Resource materials for a GIS spatial analysis course

By Gary L. Raines[1]

Open-File Report 01-221
Version 1.0

2001

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or with the North American Stratigraphic Code. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Manuscript approved ###, 2001

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

1. U.S. Geological Survey, Reno, NV 89557

Carlin Exercise

Introduction

This exercise is intended to guide a user through the process of creating a weights-of-evidence (WofE), fuzzy-logic, and two neural-network models using ArcSDM, which is available at http://ntserv.gis.nrcan.gc.ca/sdm/. The user is assumed to have a working knowledge of Arcview, the Spatial Analyst extension, and ArcSDM. All of the materials needed for this exercise are contained in the Carlin zip file. The files in this zip file will extract into a folder called Carlin. If you are copying the Carlin folder from a CD-ROM source, it may be necessary to change the read/write permissions after copying the folder to your disk. To do this, copy the Carlin folder from the source to a root folder. To have appropriate read-write permissions on the files and grids, find the clear.bat file in the carlin folder and double click it to run it. This will change the permissions so you can use the files.

The data that is provided in the Carlin folder is to be used for modeling of Carlin deposits of central Nevada. These data are purposely selected to provide simple evidential layers for learning about the ArcSDM tools, not necessarily to provide the best model of these deposits. This document summarizes the Arcview themes and APR in the Carlin folder. The processing steps to create a WofE model are discussed in detail. Guidance for fuzzy-logic and neural-network models are provided for use after completion of the WofE model. The data source for this exercise is Raines, Sawatzky, and Connors (1996). The user should review the users manual provided with the ArcSDM software to better understand the various menus.

The WofE model is discussed in detail as it provides a foundation for many of the decisions necessary to complete a fuzzy-logic or neural-network model. Fuzzy membership values are often a useful approach to reclassification of categorical data in the neural-network model, as well as - for controlling the number of classes that the neural network has to deal with. The number of classes can significantly influence the time it takes for the neural network to complete classification.

The models are primarily built using geology and antimony evidence. For the WofE model, guidance is given for using proximity to faults as evidence. The following additional data sets are provided for creating models that are more complex: multi-element stream sediment geochemistry, gravity, magnetics, and gamma ray (uranium, thorium, and potassium).

It may sometimes be necessary to change the paths within the carlin.apr. When first used the paths should be Path:"/carlin/. Once you have saved the copied APR file, the paths should be Path: "e:/carlin, if you copied the APR to the e: drive. The path Path:"/carlin/ is a generic path name that will work on any location in the directory structure. If you desire to edit these paths, open the carlin.apr file in a text editor. Search for the string Path: See what path is after the quote and change all occurrences of this string to your desired path. This is an easily way to share APRs.

Arcview project

Carlin.apr – an Arcview project with the data sets loaded and symbolized.

Summarized Metadata

Expert Assessment

An example of a Carlin model made by experts using analog methods.
Expert2 – grid file
This 3-unit grid is provided to give an example of a mineral assessment for Carlin deposits in the study area. It classifies the area into three categories, favorable, permissive, and nonpermissive. Nonpermissive areas are areas where the probability of a deposit is so low that deposits are not expected to occur. Permissive areas are areas where the age and lithology of the rocks are of the character associated with this deposit type. Favorable areas are areas where processes associated with the formation of the deposit type are known to occur. This grid is derived from the USGS National Assessment (Ludington and Cox, 1996).

Study area

The area to be studied and the analysis mask.
Studygrd3 – grid file
Studyarea.shp – shapefile

Training Sites

Defines the locations of known Carlin deposits in the study area. These are used by the supervised methods to make a model. These points are locations of deposits and occurrences that were classified by a group of experts as sediment hosted gold deposits (Carlin deposits).
Train2.shp – shapefile

Evidential themes

These themes are used to predict Carlin Deposits.

Geology

Kbgeol – grid file
This data is 1:2,500,000-scale geology polygons from the King and Beikman map of the United States

Kbgeoltbl.dbf - DBF table of attributes describing some aspects of the geologic map units.
Rockdesc – The name of the geologic map units.
Carlin – this attribute has the value T or F. T indicates that the unit is as older or older than the Carlin deposits. F indicates that the unit is younger than the Carlin deposits. This is used to define which map units might be covering deposits.

Stream Sediment Geochemistry

Naa.shp – shapefile
Source point file for antimony evidential theme. This is part of the NURE stream-sediment geochemistry data. These data are normally considered 1:250,000 scale and the units are parts per million (ppm). The theme consists of a suite of element analyses by neutron activation. A value of zero (0) in this file indicates that the element was not analyzed in the particular sample. The antimony (naa_sb) measurements were used to create sbface1 using inverse distance weighting and system default parameters. Many additional themes for use in models could be created from this shapefile.

Sb Surface (STD)

Sbface1 – grid file

The surface created from the antimony data in Naa.shp. This is a real-number grid that must be reclassified to an integer grid (reclassb2) for use in ArcSDM. The grid is symbolized using ¼ standard deviation classes.

Sb Surface (INT)

Rclassb2 – grid file

The integer grid reclassification of the antimony surface. The reclassification was done using ¼ standard deviation intervals. The 15 values in this grid represent the ¼ standard deviation intervals from 1 to 16, low to high values.

Faults

Gbfaults3.shp – shapefile

This file contains faults shown on the 1:500,000-scale Geologic map of Nevada (Stewart and Carlson, 1978). This digital representation of the faults was created by digitization of the end points of straight-line sections of the faults. The attribute Nhem_az gives the northern-hemisphere azimuth of the faults.

Faults with a northern-hemisphere azimuth near 330 can be buffered with 1000m-wide buffers to define areas proximal to Carlin deposits. Additional azimuthal groupings of faults might be used to define additional evidential themes.

Geophysics

Bouguer – grid file

Bouguer gravity anomaly at 20 milligals contour interval. This file is from Raines, Sawatzky, and Connors (1996). The source gravity data was widely spaced regional measurements.

Aeromag – grid file

Aeromagnetic data from the NURE program. The file is derived from Raines, Sawatzky, and Connors (1996). The source magnetic data were flown with 3-mile line spacing.

Gamma Ray

Uranium – grid file

Uranium gamma-ray data from the NURE program. The file is derived from Raines, Sawatzky, and Connors (1996). The source gamma-ray data were flown with 3-mile line spacing. The units are equivalent uranium.

Thorium – grid file

Thorium gamma-ray data from the NURE program. The file is derived from Raines, Sawatzky, and Connors (1996). The source gamma-ray data were flown with 3-mile line spacing. The units are equivalent uranium.

Potassium – grid file

Potassium gamma-ray data from the NURE program. The file is derived from Raines, Sawatzky, and Connors (1996). The source gamma-ray data were flown with 3-mile line spacing. The units are equivalent uranium.

Instructions for Weights-of-Evidence Model

The user should review the ArcSDM Users Manual to fully understand the menus and functions. The user is assumed to be familiar with the Spatial Analyst functions.

1. Start the Spatial Data Modeler Extension

  - In View/Properties set the Map Units to meters and Distance Units to meters or kilometers.
2. SDM/Set Analysis Parameters – use this menu to set up the Analysis Properties and set the modeling parameters.
   - Study Area Grid Theme – select Study Area Mask
   - Training Point Theme – select Training Sites
   - Define Unit Area – select 1 km
   - Missing Data – select -99
   - Select OK
3. There are three evidential data sets provided.
   - Geology – There are two reclassifications of this grid for modeling (Value2 and Fmemship1) Value2 and S_value2 are examples of the reclassification used for ArcSDM. Fmemship1 is an example of fuzzy membership values, which is discussed in the section on fuzzy-logic modeling.
     - There is a data table (kbgeoltbl.dbf) associated with the geology grid that will be used to define map units that are younger than the deposits and therefore potentially covering the map units containing deposits. This table is used to define areas of missing data.
   - Faults – This line theme contains faults and northern hemisphere azimuths so the faults can be selected by azimuth for proximity analysis.
   - Sb Sample Sites – Two grids have been derived from these points, Sb Surface (STD) and Sb Surface (Int).
     - The grid Sb Surface (STD) was made with Surface/Interpolate a Grid using the Inverse Distance Weighting (IDW) and the default parameters to make a floating (real) valued grid.
     - Sb Surface (Int) is a reclassification of the floating Sb grid into integer classes. There are two reclassifications of this grid for modeling (value 5 and Fmemship1). Value 5 and S_value5 are examples of the reclassification used for SDM. Fmemship1 is an example of fuzzy membership values, which is discussed below in the section on fuzzy-logic modeling.
     - **Because Arcview does not fully support long names, the grid Sb Surface (INT) should be renamed. A suggested name is Sbint. Use the Theme/Properties menu to do this.**
4. Analysis of categorical evidential theme (Geology) – the objective is to reclassify the geology into a binary map of areas associated with training sites (inside the pattern) and areas not associated with training sites (outside the pattern). Additionally areas of missing data will be defined using the table kbgeoltbl.dbf.
   - Check the Geology Theme so it is the active theme
   - SDM/Calculate Theme Weights – use this menu selection to explore the association of geologic map units with the training points.
     - Select Evidential Theme – Geology
     - Select Class Field – Value
     - Select Class Descriptor Field – None
     - Check Type of Data – Free
     - Check Write Results to a text file – if desired
     - Calculate Weights, Categorical should be the only option available – check it and the calculation will begin. Save the table in some appropriate place.
     - Respond Calculations of weights for Geology completed. This creates a weights table geology-ct in the tables.

- Open geology-ct (meaning geology categorical weights table) to inspect the contents. It is useful to sort the table on the #points, the number of training points in that map unit.
  - Those map units with contrast greater than zero include more points than expected by chance and are associated with the training sites. Those units with contrast less than or equal to zero are not associated with training sites. Those units that contain no deposits lack a contrast value because contrast cannot be calculated.
- SDM/Generalize Evidential Theme – use this menu to reclassify (generalize) the geology theme to a binary theme based on this contrast information.
  - Select Evidential Theme – Geology
  - Select Class Field – Value
  - Select Class descriptor field – None
  - Select Generalization Method – Define Groups. This method used the query tool to generalize based on information in the geology-ct table.
  - Select Generalize – opens the Group Classes Dialog Box.
  - Group Dialog Box
    - Select Table to Join – geology-ct. This table will be joined to the VAT for Geology and used in the query.
    - Enter New Class Field Name – Value10 (enter a field name not yet used to store an integer value for the binary reclassification). Hit Tab to move to the next field.
    - Enter Class Descriptor Field Name – S_Value10 (a field name not yet used to store a description of what Value10 means. Hit Tab to move to the next field.
    - Enter 1 or 0 in New Class. This is the value for outside the pattern. Hit Tab to move to the next field.
    - Enter Outside in New Class Descriptor. This is a short description defining what the New Class integer value means. Hit Tab to move to the next field.
    - In the Group Definition, select the query builder (hammer symbol) to construct the query. This brings up the standard Query Builder Menu.
      - Create the query [#Points] = 0 and select OK. This will enter this query into Group Definition.
    - Select the Plus button to do this query. In the large box below the Plus button, this query will be listed and #Records = 17. At the bottom of the box Number of records remaining should be 8. The cursor should now be in the New Class box.
    - In the New Class Box enter a 1. Hit Tab to move to the next field.
    - In the New Class Descriptor enter Outside. Hit Tab to move to the next field.
    - In the Group Definition, create the query [Contrast] <= 0 and select the Plus Button. As before, this will enter this new query into the large box. #Records should equal 3 and the Number of records remaining should equal 5. The cursor should be in the New Class box.
    - In the New Class Box enter a 2. Hit Tab to move to the next field.
    - In the New Class Descriptor enter Inside. Hit Tab to move to the next field.
    - In the Group Definition, create the query [Contrast] > 0 and select the Plus Button. #Records should equal 5 and the Number of Records remaining should equal 0. So the reclassification for all of the records has been defined.
    - If you make an entry mistake in any of the queries, highlight that row in the large box. This will activate the X in the lower-left bottom of the Group

Classes Dialog box. Selecting this X will remove this query, which can then be reentered properly.

- Select the Generalize Button to do the reclassification. This will add two new fields to the Geology theme, Value10 and S_Value10, with the generalization information.
- To view the results, use the legend editor to symbolize Geology with S_Value10. Inside the pattern might be colored red and outside the pattern might be colored green.

5. Some of the geologic units are younger than the deposits in Training Set; so these map units should be treated as missing data.
   - Open the kbgeoltbl.dbf file and highlight the Unit field.
   - Open the attribute table for the Geology Theme and highlight the S_Value field.
   - With the attribute table of Geology active, join the kbgeoltbl.dbf.
   - Edit the Attribute Table of Geology, Value10 and S_Value10 fields.
     - Select those records with Carlin = F.
     - For the selected records, calculate Value10 = -99 and S_value10 = "Missing".
     - Stop editing and save the edits. Remove the joins when done.
     - To view the results, use the legend editor to symbolize Geology with S_Value10. Inside the pattern might be colored red, outside the pattern might be colored green, and missing data might be colored blue.

- The results of this reclassification are shown in Figure 1.

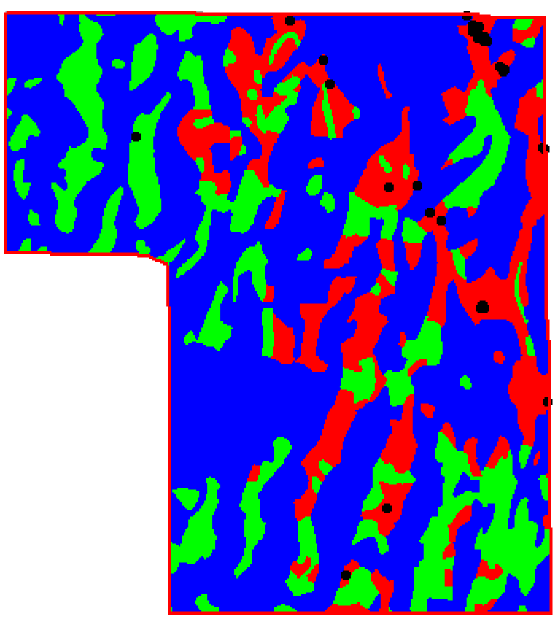


Figure 1: Generalized Geology theme with Training Points.

6. Analysis of ratio data (Antimony, Sb Surface (Int)) – the objective is to reclassify the antimony into a binary map of areas associated with training sites (inside the pattern) and areas not associated with training sites (outside the pattern).

- The Sb Surface(INT) grid can be recreated using the Surface/Interpolate Grid and then Analysis/Reclassify menu selections. An integer Grid is required for the modeling to provide a VAT file to store the generalized binary attributes.
- Check the Sb Surface (INT) grid to make it active.
- SDM/Calculate Theme Weights – use this menu selection to explore the association of Sb Surface classes with the training points.
  - Follow the same procedure as for the Geology Theme except select Type of Data as Ordered and select the Cumulative Descending button. Use this button? because the objective is to define a cutoff of the high values.
  - This will create a table Sb_surface_(INT)-cd.dbf.
  - To inspect the results open the Sb_surface_(INT)-cd.dbf table or better, create a chart. Select SDM/Create Charts. This will create a chart of descending values. Inspect this chart or the table to find the maximum contrast. For the Sb Surface (INT) provide this will be class 10 with a contrast of 3.2. Note the studentized contrast (Stud(C)) value is much larger than 2 so the contrast is significant.
    - In the Charting Parameters Dialog Box, select Table/Class Field sb_surface_(int)-cd, Class, Chart Type Line, What to Plot select Contrast.
- To reclassify the Sb Surface (INT) into binary classes, proceed with SDM/Generalize Evidential Theme as before, except for Generalization Method select Define threshold/Chart, select the table sb_surface_(INT)_cd, and select the Generalize Button. This will bring up the chart previously created and a Generalize Evidential Theme Dialog box. It should select the value and value descriptor fields defined in the Generalize Evidential Themes Dialog Box and have one line in the large box with 1 and 1-16.
- Select the Threshold Selection Tool (the Arrow) and point at the highest value on the graph (Class 10). This will enter a second line into the Generalize Evidential Theme Dialog large box.
- To edit the blank descriptions, highlight the value 1 line. The whole line should be black.
- Put the cursor in the Edit Descrip box, type *Outside*, and then hit enter. This will add the word *Outside* to the Descrip field.
- Now highlight the value 2 line and enter *Inside* to the Descrip field as above.
- Select Generalize to add the generalized attributes to Sb Suface (INT).
- Inspect the generalization by symbolizing Sb Surface (INT) with the descriptor field created by the Generalization. The result is shown in Figure 2.

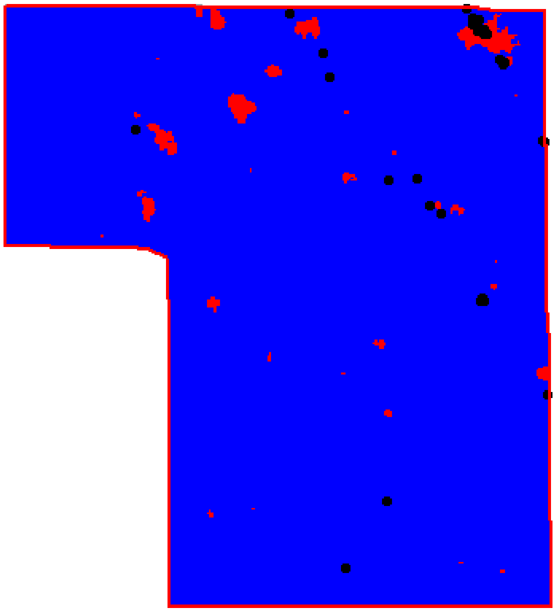


Figure 2: Generalized Antimony surface with Training Points.

7. If a third evidential theme is desired, the faults can be used.
    - Using the query builder, select a subset such as northern hemisphere azimuth (320-360) and make a new theme.
    - Use the SDM/Buffer Features menu selection to create buffers around the faults. A buffer distance of 500 meters, 20 buffers, and checking both options is a good starting place.
    - Rename the buffered grid to a short name, such as fltnw for northwest faults. Do this with Theme/Properties menu.
    - Use SDM/Calculate Theme Weights selecting the Cumulative Ascending Method, SDM/Create Chart, and SDM Generalize Evidential theme as before.

8. To integrate the evidential themes, use SDM/Calculate Response Theme menu. This produces the model shown in Figure 3.
    - **If the Sb Surface (INT) grid has not already been renamed, it must be renamed at this point to a short name, such as Sbint because Arcview does not deal with long names. Use the Theme/Properties menu.**
    - In the Inputs to Weights of Evidence Model Themes Dialog Box, select the evidential themes by highlighting them in the left box and adding them to the right box with the add button.
    - Then select the Specify Fields buttons to select the reclassification attributes desired. If you use the generalized fields already provided, for Sb Surface (INT) select Value5 and for Geology select Value2. Then select OK. This will activate the Calculate Weights button.

- Select the Calculate Weights button. This will create a series of tables as dbf files and the response map grid, which will be named woeuc1 if this is the first you have created. This name means weights of evidence unique conditions #1.
- To the question Do you want to create a table of probabilities to assess Conditional Independence now, select Yes. This will create tables of chi squared values for a pair-wise tests of conditional independence.
- To the question, Do you want to associated conditional probabilities in the response theme with the training points, select Yes. This will ask a question about overwriting RecordID, say Yes.
- A box will then come up with an Assessment of Conditional Independence. If you used only the Geology and Sb Surface generalized as provided, the CI ratio will be 0.97. Select OK to complete this box.
- A box will then inform you that the Calculations are complete for Posterior Probability. Select OK and the symbolized Posterior Probability Map will be added to your view and symbolized.
- It is often necessary to change the number of decimal places for the symbolization of Posterior Probability because these numbers are often very small. Use the Legend Editor and increase the number of decimal places to the maximum using the Classify button.
- The default number of classes is more than are appropriate for this particular model. A smaller number of classes give a more appropriate representation of this model.

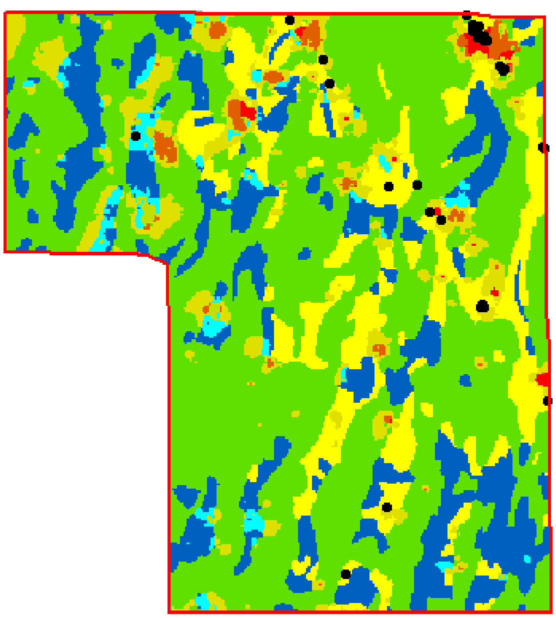


Figure 3: Posterior Probability map with Training points. The training points are shown as black dots. The highest to lowest values are symbolized red, yellow, green, cyan, through blue symbolized by natural breaks.

Guidance for a Fuzzy-Logic Model

The primary decisions when making a fuzzy-logic model are to assign fuzzy memberships to the attributes of the model and to decide which fuzzy operators to apply. ArcSDM provides a tool to help with creation of fuzzy membership values. The fuzzification functions implemented in the fuzzy.ave script provided in the Fuzzification chapter are an alternative approach. The advantage of the fuzzification functions is the fuzzy membership values are exactly reproducible and the process is easily reported.

To activate the fuzzy membership section of SDM, select Set Analysis Parameters, check the Fuzzy Logic box, and select the study area grid. Now the Define Fuzzy Membership menu selection will be active. Selection of this menu leads to a table or graphic tool that assists you to enter the fuzzy membership values.

For gaining experience in selection of fuzzy membership values, the contrast values from the WofE analysis, discussed above, provide useful guidance. For example, a contrast of zero is logically a fuzzy membership value of 0.5. Positive and negative contrast can be rescaled between 0 and 1. For those categorical variables that contain no training points and thus cannot have a contrast value, it is necessary to define a membership value. These categories might be assigned a membership value of zero or 0.5 if the category is a younger map unit that might cover a deposit that is a missing value in the WofE analysis. To select records containing blank numerical fields, a query of the contrast field should use the following format, **([contrast]).IsNull**.

Fuzzy membership values entered manually are included with the geology and reclassified antimony grids. These fuzzy membership values can be used with a fuzzy Or to create the model shown in Figure 4. This fuzzy model is by design similar to the WofE posterior probability (Figure 3). Alternatively, the application of the fuzzification script is described below.

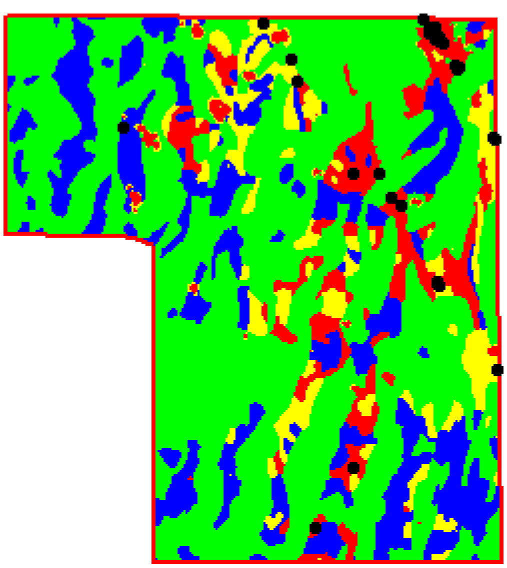


Figure 4: Fuzzy Or model using geology and antimony. The fuzzy membership valu es are Fmembr1 for geology and antimony derived using the SDM manual definition of fuzzy membership. The training points used for the WofE model are shown as black dots. The

highest to lowest values are symbolized red, yellow, green, cyan, through blue usi ng equal intervals.

Fuzzification of Geology Evidence

- Using WofE weights for kbgeol in table kbgeol-ct, join kbgeol-ct to kbgeol with the class and value attributes. Table 1 shows selected columns from these joined tables and the resulting fuzzification. If this table is not available, go back to the WofE modeling exercise above and recreate this table using the calculate weights menu selection.
- In order to use the Large fuzzification function calculated from contrast, it is necessary to have positive numbers and to deal with the classes that contain no training points, that is those classes for which contrast cannot be calculated.
  - Add attribute Rescale to kbgeol to hold the rescale and reclassified Contrast values.
  - Calculate Contrast into Rescale plus the minimum contrast value, 3.2548. Where contrast is blank (null), rescale will be blank. This results in a contrast of zero being rescaled to 3.2548, which will be used for the mid value in fuzzification to give a fuzzy membership value of 0.5. The minimum contrast will be rescaled to 0.
  - These null values are most of the classes that were reclassified as Outside and Missing in the weights-of-evidence analysis.
  - Select those records with the following function **([S_Value2] = "Outside") and ([Rescale].IsNull)**. Calculate a number near zero into these records. In order to get the fuzzy membership just above zero, I have selected arbitrarily a rescaled value of 0.5.
  - Select those remaining null records with the following function **([S_Value2] = "Missing") and ([Rescale].IsNull)**. The fuzzy membership value for the classes treated as missing will have a value of 0.5; so calculate into these selected records a value of 3.2548.
- Run the fuzzification script using the Large function with no hedge and with a spread of 3 and mid of 3.2548. The resulting fuzzy membership values are similar to the values manually defined in Fmemshp1. The intent is to calculate fuzzy membership values that reflect how the experts value the geologic map units.

Table 1: Attribute table for kbgeol showing fuzzification based on contrast. The contrast must first be rescaled to positive numbers and the blank contrasts (those classes that have zero training points) must be assigned some rescaled value. Fuz zification parameters for attribute Mbr1 are the following: function = Large, spread = 3, and mid = 3.2548 (equivalent to a contrast of zero). This table is sorted on Mbr1 and S_Value2.

Attributes Of kbgeol joined with kbgeol-ct									
Value	**S_value**	**Value2**	**S_value2**	**Fmemshp1**	**Rescale**	**Mbr1**	**Class**	**No_Points**	**Contrast**
7	TRPE	1	Outside	0.2	0.5	0.004	7	0	
10	LTV	1	Outside	0.2	0.5	0.004	10	0	
12	UPZ	1	Outside	0.2	0.5	0.004	12	0	
13	KG	1	Outside	0.2	0.5	0.004	13	0	
15	P	1	Outside	0.2	0.5	0.004	15	0	
16	JG	1	Outside	0.2	0.5	0.004	16	0	
18	TI	1	Outside	0.2	0.5	0.004	18	0	
19	LMZV	1	Outside	0.2	0.5	0.004	19	0	
21	TRG	1	Outside	0.2	0.5	0.004	21	0	
22	KC	1	Outside	0.2	0.5	0.004	22	0	
23	JMI	1	Outside	0.2	0.5	0.004	23	0	

24	KG2	1	Outside	0.2	0.5	0.004	24	0	
9	LMZ	1	Outside	0.2	2.4473	0.298	9	1	-0.8075
1	Q	-99	Missing	0.53	3.2548	0.5	1	1	-3.2548
3	TPC	-99	Missing	0.53	3.2548	0.5	3	1	-0.19
2	TPF	-99	Missing	0.53	3.2548	0.5	2	0	
6	TMV	-99	Missing	0.53	3.2548	0.5	6	0	
8	TPV	-99	Missing	0.53	3.2548	0.5	8	0	
20	TMF	-99	Missing	0.53	3.2548	0.5	20	0	
25	QV	-99	Missing	0.53	3.2548	0.5	25	0	
14	UPZE	2	Inside	0.7	3.3566	0.523	14	1	0.1018
11	LPZ	2	Inside	0.7	4.6249	0.742	11	4	1.3701
4	C	2	Inside	0.7	4.9122	0.775	4	3	1.6574
17	UPZC	2	Inside	0.7	5.4408	0.824	17	2	2.186
5	LPZE	2	Inside	0.95	6.1754	0.872	5	22	2.9206

Fuzzification of Antimony Evidence

The objective is to calculate fuzzy membership values by fuzzification similar to those manually defined in Fmemshp1, assuming these represent the opinion of the experts.

- Using the reclassified (integer) grid of the antimony evidence, rclssb2, run the fuzzification script with the Large function, no hedge, and a mid value of 9.5.
- Select the Value attribute for the fuzzification. The Value attribute is the reclassification of the antimony by quarter standard deviation classes. So Value 3 is the mean and 16 is more than 3 standard deviations above the mean.
- Mbr1, Mbr2, Mbr3, and Mbr4 are fuzzification for spreads of 3, 6, 12, and 24, respectively.

Table 2: Fuzzification of antimony evidence. Fmemshp1 is an example of fuzzy membership values defined manually. Mbr1, Mbr2, Mbr3, and Mbr4 show examples of different fuzzification

Attributes Of rclssb2							
Value	**Value5**	**S_value5**	**Fmemshp1**	**Mbr1**	**Mbr2**	**Mbr3**	**Mbr4**
1	1	Outside	0.06	0.001	0	0	0
2	1	Outside	0.08	0.009	0	0	0
4	1	Outside	0.12	0.069	0.006	0	0
5	1	Outside	0.13	0.127	0.021	0	0
6	1	Outside	0.16	0.201	0.06	0.004	0
7	1	Outside	0.17	0.286	0.138	0.025	0.001
8	1	Outside	0.19	0.374	0.263	0.113	0.016
9	1	Outside	0.21	0.46	0.42	0.343	0.215
10	2	Inside	0.81	0.538	0.576	0.649	0.774
11	2	Inside	0.84	0.608	0.707	0.853	0.971
12	2	Inside	0.87	0.668	0.802	0.943	0.996
13	2	Inside	0.9	0.719	0.868	0.977	0.999
14	2	Inside	0.94	0.762	0.911	0.991	1
15	2	Inside	0.97	0.797	0.939	0.996	1
16	2	Inside	1	0.827	0.958	0.998	1

Fuzzification Model

To create the fuzzy logic model shown in Figure 5 using geology (kbgeol with Mbr) and antimony (rclssb2 with Mbr4), use the Fuzzy Logic menu selection with an Or operator. Additional evidential layers provided with the exercise could be used to create a more complex model that could involve other types of fuzzification and fuzzy operators. This model is purposely designed to take advantage of what was learned in the WofE model, but in real applications, a fuzzy-logic model would be considered when no training sites are available to develop a WofE model.

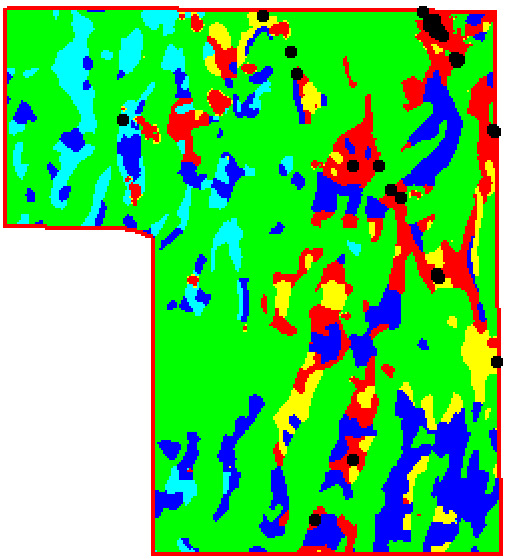


Figure 5: Fuzzy Or model using geology and antimony. The fuzzy membership values ar e Mbr1 for geology and Mbr4 for antimony derived using the fuzzification process. The training points used for the WofE model are shown as black dots. The highest to lowest values are symbolized red, yellow, green, cyan, through blue using equal intervals.

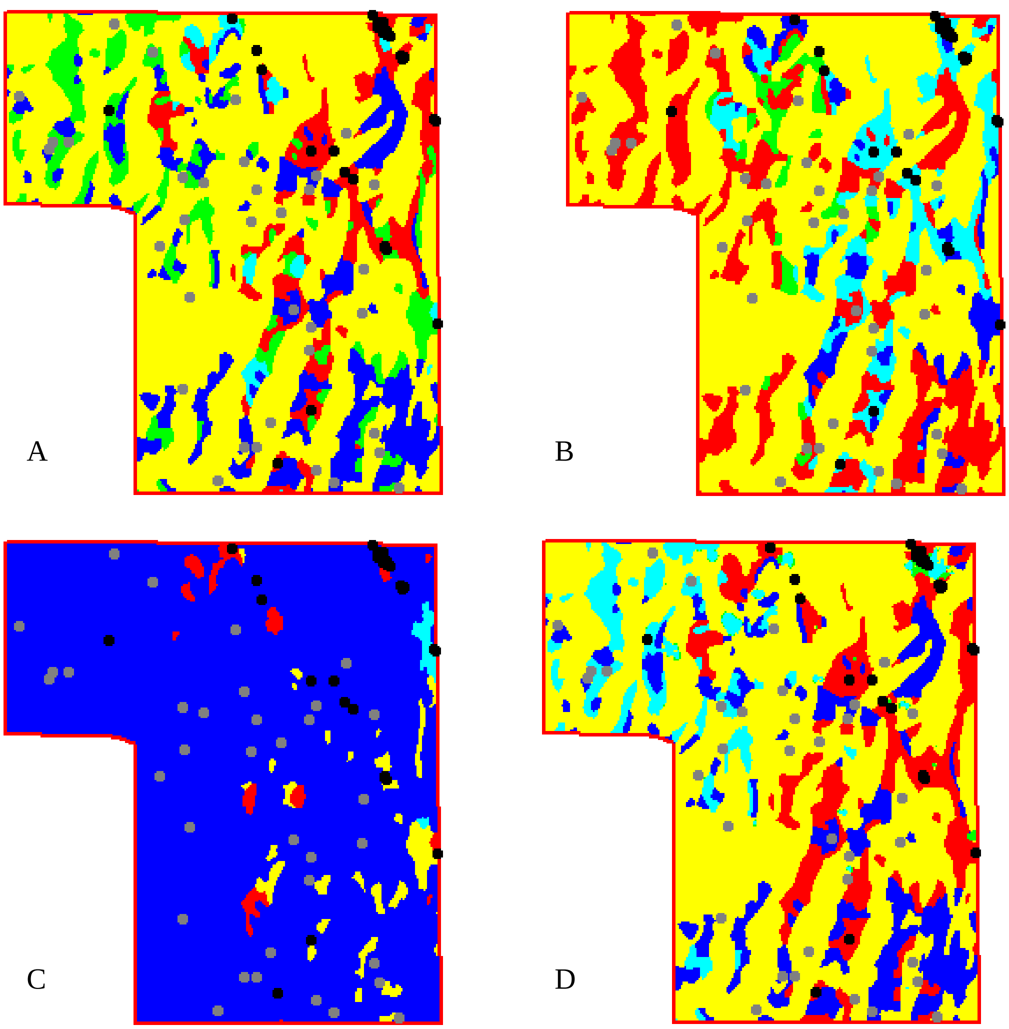
Guidance for a Neural Network Model

Interesting results can be obtained with the neural network by using fuzzy membership values as the inputs. For the neural network tool it is necessary to create a new integer grid with the value field as the input to the neural network. One way to do this is to create a grid from the fuzzy membership values using the Analysis/Map Calculator. You can calculate an integer value from the fuzzy membership value with a calculation such as **([Fmemshp1] * 100.AsGrid).int** . This will create an integer grid with values between 0 and 100. If you want fewer categories, multiply by 10, instead of 100. Before running the model, the input grids should be renamed with short names, as these names will be used in the resulting unique conditions grid.

This use of fuzzy membership can lead to problems in proximity analysis where some of the categories do not contain any training sites. This problem produces a map with zebra stripes of alternating high and low values. One possible solution is to reclassify increasing intervals of the proximity grid into binary grids, where each grid becomes an evidential layer in the neural network analysis. For example, if you buffered faults with 1000m buffers out to 10,000m. You might make a series of binary evidential layers with buffer 1 (1000m) as 1 and everything larger than 1000m as zero. Then buffers 1 and 2 (out to 2000m) would be reclassified as one and everything larger than 2000m as zero; etc. The neural network may then treat these proximity interval binary grids in a more appropriate fashion.

A training set of "non-deposits" is needed for the supervised neural network. One way to do this is provided in ArcSDM. A set of random "non-deposit" training points can be generated with the Spatial Data Modeler/Generate Random Training Points menu selection. This method of create the "non-deposit" training points will create a set of random points within the area defined by some cutoff in the WofE or fuzzy models. For this demonstration, I selected the fuzzification fuzzy model using a threshold of 0.5 for the random "non-deposits. The results of the neural net models using this training set and grids from the fuzzification fuzzy model are shown in Figure 6.

Figure 6: Neural-network models. Models A, B, and C are the three patterns created with the unsupervised (Fuzzy) neural network. Model D is created from the supervised (RBFLN) neural network. All used rescaled fuzzy membership values from the fuzzification fuzzy model; so model A and D are similar to the fuzzy and WofE models. The black and brown points are the deposit and "non-deposit" training sites. The highest to lowest values are symbolized red, yellow, green, cyan, through blue using natural breaks.



References

King, P.B., and Beikman, H.M., 1974, Geologic Map of United States: U.S. Geological Survey, scale 1:2,500,000.

Ludington, S., Cox, D. (editors), and McCammon, D. (project chief), 1996, Data base for a national mineral-resource assessment of undiscovered deposits of gold, silver, copper, lead, and zinc in the conterminous United States by U.S.G.S. Minerals Team: U.S. Geological Survey OFR 96-96, 1 CD-ROM.

Raines, G.L., Sawatzky, D.L., and Connors, K.A, 1996, Great Basin Geoscience data base: U.S. Geological Survey Digital Data Series 41, 2 CD-ROM.

Stewart, J.H. and Carlson, J.E., 1978, Geologic map of Nevada: U.S. Geological Survey, scale 1:500,000.

Reading List

This reading list contains publications important to the rapidly evolving field of spatial analysis, and relevant to students preparing for Masters of Science and Doctor of Philosophy degrees in disciplines involved with spatial modeling problems. The papers are classified for reading as follows: MSc - * and PhD – all. References noted with "&" are not available in the UNR Library.

&An, P., Moon, W.M., and Rencz, A., 1991, Application of fuzzy set theory for integration of geological, geophysical, and remote sensing data: Canadian Journal of Exploration Geophysics, v. 27, p. 1-11.

*Bonham-Carter, G.F., 1994, Geographic information systems for geoscientists – modeling in GIS: New York, Elsevier Science Inc., 398p.

*Bonham-Carter, G.F., Agterberg, F.P., and Wright, D.F., 1988, Integration of geological datasets for gold exploration in Nova Scotia: Photogrammetric Engineering and Remote Sensings, v. 54, no. 11, p. 1585-1592.

&Bonham-Carter, G.F., Agterberg, F.P., and Wright, D.F., 1989, Weights of evidence modeling: a new approach to mapping mineral potential *in* Agterberg, F.P, and Bonham-Carter, G.F., (eds.) Statistical applications in the Earth Science: Geological Survey of Canada, Paper 89-9, p. 171-183.

*Burrough, P.A., and McDonnell, R.A., Principles of geographic information systems: New York, Oxford University Press Inc., 333p. (Chapter 11 (p. 265-291) addresses fuzzy logic.)

&Harris, DeVerle, and Pan, Guocheng, 1999, Mineral favorability mapping: a comparison of artificial neural networks, logistic regression, and discriminant analysis: Natural Resources Research, v. 8, no 2., p. 93-109.

*King, J.L., and Kramer, K.L., 1993, Models, facts, and the policy process - the political ecology of estimated truth in Goodchild, M.F., Parks, B.O., and Steyaert, L.T., Environmental modeling with GIS: New York, Oxford University Press, p. 353-360.

*Levin, S.A., 1992, The problem of pattern and scale in ecology: Ecology, v.73, no.6, p. 1943-1967.

*Mensing, S.A., Elston, R.G., Raines, G.L., Tausch, R.J., and Nowak, C.L., 2000, A GIS model to predict the location of fossil packrat (Noetoma) middens in central Nevada: Western North American Naturalist, v. 60, no. 2, p. 111-120.

*&Raines, G.L., 1999, Evaluation of weights of evidence to predict epithermal-gold deposits in the Great Basin of the western United States: Natural Resources Research, v. 8, no. 4, p. 257-276.

&Singer, D.A., and Kouda, Ryoichi, 1999, A comparison of the weights-of-evidence method and probabilistic neural networks: Natural Resources Research, v. 8, no 4., p. 287-293.

Toffoli, Tommaso, and Margolus, Norman, 1987, Cellular automata machines – a new environment for modeling: Cambridge, Mass., The MIT Press, 259p.

*Tsoukalas, L.H., and Uhrig, R.E., 1997, Fuzzy and neural approaches in engineering: New York, John Wiley and Sons, Inc., 587p.

*&Wright, D.F., and Bonham-Carter, G.F., 1996, VHMS favorability mapping with GIS-based integration models, Chisel Lake-Anderson Lake area *in* Bonham-Carter, G.F., Galley, A.G., and Hall, G.E.M., (eds.), EXTECH I: a multidisciplinary approach to massive sulfide research in the Rusty-Lake-Snow Lake greenstone belts, Manitoba: Geological Survey of Canada, Bulletin 426, p. 339-376, 387-401.

Student's Posters

For the major laboratory exercise in the Spatial Analysis class, the students were assigned to prepare a weights-of-evidence model. This exercise was designed to be a group effort and provided the students an opportunity to form and work with a team whose members had diverse expertise and perspectives. The Tahoe Regional Planning Authority (TRPA) provided data for use as evidence, and nesting sites for Spotted Owls, Osprey, and Goshawks for use as training sites. The students could also prepare a model using other data and two groups did this. These students modeled individual parcel evaluation scores (IPES Scores in the TRPA terminology) in the Tahoe Basin and Mayan habitat sites in Belize. All of the models were presented in a poster format that would be appropriate for a technical meeting.

The following three posters were selected and provided with this report as the most outstanding:

- Goshawk Habitat – a model predicting goshawk habitat in the Lake Tahoe Basin. The poster is file UNRgoshawk.rtl.
- Spotted Owl Habitat – a model predicting spotted owl habitat in the Lake Tahoe Basin. The poster is file UCSBspotowl.rtl.
- IPES Scores – a model predicting the IPES scores for individual land parcels in the Lake Tahoe Basin. IPES scores are used by TRPA to determine whether construction can occur on a particular parcel. The post is file IPES.rtl.

The RTL files are the native raster format for the HP large format plotters such as the HP650, HP750, and HP2200 series of plotters. These files are stored in the zip file provided with this report.

One of the most interesting aspects of the animal habitat models was the identification of a spatial association between nesting sites and roads. Nesting sites are preferentially known near roads adjacent to large road-less areas and the interior of the road-less areas were not sampled. This leads to the conclusion that the nesting sites used for training were biased, that is the sampling programs to locate nesting sites did not sample all environments in the basin.