3.8. Ravine GIS Analysis Tutorial

**NOTE – All exercise examples will pertain to ESRI’s ArcGIS 10.0**

**Exercise 1: LiDAR DEM Data**

Ravines are small, narrow, and deep depressions, smaller than a valley, and larger than a gully (Wing et al., Ch. 3, this book). Ravines are an important source of sediment in surface waters of Minnesota, and headcutting of ravines into productive farmland diminishes the area of land available for crop production. Ravines are easily distinguished from surrounding areas using digital elevation models based on their dendritic incision patterns. In this exercise, instructions are provided for digitizing the boundary of a ravine located along the Minnesota River. The digitized boundary is then used to estimate morphometric attributes of the ravine, including length, relief, and volume. In addition, primary terrain attributes such as slope, flow direction, and flow accumulation are estimated, along with secondary terrain attributes such as stream power index (SPI).

A. Digitize Ravine Boundary

1. **Start ArcMap.**

2. **Add Spatial Analyst.** From the Customize Menu, select Extensions and make sure the box next to the Spatial Analyst extension is checked (Fig. 3.1. Click ‘Close’
3. **Add LiDAR DEM Data.** LiDAR stands for Light Detection and Ranging. It is a technique for obtaining high resolution digital elevation models (DEMs) with high spatial resolution.

   - Add data, open the “ravine_tutorial” file folder and go to “data” and add “3m_ravine1” – the LiDAR derived 3m DEM.

4. **Add aerial photography and Digital Raster Graphics (DRG) data with a Web Mapping Service (WMS).** Many spatial datasets are now disseminated using WMSs such as the Minnesota MNGEO WMS Service that will be used in this exercise. A DRG is a scanned and georeferenced image of a USGS topographic map.

   - Click on 'Add Data' and in the look-in box click on 'GIS Servers'. Highlight 'Add WMS Server' so that it appears in the Name window, and click 'Add'. An 'Add WMS Server' window will pop up (Fig. 3.2). To bring up the Imagery server, type “http://geoint.lmic.state.mn.us/cgi-bin/wms?” in the URL window. Click on the 'Get Layers' button to see a list of the layers available under the wms. Click 'OK'. Double click on “MnGeo WMS service (aerial photography) on geoint.lmic.state.mn.us”, then click on ‘MnGeo WMS service (aerial

Fig. 3.1: Extensions menu
photography)’ and then click ok and then add. The service, with all of its layers, has now been added to your ArcMap project. You should see an aerial image of the study area.

- Next you will add another WMS server, (http://geoint.lmic.state.mn.us/cgi-bin/wmsz?). Follow the same general steps and you will specifically add the ‘MnGeo WMS service (quad sheet drgs)’ dataset. This time you will see a topographic map for your study area. This is the DRG.
- Click the ‘+’ by the two new layers to expand the map services and see all available layers. You can check these layers on and off to display them as needed. Spend some time exploring the various data layers and pay specific attention to the various scales of data for the DRG layers and the different imagery products including the hillshade maps. Click ‘-’ to collapse the image tree.

Fig. 3.2: Add WMS Server menu
5. **Changing the Transparency of your Layers for Better Visualization.** By changing transparency, you can view multiple datasets in one map.

- In the Table of Contents, Drag the layers so that the order of the layers from top to bottom is as follows: ‘3m_ravine1’, ‘MnGeo WMS service (aerial photography)’, and ‘MnGeo WMS service (quad sheet drgs).’ Be sure the ‘2010 color FSA’ layer is clicked on in the imagery dataset.

- Right click on the ‘3m_ravine1’ layer in the Table of Contents and select ‘Properties’. Click the Display tab to manipulate and set the Transparency value to 40% as the value. If you have followed the steps correctly, you will see the semi-transparent DEM overlain on the orthophotos as shown in Fig. 3.3.

![Layer Properties](image)

**Fig. 3.3:** Transparent drape of DEM over orthophoto.

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6. Create a Shapefile for the Ravine Boundary

- Click on the catalog button and Navigate to the location of the “data” directory for this chapter exercise. Right click in the open portion of the “data” folder in the right-hand-pane of Arc Catalog and select “New” and then “Shapefile”.

- A dialog box will appear. Name the shapefile “ravine_bound” and set the feature type to “Polygon”. The shapefile name cannot contain spaces or some special characters, including dashes, and must have fewer than 13 characters. To define the projection of the Shapefile, click on the “Edit” edit button. Click on the plus box next to “Projected Coordinate Systems”, then the plus button next to ‘UTM’, and the plus button next to ‘NAD 1983.’ Then click on “Zone 15N”, click add, and then click OK to close “Spatial Reference Properties” box. The dialog box should appear as shown in Fig. 3.4. Click OK to close the “Create New Shapefile” box.

- If it has not been automatically added to your map, drag and drop your recently created “Ravine_bound” shapefile to the ArcMap view.

Fig. 3.4: ArcCatalog menu and dialog box for creating a new shapefile.

7. **Digitizing Ravines From the DEM.** In order to estimate the potential magnitude of sediment losses from ravines, it is important to identify the location of the ravine boundary.

- Right click on the open space on the toolbar and make sure ‘Editor’ toolbar is loaded (check mark next to name). If it is not loaded, select the ‘Editor’ and drag the floating editing toolbar to the toolbar area at the top to dock it along with the other toolbars. Make sure “Ravine_Bound” is checked on the tool bar.
- Right click on “Ravine_Bound”, select properties, and then click on the selection tab. Click the radial button next to “with this color” and click on the drop down box and indicate ‘No Color’. Click OK. This will make your selection transparent so that it is easier to edit.
- To improve the contrast of the DEM, highlight “3m_ravine1”, click on the ‘Windows’ drop down on the main menu and click Image Analysis. Select “3m_ravine1”. Then click on DRA, and be sure the ‘Stretch’ is set to ‘Std-dev’.
- Click on the ‘Editor’ button on the ‘Editor’ toolbar, and click on ‘Start Editing’. To insure that the shapefile is editable, make sure “Ravine_Bound” is highlighted in the ‘Create Features’ window. This window should appear on the right side of your screen. If you do not see the ‘Create Features’ window, then click on the ‘Create Features’ button on your ‘Editor’ toolbar which is the last button on the tool bar.
- Select the trace tool from the editor toolbar and start to trace the boundaries of your ravine, left-clicking each time you want to create vertices (Figure 3.5). As shown in Fig. 3.5 below, vertices are more closely spaced where the boundary is more curved, and less closely spaced where the boundary is less curved. Select vertices that produce a relatively smooth boundary. The boundary is located where the DEM shows a sharp transition from flatter to steeper landscape. This generally corresponds to the area with trees on the orthoquad photo. Do not identify the boundary solely based on locations of trees, as shadows can obscure the true location of trees. Ravines are narrow features whose boundaries are defined by larger slopes compared to surrounding areas. When the slope approaches zero at the base or terminus of the ravine, the feature should be closed. Ravines do not necessarily always reach the pour point or stream interface. There is generally a flat area on the DEM between the ravine and stream where sediment deposition occurs. This area should not be included in the ravine boundary.
- When fully delineated, double left-click to create the polygon. Go to Editor and select “save edits,” then “stop editing” to update your changes (Figure 3.6). The amount of detail and coverage you want should be similar to that shown in figure 3.6.
Fig. 3.5: Digitizing the ravine boundary polygon.
8. **Extracting the Ravine from the DEM.** In order to proceed with estimating morphometric features of the ravine, we need to clip out the previously digitized ravine portion of the 3 meter DEM.

- ArcToolbox > Spatial Analyst Tools > Extraction > Extract by Mask (Fig. 3.7) Click on the ArcToolbox button on the main menu and then select and expand ‘Spatial Analyst Tools’ toolbox.
- Select and expand the ‘Extraction’ toolset and double click on ‘Extract by Mask.’ For Input raster, use the black down arrow to select the “3m_ravine1” file.
- Select the “ravine_bound” shapefile for your Feature Mask Data.
- Use the folder button by output raster to navigate to your workspace and name the output raster "ravine_dem." The dialogbox should appear as shown in Fig. 3.7.
- Click OK to run. The output raster is added to the map as a new layer.

Fig. 3.6: Finished digitized ravine boundary polygon.
B. Calculate Ravine Primary and Secondary Terrain Attributes

Primary terrain attributes Slope, Flow Direction, and Flow Accumulation will be calculated to provide inputs for the Stream Power Index (SPI) secondary terrain attribute calculation. These primary and secondary terrain attributes indicate characteristics of the ravine that influence discharge of water and sediment transport. For example, steeper ravines with higher flow accumulation and SPI values will generally have larger discharges of water and greater sediment transport than flatter ravines with lower flow accumulation and SPI values.

1. Calculate Flow Direction

ArcToolbox > Spatial Analyst Tools > Hydrology > Flow Direction (Fig. 3.8)

Flow direction indicates how runoff water is routed from one region of the landscape to another as it moves downslope.

- In ArcToolbox, expand the ‘Hydrology’ toolset under Spatial Analyst Tools in the ‘Spatial Analyst Toolbox’ and double click on ‘Flow Direction’.
- Set the Input Raster to “ravine_dem” and use the folder button to save the output flow direction raster to "FlowDir_dem." (Fig. 3.8). Click OK to Run. The output raster will be added to the map as a new layer.
2. **Calculate Flow Accumulation**

ArcToolbox > Spatial Analyst Tools > Hydrology > Flow Accumulation (Figure 3.9)  
Flow accumulation indicates the size of the upslope drainage area. As flow accumulation increases, the likelihood of overland runoff increases.

- Double click on the ‘Flow Accumulation’ tool in the Hydrology group of ArcToolbox (the hydrology group should already be open). For the output accumulation raster, use the down arrows to navigate to your workspace and name the output raster "FlowAcc_dem" (Fig. 3.9). You can accept defaults for the other factors. Click OK to run. The output raster is added to the map as a new layer.
- To view the statistics of the flow accumulation analysis, right click on “flowacc_dem,” select properties, and click on the symbology tab. Click the histogram button and view the statistics. For our analysis, the average FlowAcc was 15.67 and the standard deviation was 79.95. The minimum and maximum values were 0 and 2061, respectively. The higher FlowAcc values correspond to cells that receive higher runoff.
Fig. 3.9: Flow Accumulation menu.

3. **Slope**

ArcToolbox > Spatial Analyst Tools > Surface > Slope (Fig. 3.10)

The Slope tool estimates the slope gradient in the flow direction for each grid cell in the DEM according to the eight closest neighbors. As slope increases, the potential for runoff and erosion also increase.

- In ArcToolbox select and expand the ‘Surface’ toolset in the ‘Spatial Analyst Tools’ toolbox. Double click on the Slope tool. Set the ‘Input Raster’ to "ravine_dem" and browse to output workspace and name output layer "slope_dem”. Set ‘Output measurement’ to PERCENT_RISE (Note: It is important for the rest of the analysis that you select PERCENT_RISE, even though the data will look the same). Your dialog box should appear as shown in Fig. 3.10. Click OK to run.

- Use symbology again to determine the average slope. According to our calculations, the mean slope value was 39.87 degrees, with a standard deviation of 24.34. The minimum and maximum slope steepness values were 0.05 and 111.68 degrees, respectively.

- The output raster is added to the map as a new layer.

4. **Stream Power Index (SPI)**

ArcToolbox > Spatial Analyst Tools > Map Algebra > Raster Calculator

The SPI is a sediment transport index that is calculated from primary terrain attributes Flow Accumulation and Slope as follows:

\[
\text{Stream Power Index (SPI)} = \ln((\text{Flow Accumulation} \times \text{Slope}))
\]

The raster calculator allows algebraic computations involving terrain attributes to be entered as formulas.

- Enter the formula so the result looks like the example below (Fig. 3.11):

\[
\text{SPI} = \ln((\text{"flowacc_dem"} + 0.001) \times ((\text{"slope_dem"} / 100) + 0.001)).
\]

This is the formula used to estimate Stream Power Index from primary terrain attributes Flow Accumulation and Slope. Click OK to run the calculation.

- Use symbology again to assess the mean SPI. According to our calculations, the mean SPI value was -1.26, with a standard deviation of 3.81. The minimum and maximum values were -12.59 and 5.6, respectively. Higher SPI values correspond to areas with more runoff on steeper slopes.
Fig. 3.11: Raster Calculator menu to calculate Stream Power Index.

C. Analyze Digitized Ravine Boundary

Ravines can be characterized by morphometric features including their area, length, relief and volume. These characteristics are related to water and sediment discharge from ravines.

1. Calculate Area

- In the ArcToolbox, click on the ‘Utilities’ Tool Set from the ‘Spatial Statistics Tools’ and double click on the ‘Calculate Areas’ script. Select “ravine_bound” as the input feature class, and specify “ravine_area” as the output feature class as shown in Fig. 3.12. Click OK.
- Right click on the “ravine_area” file and select “Open Attribute Table.” You should see the area under the field “F_AREA.” Leave the attribute table open. For our analysis, the size of the ravine was ~229317 m².
2. Identify Perimeter Length

- The attribute table for “ravine_area” should still be open. Click on the first area by the first icon at the top of the attribute table and chose Add Field. Click on Add Field. An Add Field box will appear. For ‘name’ type “F_PERIM” and set ‘Type’ to “Float” and click ‘OK.’ Right click on the “F_AREA” and select “calculate geometry.” A message box will pop up that asks you if you would like to do an edit session outside of ArcGIS. Click Yes. Select “perimeter” as the property and the dialog box should appear as shown in Fig. 3.13. Click OK. In the example, we calculated the perimeter to be ~6127 m.

Fig. 3.12: Calculate Areas menu.
Fig. 3.13: Calculate Geometry menu for ravine area calculation.

3. Calculate Channel Length

- In the ArcMap ‘table of contents’ on the left, drag “ravine_bound” up to be the top layer and “FlowAccDem” to be the second layer. Right click on “ravine_bound” and select properties. Click on the Symbology tab and set the “symbol” to “hollow.” Click “OK.” Use the Measure Tool (ometown) to measure the straight line distance of the main trunk of Flow Accumulation from the upper portion of the ravine to the pour point as shown in Fig. 3.14. You can see that the length of the channel in this example was 1,762 m.

Fig. 3.14: Measure Tool menu for ravine channel length.

4. Identify Relief

Examine the “ravine_dem” legend on the left and observe the difference between “High” and “Low” values as displayed in the theme symbology. In our case, the
difference was about 39 m.

5. Calculate Volume

- From the Customize Menu, select Extensions and put a check on the 3D Analyst extension (Fig. 3.15) and click Close.

![Extension menu for ravine volume calculation.](image)

**Fig. 3.15:** Extension menu for ravine volume calculation.

- In ArcToolbox expand the ‘3D Analyst Tools’ toolbox and expand the ‘Functional Surface’ tool set. Double click on the ‘Surface Volume’ tool. Use “ravine_dem” for the input surface. For ‘Output Text File,’ navigate to your working directory and name the file “ravine_volume” (Fig. 3.16). Click OK.
- The ravine_volume.txt file is automatically added to your Table of Contents.
- Right click on “ravine_volume” in your table of contents file within your filesystem to view surface volume of the ravine. In our example, the Ravine Volume was 5584525 m² according to our calculations.

Fig. 3.16: Surface Volume menu to calculate ravine volume.
Exercise 2: Tutorial Dataset Exercises

A. Perform Ravine GIS Analysis with Second Dataset

Follow all steps in Exercise 1 with the ravine in the center of the following dataset – 3m_ravine2

B. Check Values

Compute the following:

1. Slope
2. Flow Direction
3. Flow Accumulation
4. SPI
5. Area
6. Perimeter Length
7. Channel Length
8. Relief
9. Surface Volume

Check your values against this key for correctness:

**NOTE – Values should be similar but not exact, due to differences in digitization**

Slope - ~41.7 degrees

Flow Accumulation - ~22.43

SPI - ~0.83

Area – ~617291 m²

Perimeter Length – ~11455 m

Channel Length – ~2827 m

Relief – 67m

Surface Volume - ~26936056 m³