polygon	10
17	Polygon	10
18	Polygon	10
19	Polygon	10
20	Polygon	10
21	Polygon	10
22	Polygon	10
23	Polygon	10
24	Polygon	10
25	Polygon	10
26	Polygon	10
27	Polygon	10
28	Polygon	10
29	Polygon	10
30	Polygon	10

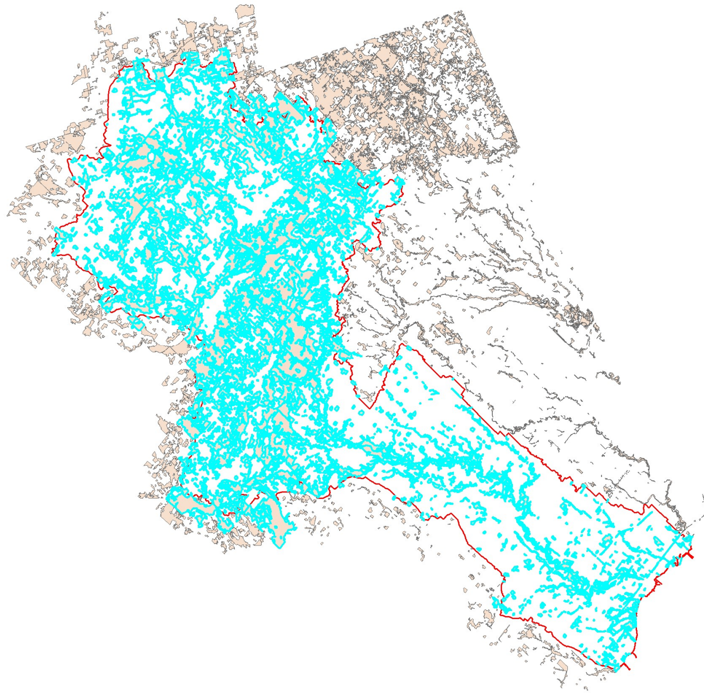

Figure 28: Attribute table of the natural areas shapefile, with selected polygons corresponding to natural areas within the CVC boundary.

H. To export the selected natural areas (polygons within or intersecting the CVC boundary) (Figure 28) into a new shapefile, right click on the natural areas shapefile (with selected polygons selected) in the ArcMap "Table of Contents" and chose the "Data" option, then click on "Export Data."
I. In "Export" select "Selected features."
J. In "Output feature class" select a destination and name the new natural areas shapefile.

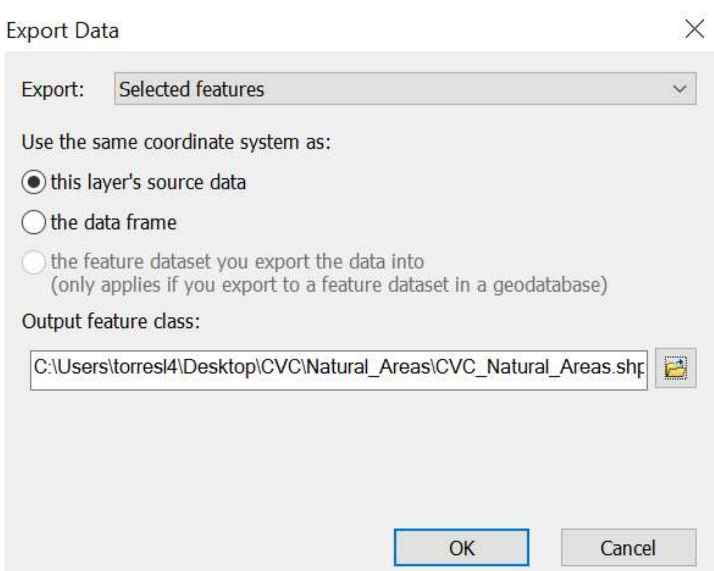

Figure 29: Export selected natural areas.

K. The resulting new natural areas shapefile will only contain polygons that are within or that intersect the CVC boundary.
L. Calculate the area of each of the selected natural areas (polygons) in hectares. Open the attribute table of the newly created natural areas shapefile (Figure 29) and add a new field called "Area." Then right click on this new field and select "Calculate Geometry." Proceed to calculate the area (ha) of each natural area (polygon).

7.2. Creating Node and Connection Files: Euclidean Distance

Before proceeding with the analysis in Conefor 2.6, we need to first prepare the corresponding input files. Conefor 2.6 requires two different files in order to estimate the importance of each natural area for the maintenance of habitat connectivity: a node and a connection file. We will begin by estimating node and connection files based on Euclidean distances.

Node files are text files that contain two columns. The first column will contain the ID of each natural area, while the second will contain an attribute of each natural area (in this case the attribute will be area of each natural area in hectares).

A connection file is also a text file consisting of three columns. The first two columns contain the IDs of the natural areas that are linked, while the third one displays the Euclidean distance between them.

To create a node and connection file based on Euclidean distances, download the Conefor Inputs add-in for ArcGIS. This extension will generate node and connection files in the format required by Conefor 2.6. This extension is free and available at http://www.jennessent.com/arcgis/conefor_inputs.htm. A manual of this extension is also available for download.

A. Install the Conefor Inputs extension into ArcGIS 10.X. A detailed description of how to install this extension in available in the Conefor Inputs manual.
B. After correct installation, a new toolbar should be available in ArcMap (Figure 30). It should be embedded into the ArcMap toolbars (after restarting the application). If this toolbar is not embedded into the standard ArcMap toolbars, then open the "Customize" menu, select "Toolbars" and make sure "Conefor" is selected.
C. This extension toolbar has two buttons (Figure 30). The first one with a "D" will open an option panel to set parameters and run the tool. The second book-like button will open the manual.

Figure 30: Conefor Inputs add-in toolbar.

D. To set parameters and run, click on "D." The following "ID Within Distance Parameters" menu will open (Figure 31):

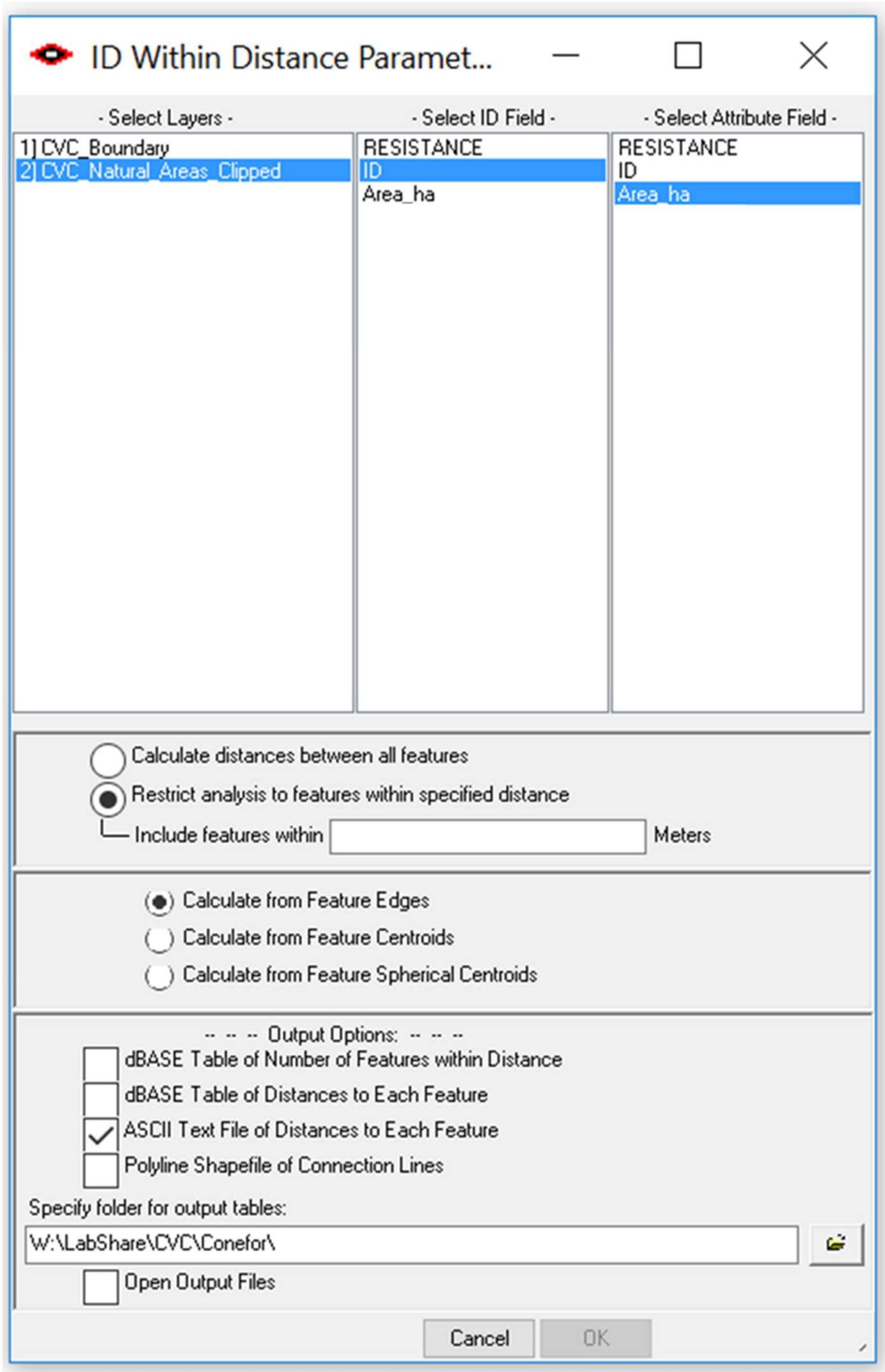

Figure 31: Creating node and connection files based on Euclidean distance.

E. In the "Select Layers" column, select the layer with the natural areas data. This layer is clipped to only include natural areas within or intersecting with the CVC boundary (Figures 27 - 29).

F. In the “Select ID Field” column, select the field that contains the ID of each natural area (The natural areas shapefile contains a unique ID attribute for each natural area polygon).
G. In the “Select Attribute Field” column, select the attribute of each natural area, which in this case is area in hectares.
H. Select whether to “Calculate distances between all features” (including all habitat areas to produce a full connection file) or to “Restrict the analysis to features within specified distance” (partial connection file). This last option will only consider natural areas as connected if they are within a specified distance threshold that is specified.
    a. For this case, enter the distance threshold in the corresponding text box (“Include features within”). When restricting the analysis with a distance threshold, only pairs of natural areas within the specified distance will be included in the output. Natural areas beyond this distance threshold will be considered unconnected. In this project, we set a maximum distance threshold of 15700m (the maximum dispersal distance).
    b. It is important to note here that this step is necessary to eliminate unnecessary calculations for connections that are too long. Note that this “distance threshold” is not biologically meaningful and is different from the “dispersal threshold” that will be set elsewhere and describes the dispersal capability of a group of organisms.
I. Select “Calculate from Feature Edges.” Under this option, connections between natural areas will originate and end at the edge of each natural area.
J. Select the option “ASCII Text File of Distances to Each Feature.” This will generate the node and connection text files, which is the input required by Conefor 2.6.
    a. The node file generated will be named “Nodes_[Layer Name].txt.”
    b. The connection file will be named “Distances_[Layer Name].txt.” Note that this connection file will calculate the distance between any pair of features a single time.
K. In “Specify folder for output tables” select the folder where the node and connection files will be saved and select whether to automatically open the results as they are produced (optional). Upon completion, the tool will produce an “Analysis Report” containing a summary of the outputs generated.
L. A node file will contain two columns (Node ID and Area in ha) (Figure 32):

0	0.520136830948865
1	0.525950690042687
2	3.185062390690800
3	12.803461960000000
4	1.189749367356230
5	0.665133094988388
6	0.680086578459123
7	1.851289530842000
8	9.208491829041580
9	0.895864483807608
10	0.659884423183179
11	0.474569826724184
12	5.554207898666540
13	1.904826819086860

Figure 32: Node file with Conefor Inputs add-in.

M. A connection file will contain three columns: Node 1 ID, Node 2 ID, and Euclidean distance between nodes (Figure 33). Note that the distances between pairs of natural areas refer to Euclidean distances:

0	1	15.876726258
0	4	154.161036321
0	5	253.263575543
0	8	194.666784833
1	2	235.371750812
1	4	45.802014677
1	8	142.416712057
2	3	25.802048795
2	4	67.722820286
2	7	187.723395218
3	7	186.318911860
4	5	286.335380449
4	8	30.998321813

Figure 33: Connection file based on Euclidean distance calculated with the Conefor Inputs add-in.

7.3. Creating and Connection Files: Least Cost Paths

Here we will create node and connection files based on least cost paths. Note that the node file from Euclidean distances and least cost paths are the same (Figure 32), as they exclusively depend on the area of each natural area polygon. To compute least cost paths between natural areas, we will use the Linkage Mapper add-in for ArcGIS.

1. Downloading and Installing Linkage Mapper for ArcGIS 10.X.

A. Linkage Mapper can be downloaded from: https://circuitscape.org/linkagemapper/. Once the software has been downloaded, follow the installation instructions. A detailed user manual is also included. Follow the instructions in the user manual to add Linkage Mapper into the ArcMap toolbox menu.

2. Setting Parameters and Running Linkage Mapper (Figure 34)

Linkage Mapper will use the previously created resistance surface (Figure 9) to compute least cost paths between natural areas.

Model Inputs in Linkage Mapper:

A. Select the "Linkage Mapper Toolkit" in the ArcMap toolbox menu and open the "Linkage Mapper" option. Click on "Build Network and Map Linkages."
B. Define a location path to save the analysis results in the "Project Directory" option. Select a folder in which all results will be saved.
C. In "Core Area Feature Class" select the shapefile which contains the natural areas that will be connected by least cost paths. These natural areas are all within or intersecting with the CVC boundary (Figures 27 - 29).
D. In "Core Area Field Name" select the ID of each natural area. Note that this field needs to include positive integers. For example, zero (0) is not a valid ID.
E. In "Resistance Surface" select the resistance surface raster (Figure 9).

Process Steps in Linkage Mapper:

A detailed description of what each of the following steps does can be found in the Linkage Mapper user manual.

F. Select the "Step 1" box.
G. Select the "Step 2" box. In the "Network Adjacency Method" pull-down option and select "Cost-Weighted" and leave the "Core Area Distance Text File" option blank.
H. Select the "Step 3" box and select the "Drop Corridors that Intersect Core Areas" option.
I. Leave the "Step 4" options unchecked.
J. Select the "Step 5" option.

Additional Options in Linkage Mapper:

K. Use the "Maximum Euclidean Corridor Distance" to input a distance threshold to indicate whether natural areas should be connected or not. This distance threshold corresponds to the same map units used (meters). Least cost paths will not be calculated for natural areas that exceed the specified distance threshold. As for the Euclidean distance connection files, several distance thresholds can be used to produce least cost paths.
    a. Again please note that that this step is necessary to eliminate unnecessary calculations for connections that are too long. Note that this "distance threshold"

is not biologically meaningful and is different from the "dispersal threshold" that will be set elsewhere and describes the dispersal capability of a group of organisms.

L. Leave the rest of the options blank.

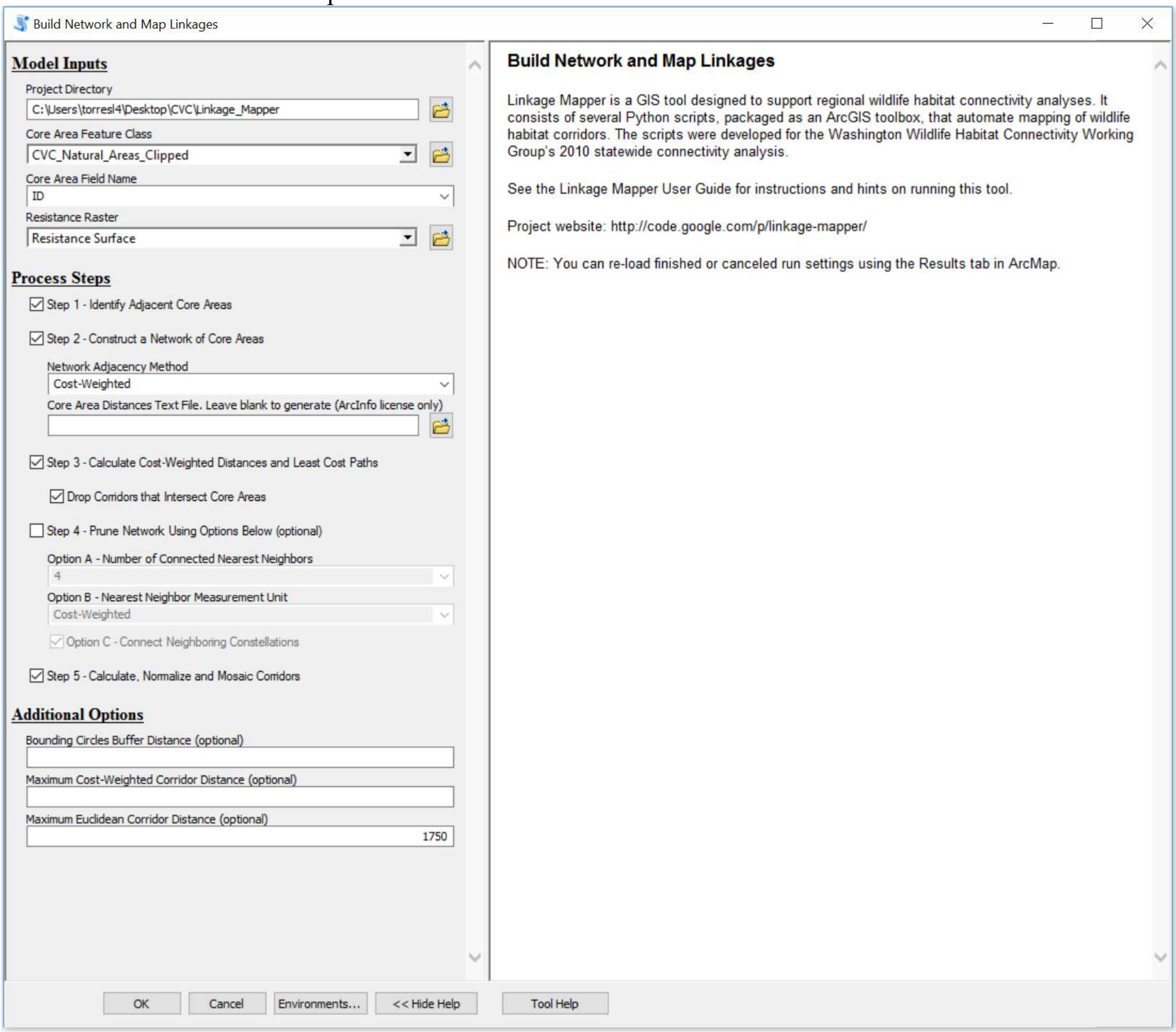

Figure 34: Setting parameters and running linkage mapper.

M. Note that running this tool is very computationally demanding and might take days, if not weeks, to complete depending on the computation resources of the machine used. A recommendation to limit computation time is to use a shorter distance threshold or a smaller number of natural areas, thus reducing the number of least cost paths considered.

7.4. Linkage Mapper Output: Format Least Cost Paths Connection File

A. Navigate to the folder where the output from Linkage Mapper was stored. Open the "output" folder and open the ".csv" file with a "linkTable_s5" ending. This file will contain the results from Linkage Mapper and will be used to prepare the connection file with least cost paths for Conefor 2.6.
B. The "linkTable_s5" file (Figure 35) contains multiple columns, but only three of them are of direct interest for the Conefor 2.6 analysis with least cost paths: "corId1", "corId2", and "lcDist." The first column of interest, "corId1", contains the ID of the first natural area in the linkage, while the second column of interest, "corId2", contains the ID of the second natural area in the link. The third column of interest, "lcDist", contains the least cost path distance between each pair of connected natural areas. Note that some least cost paths have a value of "-1", meaning that the Euclidean distance between that particular pair of natural areas was more than the maximum Euclidean corridor distance allowed in Linkage Mapper (beyond the specified distance threshold). These entries have to be removed before completing the Conefor analysis.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	#link	coreId1	coreId2	cluster1	cluster2	linkType	eucDist	lcDist	eucAdj	cwdAdj	lcpLength	cwdToEucRatio	cwdToPathRatio
2	1	1	2	-1	-1	1	15	26334.52	1	1	72	1755.63	365.76
3	2	1	4	-1	-1	1	687	54344.23	1	1	1112	79.1	48.87
4	3	1	5	-1	-1	-15	154	37293.11	0	1	215	242.16	173.46
5	4	1	6	-1	-1	1	253	27647.87	1	1	282	109.28	98.04
6	5	1	7	-1	-1	1	482	53970.55	1	1	539	111.97	100.13
7	6	1	9	-1	-1	-15	194	44640.78	1	1	489	230.11	91.29
8	7	1	10	-1	-1	1	1537	278102.1	0	1	3705	180.94	75.06
9	8	2	3	-1	-1	-15	235	28316.76	1	0	401	120.5	70.62
10	9	2	4	-1	-1	-15	600	56359.14	1	0	866	93.93	65.08
11	10	2	5	-1	-1	1	45	6656.854	1	1	66	147.93	100.86
12	11	2	9	-1	-1	-15	142	14004.52	1	1	340	98.62	41.19
13	12	3	4	-1	-1	1	25	22698.13	1	1	42	907.93	540.43
14	13	3	5	-1	-1	1	67	10071.07	1	1	100	150.31	100.71
15	14	3	8	-1	-1	-15	187	104971.2	1	1	1907	561.34	55.05
16	15	4	5	-1	-1	-15	475	38113.46	0	1	566	80.24	67.34
17	16	4	7	-1	-1	-15	1255	109206.2	1	0	1696	87.02	64.39
18	17	4	8	-1	-1	-15	186	133013.6	1	1	2373	715.13	56.05
19	18	4	10	-1	-1	-11	2302	-1	0	1	-1	-1	-1
20	19	4	13	-1	-1	1	425	131189.4	1	1	515	308.68	254.74

Figure 35: "linkTable_s5" raw output from Linkage Mapper.

C. In Excel, order the data from smallest to greatest Euclidean distance (Figure 36). The column containing this information in the "linkTable_s5" file is called "eucDist." Select and delete all entries that have a "-1" for "lcDist." Notice that all "-1" entries have a Euclidean distance that is greater than the distance threshold allowed in Linkage Mapper (Figure 34).

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	#link	coreId1	coreId2	cluster1	cluster2	linkType	eucDist	lcDist	eucAdj	cwdAdj	lcpLength	cwdToEucRatio	cwdToPathRatio
6598	658	193	252	-1	-1	1	1733	1180969	1	1	2402	681.46	491.66
6599	5334	1691	1710	-1	-1	-15	1744	320011.4	0	1	8639	183.49	37.04
6600	2978	920	961	-1	-1	1	1750	147294.4	1	1	2452	84.17	60.07
6601	983	293	345	-1	-1	-11	1751	-1	1	1	-1	-1	-1
6602	6618	2109	2156	-1	-1	-11	1751	-1	1	1	-1	-1	-1
6603	444	126	130	-1	-1	-11	1752	-1	1	1	-1	-1	-1
6604	2759	848	907	-1	-1	-11	1762	-1	1	0	-1	-1	-1
6605	5980	1904	1971	-1	-1	-11	1763	-1	1	1	-1	-1	-1
6606	679	200	217	-1	-1	-11	1772	-1	0	1	-1	-1	-1
6607	3243	1009	1115	-1	-1	-11	1784	-1	1	1	-1	-1	-1
6608	3009	930	961	-1	-1	-11	1790	-1	1	0	-1	-1	-1
6609	2942	907	978	-1	-1	-11	1797	-1	0	1	-1	-1	-1

Figure 36: Selecting connections between natural areas that are within the specified distance threshold.

D. After all the "-1" values have been deleted, arrange the excel table from least to greatest based on "corId1" value (as was originally sorted by Linkage Mapper).
E. To prepare the least cost paths connection file, in Excel delete all other columns except for "corId1", "corId2", and "lcDist." Also delete the first row containing column names.
F. Save the file with a .txt extension (tab delimited). This will be used in Conefor 2.6 as the least cost paths connection file (Figure 37).

1	2	26334.52344
1	5	37293.10938
1	9	44640.77734
1	6	27647.87305
1	7	53970.55469
1	4	54344.23047
1	10	278102.0625
2	5	6656.854004
2	9	14004.51855
2	3	28316.75586
2	4	56359.14453
3	4	22698.12891
3	5	10071.06738
3	8	104971.1875

Figure 37: Connection file based on least cost paths estimated in Linkage Mapper.

8. Quantifying the Importance of Natural Areas: Analysis in Conefor 2.6.

The importance of each natural area for the maintenance of habitat connectivity will be estimated using the Conefor 2.6 software. We are interested in calculating the percentage of variation in the probability of connectivity (probability that two randomly placed points in the landscape fall into natural areas that are interconnected) when each individual natural element is removed from the landscape or connectivity network (*dPC*). These values will also be partitioned into three fractions that represent the different ways in which a certain natural area contributes to overall habitat connectivity. The first fraction corresponds to the contribution of each natural area in terms of the available habitat area that is provided (*dPCintra*). This fraction will only depend on the area attribute of each natural area. The second fraction corresponds to the number of connections each natural area shares with other natural areas (*dPCflux*). This fraction depends both on the area attribute of each habitat area and also on the position of each natural area within the landscape. The third fraction is the contribution of each natural area as a steppingstone, as it quantifies how important natural areas are in terms of maintaining connectivity between other natural areas (*dPCconnector*). This fraction only depends on the topological position of each natural areas within the landscape network.

8.1. Downloading and Installing Conefor

A. Conefor 2.6 can be downloaded from: http://www.conefor.org/coneforsensinode.html. Once the software has been downloaded, follow the installation instructions. A detailed user manual is included.

8.2. Quantifying the Importance of Natural Areas

The basic inputs for Conefor 2.6 refer to the configuration of the natural areas in the landscape and the dispersal capabilities of the focal species (dispersal threshold). Specifically, these input files correspond to the node and connection files (with Euclidean or least cost path distances), plus information regarding dispersal capacity. Conefor 2.6 will be used to calculate the importance of each natural area for maintaining habitat connectivity and to prioritize them by their contribution to habitat connectivity.

In Conefor 2.6 (Figure 38)

A. In the "Node file" option select the node file previously created with the Conefor Inputs Extension in ArcMap (Figure 32).
    a. Remember that the node file will contain two columns: the first one will specify the ID of each natural area, while the second one will indicate the size of each natural area.
    b. Note that the node file used for analysis based on Euclidean distances or least cost paths are exactly the same, as the size of each natural area is independent of the type of connection between them.
B. Leave the "There are nodes to add" option unchecked. Unselecting this option means that there are no potential habitat areas (habitat areas that will be added in the future). By selecting this option, Conefor 2.6 can evaluate the contribution to connectivity of potential new habitat areas.
C. In the "Connection file" option select the connection file previously created with the Conefor Inputs (Euclidean distances) (Figure 33) or Linkage Mapper (least cost path distances) (Figure 37) extensions in ArcMap.
    a. These files will contain three columns: the first two will specify the ID of the natural areas connected, while the third column will indicate the distance.

b. Note that the distances between habitat areas can be Euclidean (Figure 32) or least cost path (Figure 37) distances, depending on the method selected to estimate them.
    i. Remember that the Conefor Inputs extension estimates Euclidean distances, while the Linkage Mapper extension was used to estimate least cost path distances.
    ii. Also note that different Euclidean or least cost paths distances can represent different distance thresholds that limit the number of connections within the landscape. Always keep track of which file is being used here.

D. Select the "Partial" option. This indicates that the connection file used is a partial connection file, that is, a file that does not include every possible link between all habitat areas. We are using a partial connection file because we included a distance threshold when estimating Euclidean and least cost path distances.

E. Under the "Connection type" pull-down menu, select "Distances." This indicates that the third column in the connection file corresponds to distances.

F. Leave unchecked all options in the "Binary indices" box. Binary indices of habitat connectivity consider pairs of natural areas as either connected or unconnected. We will be using probabilistic indices that use dispersal capabilities (dispersal thresholds) to estimate the probability of connectivity between two natural areas.

G. In the "Probabilistic indices" box, select the "PC" option. This corresponds to the probability of connectivity index.
    a. Under the "more" tab, the user can specify if the probability of connectivity should be calculated for all connected habitat areas, or if only calculated for habitat areas with a minimum probability of connectivity. Select "Check all paths."

H. In the "Distance" text box indicate the dispersal threshold. For example, this value can correspond to a small, medium, or large dispersal distance.
    a. Note that when using a Euclidean connection file (Figure 33), the dispersal threshold represents Euclidean distance in meters.
    b. When using the least cost paths connection file (Figure 37), the dispersal threshold represents cost-weighted distances (cumulative cost along a least cost path).
    c. Note that this "dispersal threshold" is biologically meaningful, as it represents the dispersal capability of a group of organisms. It is different from the "distance threshold", which was used previously to limit the number of connections between natural areas, thus reducing computation time.

I. To determine the corresponding dispersal threshold when using least cost path distances, multiply the selected dispersal threshold (Euclidean distance in meters) by the median value of landscape resistance.
    a. For example, to set a dispersal threshold of 300 meters with a least cost path connection file, multiply this value by 100 (median resistance value in this case). Type in the corresponding least cost weighted dispersal threshold (in this case 30,000) into the "Distance" text box.

J. In the "corresponds to probability" text box type "0.5." This means that the dispersal threshold previously specified in the "Distance" text box corresponds to a median dispersal distance. This means that half of the dispersal events can be longer than the selected dispersal threshold.

    a. If the selected dispersal threshold corresponds to the maximum dispersal distance, then use a probability of 0.1 or 0.05 (which means that 10% or 5% of the dispersal events can be longer than the distance specified).

K. Leave the “A_L” text box blank, as it will be automatically calculated by Conefor 2.6. This corresponds to the maximum landscape attribute, that is, the total landscape area including both habitat and non-habitat areas.

L. Leave all options in the “Link importances” unchecked.

M. In the “Mode” menu select “Show deltas” and “High Precision”.

N. Note that running Conefor 2.6 with large connection files (thousands of connections between natural areas) is very computationally demanding and each run can take weeks to complete.

    a. Note that this step was calculated on the supercomputing facility (Calculon) available at the University of Toronto Mississauga. Smaller number of connections could be calculated on desktop computers, as shown in the above steps.

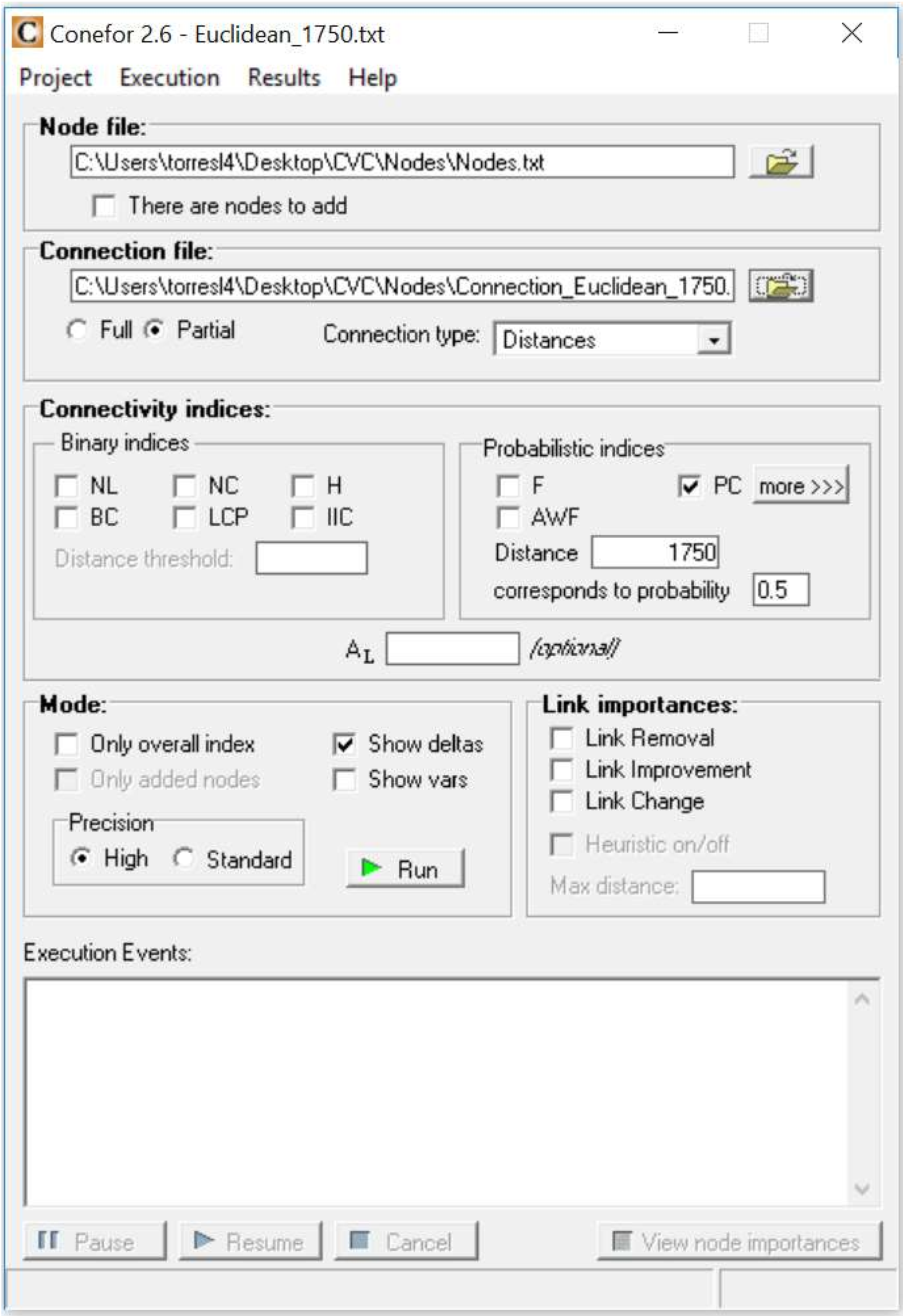

Figure 38: Quantifying the importance of natural areas in Conefor 2.6.

8.3. Output from Conefor 2.6.

It is very important to keep track of the parameters used to run Conefor 2.6. Always keep a log file of what type of connection file is being used (Euclidean vs. least cost paths) and what dispersal threshold is considered. Use informative file names and folders. The idea behind using several dispersal thresholds is to assess how the contribution of each habitat area to habitat connectivity changes with dispersal capacity (dispersal distance).

In Conefor 2.6 and Excel (Figure 39):

A. To save the results from each Conefor 2.6 run, click on the "Results" tab, select "Node importances", and select "Save as text file." Make sure to save the results using informative names.
B. The node importance file is an ASCII text file.
    a. The first column (*Node*) in the file corresponds to the ID of each habitat area.
    b. The second column (*dA*) corresponds to the proportion of total habitat area corresponding to each particular natural area.
C. The column *dPC* corresponds to the percentage of variation in the probability of connectivity when each natural area is removed from the landscape. Thus, *dPC* is used to measure the importance of each natural area for the maintenance of habitat availability.
    a. This connectivity index can range from 0 to 1 and is greater for habitat areas that are more important for the maintenance of habitat connectivity. The *dPC* values can be further portioned into three fractions that represent different ways in which habitat areas can contribute to habitat availability.
D. The *dPCintra* column represents the contribution of each natural area in terms of habitat area. This fraction only depends on the size of each natural area, as it is a measure of the available habitat area provided by each natural area (intrapatch connectivity).
E. The *dPCflux* column represents the importance of each natural area in terms of the number of direct connections to other natural areas in the landscape. This fraction will depend on the on the area of each natural area and also on its position in the landscape. It is a measure of how well connected each natural area is.
F. The *dPCconnector* column represents the importance of each natural area as a steppingstone or connective element between other natural areas.

	A	B	C	D	E	F
1	Node	dA	dPC	dPCintra	dPCflux	dPCconnector
2	0	0.00180378	0.0016421	3.89E-08	0.00164207	0
3	1	0.00182394	0.00172999	3.97E-08	0.00167089	5.90E-05
4	2	0.0110455	0.0129685	1.46E-06	0.0100298	0.00293713
5	3	0.0444011	0.0399001	2.36E-05	0.0398743	2.20E-06
6	4	0.00412593	0.00763789	2.03E-07	0.00384867	0.00378896
7	5	0.00230662	0.00233267	6.36E-08	0.00216378	0.000168766
8	6	0.00235847	0.00205884	6.65E-08	0.00201007	4.87E-05
9	7	0.00642009	0.00575553	4.92E-07	0.00575503	0
10	8	0.0319341	0.0351105	1.22E-05	0.0301334	0.0049649

Figure 39: Node importance file results from Conefor 2.6.

8.4. Visualizing Output from Conefor

The importance of each natural area for the maintenance of habitat connectivity will change based on the selected dispersal threshold used in Conefor 2.6 and whether Euclidean distances or least cost paths were used in the connection file. It is important to keep track of these parameters for interpretation. The "node importances" file from Conefor 2.6 can be visualized in ArcMap to help prioritizing natural areas based on their contribution to habitat connectivity.

In ArcMap (Figure 40 - 43):

A. Open the attribute table of the natural areas shapefile (Figures 27 - 29) and add four new fields (columns) to input the results from each Conefor 2.6 run. Each Conefor 2.6 run will contain four measures of the importance of each natural area (*dPC, dPCintra, dPCflux*, and *dPCconnector*). Note that each Conefor 2.6 run will be different depending on the distance threshold used and on the type of connection file used (Euclidean distances vs. least costs paths). Be sure to include informative names for each new field.

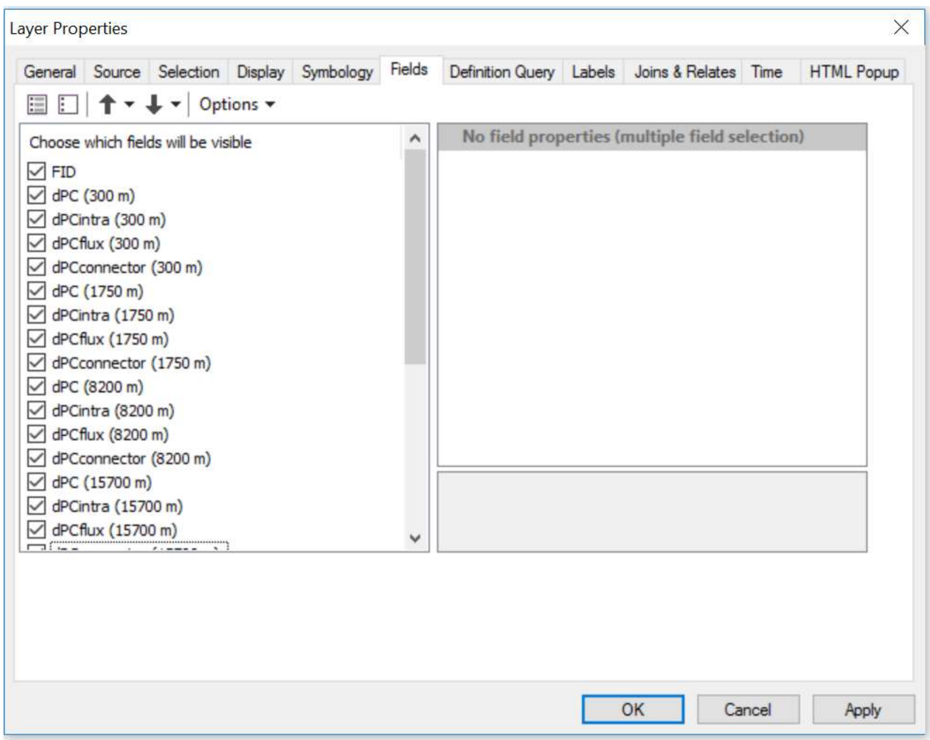

Figure 40: Adding new fields to natural areas shapefile to import results from Conefor 2.6.

B. Open the results of each Conefor 2.6 run in Excel (Figure 39).

C. Select the "Editor" tool and the "Start Editing" option in ArcMap. Select the natural areas shapefile with the empty fields created above (Figure 40). Copy each corresponding column (*dPC, dPCintra, dPCflux, dPCconnector*) from the Conefor 2.6 results in Excel (Figure 39) into its corresponding field in the natural areas attribute table in ArcMap (Figure 41). Note that the order of natural areas between the Conefor 2.6 results and the natural areas attribute table should be the same.

Table

CVC_Natural_Areas_Clipped

FID	dPC (300	dPCintra (300	dPCflux (30	dPCconnec	dPC (1750	dPCintra (1750	dPCflux (175	dPCconnect	dPC (8200	dPCintra (8200	dPCflux (820	dPCconnect	dPC (15700	dPCintra (1570	dPCflux (157	dPCconnect
0	0.000019	0	0.000019	0	0.001642	0	0.001642	0	0.003055	0	0.003055	0	0.003308	0	0.003308	0
1	0.000024	0	0.00002	0.000004	0.00173	0	0.001671	0.000059	0.003117	0	0.003093	0.000024	0.003361	0	0.003347	0.000013
2	0.00027	0.000003	0.000119	0.000148	0.012969	0.000001	0.01003	0.002937	0.019911	0.000001	0.018697	0.001214	0.020941	0.000001	0.02025	0.00069
3	0.00044	0.000042	0.000398	0	0.0399	0.000024	0.039874	0.000002	0.074984	0.000021	0.074963	0.000001	0.0813	0.00002	0.081279	0
4	0.000232	0	0.000051	0.000181	0.007638	0	0.003849	0.003789	0.008588	0	0.007025	0.001563	0.008476	0	0.007587	0.000889
5	0.000045	0	0.000029	0.000017	0.002333	0	0.002164	0.000169	0.004009	0	0.003932	0.000077	0.004289	0	0.004245	0.000044
6	0.000017	0	0.000017	0	0.002059	0	0.00201	0.000049	0.003964	0	0.003939	0.000026	0.004309	0	0.004294	0.000015
7	0.000061	0.000001	0.00006	0	0.005756	0	0.005755	0	0.010838	0	0.010838	0	0.011754	0	0.011754	0
8	0.000603	0.000022	0.000372	0.000209	0.035111	0.000012	0.030133	0.004965	0.056566	0.000011	0.054493	0.002062	0.059971	0.00001	0.058787	0.001173

Figure 41: Conefor 2.6 results viewed in the attribute table of the natural areas shapefile.

D. Once the results from each Conefor 2.6 run have been pasted into the attribute table of the natural areas shapefile (Figure 41), the results can be visualized in ArcMap.
E. Open the "Symbology" tab of the natural areas shapefile and select "Quantities", then select "Graduated Colors." In the "Value" option select the Conefor 2.6 result for visualization (*dPC, dPC intra, dPCflux, dPCconnector)* (Figure 42).
    a. Remember that each one of these parameters corresponds to a particular Conefor 2.6 run, which will be unique depending on the dispersal threshold and the type of connection file used.
F. Select a "Color Ramp" that will allow the identification of natural areas that are most important for habitat connectivity (Figure 42). For example, higher values of *dPC* could be represented by warm colors, while lower values by cooler colors (Figure 43).

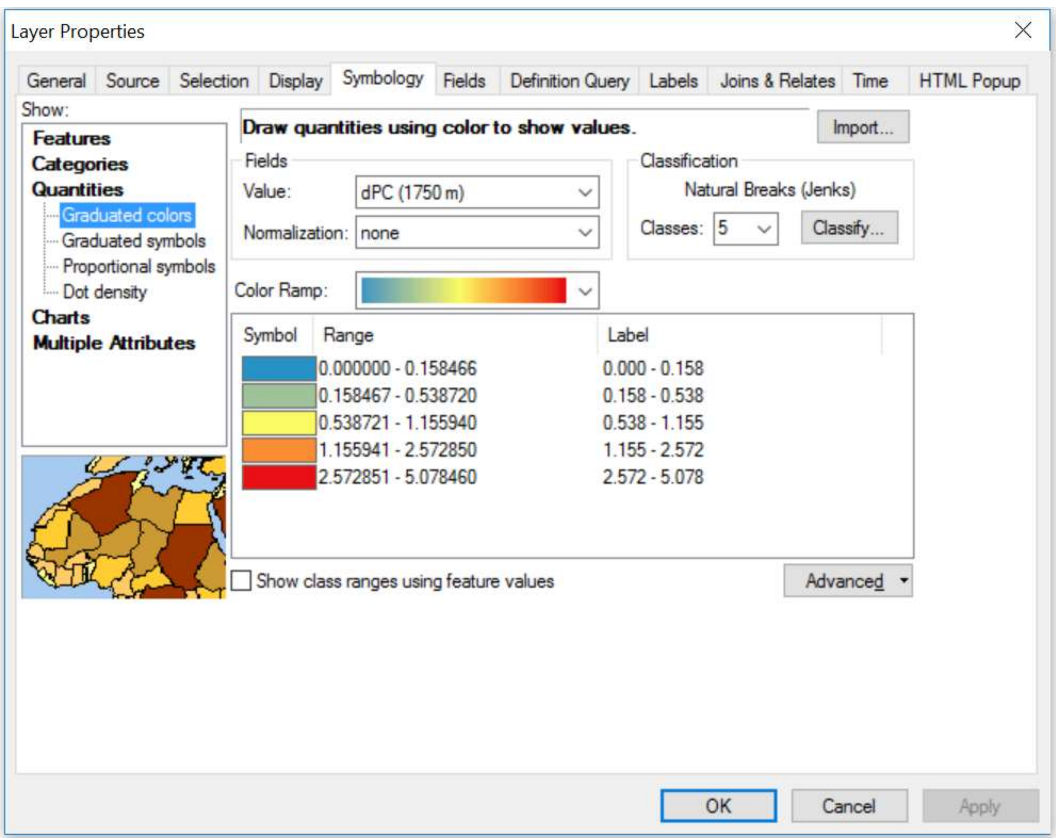

Figure 42: Changing the symbology of the natural areas shapefile to visualize the Conefor 2.6 results in ArcMap.

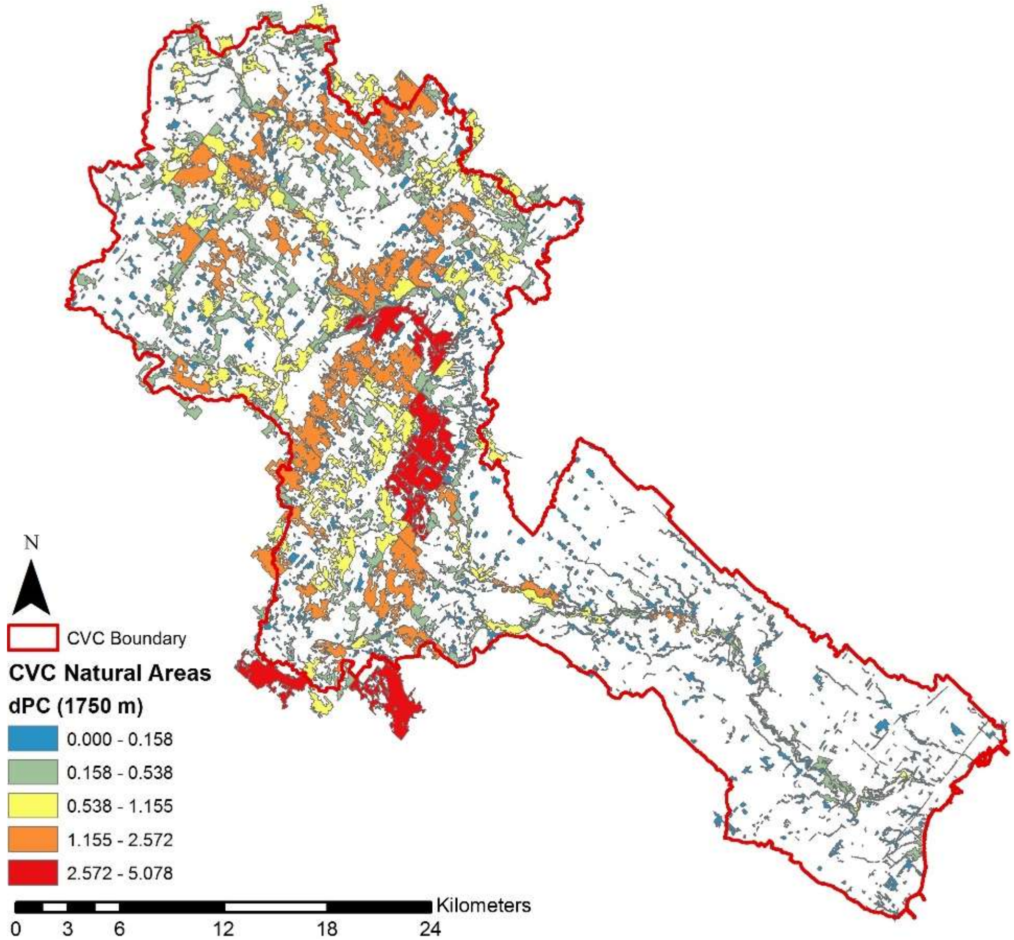

Figure 43: Visualization of the Conefor 2.6 results in ArcMap.

9. References

Abdel Moniem, H. E., Torres-Vanegas, F., and Wagner, H. H. 2020. Evaluating Natural Heritage Connectivity in the Credit River Watershed. Final Report. 70p.

Bowman, J., and Cordes, C. 2015. Landscape Connectivity in the Great Lakes Basin. https://www.researchgate.net/publication/296845907_Landscape_Connectivity_in_the_Great_Lakes_Basin