

Assessing Point Groundwater Contamination Potential

The Floridan Aquifer

— by Can Denizman

Introduction

Problem

Where might the Floridan aquifer be more susceptible to point contamination sources such as Superfund sites?

Point contamination originates when contaminants are released at readily identifiable spots such as underground gasoline tanks, septic tanks, or industrial and municipal landfills. This lab assesses point contamination potential for the Floridan aquifer by creating a cost-weighted distance grid for designated Superfund contamination sites.

Location

The study area is located along the Suwannee River, Florida (figure 1).

Time to complete the lab

It should take approximately three hours to complete this lab.

Prerequisites

Students should have advanced GIS experience.

Keywords: point groundwater contamination; karst aquifers; Superfund sites; hazardous material; buffer; cookie cutter; clip; join; interpolation; reclassification; map calculation; conditional operations; cost grid analysis

Data used in this lab

Raster data layers:

- Thickness of the Geologic Unit Overlying the Floridan Aquifer (Overburden Thickness): Prepared by the Florida Geological Survey (FGS)
- Soil Permeability: Prepared by the Florida Department of Environmental Protection (DEP)

Vector data layers

- Superfund Sites: Created by the U.S. Environmental Protection Agency (EPA) in 2005
- Karstic Depressions: Compiled by Can Denizman
- Geographic coordinate system: GCS_North_American_1983_HARN
- Datum: D_North_American_1983_HARN
- Projection: Albers conical equal area (Florida Geographic Data Library)

Student activity

A geospatial approach to groundwater contamination potential requires some background information about groundwater storage and movement. *Aquifer* is defined as a geologic material that stores and transmits groundwater. Groundwater flow is slow, and recharge to the aquifer takes place by diffuse infiltration through the overlying geologic units. Therefore, contaminant plumes do not spread rapidly and are attenuated by the aquifer material.

Karst aquifers are significantly different. Most groundwater storage and flow in karst aquifers occur in enlarged cavities, conduits, and caves formed by the dissolution of the aquifer material such as limestone, dolomite, and gypsum. Karst aquifers are susceptible to groundwater contamination for the following reasons:

- There is a close interaction between surface water and groundwater in karst aquifers. Surface water readily combines with groundwater through sinkholes. It is very common to see disappearing streams in karst regions, making groundwater susceptible to surficial contamination.
- Once in the aquifer, water moves rapidly through solutional conduits and caves with very little natural filtration and remediation. Thus, groundwater contamination in karst aquifers can spread long distances over short periods of time.

The goal of this project is to assess point contamination potential for the Floridan aquifer by creating a cost-weighted distance grid for designated Superfund contamination sites.

Because of the vulnerability of karst aquifers to surficial contamination, you should be concerned about the point contamination sources in areas where

- The Floridan aquifer is unconfined or semiconfined (i.e., not covered by a thick, impermeable geologic unit).
- Soil is permeable.
- Sinkhole density is high.

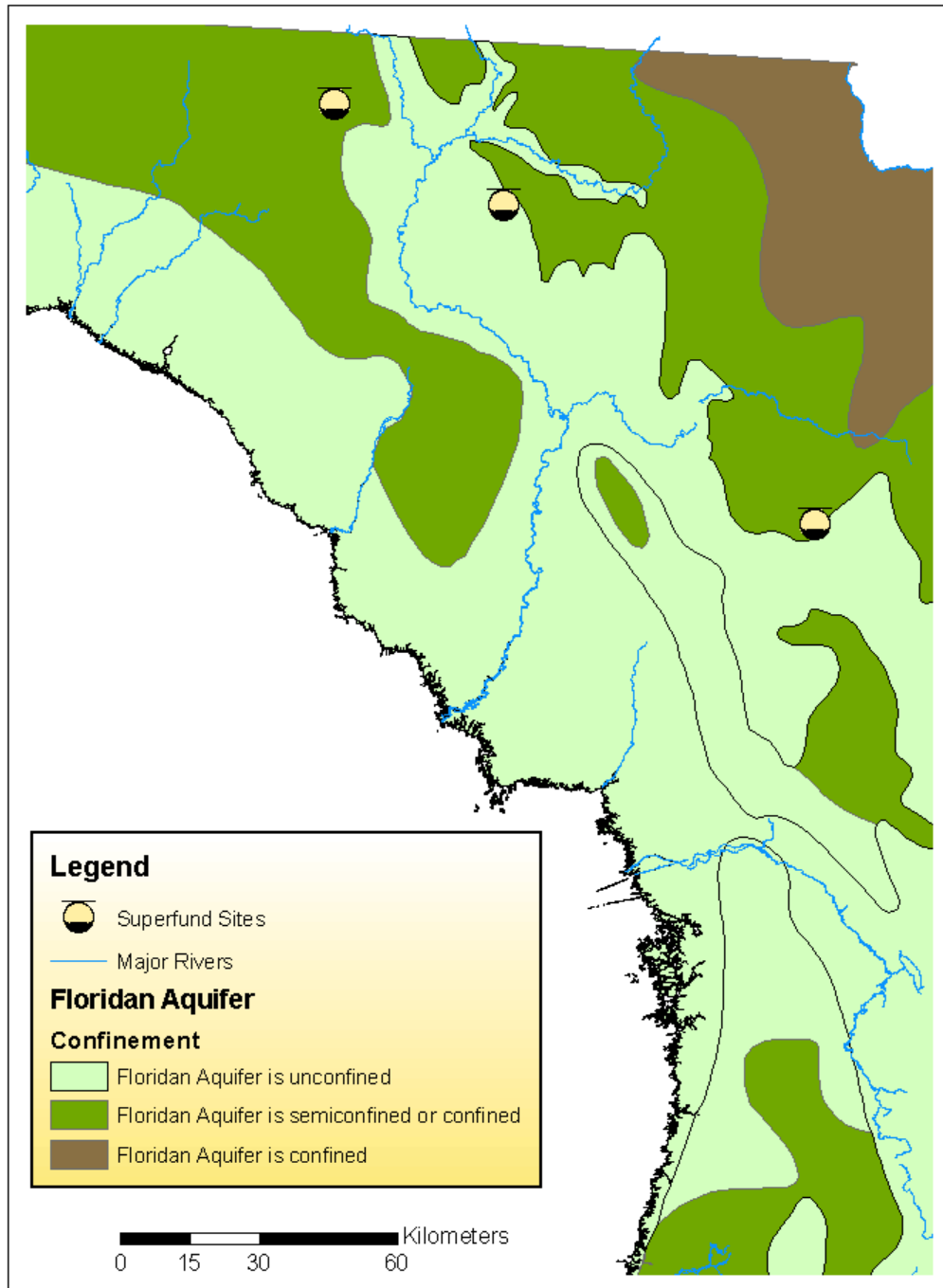


Figure 1. The study area along Suwannee River, Florida, comprising caves and aquifers

The GIS application for this project involves a number of ArcGIS Spatial Analyst functions using raster data. The tasks are

- Create a sinkhole density raster layer using the point sinkhole (karstic depressions) shapefile.
- Reclassify raster layers according to their functions in controlling the contaminant input to the Floridan aquifer.
- Create a cost grid using the reclassified raster layers. A cost grid is required to run the Cost Weighted Distance function using Spatial Analyst. It identifies the cost of traveling through each cell. In this study, a cost grid will be calculated based on the thickness of the overlying unit, soil permeability, and sinkhole density. This will determine the cost of contaminant infiltration (contamination potential) to the Floridan aquifer.
- Create a cost-weighted distance grid based on the Superfund site locations. This geospatial dataset is generated by a Spatial Analyst function that uses a cost grid to calculate the accumulative cost of traveling from every cell in the raster to a source or a set of sources (Superfund sites).

SET UP THE ANALYSIS ENVIRONMENT

- 1 Start ArcMap and open the map document *point_contamination.mxd*.
- 2 Save the map document in your own folder using *Save As*.
- 3 Explore the data layers in the data frame. What are the cell sizes for the two raster layers? What are the names of the three Superfund sites in the study area?
- 4 Load the Spatial Analyst extension if it is not already activated. Click *Customize » Extensions*, and check the *Spatial Analyst* box. Make it visible by clicking *Customize » Toolbars » Spatial Analyst*. You should have a *Spatial Analyst* toolbar available.
- 5 Now set the analysis environment. Click *Geoprocessing* and select *Environments* (figure 2). Click the *Workspace* tab and set the following as the current workspace and scratch workspace:
.../your_folder/lab_2/raster_data.

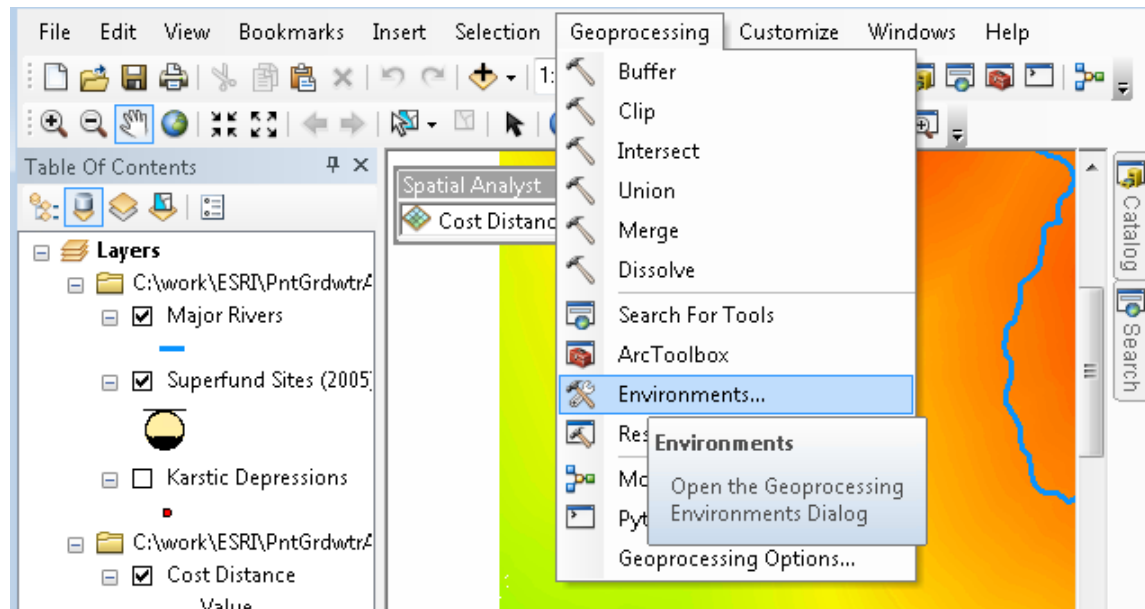


Figure 2. Setting the analysis environment

- 6 Click the *Processing Extent* tab in *Environment Settings* and select *Soil Permeability* as the *Snap Raster*.
- 7 Finally, click the *Raster Analysis* tab and set the cell size to *Same as Layer Soil Permeability*. Click *OK*.

CREATE A RASTER LAYER FOR THE DEPRESSION DENSITY

To create a cost grid, you need three raster layers: Overburden Thickness, Soil Permeability, and Depression Density. As you can see, you do not have the Depression Density raster layer. You can create it by using the Density function in ArcToolbox.

Point density calculates the magnitude per unit area from point features that fall within a neighborhood around each cell.

- 1 Open ArcToolbox and click the plus sign next to *Spatial Analyst Tools*.
- 2 Click the plus sign next to the *Density* tool and double-click *Point Density* to open its dialog box. Fill the dialog box as follows (see figure 3):
 - Input point features: Karstic Depressions
 - Population field: NONE
 - Output raster: ...(your_folder)/lab_2/raster_data/dep_dens
 - Output cell size: 100
 - Neighborhood: Rectangle

- Height: 1000
- Width: 1000
- Units: Map
- Area units: SQUARE_KILOMETERS

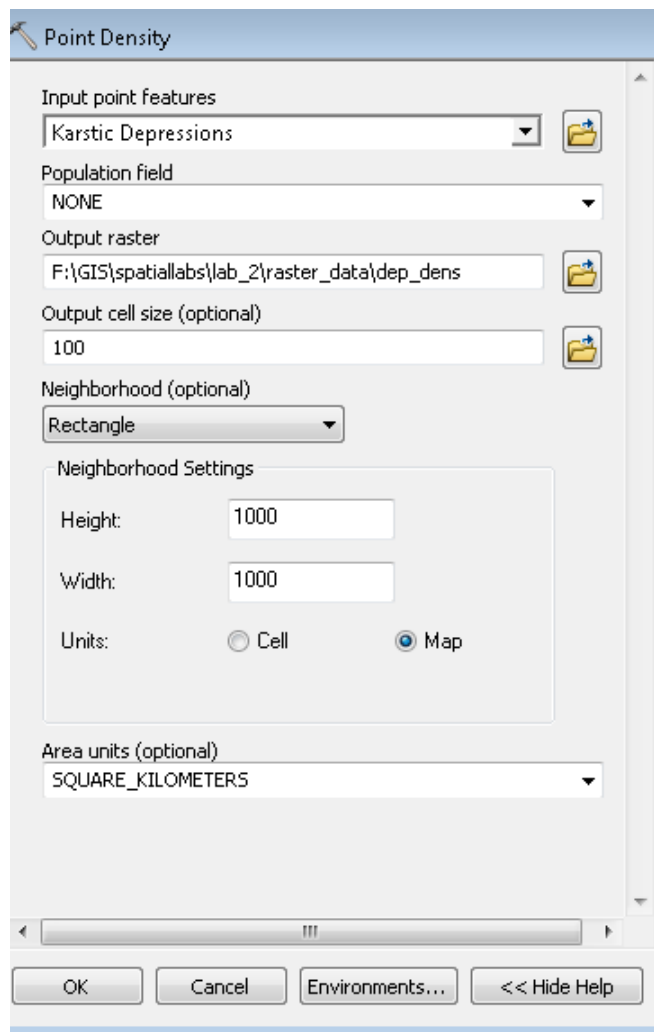


Figure 3. Using the Point Density tool

3 Click *OK*.

You now have a raster layer that shows karstic depression density in the study area.

4 Open the properties of the layer by right-clicking its name, and click the *Symbology* tab.

5 Format the labels with zero decimal places and select a multicolor color ramp to display it. Also, in the table of contents, rename *dep_dens* to *Depression*.

Problems with the overburden thickness values

- 1 Explore the Overburden Thickness raster layer. Symbolize it with 10 classes and a multicolor color ramp. Do you see anything wrong with the thickness values?
- 2 You can also check the values in the layer's attribute table. Open the attribute table and select negative values using the *Select by Attributes* option. Observe where negative values are located. They are generally located along the river valleys. Clear the selection and close the attribute table.

How can there be negative thickness values? Apparently those cells have erroneous values. These are areas where the Floridan aquifer is exposed, that is, the overburden thickness is zero.

You should change those negative values to zero. You can do this by using a conditional statement in Spatial Analyst.

MODIFY THE OVERBURDEN THICKNESS WITH A CONDITIONAL STATEMENT

There is a tool with the word *con* in ArcToolbox, but where is it?

- 1 Click the *Search* tab and type *con* as the keyword. The first entry, *Con (Spatial Analyst)*, looks promising.

This tool allows you to construct conditional statements for raster data. In your case, cells with negative values (your condition) will be assigned a zero value. Try this for the Overburden Thickness layer.

- 2 Double-click the *Con* tool to activate its dialog box. Enter *Overburden Thickness* for both *Input conditional raster* and *Input false raster or constant value*.
- 3 Click the *SQL* icon next to the *Expression* box and create the following statement using the Query Builder:

```
"VALUE" < 0
```

Click *OK*.

Enter the value *0* for *Input true raster or constant value*, then

Finally, enter the `../(your_folder)/lab_2/raster_data/rev_thick` path for *Output raster* (see figure 4). The name of the new raster layer is *rev_thick* (short for revised thickness).

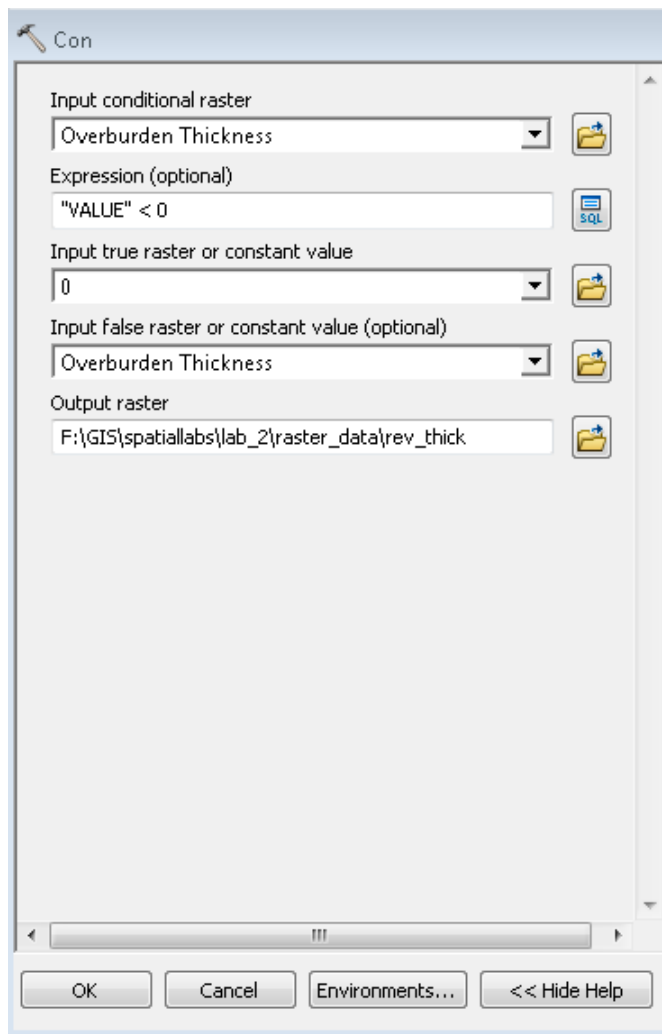


Figure 4. Using the Con tool

- 4 Click *OK*.
- 5 Rename *rev_thick* to *Revised Thickness* in your table of contents and display it with the same symbology as *Overburden Thickness*. Are there any negative values?

The conditional statement checked the value of every cell:

- If the cell was less than zero (condition was TRUE), the tool assigned a new value (zero).
- If the cell was not less than zero (condition was FALSE), it kept the same value.

RECLASSIFY RASTER DATA

You need to assign cost values to your raster layers. What would cause contaminants to enter the Floridan aquifer for various values of your raster layers? In other words, what would make it easier to contaminate the Floridan aquifer? Do you want low or high values of soil permeability, overburden thickness, and depression density? From the hydrogeological standpoint, the following conditions are expected:

- Low values of soil permeability » less infiltration through the soil » more difficult for contaminants to enter the Floridan aquifer » high cost values
- High values of soil permeability » more infiltration through the soil » less difficult for contaminants to enter the Floridan aquifer » low cost values
- Low values of overburden thickness » Floridan aquifer closer to the surface » less difficult for contaminants to enter the Floridan aquifer » low cost values
- High values of overburden thickness » Floridan aquifer deeper » more difficult for contaminants to enter the Floridan aquifer » high cost values
- Low values of depression density » less developed karst » more difficult for contaminants to enter the Floridan aquifer » high cost values
- High values of depression density » more developed karst » less difficult for contaminants to enter the Floridan aquifer » low cost values

Based on these conditions, you can assign cost values to your raster layers. You do that by reclassifying them. Reclassify is a common Spatial Analyst function to change values in raster layers.

Start with the soil permeability layer:

- 1 In ArcToolbox, click *Spatial Analyst Tools* » *Reclass*, then select *Reclassify*.
- 2 *Input raster* is *Soil Permeability*; *Reclass field* is *VALUE*. Reclassify the layer into 20 classes as follows:

190 – 200: 1
 180 – 190: 2
 170 – 180: 3
 160 – 170: 4

- 3 Click *Classify* and select *Equal Interval* and *20* for *Classification Method* and *Classes*, respectively (figure 5).

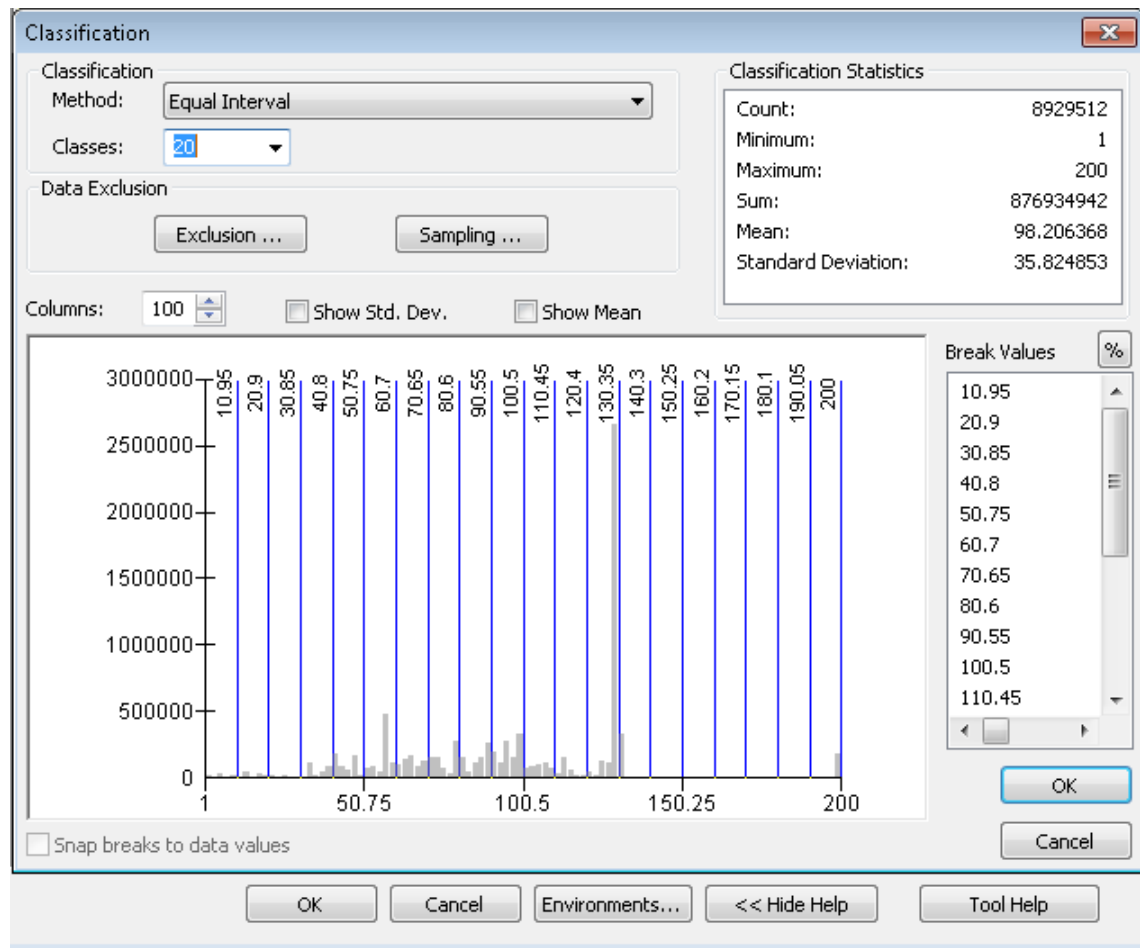


Figure 5. Using Equal Interval to partition soil permeability values into 20 classes

- 4 Double-click the first value in the *Break Values* window (10.95) and delete digits after the decimal point. Press the ENTER key.

- 5 Notice that *Classification Method* has changed to *Manual* (figure 6). That's fine. Continue deleting all digits in the decimal place for each break value and click *OK* when completed.

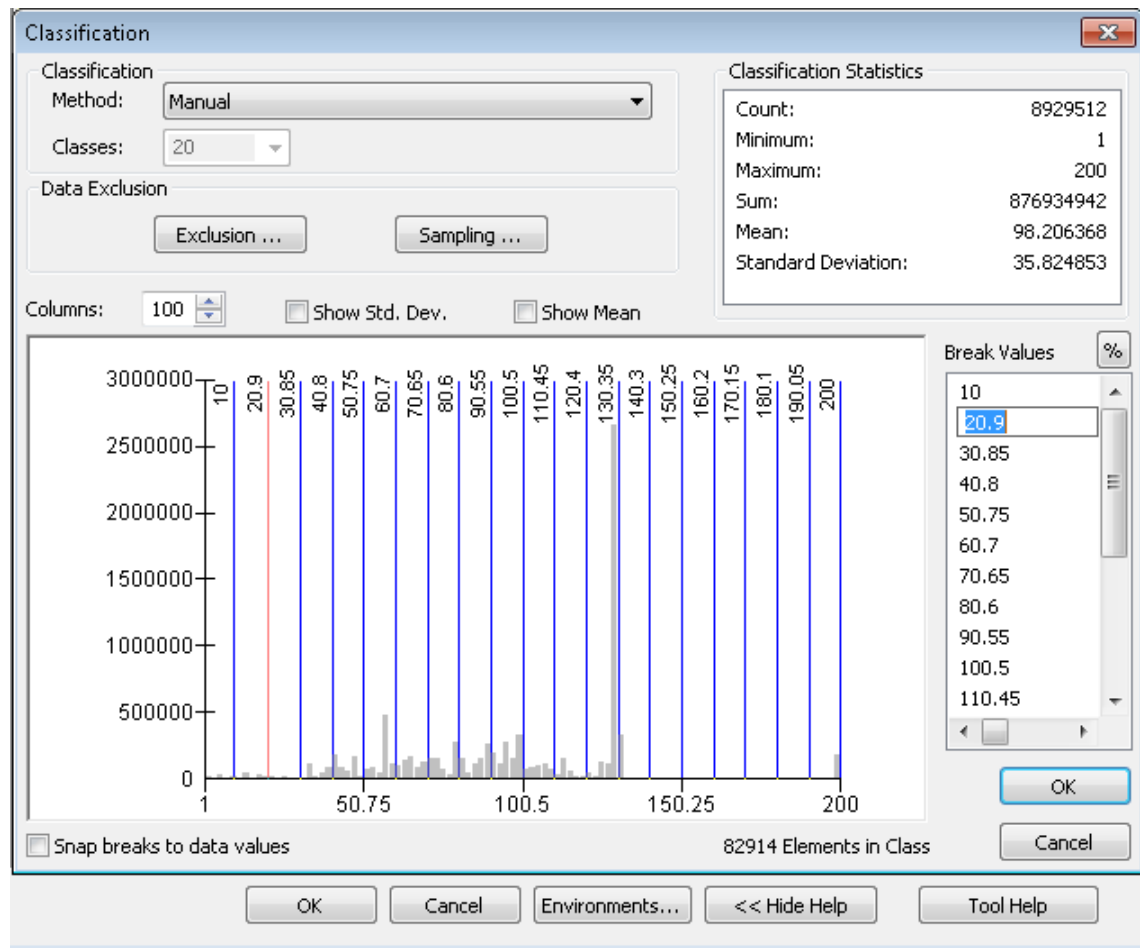


Figure 6. Manually modifying the equal interval break values

6 Starting from the first row, under *New values*, type integers from 20 to 1 (figure 7).

20
19
.....
1

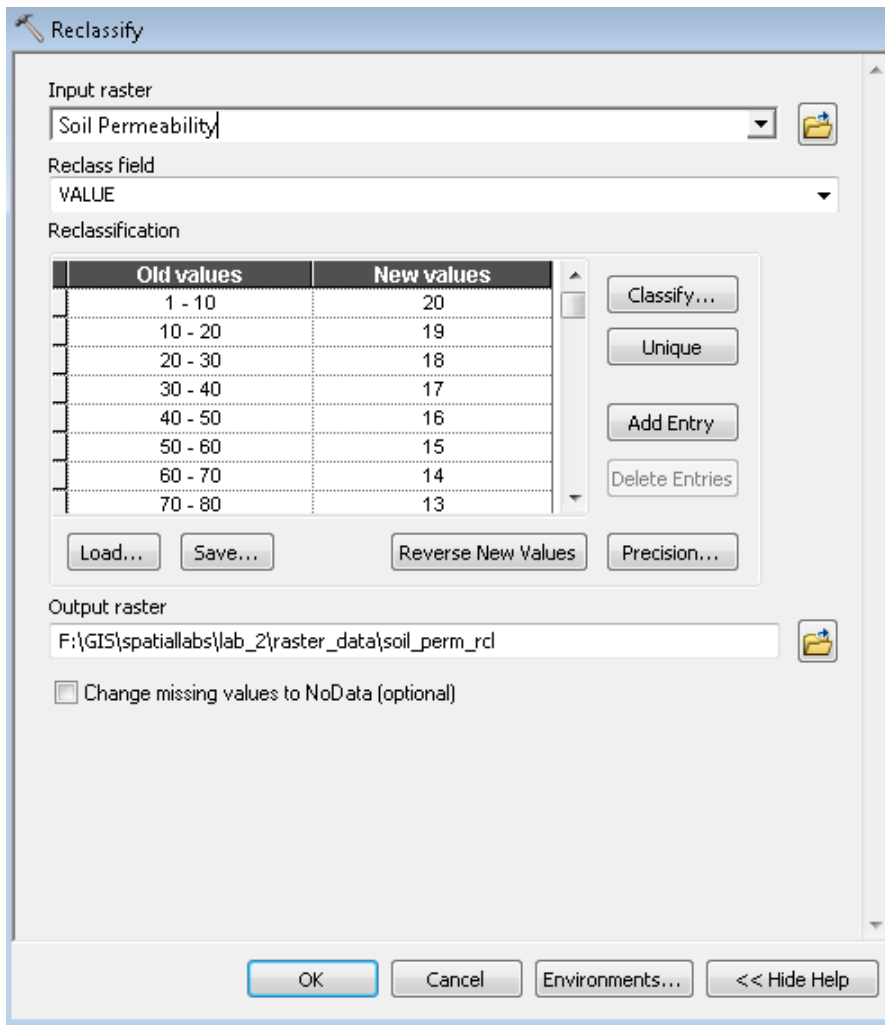


Figure 7. Using the Reclassify tool

7 For *Output raster*, locate your folder and save the reclassified soil permeability as

...(your_folder)/lab_2/raster_data/soil_perm_rcl

Note: Grid functions do not accept layer names longer than 13 characters including spaces. Always use a consistent naming convention that is short and descriptive. Never use the default names, such as recls1, unless you are testing a function. It is always a good idea to take notes about layer names, where they are saved, and how they are created. You can also find log files in each raster layer's folder that describe the geospatial processes for that layer.

- 8 Click *OK*.
- 9 This creates a new raster layer in the map document. Turn on the Superfund Sites layer to see the cost values where the sites are located (figure 8).

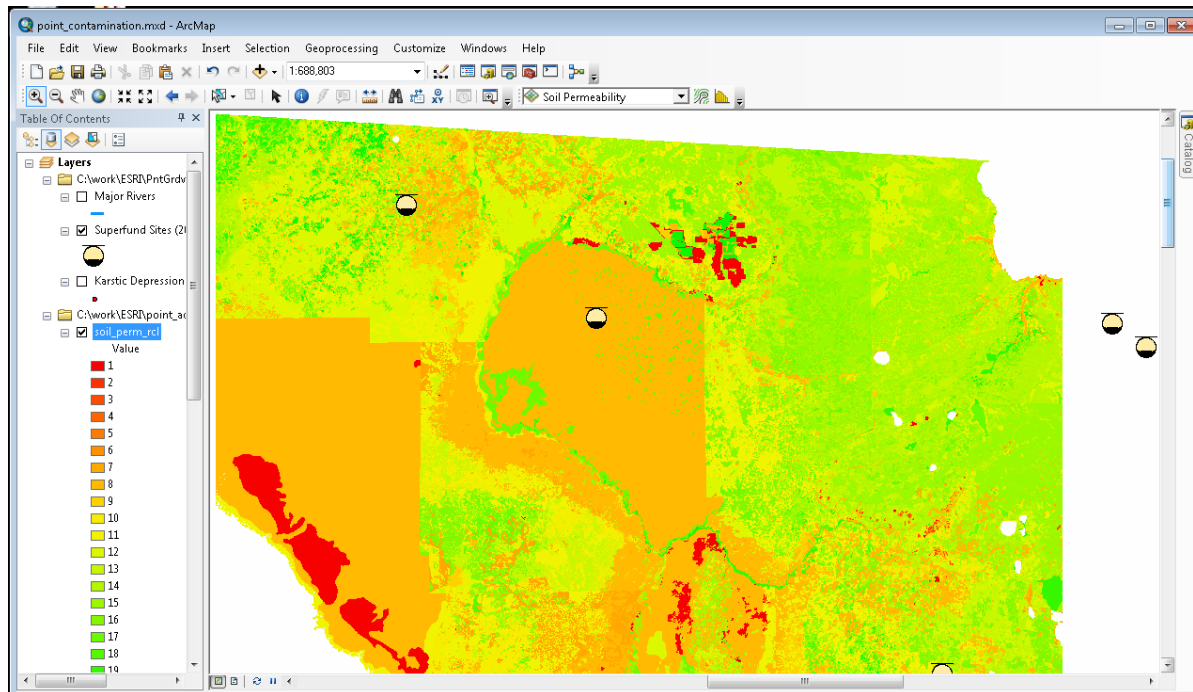


Figure 8. Map of reclassified soil permeability with Superfund sites overlaid

- 10 Reclassify Revised Thickness (*rev_thick*) as follows:

Old values	New values
0 – 10	1
10 – 20	2
.....
170 – 180	18
180 – 190	19
190 – 476	20

- 11 Save the layer as *ov_thick_rcls* (figure 9). Change its name to *Reclassified Revised Thickness* in the table of contents.

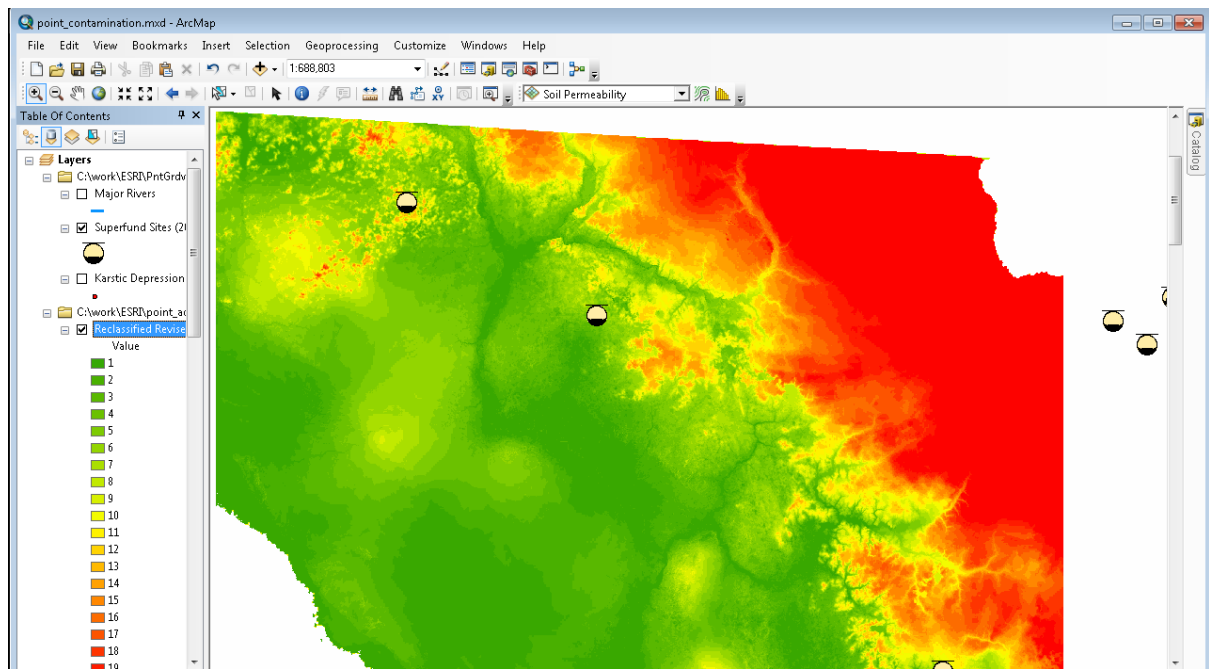


Figure 9. Map of reclassified overburden thickness with Superfund sites overlaid

- 12 Reclassify Depression Density (*dep_dens*) in 10 classes as follows:

Old values	New values
45 – 51	1
40 – 45	2
.....
5 – 0	10

- Save the layer as *dep_dens_rcls* (figure 10). Change its name to *Reclassified Depression Density* in the table of contents.

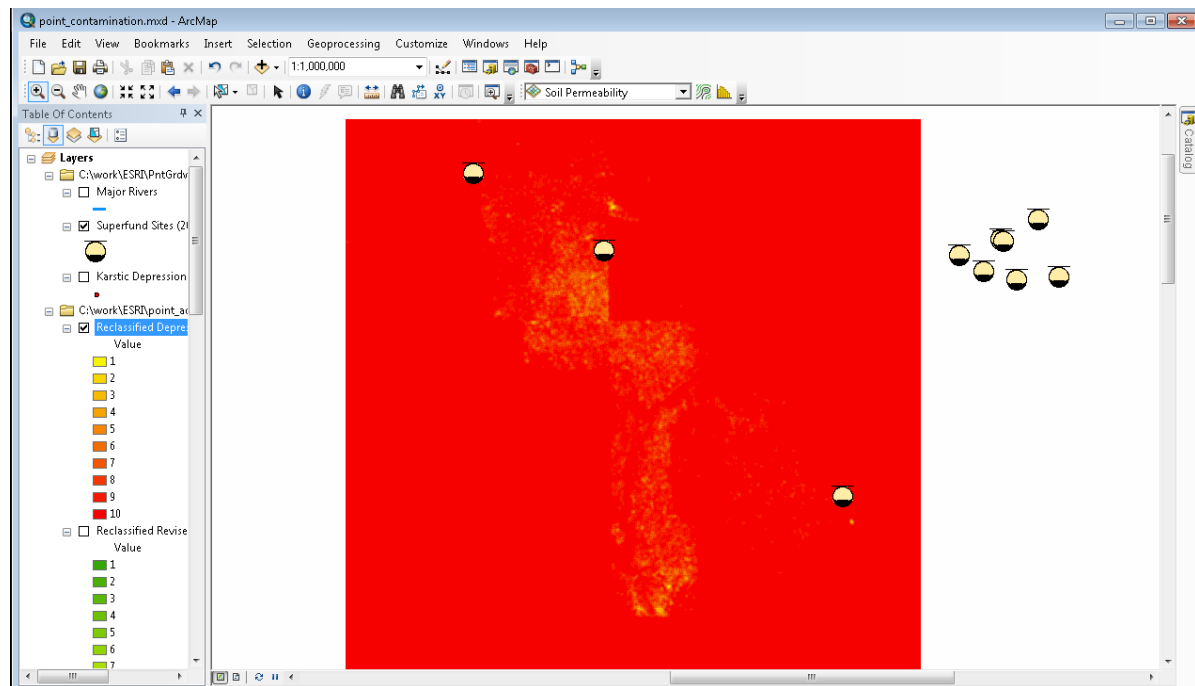


Figure 10. Map of reclassified depression density with Superfund sites overlaid

CALCULATE COST GRID

Now you are ready for the cost grid. You will calculate a new raster layer (grid) by adding the values of three raster layers. Spatial Analyst allows you to make calculations (map algebra) on a cell-by-cell basis. That is an important advantage of working with raster data over vector data.

- In the ArcToolbox Spatial Analyst Tools, select *Map Algebra » Raster Calculator*. Enter the following expression:

Reclassified Depression Density + Reclassified Soil Permeability + Reclassified Revised Thickness

- 2 Call the output raster *cost_grid* and click *OK* (figure 11).

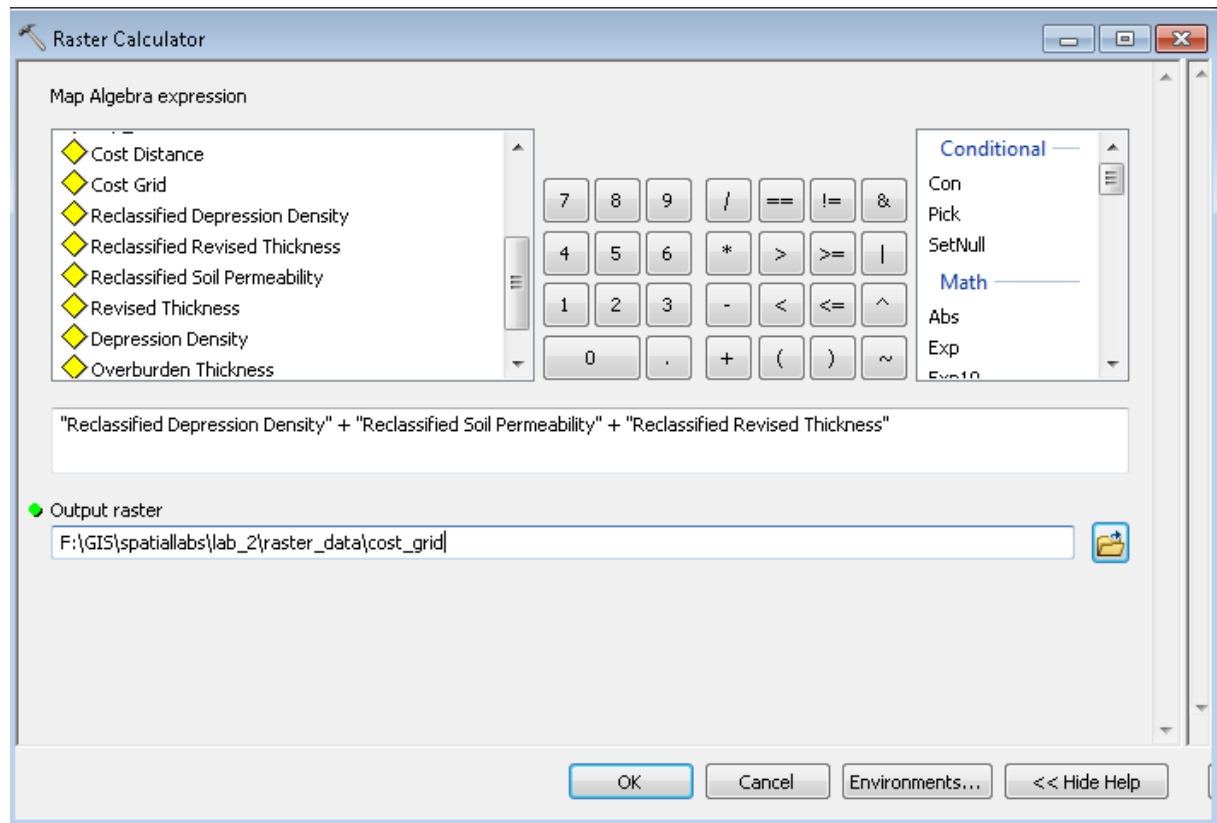


Figure 11. Using the Raster Calculator

- 3 Rename it *Cost Grid* in the table of contents.

- 4 Display it similarly to figure 12 (use the *Stretched* option under the *Symbology* tab).

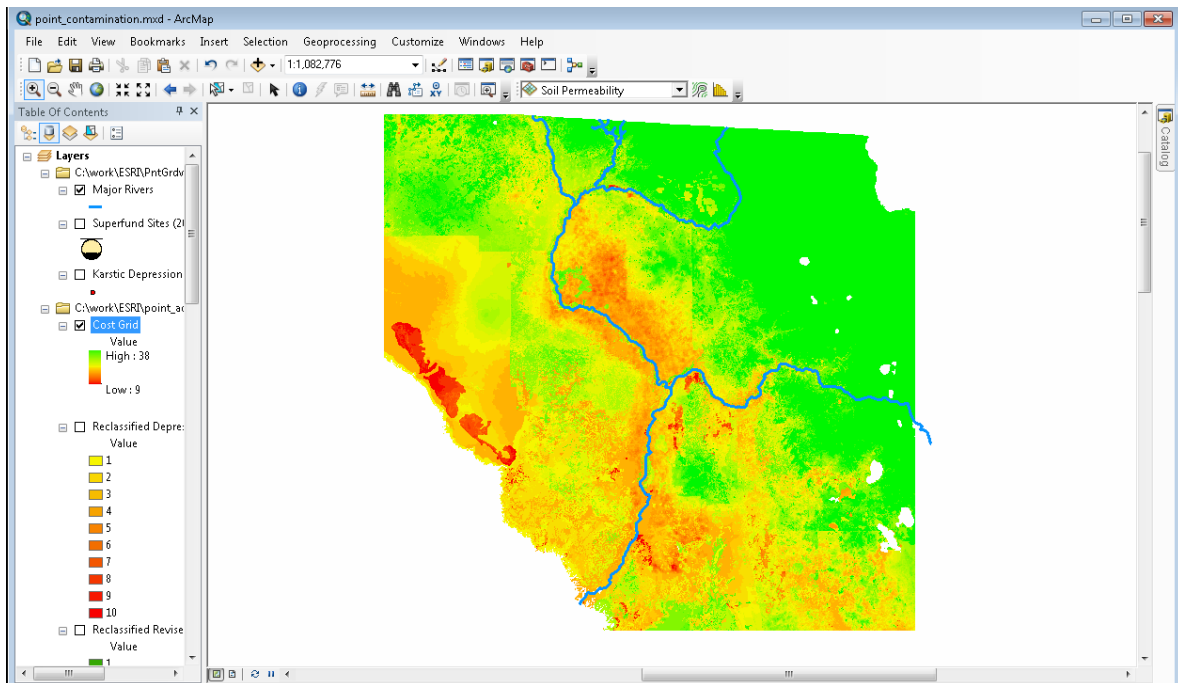


Figure 12. Map of the cost grid

CALCULATE COST WEIGHTED DISTANCE GRID

A cost-weighted distance function uses a cost raster to assign a value, calculated as the least accumulative cost of getting back to the source, to each cell of an output raster. In your project, a cost-weighted distance grid will provide you with values for each grid cell that show relative potential for contamination from designated sources (Superfund sites).

- 1 Locate the *Cost Distance* tool in ArcToolbox under *Spatial Analyst Tools* » *Distance*. Double-click to open the dialog box.

- 2 Enter *Superfund Sites* as feature source data and *Cost Grid* as cost raster. Save the output distance raster as *cost_distance* under *.../lab_2/raster_data* (figure 13).

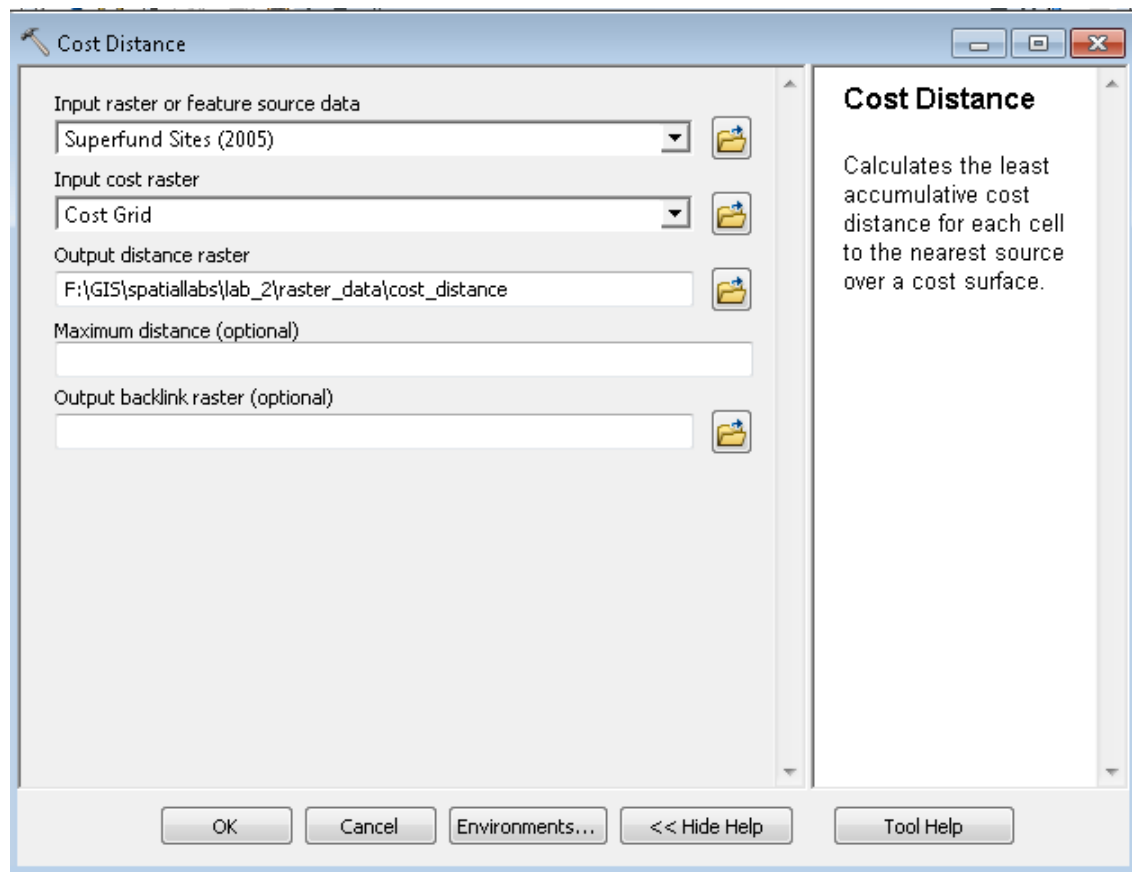


Figure 13. Using the Cost Distance tool

- 3 Click *OK* and wait. This process may take a while.

- 4 Rename it *Cost Distance* in the table of contents and display it stretched as in figure 14.

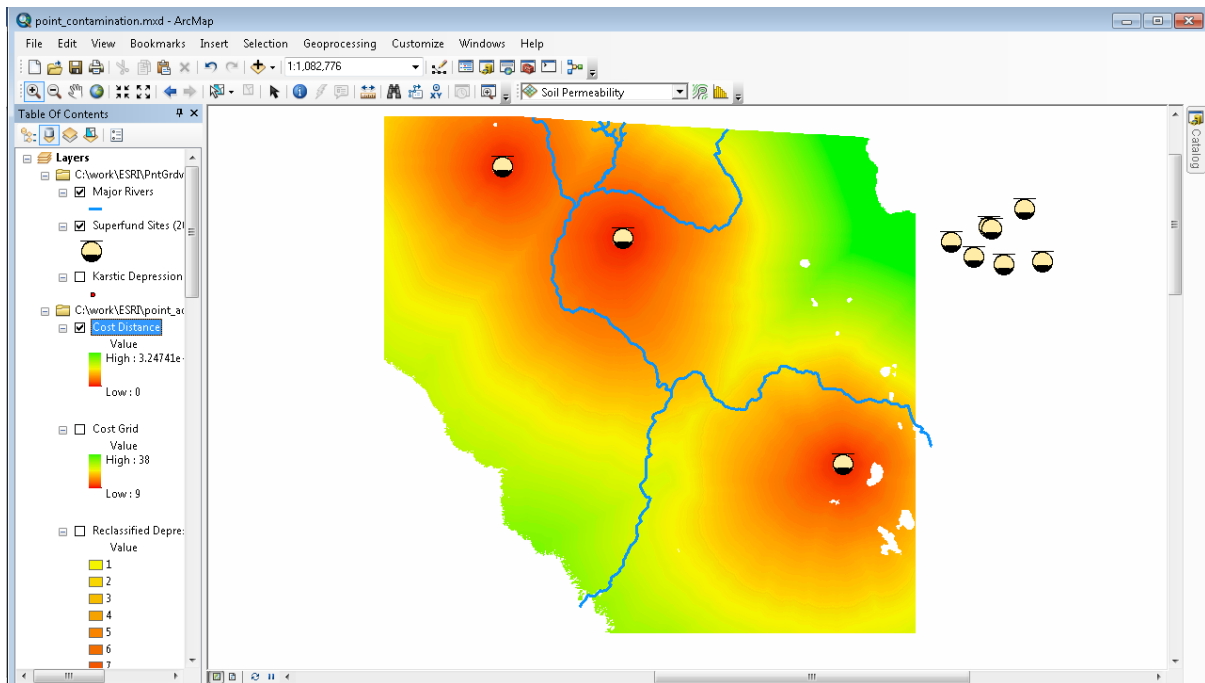


Figure 14. Map of the cost distance with Superfund sites overlaid

Areas with high potential of groundwater contamination from the Superfund sites are represented by low-cost distance values.

- 5 Create a layout that shows the Cost Distance grid, Superfund Sites, and Major Rivers. Label the three Superfund sites in the study area. Add a legend, scale, and north arrow.

Submit your work

Write a report assessing the point groundwater contamination potential in the study area. Address the following in your report:

- Discuss the applicability of GIS to the problem addressed in this exercise.
- What is the advantage of using raster data over vector data in this analysis? Do you think you could determine the areas of potential groundwater contamination using vector data?
- What would be the shortcomings of using a cost grid and cost-weighted distance grid in addressing this problem?
- Which parts of the study area present high risks of groundwater contamination? Based on the available data, where would you propose a landfill site? Why?

Create a layout that shows the Cost Distance grid, Superfund Sites, and Major Rivers. Label the three Superfund sites in the study area. Add a legend, scale, and north arrow. Export your map as an image and include it in your report.

Glossary

aquifer Geologic material that stores and transmits groundwater.

karst aquifer Type of aquifer that comprises soluble rocks such as limestone. Most groundwater storage and movement take place within the solutionally enlarged cavities and conduits within the rock.

Superfund sites U.S. hazardous waste sites on the National Priority List (NPL) of EPA's Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS).

Credits

Sources of supplied data

point_contamination.mxd, created by author.

raster_data\cost_distance, created by author.

raster_data\cost_grid, created by author.

raster_data\dep_ens, created by author.

raster_data\dep_dens_rcl, created by author.

raster_data\ov_thick_rcls, created by author.

raster_data\ovr_bur_thick, courtesy of Florida Geological Survey

raster_data\rev_thick, created by author.

raster_data\soil_perm, courtesy of Florida Geological Survey

raster_data\soil_perm_rcl, created by author.

vector_data\depressions.shp, created by author.

vector_data\haz97.shp, courtesy of Florida Department of Transportation

vector_data\maj_hydrology.shp, courtesy of Florida Geographic Data Library

vector_data\superfund_2005.shp, courtesy of Florida Geographic Data Library

Instructor resources

Updates for 2013 edition

This lab activity has been updated to work with ArcGIS 10.1.

Additional information

This lab complements two others: *Assessing Non-Point Groundwater Contamination: Florida Caves* and *Assessing Point Groundwater Contamination Potential: Florida Caves*.

Groundwater, the largest liquid freshwater reservoir of the hydrologic cycle, is under severe threat. Population growth and development bring not only a decline in this resource but also significant degradation of its quality. Point source contamination originating from readily identifiable sources, such as underground or aboveground waste disposal sites, landfills, and underground gasoline tanks, significantly threatens groundwater quality.

Contamination sources are especially critical for karst aquifers where groundwater storage and movement take place in enlarged cavities, conduits, and caves. Surficial karst features, such as sinkholes, provide direct avenues for contaminants to enter karst aquifers and continue spreading rapidly with little or no natural attenuation of the contaminant.

In this lab, GIS is used to assess contamination potential of the Floridan aquifer from three Superfund sites. The geospatial methodology applied in this project involves a number of raster data analyses using the Spatial Analyst extension of ArcGIS. Advanced raster analysis techniques such as reclassification, map algebra, conditional statements, and cost distance analysis are applied to a real-world environmental geology problem.

References

A brief explanation of karst aquifers and their environmental susceptibility can be found at the following websites:

igs.indiana.edu/Geology/karst/karstInIndiana/karstInIndiana04.cfm

Data information

Raster data layers

- Thickness of the Geologic Unit Overlying the Floridan Aquifer (Overburden Thickness): Prepared by the Florida Geological Survey by subtracting the top of the Floridan aquifer elevation raster layer from the digital elevation model (DEM)
- Soil Permeability: Prepared by the Florida Department of Environmental Protection by assigning permeability values (inch/hour) for each soil type

Vector data layers

- Superfund Sites: This dataset contains point locations for U.S. hazardous waste sites on the National Priority List of EPA's Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS). These sites are also known as Superfund sites. This point layer was created by the EPA in 2005.
- Karstic Depressions: This point layer represents a combination of two geospatial data sources:
 - Karstic Depressions Database: This geospatial database was created by the author based on the topographic depressions on 7.5-minute topographic quadrangles. Points indicate centroids of depressions (see home.earthlink.net/~denizman/research.html for more information).
 - Florida Geological Survey Sinkhole Database: This dataset represents a set of points for reported sinkhole events. These reported events have not been verified or validated as karst sinkholes by FGS. The coverage represents only a partial spatial representation of sinkholes in Florida, as most are reported from population centers.

Projection information for both data types:

- Projected coordinate system: Albers conical equal area (Florida Geographic Data Library)

Projection:	Albers
False_Easting:	400000.00000000
False_Northing:	0.00000000
Central_Meridian:	-84.00000000
Standard_Parallel_1:	24.00000000
Standard_Parallel_2:	31.50000000
Central_Parallel:	24.00000000
Linear unit:	Meter
- Geographic coordinate system: GCS_North_American_1983_HARN
- Datum: D_North_American_1983_HARN
- Prime meridian: Greenwich
- Angular unit: Degree