GIS Applications in Hydrologic Processes
GLG3041 - Hydrogeology

Introduction:

Over the course of the semester you have used a number of traditional techniques to characterize and quantify hydrologic processes. The exercises in this assignment will illustrate how you can utilize ArcGIS to perform similar analyses. Some of these GIS-based analyses will offer an expedited but less accurate representation and others will be more accurate and take less time than traditional techniques. Up to this point in the semester we have focused on learning how to organize data and utilize basic ArcGIS tools but these exercises will focus on addressing or characterizing processes specific to hydrogeology.

Exercises:

(1) To delineate Thiessen polygons and calculate areal precipitation.
(2) To delineate watersheds using a digital elevation model
(3) To estimate evapotranspiration using the Hargreaves Method

Your Mission:

Using the following instructions I would like you to provide a short 2-3 page summary of the operations you performed, the results of your analyses and interpretations. This summary should take the form of a professional report, complete with tables and professional maps, comparing the results of the various methods you use, a discussion of the assumptions required for these calculations, and your thoughts on the costs and benefits of using a GIS based methodology versus the traditional methodology you have already used.

Exercise 1: Calculating Areal Precipitation

You already used the traditional technique for calculating areal precipitation in the Lamoille Quadrangle by delineating Thiessen polygons using a topographic map and graph paper. This exercise will illustrate how you can perform the same calculations within a GIS:

Equations

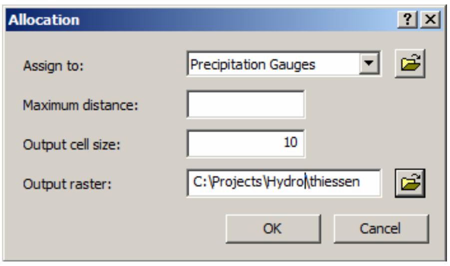
$$P_{avg} = \sum_{i=1}^{m} w_i P_i$$

$$w_i = \frac{A_i}{A_T}$$

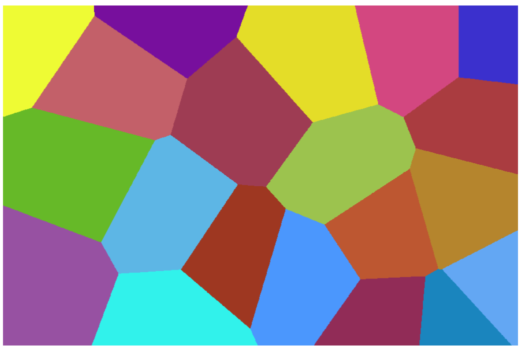
Where:

P_{avg} = average precipitation
A_i = Area defined by each Thiessen polygon
A_t = Total basin or watershed area
P_i = Precipitation within each Thiessen polygon

The calculations are exactly the same you just won't be counting squares on a sheet of graph paper to estimate area, you'll be using a GIS. Your first step is to create Thiessen polygons for your precipitation gauge network (identified in the table of contents as "Rain Gauges"). To accomplish this you need to click on Spatial Analysis → Distance → Allocation and make sure you select Precipitation Gauges as your "Assign to" layer and provide a name for the output raster.

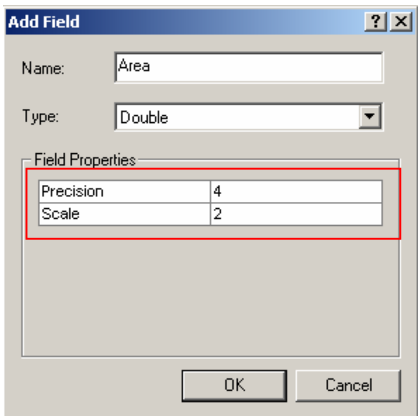


After you click OK, you should see a raster layer depicting Thiessen boundaries that looks like this (your color scheme may vary):

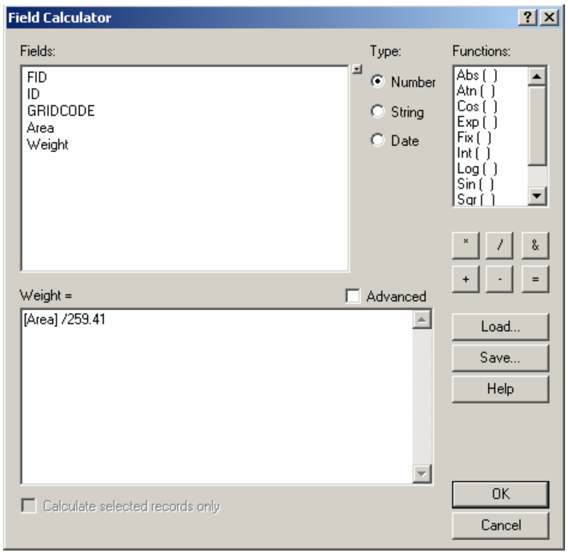


You need to convert this raster layer to a shapefile to create polygons. You can accomplish this by clicking Spatial Analyst → Convert → Raster to Features and make sure you name the output grid something that indicates this is your Thiessen Polygon layer.

You need to calculate the area of each resulting polygon by creating a new Field and using the Calculate Geometry function. Open the Thiessen Polygon attribute table, click Options → Add Field. Name this field Area and input the field properties shown to the right →



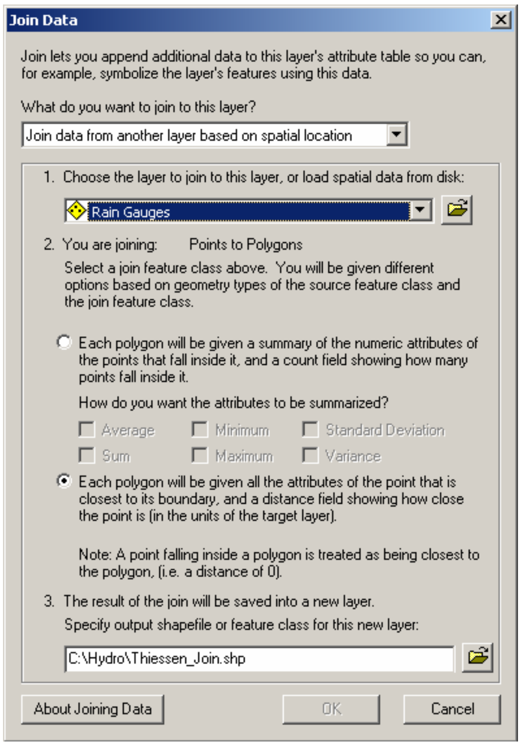
Once you have created the field, you can right-click on the name (Area) and select Calculate Geometry. Make sure you choose Area and use square kilometers. You should now have a column of values representing the area of each polygon. To determine the weighting factor for each polygon, you need to divide the area of each polygon by the total area.



You can find this value by right-clicking on the Area field again and clicking Statistics – the Sum value is the total area of all polygons. You can now calculate the weighting factor for each polygon by creating another new Field (following the example above but set Precision to 5 and Scale to 3) and using the Field Calculator to divide each Thiessen polygon area by the total area.

At this point you have created Thiessen polygons and calculated area and weighting values for each polygon. However, you need to incorporate data from your rain gauges to estimate areal precipitation. You're going to make use of spatial overlay analysis to join data from the rain gauges layer to the Thiessen polygon layer. You can accomplish this by right-clicking on the Thiessen polygon layer and selecting Joins and Relates → Join.

Choose the settings shown to the right →



These settings will extract the values from the Rain Gauges attribute table and join them to the underlying Thiessen polygon corresponding to each Rain Gauge. To clean the attribute table up you can delete the following fields: FID_2, ID_1, and Distance.

You should now have a Thiessen polygon layer with an attribute layer that contains fields summarizing the area of each polygon, weighting factors, and precipitation (recorded in centimeters) for two individual storms. You can now estimate areal precipitation for each storm by creating two fields labeled S1_Weight and S2_Weight. Using the Field Calculator you can multiply the weighted value by the precipitation value to produce a weighted precipitation value and then look at the field statistics to determine the summed weighted precipitation values for each storm.

To export this table for manipulation in Excel, click on Options → Export and name the table Areal.xls. Please include this table in your report and provide the weighting factors and the cumulative precipitation value for the area of interest.

Exercise 2: Calculating Watersheds

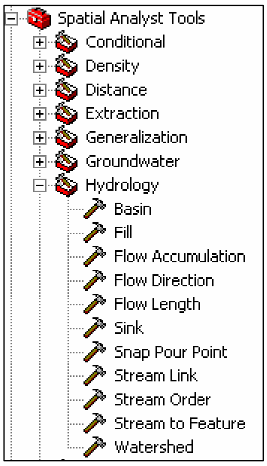
You also used the traditional topographic map methods for defining and characterizing a watershed within the Lamoille Quadrangle. You can perform similar analyses within ArcGIS using the Hydrology Functions. You access these tools through ArcToolbox → Spatial Analyst Tools → Hydrology. You are going to use the following functions:

(1) DEM → Fill
   a. This function fills in "pits" in the DEM surface that would cause water to flow or drain in an unrealistic manner.

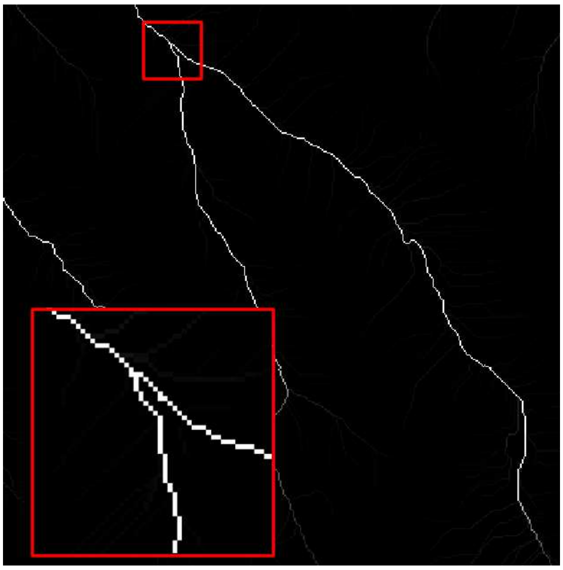
(2) Filled DEM → Flow Direction
   a. This function determines the flow direction of water from each cell to the steepest down slope neighboring cell

(3) Flow Direction → Flow Accumulation
   a. This function evaluates the cumulative additions of water from each upslope contributing cell

Once you have created these 3 grids, you can define a watershed within this area of interest. You need to select the Watershed Function, input the Flow Direction layer and select the Outlet layer for the Pour Point data. Name the output Watershed_1. How does this watershed compare with the one you hand-drew? Does it seem realistic when you compare the GIS-calculated boundaries with the DRG?

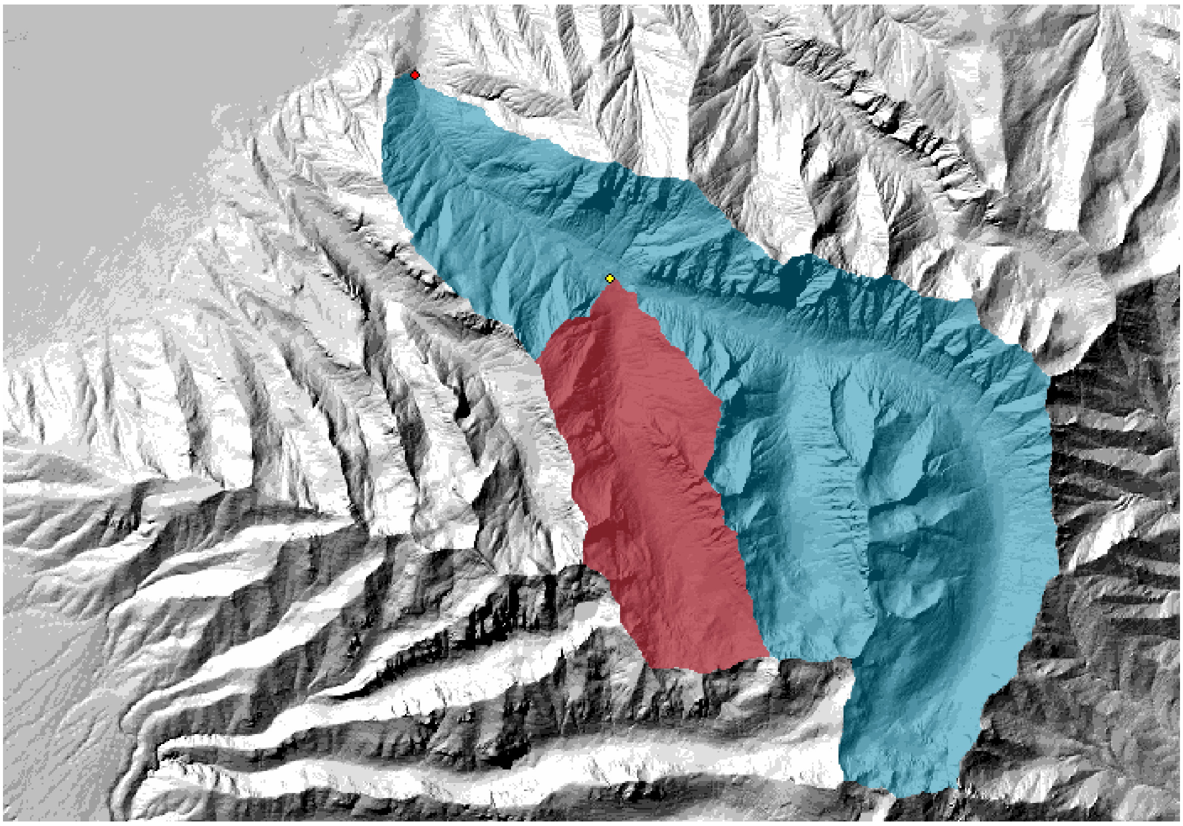


You can use the flow accumulation grid to identify more than one watershed by creating more pour points. To keep the watersheds separate, you need to create a new shapefile and add a new pour point over areas of high flow accumulation, which indicate the presence of 'tributaries' entering the main trunk stream.



You need to make sure you zoom in enough so that you place your pour points in grid cells exhibiting higher flow accumulation values. They should be positioned in the last cell before the flow enters the main stem. Once you have created at least two new shapefiles, each containing a pour point, you can use the Watershed function to identify sub-watersheds within the original watershed you created.

You should see something similar to the image below, however this image only illustrates two pour points and it will depend on what flow accumulation convergence you choose to create your pour points.



Exercise 3: Estimating Evapotranspiration (ET)

Introduction:

In this exercise you are going to estimate ET using the Hargreaves Equation (see Wu, 1997). You have already used this equation in homework assignments using online data and Excel for a specific location, however using a GIS you can quantify the spatial variation in ET within a much larger landscape. Keep in mind the variety of assumptions and limitations of this model as you progress through the analysis to include in your final report.

Your Mission:

You need to use the provided Mean Monthly Temperature data[1] and calculate Solar Radiation values for the area of interest to estimate the monthly mean ET for Owens Valley. You will report these values out in a graphic or table of your choosing to best illustrate these variations.

Methodology:

You're going to use this equation:

$$ET_0 = 0.0135\,(T + 17.78)\,R_S\left(\frac{238.8}{595.5 - 0.55T}\right)$$

Note: You need to convert the radiation themes from Wh/m^2 to MJ/m^2. However, in this scenario you are converting between power and energy and there isn't a direct unit conversion, you need to make assumptions about the variations in total solar radiation over the duration of the day (i.e. – impossible to account for clouds).

Therefore you need to convert Watt Hours to Watts by using the power equation: Power (watt hours) = work (watts) x time (hours). To convert Watt Hours to Watts, you can divide Watt Hours by time (# of hours of solar insolation x # of days per month). To account for the variations in hours of sunlight you can use the Sunlight.xls file to find the difference between sunrise and sunset and then find the monthly mean value for # of hours of insolation. Remember to account for the variations in the number of days per month.

To utilize the equation, you then need to assume that 1 watt = 0.0036 MJ[2]. You should use the raster calculator to perform these conversions.

To calculate total solar radiation (R_s) using ArcGIS you will make use of the Solar Analyst function found within ArcToolbox → Spatial Analyst Tools → Solar Radiation → Area Radiation.

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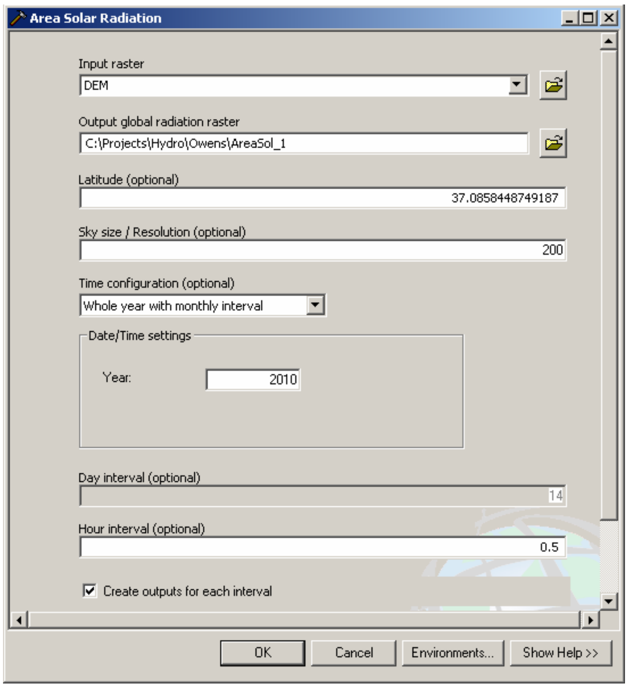
[1] Monthly temperature grids created using lapse rates derived from local climate data using a program written in Visual Basic (see Lapse folder in the Owens directory for more information).
[2] See http://www.pnet.sr.unh.edu/ for an explanation of these assumptions

Make sure your input raster is the DEM, change the time configuration to “Whole year with monthly interval,” and check the “Create outputs for each interval.” You will need to use ArcCatalog to re-name the grids appropriately (i.e. – January, February, etc). These calculations will take some time so be patient.



Once you have performed the calculations and conversions to create monthly radiation grids for Owens Valley you can use the raster calculator to evaluate the Hargreaves equation for each month. To identify the monthly mean you can right-click on the Hargreaves grid layer, click the Source tab and scroll down until you see the statistics section where you will find the mean value reported.

Please include a table in your final report that summarizes the mean monthly ET values for Owens Valley. In addition, please discuss any assumptions you were required to make when using these techniques (i.e. - the GIS technique and Hargreaves equation).

Your final report should include the following components:

(1) A brief description of what analyses you performed
(2) A comparison of the “traditional” versus GIS techniques
(3) A discussion of the results from each of these methods (e.g. – assumptions, pros versus cons, ease of use, what is required before you can actually use them, when they would not be applicable, etc).