Exercise 3: Spatial Analysis
GIS in Water Resources

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Updated to ArcGIS Pro by Paul Ruess, August 2016

Goal
The goal of this exercise is to serve as an introduction to Spatial Analysis with ArcGIS.

Objectives

- Calculate slope from a grid digital elevation model
- Apply model builder geoprocessing capability to program a sequence of ArcGIS functions
- Use ArcGIS.com services to access and extract elevation data
- Interpolate data values at points to create a spatial field to use in hydrologic calculations. Use this to calculate watershed area average precipitation
- Use raster data and raster calculator functionality to calculate watershed attributes such as mean elevation, mean annual precipitation and runoff ratio.

Computer and Data Requirements

To carry out this exercise, you need to have a computer, which runs ArcGIS Pro 1.2 or higher. The necessary data are provided in the accompanying zip file,
http://www.caee.utexas.edu/prof/maidment/giswr2016/Ex3/Ex3Data.zip

Part 1. Slope calculations

1.1 Hand Calculations
Given the following grid of elevations. Calculate by hand the slope and aspect (slope direction) at the grid cell labeled **A** using
(i) The standard ESRI surface slope function (see lecture 7 slides 42-45 in SpatialAnalysis.pptx)
(ii) The 8 direction pour point model (see lecture 7 slides 46-47 in SpatialAnalysis.ppt)
This subject is also described in pp. 5-7 of the Slope handout
http://hydrology.usu.edu/dtarb/giswr/2016/Slope.pdf

Refer to the slides http://www.caee.utexas.edu/prof/maidment/giswr2016/Visual/SpatialAnalysis.pptx from lecture 7 to obtain the necessary formulas for each of these methods. Refer also to the "Computation of Slope" readings for a deeper understanding of slope.

Grid cell size 10m

45.4	**46.1**	**47**	**48.6**	**47.7**
45	**46.1**	**46.4 B**	**47.9**	**47.4**
45.1	**45.8**	**46.8 A**	**48.6**	**47.6**
47.5	**48**	**47.7**	**50.6**	**48.3**

Comment on the differences and indicate which you think is a better approximation of the direction of water flow over the surface.

To turn in: Hand calculations of slope at point A using each of the two methods and comments on the differences.

1.2 Verifying calculations using ArcGIS

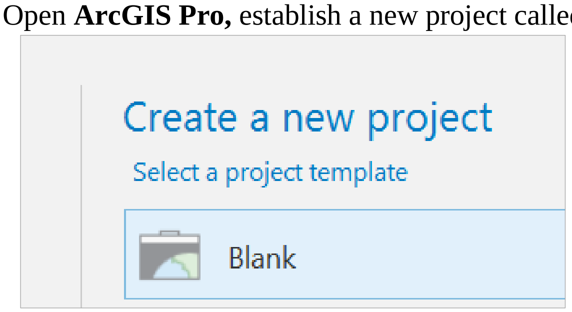
Verify the calculations in (1.1) using ArcGIS Hydrology and Surface Toolbox functions.

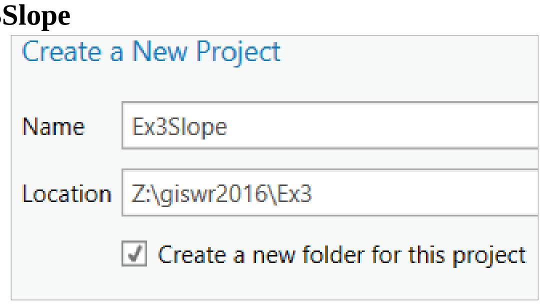
Save the following to a text file 'elev.asc' (This file is also included in http://www.caee.utexas.edu/prof/maidment/giswr2016/Ex3/Ex3Data.zip)

```
ncols         5
nrows         4
xllcorner     0
yllcorner     0
cellsize      10
NODATA_value  -9999
45.4  46.1  47    48.6  47.7
45    46.1  46.4  47.9  47.4
45.1  45.8  46.8  48.6  47.6
47.5  48    47.7  50.6  48.3
```

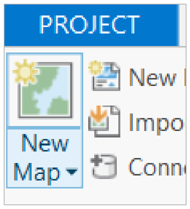
This shows how raw grid data can be represented in an ASCII text format that ArcGIS can import. Knowing how to get raw information into a form where it can be imported and analyzed using GIS is a useful skill.

Open **ArcGIS Pro,** establish a new project called **Ex3Slope**

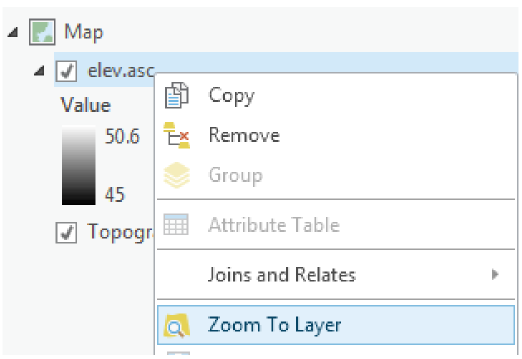




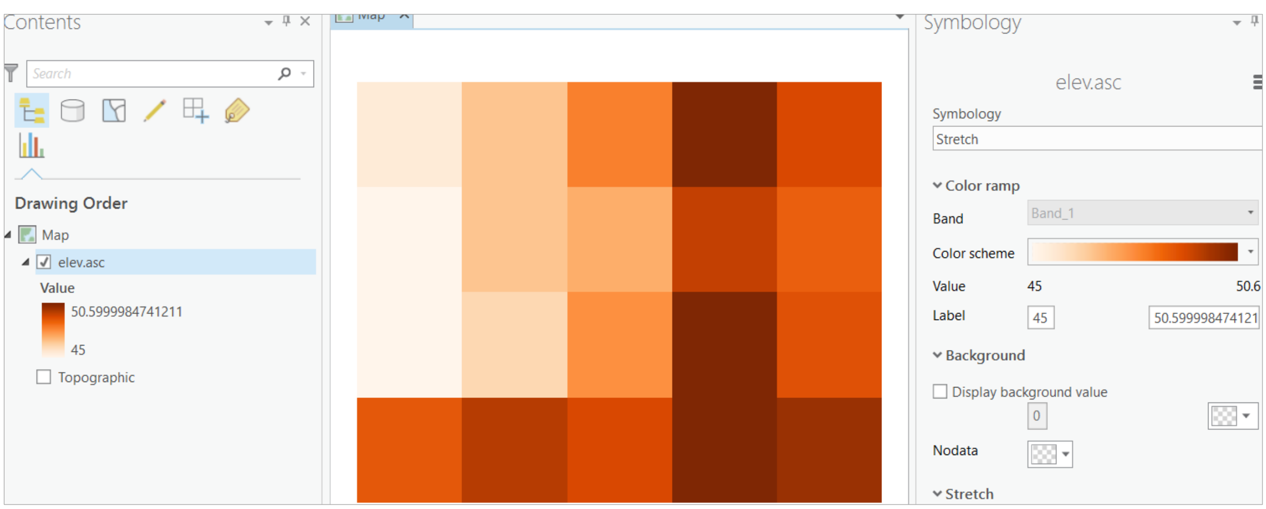
Add a New Map to the Project



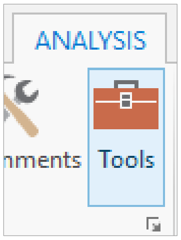
and use **Add Data** to add this file to the map. Note that ArcGIS interprets files with the .asc type extension as raster files in this ASCII format and can work with them directly. There is also an **ASCII to Raster (Conversion)** toolbox tool that could be used to convert text files into other raster formats.



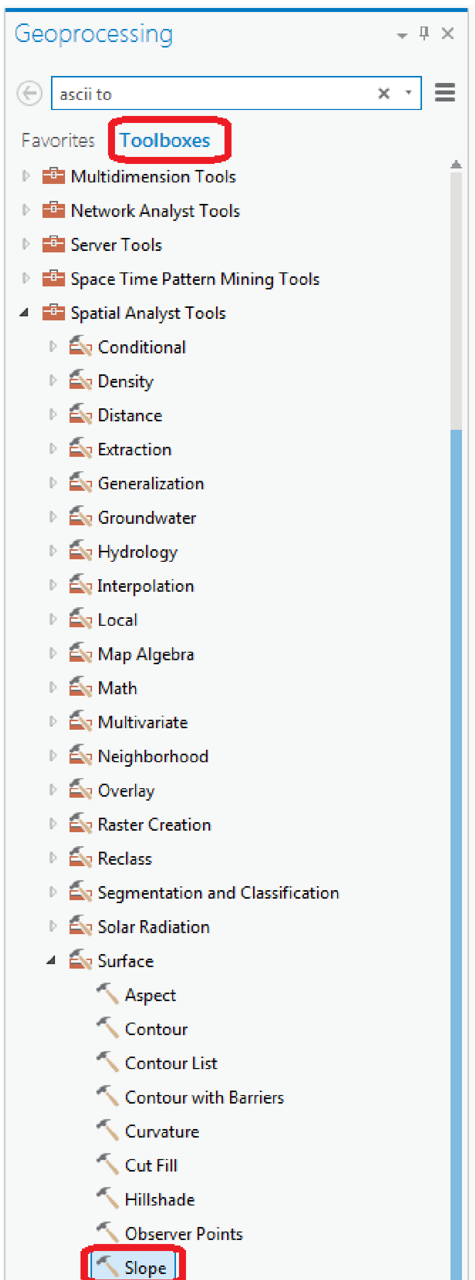
The first thing you'll notice is that this grid is in the middle of the ocean. This is fine for this particular exercise. Turn off the Topography layer because the background map is not needed. Right click on the elev.asc layer and using Symbology, color the layer so that the range in elevation values is more readily visualized. You can click on any of these cells to verify that the numbers correspond to the values in the table above.



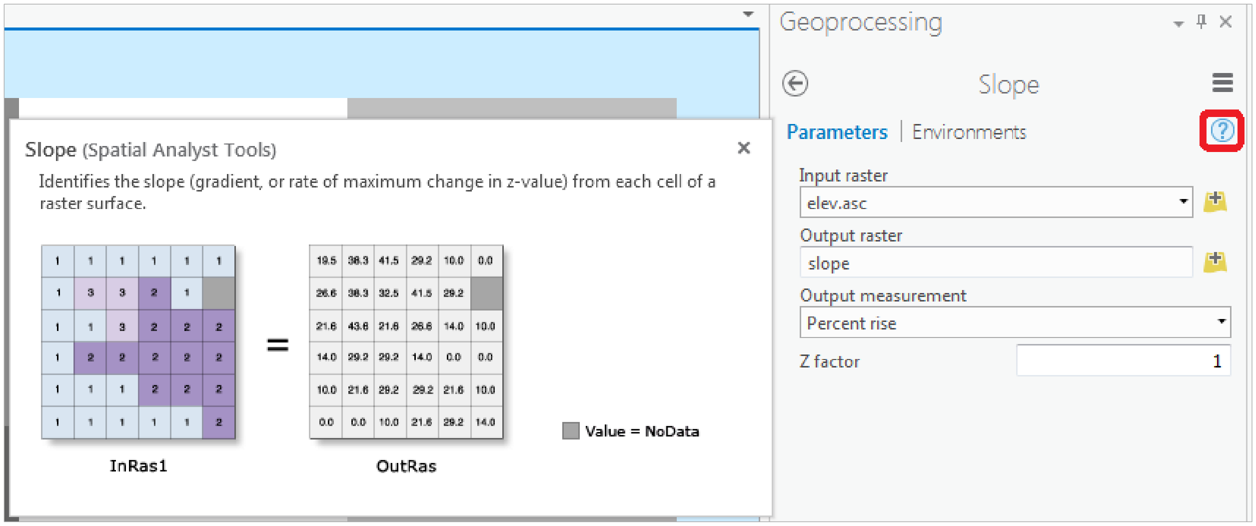
Select **Analysis/Tools** to add **Toolboxes** to the **Geoprocessing** toolbar



In the **Geoprocessing** panel, select the **Toolboxes** header and open the tool **Spatial Analyst Tools → Surface → Slope.**

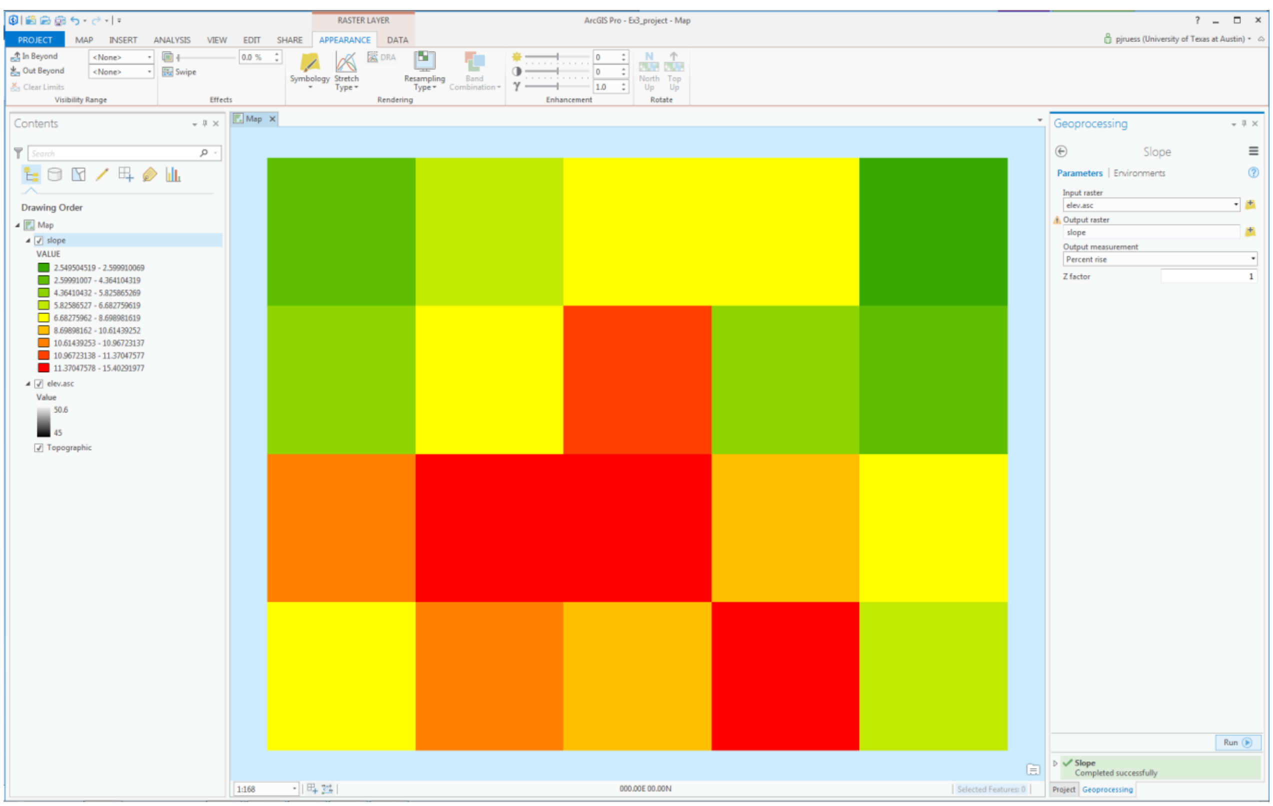


Hover over the  to see help information, and click on the  to open up a webpage with more details.

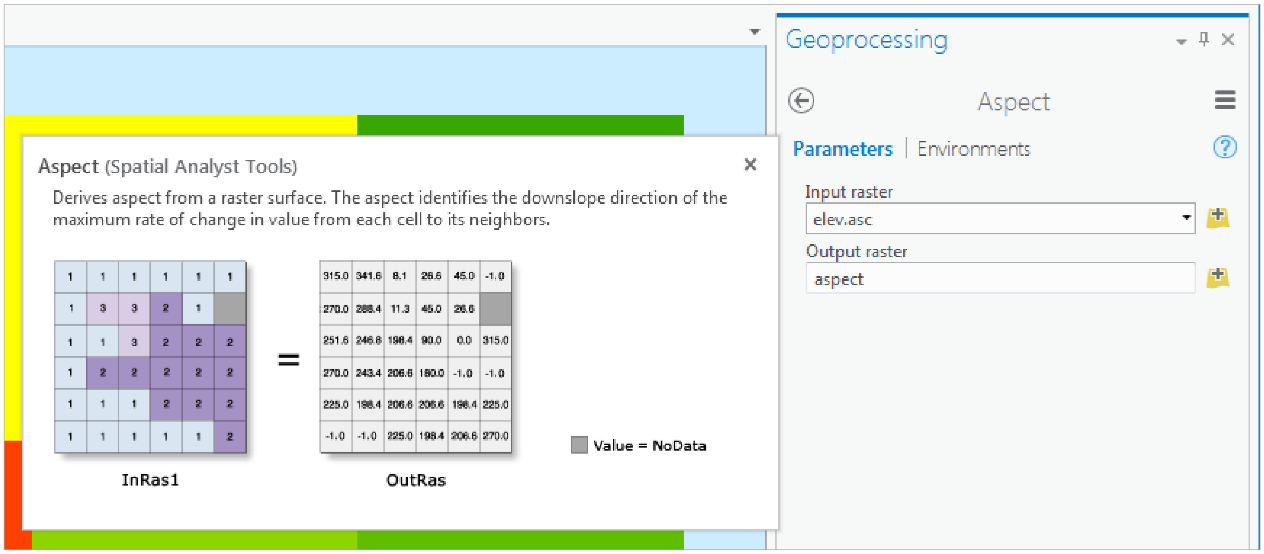


Select **elev.asc** as the input raster and specify names for the output raster (e.g. **slope**). Note that the extension you put on an output raster name designates its type. (e.g. no extension for an ESRI grid, .tif for a geotiff file, .img for an Image file). Note that ESRI GRID file names cannot exceed 13 characters. Set the Output measurement to **PERCENT_RISE** and leave the Z factor at **1**. Click OK.

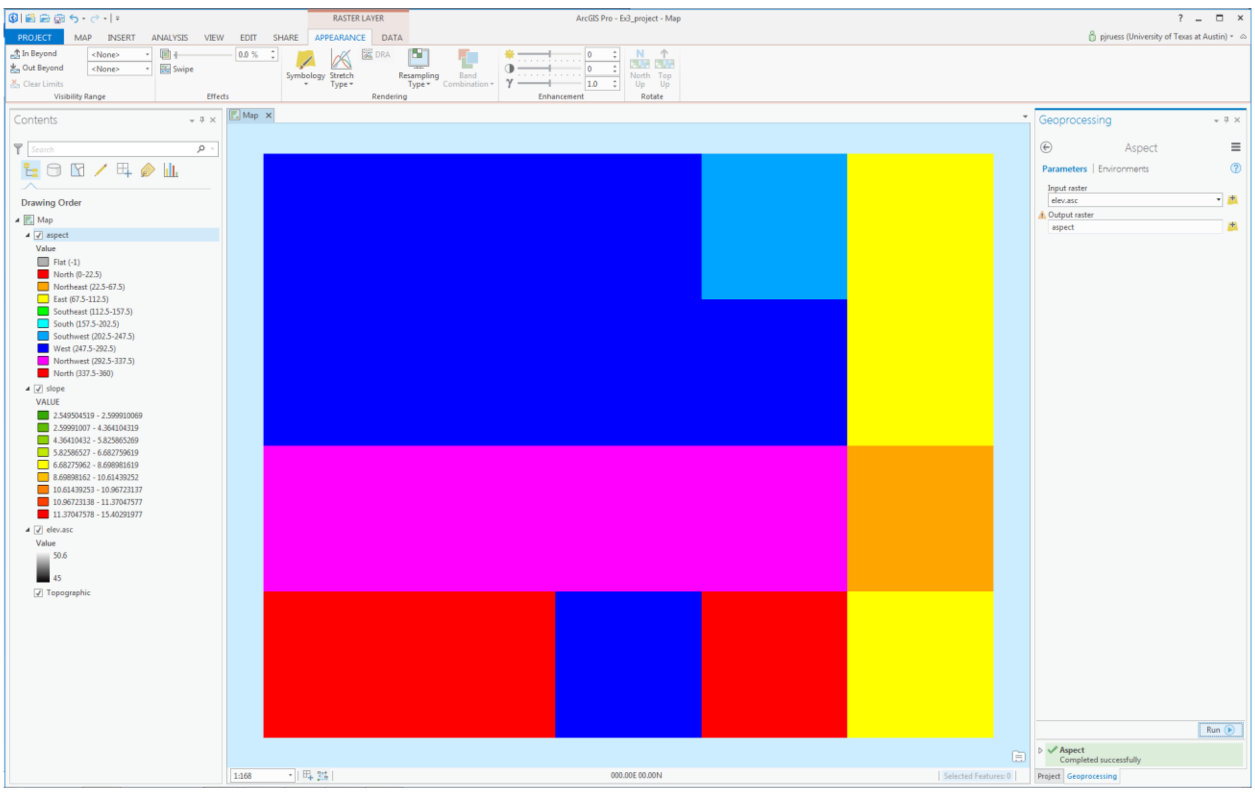
The resulting Slope grid should be added to the display. Click on the raster to verify your hand calculation for grid cell A and note the value of slope for grid cell B.



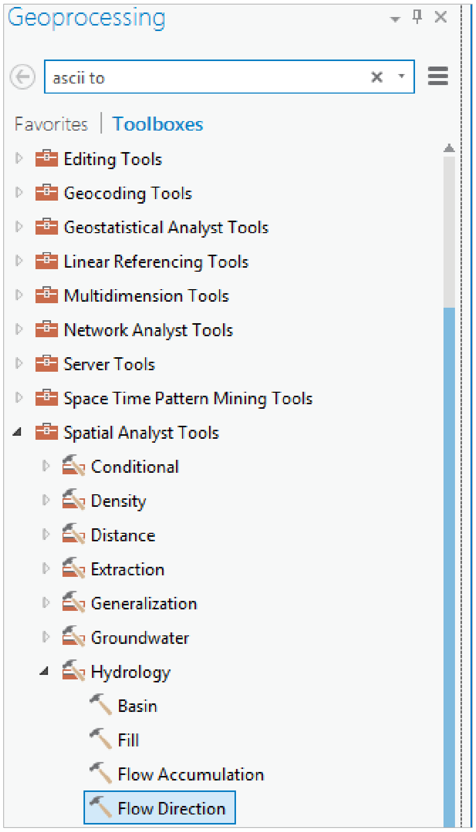
Open the tool **Spatial Analyst Tools → Surface → Aspect**. Select **elev.asc** as the Input raster and specify a name for the output raster (e.g. **aspect**). Click OK.



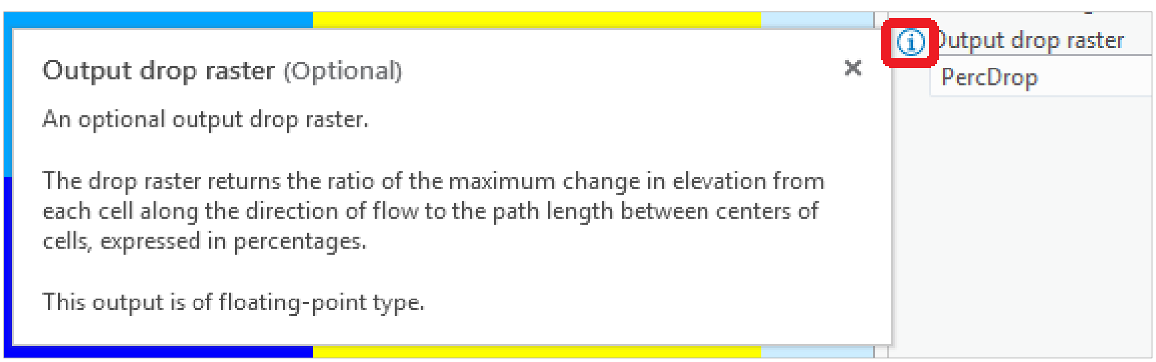
The resulting Aspect grid should be computed and added to the display. Click on the raster to verify your hand calculation for grid cell A and note the value of aspect for grid cell B.

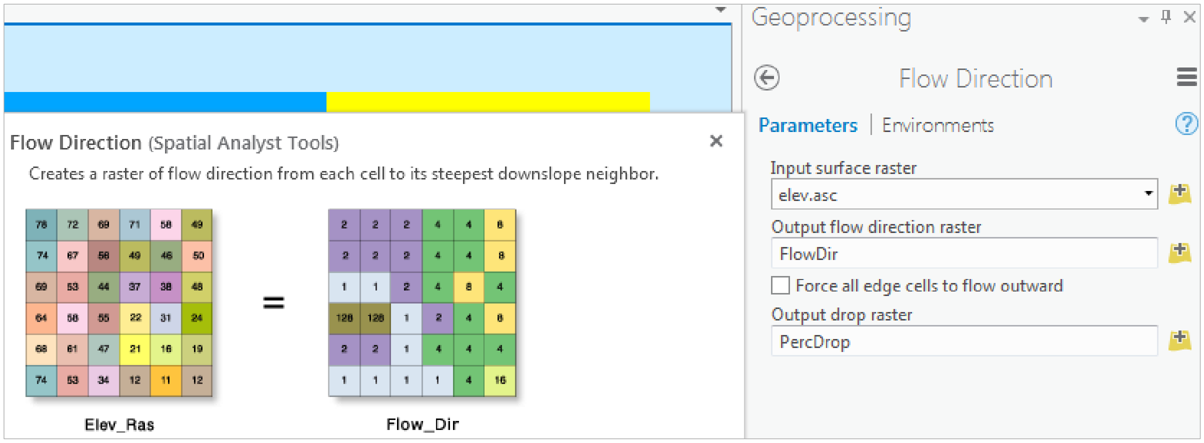


Open the tool **Spatial Analyst Tools → Hydrology → Flow Direction**

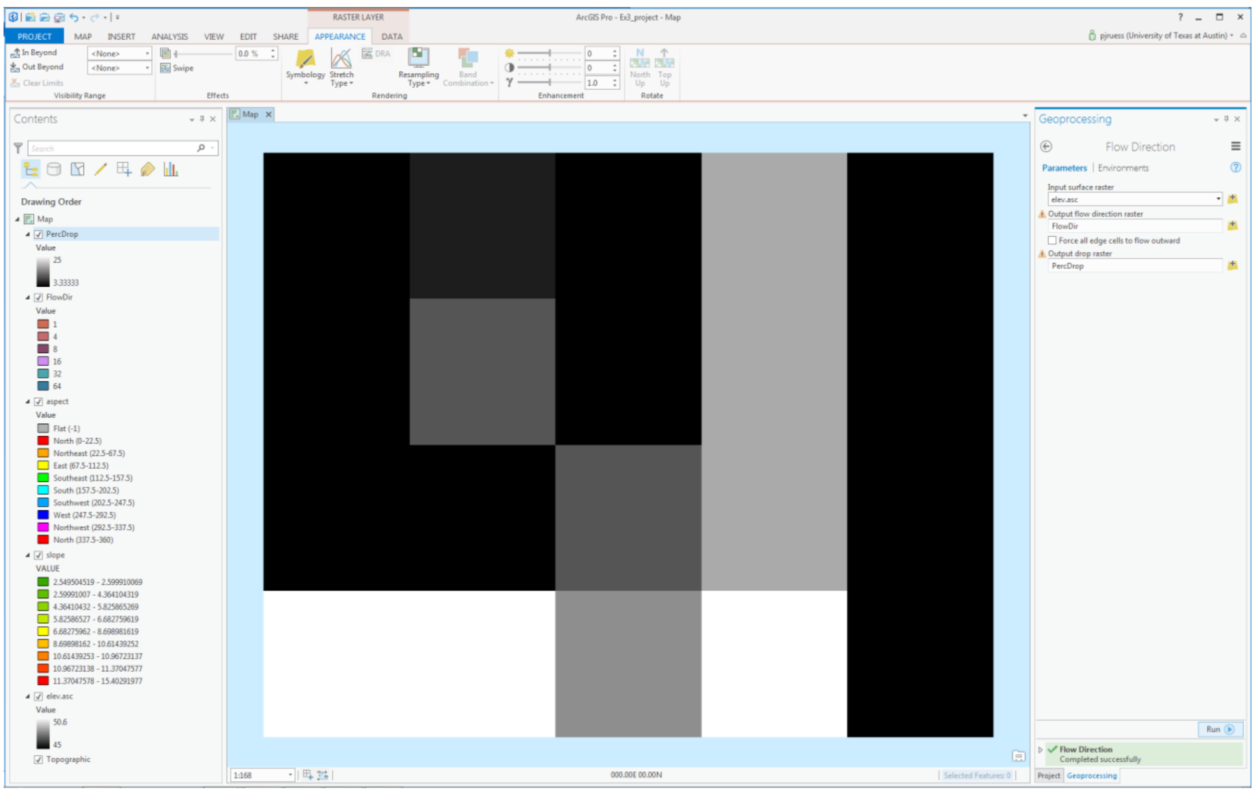


Select **elev.asc** as the input raster and specify names for output rasters (e.g. **FlowDir** and **PercDrop**). Note that the help explanation that appears when click on the output drop raster field in the dialog box explains that the Output drop raster is really the slope expressed as a percentage. Click OK.





Click on the FlowDir and PercDrop grids that are created to verify that the numbers correspond to the values you calculated by hand; resolve or reconcile any differences. Record in a table the ArcGIS calculated flow direction and hydrologic slope (Output drop) at grid cells A and B.

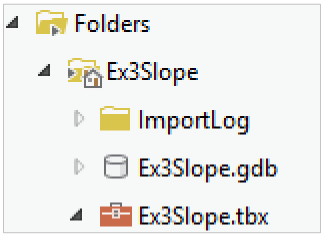


To turn in: Table giving slope, aspect, hydrologic slope and flow direction at grid cells A and B. Please turn in a diagram or sketch that defines or indicates what each of these numbers means for the specific values obtained for cells A and B.

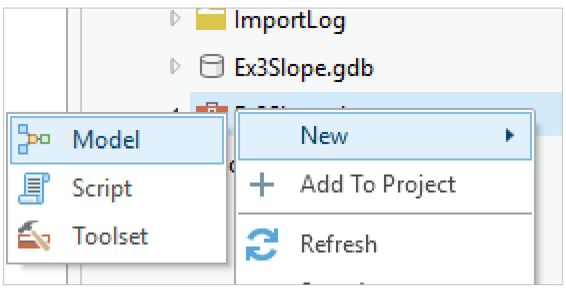
1.3 Automating procedures using ModelBuilder

ModelBuilder provides a convenient way to automate and combine together geoprocessing tools in ArcToolbox. Here we will develop a ModelBuilder tool to automate the importing of the ASCII grid and calculation of Slope, Aspect, Hydrologic Slope and Flow direction.

ArcGIS Pro projects come with toolboxes already created, where you can create new models, scripts, and toolsets. In the **Project** panel, select the **Ex3Slope** toolbox and click Open.

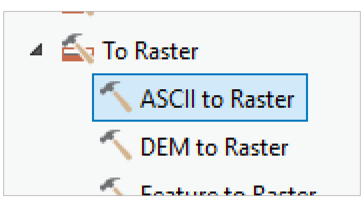


Navigate to your **Project** panel and right-click on **Toolbox → Ex3Slope.tbx**. Select **New → Model**.

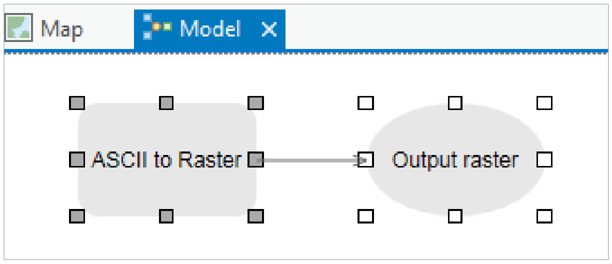


The model window should open. This is a window where you can drag, drop and link tools in a visual way much like constructing a flow chart.

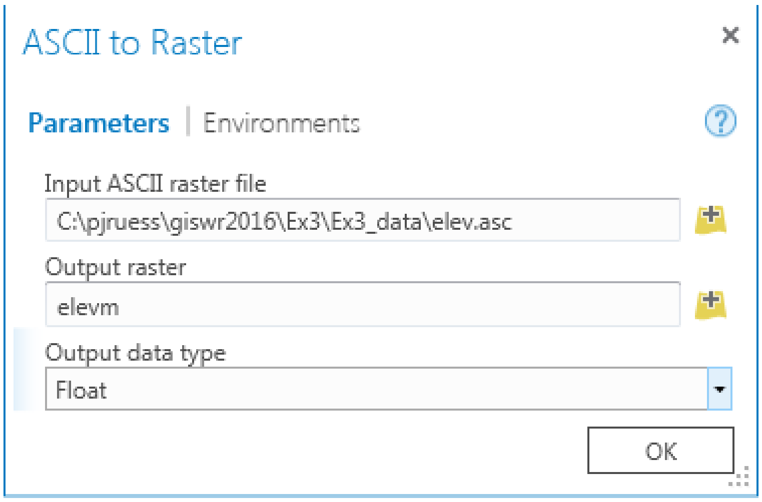
In the **Geoprocessing** panel, browse to **Conversion Tools → To Raster → ASCII to Raster**.



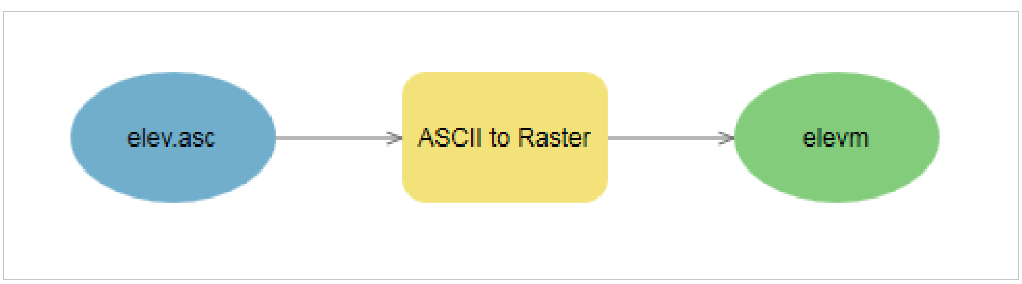
Drag this tool onto the model window. Note that in this model I am choosing to first import the ASCII text file to a tif format, rather than work with it in text format. It is faster to work with binary formats like .tif or ESRI GRID.



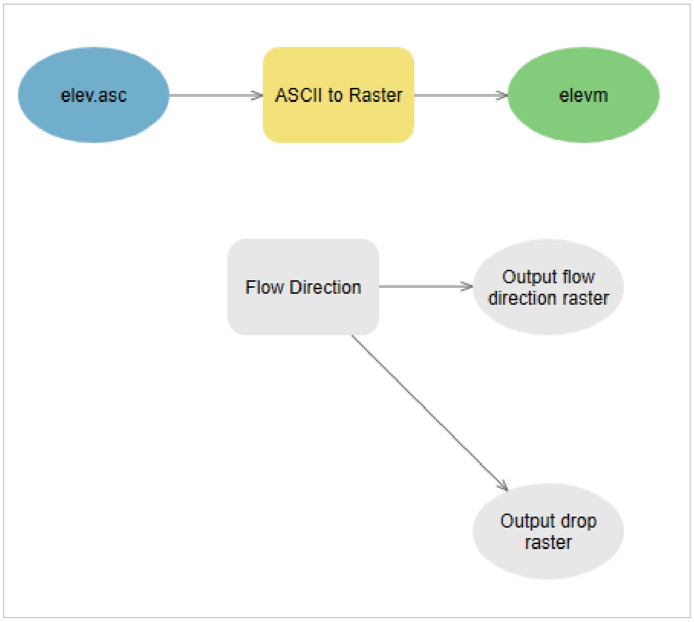
Double click on the **ASCII to Raster rectangle** to set this tool's inputs and outputs.



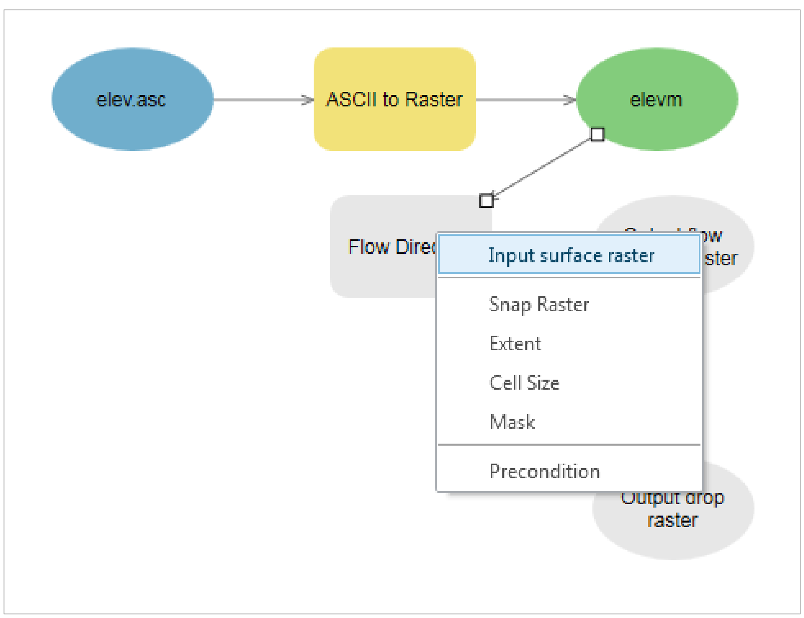
Set the Input ASCII raster file to **elev.asc** and Output raster to **elevm** (I used elevm so as not to conflict with elev that already exists). Set the output data type to be Float. Click OK to dismiss this dialog. Note that the model elements on the ModelBuilder palette are now colored indicating that their inputs are complete.



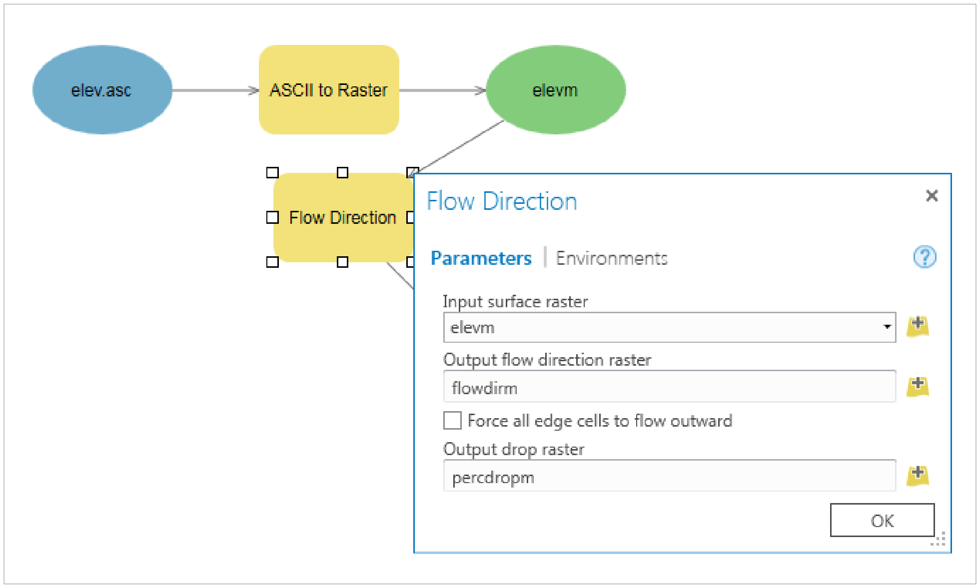
Locate the tool **Spatial Analyst Tools → Hydrology → Flow Direction** and drag it on to your window. Your window should appear as follows.



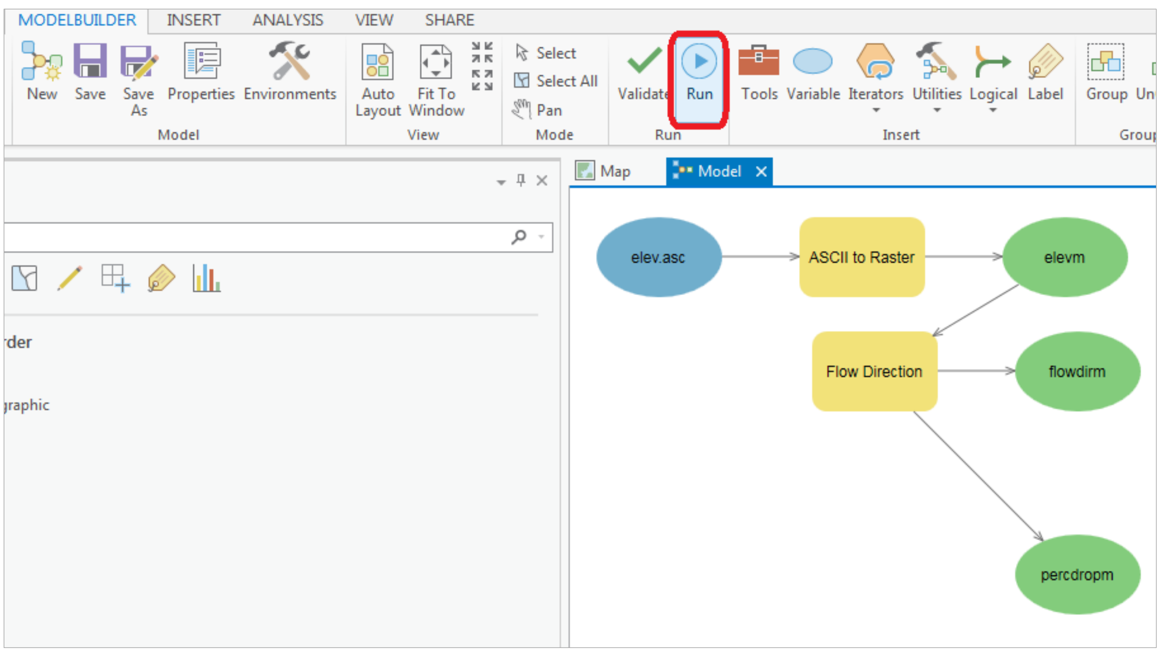
The output from the ASCII to raster function needs to be taken as input to the Flow Direction function. To do this click-and-drag a line from **elevm**, the Output raster of ASCII to Raster, to the **Flow Direction** tool rectangle. At the dialog that pops up select **Input surface raster** to indicate that elevm is to be used as the input Surface raster for the Flow Direction tool. The "m" in these names is to signify that the results are being created from a model rather than by using the tools one by one.



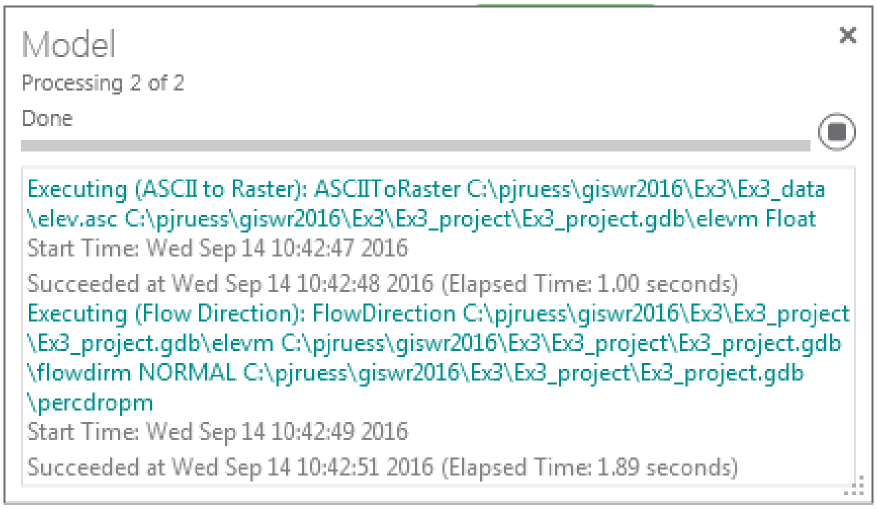
Notice that the "output drop" oval is hollow. This is because this is an optional output that has not been specified. Double click on the Flow Direction tool and specify names for both the Output flow direction raster and optional Output drop raster.



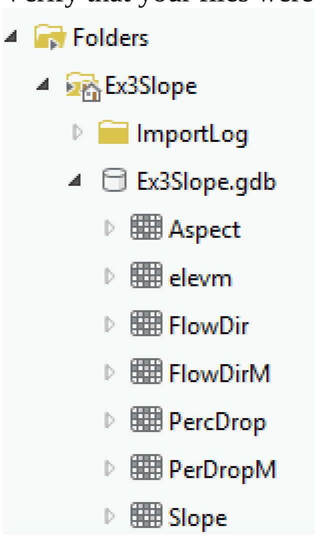
Click OK. Alternatively you could double click on output ovals individually to specify the output rasters. The model is now ready to run. Run the model by clicking the **Run** button in the ModelBuilder tab.



The yellow boxes will briefly flash red as each step is executed. The Model progress box opens and the progress bar indicates when the model completes. You can then add the outputs to the map and examine the results. Note that a ModelBuilder can be a bit finicky, and may take a few runs to work correctly! Also note that, if the ModelBuilder fails midway through (e.g. if the model fails after creating the elevm file), you will either need to re-name any previously computer outputs, or delete them using the Projects panel.



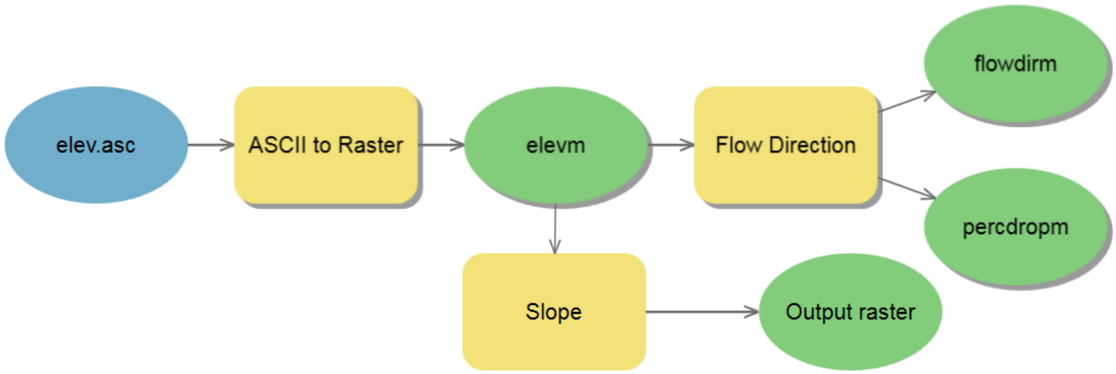
Verify that your files were created successfully in the **Project** pane.



Save your Project to make sure you don't lose what you've done.

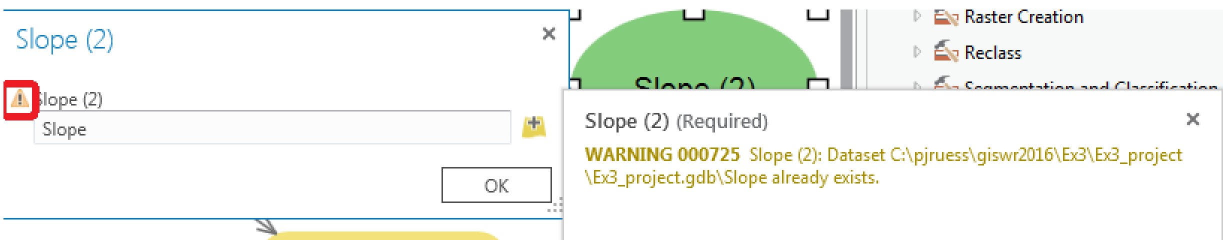
In the model, use the **Auto Layout** tool  in the **ModelBuilder** pane to organize the layout.

Add the **Spatial Analyst → Surface → Slope** tool to your model by dragging it onto the model window. Connect the elevm output to this tool, specifying that it is the Input Raster for the Slope Tool.

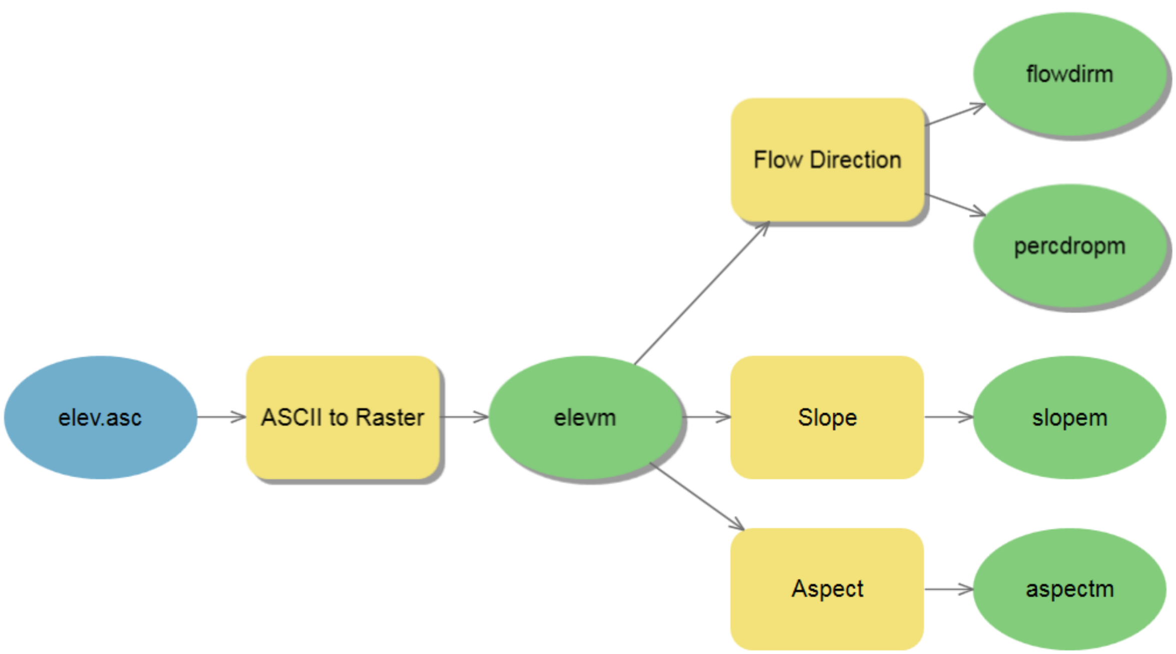


Add the **Spatial Analyst → Surface → Aspect** tool to your model connecting it to elevm as an input in a similar way. Double click on the Slope and aspect tool outputs and specify file names for the outputs.

When setting names you need to be careful that you do not use a name of a grid that already exists, or else you will get a yellow warning sign in the display and the model will not run, as shown below:

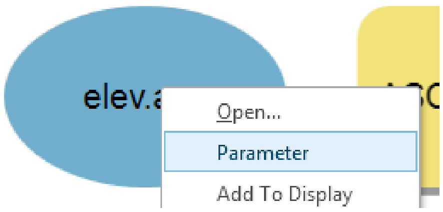


Double click on the Slope tool and set the Output measurement to **Percent_Rise**. Your model should appear as follows. If you have trouble adding the Slope or Aspect tools, save your Project, close ArcGIS Pro, then open it again it should work better.

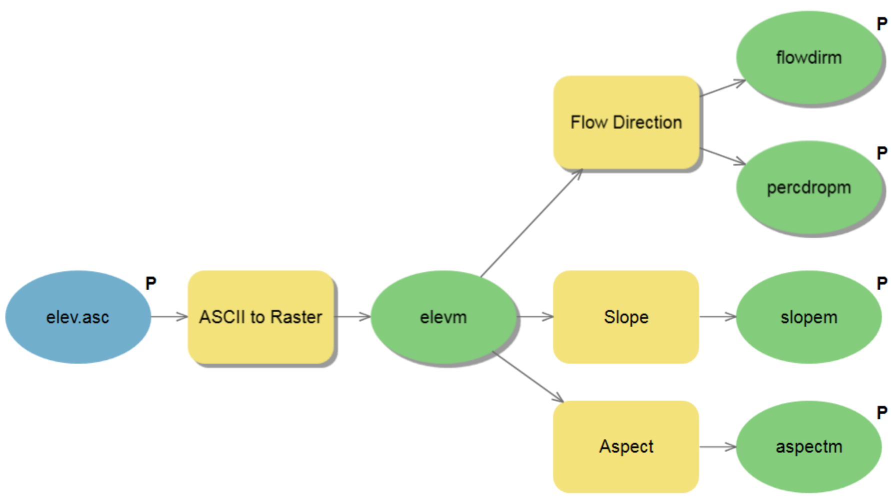


You can click run and do all the processing required to import the data, compute Slope, Aspect, Flow Direction and Hydrologic Slope at the click of a single button. Pretty slick!

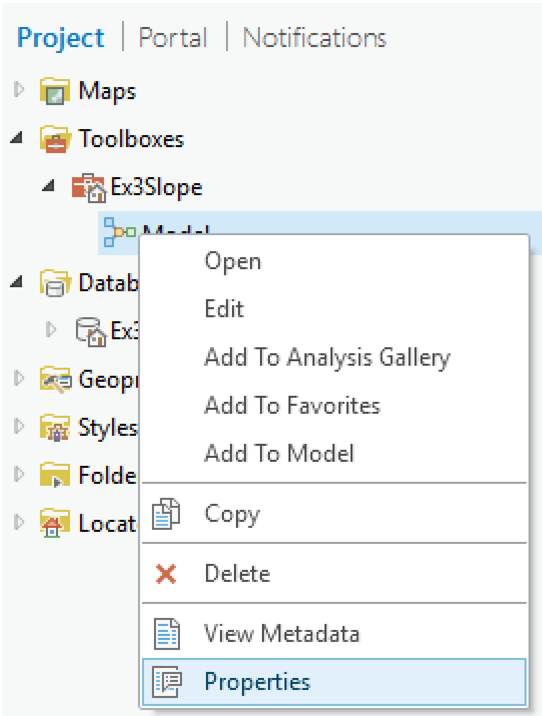
Right click on elev.asc and select Parameter.

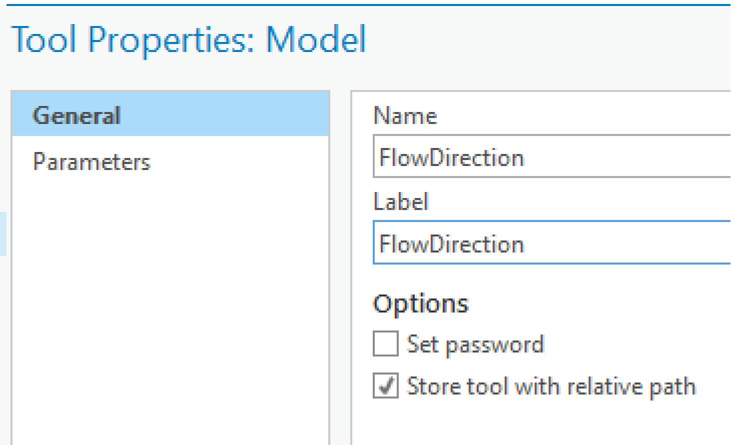


Right click on each of the outputs **flowDirm**, **percdropm**, **slopem** and **aspectm** in turn and select **Parameter** and **Add to Display**.

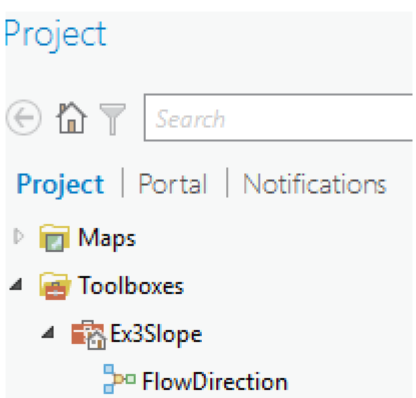


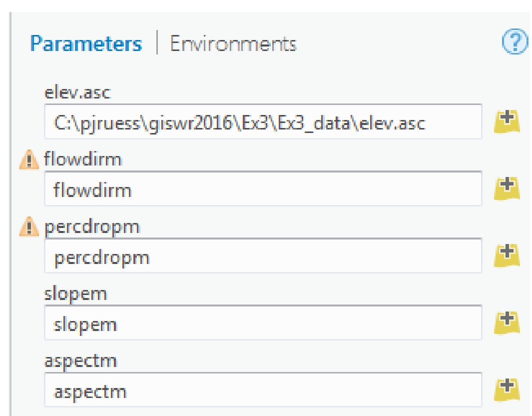
A P now appears next to these elements in the diagram indicating that they are 'parameters' of the model that may be adjusted at run time. Also note that by selecting "Add to Display", the parameters that you previously computed are now on the Map; "slopem" and "aspectm" have not yet been computed, which is why these do not appear on the map. Close your model. Right click on the model in the Toolbox window and select **Properties** to rename it something you like (e.g. **FlowDirection**).





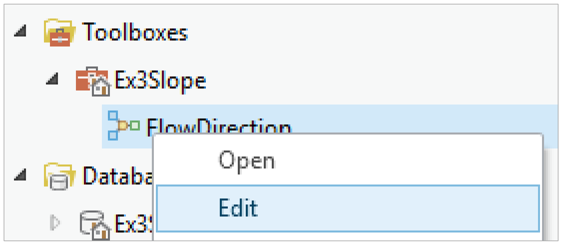
If you go back to your model and now **double click** on it or right-click and **Open** it, you'll see that the input files are shown as parameters of the model just like when you execute a tool in ArcToolBox.





Where you see warnings near one of your files, it usually either means that there is already a file of that name in the place where you propose to put the output, or there is no input file. These can be resolved by setting the inputs and outputs correctly.

If at some point you want to go back and modify your model you should open it to **Edit** and make the changes you want.

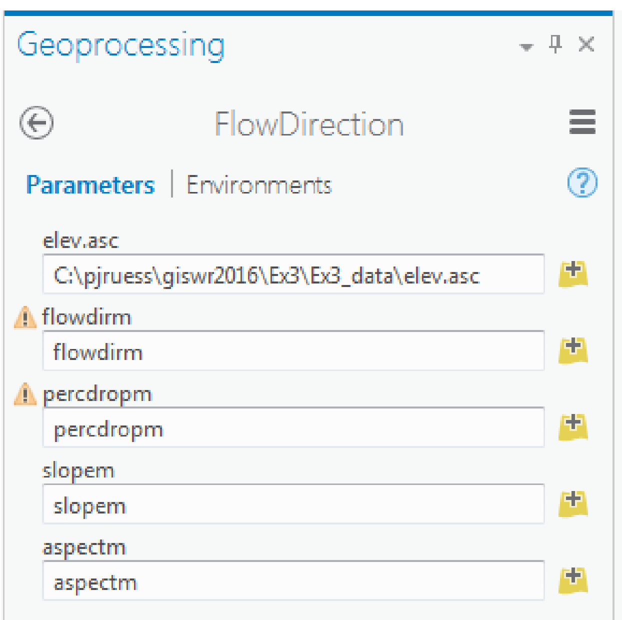


You are done creating this model. Save your Project and Close ArcGIS Pro.

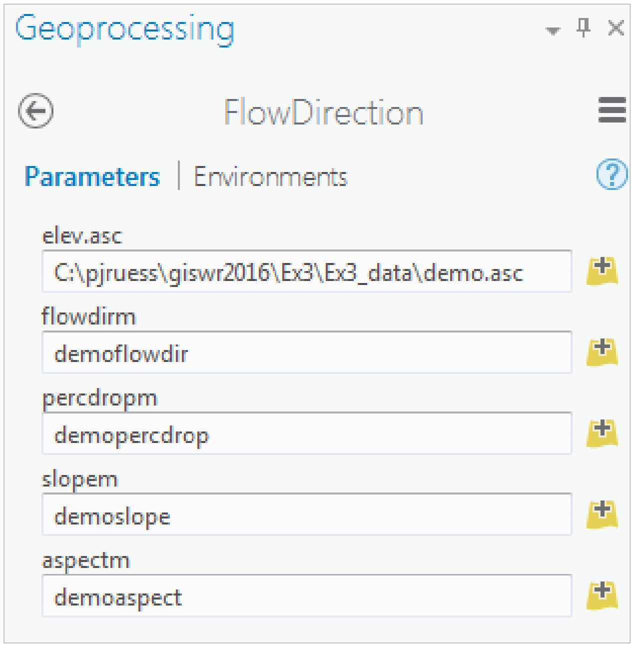
ModelBuilder is a very powerful way of creating complex analyses, and documenting your "workflow" in a form that is visual and can readily be described. In this way, analyses that you've done can be passed on to other analysts, and you can also use the visual palette display in your term project report or thesis to document how you've done your analysis, so the visual aspect of the display helps with documenting your work, as well as in organizing it.

To turn in: A screen capture of your final model builder model.

We will now use this model for different data. Reopen ArcGIS Pro. Locate the file **demo.asc** extracted from the zip file of data provided at the beginning of this exercise. Double click on your **FlowDirection** model in the Ex3 toolbox to run it. If you elected to create a new toolbox in a different file location earlier, you may need to re-add the Ex3 toolbox using the insert tab. The following panel for the tool you created should appear when you open it.



Select as input under elev.asc the file **demo.asc**. Specify different names for the outputs to avoid the conflicts with existing data.



Click Run and the model should save the results to your Ex3 geodatabase and directly on your map. Examine the ArcGIS table of contents and record the minimum and maximum values associated with each of the outputs. If you don't see anything in your screen once this function is complete, right click on one of the new layers produced and select "**Zoom to Layer**" and you'll see the new information show up.

To turn in: A table giving the minimum and maximum values of each of the four outputs Slope, Aspect, Flow Direction, and Hydrologic Slope (Percentage drop), for the digital elevation model in demo.asc.

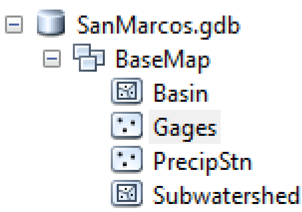
Congratulations, you have just built a Model Builder geoprocessing program and used it to repeat your work for a different (and larger) dataset. If you would like to save this tool to take to another computer or share with someone else you can copy the file Ex3.tbx from its location to a removable media to take with you. If you are going to be sharing this tool more widely there are additional steps to take to clean up the interface (to avoid red X's), label the input fields and write help documentation for it. Close ArcGIS Pro.

Part 2. San Marcos Elevation and Precipitation

The purpose of this part of the exercise is to calculate average watershed elevation for subwatersheds of the San Marcos basin, and to calculate average precipitation over each of these subwatersheds using different interpolation methods. Average precipitation is then converted to a volume of precipitation and compared to runoff volumes using a runoff ratio. This provides an insight into the annual water balance of these watersheds, namely what fraction of precipitation is streamflow and what fraction is lost to evapotranspiration and other losses such as infiltration and groundwater recharge.

The following data is provided in the Ex3Data.zip file:

SanMarcos.gdb file Geodatabase.



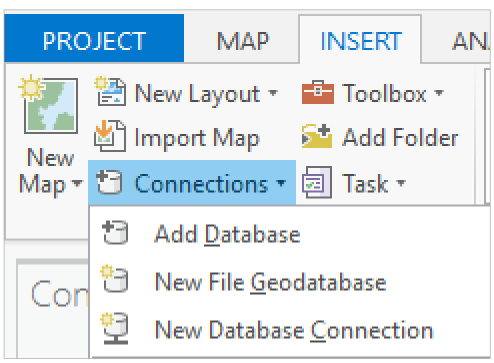
There are the following feature classes:

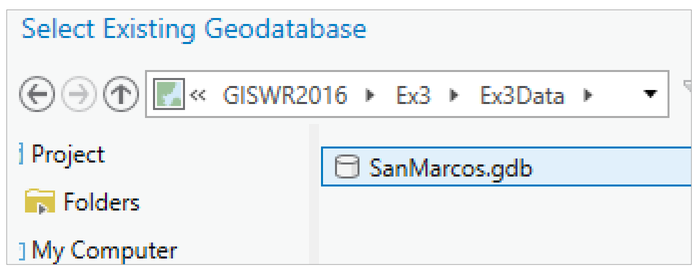
- **Basin.** The San Marcos Basin feature class from exercise 2.
- **Gages.** The San Marcos Gages from exercise 2 that includes Mean Annual Flow.
- **PrecipStn**. PrecipStn contains mean annual precipitation data from precipitation stations in and around the San Marcos basin downloaded from NCDC following the procedures given in http://www.ce.utexas.edu/prof/maidment/gradhydro2005/docs/ncdcdata.doc. (The NCDC website has changed so it is no longer possible to get this data this way. You can obtain NCDC data from http://gis.ncdc.noaa.gov/map/viewer, but after you have selected data it requires a 24-36 hour period of processing before delivery so we are providing data for you to use.) This data was prepared by downloading all years of available precipitation data for the counties in and around the San Marcos basin, then averaging over these years, retaining only those stations with 6 or more years of annual total data reported by NCDC.
- **Subwatershed**. Subwatersheds delineated to each of the stream gages used in exercise 2 following the procedures that will be learned in a future exercise.

Note that in this geodatabase these feature classes have been projected to the USA_Contiguous_Albers_Equal_Area_Conic coordinate system. It is generally better to do the sort of hydrologic analysis done here involving volumes and areas in an equal area projection and I chose this projection for this exercise.

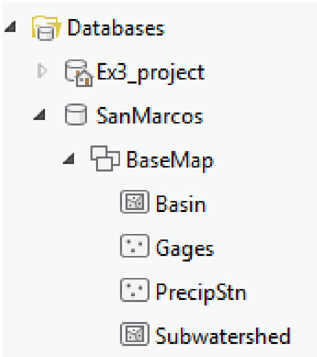
1. Loading the Data

Open ArcGIS Pro and create a new project, **Ex3_project**. Right-click in the **Project** panel and select **Add Database**

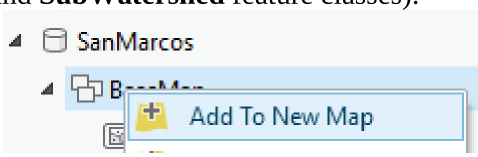




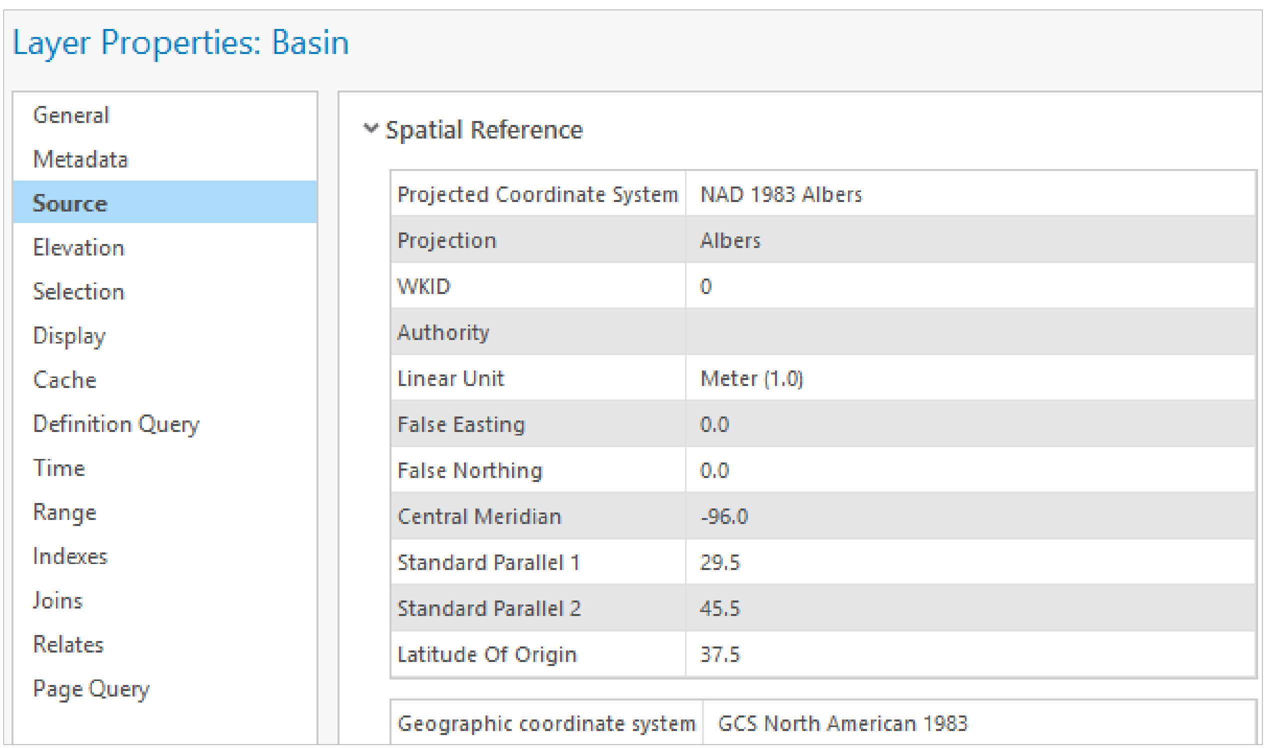
to add the **SanMarcos.gdb** to the project



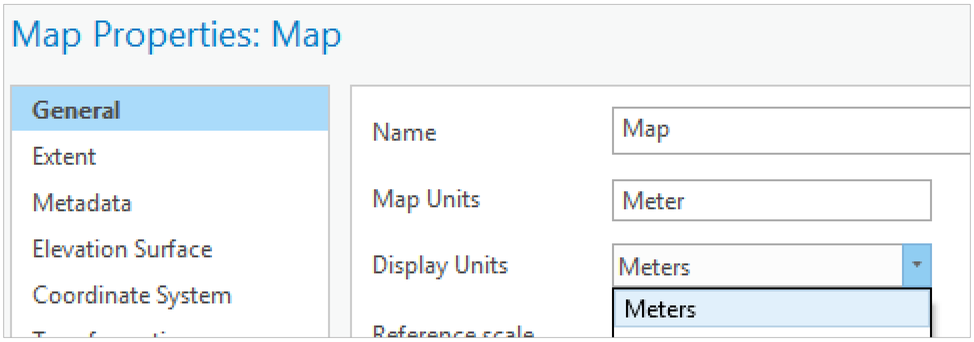
then add the contents of the **BaseMap** feature dataset to the map display (the **Basin**, **Gages, PrecipStn** and **SubWatershed** feature classes).



If you right-click on one these feature classes in the map legend, select **Properties** and scroll down until you see **Spatial Reference** at the bottom of the layer properties, you'll see that they have the **NAD 1983 Albers** coordinate system with the North American Datum of 1983.



If you move the cursor around on the map, you'll see that the coordinates are in meters in the NAD_83_Albers projection coordinate system. Note that in ArcGIS Pro, the map unit display may default to degrees; if this is the case, right-click on **Map** and under **Properties → General → Display Units**, select **Meters**.

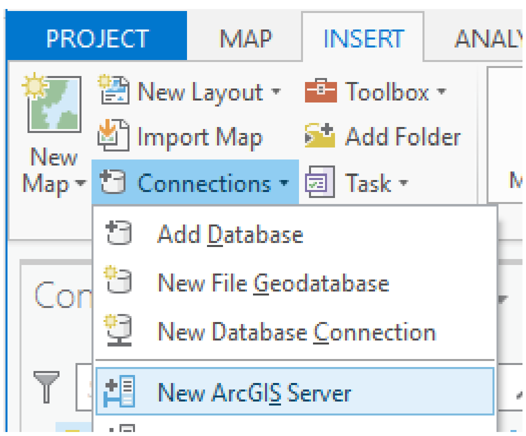


Zoom-to-Layer on the San Marcos **Basin** and you will notice that the X-value is negative because the San Marcos Basin is West of the Central Meridian of this projection (96°W). The Y-value is negative because the basin is below the Latitude of Origin (37.5°N) (and both the False Easting and False Northing are 0). This is called the **USA Contiguous** version of this projection because the Standard Parallels (29.5°N and 45.5°N) lie within the continental US. Here is an example coordinate pair that you might see:

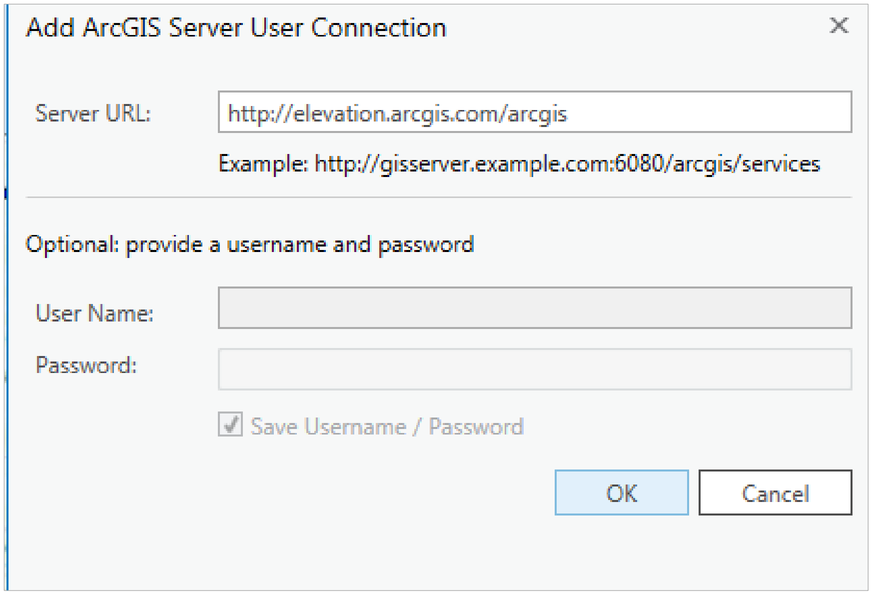
-174,737.89 -888,250.94 m

We will use this specific NAD_1983_Albers projection, which is the USA Contiguous Albers Equal Area Conic projection, for this exercise.

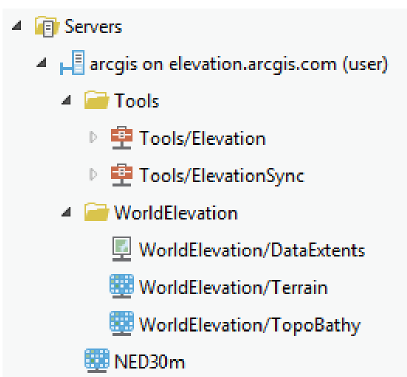
Right-click in the **Project** panel and **Insert** "New ArcGIS Server Connection".



Enter the Server URL http://elevation.arcgis.com/arcgis and, optionally, your ArcGIS.com user name and password (which are not needed since ArcGIS Pro is already signed into ArcGIS Online.)



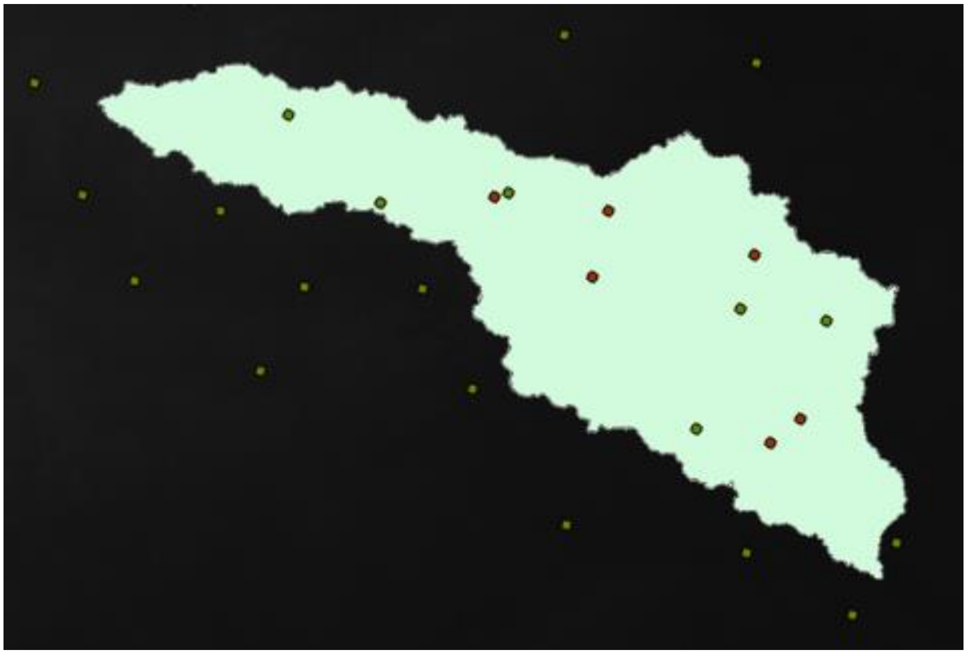
Expand the tool to see what services it has available



NED30m is the USGS National Elevation Dataset digital elevation model with 30m cells and elevation in height above NAVD88 Datum in meters. Drag and drop NED30m onto your map to add this data. Turn off the Topographic map display so that you can see the NED30m display underneath it.

If you do not have access to such a service, the national elevation dataset can be downloaded from the National Map viewer, http://viewer.nationalmap.gov/viewer/, although the process is more tedious.

At this scale your map likely appears very dark as Texas is at low elevation compared to the range of elevation data in the US. Your map should look similar to the following:

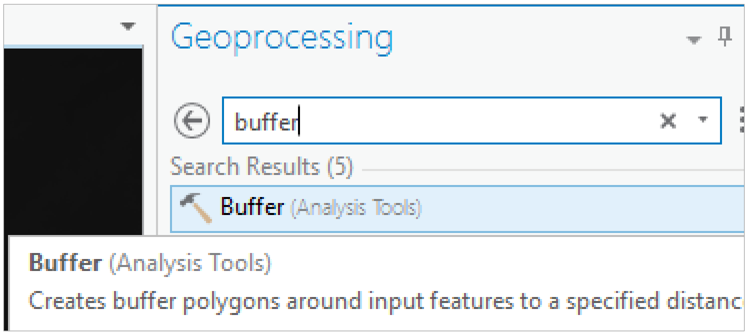


Following a similar procedure add the http://landscape1.arcgis.com/arcgis ArcGIS service and add **USA_NHDPlusV2** service to the map. Its display is grayed out because at this scale none of the feature classes will be shown in the map – they show up if you zoom in closer to the basin and

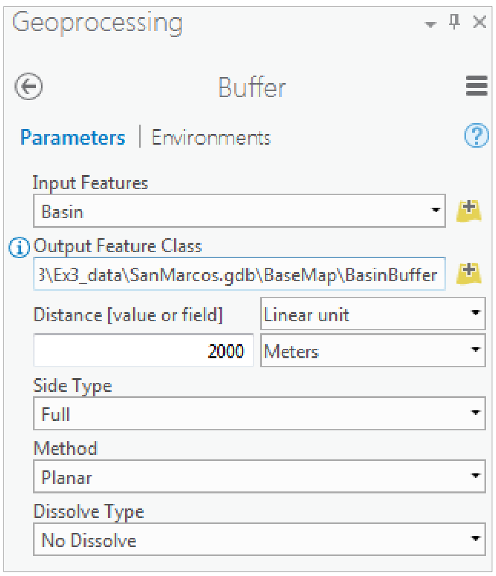
Save your **Project** document if you have not already.

Let's export data from NED30m to have a local copy to work with. First we need to define the area that we want to work with. Let's pick an area that has a 2000 m buffer around the basin.

In the Geoprocessing Panel, use the search box to search on "buffer" and select the **Buffer (Analysis)** tool.

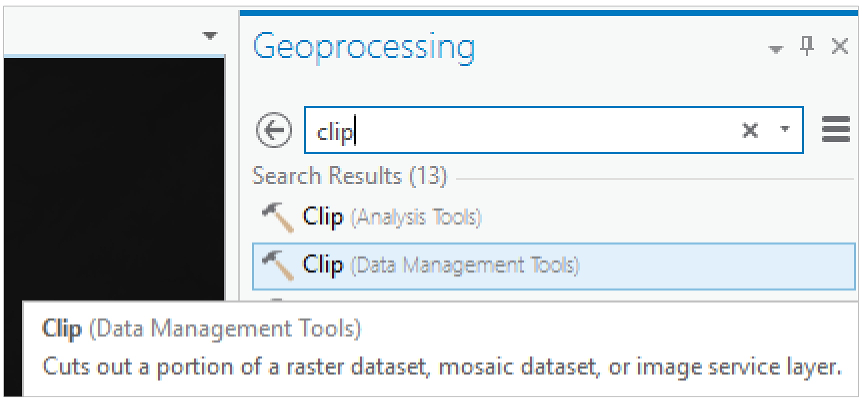


Set the inputs as follows and **Run** the tool.

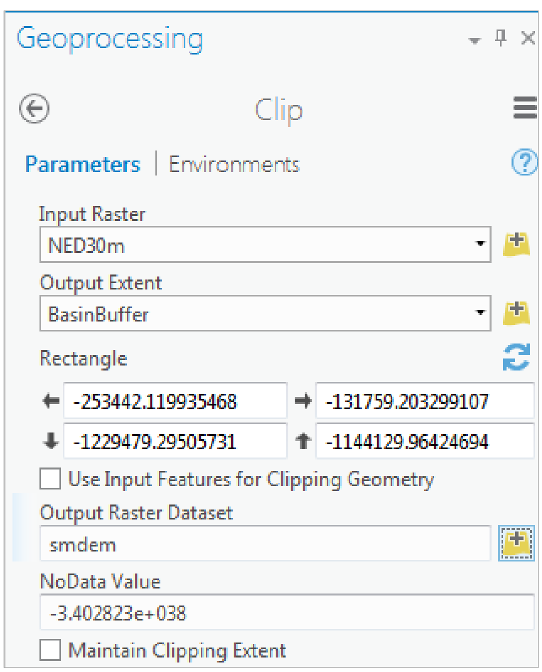


The result should be a polygon that is 2000 m larger around the edge of the basin. Use the Symbology tool to change the Buffer symbology to an **Outline** and then you can see the other feature classes underneath it.

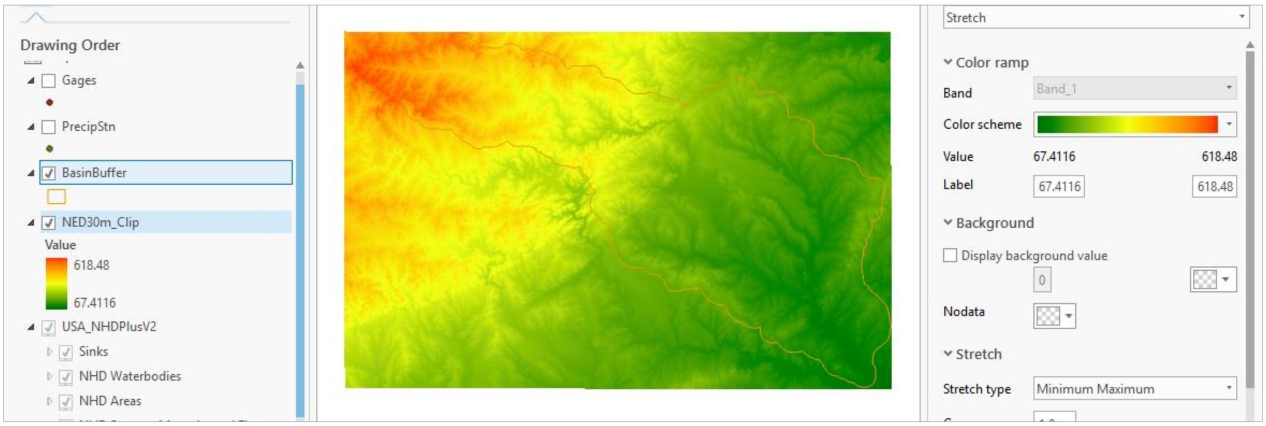
Use the search box to search on "clip" and select the **Clip (Data Management)** tool. This tool was chosen because one of its allowable inputs is an image service.



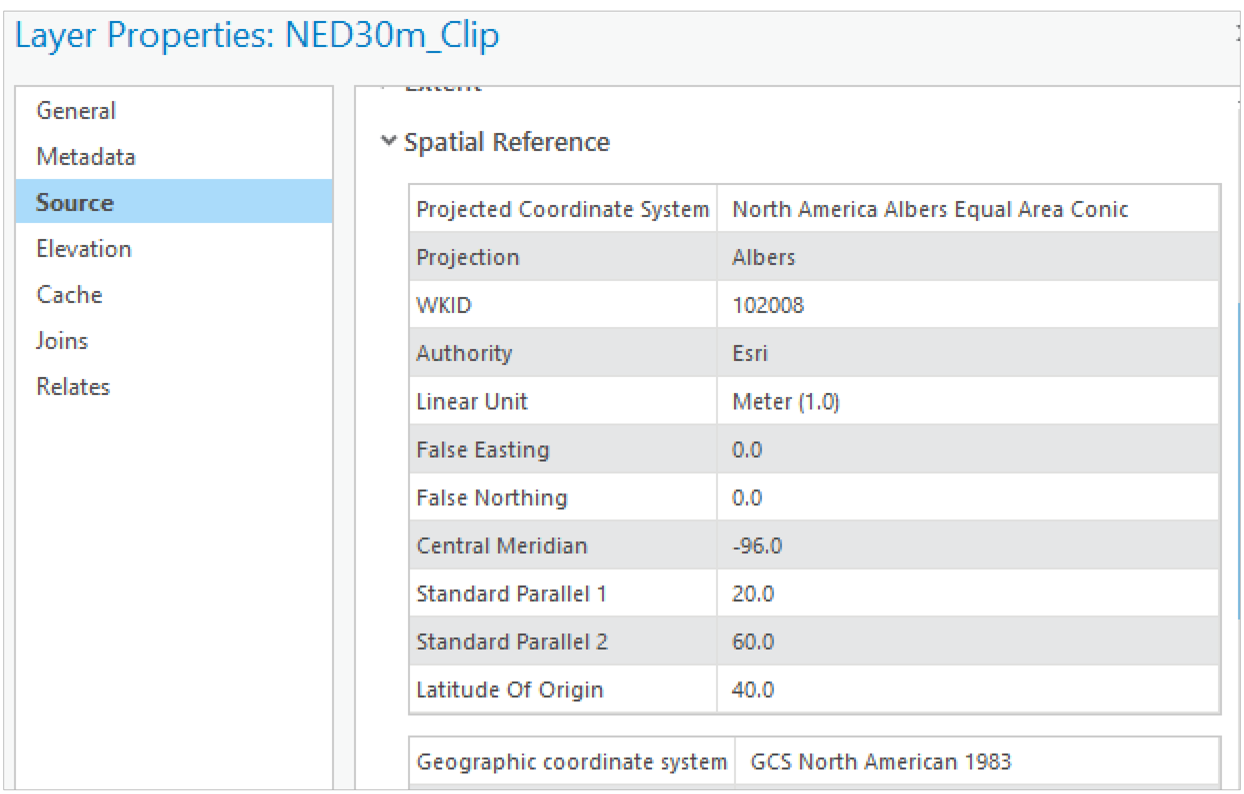
Set the inputs as follows and **Run** the tool.



You should have a raster layer added to your ArcMap with a local subset from the NED30m DEM, that has the extent of BasinBuffer and is easier to symbolize. Turn off the Gages, PrecipStn and NED30m layers to see this display.



If you examine the **Layer Properties** for **Raster Information** for this you will see that it has a cell size of 30.92 m and **North America Albers Equal Area Conic** spatial reference. This is the resolution and coordinate system of the data as stored in the ArcGIS elevation image service.   If you look at its spatial reference, you'll see it has the same projection (Albers) and Geographic Coordinate System (NAD83) but the projection parameters are different from those of the BaseMap feature dataset for the San Marcos Basin that we're working with. These parameters are appropriate for display for all of North America, not just for the continental US.

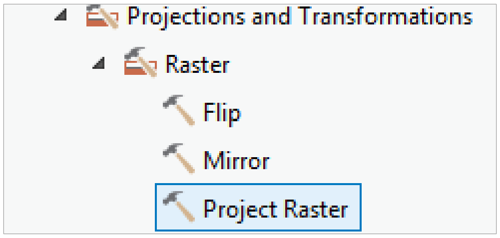


Projected Coordinate System	North America Albers Equal Area Conic
Projection	Albers
WKID	102008
Authority	Esri
Linear Unit	Meter (1.0)
False Easting	0.0
False Northing	0.0
Central Meridian	-96.0
Standard Parallel 1	20.0
Standard Parallel 2	60.0
Latitude Of Origin	40.0

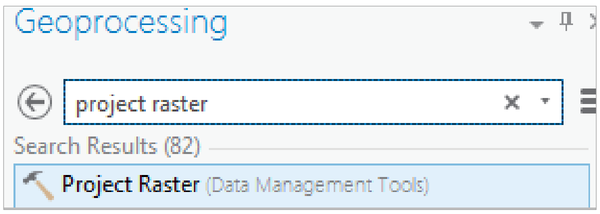
Geographic coordinate system	GCS North American 1983

2. Projecting the DEM

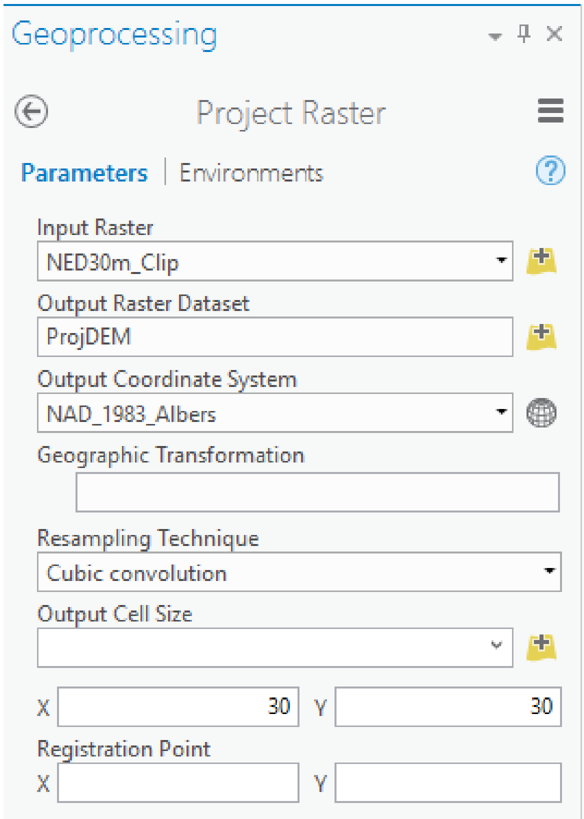
It is desirable to work with data in consistent coordinate systems. Let's project this DEM into the same projection as the BaseMap Feature dataset provided. Open the Toolbox and open the tool **Data Management Tools → Projections and Transformations → Raster → Project Raster**. If you find this tool hard to locate,

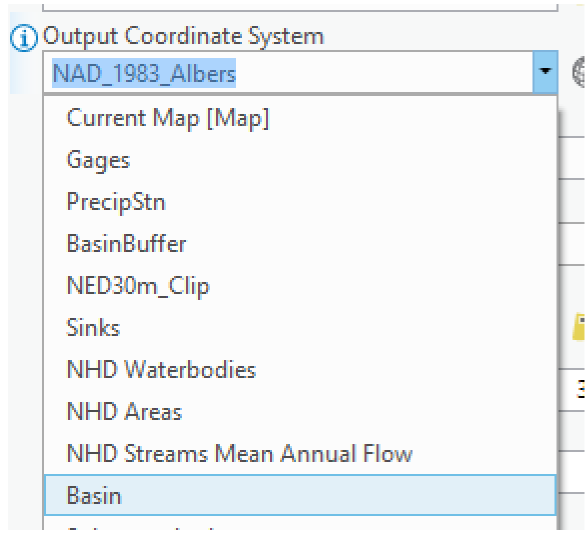


you can Search for it also:

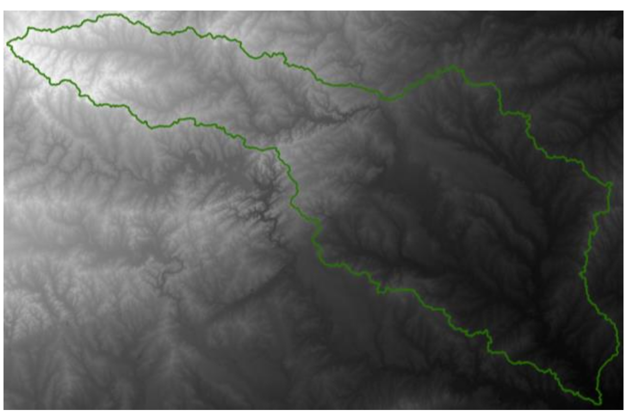


Set the inputs as follows to produce a projected raster **ProjDEM** in your Ex3_project geodatabase with **30m** cells and the NAD 1983 Albers projection.





The **NAD 1983 Albers** projection is most easily set by clicking next to Output Coordinate System and selecting the Basin feature class, which has the required NAD 1983 Albers projection.
The result should appear similar to:



The spatial information about the DEM can be found by right clicking on the ProjDEM layer, then clicking on **Properties → Source → Raster Information**, and **Statistics**

Raster Information

Columns	4222
Rows	2745
Number of Bands	1
Cell Size X	30
Cell Size Y	30
Uncompressed Size	44.21 MB
Format	FGDBR
Source Type	Elevation
Pixel Type	floating point
Pixel Depth	32 Bit
NoData Value	
Colormap	absent
Pyramids	level: 5, resampling: Nearest Neighbor
Compression	LZ77
Mensuration Capabilities	Basic

Statistics

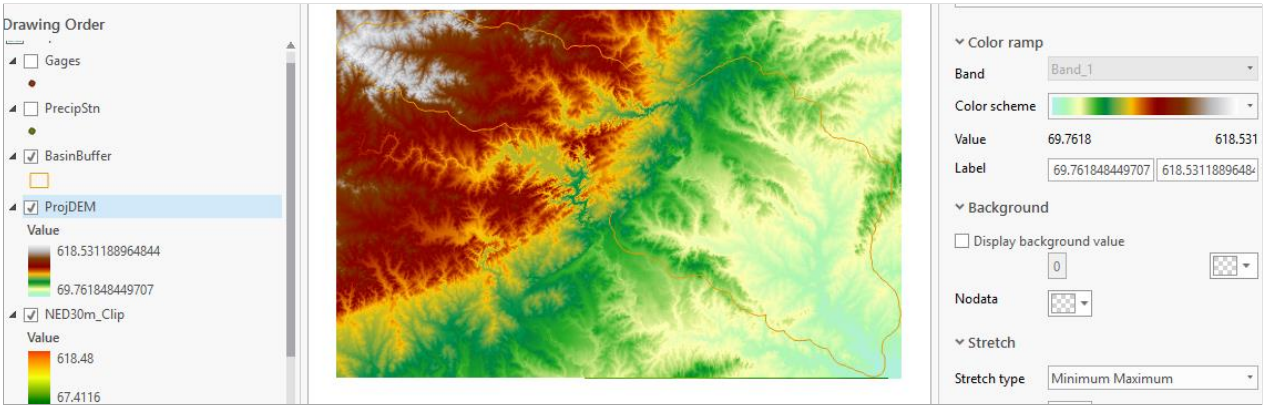
Build Parameters: skipped columns: 1, rows: 1, ignored value(s): None

Band Name	Minimum	Maximum	Mean	Std. Deviation
Band_1	69.761848449707	618.53118896484	259.29586895443	116.28632131283

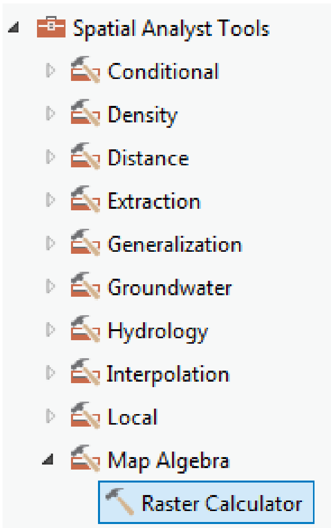
To turn in: The number of columns and rows in the projected DEM. The cell size of the projected DEM. The minimum and maximum elevations in the projected DEM.

3. Exploring the DEM

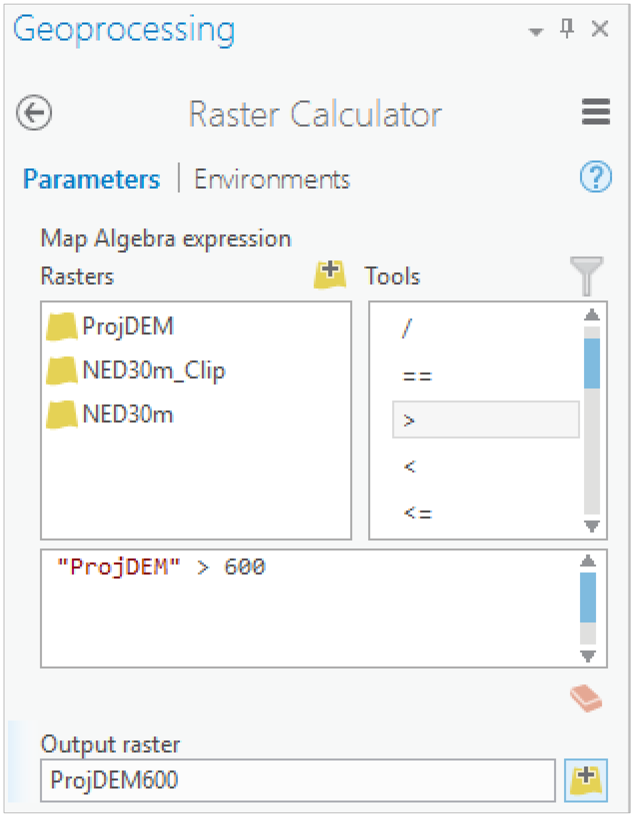
Change the symbology of the ProjDEM layer.



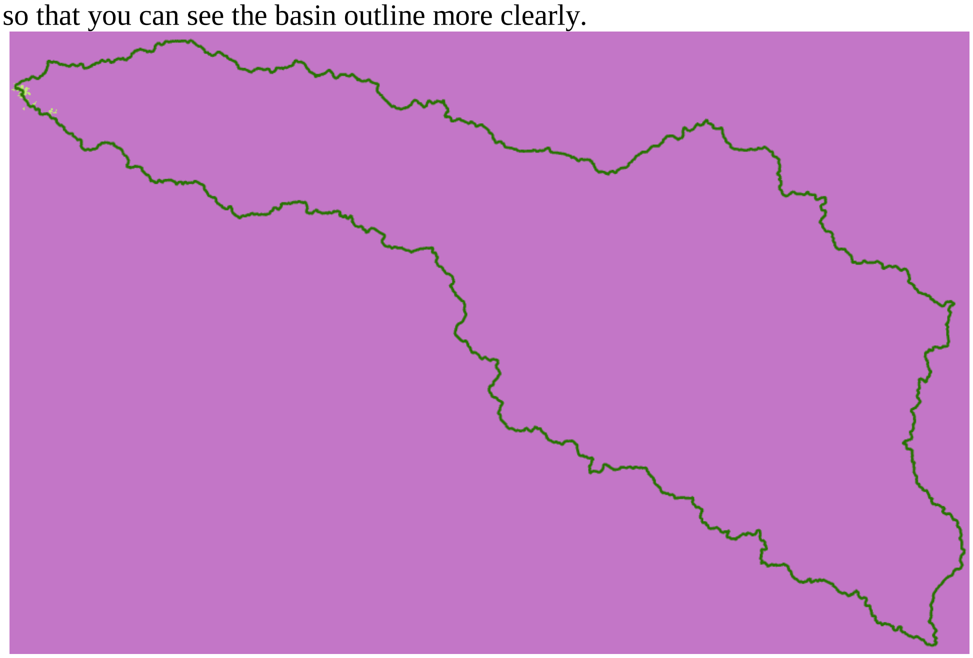
To explore the highest elevation areas in your DEM select **Spatial Analyst Tools → Map Algebra → Raster Calculator**.



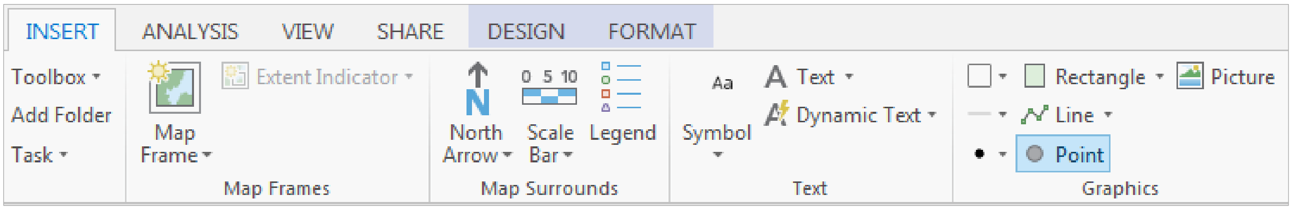
Double click on the **projdem** layer with the DEM for San Marcos. Click on the ">" symbol and select a number less than the maximum elevation. This arithmetic raster operation will select all cells with values above the defined threshold. In the example below a threshold of 600m was used.

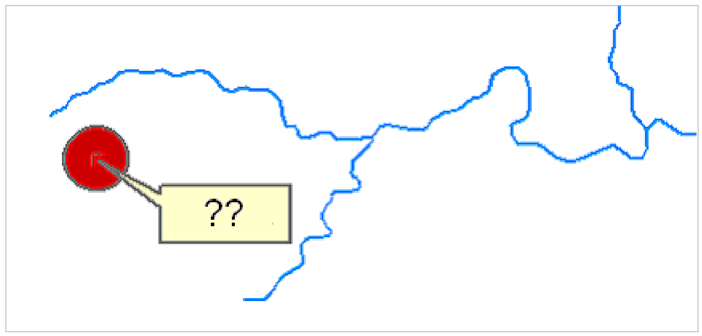


A new layer appears on your map. The majority of the map (pink color in the figure below) has a 0 value representing false (values below the threshold), and the lime-green region has a value of 1 representing true (elevations higher than 600 meters). If necessary, change the symbology of the resulting map display so that you can see the basin outline more clearly.



Use the raster calculator again (with elevation 618 meter threshold) to identify the grid cell of maximum elevation in **ProjDEM**. Create a Layout of this map, and use the draw tools to mark your point of maximum elevation and label it with the elevation value for that pixel (See Ex2, pg. 39-40 for details on creating a label).

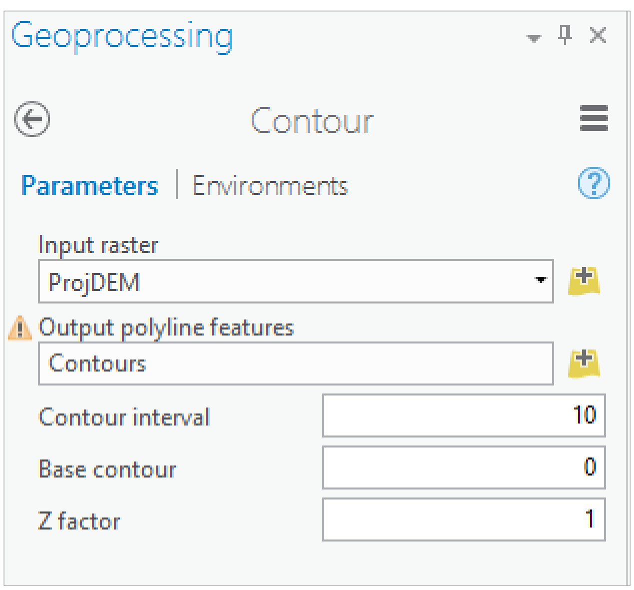




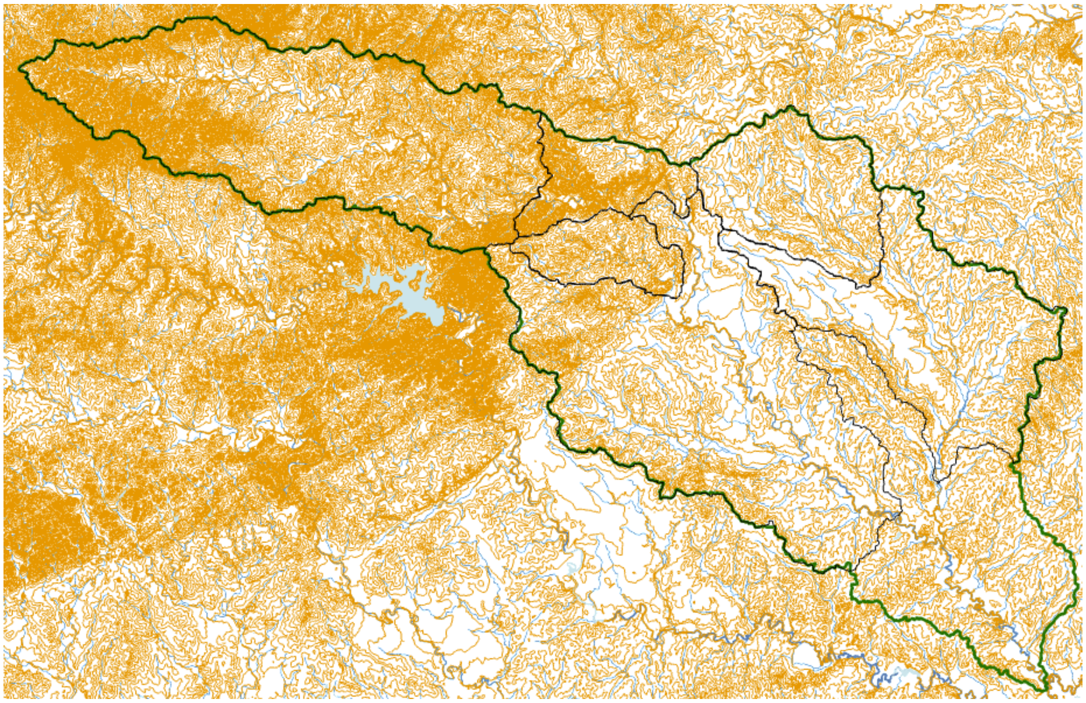
To turn in: A layout showing the location of the highest elevation value in the San Marcos DEM. Include a scale bar and north arrow in the layout.

4. Contours and Hillshade

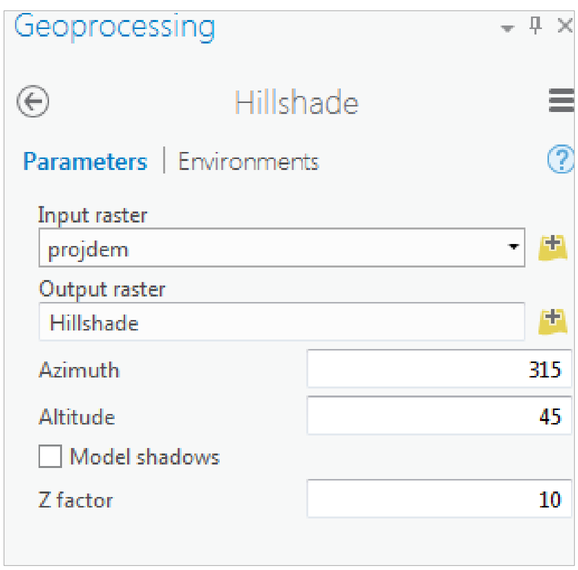
Contours are a useful way to visualize topography. Select **Spatial Analyst Tools → Surface → Contour**. Select the inputs as follows, with a 10m contour interval:

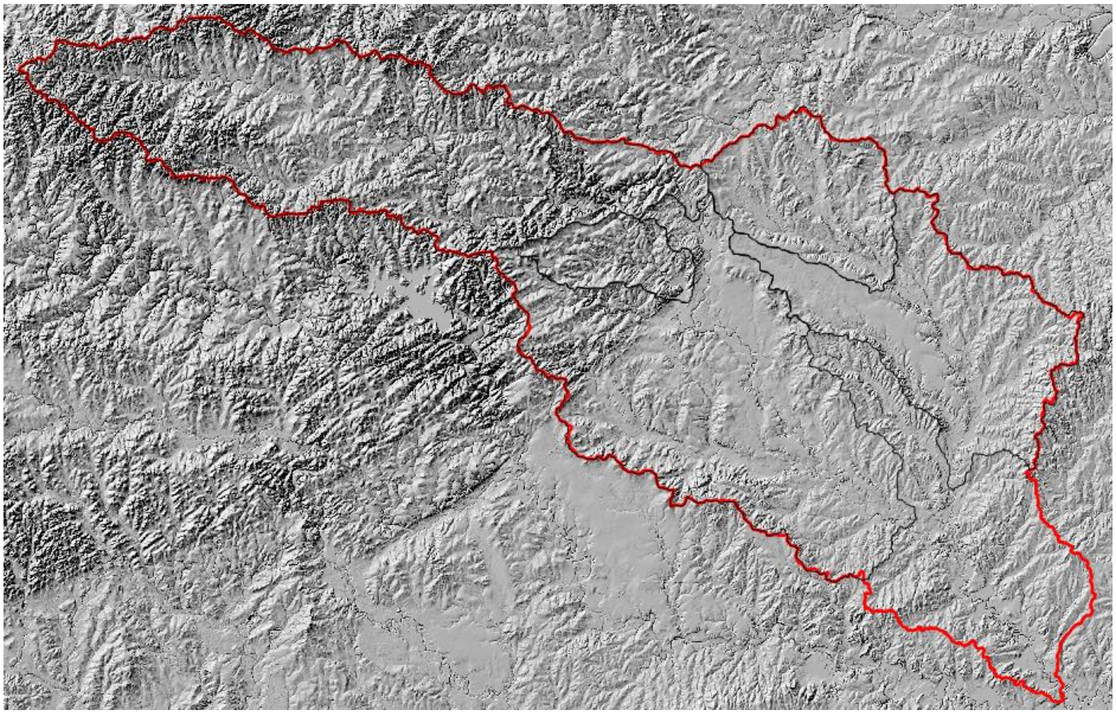


A layer is generated with the topographic contours for San Marcos. Notice the big difference in Terrain Relief to the west of the basin compared to the east. This results from the fact that the Balcones fault zone runs through the middle of this basin, to the west of which lies the rolling Texas hill country and to the east the flatter coastal plain. There is a tower located in the City of San Marcos on which you can stand and see these differences in topography to east and west!



Another option to provide a nice visualization of topography is Hillshading.
Select **Spatial Analyst Tools → Surface → Hillshade** and set the factor Z to a higher value to get a dramatic effect and leave the other parameters at their defaults (the following hillshade is produced with a Z factor of 10). Click OK. You should see an illuminated hillshaded view of the topography.



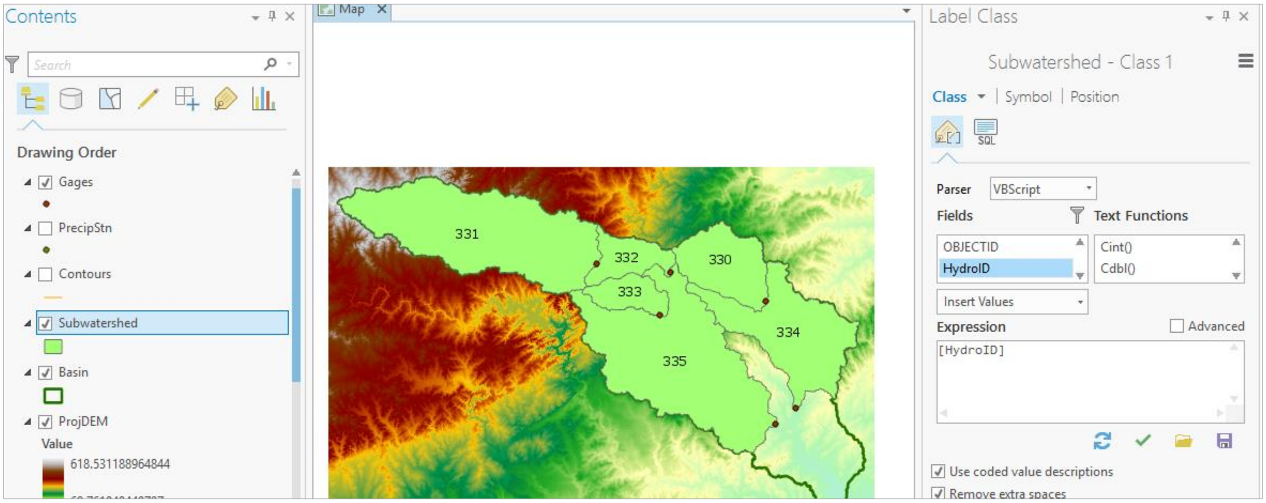


To turn in: A layout with a depiction of topography either with elevation, contour ***<u>or</u>*** *hillshade in nice colors. Include the streams from the NHDPlus Service and Basin and sub-watersheds from the SanMarcos.gdb Basemap feature dataset.*

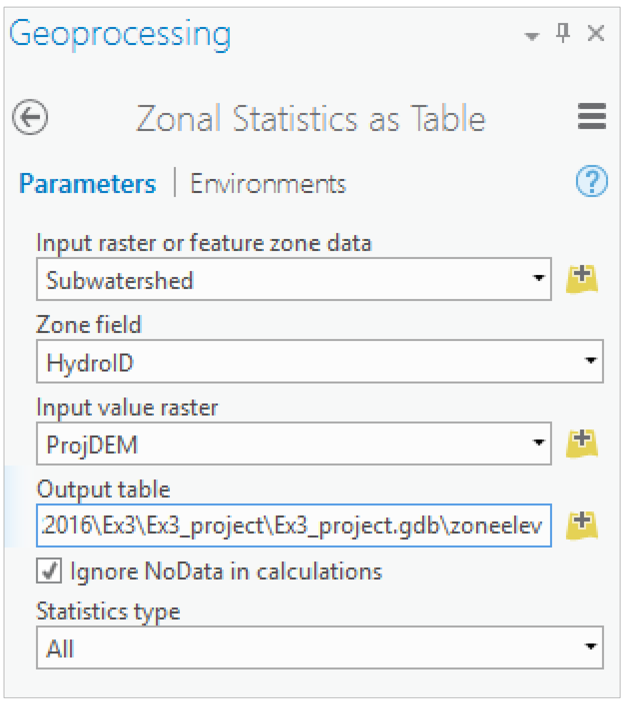
You may omit the NHDPlus streams if they do not display on your screen at the resolution you are working.

5. Zonal Average Calculations

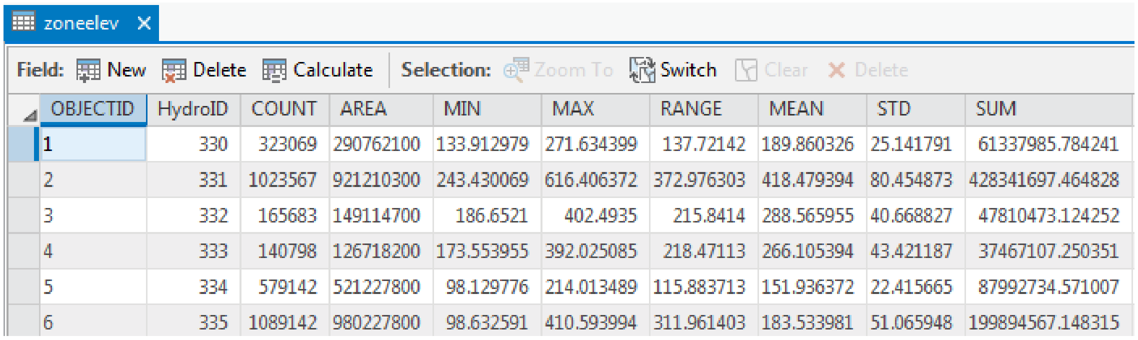
In hydrology it is often necessary to obtain average properties over watersheds or subwatersheds. The Zonal functions in Spatial Analyst are useful for this purpose. If you rearrange the map display as shown below and label the **Subwatersheds** with the attribute **HydroID**, you'll see that there is a unique Subwatershed for each stream gage location that you created in Exercise 2.



Select **Spatial Analyst Tools → Zonal → Zonal Statistics as Table**. Set the inputs as follows:



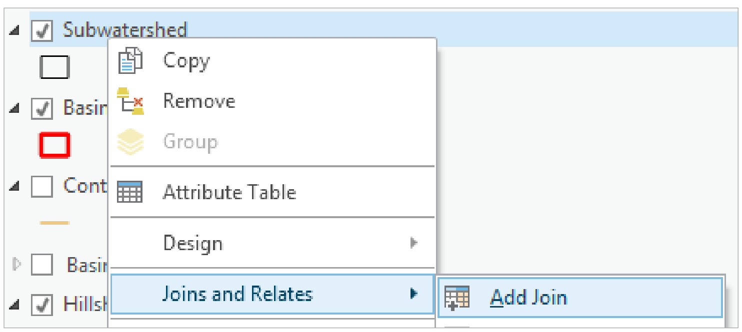
Click OK. A table with zonal statistics is evaluated and added to the map (at the bottom of the map display). Right-click to **open** the table.



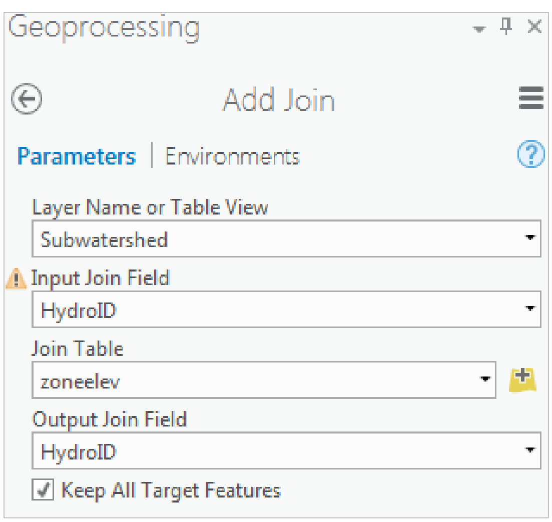
OBJECTID	HydroID	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
1	330	323069	290762100	133.912979	271.634399	137.72142	189.860326	25.141791	61337985.784241
2	331	1023567	921210300	243.430069	616.406372	372.976303	418.479394	80.454873	428341697.464828
3	332	165683	149114700	186.6521	402.4935	215.8414	288.565955	40.668827	47810473.124252
4	333	140798	126718200	173.553955	392.025085	218.47113	266.105394	43.421187	37467107.250351
5	334	579142	521227800	98.129776	214.013489	115.883713	151.936372	22.415665	87992734.571007
6	335	1089142	980227800	98.632591	410.593994	311.961403	183.533981	51.065948	199894567.148315

This contains statistics of the value raster, in this case elevation from **ProjDEM** over the zones defined by the polygon feature class **Subwatershed**. The Value field in this zone table contains the HydroID from the subwatershed layer and may be used to join these values with attributes of the Subwatershed feature class.

Right click on Subwatershed and select **Joins and Relates → Join**.



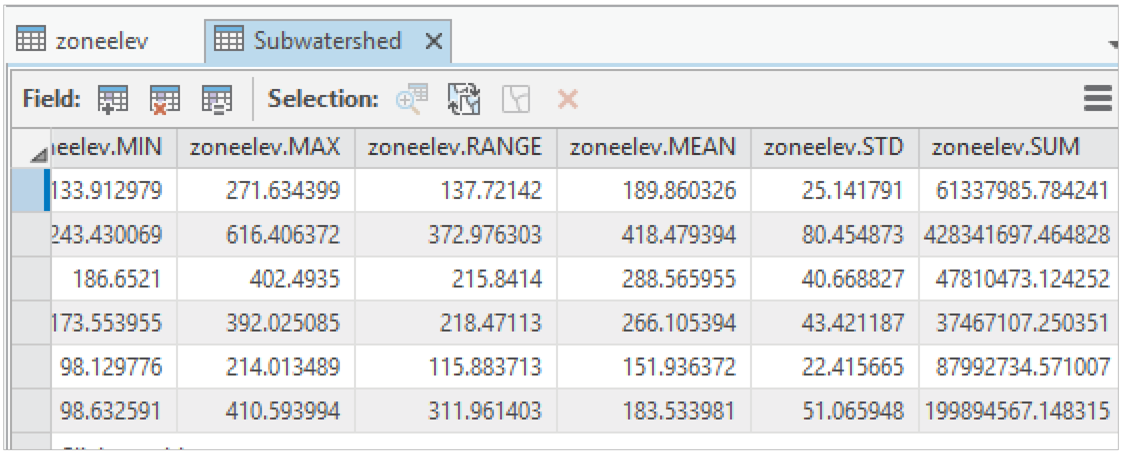
Select HydroID as the field in this layer (Subwatershed) that the join will be based on, zoneelev as the table to join to this layer, and HydroID again as the field in the table to base the join on.



Note the warning, which states: "The join field HydroID in the join table Subwatershed is not indexed. To improve performance, we recommend that an index be created for the join field in the join table."

This warning can be ignored for this particular dataset because this table is sufficiently small, so the presence of indices to speed up the data queries does not make any noticeable difference.

Open the Subwatershed attribute table and scroll across. You'll see the statistics have been added to the attributes that this feature class already held.

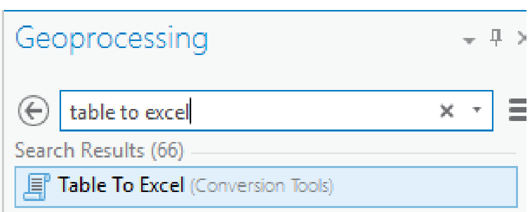


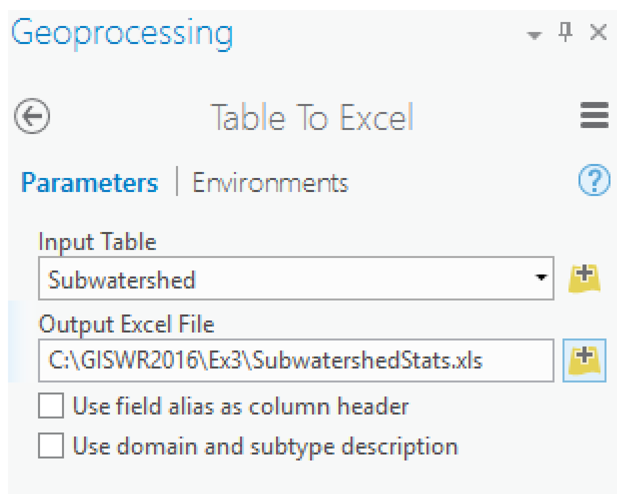
zoneelev | Subwatershed

Field: Selection:

ieelev.MIN	zoneelev.MAX	zoneelev.RANGE	zoneelev.MEAN	zoneelev.STD	zoneelev.SUM
133.912979	271.634399	137.72142	189.860326	25.141791	61337985.784241
243.430069	616.406372	372.976303	418.479394	80.454873	428341697.464828
186.6521	402.4935	215.8414	288.565955	40.668827	47810473.124252
173.553955	392.025085	218.47113	266.105394	43.421187	37467107.250351
98.129776	214.013489	115.883713	151.936372	22.415665	87992734.571007
98.632591	410.593994	311.961403	183.533981	51.065948	199894567.148315

In the Geoprocessing panel, select Table to Excel and specify Subwatershed as the input Table, and SubwatershedStats as output Excel file.





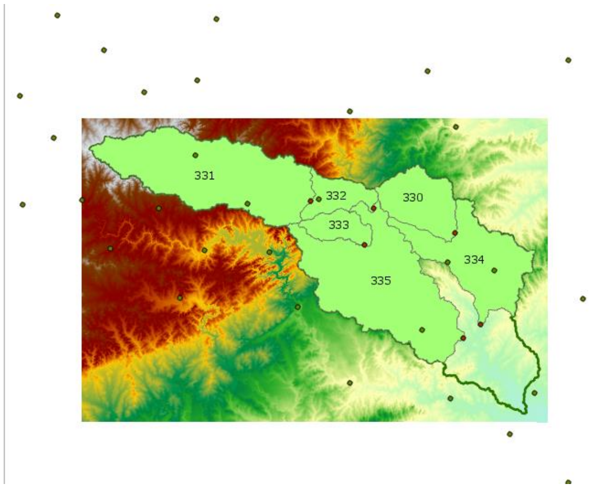
If you open up the resulting SubwatershedStats Excel file you'll see the descriptive statistics there for the San Marcos subwatersheds.

Determine the mean elevation and elevation range of each subwatershed in the SanMarcos Subwatershed feature class.

To turn in: A table giving the HydroID, Name, mean elevation, and elevation range for each subwatershed in the SanMarcos Subwatershed feature class. Which subwatershed has the highest mean elevation? Which subwatershed has the largest elevation range?

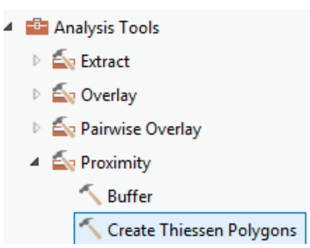
6. Calculation of Area Average Precipitation using Thiessen Polygons

Now to do something really useful. We will calculate the area average mean annual precipitation over the watershed using Thiessen polygons. Thiessen polygons associate each point in a watershed with the nearest raingage. Turn on the **PrecipStn** stations in the map display and open their attribute table. You'll see an **AnnPrecip_in** attribute which is the mean annual precipitation at each gage in inches.

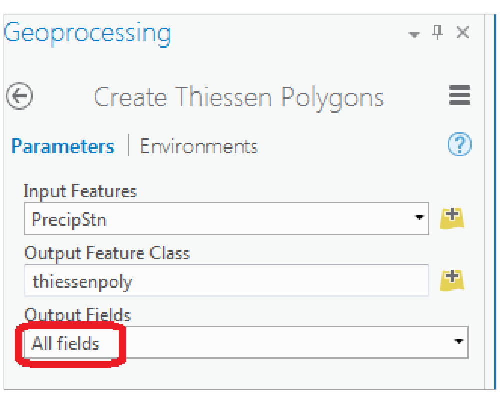


ELEVATION	ELEM	Nyr	AnnPrecip_in
200.6	TPCP	24	35.175
146.3	TPCP	6	34.515
533.4	TPCP	19	32.607368
118.3	TPCP	6	30.798333
417.6	TPCP	25	35.8844
335.3	TPCP	20	35.657
304.8	TPCP	17	39.082353
94.5	TPCP	10	37.358
437.4	TPCP	11	38.551818

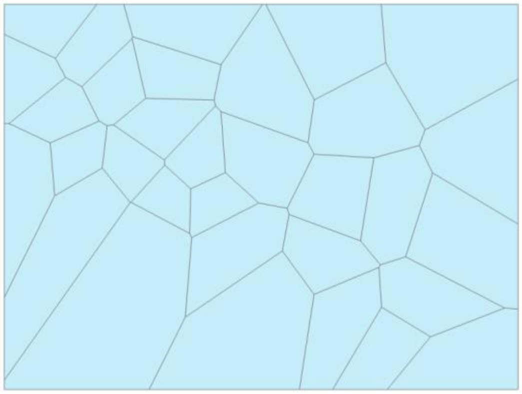
Select the tool **Analysis Tools → Proximity → Create Thiessen Polygons**



Specify **PrecipStn** as the Input Features. Save the output feature class in the BaseMap feature dataset and indicate that **ALL** fields should be output. By saving to the BaseMap feature dataset you ensure that the Thiessen polygon feature class inherits the spatial reference information from this feature dataset, keeping all your work in a consistent spatial reference. Click OK. It's really important that you select "All" here to carry the attributes of the Precipitation stations to the polygons associated with them.



The result is a Thiessen polygon feature class. This tessellates the landscape into regions that are closer to a particular gage than to any other.



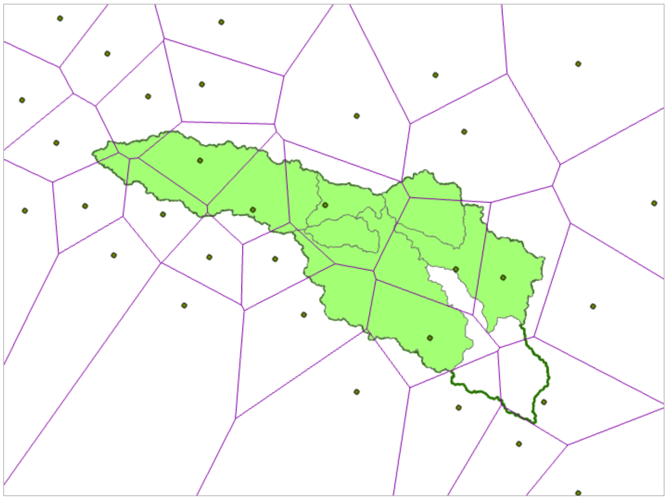
Here is what your attribute table should look like for thiessen polygons. If it doesn't have all these attributes at the right hand end, delete the result you just computed and do it over with the ALL option selected to make sure you transfer all the attributes from the gages to the polygons.

thiessenpoly

Field: New Delete Calculate Selection: Zoom To Switch Clear Delete

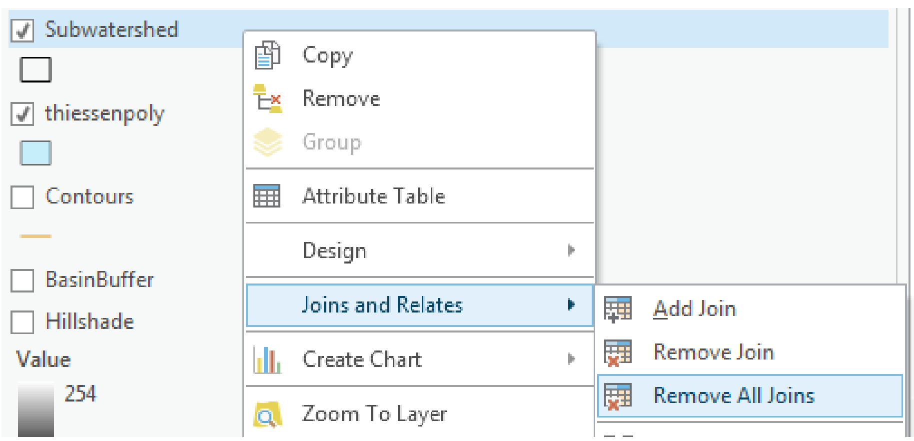
OBJECTID	Shape	Shape_Length	Shape_Area	Input_FID	COOPID	stname	latdd	longdd	ELEVATION	ELEM	Nyr	AnnPrecip_in
1	Polygon	219160.88469	2743248246.425552	6	411215	BULVERDE	29.75	-98.45	335.3	TPCP	20	35.657
2	Polygon	180867.160187	1912782695.771555	27	418187	SEGUIN 1 SSW	29.55	-97.966667	153.3	TPCP	14	35.712857
3	Polygon	115197.971824	721528046.483713	15	413622	GONZALES 1N	29.533333	-97.45	115.8	TPCP	25	35.1448
4	Polygon	144172.839934	1126878591.586405	29	418415	SMITHVILLE	30.016667	-97.15	103.6	TPCP	20	36.1115
5	Polygon	122727.252192	994385367.29268	2	410429	AUSTIN-BERGSTRO...	30.183333	-97.683333	146.3	TPCP	6	34.515
6	Polygon	109158.064602	742107271.512506	32	419815	WIMBERLEY 1 NW	30	-98.066667	253	TPCP	21	40.47619
7	Polygon	77451.84468	352989955.07953	28	418358	SISTERDALE	29.983333	-98.733333	426.7	TPCP	11	40.497273
8	Polygon	89625.880912	429818644.007928	31	418877	TEAGUE RANCH	30.433333	-98.816667	496.8	TPCP	25	32.5052
9	Polygon	131274.279442	1012438076.842714	1	410428	AUSTIN MUELLER M...	30.316667	-97.766667	200.6	TPCP	24	35.175
10	Polygon	164610.415862	1717347186.543875	11	412820	ELGIN	30.35	-97.366667	176.5	TPCP	26	35.094231
11	Polygon	125274.58415	834148826.922078	24	416276	NEW BRAUNFELS	29.733333	-98.116667	216.4	TPCP	17	34.270588
12	Polygon	98482.889825	579456544.809058	21	414805	KINGSBURY	29.683333	-97.766667	155.4	TPCP	7	38.788571
13	Polygon	144148.611523	1227871182.469289	18	414575	JEDDO 3S	29.766667	-97.316667	126.5	TPCP	21	38.240952
14	Polygon	99985.574528	549126330.644352	16	413624	GONZALES 10 SW	29.433333	-97.516667	111.3	TPCP	9	37.571111
15	Polygon	135071.554432	946265922.719634	8	411671	CHEAPSIDE	29.316667	-97.35	94.5	TPCP	10	37.358
16	Polygon	121607.561971	788948118.508672	4	410660	BELMONT	29.516667	-97.683333	118.3	TPCP	6	30.798333
17	Polygon	111466.266672	754447386.159967	23	415430	LULING 12 NE	29.833333	-97.566667	135.6	TPCP	10	36.803
18	Polygon	104164.265515	674860878.823766	22	415285	LOCKHART 2 SW	29.85	-97.7	149.4	TPCP	10	36.125

If you turn off the Subwatershed labeling and rearrange the map display you can get a map looking something like the below. What we're going to do is to find the area of each thiessen polygon that overlays each subwatershed. This is done using the **Intersect** function, one of the most powerful functions of spatial analysis.

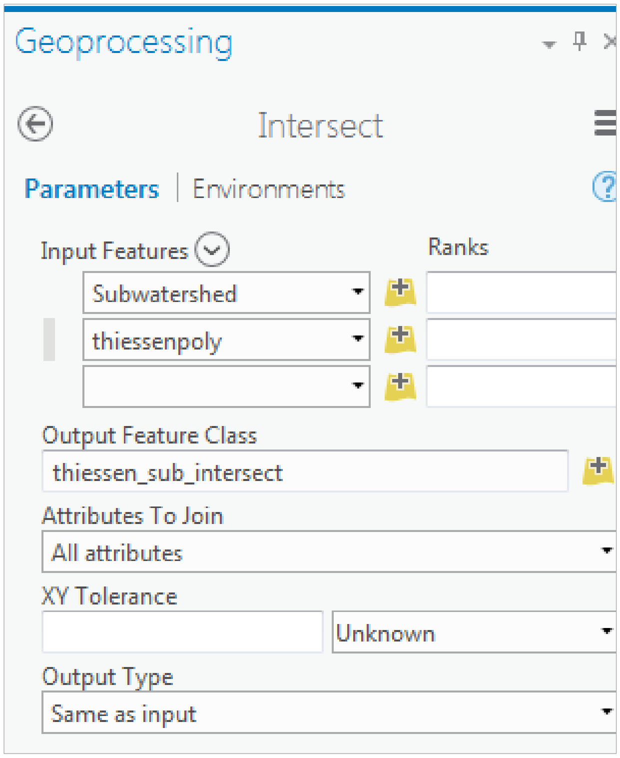


To average precipitation values in these polygons over the subwatersheds we need to intersect the thiessen polygons with the subwatersheds and compute area weighted averages for each subwatershed. The following calculations achieve this.

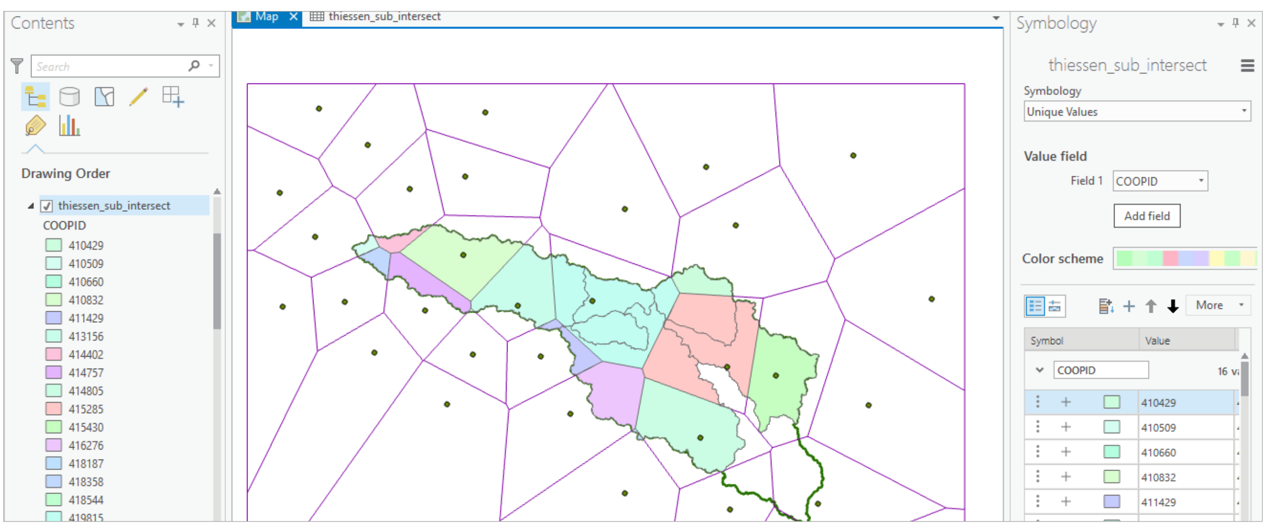
First right click on the Subwatershed layer and remove all joins (to remove the join with zonelev that we created earlier).



Use the search window to locate the **Intersect (Analysis)** tool and set the inputs as follows



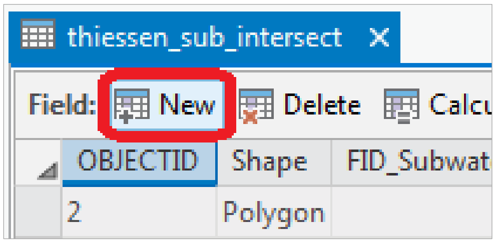
Following is the result, the thiessen_sub_intersect polygons symbolized with **COOPID** as the Unique Value field – this is the identifying number of the rain gage in the cooperative program by which volunteers supply precipitation data from their gages to the National Weather Service.



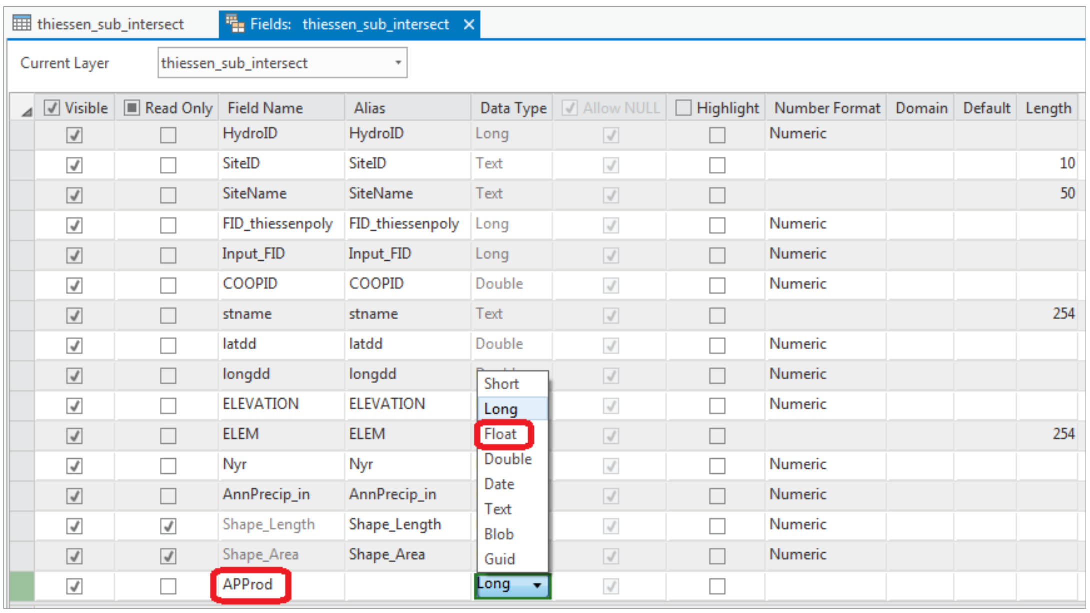
If you open the ThiessenSubIntersect attributed table you will see that from the 6 subwatersheds there are now 24 polygons, each contributing to part of a subwatershed and associated with a single rain gage. Let $\mathbf{P}_k$ denote the precipitation associated with each rain gage and $\mathbf{A}_{ik}$ the area of intersected polygon associated with rain gage k and subwatershed i. Then the area weighted precipitation associated with each subwatershed is

$$P_i = \frac{\sum_k A_{ik} P_k}{\sum_k A_{ik}}$$

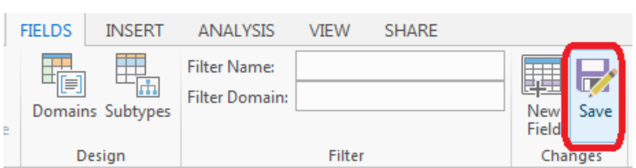
Open the attribute table for the intersected thiessen polygons and add a new field to the table, **APProd**.



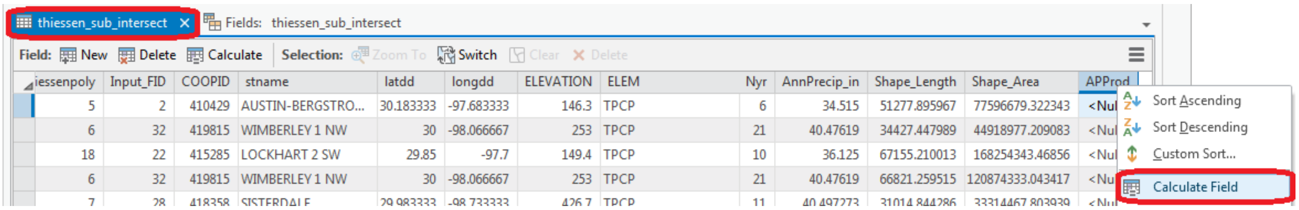
Double-click on the greyed-out “Data Type” column, where it says Long, and change the Data Type of APProd to **Float**. If you don’t change this data type, your calculations will fail on a datatype mismatch error.



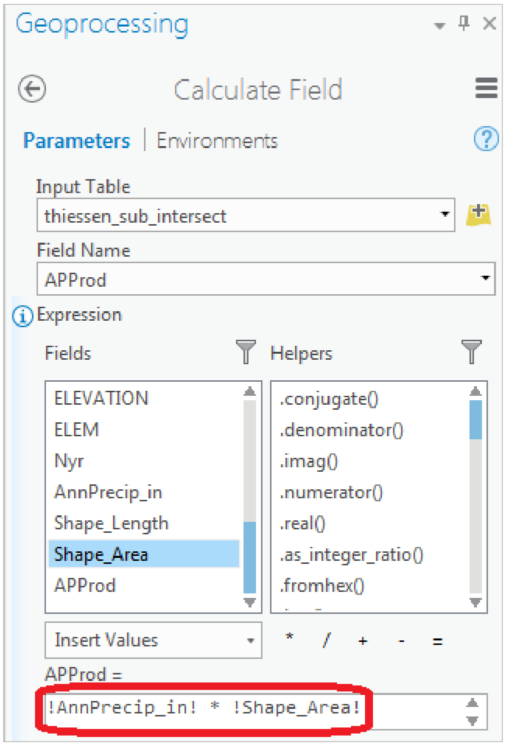
Make sure to save your changes using the save button in the **Fields** tab at the top of the screen.



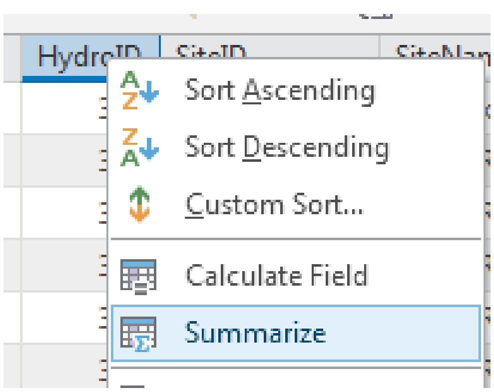
Go back to the thiessen-subwatershed polygon attribute table and right-click on the header of APProd, selecting “Calculate Field”.



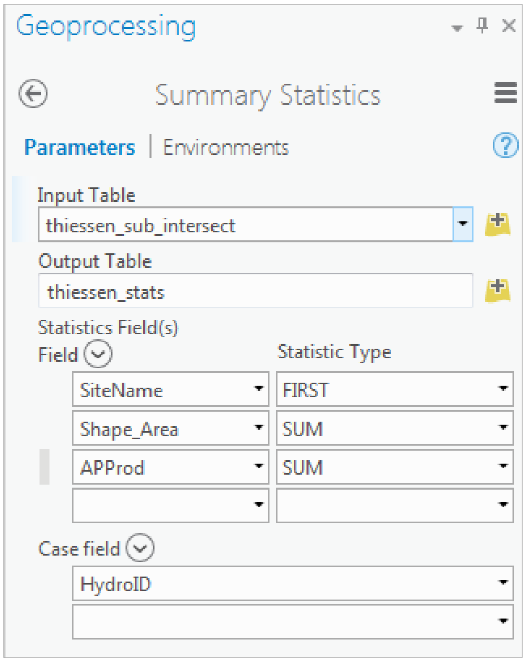
Create the expression **!AnnPrecip_in!** * **!Shape_Area!** and click OK.



The result is a new field with the numerator terms for the equation above. Now locate the column HydroID. These are unique identifiers for each Subwatershed. Right click on the header and select Summarize



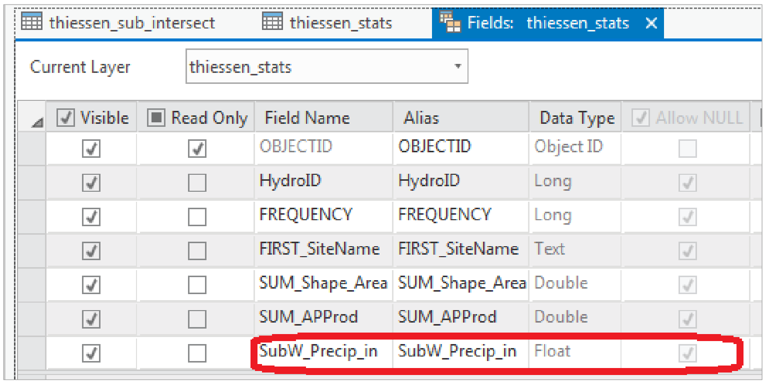
Carefully select the summary statistics you need. I selected the following: SiteName - First, Shape_Area - Sum, APProd – Sum, and the HydroID Case field.



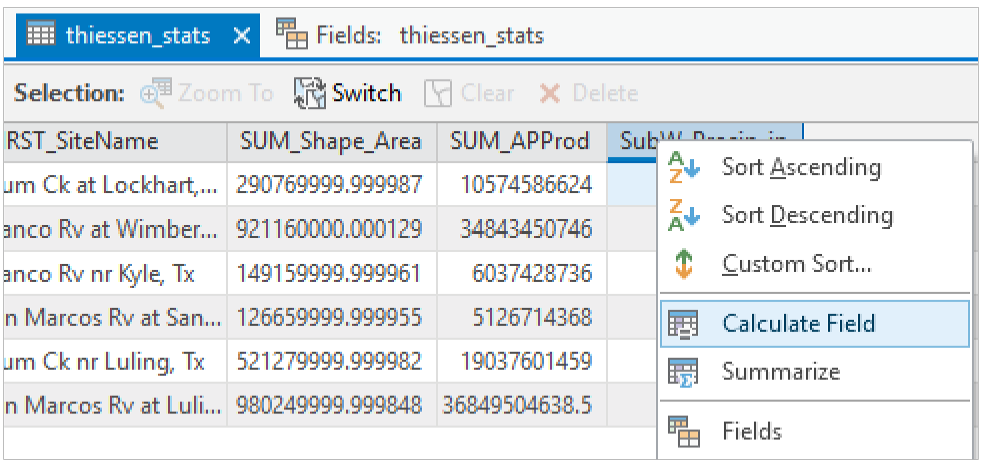
Navigate to your output table, and you'll see that the resulting table gives the numerator and denominator in the equation above for each subwatershed.

OBJECTID	HydroID	FREQUENCY	FIRST_SiteName	SUM_Shape_Area	SUM_APProd
1	330	3	Plum Ck at Lockhart,...	290769999.999987	10574586624
2	331	9	Blanco Rv at Wimber...	921160000.000129	34843450746
3	332	1	Blanco Rv nr Kyle, Tx	149159999.999961	6037428736
4	333	1	San Marcos Rv at San...	126659999.999955	5126714368
5	334	3	Plum Ck nr Luling, Tx	521279999.999982	19037601459
6	335	7	San Marcos Rv at Luli...	980249999.999848	36849504638.5

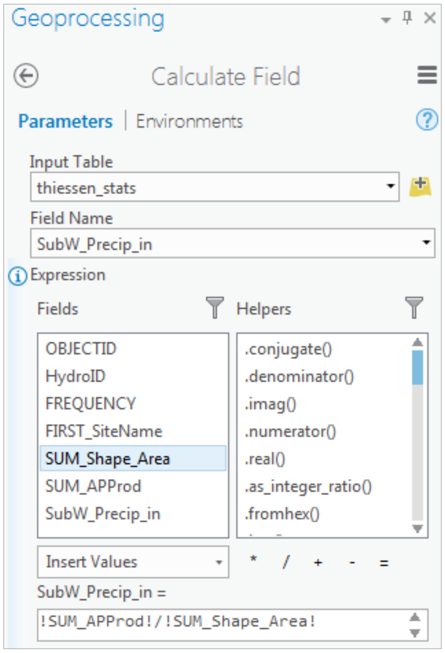
Add a **New** field **SubW_Precip_in** to this table, and **Save** the result.



Go back to the thiessen_stats table and right click



and use **Calculate Field** to evaluate this as **!Sum_APProd! / !Sum_Shape_Area!**

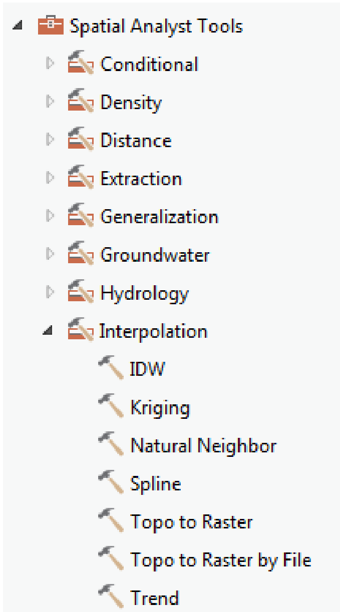


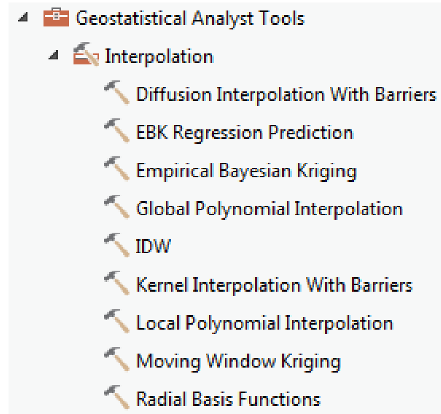
The result is the precipitation in inches for each subwatershed. This is pretty cool! And you can see how the tools in ArcGIS can give you a spatially area-weighted result that would be very difficult to derive otherwise.

To turn in: A table giving the HydroID, Name, and mean precipitation by the Thiessen method for each subwatershed in the SanMarcos Subwatershed feature class. Which subwatershed has the highest mean precipitation?

7. Estimate basin average mean annual precipitation using Spatial Interpolation/Surface fitting

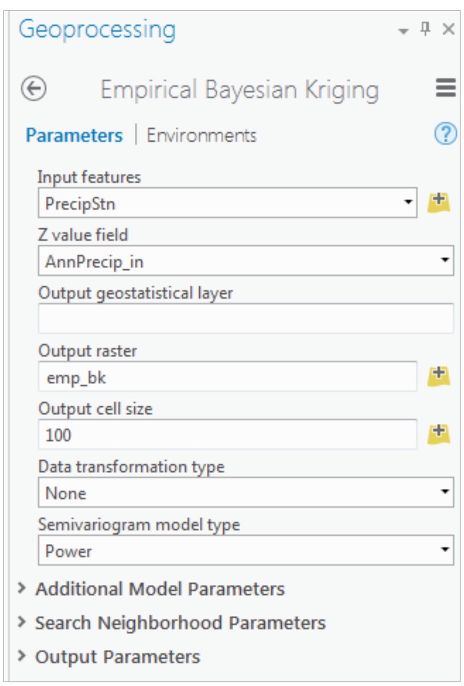
Thiessen polygons were effectively a way of defining a field based on discrete data, by associating with each point the precipitation at the nearest gage. This is probably the simplest and least sophisticated form of spatial interpolation. ArcGIS provides other spatial interpolation capabilities in both the Spatial Analyst and Geostatistical Analyst Toolboxes. Following are the interpolation tools in each.



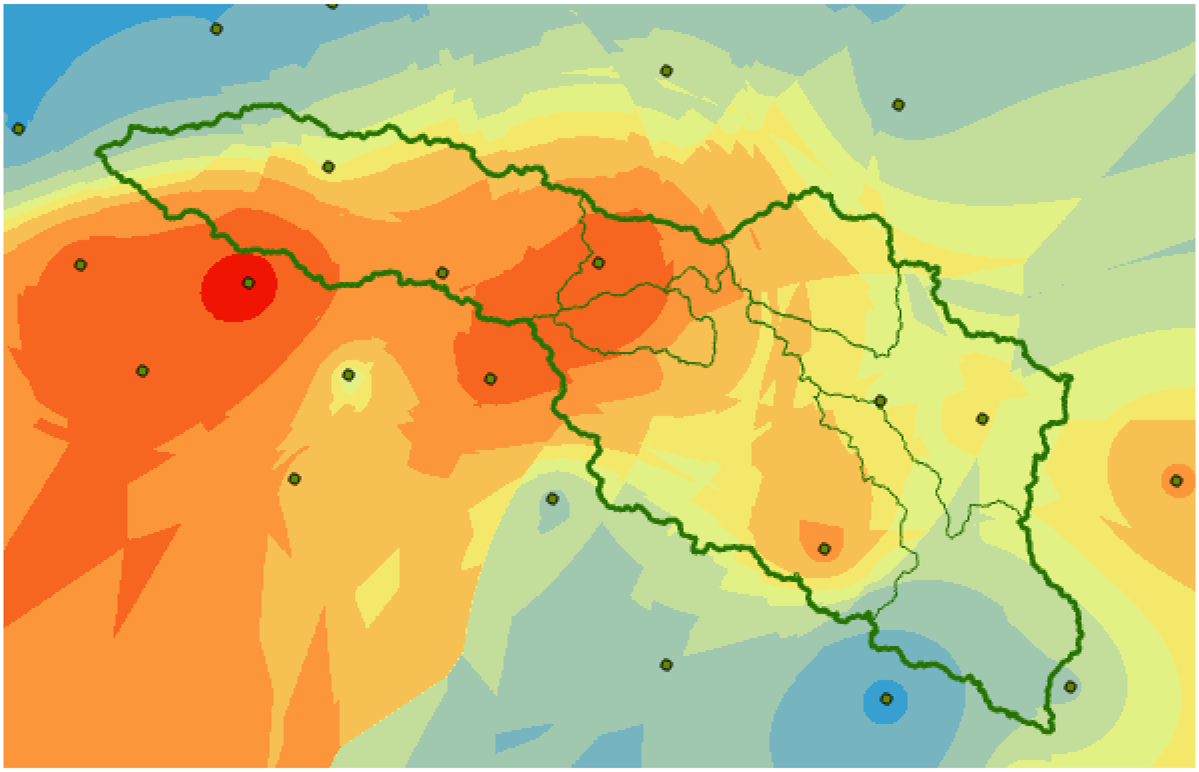


We will not, in this exercise, concern ourselves too much with the theory behind each of these methods. You should however be aware that there is a lot of statistical theory on the subject of interpolation, which is an active area of research. This theory should be considered before practical use of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

In preparing this exercise we experimented with Empirical Bayesian Kriging which is reported to be one of the most advanced of these. We found that it took a very long time to complete, however you are welcome to try it with the following inputs. Use the input points from "PrecipStn" and Z value field as "AnnPrecip_in". Set the output cell size to 100 m to improve the spatial resolution.

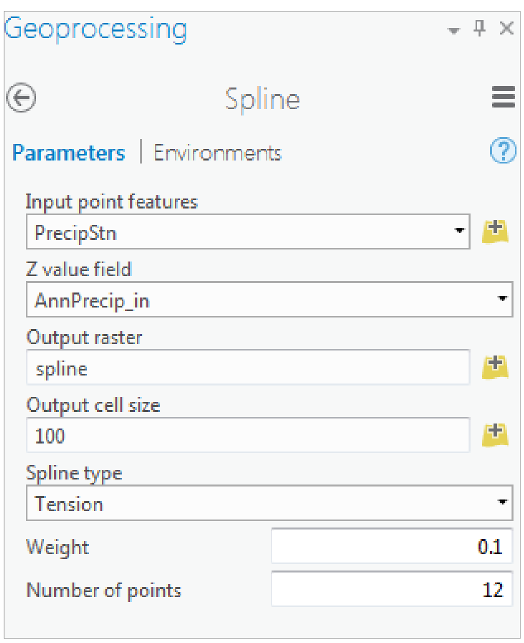


Following is the result from Empirical Bayesian Kriging

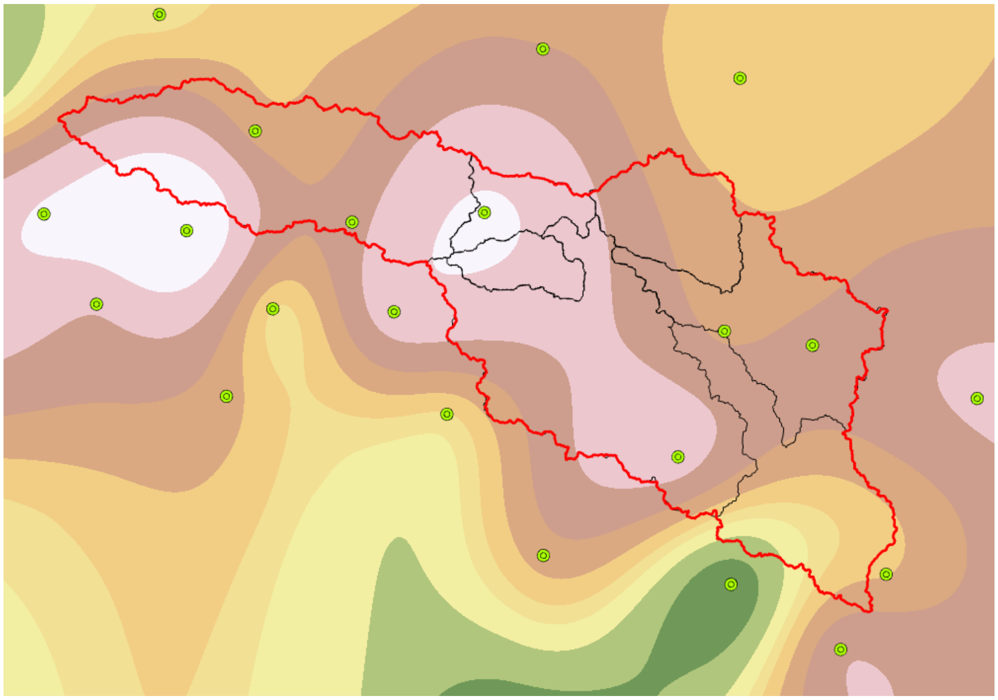


The irregularity of the surface is displeasing.

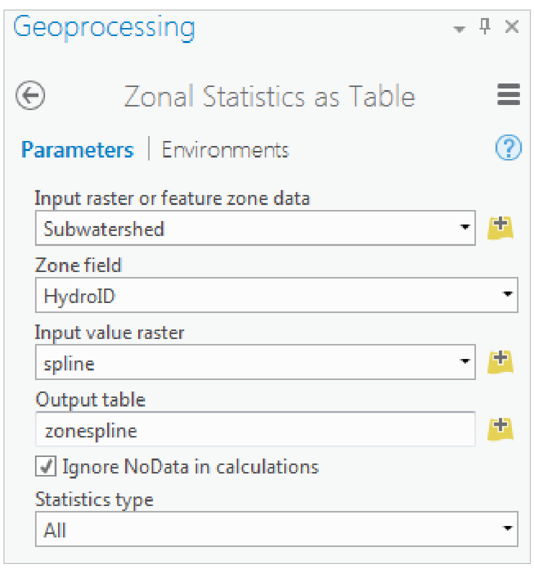
Following are inputs for tension **Spline** interpolation (Spatial Analyst tools). Use the input points from **PrecipStn** and Z value field as **AnnPrecip_in**, and set the spline type as **Tension** with parameters as follows. I reduced the output cell size to 100 m to improve the spatial resolution. The result follows:



This runs a lot faster.



Now, let's use Zonal Statistics to compute the average value of the spline precipitation map over each subwatershed. Select **Spatial Analyst Tools → Zonal → Zonal Statistics as Table**. Set the inputs as follows:



Click OK. A table with zonal statistics is created. This contains statistics of the value raster, in this case mean annual precipitation from **Spline** over the zones defined by the polygon feature class **Subwatershed**.

zonespline

Field: New Delete Calculate Selection: Zoom To Switch Clear Delete

OBJECTID	HydroID	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
1	330	29077	290770000	35.096046	38.188869	3.092823	36.217122	0.733394	1053085.251297
2	331	92116	921160000	35.204449	42.596184	7.391735	37.891757	1.616637	3490437.066021
3	332	14916	149160000	38.079189	40.546021	2.466831	39.785346	0.631229	593438.21413
4	333	12666	126660000	38.473598	40.502689	2.029091	39.656497	0.544171	502289.195576
5	334	52128	521280000	35.207996	37.884964	2.676968	36.461584	0.51532	1900669.450237
6	335	98025	980250000	34.351402	40.285641	5.934238	37.992039	0.884508	3724169.667896

The HydroID in this table may be used to join it to the attribute table for the Subwatershed feature class. As for the elevations above this joined statistics table can be exported to Excel.

To turn in: A table giving the HydroID, Name, and mean precipitation by the Tension Spline method for each subwatershed in the SanMarcos Subwatershed feature class. Which subwatershed has the highest mean precipitation using a Tension Spline interpolation?

Summary of Items to turn in:

1. Hand calculations of slope at point A using each of the two methods and comments on the differences.

2. Table giving slope, aspect, hydrologic slope and flow direction at grid cells A and B. Please turn in a diagram or sketch that defines or indicates what each of these numbers means for the specific values obtained for cells A and B.

3. A screen capture of your final model builder model.

4. A table giving the minimum and maximum values of each of the four outputs Slope, Aspect, Flow Direction, and Hydrologic Slope (Percentage drop), for the digital elevation model in demo.asc.

5. The number of columns and rows in the projected DEM. The cell size of the projected DEM. The minimum and maximum elevations in the projected DEM.

6. A layout showing the location of the highest elevation value in the San Marcos DEM. Include a scale bar and north arrow in the layout.

7. A layout with a depiction of topography either with elevation, contour or hillshade in nice colors. Include the streams from the NHDPlus Service and Basin and sub-watersheds from the SanMarcos.gdb Basemap feature dataset.

8. A table giving the HydroID, Name, mean elevation, and elevation range for each subwatershed in the SanMarcos Subwatershed feature class. Which subwatershed has the highest mean elevation? Which subwatershed has the largest elevation range?

9. A table giving the HydroID, Name, and mean precipitation by the Thiessen method for each subwatershed in the SanMarcos Subwatershed feature class. Which subwatershed has the highest mean precipitation?

10. A table giving the HydroID, Name, and mean precipitation by the Tension Spline method for each subwatershed in the SanMarcos Subwatershed feature class. Which subwatershed has the highest mean precipitation using a Tension Spline interpolation?