

CEVE Hydrology Lab 2

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In this lab, you will continue to practice downloading, manipulating, mapping, and analyzing hydrology data that is publicly available online to continue your study of the Buffalo-San Jacinto watershed subbasin. Specifically, you will work with elevation data from the National Elevation Dataset (NED) accessed through The National Map Viewer and rainfall data from the National Climatic Data Center (NCDC) accessed through Climate Data Online (CDO). You will also learn how to calculate statistics by watershed, such as mean elevation and mean annual precipitation.

Part 1: Continuing an Existing GIS Project

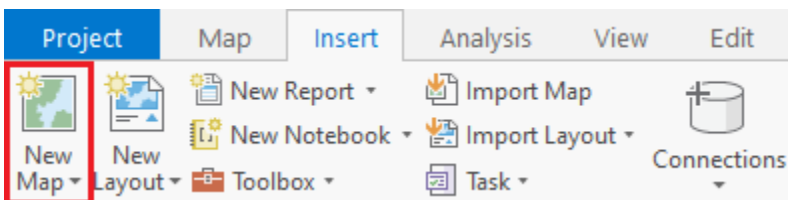
Opening an existing project

1. Using Windows, navigate to your **HydrologyLab** folder from Lab 1.
2. Double-click the **HydrologyLab.aprx** ArcGIS Project File.

Creating a new map

You will begin by creating a new map for Lab 2.

1. On the Standard toolbar, click the **Insert** tab and click **New Map**.



2. At the top of the Contents pane, rename the map to "**Lab2**".

Projecting vector data

Before downloading any new data, you will further process data from Lab 1 in preparation for this lab.

1. In the Catalog pane, expand the **Databases** section and the **HydrologyLab.gdb** geodatabase.
2. Drag the **Watersheds** feature class into the Lab2 map view.
3. In the Contents pane, double-click the **Watersheds** layer.
4. In the 'Layer Properties' window, click the **Source** tab.
5. Scroll down and expand the **Spatial Reference** section.

Notice that the layer is in a geographic coordinate system called *NAD 1983*, which stands for North American Datum 1983. Because the data has a geographic coordinate system, the coordinates are stored in degrees, which indicate the three-dimensional location of the data on Earth's spheroid. Though the data itself is stored in a geographic coordinate system, your computer monitor is flat, so, even though no projection has been defined, the data must be displayed in a particular projection. Whenever ArcGIS displays data in a geographic coordinate system, it uses a pseudo plate carrée projection, where one degree of latitude by one degree of longitude is represented as a square, rather than a curved trapezoid. In other words, all lines of latitude and longitude are evenly spaced. This type of projection results in stretching in the east-west direction, which increases the farther north or south from the equator you are mapping.

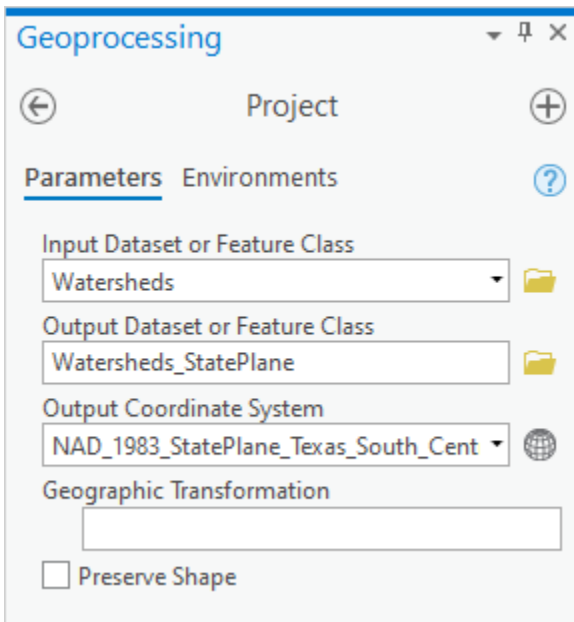
1. Close the '**LayerProperties**' window.

Working with geographic coordinate systems is fine for creating purely visual maps, as you did in Lab 1 (though the visual distortion can be disorienting and misleading), but, in this lab, you will be calculating areas, distances, and overlaps between features. Such calculations require the three-dimensional coordinates to be projected down onto a two-dimensional plane, so that the coordinates are stored in linear units, such as feet or meters, rather than degrees. In order to facilitate measurements of distance and area, you will now project the *Watersheds* layer into the State Plane Texas South Central projection which is best suited to mapping the greater Houston region.

1. In the Analysis tab, click the **Tools** button to open the Geoprocessing pane.
2. In the 'Find Tools' search box, type "**project**".
3. Click the **Project** tool.
4. For 'Input Dataset or Feature Class', use the drop-down menu to select the **Watersheds** layer.
5. For 'Output Dataset or Feature Class', rename "*Watersheds_Project*" to "**Watersheds_StatePlane**", since that is the name of the projection you will be using.
6. Next to the 'Output Coordinate System' box, click the **Select Coordinate System** button.
7. Double-click **Projected Coordinate Systems State Plane NAD 1983 (US Feet)**.
8. Select **NAD 1983 StatePlane Texas S Central FIPS 4204 (US Feet)** and click **OK**.

Because both the input and output coordinate systems are based on the NAD 1983 geographic coordinate system, no geographic transformation is required.

1. Ensure your 'Project' window appears as shown below and click **Run**.



Now that you have the correctly projected layer, you no longer need the original NAD 1983 layer.

1. In the Contents pane, right-click the original **Watersheds** layer and select **Remove**.
2. Double-click the new **Watersheds_StatePlane** layer.
3. Scroll down and expand the **Spatial Reference** section.

Notice that the layer is now in a projected coordinate system, *NAD 1983 StatePlane Texas S Central FIPS 4204 (US Feet)*.

1. Close the '**Layer Properties**' window.

You may have noticed that the visual appearance of the watersheds did not change in your Map Display, even though you projected them. That is because the data frame takes on the projection of the first layer added to it. Since you first added the original unprojected *Watersheds* layer into the data frame, which was in NAD 1983, the data frame still displays the data in NAD 1983 (or pseudo plate carrée). Currently, the projected *Watersheds_StatePlane* layer is being projected-on-the-fly back into NAD 1983 for visual purposes.

Move the cursor around the screen and notice that the coordinates at the bottom of the map view are shown in decimal degrees. This is another clue that the data frame is still using a geographic coordinate system; however, you would like the data frame to display data using the local Houston projection.

1. At the top of the Contents pane, double-click the **Lab 2** map to open the 'Map Properties' window.

2. Click the **Coordinate Systems** tab.

While you could search for or navigate to the State Plane Texas South Central projection, as you did before, in this case, you know that the same coordinate system is already used by the *Watersheds_StatePlane* layer. In such an instance, it is often easier to import the coordinate system from another known layer, especially if you are not familiar with the hierarchy of the coordinate system folders

1. Scroll to the **top** of the 'XY Coordinate Systems Available' list.
2. Expand Layers.

Notice that all of the coordinate systems used by layers currently in the map are displayed. You can expand the coordinate systems to determine exactly which layers are stored in which coordinate systems.

1. Click **NAD 1983 StatePlane Texas S Central FIPS 4204 (US Feet)**.
2. Click **OK**.

Notice that the watershed boundaries are now more compact in the east-west direction, as expected, because the local projection results in less distortion than the pseudo plate carrée projection used to represent geographic coordinate systems.

Part 2: Downloading DEM Data

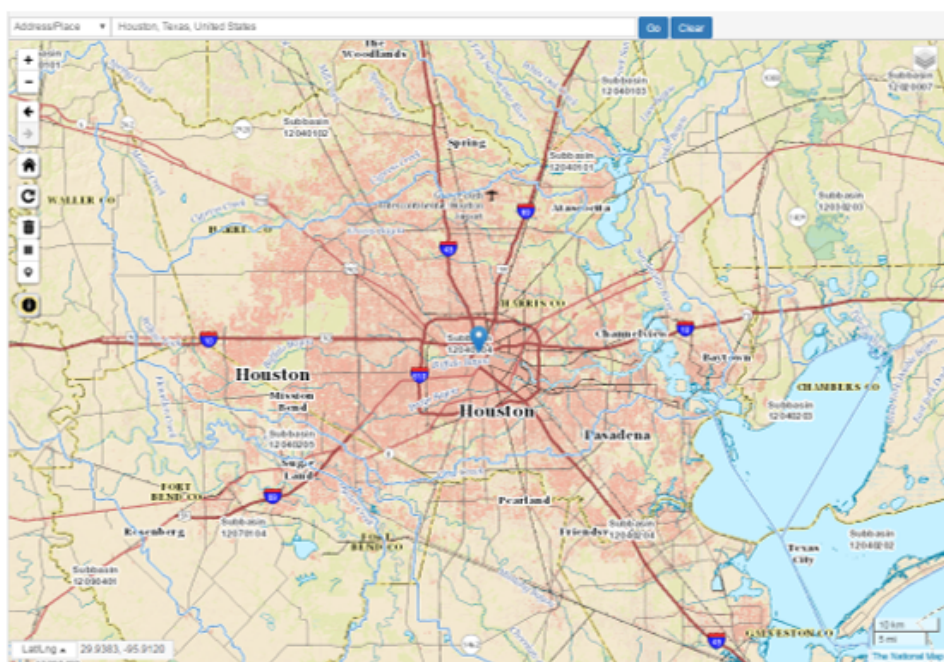
Downloading data from the National Map Viewer

Now you are ready to download digital elevation model (DEM) data for the Buffalo-San Jacinto subbasin. Some local government agencies, such as the Houston-Galveston Area Council (H-GAC) contract to have LiDAR data collected, which provides high resolution data containing both the elevation of the bare land and the heights of features in the built environment. Though we are lucky to have this high-quality data available in this particular region, for projects anywhere in the U.S., the best available DEM data generally comes from the National Elevation Dataset (NED) produced by the USGS. More information regarding NED data can be found at ned.usgs.gov. You will download NED data from The National Map Download Client.

1. In a web browser, go to <https://apps.nationalmap.gov/downloader/>.

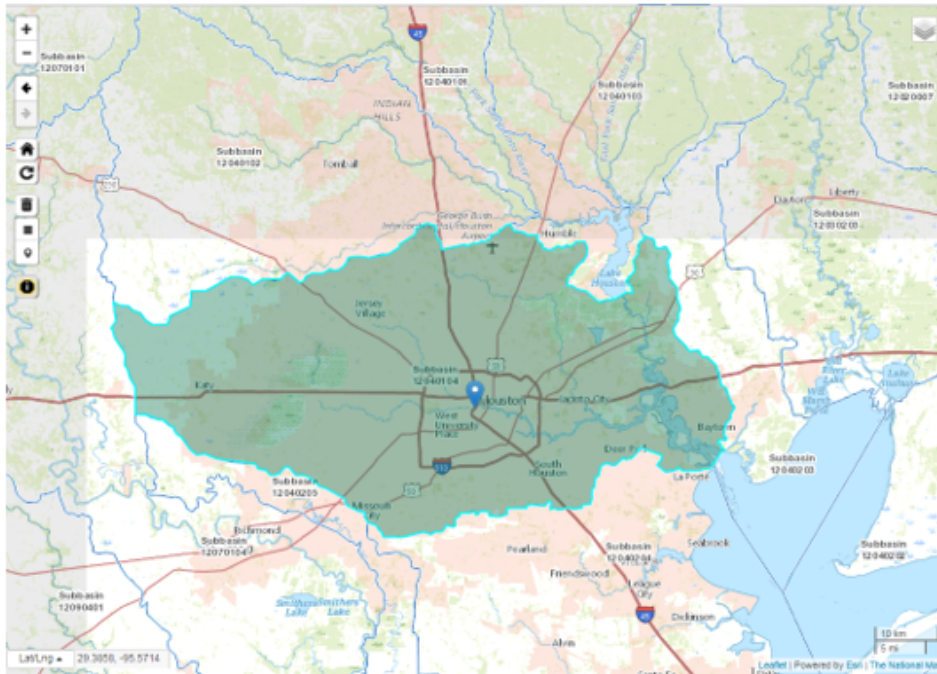
First, you will constrain your downloads to your area of interest.

1. In the 'Area of Interest' section, use the 'Map Extent/Geometry' drop-down menu button to select **Selectable Polygon**.
2. Use the 'Select...' drop-down menu to select **8-digit HU (Subbasin)**.
3. At the top right of the map, in the 'Find address or place' search box, type **"Houston"** and press **Enter**.



After zooming into Houston, you can see the blue boundaries of the individual subbasins and each subbasin is labeled with its HUC-8 number on the map.

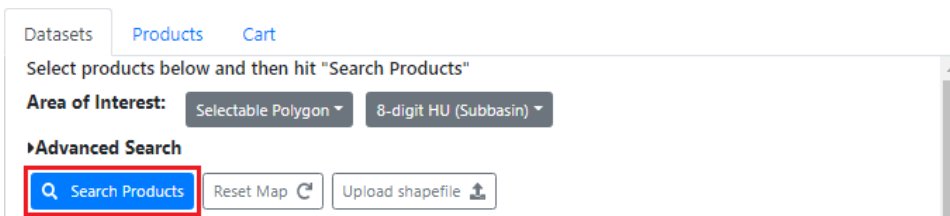
1. Near the center of the map, click within **Subbasin 12040104** to select it.



Your data search will now be constrained to the polygon for subbasin 12040104.

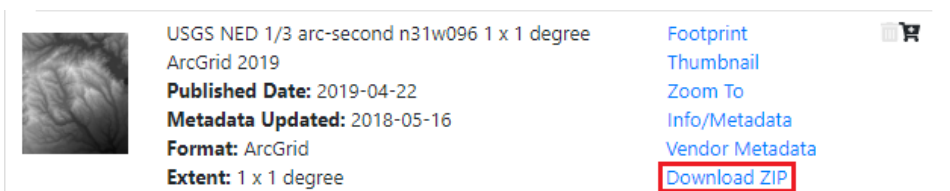
Next, you will select the data products you are interested in viewing and downloading.

1. On the left side bar, under the 'Data' section, check the **Elevation Products (3DEP)** section to expand it.
2. If necessary, within the 'Subcategories' section, check **1/3 arc-second DEM**.
3. Under the 'File Formats' section, select **All**, which will make the ArcGrid file format available (rather than only the GeoTIFF and IMG file formats)
4. Scroll back to the top of the left side bar and click the **Search Products** button.



You are now provided with a listing of all the DEM tiles covering the area of subbasin 12040104. Although 12 results are listed, there are only 3 areas of coverage provided in 4 different file formats: ArcGrid, GeoTIFF, GridFloat, and IMG. You will download only the 3 files in the ArcGrid format

1. In turn, click **Download ZIP** for USGS NED 1/3 arc-second 1 x 1 degree ArcGrid 2019 for **n30w096**, **n30w095**, and **n31w096**.



2. Once all files have finished downloading, navigate to the location where the **three zipped folders** have been downloaded. The downloads may take a few minutes to complete.
3. Select and copy **all three zipped folders**.
4. Using Windows Explorer, navigate to your **HydrologyLab** folder.
5. Paste **all three zipped folders** directly inside your **HydrologyLab** folder. Do NOT paste them inside the *HydrologyLab.gdb* geodatabase folder.
6. Select **all three zipped folders**.
7. Right-click **any of the three selected folders** and select **7-Zip Extract to "*"**, which will create one unzipped folder for the contents of each zipped folder. (If you are on a personal computer without 7-Zip installed, then right-click **each folder in turn** and select **Extract All**. Leave the default location, which is the same location as the original zipped folder, and click **Extract**.)
8. Return to **ArcGIS Pro**.

Since you just added new files to your folder, you will need to refresh it in order for them to appear in the Catalog pane.

1. At the bottom of the Geoprocessing pane, click the **Catalog** tab.
2. Double-click **Folders > HydrologyLab**.
3. If you do not see your newly download folders, right-click the **HydrologyLab** folder and select **Refresh**.
4. Expand all three **USGS** folders to preview their contents.

Each raster file with a name such as *grdn30w095_13* corresponds to a 1x1 degree tile. The file name contains "grd" for grid, followed by the latitude and longitude of the top left corner of the tile.

Adding raster data in ArcMap

1. Drag the *grdn30w095_13* raster into the *Lab2* map view.

You will be asked if you would like to create pyramids. Pyramids cache the raster at multiple reduced resolutions, resulting in an increased file size, but better rendering performance in your map view. It is normally a good idea to create pyramids, but since you will be processing the corresponding rasters into a new file in the next step, you will not create pyramids at this time.

1. In the 'Build pyramids' window, click **No**.
2. Repeat the previous two steps with the *grdn30w096_13* and *grdn31w096_13* rasters.

Notice that the 1x1 degree tiles appear as angled rectangles, because they are being displayed in the State Plane Texas South Central projection. If the data frame were still in the NAD 1983 geographic coordinate system, the tiles would look like squares. Now you will look up the native coordinate system of the raster files.

1. In the Contents pane, double-click the *grdn31w096_13* layer to open the 'Layer Properties' window.
2. In the Source tab, expand the '**Spatial Reference**' section.

Notice the Geographic Coordinate System is *NAD 1983* and that no projected coordinate system is listed. Since this coordinate system is not the same as the one currently used by the data frame, the raster layer is being projected-on-the-fly into the State Plane Texas South Central projection.

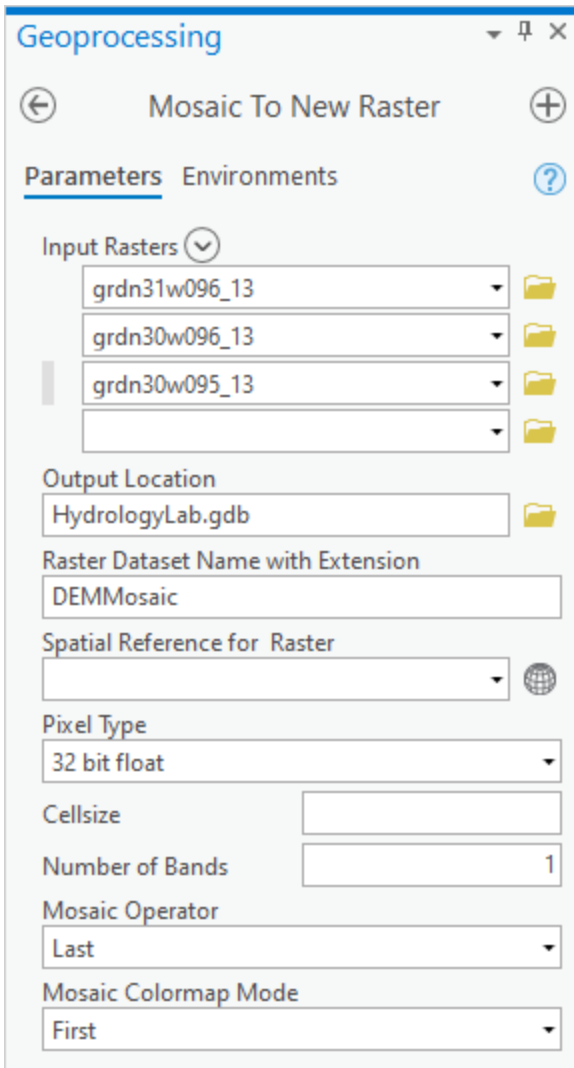
Mosaicking raster files

The edges where the three tiles meet are currently visible, because the minimum and maximum elevation is different in each raster, causing the same value to be represented with a different shade of gray in each raster. To solve that visual problem and also simplify future processing steps, you will mosaic the three rasters into a single raster. Before creating a mosaic, you will need to look up some information from the original rasters.

1. Scroll back to the **top** of the 'Layer Properties' window and expand the '**Raster Information**' section.

Notice that there is 1 band, meaning that each pixel only stores a single value: the height above sea level in meters. Aerial imagery has 3 bands to store the 3 RGB values. The format is listed as GRID, which stands for an Esri Grid, which is a raster file format native to Esri software. The pixel type and depth is 32-bit floating point, which indicates that the cells can store decimal data.

1. Close the '**Layer Properties**' window.
2. At the bottom of the Catalog pane, click the **Geoprocessing** tab.
3. At the top left of the Geoprocessing pane, click the **Back** button.
4. In the search box, type "**mosaic to new raster**".
5. Click the **Mosaic to New Raster** tool.
6. For 'Input Rasters', select the **three 1x1 degree** raster layers.
7. For 'Output Location', click the **Browse** button.
8. In the bottom right corner of the 'Output Location' window, use the drop-down menu to select **File Geodatabases** (instead of Folders), if necessary.
9. Select the **HydrologyLab.gdb** geodatabase and click **OK**.
10. For 'Raster Dataset Name with Extension', type "**DEMmosaic**". No extension is necessary when storing the raster in a file geodatabase.
11. Use the 'Pixel Type' drop-down menu to select **32 bit float**, since that was the same type stored in the original rasters.
12. For 'Number of Bands', type "**1**". (The text appears on the right side of the field.)
13. Ensure your 'Mosaic To New Raster' pane appears as shown below and click **Run**.



The mosaic may take a couple minutes to process. When it is complete, notice there are no longer visual seams between the tiles in the mosaicked raster. Now that you have a single mosaic, you no longer need the three original tiles.

1. In the Contents pane, remove **all three original** raster layers.

Projecting raster files

Now you need to project your mosaic into the State Plane Texas South Central projection, so that you can properly calculate spatial statistics based on the data it contains.

1. At the top left of the Geoprocessing pane, click the **Back** button.
2. In the search box, type "project raster".
3. Click the **Project Raster** tool.
4. Use the 'Input Raster' drop-down menu to select the **DEMMosaic** layer.
5. For 'Output Raster Dataset', rename the raster from *DEMMosaic_ProjectRaster* to "**DEMStatePlane**".
6. Use the 'Output Coordinate System' drop-down menu to select **Watersheds_StatePlane**, which will import the same coordinate system used by that layer.

You should now see the NAD_1983_StatePlane_Texas_South_Central_FIPS_4204_Feet displayed for the Output Coordinate System.

1. Use the 'Resampling Technique' drop-down menu to select **Cubic Convolution**.

For cell size, you may normally want to keep the original resolution, which was approximately 30 m, but, in this case, you will reduce the resolution to expedite processing times during this lab. The cell size is always specified in the same units as the projection, which in this case is feet, so you will select a cell size of 300 feet.

1. Leave 'Output Cell Size' blank, but type "300" for the 'X' and 'Y'.
2. Ensure your Geoprocessing pane appears as shown and click **Run**.

Geoprocessing

Project Raster

Parameters | Environments

Input Raster
DEMMosaic

Output Raster Dataset
DEMStatePlane

Output Coordinate System
NAD_1983_StatePlane_Texas_South_Cent

Geographic Transformation

Resampling Technique
Cubic convolution

Output Cell Size

X 300 Y 300

Registration Point
X Y

Remember that the data frame was already displaying all layers in State Plane Texas South Central, so you should not notice much of a difference between the two layers, other than that the cell size has increased, meaning the resolution has decreased.

1. Remove the **DEMMosaic** layer from the Contents pane.

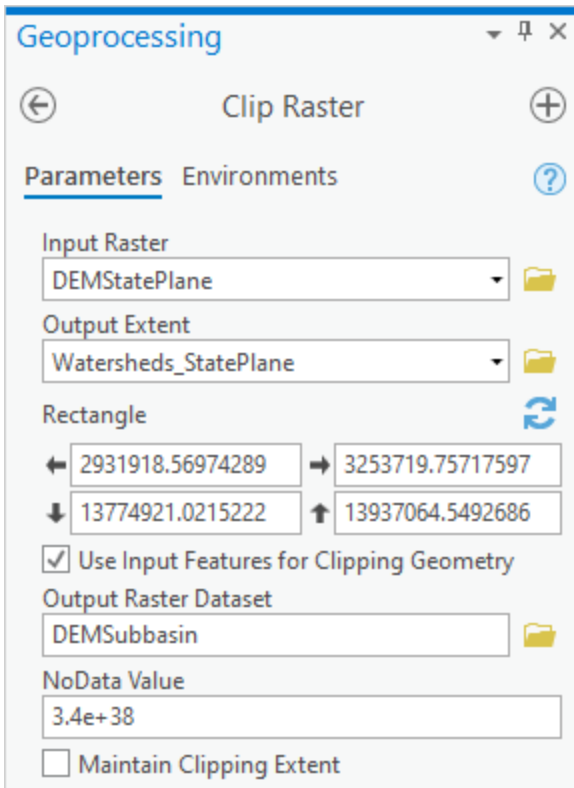
Clipping raster files

Now you are ready to clip the DEM mosaic to the Buffalo-San Jacinto subbasin.

1. At the top left of the Geoprocessing pane, click the **Back** button.
2. In the search box, type "clip raster".
3. Click the **Clip Raster** tool.
4. For 'Input Raster', select **DEMStatePlane**.
5. For 'Output Extent', select **Watersheds_StatePlane**.
6. Check **Use Input Features for Clipping Geometry**.

Checking that box ensures that the raster is limited to the actual shape of the watersheds, rather than a rectangle covering the same extent.

1. For 'Output Raster Dataset', rename the raster from "**DEMStatePlane_Clip**" to "**DEMSubbasin**".
2. Ensure your Geoprocessing pane appears as shown below and click **Run**.



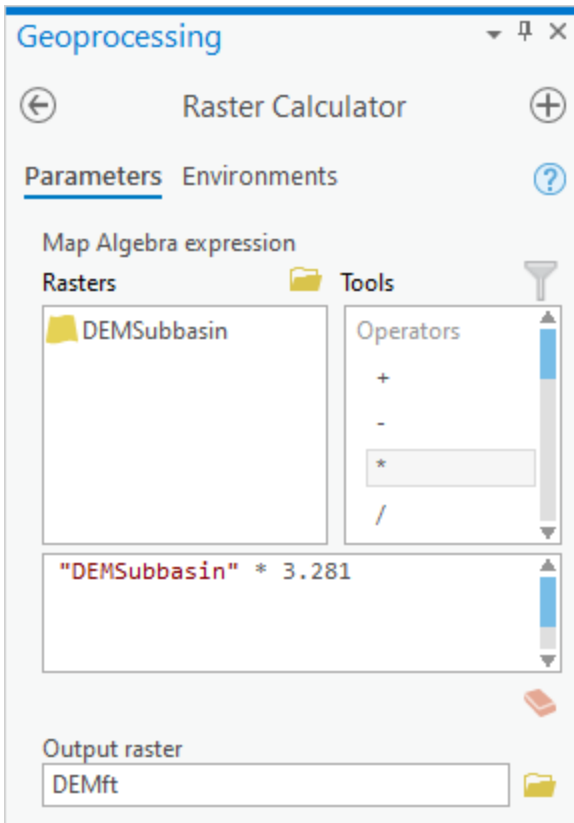
3. In the Contents pane, remove the **DEMStatePlane** layer.
4. Turn off the **Watersheds_StatePlane** layer to view the **DEMSubbasin** layer.

The **DEMSubbasin** layer is now clipped to the shape of the Buffalo-San Jacinto subbasin.

Converting raster units using the raster calculator

Right now, the elevations in the DEM are in units of meters. In order to convert these units into feet, you will use the raster calculator.

1. At the top left of the Geoprocessing pane, click the **Back** button.
2. In the search box, type "**raster calculator**".
3. Click the **Raster Calculator** tool.
4. In the list of 'Rasters', double-click the **DEMSubbasin** layer.
5. In the list of 'Tools', double-click the * symbol.
6. In the equation box, type "**3.281**", which is the conversion factor from meters to feet.
7. For 'Output raster', rename the raster "**DEMft**".
8. Ensure your 'Raster Calculator' window appears as shown below and click **Run**.



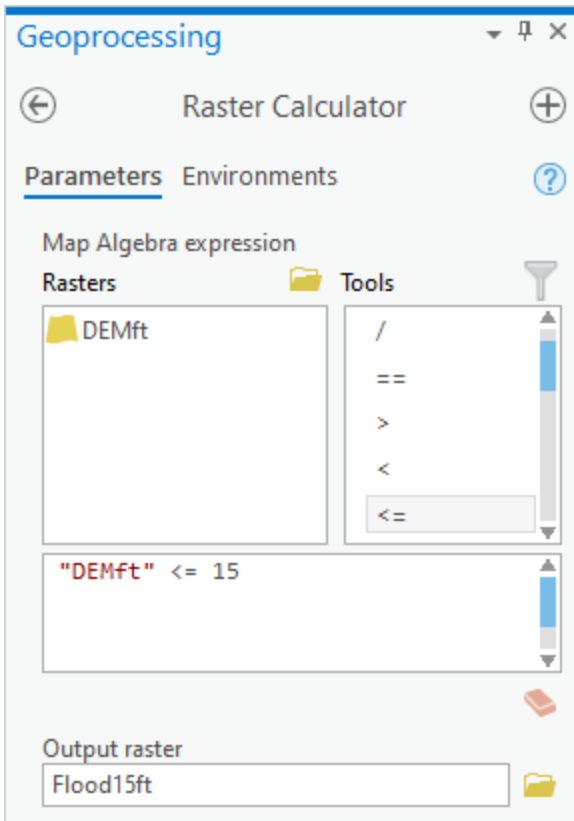
Visually, the meters and feet layers should be identical, but, if you look at the layers in the Contents pane, you will notice that the original layer goes from elevations of -8 to 62 meters and the newly calculated layer goes from elevations of -26 to 204 feet.

1. Remove the **DEMSubbasin** layer from the Contents pane.

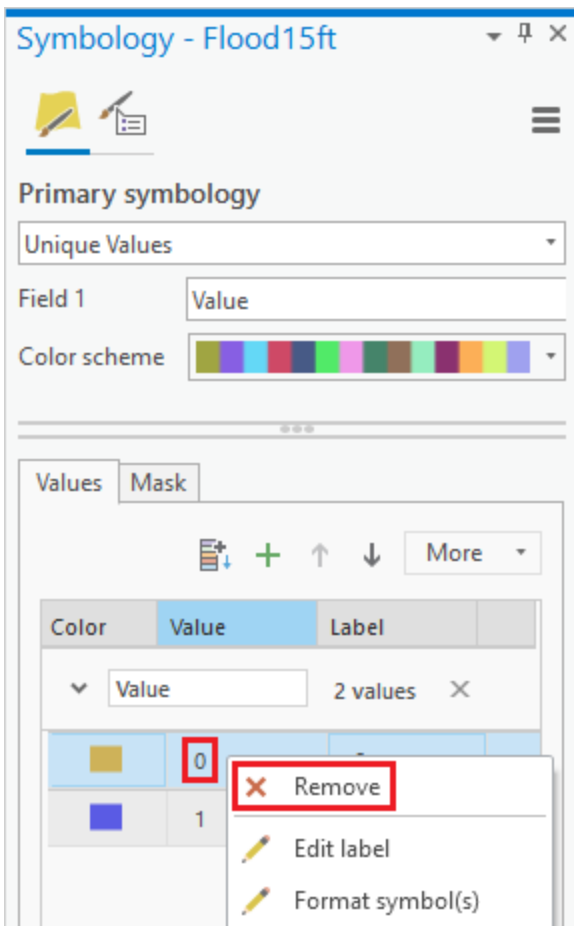
Exploring elevation using the raster calculator

Now you will determine which portions of land may be affected by a 15' storm surge. Obviously, complex inundation models will take more variables into account, but, in this instance, you will simply highlight all the areas of land with an elevation of 15' or less.

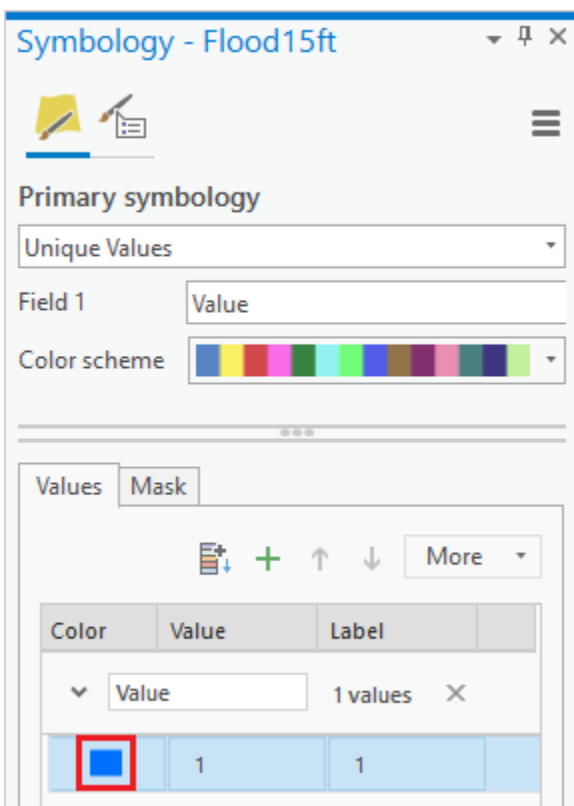
1. In the Raster Calculator tool, delete the previous expression "**DEMSubbasin**" * 3.281.
2. In the list of 'Rasters', double-click the **DEMft** layer.
3. In the list of 'Tools', double-click the <= symbol.
4. In the equation box, type "15".
5. For 'Output raster', rename the raster from *demft_raster* to "**Flood15ft**".
6. Ensure your Geoprocessing pane appears as shown below and click Run.



7. In the Contents pane, right-click the **Flood15ft** layer and select **Symbology**.
8. In the Symbology pane, right-click the **0** value and click **Remove**.



9. Click the rectangle symbol to the left of the 1 value and select **Blue**.

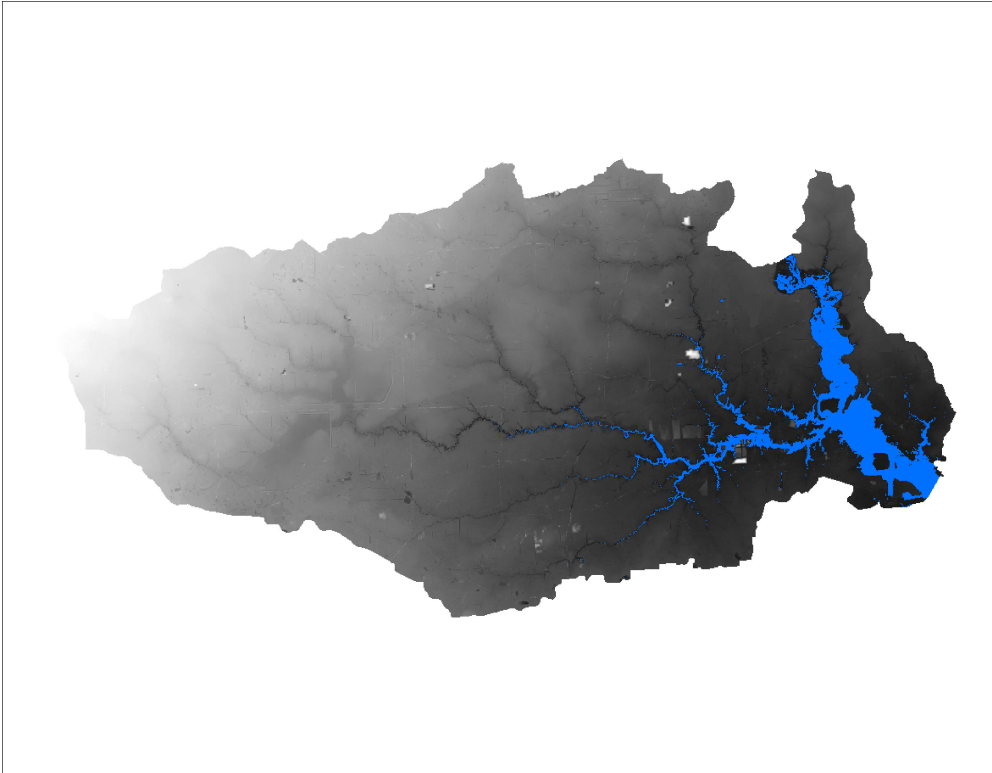


Now the cells containing an elevation of 15 feet or less are highlighted on top of the elevation raster.

1. In the Contents pane, uncheck the **Watersheds_StatePlane** layer and the **Topographic** basemap.
2. Save your **project**.

FOR MAP LAYOUT TO BE TURNED IN

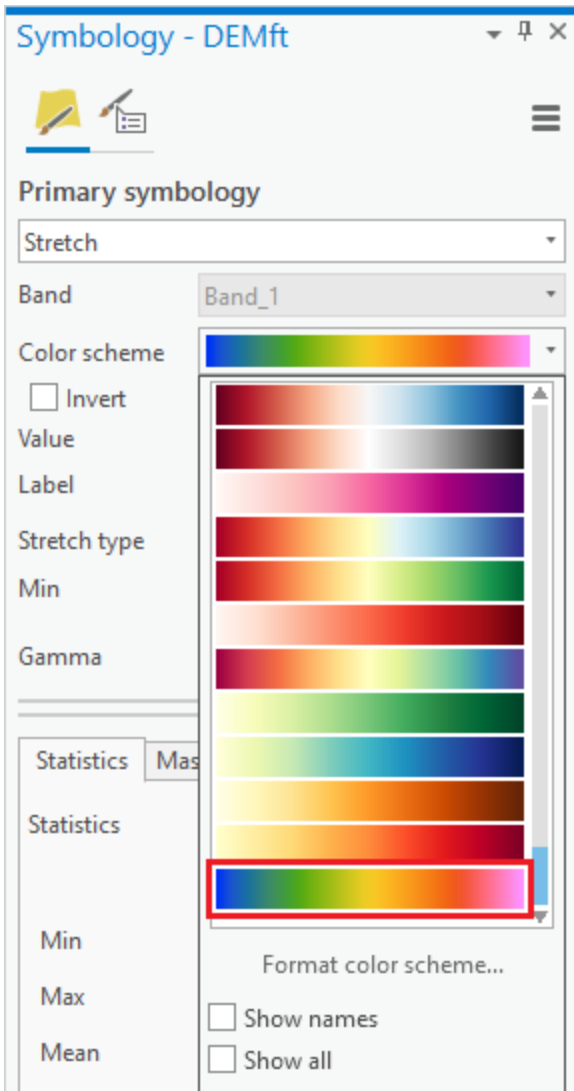
Create an 8.5 x 11 layout showing the DEM clipped to the subbasin with areas less than or equal to 15 feet in elevation highlighted.



Symbolizing raster files

Now you will create a new map from the one you are currently using.

1. On the ribbon, click the **Insert** tab and click the **New Map** button.
2. In the Contents pane, rename the map "**Lab2Topo**".
3. Return to the **Catalog** pane.
4. Expand the **HydrologyLab.gdb** geodatabase.
5. Drag the **DEMft** and **Watersheds_StatePlane** layers into the **Lab2Topo** map view.
6. In the Contents pane, uncheck the **Watersheds_StatePlane** layer.
7. Right-click the **DEMft** layer and select **Symbolology**.
8. For 'Color scheme', scroll down to the very bottom and select the **Multipart Color Scheme** or another continuous color scheme of your choice.



Patterns within the data are now easier to see, especially at the lower elevations.

Generating contour lines

In addition to raster DEM data, it is sometimes useful to be able to represent elevation using vector contour lines. Contour lines at any regular intervals or discrete values can be created from DEM data.

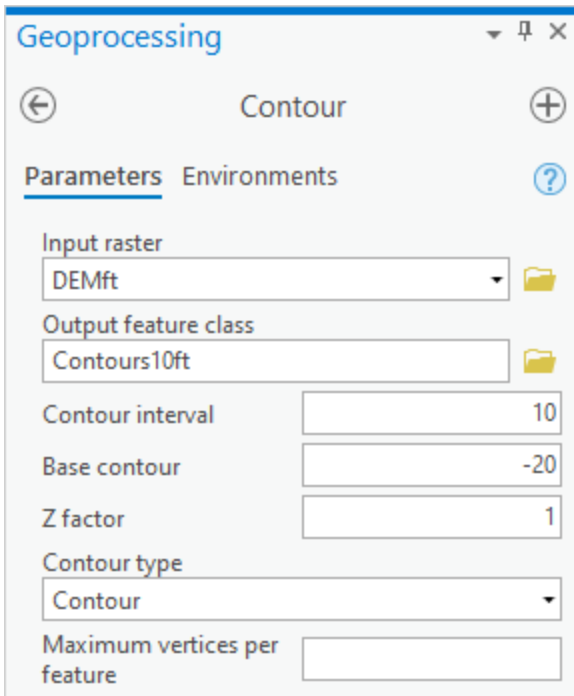
1. Return to the **Geoprocessing** pane.
2. At the top left of the Geoprocessing pane, click the **Back** button.
3. In the search box, type "**contour**".
4. Click the **Contour** (Spatial Analyst Tools) tool.
5. For 'Input raster', select the **DEMft** layer.
6. For the 'Output polyline features', rename the feature class from "Contour_DEMft1" to "**Contours10ff**".
7. For 'Contour interval', type "**10**".

The base contour is the lowest contour that will be shown. Since the lowest elevation is -26 ft, you will set your base contour to -20 ft.

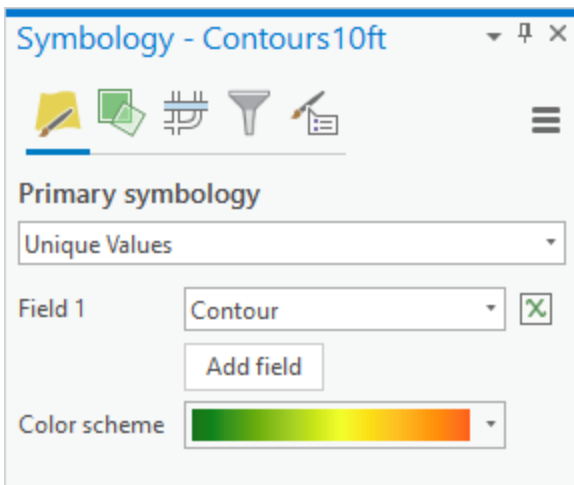
1. For 'Base contour', type "**-20**".

Since the XY coordinates are in the units of your State Plane Texas South Central projection, which is feet, and you have also used the Raster Calculator to convert the Z units stored within the raster cells to feet, you do not need a custom Z factor.

1. For 'Z factor', leave the default value of **1**.
2. Ensure your Geoprocessing pane appears as shown below and click **Run**.



3. Turn off the **DEMft** layer to better see the contours.
4. Right-click the **Contours10ft** layer and select **Symbology**.
5. In the Symbology pane, use the 'Primary symbology' drop-down menu to select **Unique values**.
6. Use the 'Field 1' drop-down menu to select the **Contour** field.
7. At the bottom of the 'Color scheme' drop-down menu, check **Show All** and select one of the continuous color schemes, as shown below.



Now you can tell which contours are highest and lowest.

1. In the Contents pane, turn off and collapse the **Contours10ft** layer.
2. Turn back on the **DEMft** layer.

Generating a hillshade

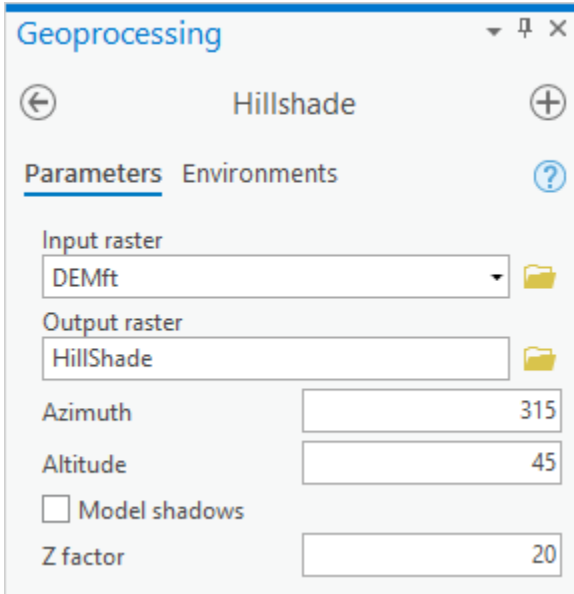
Now you will create a hillshade raster, which provides a shaded relief of the terrain based on a certain sun angle. It stores a value between 0 and 255 indicating the extent to which the cell would be shaded from the sun.

1. Return to the **Geoprocessing** pane.
2. At the top left of the Geoprocessing pane, click the **Back** button.
3. In the search box, type **"hillshade"**.
4. Click the **Hillshade** (Spatial Analyst Tools) tool.
5. In the Surface toolset, double-click the **Hillshade** tool.
6. For 'Input raster', select the **DEMft** layer.
7. For 'Output raster', rename the raster from **"HillSha_DEMft"** to **"Hillshade"**.

The azimuth and altitude refer to sun angles. For now, you will stick with the default values.

As previously mentioned, the Z factor is used when the horizontal units of the projection and units of the elevation measurements stored in the raster cells are not the same. In this case, both are measured in feet, so a value of 1 is technically correct. Typically, hillshades are used to create realistic three-dimensional representations of mountains, which can be much easier for an audience to interpret than a flat DEM or contour lines. Unfortunately, the opposite is true in Houston, because the area is so flat. It would be difficult to see any changes in elevation using a hillshade, since few shadows would be cast by the terrain itself. To compensate visually for the flat terrain, you will exaggerate the vertical elevations.

1. For 'Z factor', type "20".
2. Ensure your 'Hillshade' window appears as shown and click **Run**.



Typically, hillshades are shown beneath transparent layers conveying other information, just to give the map a realistic appearance.

1. In the Contents pane, drag the **Hillshade** layer beneath the *DEMft* layer, but above the *Topographic* basemap.
2. In the Contents pane, select the *DEMft* layer.
3. In the ribbon, click the contextual **Appearance** tab.
4. In the Effects group, slide the transparency to **60%**.

Now the gradual changes in elevation are apparent from the coloring and are complimented by a realistic display of the terrain created with the hillshade.

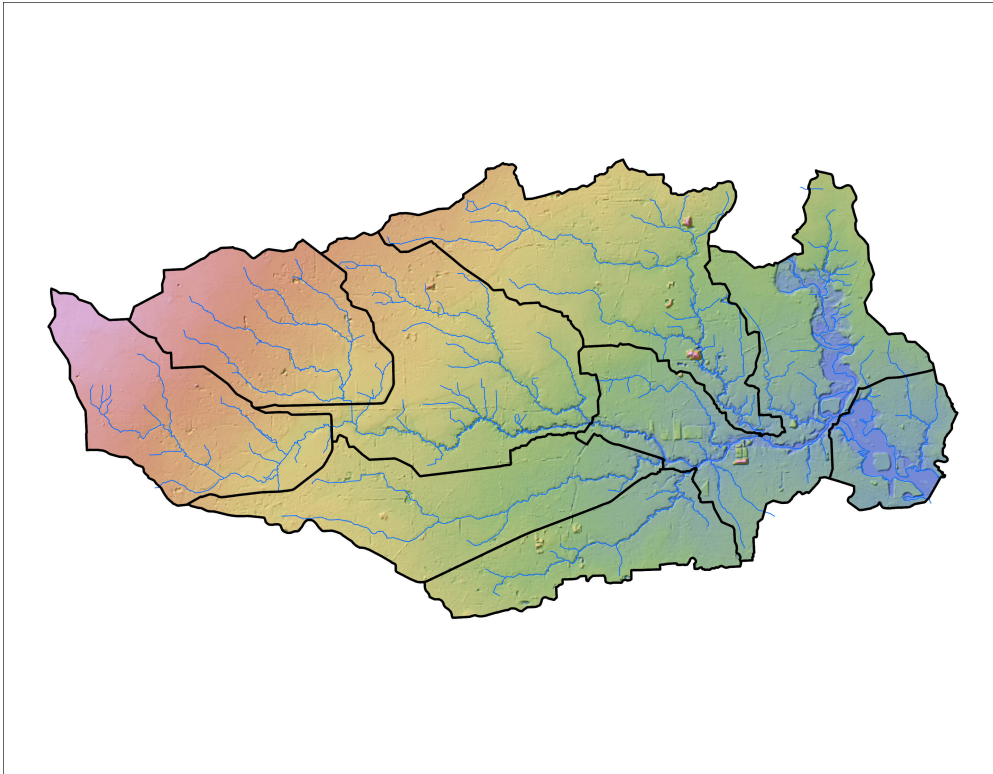
1. Turn on the **Watersheds_StatePlane** layer.
2. Symbolize the **Watersheds_StatePlane** layer with no transparency, a hollow fill, and thick black outline.

As a final touch, you will add the flowlines you downloaded in Lab 1 to your Map Display.

1. Click the **Catalog** tab.
2. In the *HydrologyLab* geodatabase, drag the **Flowlines** feature class into the *Lap2Topo* map view.
3. In the Contents pane, drag the **Flowlines** layer above the *DEMft* layer, but beneath the *Watersheds_StatePlane* layer.
4. Symbolize the **Flowlines** layer with a thin blue line.
5. Save your project.

FOR MAP LAYOUT TO BE TURNED IN

Create an 8.5 x 11 layout showing transparent elevation in graduated colors on top of a hillshade, with watershed boundaries and flowlines visible.



Calculating zonal statistics

Now you will calculate elevation statistics by watershed.

1. Return to the **Geoprocessing** pane.
2. At the top left of the Geoprocessing pane, click the **Back** button.
3. In the search box, type "**zonal statistics**".
4. Click the **Zonal Statistics as Table** (Spatial Analyst Tools) tool.
5. Use the 'Input raster or feature zone data' drop-down menu to select the **Watersheds_StatePlane** layer.
6. For 'Zone field', select the '**HU_10_NAME**' field.
7. For 'Input value raster', select the **DEMft** layer.
8. For 'Output table', rename the table from "**ZonalSt_Watersh1**" to "**WatershedElevation**".
9. Ensure your Geoprocessing pane appears as shown and click **Run**.

Geoprocessing

Zonal Statistics as Table

Parameters Environments

Input raster or feature zone data
Watersheds_StatePlane

Zone field
HU_10_NAME

Input value raster
DEMft

Output table
WatershedElevation

☒ Ignore NoData in calculations

Statistics type
All

☐ Process as multidimensional

10. At the bottom of the Contents pane, right-click the **WatershedElevation** table and select **Open**.

This table tells you the statistics regarding all the elevation values within each watershed zone.

1. In the Geoprocessing pane, search for "table to excel".
2. Click the **Table To Excel** tool.
3. For 'Input Table', select **WatershedElevation**.
4. For 'Output Excel File', click the **Browse** button.
5. Locate and double-click the **HydrologyLab** folder to save the file within the folder.
6. For 'Name', type "**WatershedElevation**".
7. Click **Save**.
8. In the Geoprocessing pane, click **Run**.
9. Close the **WatershedElevation** table.

Now you will open the exported text file in Excel.

1. Using File Explorer, open your **WatershedElevation.xls** spreadsheet in Microsoft Excel.
2. Delete the **OBJECTID**, **ZONE_CODE**, **COUNT**, **AREA**, and **SUM** fields.
3. Highlight the minimum and maximum values in each column.

Continue formatting the table until you are satisfied with its appearance.

1. Click the File menu and select **Save As**.
2. Navigate to your **HydrologyLab** folder.
3. For 'File name:', type "**WatershedElevation**".
4. Use the 'Save as type:' drop-down menu to select **Excel Workbook (*.xlsx)**.
5. Click **Save** and close **Excel**.

FOR TABLE TO BE TURNED IN

Create a table highlighting the minimum and maximum values for the minimum, maximum, range, mean, and standard deviation of all elevation values within each watershed.

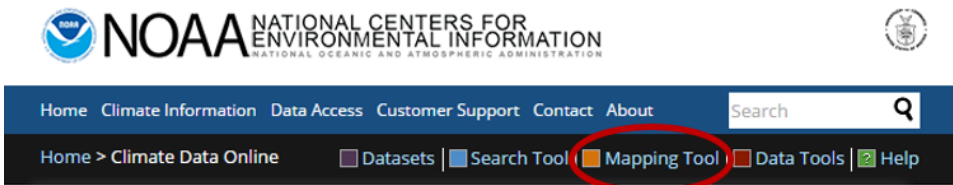
HUC-10 WATERSHED NAME	MIN	MAX	RANGE	MEAN	STD
Addicks Reservoir	52.26874161	176.1098328	123.8410912	132.1526735	22.41935789
Barker Reservoir	79.0615921	204.5362091	125.474617	136.7137891	29.46773305
Brays Bayou	-0.847274601	125.3090897	126.1563643	65.58334423	19.35789672
Buffalo Bayou-San Jacinto River	-6.422118187	182.0424652	188.4645834	34.06303519	16.06072267
East Fork Goose Creek-Frontal Galveston Bay	-8.17120266	57.56740952	65.73861217	16.65401267	11.09514906
Greens Bayou	-26.46365929	193.2014771	219.6651363	71.5731662	26.54297872
Sims Bayou	-2.798070669	119.7956238	122.5936944	45.96954918	14.10813035
Whiteoak Bayou-Buffalo Bayou	-3.632341385	153.6858063	157.3181477	82.19689409	22.36053882

Part 3: Downloading rainfall data

Downloading data from Climate Data Online.

Now you will download rain gauge station data created by the National Climatic Data Center (NCDC) using the Climate Data Online (CDO) interface.

1. In a web browser, go to www.ncdc.noaa.gov/cdo-web/.
2. Click the **Mapping Tool** tab.

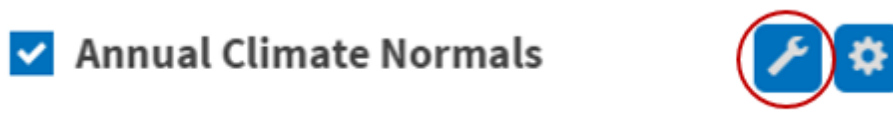


You will search for data using the NHD hydrologic units. Previously, you had been working with the Buffalo-San Jacinto subbasin (HUC = 12040104). In this case, you will step up two levels to the Galveston Bay-San Jacinto subregion (HUC = 1204).

1. On the Surface Maps tab, click **Normals**.








2. In the left sidebar, on the Layers tab, uncheck **Daily Climate Normals**, and check **Annual Climate Normals**.
3. To the right of Annual Climate Normals, click the Map Tools button.



4. In the new 'ANNUAL CLIMATE NORMALS TOOLS' window, click **Location**.
5. Use the drop-down menu to select **USGS HUC**.
6. Use the 'Select a HUC type' drop-down menu to select **Subregions (4-digit)**.
7. Use the 'Select a HUC' drop-down menu to select **Galveston Bay-San Jacinto**.

ANNUAL CLIMATE NORMALS TOOLS ✕

 Identify
  Location
  Rectangle
  Polygon
  Proximity

Select a location to view on the map

USGS HUC ▼

Subregions (4-digit) ▼

Galveston Bay-San Jacinto ▼

[Zoom to location](#)

8. Click **Zoom to location**.

9. The left sidebar switches to the Results tab. Click **Get All Location Data**.

Layers Results ▼

☐ Select All [Download Station List](#)

GALVESTON BAY-SAN JACINTO
Location ID: HUC:1204
[Get All Location Data](#)

☐ RICHARDS, TX US
[View Station Details](#)
Station ID: GHCND:USC00417586
Period of Record: 1981-01-01 to 2010-12-31

10. For Step 1, select **Custom Annual/Seasonal Normals CSV** for the output format and click **CONTINUE**.

☒ **Custom Annual/Seasonal Normals CSV**
(Additional options available on next page)

11. For 'Station Detail & Data Flag Options', check **Station Name**, **Geographic Location**, and **Include Data Flags** to include those variables the data table.

☒ Station Name
☒ Geographic Location
☒ Include Data Flags
 Units Standard ▼

12. For 'Select data types for custom output', expand the **Annual Precipitation** category.

13. Check **Long-term averages of annual precipitation totals (ANN-PRCP-NORMAL)**.


[Show All / Hide All](#) | [Select All / Deselect All](#)

- ☐ ☐ Annual Agricultural
- ☐ ☐ Annual Degree Days
- ☒ ☐ Annual Precipitation
- ☒ Long-term averages of annual precipitation totals (ANN-PRCP-NORMAL)

14. At the bottom of the window, click **CONTINUE**.
15. Type your **email address** twice and click **SUBMIT ORDER**.

Check your email. You should receive two emails a couple minutes apart, although it may take a few hours to receive the second email. The first one indicates that your data request was submitted and the second one includes the requested data.

1. In your email, click the **Download** link to download the requested CSV file.



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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION


Order Complete

Your order has been processed and is ready for download. Use the links below to download the individual orders.

If any part of your order has certifiable data, a link will be supplied that will help you with the certification process.

Documentation for each dataset is linked from within the order for your convenience.


Order Details

Order #850264 (Custom Annual/Seasonal Normals CSV)	
File	Download 
Order ID	850264
Date Submitted	2016-11-30 04:30
Order Summary	View Summary
Documentation	View Documentation


Excel

1. Navigate to the **location** where the CSV file was stored.
2. Double-click the **CSV file** to open it using Excel.

The first column contains the unique station identification code and the second column contains the station name. Next are the latitude, longitude, and elevation of the stations. The annual precipitation field contains long-term averages of annual precipitation totals in hundredths of inches. More information is available on the Datasets portion of the CDO website.

 As of March 7, 2021, the CSV download includes ALL climate variables, even though only ANN-PRCP-NORMAL was selected for download. In this case, the annual precipitation field, *ANN-PRCP-NORMAL*, will not appear in column F, after the *ELEVATION* field. Instead, it appears in column BP. In this case, you will need to copy and paste the data from column BP to column F.

Before opening this table in ArcGIS, you must reformat some of the field names, which cannot have special characters and are recommended to be 13 characters or less.

1. Rename "ANN-PRCP-NORMAL" to "**ANNPRCP_HI**", for annual precipitation in hundredths of inches.
2. Along the top of the worksheet, drag across the column letters to select columns **A** through **F**.
3. Copy the **selected** columns.
4. At the bottom left of the worksheet, click the **New sheet** button  to create a new worksheet. In cell A1, paste your previously copied columns.
5. Delete the **previous** sheet.
6. Along the top of the worksheet, drag across the column letters to select columns **A** through **F**.
7. Hover your mouse between columns **E** and **F** until the cursor changes to two outward facing arrows and double-click to auto-size the column widths.
8. At the bottom left of the worksheet, rename the worksheet from *Sheet1* to "**PrecipStations**".
9. Click the **File** menu and select **Save As**.
10. Navigate to your **HydrologyLab** folder.
11. For 'File name:', type "**PrecipStations**".
12. Use the 'Save as type:' drop-down menu to select **Excel Workbook**.
13. Click **Save**.
14. Close **Excel**.

Displaying XY data

Now you are ready to start a new map and display the tabular rain gage data you just downloaded.

1. Return to **ArcGIS Pro**.
2. On the ribbon, click the **Insert** tab and click the **New Map** button.
3. In the Contents pane, rename the map "**Lab2Precip**".
4. Return to the **Catalog** pane.
5. Drag **Watersheds_StatePlane** into the **Lab2Precip** map view.
6. Right-click the **HydrologyLab** folder and select **Refresh**.
7. Expand the **PrecipStations.xlsx** Excel file to see the individual worksheets it contains.
8. Drag the **PrecipStations\$** worksheet into the **Lab2Precip** map view.
9. In the Contents pane, right-click the **PrecipStations\$** table and select **Display XY Data**.
10. For 'X Field:', select the **LONGITUDE** field.
11. For 'Y Field:', select the **LATITUDE** field.
12. For 'Coordinate System', click the **Select coordinate system** button.

Because the coordinates are in the form of latitude and longitude in decimal degrees, you know you will need to select a geographic coordinate system, rather than a projected coordinate system. While the data could theoretically be in any geographic coordinate system, you will select the North American Datum 1983, commonly abbreviated NAD 83, because this is coordinate system of the data provided on the NCDC website.

1. Scroll towards the top of the 'XY Coordinate Systems Available'.
2. Ensure that **Geographic Coordinate Systems** is already expanded, then expand **North America > USA and Territories**.
3. Select **NAD 1983** and click **OK**.

4. Ensure that your window matches that below and click **OK**.

Display XY Data

Parameters Environments

Input Table
PrecipStations\$

Output Feature Class
PrecipStations_XYTableToPoint

X Field
LONGITUDE

Y Field
LATITUDE

Z Field

Coordinate System
GCS_North_American_1983

OK

The points should now appear on top of the watersheds, though they also extend beyond the watersheds in the Buffalo-San Jacinto subbasin, since we downloaded them for the entire Galveston Bay-San Jacinto subregion.

1. In the Contents pane, right-click the **PrecipStations\$** table and select **Remove**.

Projecting vector data

Repeating the technique you learned earlier in this lab to project vector data, project the *PrecipStations_XYTableToPoint* layer into the State Plane Texas South Central projection. Save the resulting feature class and name it "*PrecipStations_StatePlane*". Remove the original *PrecipStations_XYTableToPoint* layer from the Contents pane.

Create Thiessen polygons

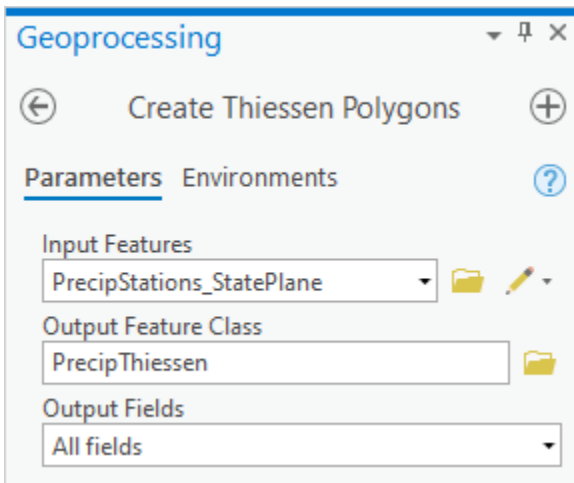
Now you will calculate the mean annual precipitation over each watershed using Thiessen polygons, which associate every cell in the watershed with the nearest rain gage.

1. In the Contents pane, Ctrl-select the **PrecipStations_StatePlane** and **Watersheds_StatePlane** layers.
2. Right-click either **selected** layer and select **Zoom To Layers**.
3. Return to the **Geoprocessing** pane.
4. At the top left of the Geoprocessing pane, click the **Back** button.
5. In the search box, type "**thiessen**".
6. Click the **Create Thiessen Polygons** tool.

Before populating the variables in this tool, you will change an Environment setting so that the Thiessen polygons are calculated for the entire region that you just zoomed to.

1. At the top of the Geoprocessing window, click the **Environments** tab on the right.
2. Under the 'Processing Extent' section, for 'Extent', select **Current Display Extent**.
3. At the top of the Geoprocessing window, return to the **Parameters** tab on the left.

4. For 'Input Features', select the **PrecipStations_StatePlane** layer.
5. For 'Output Feature Class', rename the feature class from "*PrecipStations_StatePlane_Cr*" to "**PrecipThiessen**".
6. For 'Output Fields', select All fields.
7. Ensure your 'Create Thiessen Polygons' window appears as shown below and click Run.



You will notice that polygons now fill the entire Map Display indicating which areas are closest to which rain gages.

1. Open the **PrecipThiessen** layer attribute table.

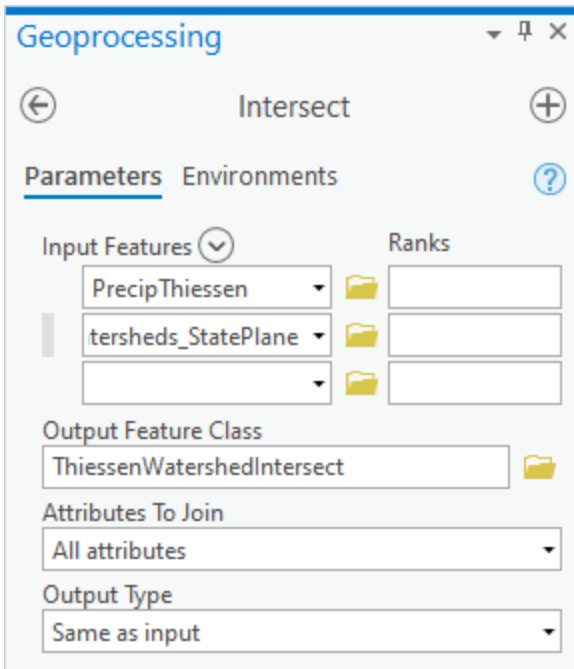
Notice that all of the fields that you originally downloaded from CDO are still included, because you selected to output all fields when running the Create Thiessen Polygons tool. If you do not see all of the same fields, re-run the tool and this time output all fields.

1. Close the **PrecipThiessen** attribute table.

Intersecting two polygon layers

In order to determine which portions of the resulting polygons overlap with which watersheds, you will now perform an intersect operation between the two layers. The result will allow you to calculate weighted averages of the precipitation in each watershed.

1. At the top left of the Geoprocessing pane, click the **Back** button.
2. In the search box, type "**intersect**".
3. Click the **Intersect** tool.
4. For 'Input Features', select the **PrecipThiessen** and the **Watersheds_StatePlane** layers.
5. For 'Output Feature Class', rename it from *PrecipThiessen_Intersect* to "**ThiessenWatershedIntersect**".
6. Ensure your 'Intersect' window appears as shown below and click Run.



7. In the Contents pane, remove the **PrecipThiessen** layer.
8. Zoom to the **ThiessenWatershedIntersect** layer.

The resulting layer integrates all of the boundaries from both the Thiessen polygons and the watersheds, limited to the extent of their overlap.



1. Open the **ThiessenWatershedIntersect** layer attribute table.

Notice that the original 8 watersheds have now been divided into 41 sections indicating which areas of each watershed are closest to each rain gage. Let P_k denote the annual precipitation associated with each rain gage and A_{ik} denote the area of the intersected polygon associated with rain gage k and watershed i . The area weighted precipitation associated with each watershed is

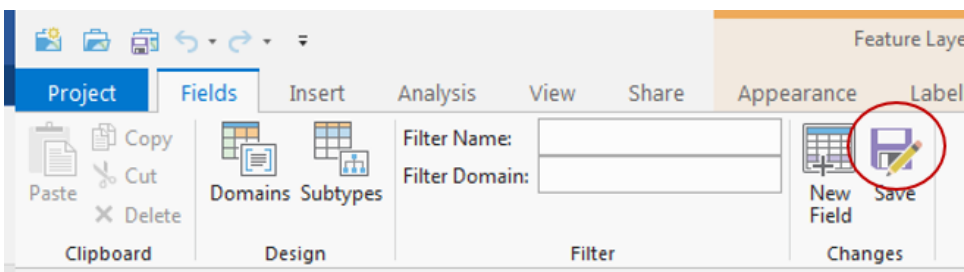
$$P_i = \frac{\sum_k A_{ik} P_k}{\sum_k A_{ik}}$$

You will add a new field to the table to calculate the elements of the numerator of the equation.

2. At the top left of the attribute table, click the **Add Field...** button, which will open up the Fields view of the table.

Field: 		Selection: 			
OBJECTID	Shape	FID_PrecipThiessen	Input_FID	STATION	
1	Polygon	4	31	USC004118	
2	Polygon	4	31	USC004118	
3	Polygon	4	31	USC004118	

3. At the bottom of the Fields table, rename the new field from *Field* to **APProd**.
4. Use the 'Data Type' drop-down menu to select **Double**.
5. On the Ribbon, on the Fields tab, click the **Save** button.



6. Close the **Fields** view of the table.
7. Scroll to the far right of the **ThiessenWatershedIntersect** table.
8. Right-click the **APProd** field name and select **Calculate Field**.
9. In the 'Fields' list, double-click **ANNPRCP_HI**.
10. Underneath the 'Helpers' list, click the * button.
11. In the 'Fields' list, double-click **Shape_Area**.
12. Ensure your 'Calculate Field' window appears as shown below and click **OK**.

Calculate Field

Input Table
ThiessenWatershedIntersect

Field Name (Existing or New)
APProd

Expression Type
Python 3

Expression

Fields

- LONGITUDE
- ELEVATION
- ANNPRCP_HI
- FID_Watersheds_StatePlane
- HU_10_NAME
- Shape_Length
- Shape_Area

Helpers

- .as_integer_ratio()
- .capitalize()
- .center()
- .conjugate()
- .count()
- .decode()
- .denominator()

Insert Values
*

APProd =
!ANNPRCP_HI! * !Shape_Area!

Enable Undo ☒

Apply OK

The **APProd** field now contains the numerator values in the equation. You are now ready to summarize the calculated statistics by watershed.

1. Right-click the **HU_10_NAME** field name and select **Summarize**.
2. For 'Output Table', rename the table from **ThiessenWatershedIntersect_S** to "**WatershedPrecip**".
3. For 'Statistics Field(s)', use the drop-down menu to select the **Shape_Area** 'Field' and the **Sum** 'Statistic Type'.
4. For the second statistics field, select the **APProd** 'Field' and the **Sum** 'Statistic Type'.
5. Ensure the 'Case field' is the **HU_10_NAME** field, which will summarize the statistics by watershed.
6. Ensure your 'Summary Statistics' window appears as shown below and click **OK**.

Summary Statistics

Input Table: ThiessenWatershedIntersect

Output Table: WatershedPrecip

Statistics Field(s)

Field	Statistic Type
Shape_Area	Sum
APProd	Sum

Case field: HU_10_NAME

The resulting table gives the numerator and denominator in the equation for each watershed.

1. Open the **WatershedPrecip** table.

Repeating the techniques you just learned, add a new field to the *WatershedPrecip* table called "Precip" of type double. Use the field calculator to evaluate $[\text{Sum_APProd}] / [\text{Sum_Shape_Area}]$. The result is the precipitation for each subwatershed. Export the table to Excel and format it. Also include the mean annual precipitation over the entire watershed.

FOR TABLE TO BE TURNED IN

Create a table containing the weighted mean annual precipitation for each watershed, as calculated using Thiessen polygons, along with the total mean annual precipitation over the entire subbasin.

Interpolating point values

Now you will calculate precipitation for each watershed using a different interpolation method.

1. Close the **WatershedPrecip** table and the **ThiessenWatershedIntersect** attribute table.
2. Turn off the **ThiessenWatershedIntersect** layer.
3. Right-click the **Watersheds_StatePlane** layer and select **Zoom to Layer**.
4. At the top left of the Geoprocessing pane, click the **Back** button.
5. In the search box, type "**spline**".
6. Click the **Spline** (Spatial Analyst Tools) tool.
7. At the top of the Geoprocessing window, click the **Environments** tab on the right.
8. Under the 'Processing Extent' section, for 'Extent', select **Current Display Extent**.
9. Under the 'Raster Analysis' section, for 'Mask', select the **Watersheds_StatePlane** layer, which will clip the resulting raster.
10. At the top of the Geoprocessing window, return to the **Parameters** tab on the left.
11. For 'Input point features', select the **PrecipStations_StatePlane** layer.
12. For 'Z value field', select the **ANNPRCP_HI** field that contains the values you wish to interpolate.
13. For 'Output raster', rename the exported raster from *Spline_Preci1* to "**AnnPrecip**".
14. For 'Spline type', select **Tension**.
15. Ensure your Geoprocessing pane appears as shown below, and click **Run**.

Geoprocessing

Spline

Parameters Environments

Input point features
PrecipStations_StatePlane

Z value field
ANNPRCP_HI

Output raster
AnnPrecip

Output cell size
1417.45035174068

Spline type
Tension

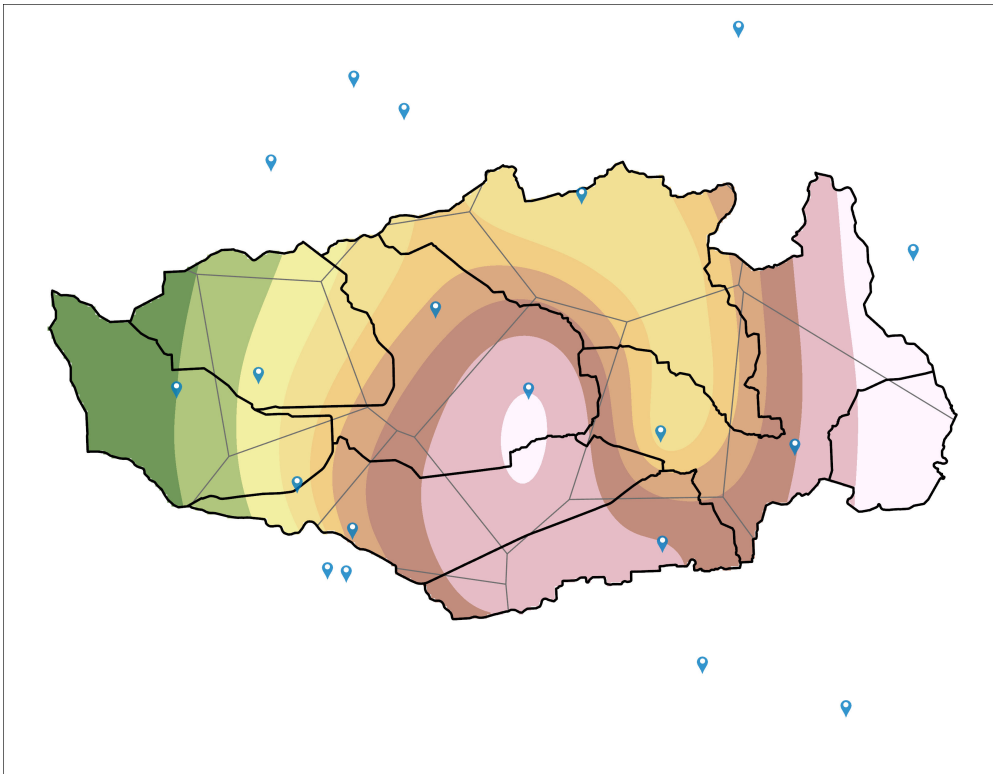
Weight 0.1

Number of points 12

The result is a solid surface estimating the rainfall at each cell, based on the data collected at each rain gage. Turn the *ThiessenWatershedIntersect* polygons back on and give them a hollow fill. Also symbolize the *Watersheds_StatePlane* layer and put it on top of the *Thiessen* layer. Symbolize the rain gages as you desire.

FOR MAP LAYOUT TO BE TURNED IN

Create an 8.5 x 11 layout showing the Thiessen polygon boundaries, interpolated rainfall layer and rain gage locations.



Using the techniques you learned earlier in this lab, use the Zonal Statistics as Table tool to export a table containing the total annual rainfall for each watershed, as calculated from the *AnnPrecip* spline interpolation layer and format the table in Excel.

FOR TABLE TO BE TURNED IN

Create a table containing the total annual precipitation for each watershed, as calculated using the spline interpolation method, along with the total annual precipitation over the entire subbasin.

Deliverables

1. Create an 8.5 x 11 layout showing the DEM clipped to the subbasin with areas less than or equal to 15 feet in elevation highlighted.
2. Create an 8.5 x 11 layout showing transparent elevation in graduated colors on top of a hillshade, with watershed boundaries and flowlines visible.
3. Create a table highlighting the minimum and maximum values for the minimum, maximum, range, mean, and standard deviation of all elevation values within each watershed.
4. Create a table containing the weighted mean annual precipitation for each watershed, as calculated using Thiessen polygons, along with the total mean annual precipitation over the entire subbasin.
5. Create an 8.5 x 11 layout showing the Thiessen polygon boundaries, interpolated rainfall layer, and rain gage locations.
6. Create a table containing the total annual precipitation for each watershed, as calculated using the spline interpolation method, along with the total annual precipitation over the entire subbasin.