

Assessing Point Groundwater Contamination Potential

Florida caves

— by Can Denizman

Introduction

Problem

Where might caves in Florida be susceptible to potential point contamination sources such as hazardous material sites (HMS)? If there is leakage from these sites, which caves are more likely to be impacted?

Point contamination originates from readily identifiable contamination spots such as underground gasoline tanks, septic tanks, or industrial and municipal landfills. This lab assesses potential contamination of caves in Florida traceable to hazardous material sites.

Location

The study area is located along the Suwannee River, Florida.

Time to complete the lab

It should take approximately two hours for students to complete this lab.

Keywords: point groundwater contamination; karst aquifers; HMS; caves; vector analysis; XY table; table joins; spatial joins; spatial analysis; density; zonal statistics

Prerequisites

Students with intermediate GIS experience should be able to perform this assignment.

Data used in this lab

Raster data layers

- `cost_grid`: Raster layer describing the cost of contaminant infiltration (i.e., contamination potential) to the Floridan aquifer.
- Census county boundaries (U.S. Census Bureau)

Vector data layers

- Caves (prepared by Can Denizman for the Florida Geological Survey)

Other

- Locations of hazardous material sites in the study area as of 1997, provided in an Excel spreadsheet (Florida Department of Transportation)
- 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. An 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.

In this study, you will assess the susceptibility of the Floridan aquifer and caves in the study area to potential point contamination sources such as hazardous material sites.

The geographic information system (GIS) application for this project involves a number of vector and raster analyses and functions. The tasks to be completed are

- Create a point shapefile of hazardous material sites from an XY (latitude, longitude) table.
- Project the new shapefile.
- Perform a spatial join between the hazardous material sites and caves to determine which caves are closer to hazardous material sites.
- Create a density layer for the hazardous material sites.
- Summarize the density of hazardous material sites within the zones of the cost grid.

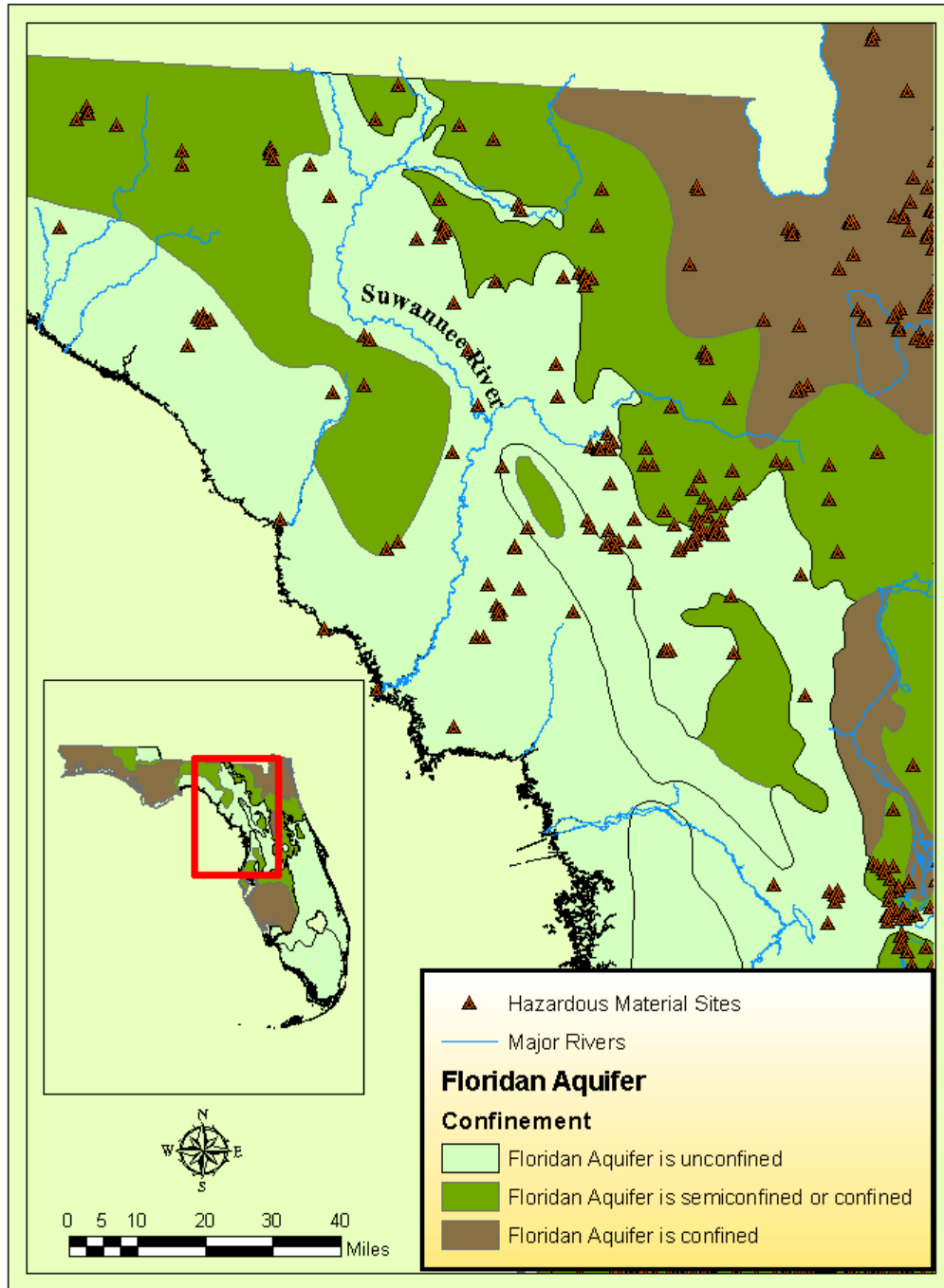


Figure 1. The study area in Suwannee River, Florida, comprising caves and aquifers

SET UP THE ANALYSIS ENVIRONMENT

- 1 Start ArcMap and open the map document *Hazardous_Material.mxd*.
- 2 Save the map document in your own folder using *Save As*.
- 3 Explore the data layers in the data frame.
- 4 Load the ArcGIS 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*.

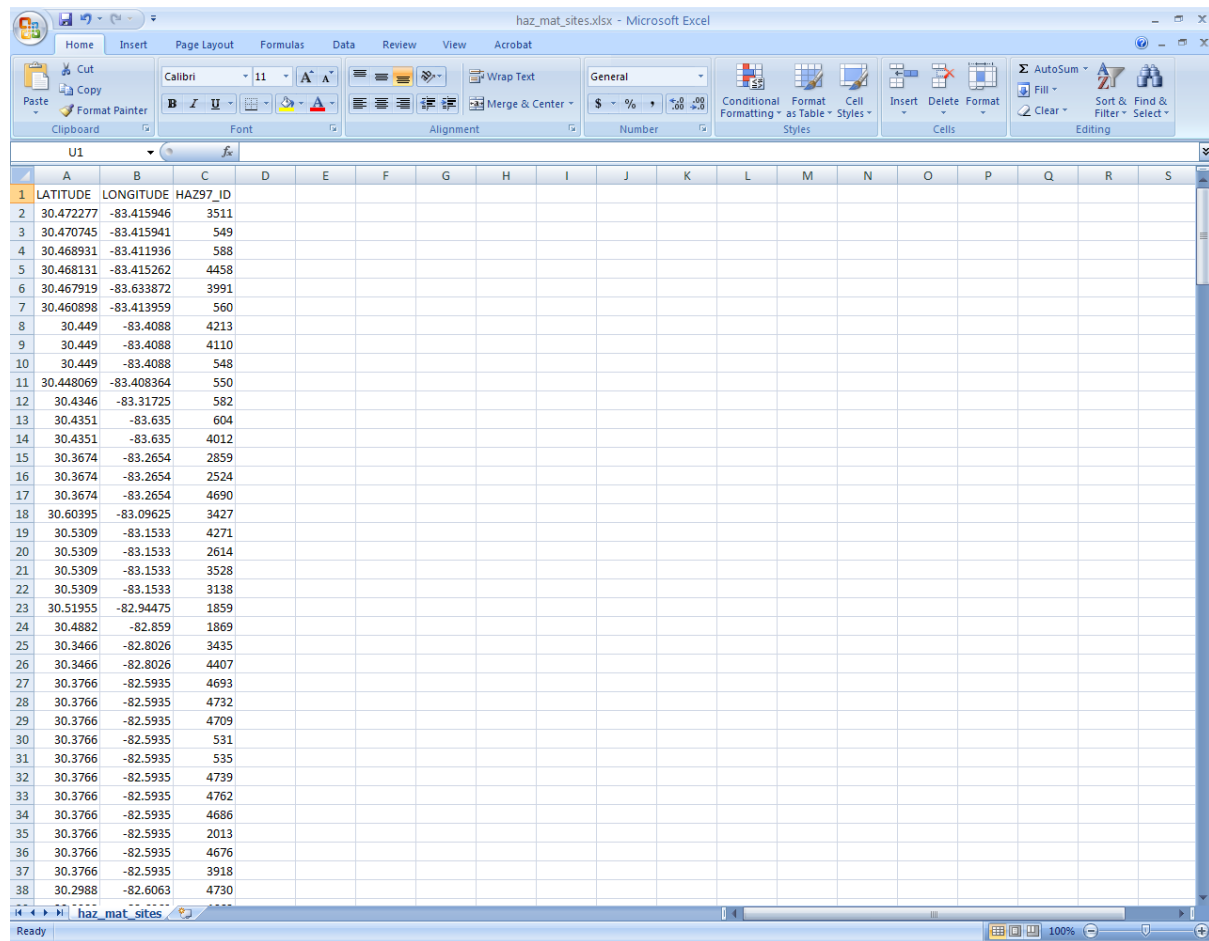
PREPARE DATA FOR SPATIAL JOIN

CREATE A POINT SHAPEFILE OF HAZARDOUS MATERIAL SITES FROM AN XY (LATITUDE, LONGITUDE) TABLE

You do not have a geospatial layer for the hazardous material sites (HMS). Create a point shapefile from an Excel spreadsheet of x,y (latitude, longitude) coordinates of HMS. First, create a tab-delimited text file of x,y values.

- 1 Start a Microsoft Office Excel session and open *haz_mat_sites.xlsx*.

Locations of hazardous material sites are given in decimal degrees. Each site is also assigned a HAZ97_ID unique identifier (figure 2). You will need that identifier later.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	LATITUDE	LONGITUDE	HAZ97_ID																
2	30.472277	-83.415946	3511																
3	30.470745	-83.415941	549																
4	30.468931	-83.411936	588																
5	30.468131	-83.415262	4458																
6	30.467919	-83.633872	3991																
7	30.460898	-83.413959	560																
8	30.449	-83.4088	4213																
9	30.449	-83.4088	4110																
10	30.449	-83.4088	548																
11	30.448069	-83.408364	550																
12	30.4346	-83.31725	582																
13	30.4351	-83.635	604																
14	30.4351	-83.635	4012																
15	30.3674	-83.2654	2859																
16	30.3674	-83.2654	2524																
17	30.3674	-83.2654	4690																
18	30.60395	-83.09625	3427																
19	30.5309	-83.1533	4271																
20	30.5309	-83.1533	2614																
21	30.5309	-83.1533	3528																
22	30.5309	-83.1533	3138																
23	30.51955	-82.94475	1859																
24	30.4882	-82.859	1869																
25	30.3466	-82.8026	3435																
26	30.3466	-82.8026	4407																
27	30.3766	-82.5935	4693																
28	30.3766	-82.5935	4732																
29	30.3766	-82.5935	4709																
30	30.3766	-82.5935	531																
31	30.3766	-82.5935	535																
32	30.3766	-82.5935	4739																
33	30.3766	-82.5935	4762																
34	30.3766	-82.5935	4686																
35	30.3766	-82.5935	2013																
36	30.3766	-82.5935	4676																
37	30.3766	-82.5935	3918																
38	30.2988	-82.6063	4730																

Figure 2. Excel file of hazardous material sites showing unique identifier HAZ97_ID

- 2 Save this file as a tab-delimited text file to make it accessible by ArcGIS:
 - a. Click *Save As*.
 - b. From the *Save as type* list, choose *Text (tab delimited)(*.txt)* and save it to your student folder.
 - c. Exit Excel when done.

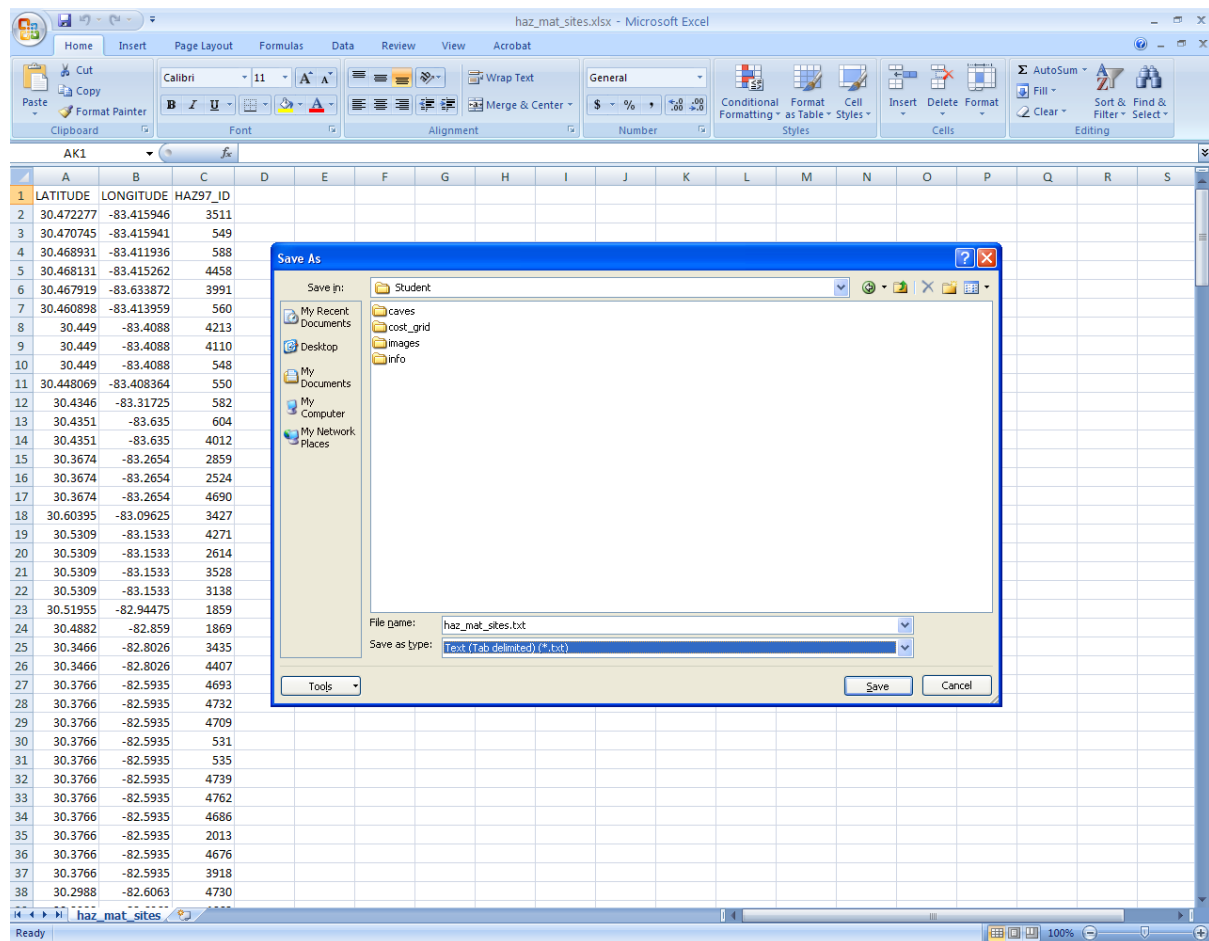


Figure 3. Saving as a tab-delimited text file in Excel

Now your HMS locations are stored in a text file with latitude and longitude values. You can create a feature class (a point shapefile) from these latitude and longitude values. You will need ArcCatalog to do that.

- 3 Click the *ArcCatalog* icon in the ArcMap document to start ArcCatalog. Navigate to the folder where the newly created text file is located.
- 4 Right-click the text file to create a feature class from the XY table. *Right-click* » *Create Feature Class* » *From XY Table*.

- 5 Specify the *Output* shapefile as *haz_mat_sites.shp* under your student folder (figure 4).

You need to define the coordinate system so the HMS file will display in the same projection as the other layers in the ArcMap project.

- 6 Click *Coordinate System of Input Coordinates » Geographic Coordinate Systems » North America » NAD 1983 HARN* (figure 5).
- 7 Click *OK*.
- 8 Click *OK* again to create the new shapefile.

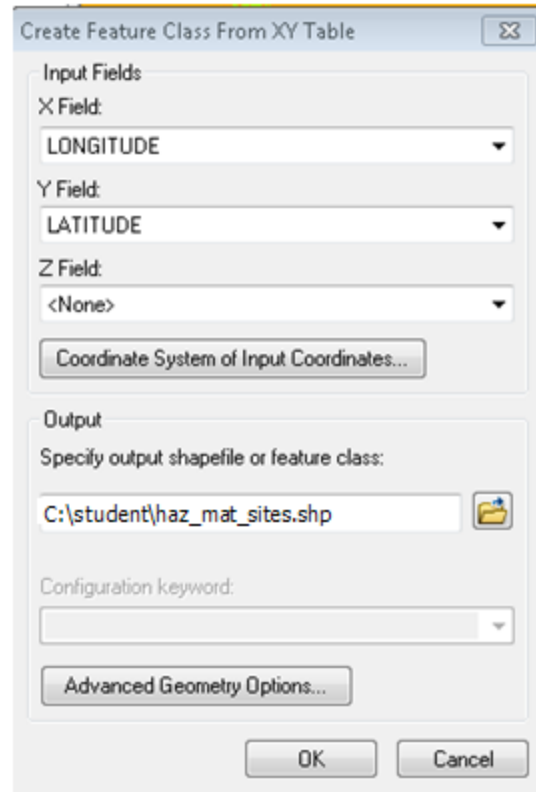


Figure 4. Creating a feature class from an XY table

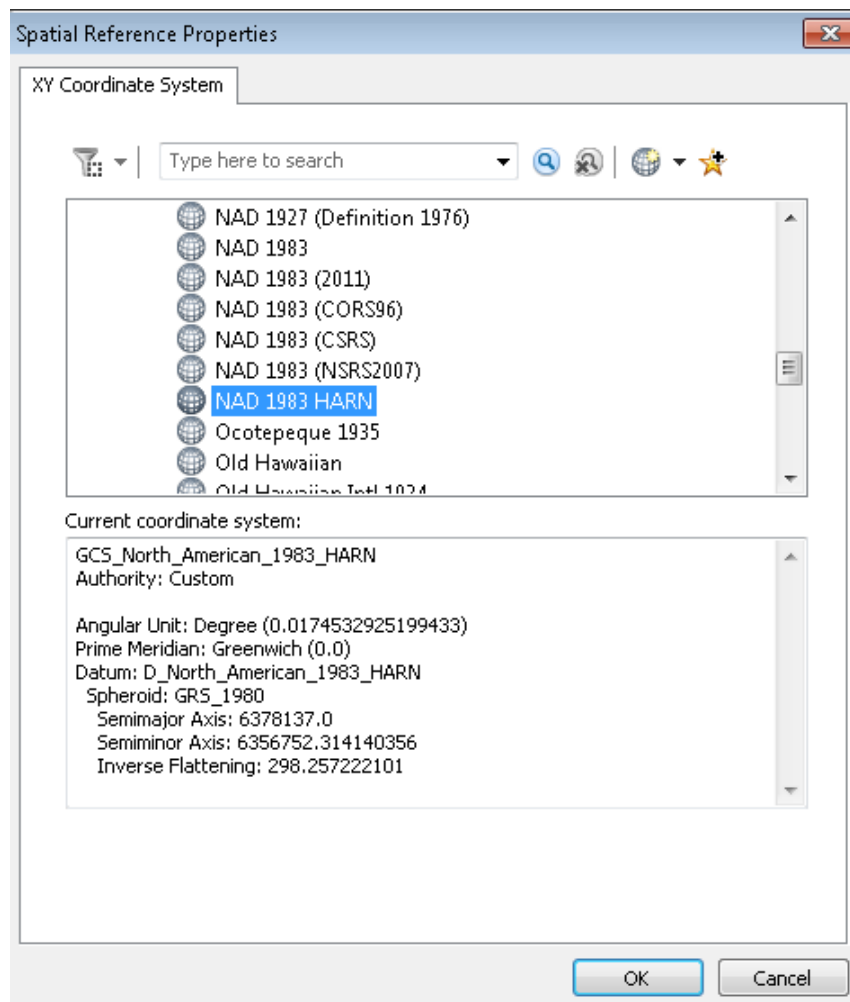


Figure 5. Defining the coordinate system of the hazardous material sites shapefile

- 9 Right-click your student folder and refresh it. There is a new shapefile named haz_mat_sites. Preview its geography and table in ArcCatalog. How many records (hazardous material sites) are there?

PROJECT THE NEW SHAPEFILE

The new shapefile does not have a projection. It would still be displayed in ArcMap, but for geospatial analyses it would be a good idea to project it to the same projection as the other layers. Here is how you can project this shapefile:

- 1 You need ArcToolbox. Click its icon in the ArcCatalog menu and activate it. How can you find the Project tool?

You can visually search for it under each folder in ArcToolbox, or you can use the Search tool.

- 2 Click *Tools* and type *Project* in the keyword window (figure 6). There is a tool called *Project (data management)*, which looks promising. Click the *Project (data management)* tool to activate it.
- 3 Click and drag the *haz_mat_sites* shapefile in your Catalog tree to the *Input Dataset or Feature Class* window (alternatively, you can browse and locate this shapefile using the folder icon beside the input window). Name the new shapefile *haz_mat_sites_Project* and make sure it is saved to your student folder.

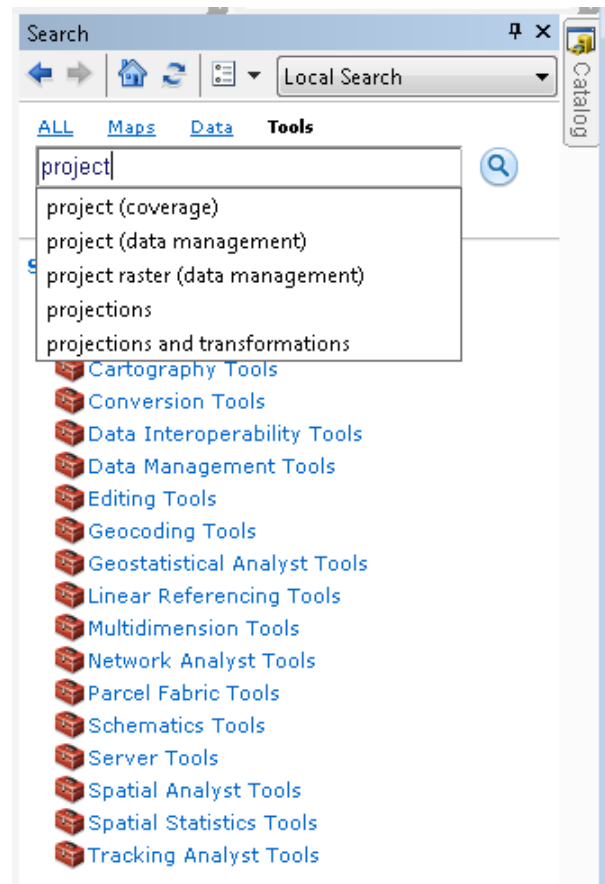


Figure 6. Searching for the Project tool

You need to specify the output coordinate system. Import it from an existing geospatial data layer in your student folder.

- 4 Click the icon beside the *Output Coordinate System* window. A new window called *Spatial Reference Properties* opens. Import by clicking on the dropdown next to the small globe shaped icon and choosing *Import*. Then browse to your student folder. Select *cost_grid* as the dataset from which projection information will be imported and click *Add* (figure 7). Click *OK*, then click *OK* again to initiate the projection.

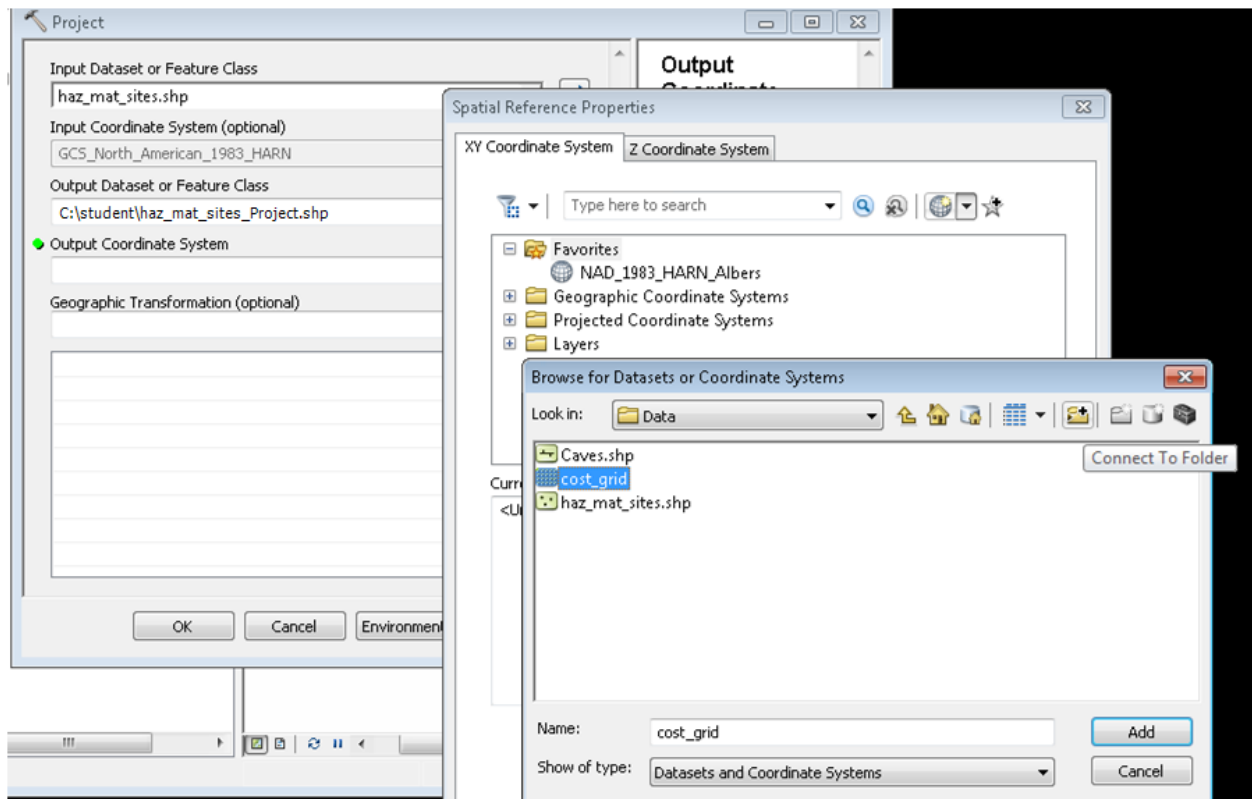


Figure 7. Projecting the hazardous material sites using an imported coordinate system

- 5 Refresh your student folder to see the new shapefile named `haz_mat_sites_Project`.
You have created a shapefile from an XY table and projected it.
- 6 Close ArcCatalog and go back to your ArcMap document (`Hazardous_Material.mxd`).
- 7 Add `haz_mat_sites_Project` to the ArcMap document and rename it in the table of contents as *Hazardous Material Sites*.

PERFORM A SPATIAL JOIN BETWEEN THE CAVES AND HMS

A spatial join allows you to join attributes from two geospatial layers based on the location of spatial features. You will perform two spatial joins to find

- The closest HMS to each cave
- The number of HMSs closest to each cave

DETERMINE THE CLOSEST HMS TO EACH CAVE

This is a simple distance join. You will start from the target layer (caves) and find the closest HMS for each cave as follows:

- 1 Right-click *Caves* » *Joins and Relates* » *Join*. Select *Join data from another layer based on spatial location* (figure 8). Use *Hazardous Material Sites* as the layer to join with this layer. Select the choice that says that each line will be given all the attributes of the point that is closest to it and a distance field showing how close that point is. Make sure the new shapefile (Join_Output.shp) is saved in your student folder.

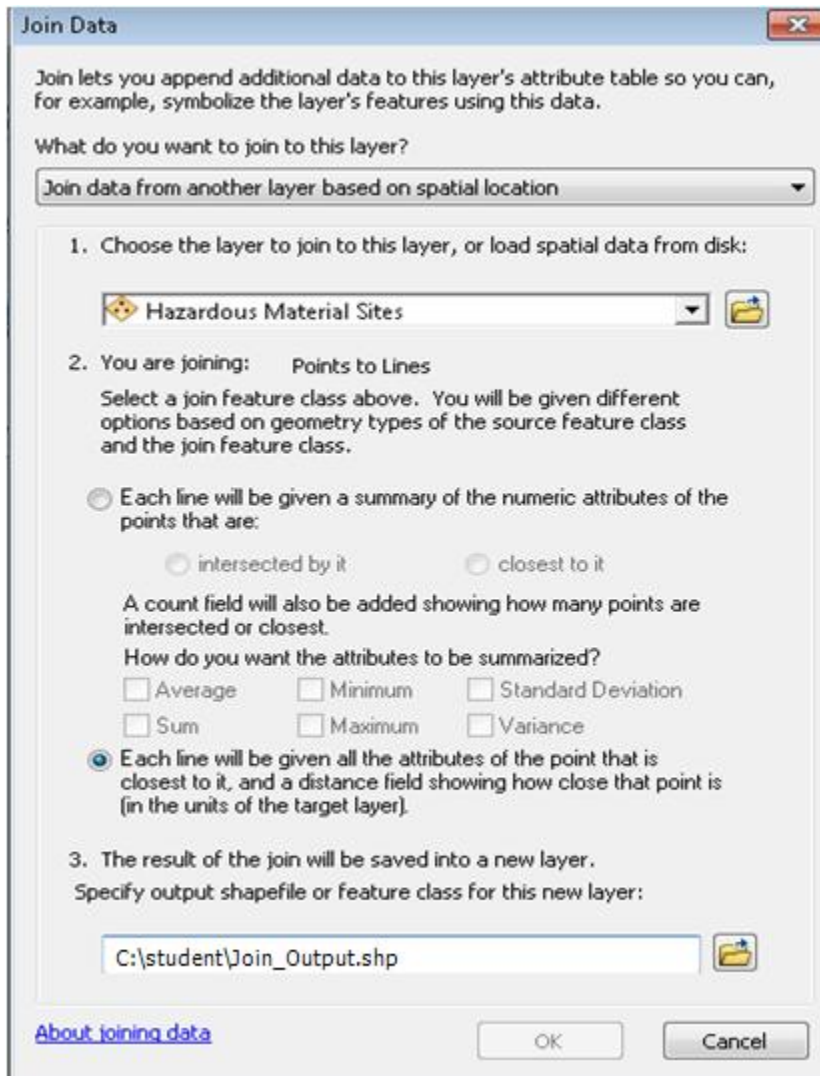


Figure 8. Using a spatial join to find the closest hazardous material site for each cave

- 2 Now, you have a new shapefile in your map document that shows caves. Rename it in the Table of Contents to *Simple Distance Join* and explore its attribute table.

- When you look in the attribute table, you notice that there is one HMS for each cave, with its distance in the units of the *Caves* shapefile (meters) (figure 9). However, you do not have any information about each HMS other than its HAZ97_ID. Detailed HMS information is provided in a text file (*haz_mat_sites_lookup_table.txt*). You can join that table to the feature attribute table of the *Simple Distance Join* shapefile.

FID	Shape	haz_mat_sites_project_FID	Cave	FID_2	LATITUDE	LONGITUDE	HAZ97_ID	Distance
0	Polyline	12	Madison Blue	10	30.4346	-83.31725	582	7535.395918
1	Polyline	14	Morgan	13	30.3674	-83.2654	2859	8082.483602
2	Polyline	17	Suwanacoochee	13	30.3674	-83.2654	2859	8902.329348
3	Polyline	1	Blue Hole	46	30.00435	-82.710449	4721	5239.294993
4	Polyline	3	Cathedral-Falmouth	65	30.276	-83.0534	1074	6061.308994
5	Polyline	10	Little River	74	30.0361	-82.9288	2379	5090.177759
6	Polyline	2	Bonnet	93	30.067516	-83.185951	3493	7727.985469
7	Polyline	7	Green	93	30.067516	-83.185951	3493	6949.994859
8	Polyline	11	Luraville	93	30.067516	-83.185951	3493	5020.22367
9	Polyline	15	Peacock	93	30.067516	-83.185951	3493	7932.255773
10	Polyline	18	Telford	93	30.067516	-83.185951	3493	4722.905863
11	Polyline	4	Convict	94	30.05885	-83.171653	585	7627.868315
12	Polyline	5	Cow	94	30.05885	-83.171653	585	7474.962035
13	Polyline	9	Hornsby	119	29.8521	-82.5882	4683	227.953809
14	Polyline	6	Ginnie	125	29.827	-82.6279	4706	6969.723347
15	Polyline	0	Alachua	154	29.78535	-82.49575	3796	1976.130349
16	Polyline	8	Hart	235	29.816	-82.8184	566	13441.438203
17	Polyline	16	Rock Bluff	237	29.818	-82.9685	4652	5162.056428
18	Polyline	13	Manatee	253	29.4206	-82.9135	4642	7704.928852

Figure 9. Attribute table showing the closest hazardous material site for each cave

JOIN TABLES

- Add *haz_mat_sites_lookup_table.txt* to the ArcMap document using the *Add Data* icon.
- Open the table and compare it with the attribute table of the *Simple Distance Join* shapefile. What is the common item?

To perform a table join, you need a common item in both tables. In this case, HAZ97_ID is your common item.

- 3 Join the lookup table to your shapefile attribute table (target table). Right-click *Simple Distance Join* and perform a table join with the lookup table (figures 10 and 11). Use HAZ97_ID for both join fields and the lookup table as the table to join to this layer.

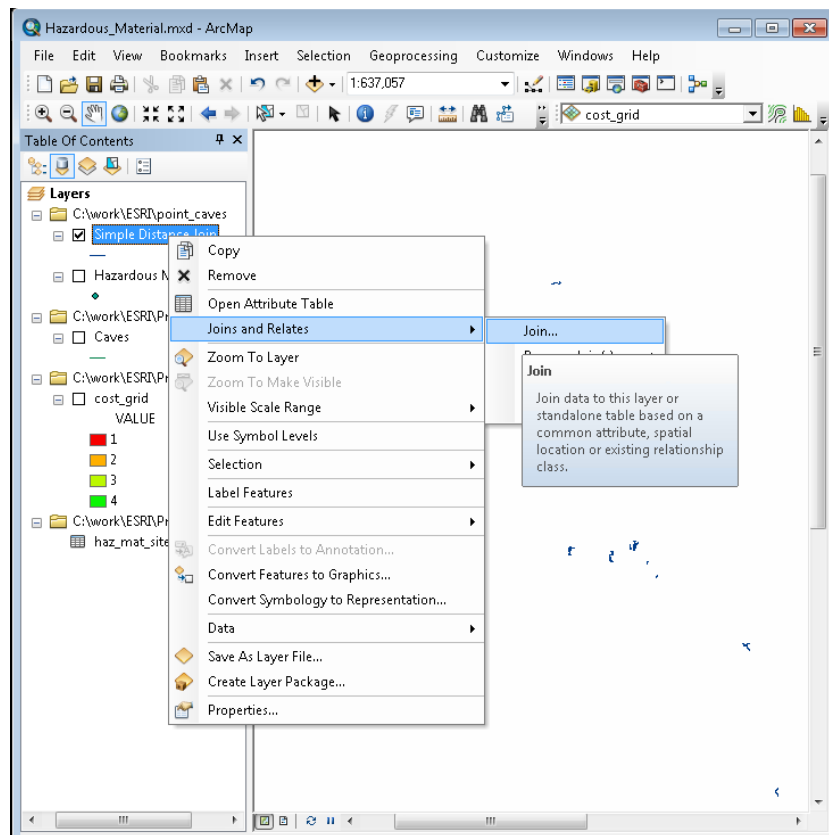


Figure 10. Locating the Join tool

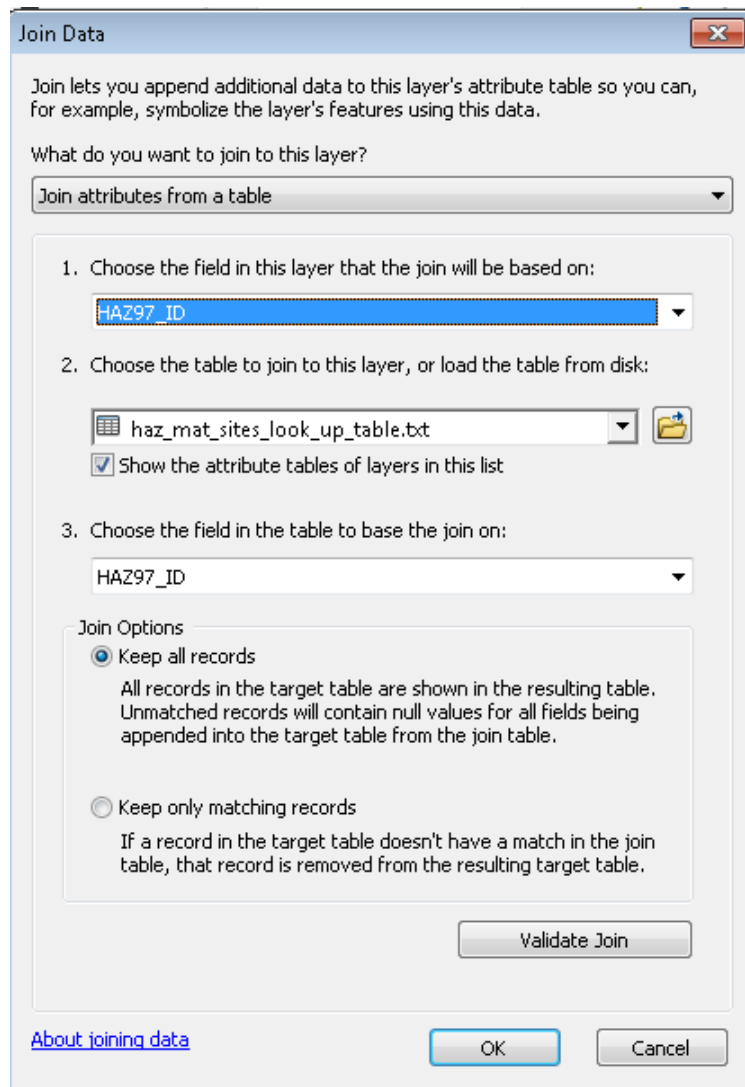


Figure 11. Using a table join to join the hazardous material sites lookup table with the Simple Distance Join shapefile

- 4 Explore the attribute table of *Simple Distance Join*. Locate the names and distances of closest HMS to the following caves: Madison Blue, Luraville, Peacock, Little River, Manatee, and Hart.

Question 1: Which cave has the closest HMS?

Question 2: Which cave's closest HMS is farthest?

DETERMINE THE NUMBER OF HMS CLOSEST TO EACH CAVE

This operation involves a summarized distance spatial join. You will determine how many hazardous material sites are near each cave as follows:

- 1 Right-click *Caves* » *Joins and Relates* » *Join* » *Join data from another layer based on spatial location* (figure 12). Choose *Hazardous Material Sites* as the layer to join to this layer. Select the buttons that say *Each line will be given a summary of the numeric attributes of the points that are and closest to it*. Check the box labeled *Sum*. Make sure the new shapefile (*Join_Output_2.shp*) is saved in your student folder.

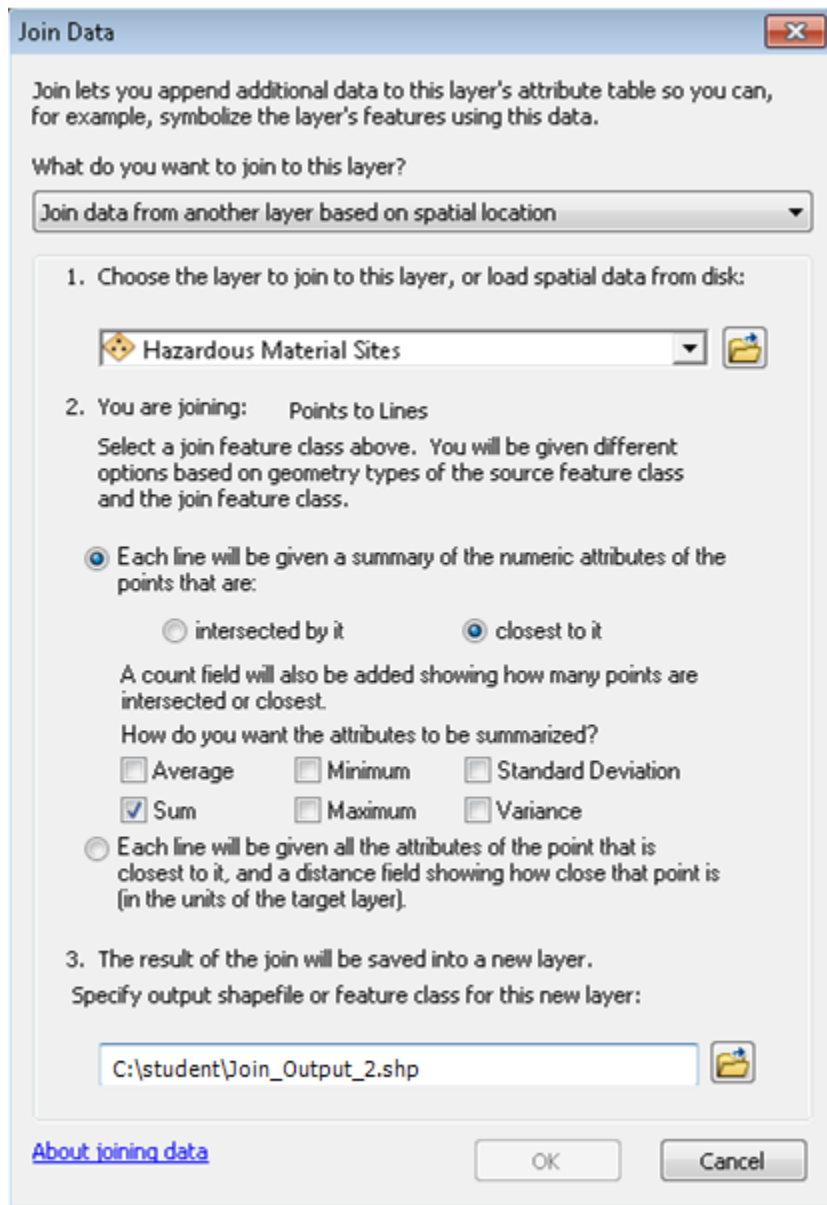


Figure 12. Using the Join tool to determine how many hazardous material sites there are near each cave

- Rename the new shapefile (Join_Output_2) *Summarized Distance Join* in the table of contents and explore its attribute table (figure 13).

FID	Shape	haz_mat_sites_project_FID	Cave	Count	Sum_LATITU	Sum_LONGIT	Sum_HAZ97
0	Polyline	0	Alachua	105	3124.096105	-8648.582069	299829
1	Polyline	1	Blue Hole	29	877.56979	-2395.143775	97304
2	Polyline	2	Bonnet	0	0	0	0
3	Polyline	3	Cathedral-Falmouth	17	515.510041	-1410.464954	44161
4	Polyline	4	Convict	5	149.9838	-415.7135	8070
5	Polyline	5	Cow	0	0	0	0
6	Polyline	6	Ginnie	0	0	0	0
7	Polyline	7	Green	10	300.799664	-835.58014	16364
8	Polyline	8	Hart	28	830.068131	-2320.377913	101788
9	Polyline	9	Hornsby	12	358.030011	-991.137885	50463
10	Polyline	10	Little River	11	329.9729	-911.9402	46487
11	Polyline	11	Luraville	0	0	0	0
12	Polyline	12	Madison Blue	18	548.63632	-1500.63838	45254
13	Polyline	13	Manatee	21	618.095068	-1740.407749	79430
14	Polyline	14	Morgan	3	91.1022	-249.7962	10073
15	Polyline	15	Peacock	0	0	0	0
16	Polyline	16	Rock Bluff	10	297.8875	-828.5987	46859
17	Polyline	17	Suwanacoochee	0	0	0	0
18	Polyline	18	Telford	2	60.126366	-166.357604	4078

Figure 13. Exploring the attribute table of the Summarized Distance Join shapefile

Numeric fields—latitude, longitude, and so on—were summarized in this process and don’t really mean anything. You are interested in Count, which shows the number of closest HMSs for each cave.

Question 3: *How many of the HMSs are closest to Manatee Cave?*

Question 4: *Which cave has the highest number of HMSs closest to it?*

Question 5: *Which cave has the lowest number of caves closest to it?*

ZONAL STATISTICS FOR HMS

You have determined the spatial relationship between the caves and HMSs in the study area. How can you determine the risk of groundwater contamination in the Floridan aquifer from HMS sites?

A general susceptibility status of the Floridan aquifer to surficial contamination is represented by a cost grid that was prepared based on the soil permeability, thickness of the confining geologic unit above the Floridan aquifer, and on sinkhole (also called depression) density. A low value cost indicates relative ease of contaminant infiltration to the Floridan aquifer, whereas a high cost value represents better protection of the aquifer from surficial contaminants.

You can determine the HMS distribution within the zones (values) of the `cost_grid` using Zonal Statistics. To perform this analysis, you will need to create a density layer for the HMS points. Add `cost_grid` from your student folder if it is not in the map document.

SETTING UP THE ANALYSIS ENVIRONMENT

- 1 Click the *Geoprocessing* pull-down menu and select *Environments*. Click the *Workspace* tab and set your working directory as the current workspace and scratch workspace. On the *Raster Analysis* tab, set `cost_grid` to the *Mask Grid*.
- 2 On the *Processing Extent* tab, set the *Snap Raster* to `cost_grid`.
- 3 On the *Raster Analysis* tab, set *Cell Size* to *Same as layer cost_grid* (figure 14).

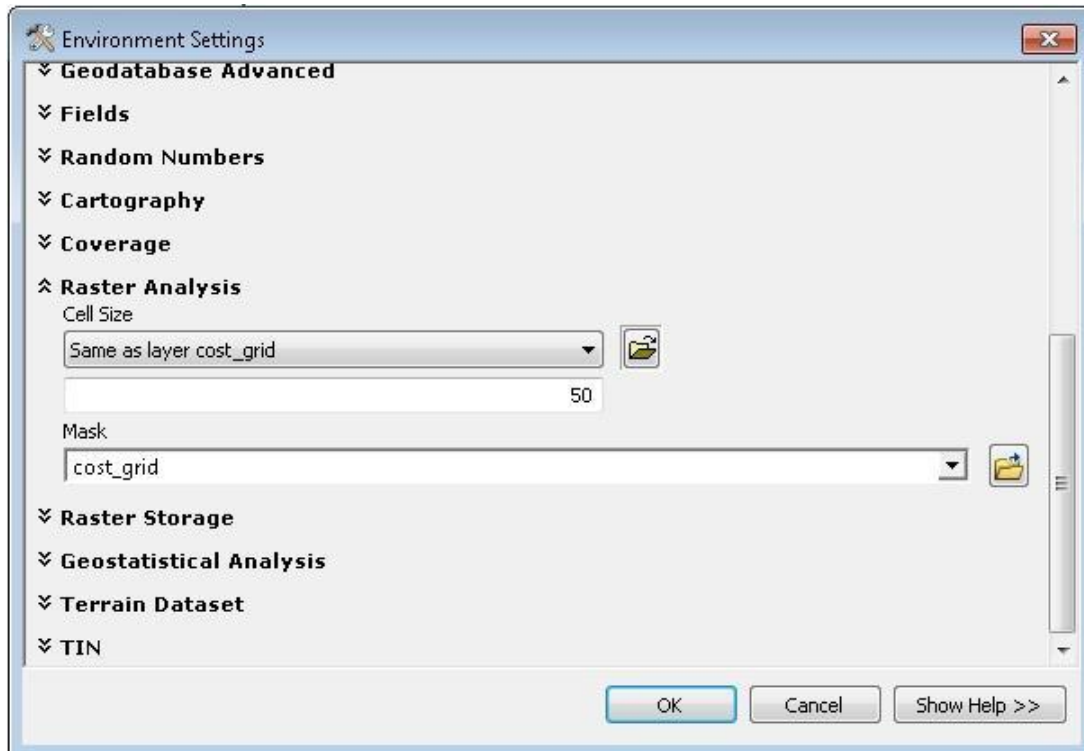


Figure 14. Setting the analysis environment

- 4 Click *OK* to close the *Options* window.

CREATE A DENSITY LAYER FOR THE HMS POINTS

The Density function of Spatial Analyst allows you to create a continuous density surface from a set of input features. In your study, you will create a density surface that represents a magnitude per unit area from the points of hazardous material sites. The calculation will use a kernel function to fit a smoothly tapered surface to each point.

1 Select *Density* » *Kernel Density* from *Spatial Analyst Tools* in *ArcToolbox* (figure 15):

- Input point or polyline features: Hazardous Material Sites
- Population field: NONE
- Output raster: Save as Density in your student workspace
- Output cell size: 50
- Search radius: 10000
- Area units: SQUARE_KILOMETERS

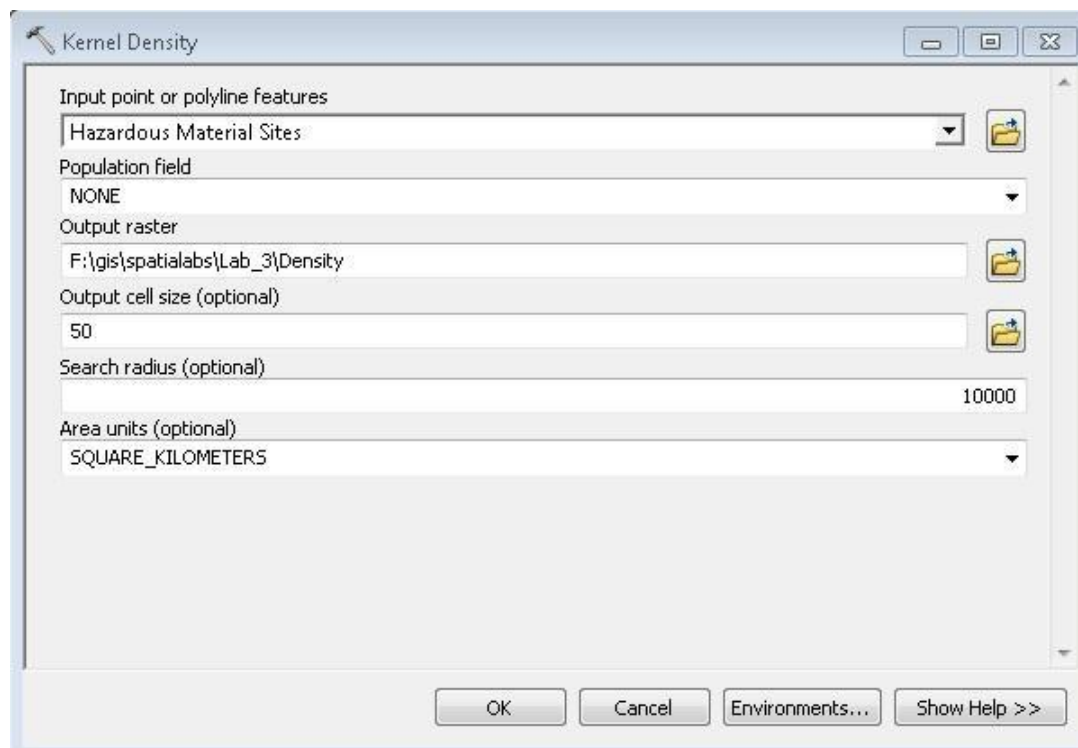


Figure 15.. Using the Kernel Density tool

2 Click *OK* to create the density layer.

The density layer you have created displays the number of HMS sites for each square kilometer. The spatial resolution of the layer is 50 meters.

CREATE A ZONAL HISTOGRAM

To compare the HMS density within the zones of cost_grid, you need to perform a zonal statistics operation in Spatial Analyst.

1 Select *Zonal » Zonal Statistics as Table* from *Spatial Analyst Tools* in ArcToolbox (figure 16):

- Input raster or feature zone data: cost_grid
- Zone field: VALUE
- Input value raster: Density of Hazardous Material Sites
- Statistics type: Sum
- Output table: .../student/zstats.dbf

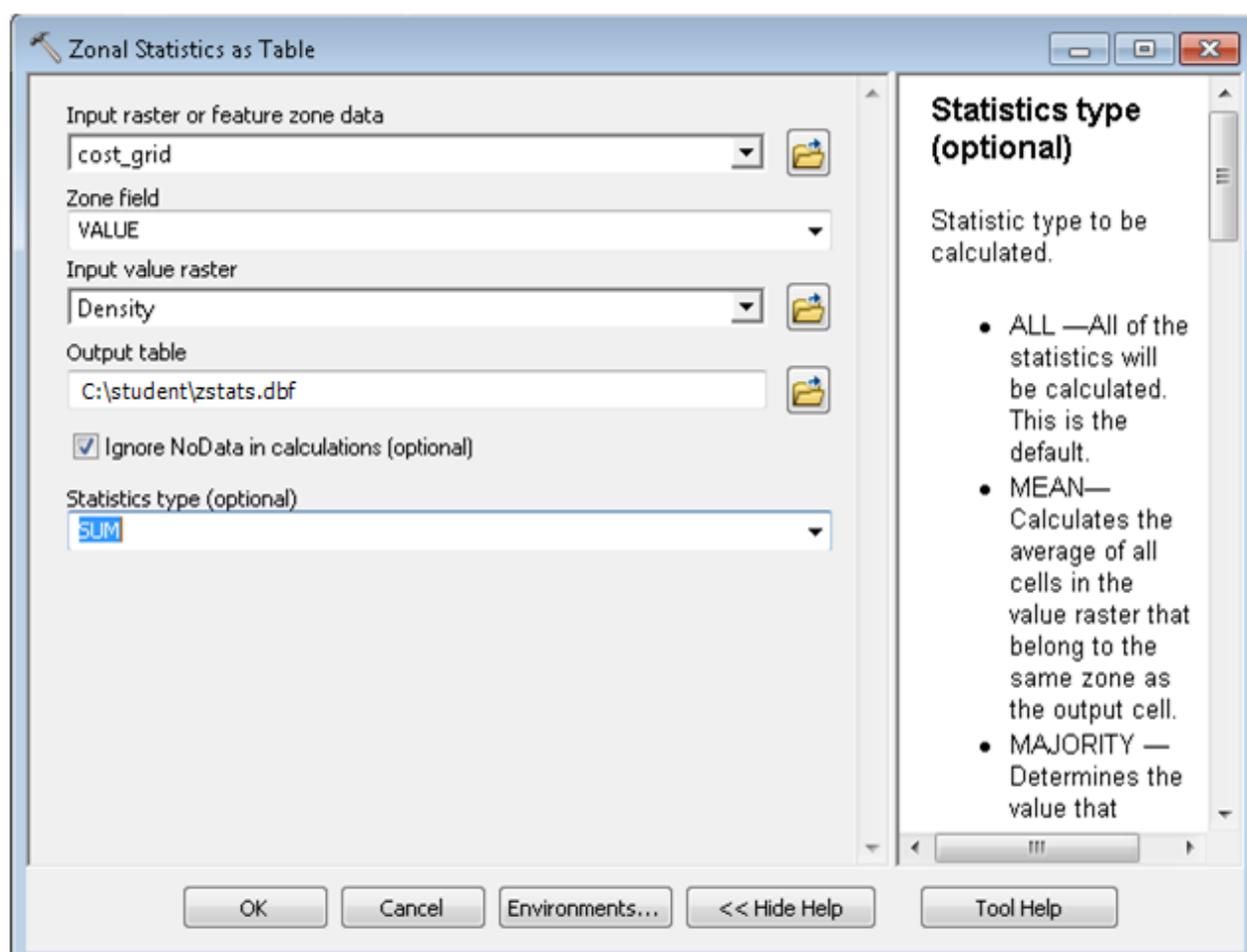


Figure 16. Using Zonal Statistics as Table to compare hazardous material site density within the zones of groundwater contamination potential

2 Click *OK*.

You have a zonal statistics table that shows sums of HMS density within the zones (values) of the cost_grid.

- Close the table and change the chart's title to something more meaningful such as Hazardous Material Site Density and Zones of Groundwater Contamination Potential. Make a histogram of the results by opening the attribute table, selecting *Table Options* » *Create Graph*, and choosing Vertical Bar from the *Graph Type* options.

You may also change the legend of the chart as follows:

- Very high
- High
- Medium
- Low

- Print and interpret the chart (figure 17).

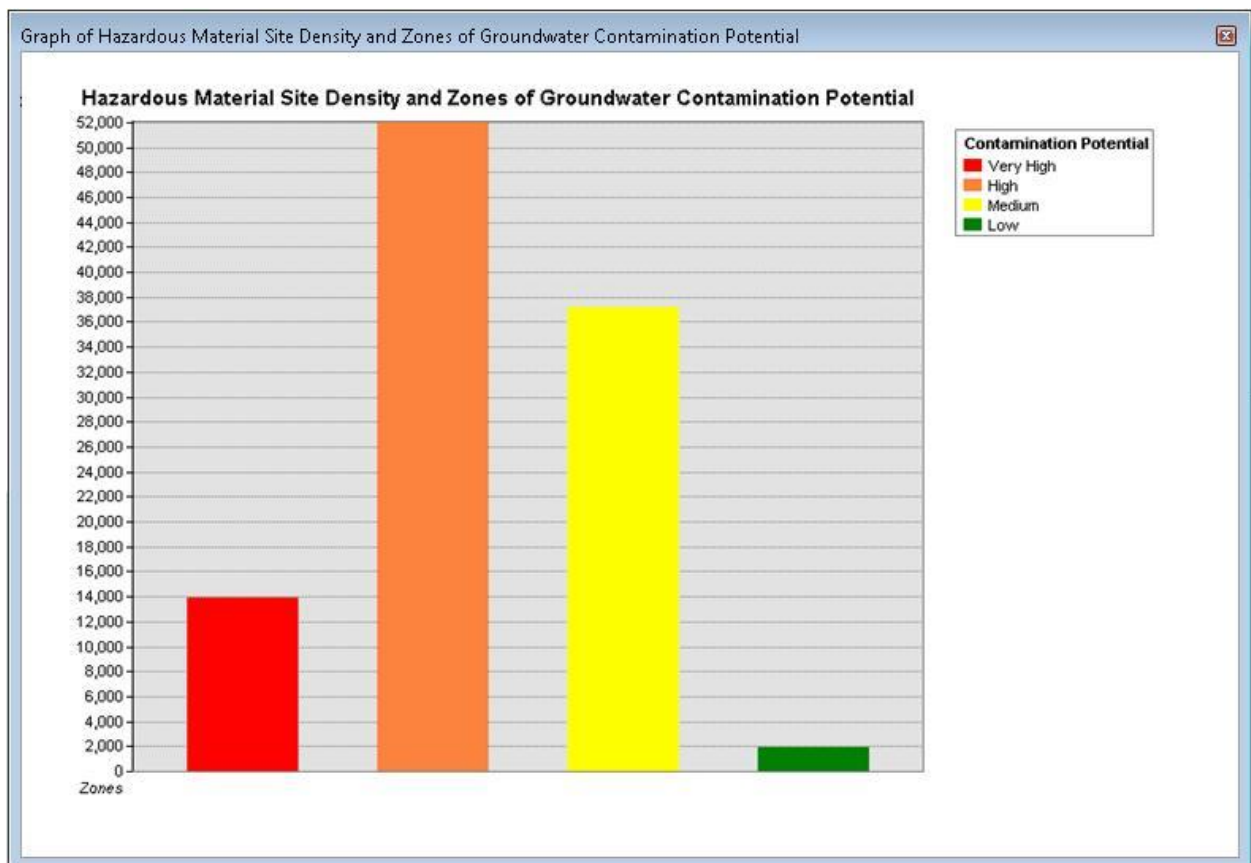


Figure 17. Histogram showing hazardous material site density and zones of groundwater contamination potential

Question 6: Which groundwater contamination potential zone(s) has the highest density of HMS?

Question 7: How do you assess the potential for contamination from HMS for the Floridan aquifer?

Submit your work

Submit your answers to the questions in the activity.

Separately, write a report assessing the point contamination potential in the study area. Address the following in your report:

- Based on your calculations, which caves are more susceptible to contamination originating from hazardous materials sites?
- What other spatial information might help more accurately assess the potential for contamination of caves?

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.

Credits

Sources of supplied data

Caves.shp, created by author.

cost_grid, created by author.

haz_mat_sites.xlsx, courtesy of Florida Department of Transportation

haz_mat_sites.shp, courtesy of Florida Department of Transportation

haz_mat_sites.txt.xml, courtesy of Florida Department of Transportation

haz_mat_sites_look_up_table.tx, courtesy of Florida Department of Transportation

Hazardous_Material.mxd, created by author.

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 Nonpoint Groundwater Contamination: Florida caves* and *Assessing Point Groundwater Contamination Potential: The Floridan aquifer*.

Groundwater, the largest liquid freshwater reservoir of the hydrologic cycle, has experienced severe threats in terms of its quality and quantity. Population growth and development result not only in groundwater resource decline but also in 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, causes significant impact to 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 software is used to assess contamination potential of the Floridan aquifer and caves in the study area from hazardous material sites. The geospatial methodology applied in this project includes feature class creation from an XY table, spatial joins, and zonal statistics using the Spatial Analyst extension of ArcGIS.

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

This study is based on spatial data about caves, HMS, and contamination potential for the Floridan aquifer.

Raster data layers

- **cost_grid:** This raster layer describes the cost of contaminant infiltration (i.e., contamination potential) to the Floridan aquifer. Low values indicate relatively easy access of the surficial contaminants to the aquifer, whereas high values describe better isolation of the Floridan aquifer from point contamination sources. The cost grid was generated based on the thickness of the overlying impermeable or semipermeable geologic unit above the Floridan aquifer, soil permeability, and on sinkhole (also called depression) density.

Vector data layers

- **Caves:** The polyline cave shapefile was generated by digitizing hard-copy maps of 19 phreatic (below the groundwater table) caves. Original cave maps were prepared by various cave divers during numerous cave-diving expeditions.

Other

- Locations of hazardous material sites in the study area as of 1997 are provided in Excel spreadsheet format. The dataset was prepared by the Florida Department of Transportation.

Projection information for both data types are as follows:

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