

# CEE6400 Physical Hydrology

## Homework 3. Precipitation

Date: 9/18/13

Due: 9/25/13

### Learning Objectives.

- Be able to estimate area average precipitation from point measurements using a variety of methods
- Be able to quantify the uncertainty in an areal precipitation estimate
- Estimate design rainfall amounts and intensities
- Develop ArcGIS skills for analysis of hydrologic data

1. Dingman 4.6.
2. a) Dingman 4.7.  
b) Compute, for the information given in Dingman 4.7 the uncertainty, quantified by standard deviation, associated with the estimate of area average precipitation in any one specific year (assuming that gages are randomly positioned). Compare your result to the uncertainty that would have resulted had there only been 1 rain gage.  
c) Explain physically what it means for the correlation structure of annual precipitation in the region to have a value of  $c=0.0386 \text{ km}^{-1}$ , and comment on how physically realistic such a value is.
3. Dingman 4.9.

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### Estimation of area average precipitation from point measurements as an Introduction to ArcGIS (This exercise should work for versions 10.1 and 10.2)

#### Overview of what is to be done

1. Display the watershed boundary, state boundaries and Digital Elevation Model (DEM) in ArcMap. Create and display contours from the DEM.
2. Convert tabular latitude and longitude data from reyprecip.txt to add to your map the display of raingage locations. Identify geographically, attributes of the raingage data. Report the rainfall and elevations associated with certain raingages.
3. Prepare a layout showing the watershed boundary and topography of Reynolds Creek and its location in the Western U.S.
4. Estimate basin average mean annual precipitation using the ArcGIS Thiessen polygons tool then exporting the data into Excel for weighted averaging.

5. Use the interpolation capability within Spatial Analyst to estimate mean annual precipitation surfaces using kriging or smoothing splines. Estimate basin average mean annual precipitation based on these surfaces.
6. Use the elevation at each precipitation gage to develop a relationship between elevations and mean annual precipitation. Use this relationship to estimate basin average mean annual precipitation (the Hypsometric method) accounting for topography.

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## Computer and Data Requirements

To carry out this exercise, you need to have access to a computer which runs ArcGIS. You need the following data:

1. A shape file giving the Reynolds Creek watershed boundary (rcout.shp).
2. A table of annual average rainfall data called reyprecip.txt.
3. A digital elevation model grid file called reydem.
4. A shape file giving the US State boundaries.

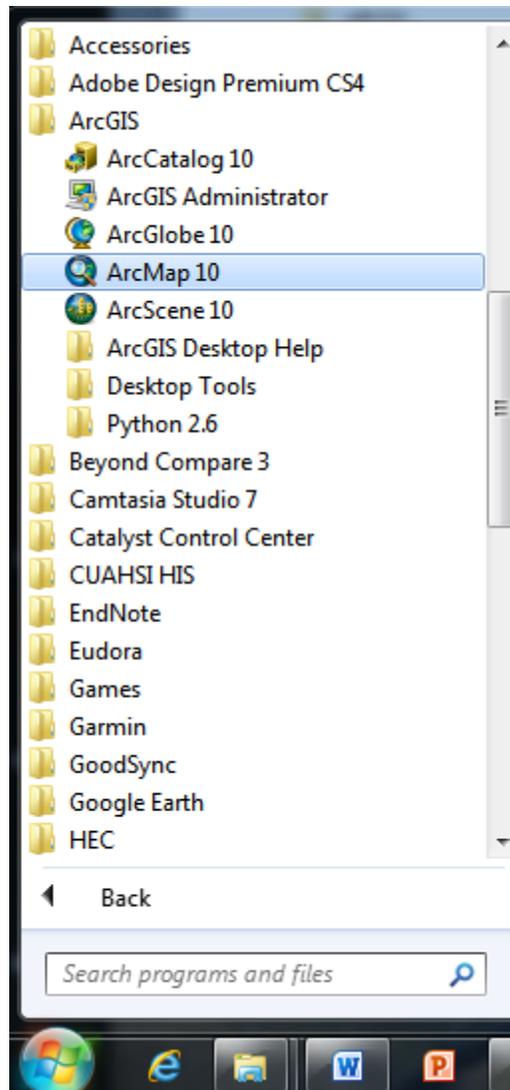
These data are in the file **hw3.zip** (downloadable from the class web page). Unzip all the files into a single folder (directory).

For illustrative purposes I will assume this directory is 'C:\rain\'. The files in the zipfile consist of the following files: **rcout.shp**, **states.shp**, **reydem**, reyprecip.txt. The files in **bold** are GIS files that physically comprise several files with different extensions. Do not concern yourself with this, just extract the whole zipfile, then you should have all the pieces you need and ArcGIS will see the multiple files as one.

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### 1. Viewing data ArcMap and examining data

- (1) Open ArcMap and select the "A new empty map" option.

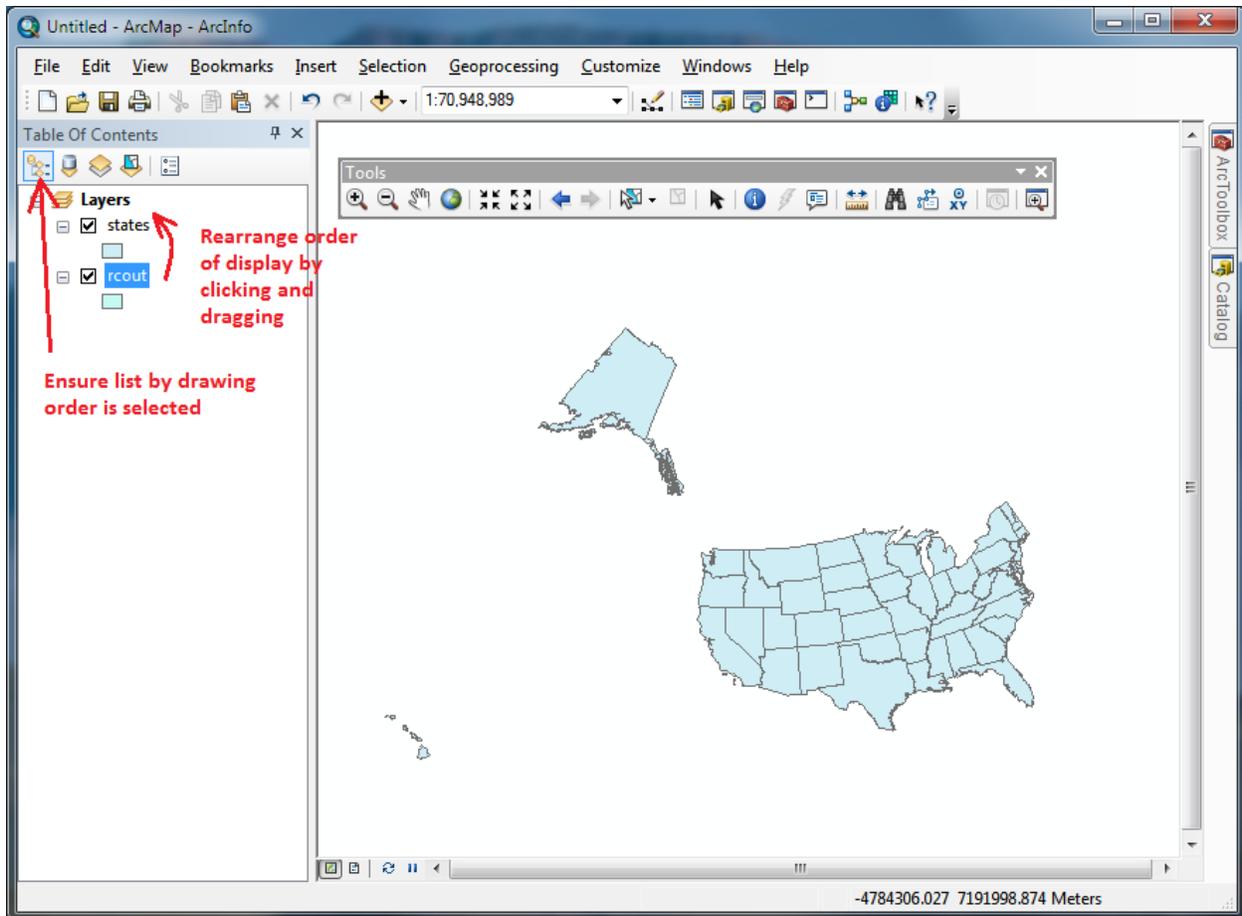
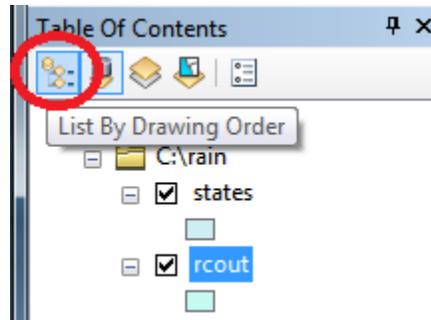


(2) Use the  (Add Data) button to **Add Data**. At the dialog that appears navigate to the folder, which contains the data (c:\rain) and select the file **rcout.shp**. This is a shapefile giving the boundary of Reynolds Creek Experimental Watershed. This should be loaded first because it has associated with it the UTM projection that the ArcMap Data frame will inherit. (This projection information is in the file rcout.prj.)

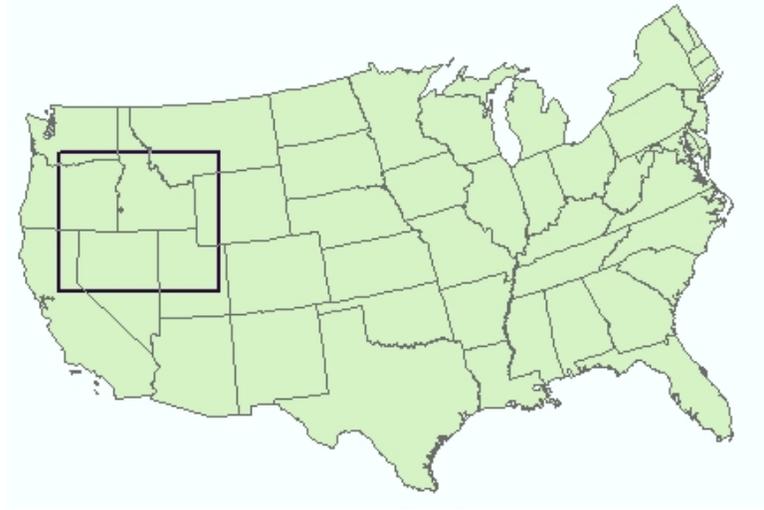
(3) Use the  (Add Data) button to add the **states.shp** data. Click CLOSE to the warning about a different geographic coordinate system.

(4) Select **Customize/Toolbars/Tools**

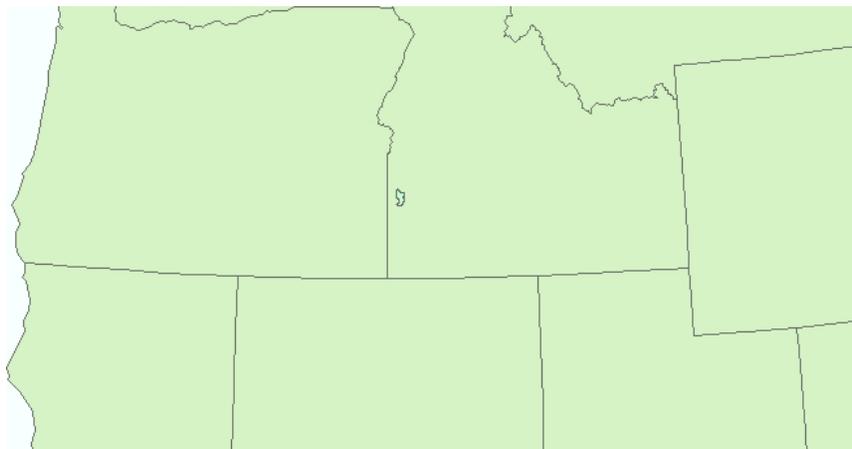




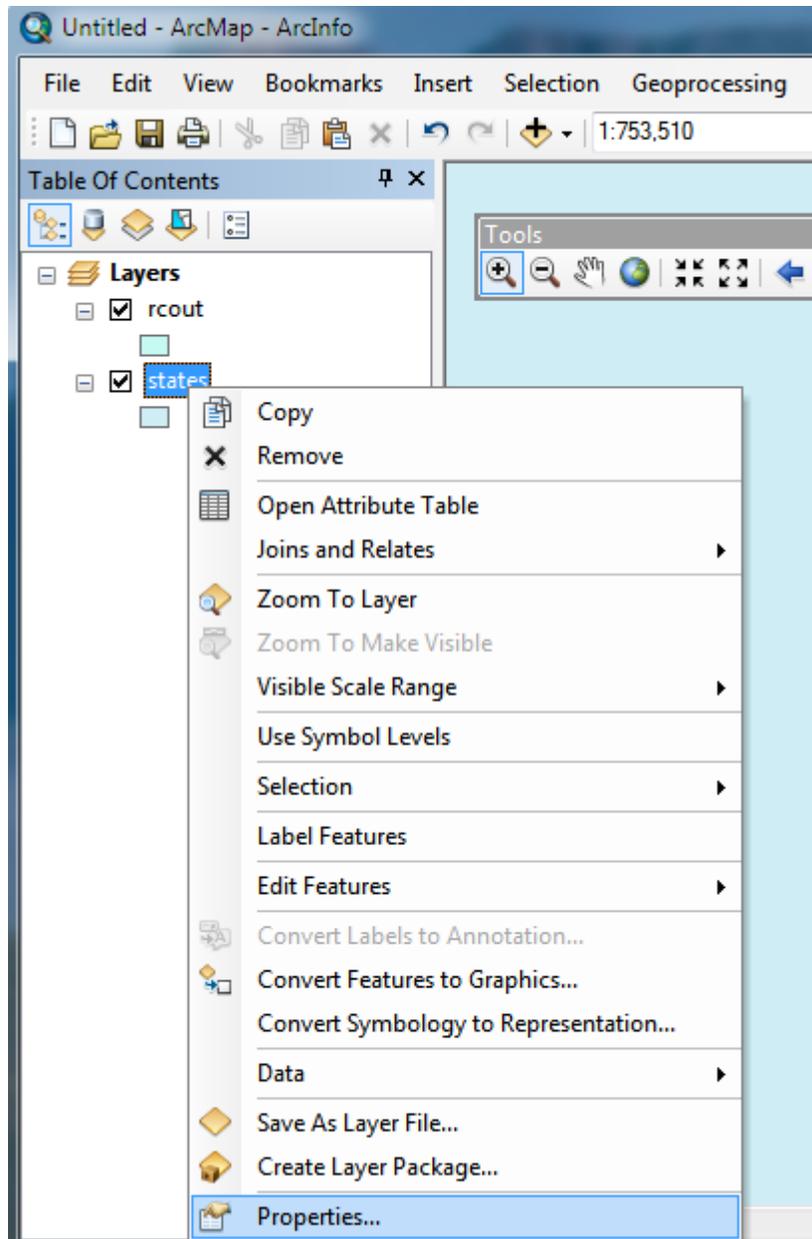
You should then see Reynolds Creek as a small dot in the south west corner of Idaho. Click the  (zoom in) button then drag over this area to zoom in on the basin.



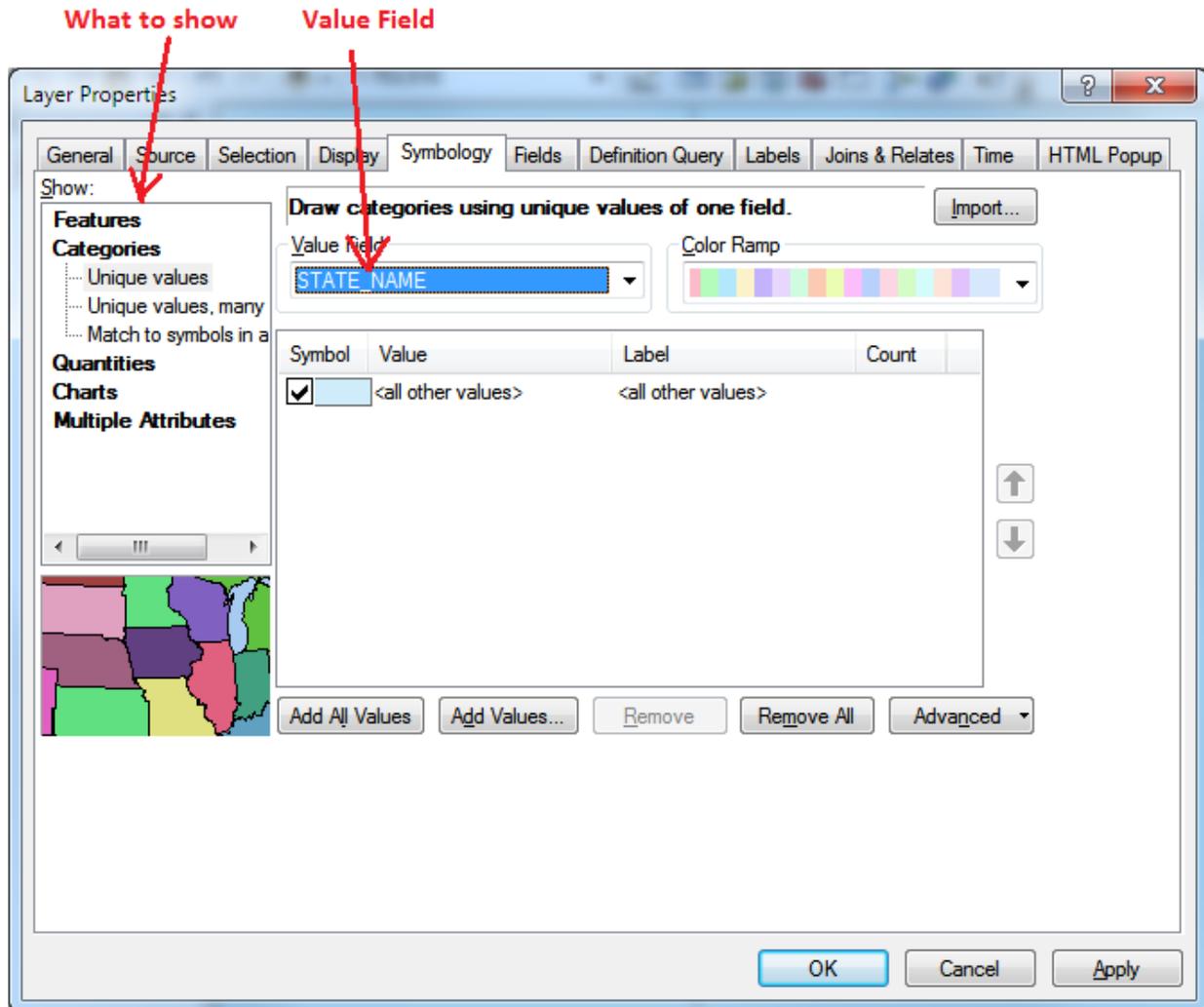
until you have a picture something like this showing the location of the watershed in the SW corner of Idaho.



Right click on the layer name "states" in the contents panel and select properties.

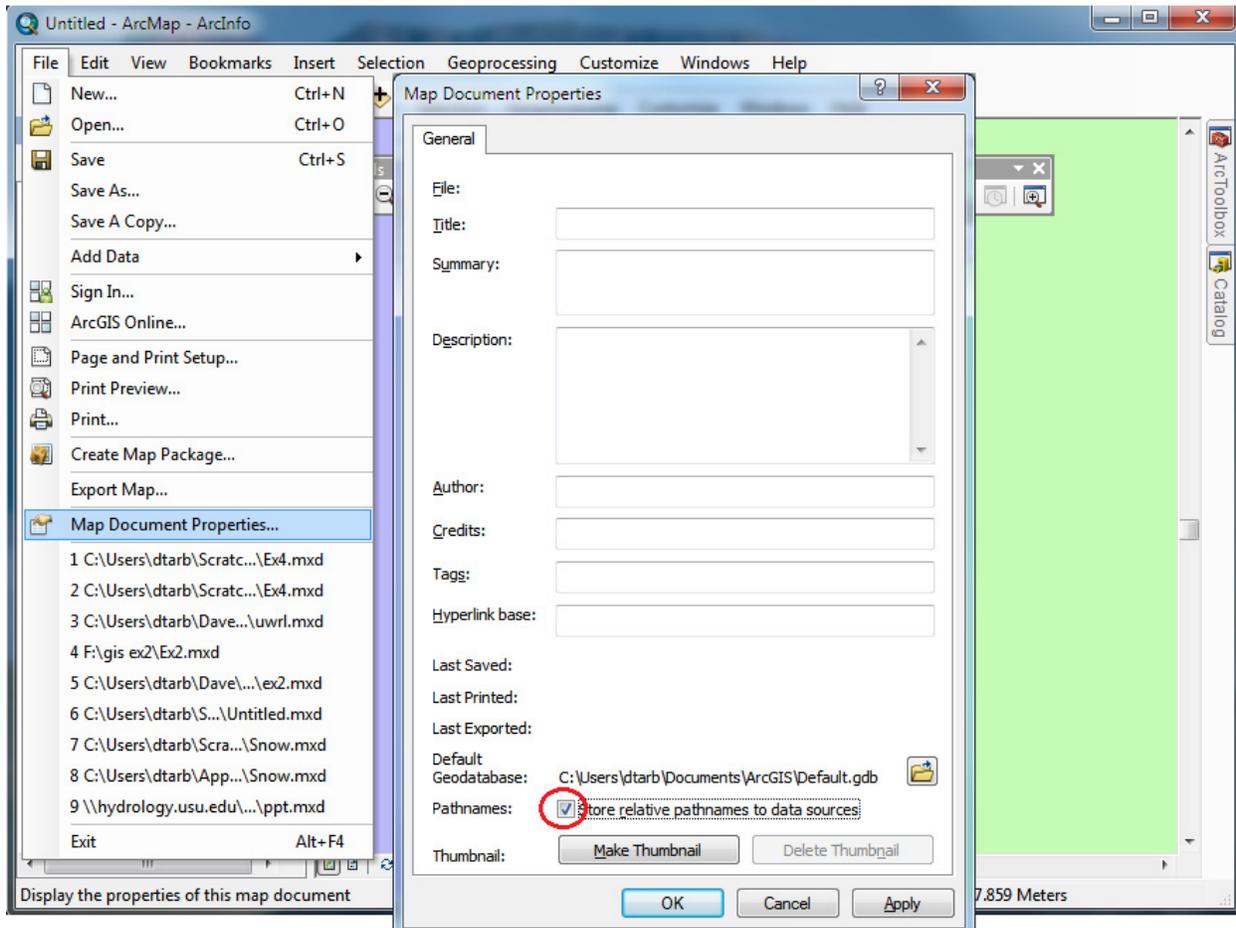


Select the **symbology tab** to adjust colors and line thickness etc. You may wish to color the states different colors using the "Categories", "Unique values" in the "Show" box., with State Name as the value field.



Or you may wish to make the feature symbol transparent to show only the outlines of the states. Click OK or Apply to activate your choices.

(5) Click **File/Map Document Properties** and select "Store relative pathnames to data sources". This has the effect of setting the path from your map document file to the data that it contains using relative paths so that if you stop work and move the data and map document file to another computer, but retain the data in the same relative positions in a folder, the map document will correctly locate and display the data.

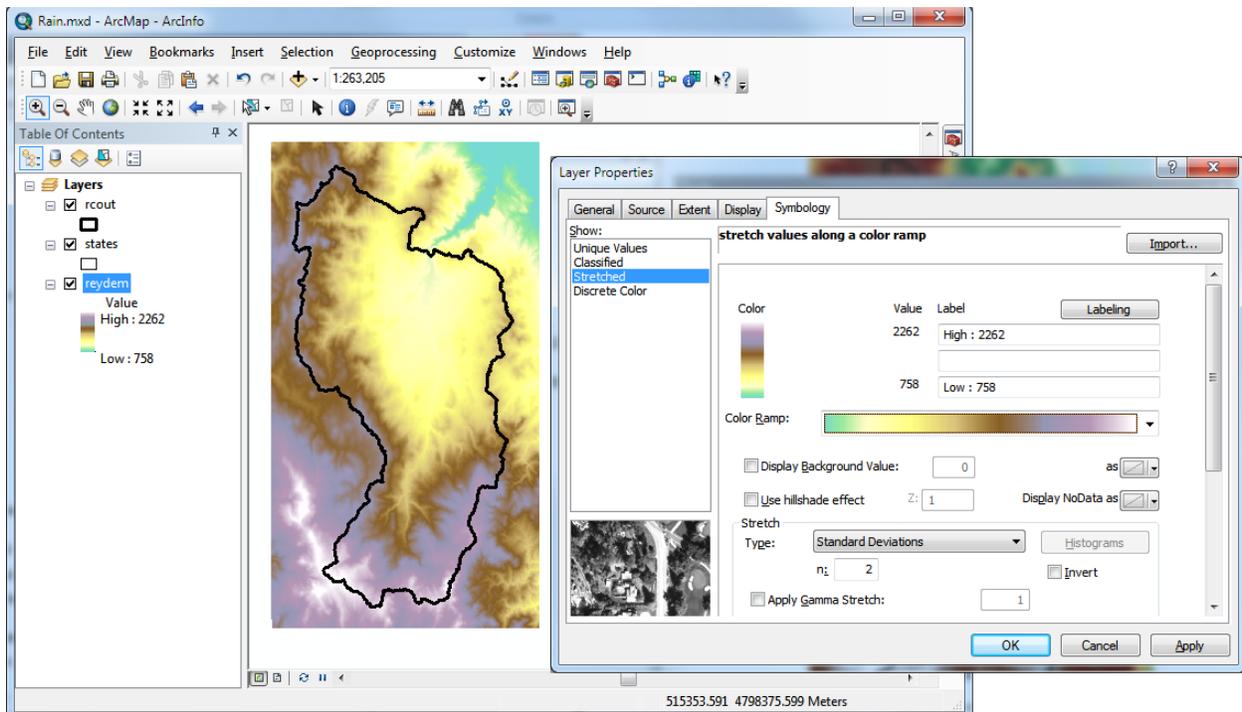


(6) Save your work in ArcMap by choosing **File/Save** and selecting a file name (the file will be assigned extension mxd). I suggest you put the map document in the same folder as the data and then if you want to move to another computer you move the whole folder taking advantage of the relative path setting just set. If you do not do this, and move the data, ArcMAP will try find the data in exactly the same path (e.g. C:\users\yourname\...) and if the path is different will not locate and be able to display the data.

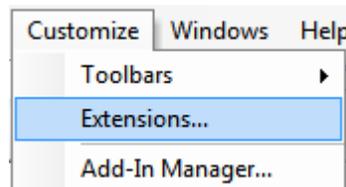
(7) Use the  (Add Data) button to add the digital elevation model raster "**reydem**". The added file is listed in the Arc Map Table of contents.

A **raster** or **grid** is a data structure that supports numerical values on a square grid. In this case the values represent topographic elevation. In ArcMap raster data is stored in an ESRI proprietary grid data structure comprising the principle folder (here named reydem), files inside it (which you do not need to concern yourself about) as well as \*.aux files and files in the "info" folder. These should have been extracted in their entirety from the **hw3.zip** data file. These files should not be manipulated except through Arc software (ArcMap or ArcCatalog). ArcCatalog is a utility similar to Windows explorer for managing GIS data. If you move one of the files in a raster folder, but not the other ones the raster may become corrupt and unusable.

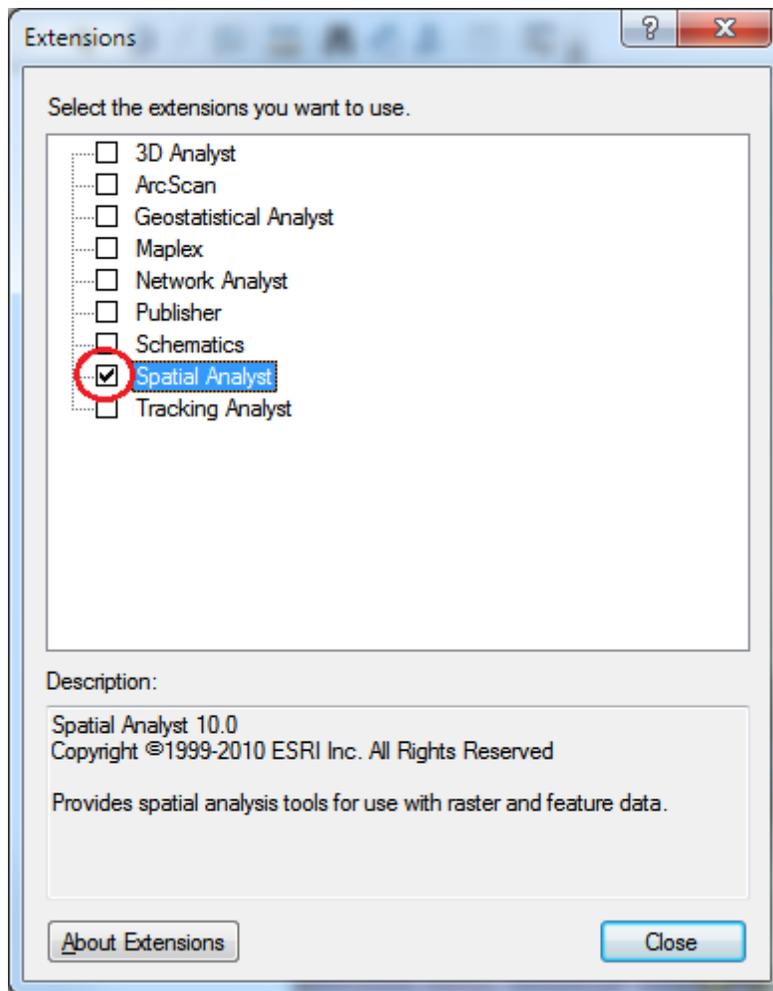
(8) Zoom right in over the watershed, turn the states layer off and adjust the rcout layer so that it is transparent so that the watershed boundary is displayed relative to the DEM. You can recolor the raster by going to the theme's Properties/Symbology and choosing a new color ramp



(9) Select **Customize/Extensions**.

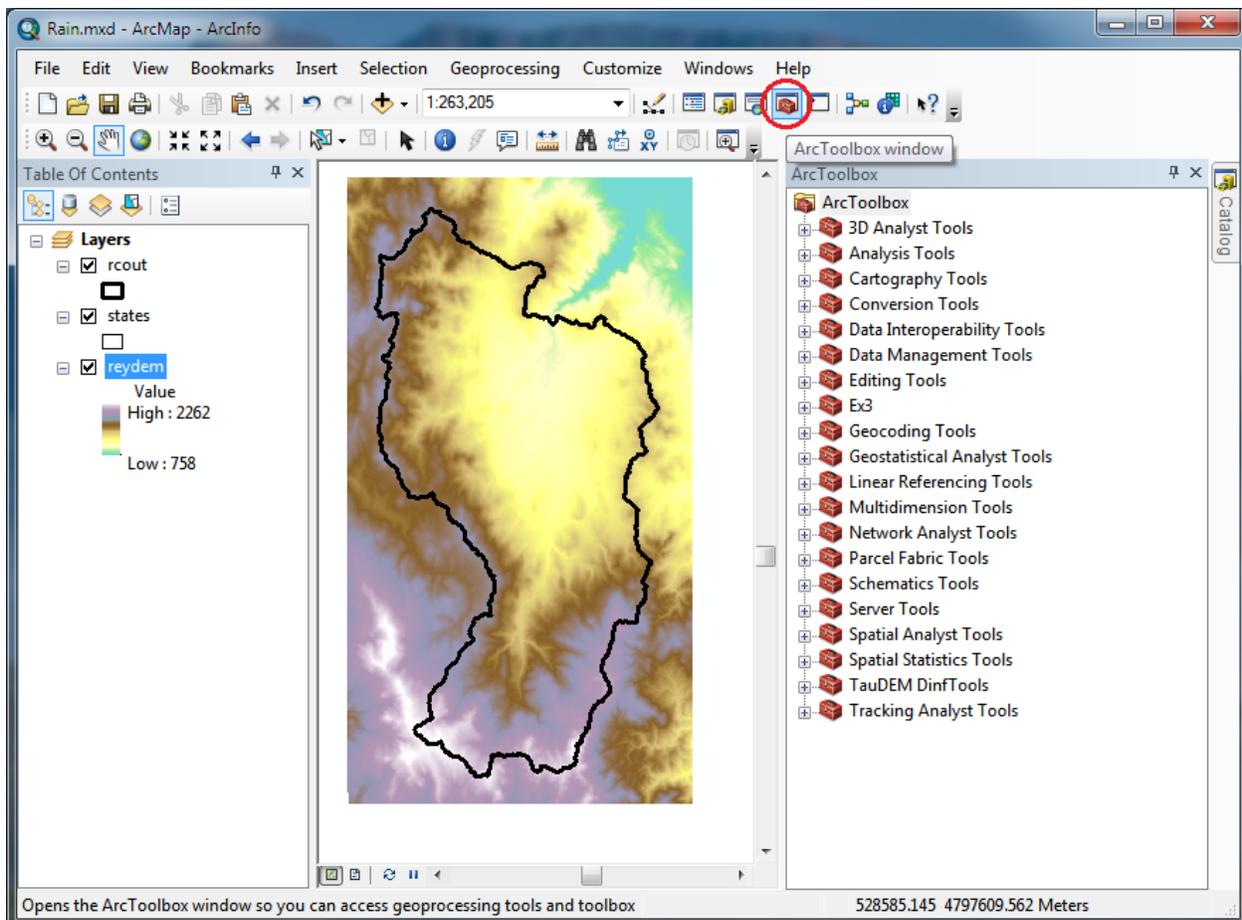


Make sure that "Spatial Analyst" is checked and select "Close". This activates tools that are part of the "Spatial Analyst" package, that we will use for contouring and the analysis required to calculate spatial rainfall.

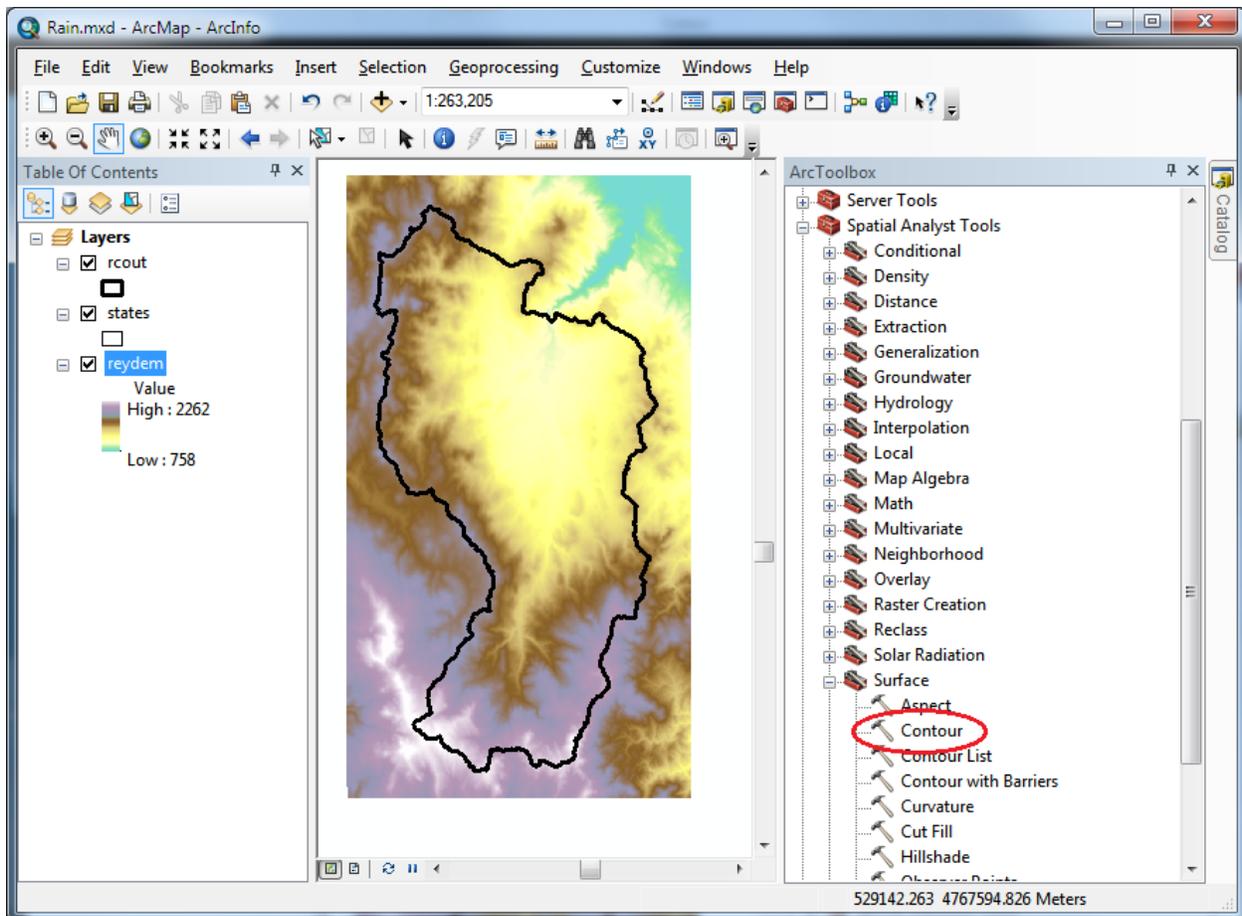


## Contours

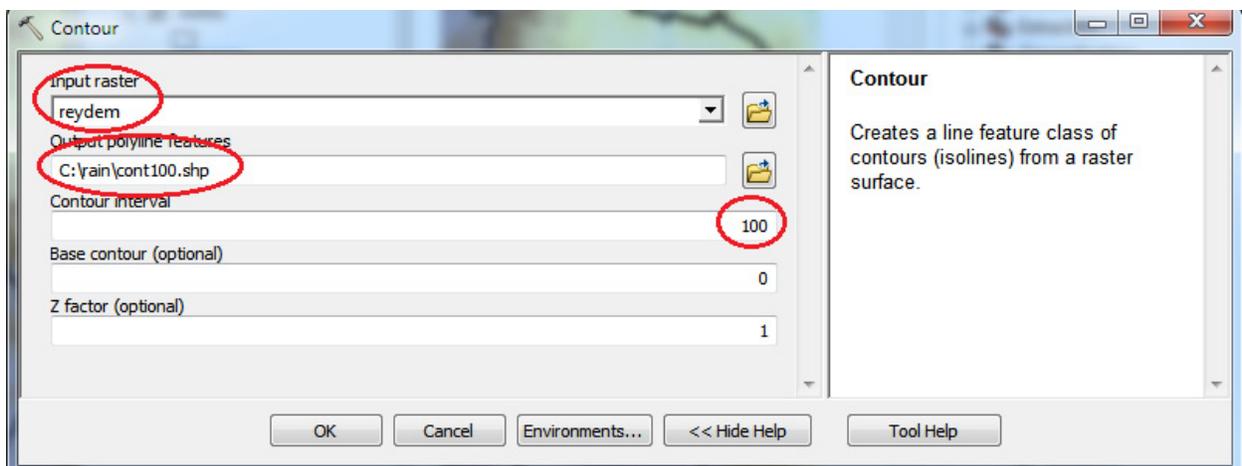
Contours are a useful way to visualize topography. Contours can be generated using a tool in the Spatial Analyst Tools toolset. First click on the ArcToolbox button to display ArcToolbox. This may appear in a tab on the right and need expanding.



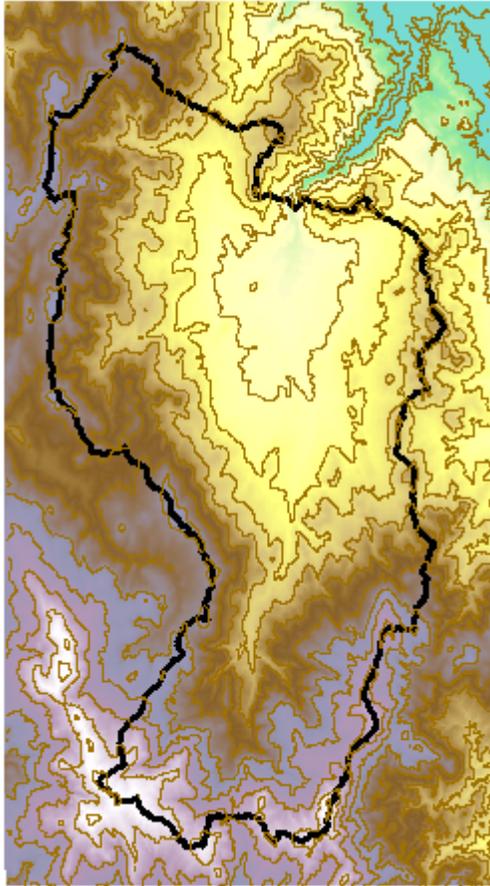
Expand on the tools as necessary clicking on the + sign and select the tool **Spatial Analyst > Surface > Contour...**



Set the inputs as follows with Input raster "reydem", output polyline features "cont100.shp" in the folder you are working in and contour interval 100. Click OK.



After a short while the Contour tool should complete and contours should be added to your map.



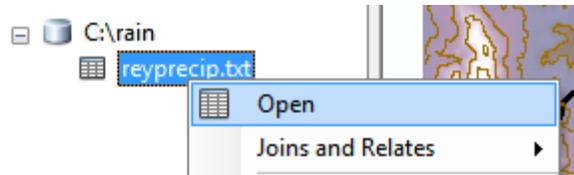
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## 2. Adding tabular data and identifying associated grid data.

The file `reyprecip.txt` contains annual average precipitation data for 25 stations in Reynolds Creek, with their coordinates. This data is described in (Hanson, C. L., (2001), "Long-Term Precipitation Database, Reynolds Creek Experimental Watershed, Idaho, United States," [Water Resources Research](#), 37(11): 2831-2834.) and is available from <ftp.nwrc.ars.usda.gov>. This data has already been processed from the hourly and breakpoint raw form into annual averages. I have used here only the 25 stations with 14 years or more of precipitation record.

(1) Use the  (Add Data) button to add the data table "**reyprecip.txt**". This file should then appear in the table of contents (source tab) of the active data frame, but not on the map, because the system does not (yet) know how to interpret the data geographically.

(2) Right click on this table of contents entry and select **Open**

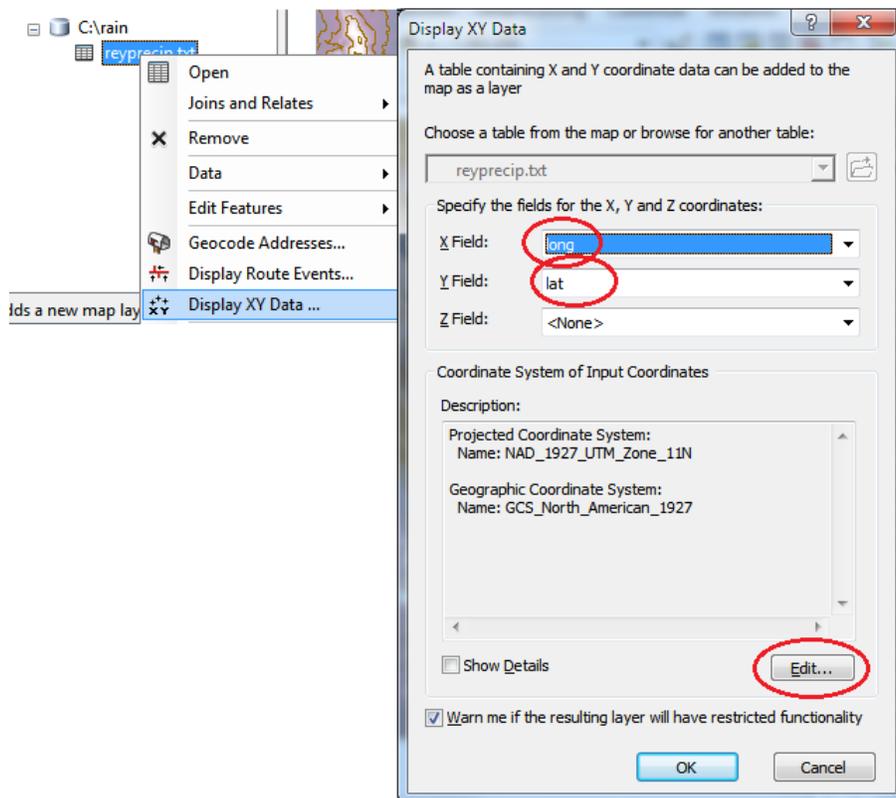


This displays in tabular form the data read from file reyprecip.txt.

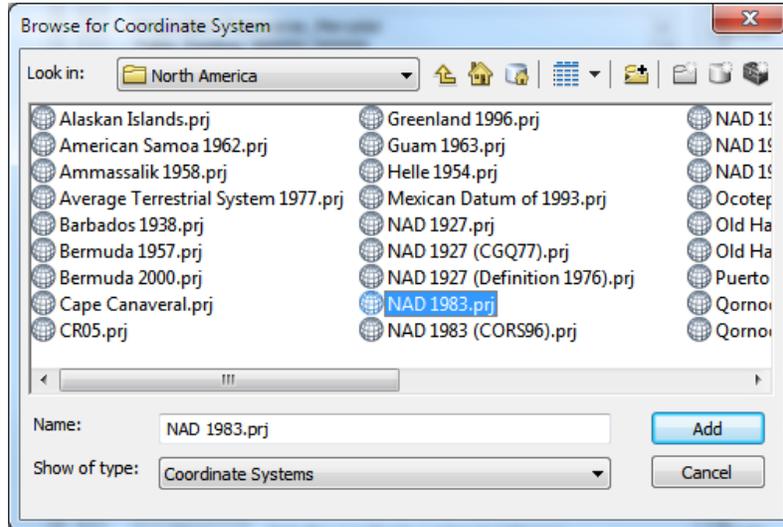
staid	long	lat	anntot	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
p012	-116.82704	43.296918	558.62	83.58	40.71	52.52	61.85	40.5	50.9	7.93	18.7	24.6	43.7	64.47	68.81
p015	-116.778196	43.287189	359.82	48.27	23.76	27.22	37.27	27.8	39.9	4.97	19.0	17.3	32.4	38.67	42.99
p023	-116.824586	43.284514	546.35	69.92	44.77	52.73	56.17	48.5	45.0	9.37	20.3	25.0	39.8	64.11	70.57
p024	-116.794887	43.27555	407.04	65.24	30.43	31.2	38.28	26.4	41.9	5.63	18.1	18.3	35.0	44.61	51.66
p033	-116.815216	43.260925	504.02	83.5	38.95	43.94	48.77	32.2	45.9	7.6	20.3	23.6	38.8	58.8	61.41
p049	-116.706134	43.247226	223.71	21.64	16.41	21.91	22.31	24.0	23.1	5.78	14.9	10.7	14.2	24.95	23.62
p053	-116.824106	43.228522	507.89	57.88	43.09	54.87	46.16	36.1	39.9	14.1	23.4	29.0	39.3	56.65	67.05
n057	-116.736589	43.228723	236.61	24.15	18.73	20.79	22.9	25	26.6	6.87	15.8	11.0	15.4	25.6	23.68

Note that there are fields named long and lat that give the locations of the precipitation stations in geographic coordinates. Close the table.

(3) Right click on the table of contents entry for 'reyprecip.txt' and select **display XY data**. At the display XY data dialog adjust the X field to **long** and Y field to **lat**. Do not click OK just yet.

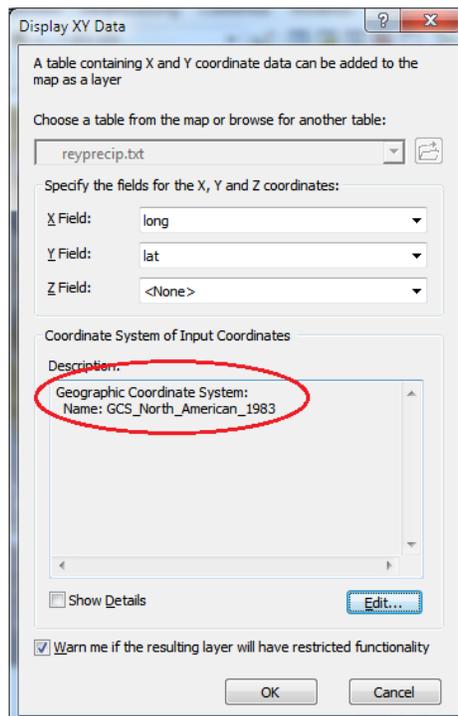


Click on the **Edit** button in the coordinate system of input coordinates. This allows you to specify the coordinate system of the X-Y data that is being displayed. In this case the rain gauge locations are in geographic coordinates and we are going to assume that they are relative to the North American Datum of 1983. At the spatial reference properties dialog click **Select**, then navigate the folders to Geographic Coordinate Systems/North America/NAD 1983.prj.



Click Add. The Spatial Reference Properties dialog should now show details of the spatial reference system you just chose. In GIS it is important that the Spatial Reference system for each data set is correctly specified, or else the system may not display and analyze it correctly.

Click **OK**. The Display XY-data dialog should now show the coordinate system that you chose.



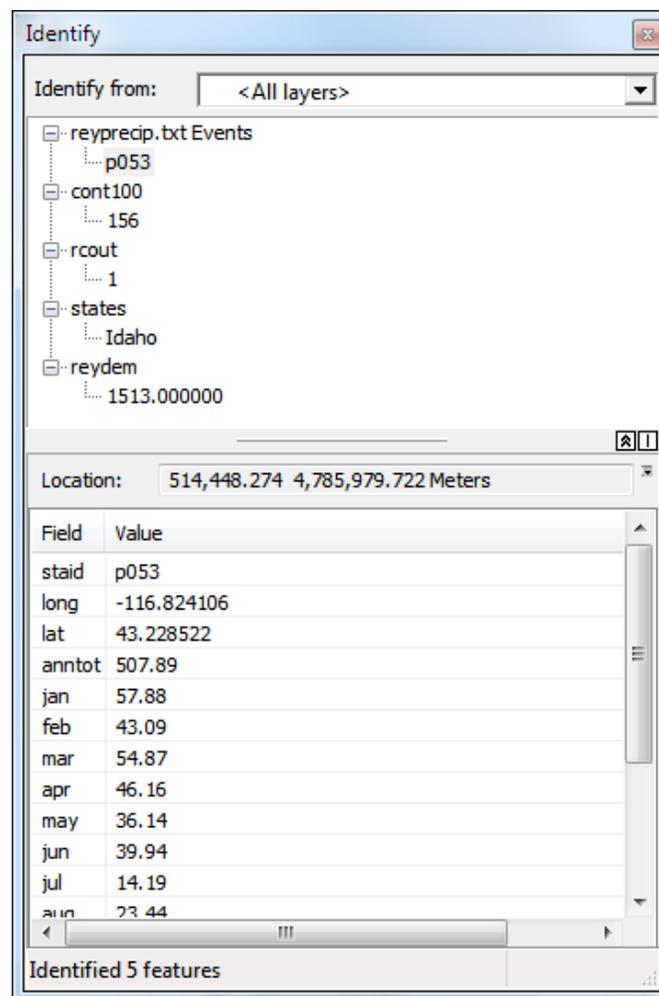
Click OK. Click OK to the warning about object IDs. The raingage locations should now be displayed on the map.

Something quite incredible has actually occurred here. The map data frame is in UTM coordinates inherited from the first dataset loaded. (One of the reasons you were instructed to load rcout.shp first is because it has a \*.prj file giving the coordinate system or projection associated with it.). However the precipitation gages were specified in latitude and longitude. By specifying that coordinate system for the data being displayed, the system has on the fly made the adjustment to display the data correctly. Change the symbology of these to something that depicts raingages.

(4) In addition to being useful for the display of geographic data, GIS is useful for the querying of numerical and text attribute data associated with the geographic data items. The identify

features tool  on the "Tools" toolbar is used to display attribute data of features in the Map

by clicking on them. Click on the Identify Features tool , then Click on the location on the map you are interested in, and in the **Identify Results** window select the object you are interested in.



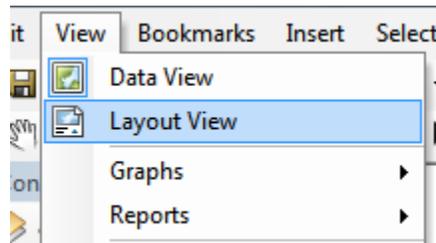
For example the above display indicates that the station identifier 'staid' of the gage I clicked on was P053, the annual precipitation 'anntot' at this location was 507.89 mm (The units need to be ascertained independently of the database). The elevation from the DEM is 1513 m, and this is in the state Idaho. You may need to adjust the layers selection at the top to control the layers you want to identify information from. Use the identify features tool to examine the attributes associated with raingages and other layers displayed.

1. *To hand in. Report the Station Identifier (staid), elevation and mean annual precipitation at the most northern and most southern rain gages in this dataset.*

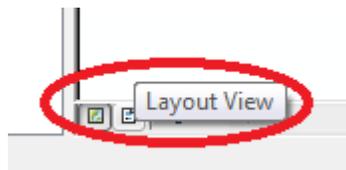
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### 3. Preparing a Layout for Presentation

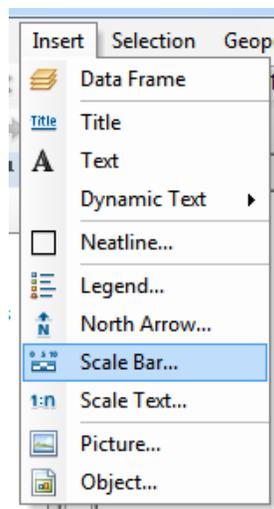
(1) Change the format of the display window from Data View to Layout View by clicking on **View/Layout View**,



You may also toggle between **layout** and **data** view using the buttons on the bottom of the map display

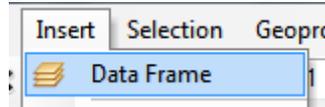


The Layout View is used to decorate the map for printing or presentation. **Insert/Scale bar**

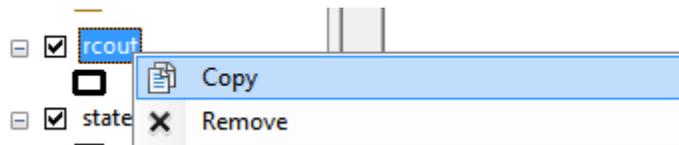


and **Insert/North arrow** to add presentation items to your layout.

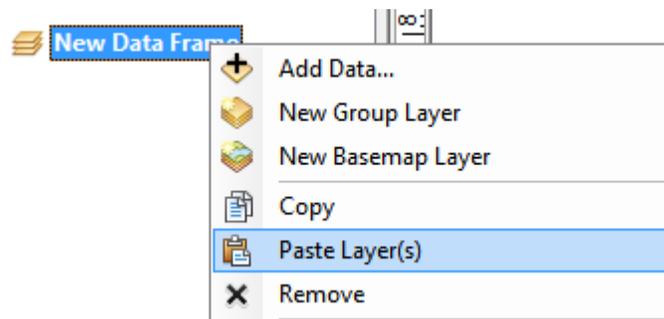
(2) Make a location map by inserting a new data frame.



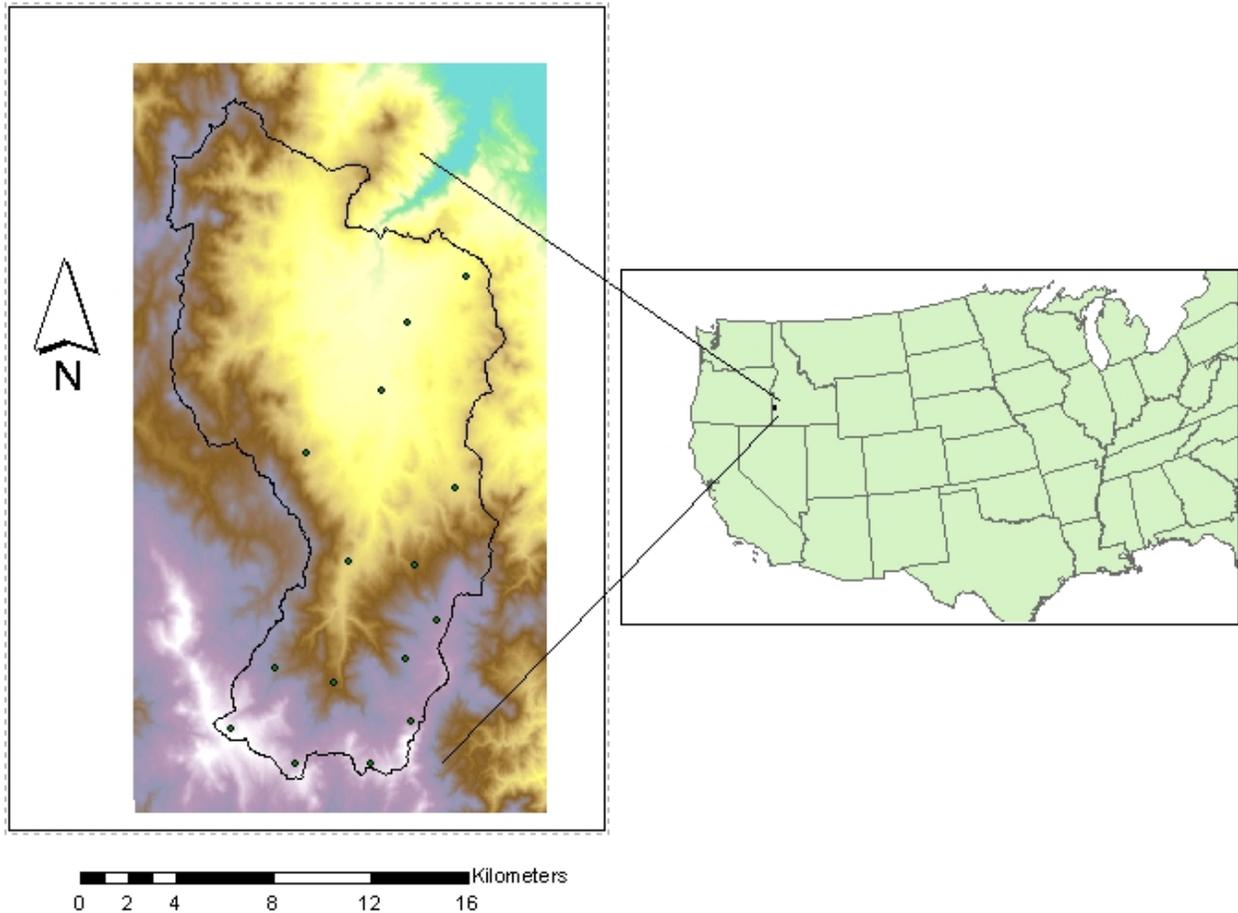
Data frames are groups of feature classes, symbology, and display attributes (projection, extent etc.) that form part of a map. In Data View only one is displayed (the active data frame). In Layout View each data frame is displayed in a box indicating where it appears in the larger layout document. With multiple data frames present the right click menu item **activate** is used to control which is active. Right click on layers in the table of contents to copy then paste between the data frames. Copy the rcout shapefile first so that the new dataframe inherits the correct projection properties, then copy the states shapefile.



Right click and "paste layer" on the new data frame



Use the tools on the "tools" toolbar, and the "layout" toolbar to adjust the layout and positioning of data frames. Use the draw toolbar to add lines or annotation. Produce a layout showing the location of Reynolds Creek similar to below.



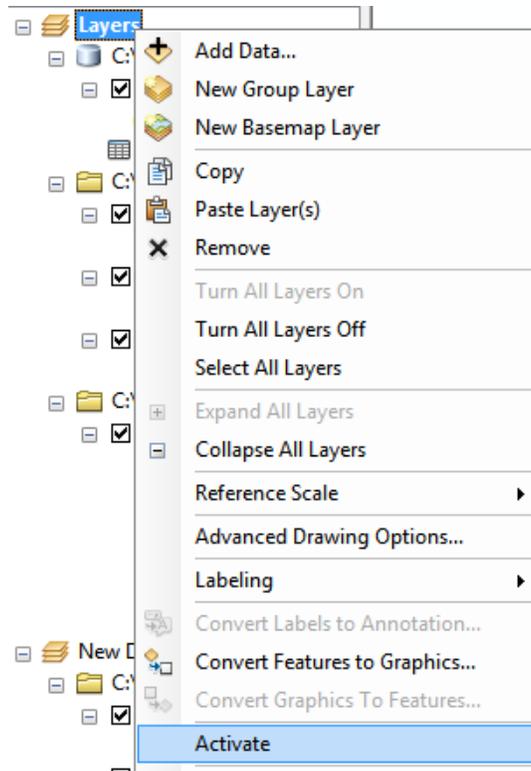
2. To hand in. A layout showing the watershed boundary and topography of Reynolds Creek and its location in the Western U.S.

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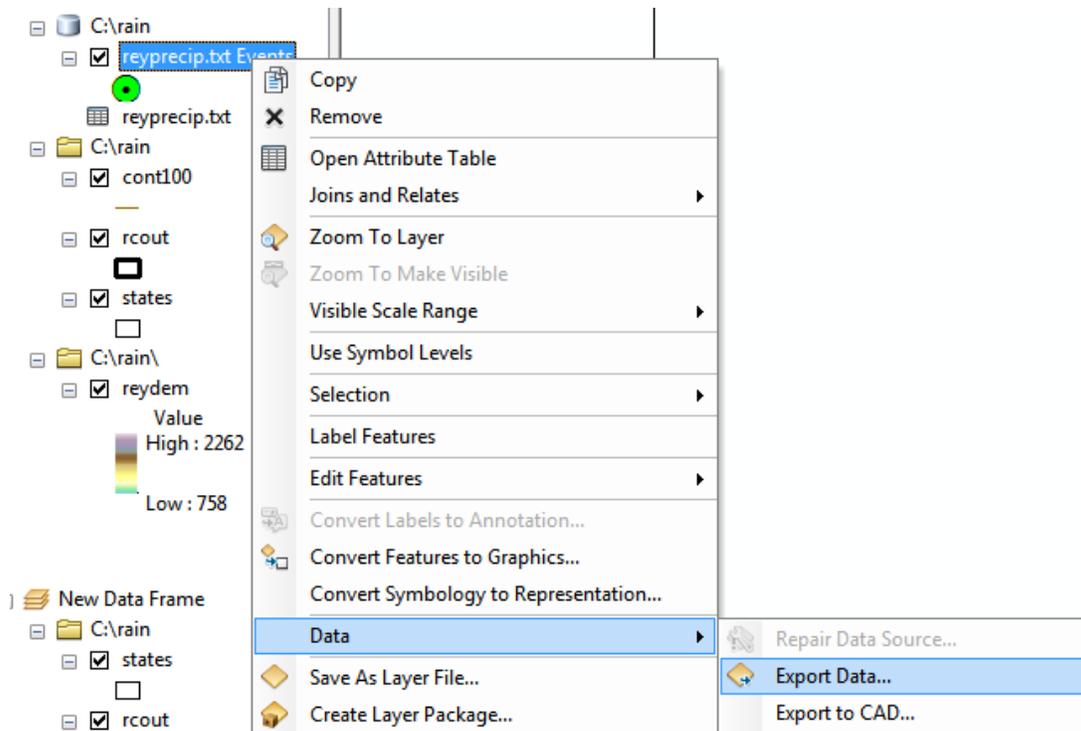
#### 4. Calculation of Area Average Precipitation using Thiessen Polygons

With this bare essentials introduction to ArcMap will will now turn our focus back to hydrology and the calculation of the area average mean annual precipitation over the watershed using Thiessen polygons.

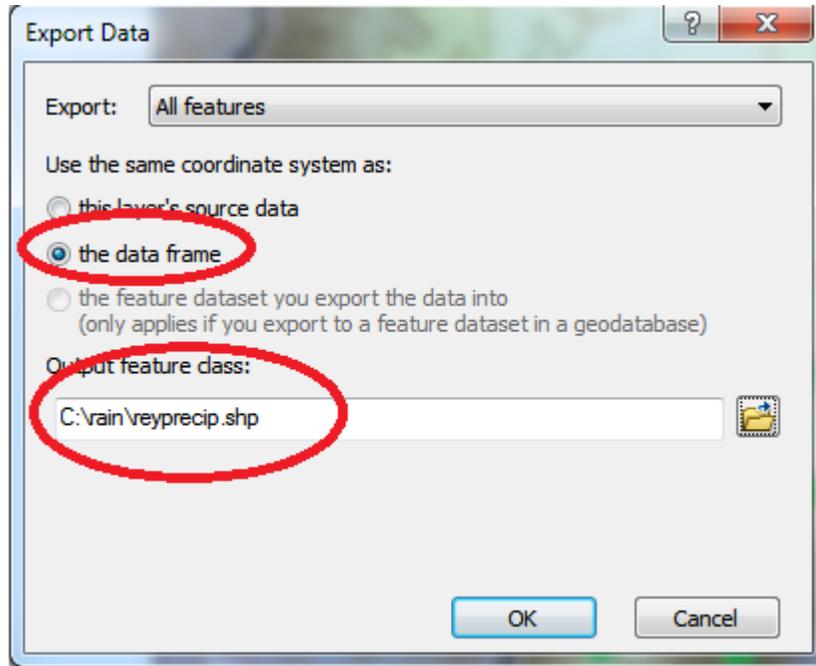
(1) Preparation of rain gage shapefile. If you are still in layout view toggle back to data view and if necessary right click on the "Layers" dataframe and select activate.



Convert the reyprecip.txt events display to a shapefile. Right click on "reyprecip.txt events" and select **Data/Export Data**.



At the export data box, click **use the same coordinate system as the data frame** (to convert from latitude and longitude to UTM coordinates) and specify the output name "reyprecip.shp". Click OK.

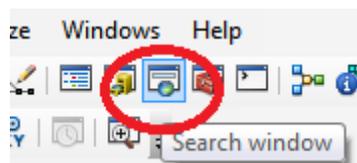


Click "Yes" to add the exported layer to the map. Right click on reyprecip.txt in the table of contents to remove this from the map. "Events" are a temporary dataset and by converting to a shapefile we have made the geographic expression of the raingauges permanent so no longer need this temporary layer.

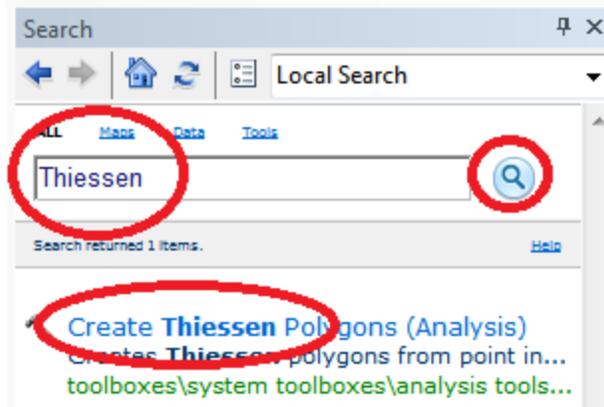
Thiessen polygons associate each point in a watershed with the nearest raingage. Select the tool **Analysis Tools → Proximity → Create Thiessen Polygons**



In case you do not know where to find a tool that you think you need, ArcInfo also has a handy search capability. Click on the Search Window button

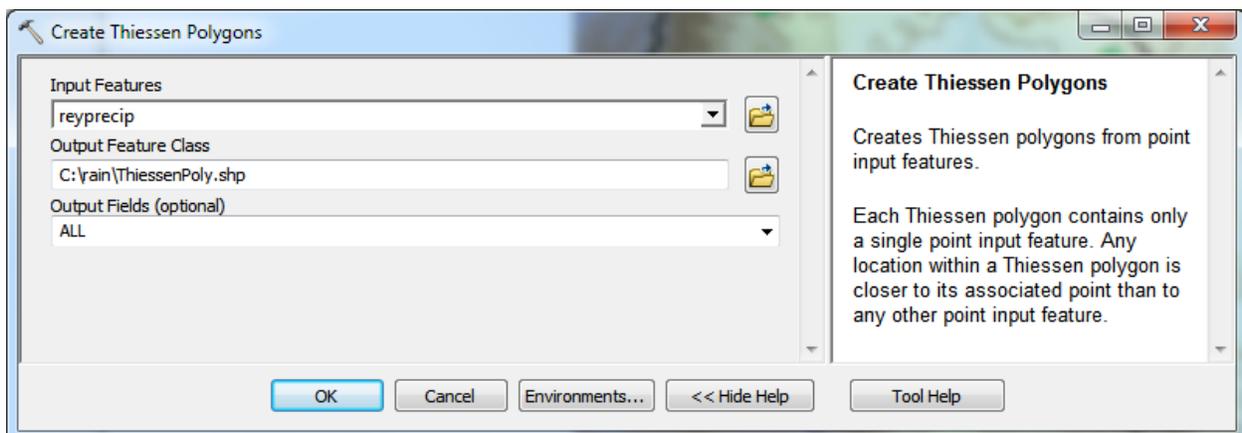


Then enter the term Thiessen in the Search Window and click on the search button

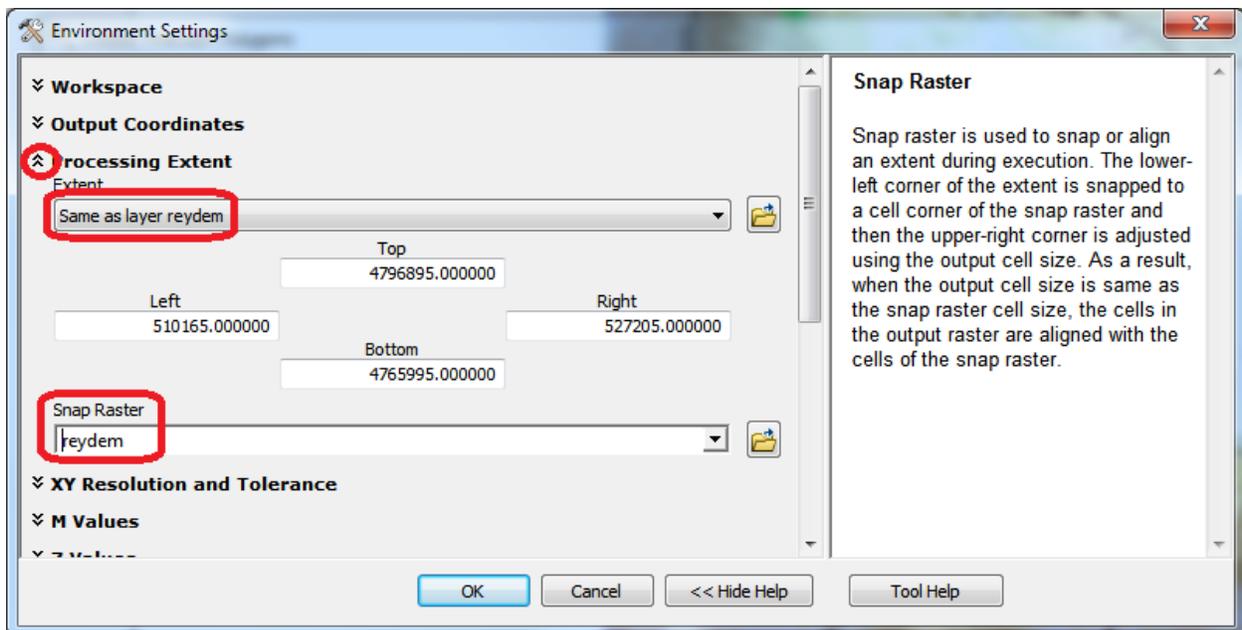


The Create Thiessen Polygons tool can also be opened from the link in Search returned items.

Specify **ReyPrecip** as the Input Features. Set the output feature class to be **ThiessenPoly.shp** (saving it in the folder where you are working, e.g. c:\rain) and indicate that ALL fields should be output. Do not click on OK just yet

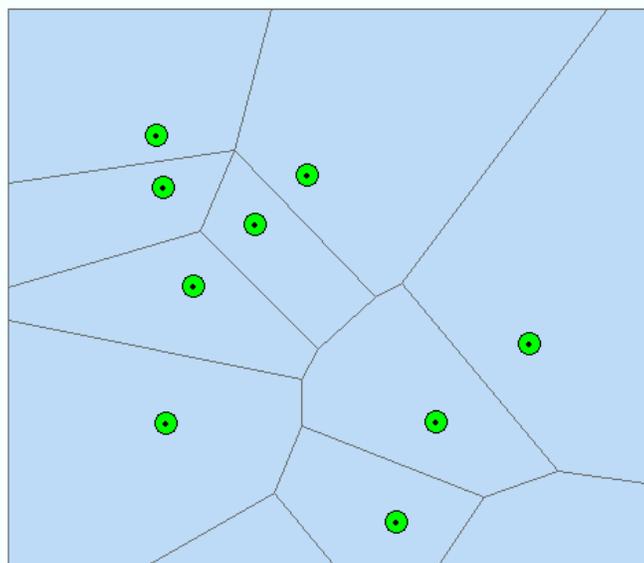


Click on Environments, then expand Processing Extent and in the Extent dropdown select "Same as layer reydem". Also select "reydem" for Snap Raster.

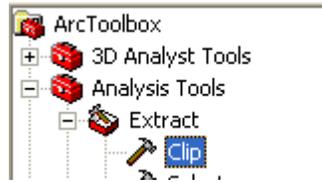


These settings ensure that the Thiessen polygons being created will cover the full extent of the DEM which includes the entire watershed. If you forget to do this you may end up with Thiessen polygons that do not cover your entire watershed. Now click OK to dismiss the Environment settings and OK again to create Thiessen polygons..

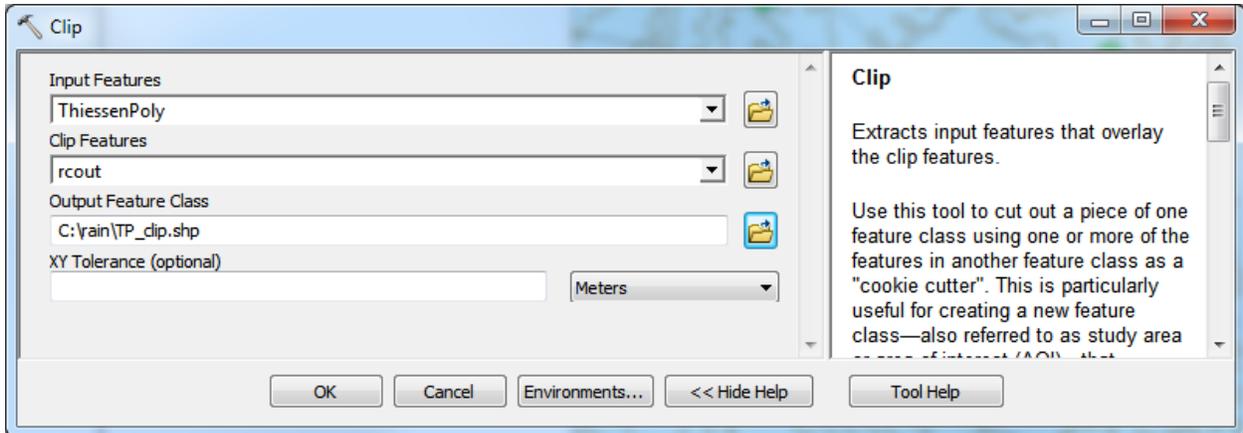
The result is a Thiessen polygon shapefile.



Next task is to clip these polygons to the watershed boundary. Open the clip tool

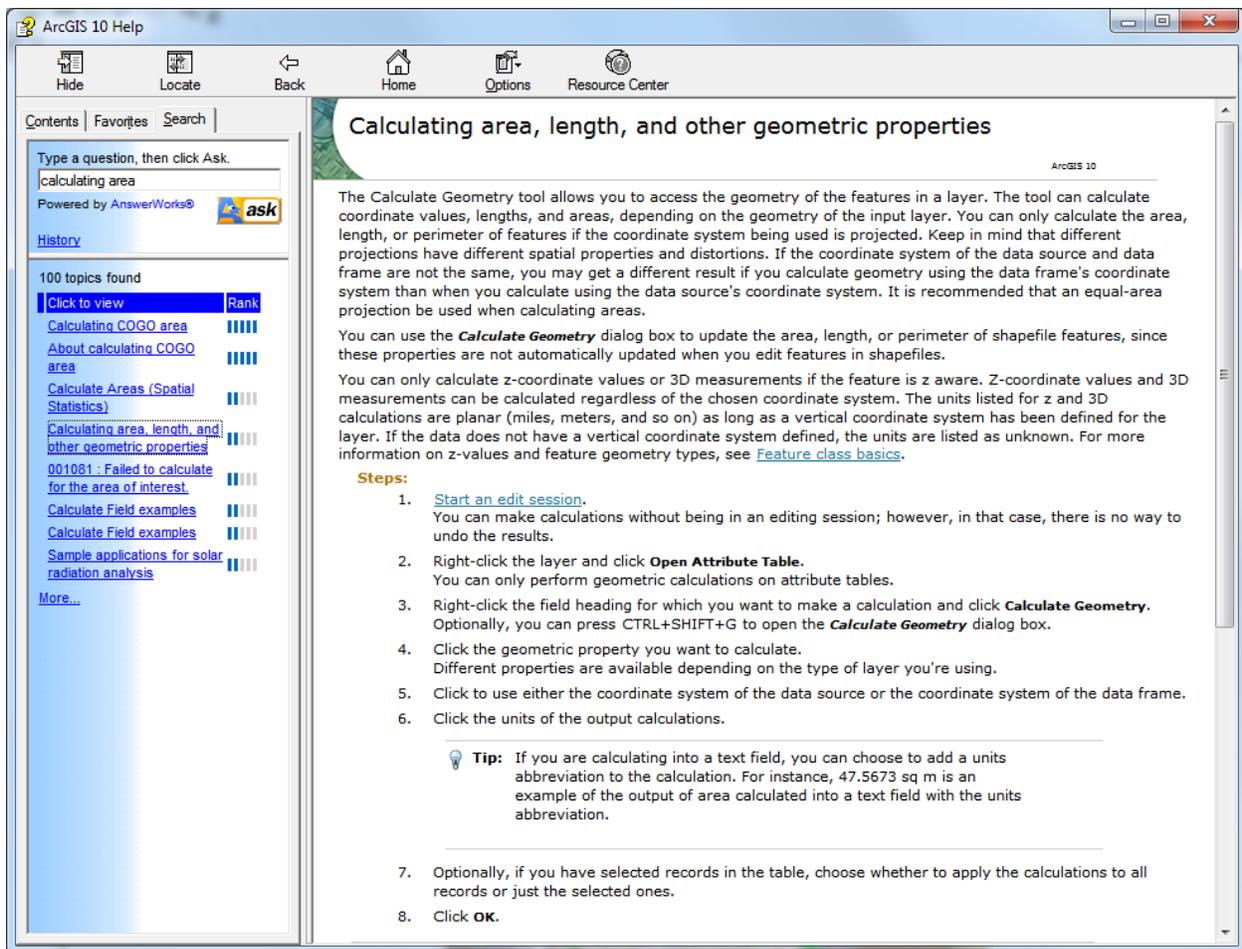


Specify the Input Features as ThiessenPoly and Clip Features rcout. Save the resulting Output Feature class in a shapefile TP\_clip.shp (in the folder you are working in, e.g. c:\rain). Click OK.

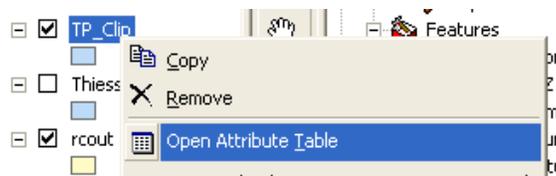


The result is a shapefile of Thiessen polygons clipped to the watershed boundary.

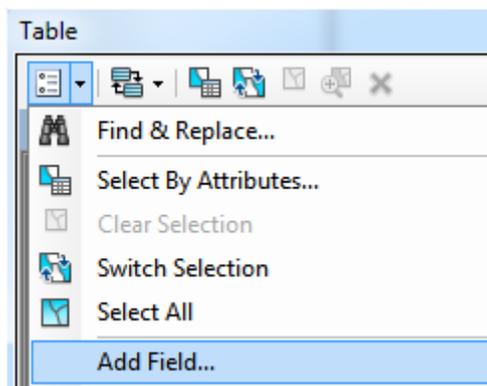
Next we need the area of each of these polygons to do the area weighted averaging. Open ArcGIS help and type “Calculating area” in the search entry. Select the “Calculating area, length, and other geometric properties” topic and read how to calculate geometry (area) for a Feature class.



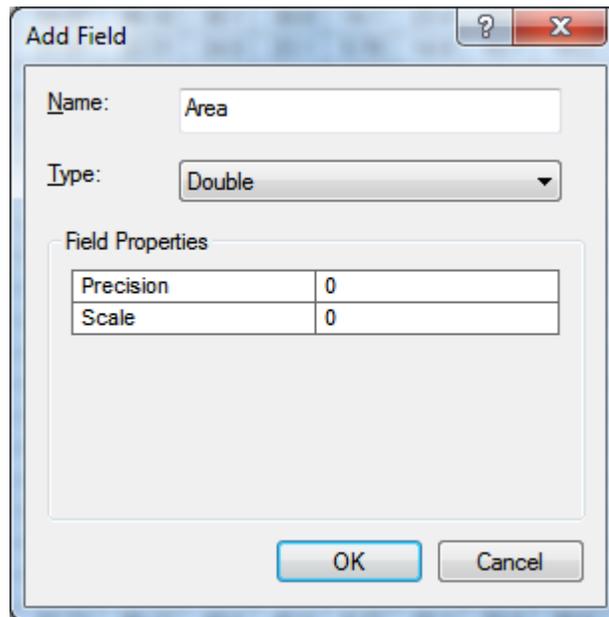
Right click on the TP\_Clip table of contents entry and open attribute table



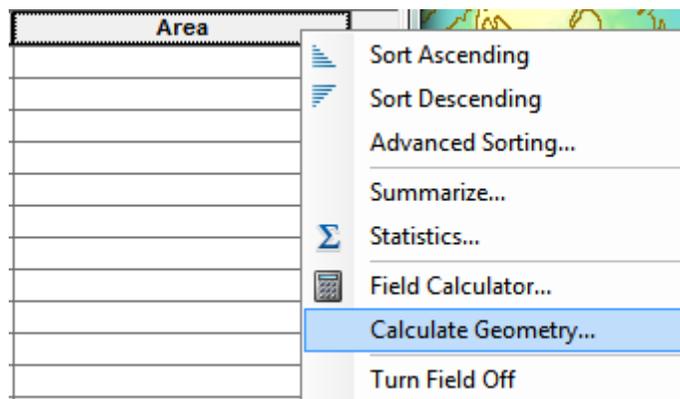
Click on the Table Options button (top left) and select Add Field.



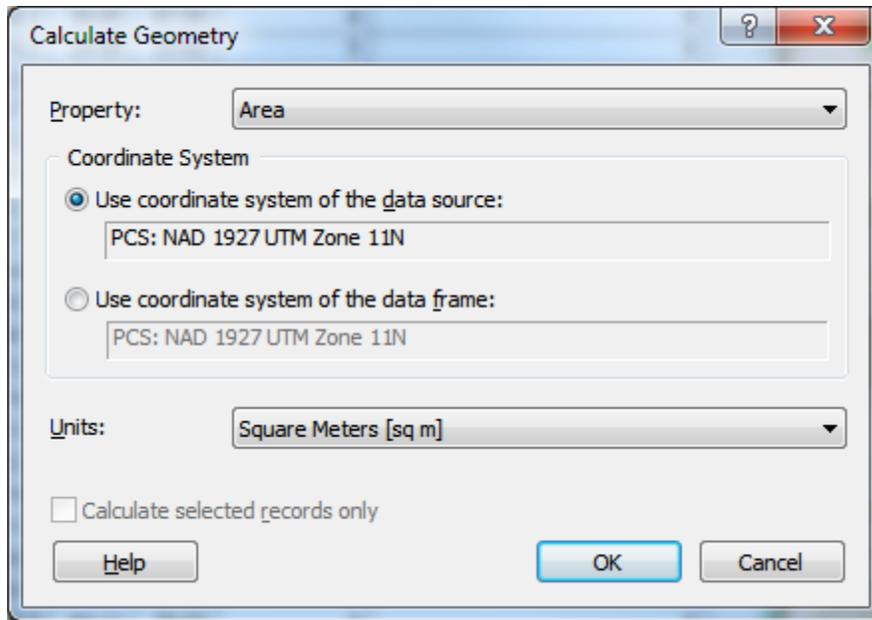
Specify the Name as Area and Type as Double. Click OK.



Note that a field named Area that is filled with 0 has been added to the attribute table. Right click on the header of the new Area field and select Calculate Geometry.



Click Yes to the warning about not being able to undo the calculations, verify that the settings for calculating area are what you want and click OK



Note that Area values have now been computed.

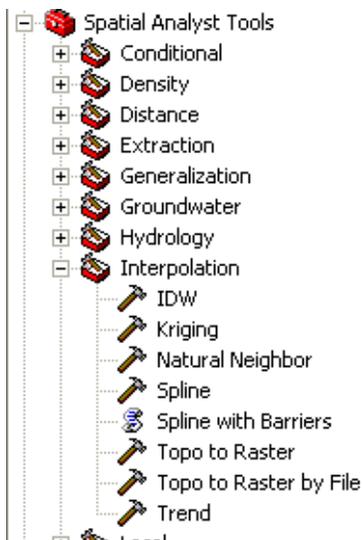
Shapefiles are actually comprised of multiple files, one of which is a \*.dbf file that contains the attribute table. This is a format that Excel can read. Locate the file TP\_clip.dbf in the folder where you are working and open it using Excel. Use Excel to calculate the area weighted average of annual total precipitation.

*3. To hand in. A layout showing the Thiessen polygons. Report the station identifier of the precipitation gage that is associated with the largest Thiessen polygon. Report the Thiessen polygon Basin average mean annual precipitation.*

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## **5. Estimate basin average mean annual precipitation using Spatial Interpolation/Surface fitting.**

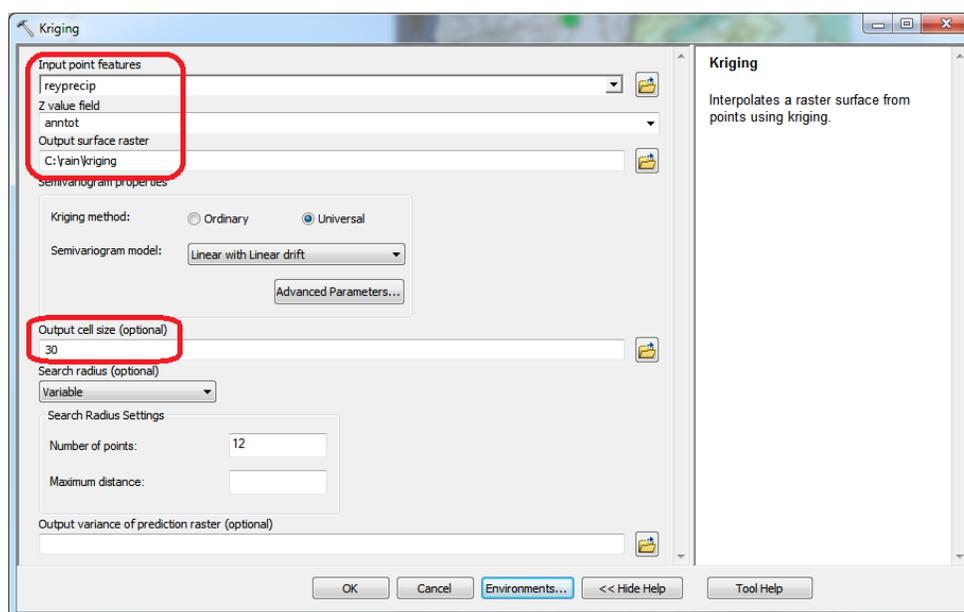
The Thiessen polygons method is probably the simplest and least sophisticated form of rainfall averaging. ArcGIS provides other spatial interpolation capabilities in the **Spatial Analyst Tools** → **Interpolation toolbox**.



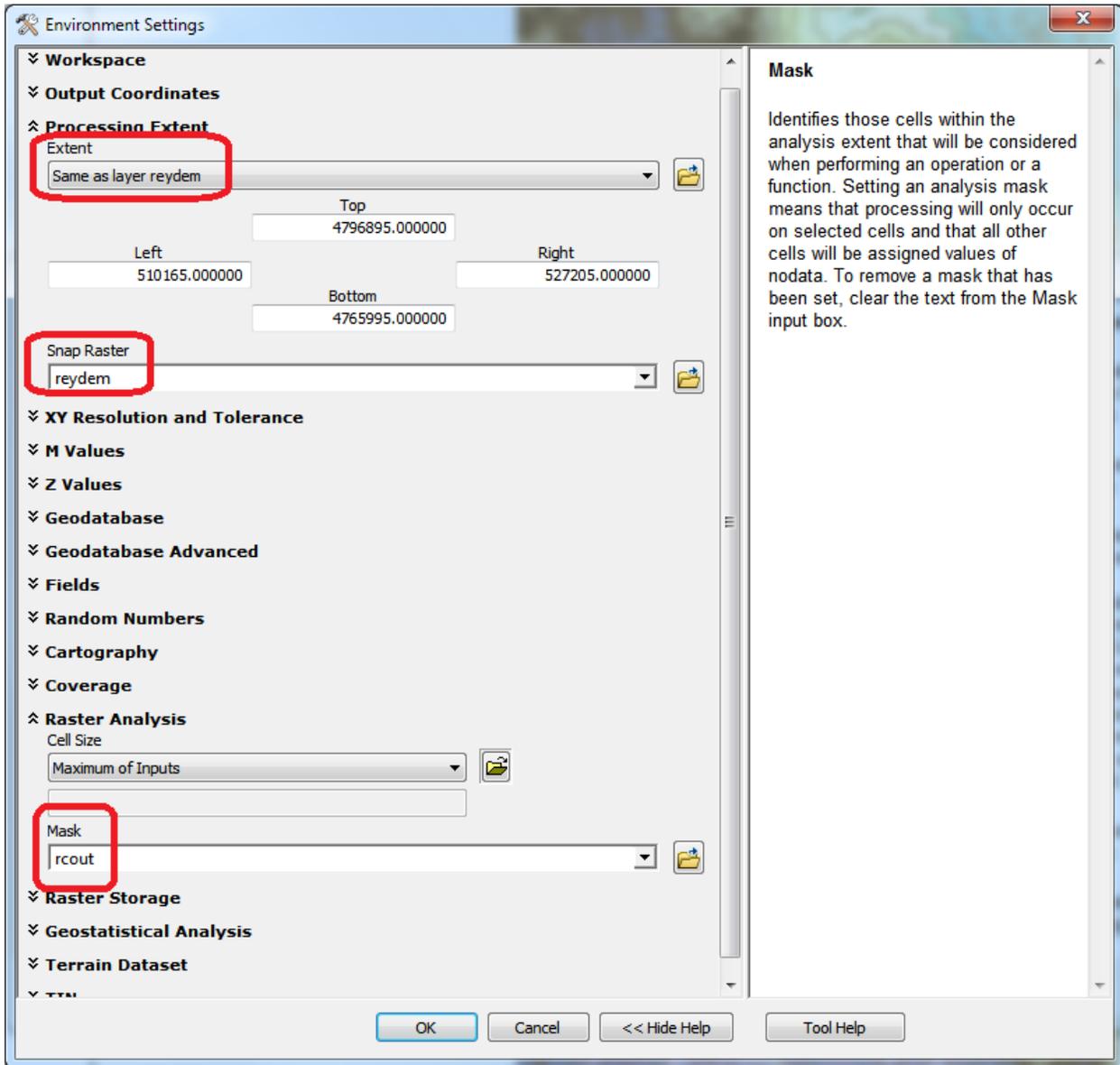
We will not, in this exercise, concern ourselves too much with the theory behind each of these methods. You should however be aware that there is a lot of statistical theory on the subject of interpolation, which is an active area of research. This theory should be considered before practical use of these methods.

For this exercise I suggest you just try a few of the methods, examining the surface that results to see if you like them. Some options do not work due to insufficient data to estimate the necessary variogram (a statistical function quantifying the spatial dependence used as a basis for kriging interpolation) and some options result in negative precipitation. Use the input points from "reyprecip" and Z value field as "anntot". You should also use the Environments Settings for the Tool chosen to control the extent (Processing Extent) and mask (in Raster Analysis) the output to the watershed boundary (rcout).

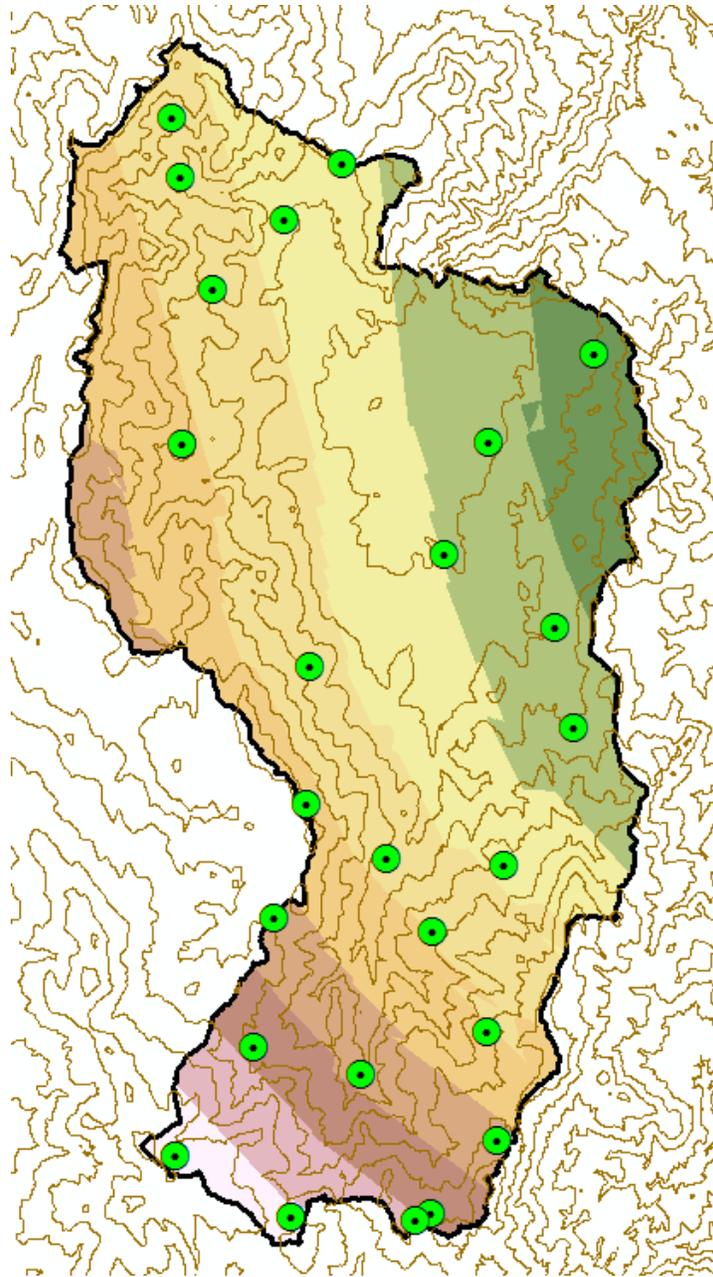
Following is how I set up a Universal Kriging interpolation.



I used the following Environment Settings.

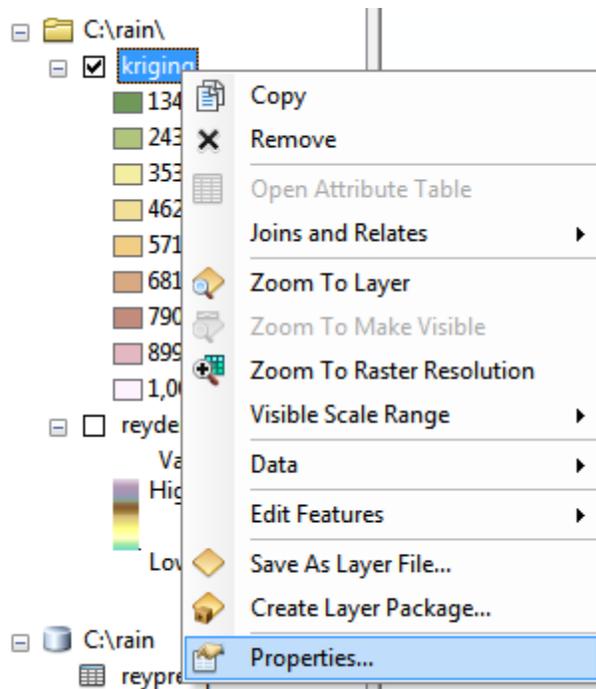


These resulted in a raster grid being evaluated within the boundaries of the Reynolds Creek Outline giving a precipitation surface interpolated by Universal Kriging.

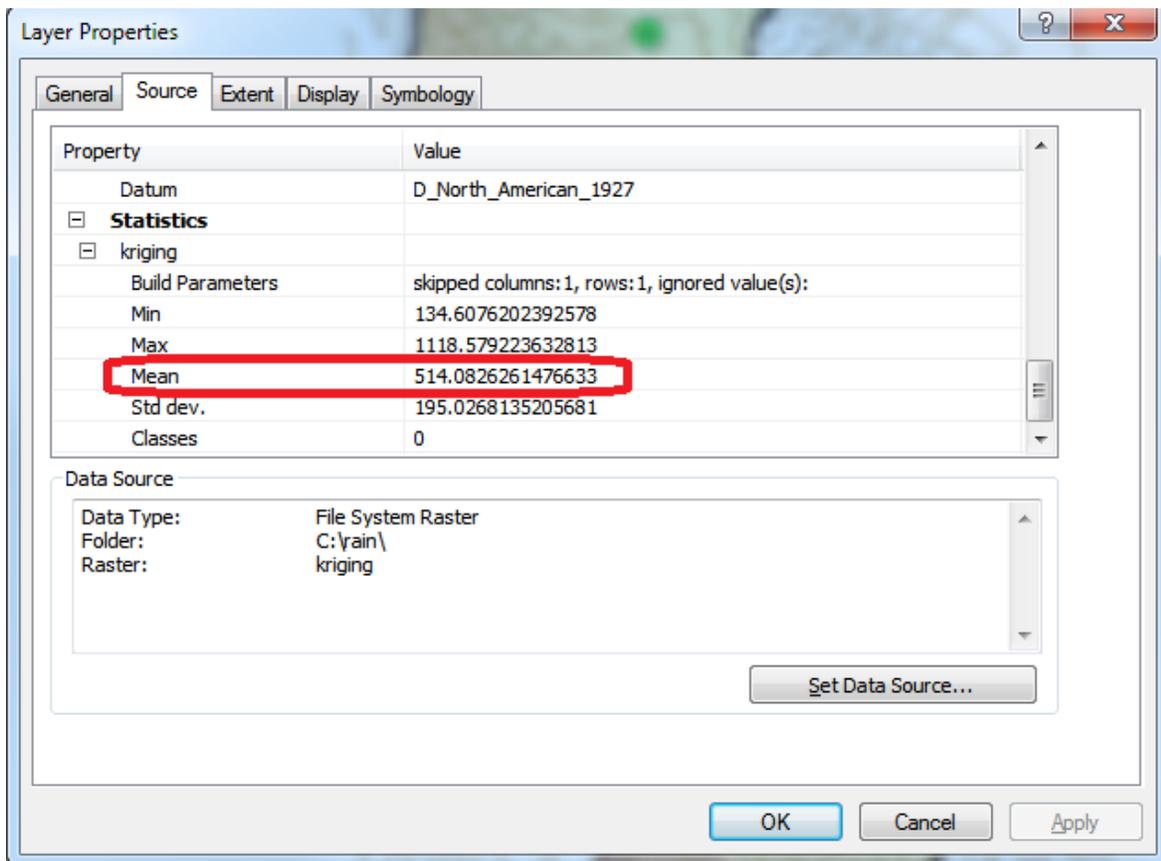


Other methods may be similarly configured.

Right click on the interpolated layer created and select Properties.



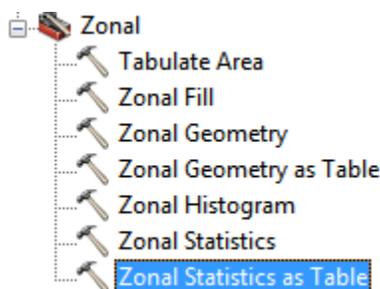
Then select the Source tab and scroll down to where statistics are reported and read off the Mean Interpolated precipitation value



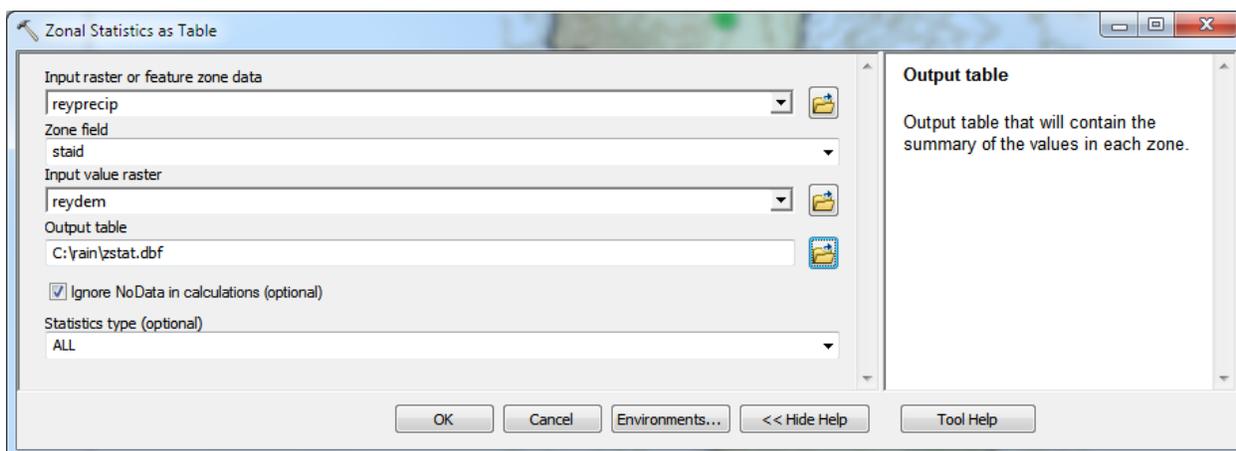
4. To hand in. A layout showing the interpolated mean annual precipitation surface over Reynolds Creek. Report what method you used. Report the basin average mean annual precipitation from the "anntot" attribute, as well as minimum, maximum and standard deviation for this within the basin area (i.e. the analysis mask must have been set using rcout.shp).

## 6. Estimation of area average mean annual precipitation by the Hypsometric method using a precipitation versus elevation relationship.

The elevation values associated with each precipitation gage may be determined automatically using the **Spatial Analyst/Zonal/Zonal Statistics as Table** function



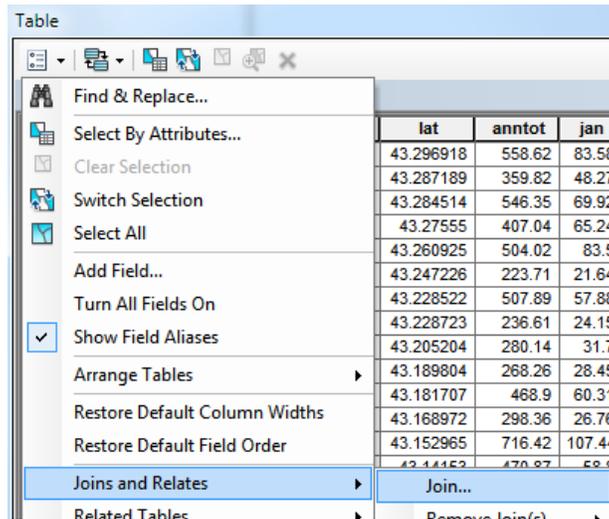
Set the Input raster or feature zone data to "reyprecip" (this is the dataset defining the locations for which statistics are to be evaluated), the zone field as "staid" (a unique field in reyprecip to join the table produced to reyprecip). Set the input value raster to "reydem". This is the raster whose values will be used in calculating statistics at the points (zones in general) specified by the zone data. Choose an output table name that you like (or stick with the default). By naming the Output table \*.dbf the result is in DBF format that is Excel Readable. Click OK.



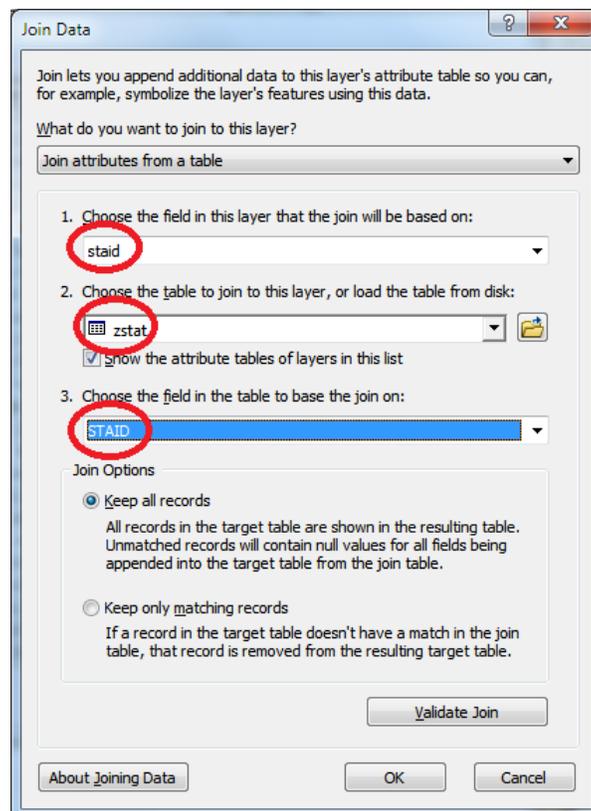
Upon completion a table "zstat" should be added to your map table of contents. You can right click on it and open it to see the zonal statistics calculated (minimum, maximum, mean, range etc.). These relate to the elevation values at the points in reyprecip.shp. Because reyprecip.shp

is a point shape file the minimum, mean, etc are all the same. Had reyprecip.shp been a polygon or line shape file these would have been statistics over the space covered by the polygons or lines.

Close the zstat table and open the attribute table associated with "reyprecip". From table options select **Joins and Relates/Join**.

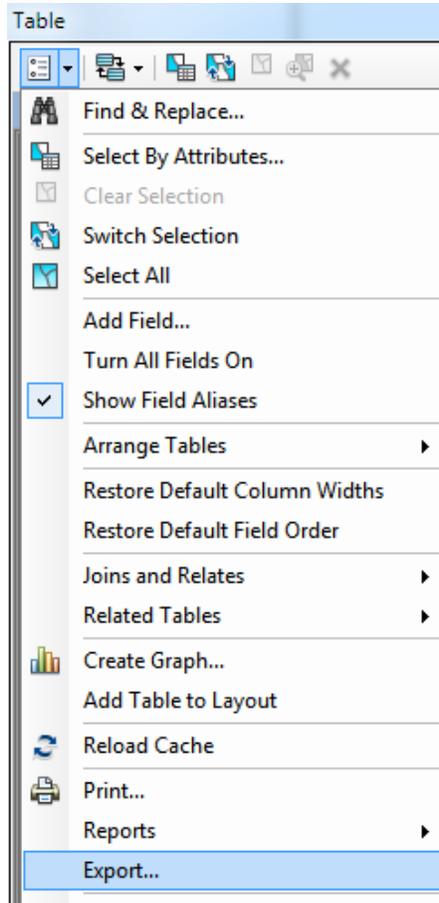


At the Join Data box set the inputs as follows and click OK. Click Yes (or No – it does not matter) to the Create Index box.

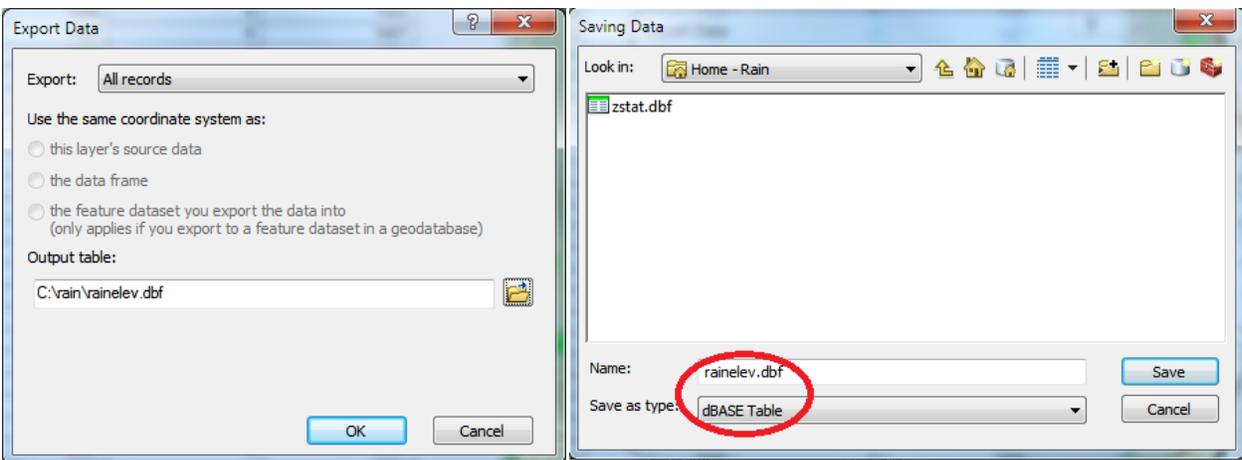


This joins together the two tables using the "staid" field to match records. The result is an extended reyprecip attribute table that also includes the join results on the right.

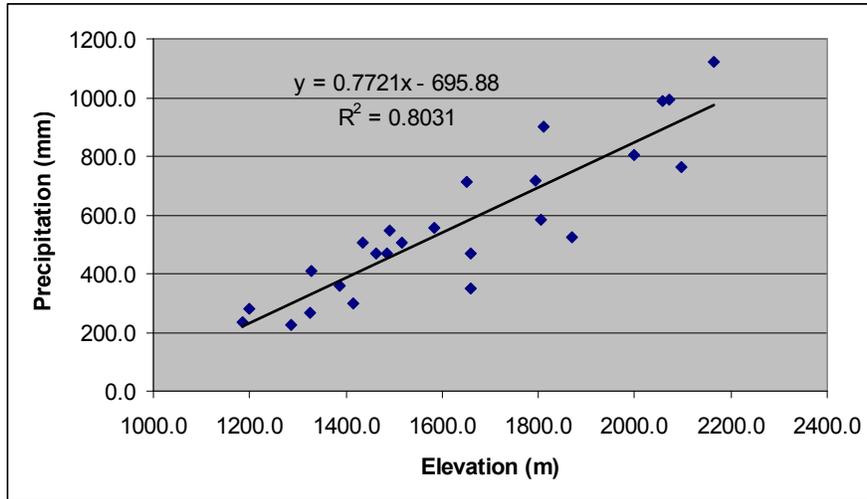
From table options select Export.



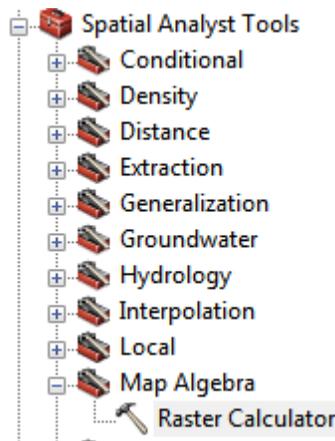
Specify an Output table name (e.g. rainelev.dbf) being sure to set "Save as type" as dBASE Table.



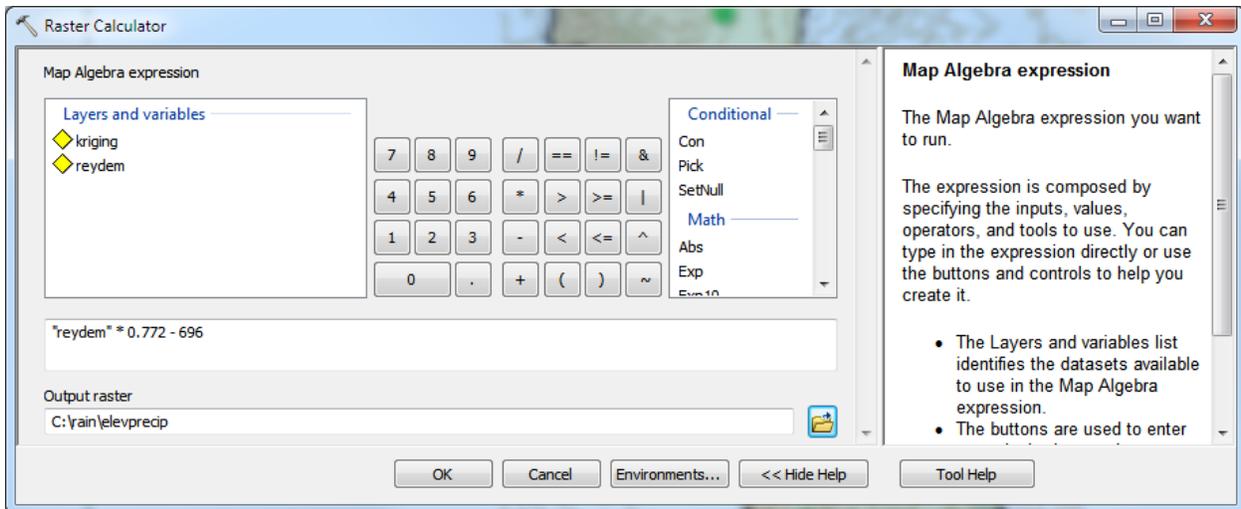
There is no need to add the new table to the current map. Open the rainelev.dbf table using Excel. Develop a relationship between total precipitation (i.e. anntot in column D) and one of the fields representing elevation (e.g. Mean in column Y)



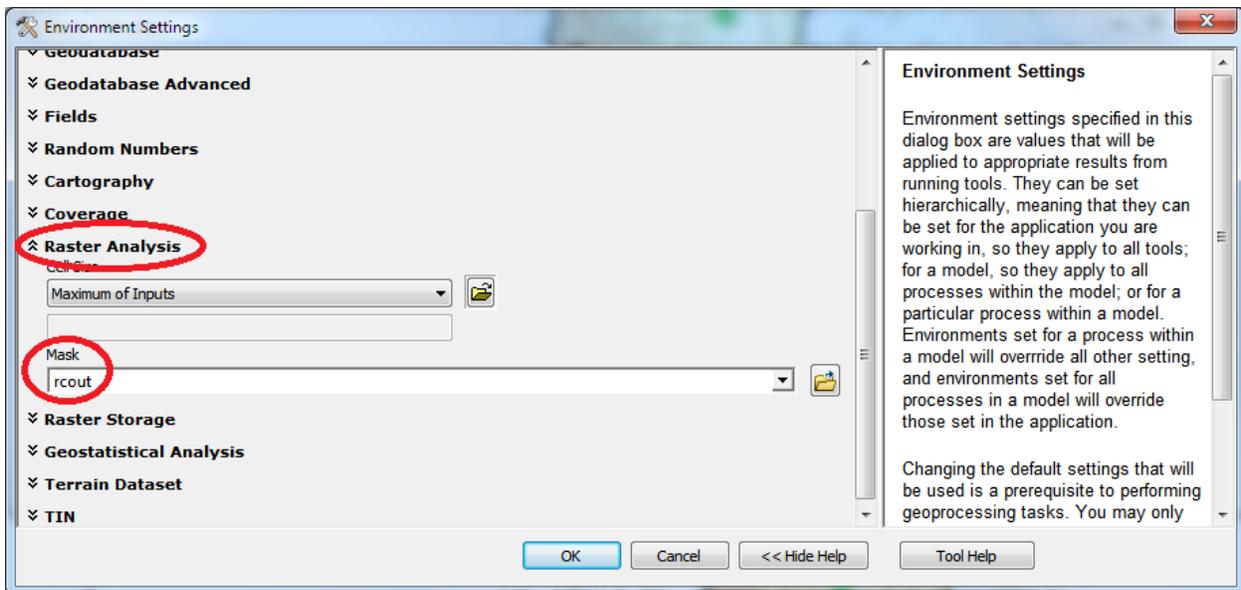
This represents a relationship that gives precipitation as a function of elevation. Now use **Spatial Analyst Tools/Map Algebra/Raster Calculator** to compute a raster of precipitation based upon elevation data and this relationship, e.g.  $([Reydem] * 0.772 - 696)$



Set the inputs as follows



Do not click OK, just yet. First click **Environments** and expand Raster Analysis and set Mask to rcout. This controls the results calculated to be within the rcout polygon that represents the watershed.



Click OK to this box and again to the Raster Calculator box. The result is a raster that is a rescaling of the individual raster cell elevation values to their corresponding precipitation estimated based on the elevation relationship,

Right click on the new "elevprecip" raster and select **Properties/Source**. Scroll down to Statistics to examine the mean of the result. This represents the mean annual precipitation estimated using the hypsometric method.

5. To hand in. A layout showing the mean annual precipitation surface over Reynolds Creek estimated from elevation. Report the basin average annual total precipitation, as well as

*minimum, maximum and standard deviation for this within the basin area (i.e. the analysis mask must have been set using rcout.shp). Report your precipitation vs elevation relationship.*

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### **Summary of GIS work to be turned in**

- 1. To hand in. Report the Station Identifier (staid), elevation and mean annual precipitation at the most northern and most southern rain gages in this dataset.*
- 2. A layout showing the watershed boundary and topography of Reynolds Creek and its location in the Western U.S.*
- 3. A layout showing the Thiessen polygons. Report the station identifier of the precipitation gage that is associated with the largest Thiessen polygon. Report the Thiessen polygon Basin average mean annual precipitation.*
- 4. A layout showing the interpolated mean annual precipitation surface over Reynolds Creek. Report what method you used. Report the basin average mean annual precipitation from the "anntot" attribute, as well as minimum, maximum and standard deviation for this within the basin area (i.e. the analysis mask must have been set using rcout.shp).*
- 5. A layout showing the mean annual precipitation surface over Reynolds Creek estimated from elevation. Report the basin average annual total precipitation, as well as minimum, maximum and standard deviation for this within the basin area (i.e. the analysis mask must have been set using rcout.shp). Report your precipitation vs elevation relationship.*