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1. Introduction

Digitizing is the process of converting the features on an image into digital and spatial formats that can be analyzed geographically as vectors. Features on a paper or existing digital map are traced, and the x,y coordinates of these features are automatically recorded and stored as spatial data along with any attributes you attach.

One of the most common digitizing scenarios is taking raster data - often aerial imagery - and converting it to vector data such as polygons or lines. Having vector versions of geographic features such as lakes or rivers allows us to do things like attach attribute data to them (name, size, etc) and compare those attributes in different ways.

Mono Lake is a large terminal lake located in the Great Basin east of Yosemite National Park. In 1941, the Los Angeles Department of Water began to divert water from streams flowing into Owens Lake. Eventually, the amount diverted was high enough that water began to evaporate faster than water was flowing into the lake, and by 1990, the lake had dropped 45 vertical feet and had lost half its volume relative to the 1941 pre-diversion water level. In 1994, the CA State Water Resources Control Board issued an order protecting Mono Lake and its tributaries after a long conservation campaign by the Mono Lake Committee and the Audubon Society and a decade of legal battles. Since then, lake levels have rebounded significantly, although not to pre-diversion levels.

In this lab, we will use ArcGIS Pro editing tools and satellite imagery of Mono Lake from two different years (pre- and post-restoration) to compare how the lake surface area has changed over time. We will also explore how digitizing at different scales can produce different results and potentially introduce errors into the process.

2. Open the Project Package

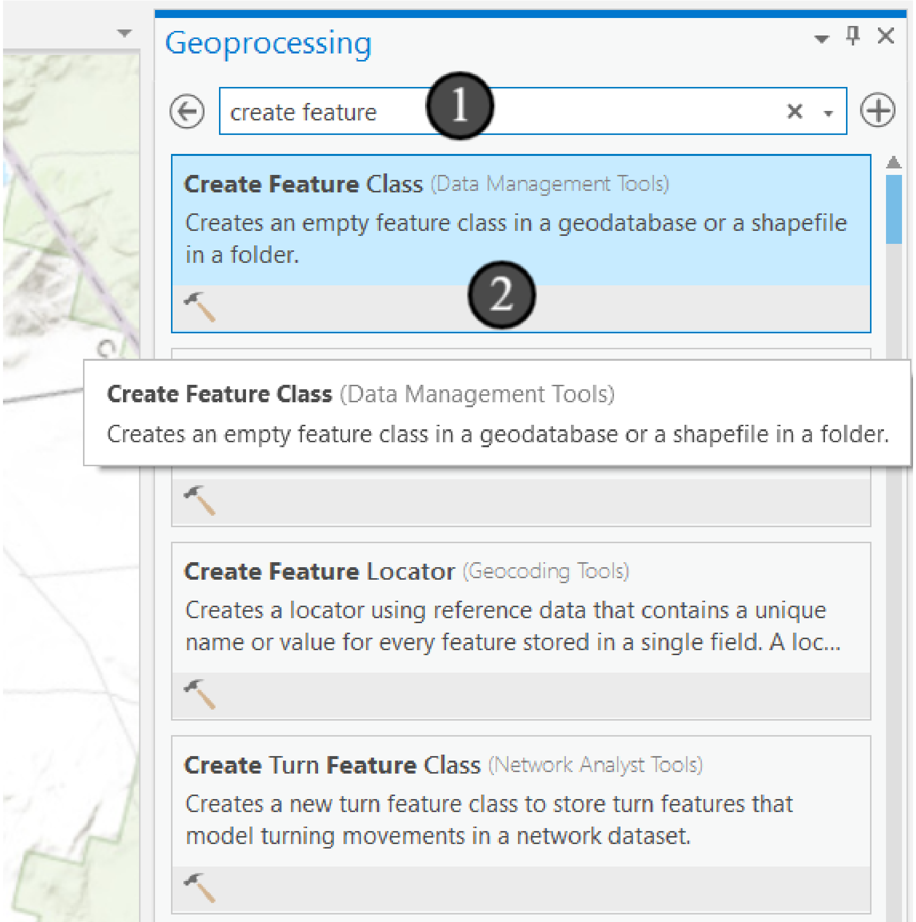
The data for this lab are provided as a project package, which is a compressed archive of all project components and data, including the project file, toolboxes, and geodatabase data included in either the project's geodatabase or referenced in another data source within the project. They're a great way to send everything about a project to someone else. The used in this project come from the long-running Landsat program, downloadable for free from USGS Earth Explorer.

Projects are easy to open and get started with - **just double click the file and ArcGIS will decompress it** and open it up. If you ever need to open it up again, it will be in your Documents folder, under ArcGIS, then in the Packages folder - there will be a folder for each project package you open in there.

3. Create a New Feature Class

In order to create vector data, we need to create a new container for that data. To begin, bring up the geoprocessing pane (select the *Analysis* tab and click the *Tools* button).

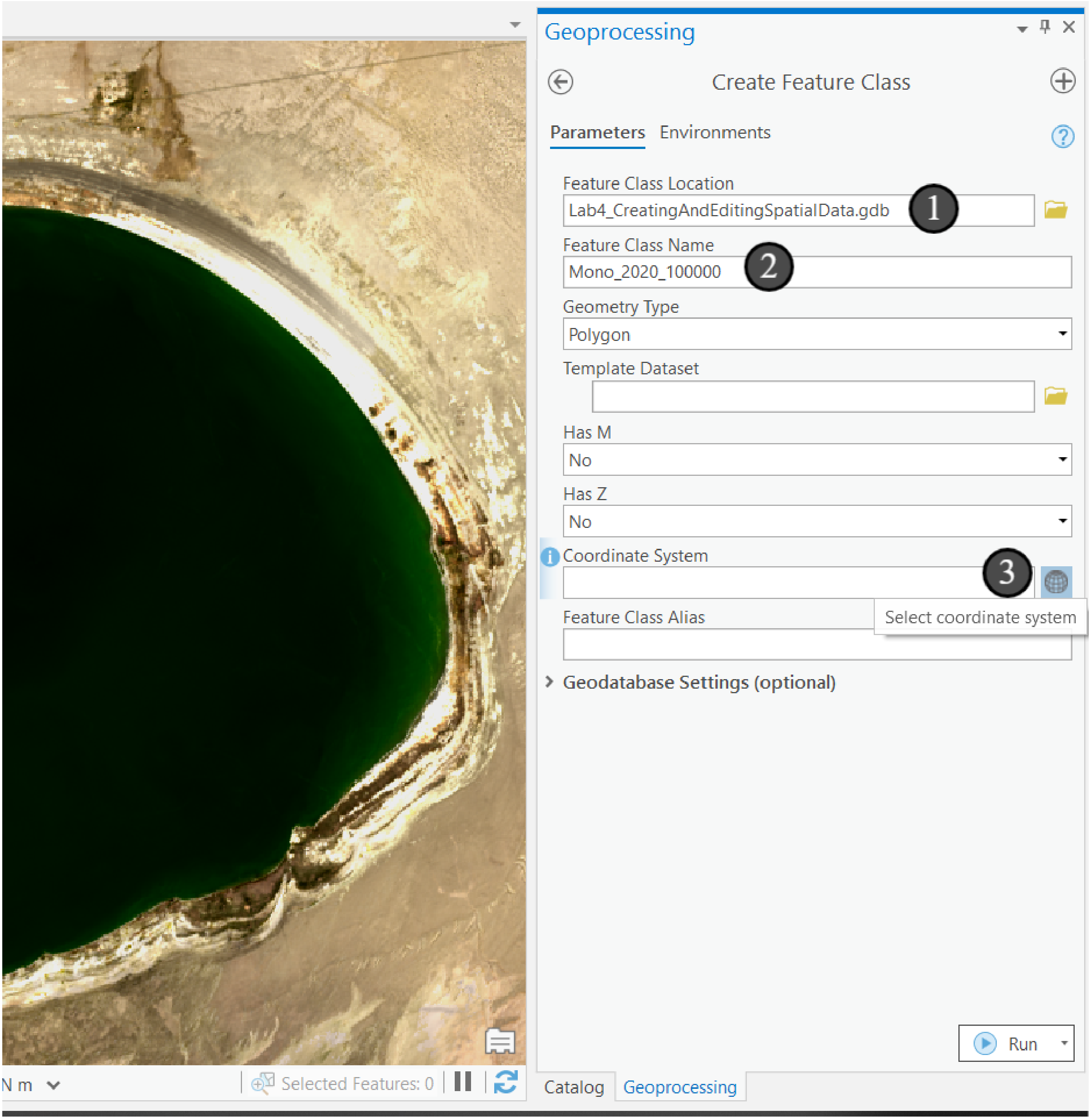
1. Begin to type "create feature" in the search box,
2. Then select the *Create Feature Class* option that appears in the search results.



3.1 The Create Feature Class Tool

For this lab, we will create a *Feature Class* within our existing project *geodatabase*.

1. For *Feature Class Location*, leave the default option (the project geodatabase).
2. Enter *Mono_2020_100000* for *Feature Class Name*.
3. Leave the *Geometry Type* as *Polygon* (why are we using polygons here?) and the next three options as the default, then click on the globe button for *Coordinate System*.



3.2 Select Coordinate System

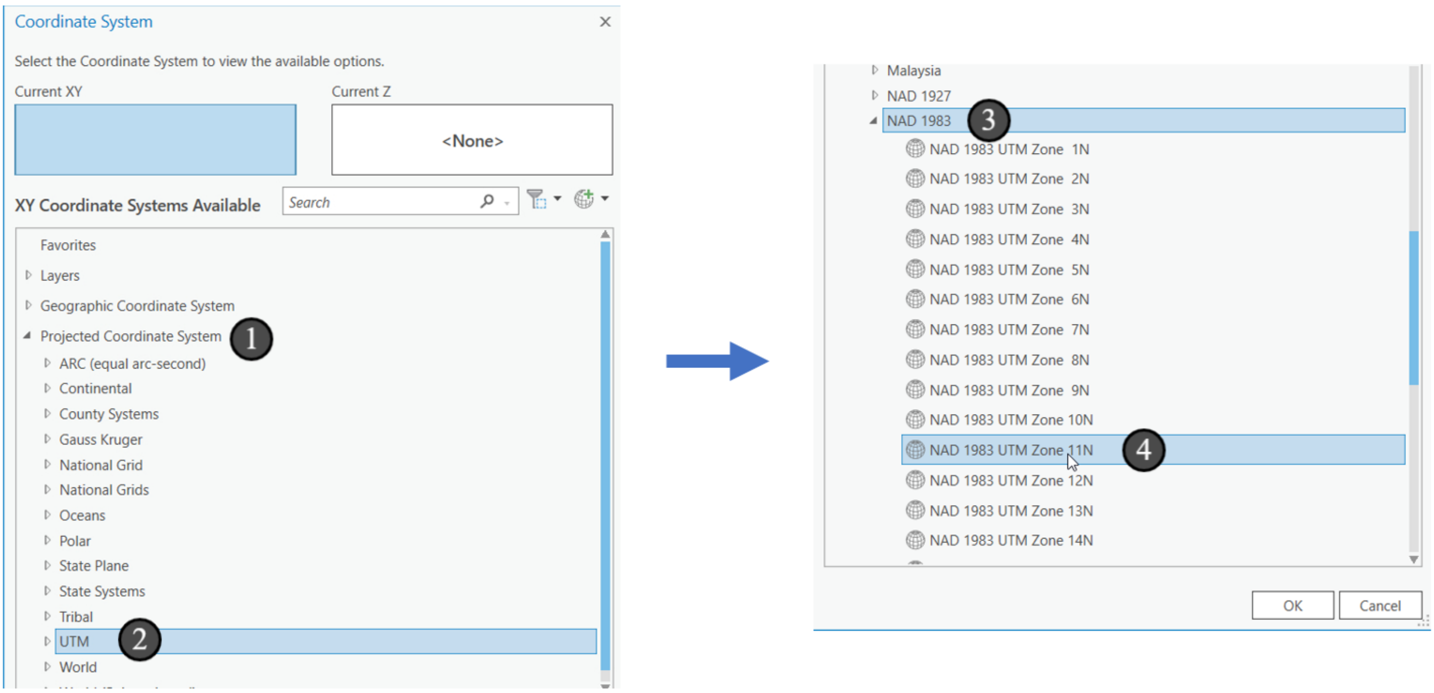
In the Coordinate System dialog that pops up, we can choose our projection. We want to select a Projected Coordinate System, because these systems use linear units of measurement (meters, feet, etc) rather than degrees (fractions of the globe), and we eventually want to measure the surface of Mono Lake in square meters.

For this project, we'll use the Universal Transverse Mercator (UTM) projection, which divides the earth into a series of zones which can each be modeled with high accuracy within the zone, and with accuracy tapering off if you try to use data outside of the zone. In this case, Mono Lake is in Zone 11N (11 North). UTM's name sounds a little dense, but if we break it down, the series of zones are the "Universal" part because generally speaking, every spot on earth is covered by at least one zone. "Transverse" means it's sideways, so rather than the projection occurring on a cylinder whose open ends are north and south, the open ends instead are perpendicular to north and south. *Mercator* refers to the common Mercator projection that forms the basis of this. Despite what you may have heard about Mercator's problems, it has many advantages (local directions are accurate, for one, which is why it's used commonly in web maps), and it's actually a fairly accurate projection near the Equator, despite how much it distorts the poles. UTM divides up the world and turns Mercator on its side so that within each zone you have the accuracy that normal Mercator projections have at the Equator.

This is a bit of an aside, but it's important to choose the right projection. We'll consider this a bit more later when we look at the projection of the images.

To navigate to the appropriate system for this location,

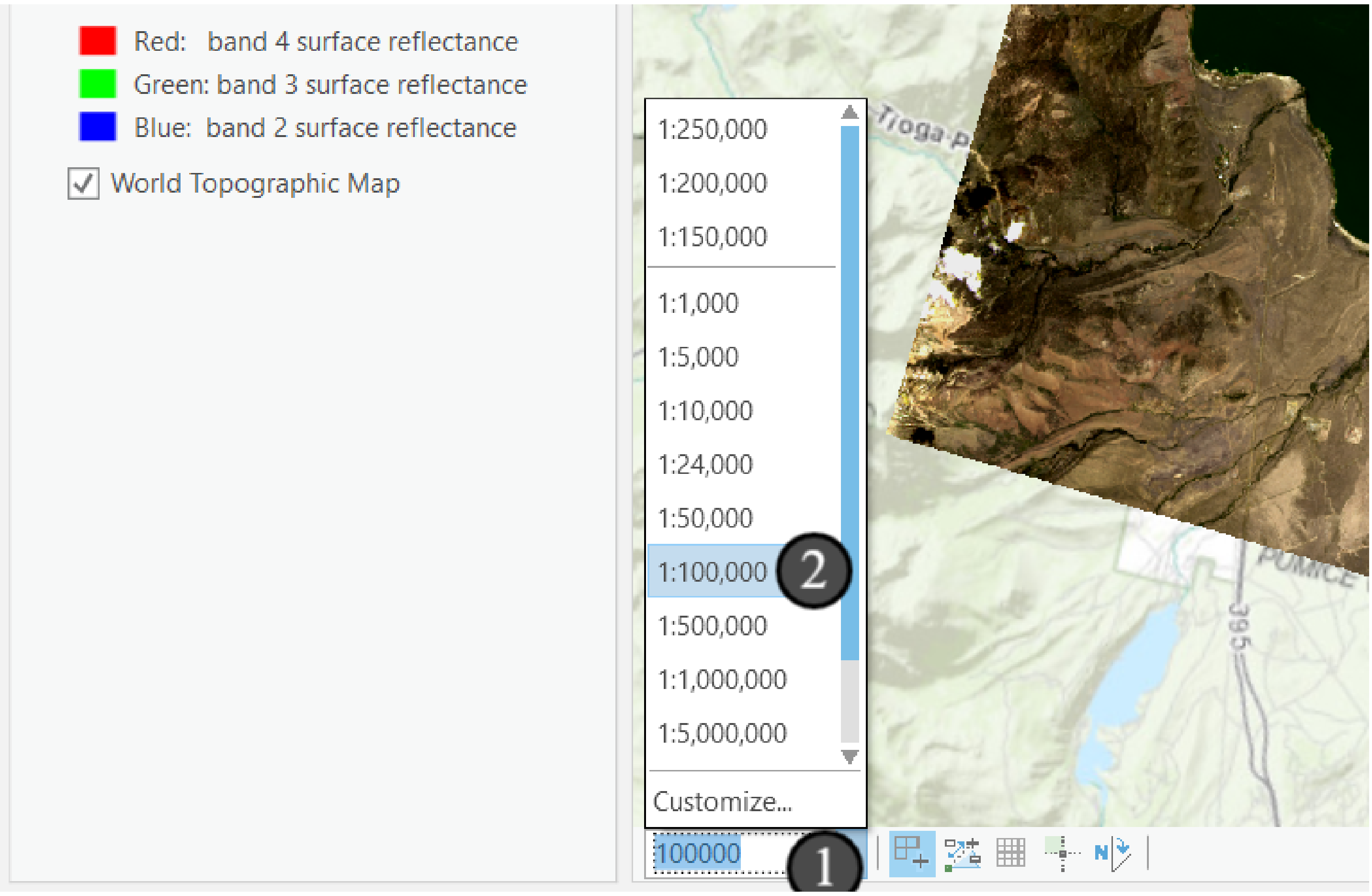
1. Select Projected Coordinate System,
2. Followed by UTM,
3. NAD 1983,
4. And finally NAD 1983 UTM Zone 11N. Click OK to close the Coordinate System dialog, then click *Run* at the bottom of the *Create Feature Class* pane.



4. Digitize Mono Lake in 2020

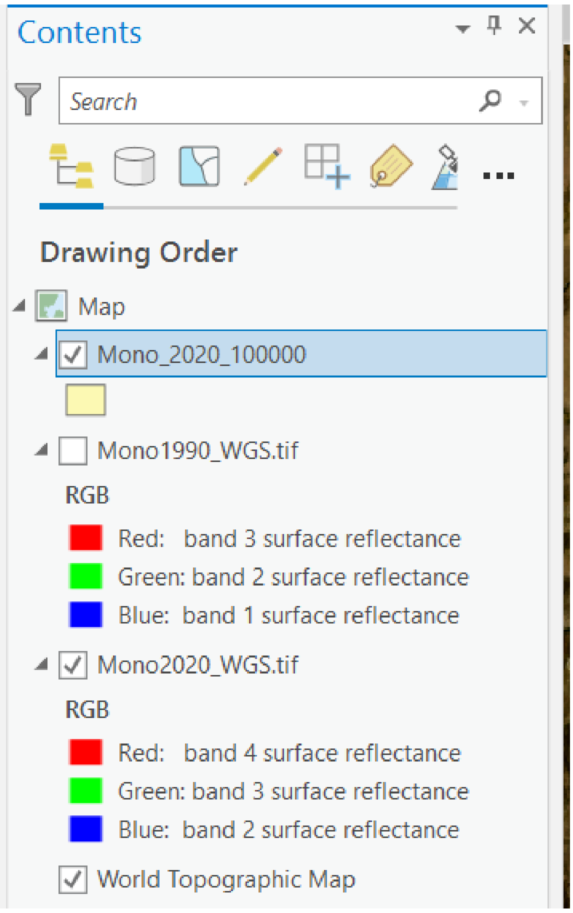
Before we begin digitizing the lake and drawing our new polygon, we're going to set the scale of the map. The scale we digitize at matters - it defines the amount of detail that our features have captured. As a result, feature classes and shapefiles are often talked about with their scale prepended (e.g. watershed boundaries referred to as 1:24000 HUC12s) because it helps us establish how accurate and valid a dataset is for a given purpose. For a dataset digitized at 1:24000, we wouldn't consider it to be accurate at a larger scale than that, such as 1:20,000, so the scale tells us the limits of how we can use the dataset. Knowing this, we should digitize at a constant scale for each shapefile or feature class we create. This can be hard - I constantly resist the temptation to zoom in and get a more accurate boundary on data I digitize - the lesson is that if you want that accuracy, then stay at the scale for the entire digitization process, not just that one location.

1. Set the scale to 1:100000 by clicking on the arrow next to the scale box in the lower left hand corner of the Map window
2. Select 1:100,000 (2). Alternately, you can type in 100000 in the box and press enter. The map should zoom in towards the lake, depending on your current zoom level



4.1 Check Your Layers

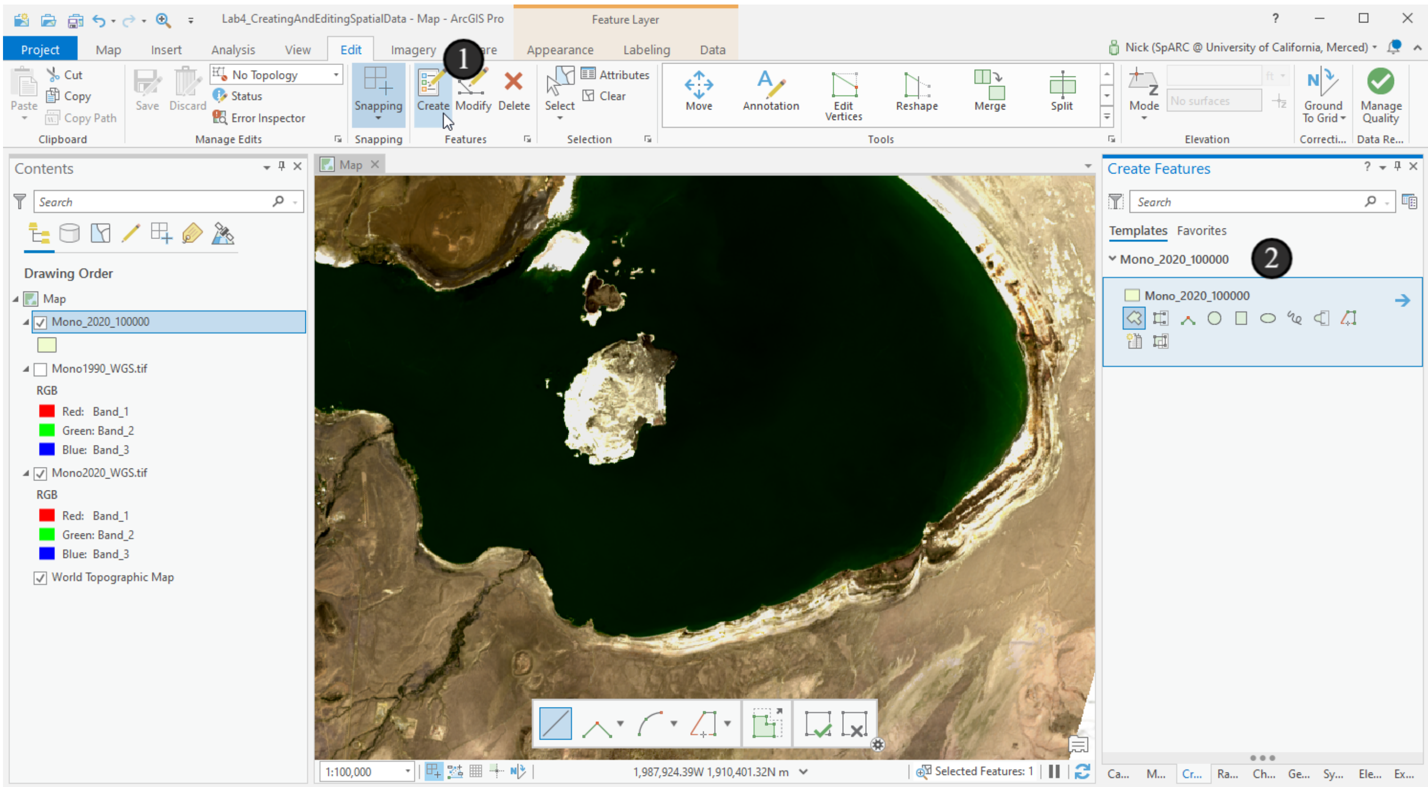
In the *Contents* pane on the left, make sure that Mono2020_WGS.tif is checked and Mono1990_WGS.tif is unchecked. Make sure that your new *Mono_2020_100000* feature class is checked.



4.2 Create Features Pane

1. Now, navigate to the Edit tab of the ribbon and click *Create.*
2. Under *Templates*, expand *Mono_2020_100000 to see the different feature creation tools*. Take a minute to hover over the different buttons that appeared under the selected layer. What do you think that they do?

For now, we'll stick to the default *Polygon* button on the far left, but don't click it just yet.



4.3 An Important Note About Coordinate Systems

And now we're back to projection concerns.

Coordinate Systems are a complex and frequently overlooked part of spatial data - in part because modern software has made it easy for everything to just work correctly even when data are in different coordinate systems. But we should be thinking about the impact that coordinate systems have in our GIS operations. It's especially important when creating new data, whether in a desktop GIS or in the field.

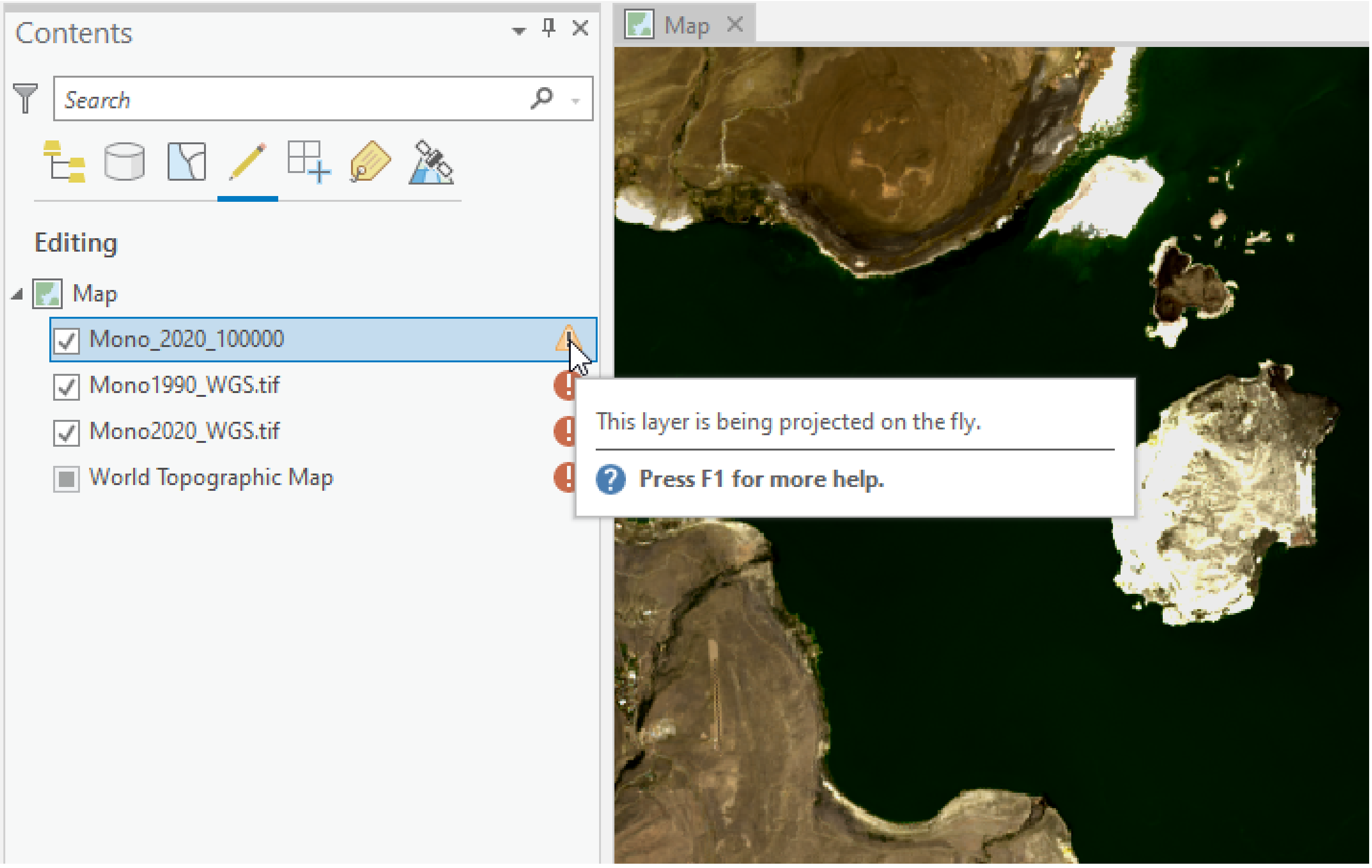
When you are digitizing layers, you typically want to match your coordinate system to the layer that you are digitizing from if you want it to be as accurate as possible. Here, we can see that if we switch the Contents pane to the Editing tab and hover over the warning next to our polygon layer, ArcGIS is telling us that this layer is being projected on the fly - try this yourself, and then press the F1 for more help to see what it tells you.

As of this writing, that help document doesn't actually tell you much! Fortunately, Esri has a much more helpful article from an older version of ArcGIS that explains the problem and some conditions where we might want to avoid this and where it might be OK: https://desktop.arcgis.com/en/arcmap/latest/manage-data/editing-fundamentals/about-editing-data-in-a-different-projection-projecting-on-the-fly-.htm

Look at the layer properties (right click menu) for one of the images, then remember what coordinate system we're using. Importantly, they each use different *datums,* which means that the translation of coordinates to align these data isn't always exact, can vary by location, and is more involved than if we had two planar coordinate systems built on the same geographic coordinate system and datum.

Now we'll consider our use case - we want to digitize polygons so we can compare areas between them, and also assess the scale impacts. Mono Lake also falls well within UTM Zone 11 increasing the accuracy of our digitizing. Since our data will mostly be compared to other data digitized in the same way, internal consistency should make this process fine. But if we wanted the highest accuracy data to use in other workflows, we might want to go recreate our polygon feature class in the same projection as the images (consider why we might do this instead of reprojecting the rasters. How is projecting a raster vs. vector dataset different?) and then reproject the polygons after digitizing if we wanted them in a different projection. This later reprojection would give us more control over the coordinate translation to ensure as accurate of data as possible.

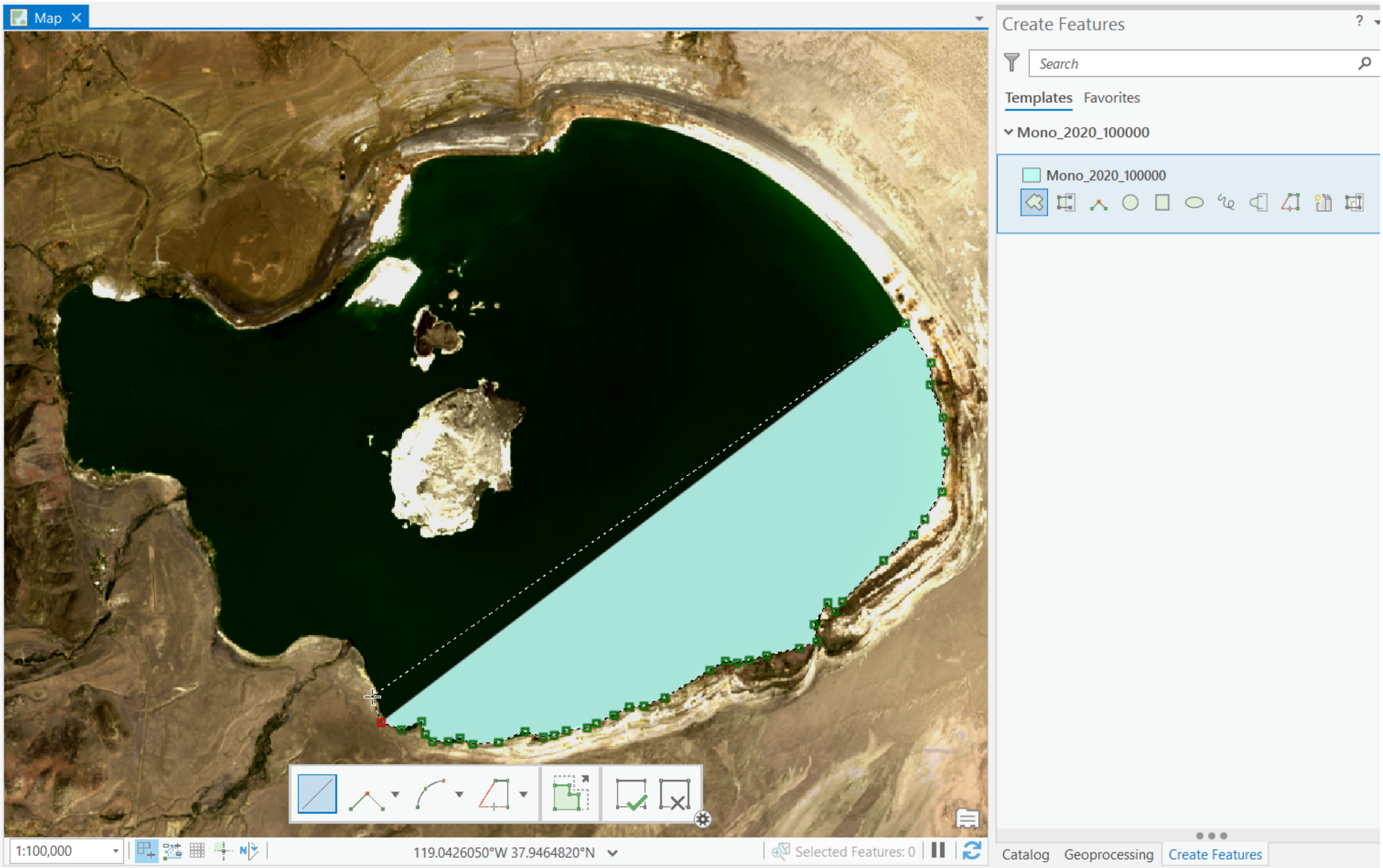
When you're ready to proceed, click the *Polygon* button in the *Create Features* pane.


Contents
Search
Editing
Map
Mono_2020_100000
Mono1990_WGS.tif
Mono2020_WGS.tif
World Topographic Map
Map
This layer is being projected on the fly.
Press F1 for more help.

4.4 Start Digitizing!

Begin to trace the shoreline of Mono Lake as accurately as possible - without changing scales by zooming in or out. Stay at 1:100,000 scale! Click on a spot on the edge of the lake and a point will appear. Click again at the next location where the shore is about to change. You're adding vertices to
your polygon - the points that define the boundary. Think about that as you choose your point locations.

For now, don't worry too much about the islands. We'll leave them alone - just focus on the main shoreline of the lake. See the next step for some shortcuts that will help you while you're digitizing the boundary.



4.5 Useful Keyboard Shortcuts

As you click, you may make mistakes - that's okay! Keyboard shortcuts are your friend: you can use CTRL+Z to undo the last vertex (or last several vertices) that you created.

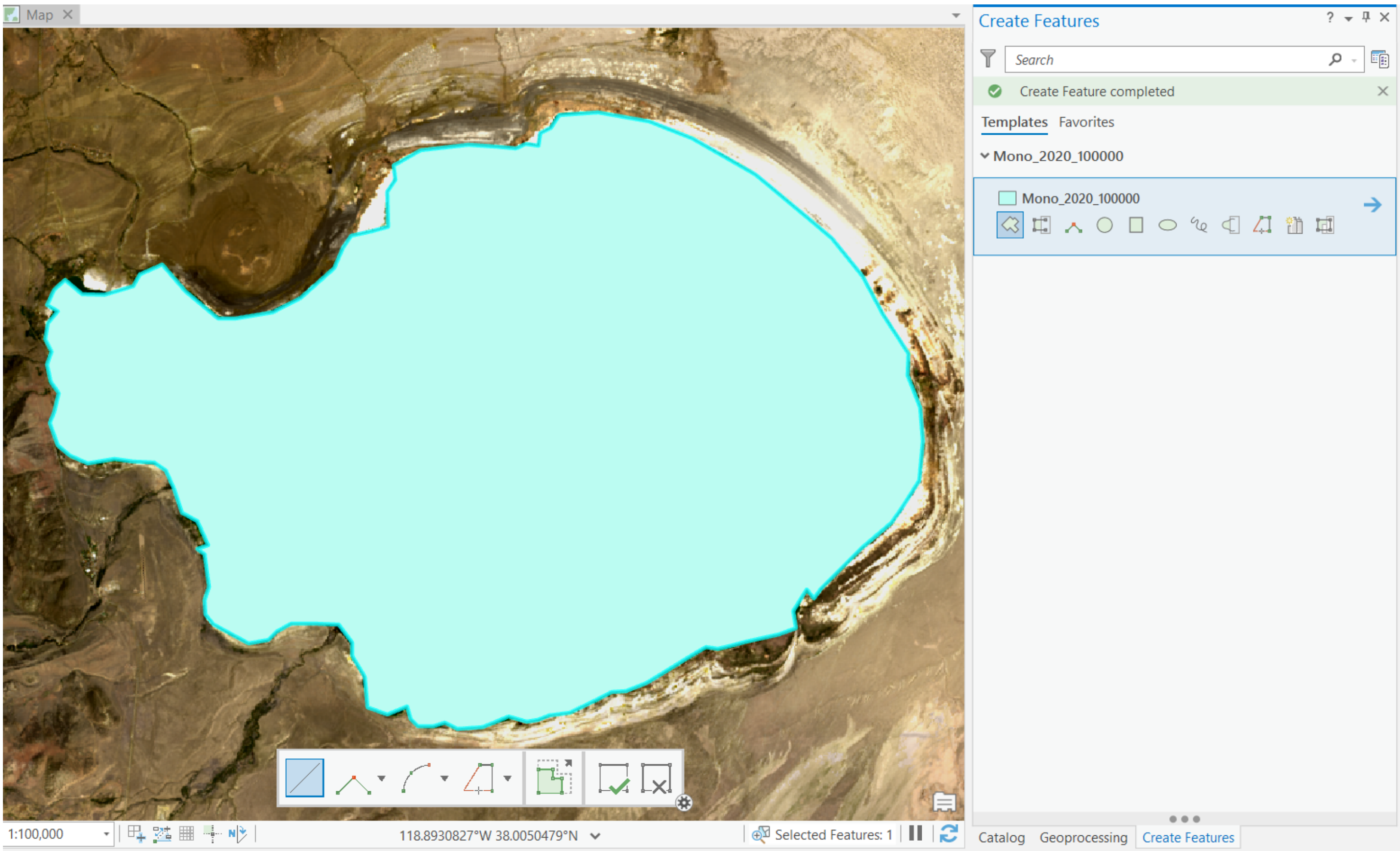
The most important one I use all the time is holding C, then clicking and dragging - this is the most useful tool in making sure I digitize at a consistent scale because I can move the extent around without zooming or switching tools.

If you're having issues with the editor wanting to put a vertex on the line of the polygon that you're creating (a behavior that is very handy when you're creating a new polygon that needs to line up perfectly with an already existing polygon, but not useful here), try turning off the *snapping* behavior by pressing the spacebar. Alternately, go into the Editing tab on the ribbon, click the snapping dropdown, and click on the line where it says *Snapping is on*.

C+drag	Pan	Pan the view.
X+drag	Zoom out	Press and drag the pointer. Release the pointer to zoom out.
Z+drag	Zoom in or out	Zoom the view in or out.
T	Show vertices.	Press and hold to show vertices of existing features near the pointer as you draw a new line.
Spacebar	Snapping	Press and hold to turn snapping on or off as you create or modify features.
Ctrl+Z	Undo	Incrementally undo actions and edits
Ctrl+Y	Redo	Incrementally restore actions and edits
Esc or Ctrl+Delete	Cancel edits	Deactivate the current interactive editing tool and cancel any unfinished edits.

4.6 Finish the Polygon

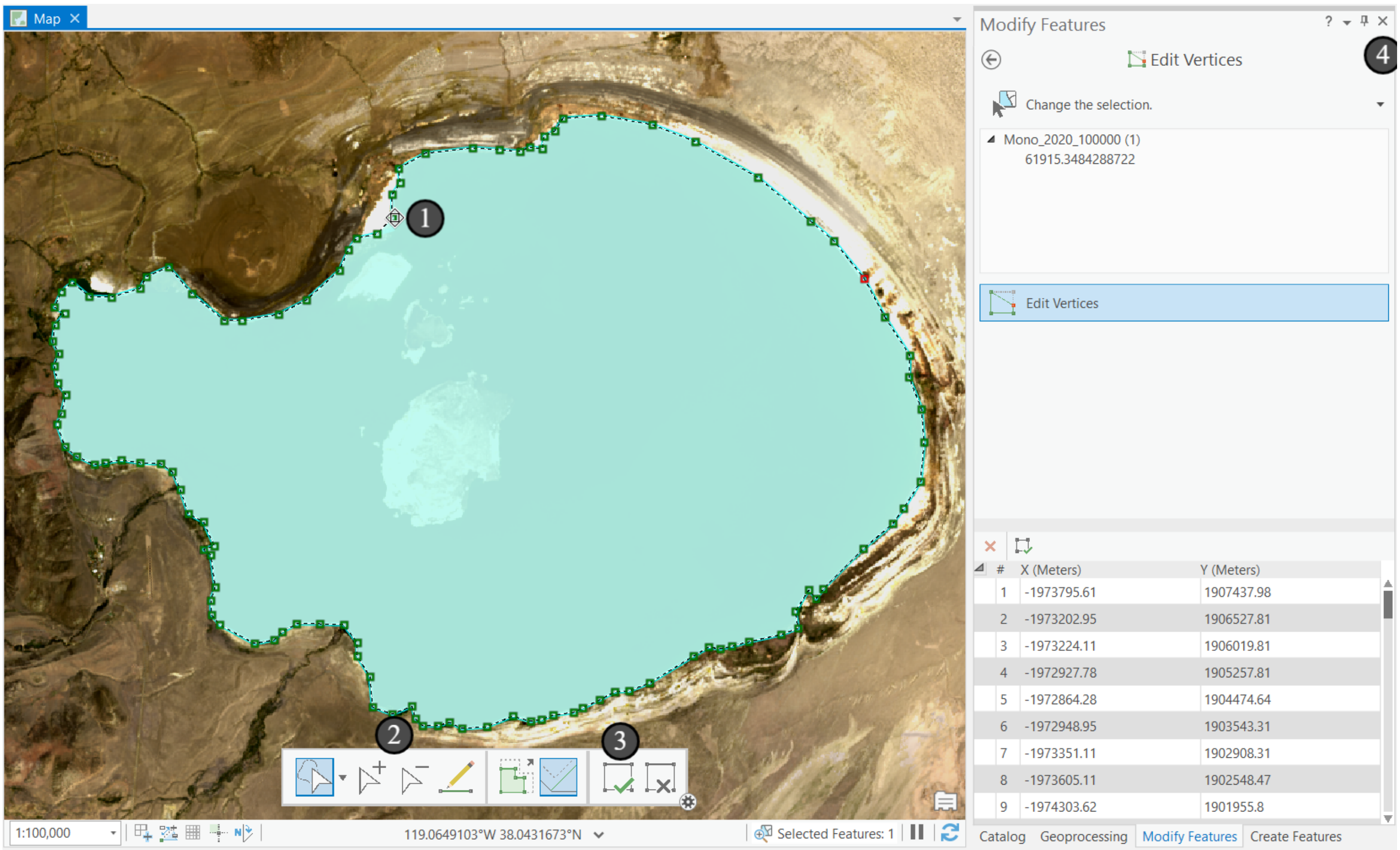
When you've come full circle around the shoreline, *double-click* as you create the final vertex. The vertices that you created will disappear, and the polygon border will turn bright blue (it's now selected!)



4.7 Editing Existing Polygons

Take a look at your polygon (stay at the current scale for now). How did you do? If you notice a spot that doesn't line up well, you can click on the *Edit Vertices* button in the Edit tab of the ribbon. This will bring up the vertices again and you can move them around (1). You can also delete or add vertices using the *Add* and *Delete* buttons (2) in the floating Editor toolbar at the bottom of the screen. Feel free to experiment with the buttons, but don't spend too much time fixing the outline (and don't zoom in to edit this polygon, we'll get there later!).

When you're finished, click on the *Finish* button in the floating Editor toolbar at the bottom (3). The vertices will disappear and the outline will become bright blue again. Close out of the *Modify Features* pane on the right hand side (4).



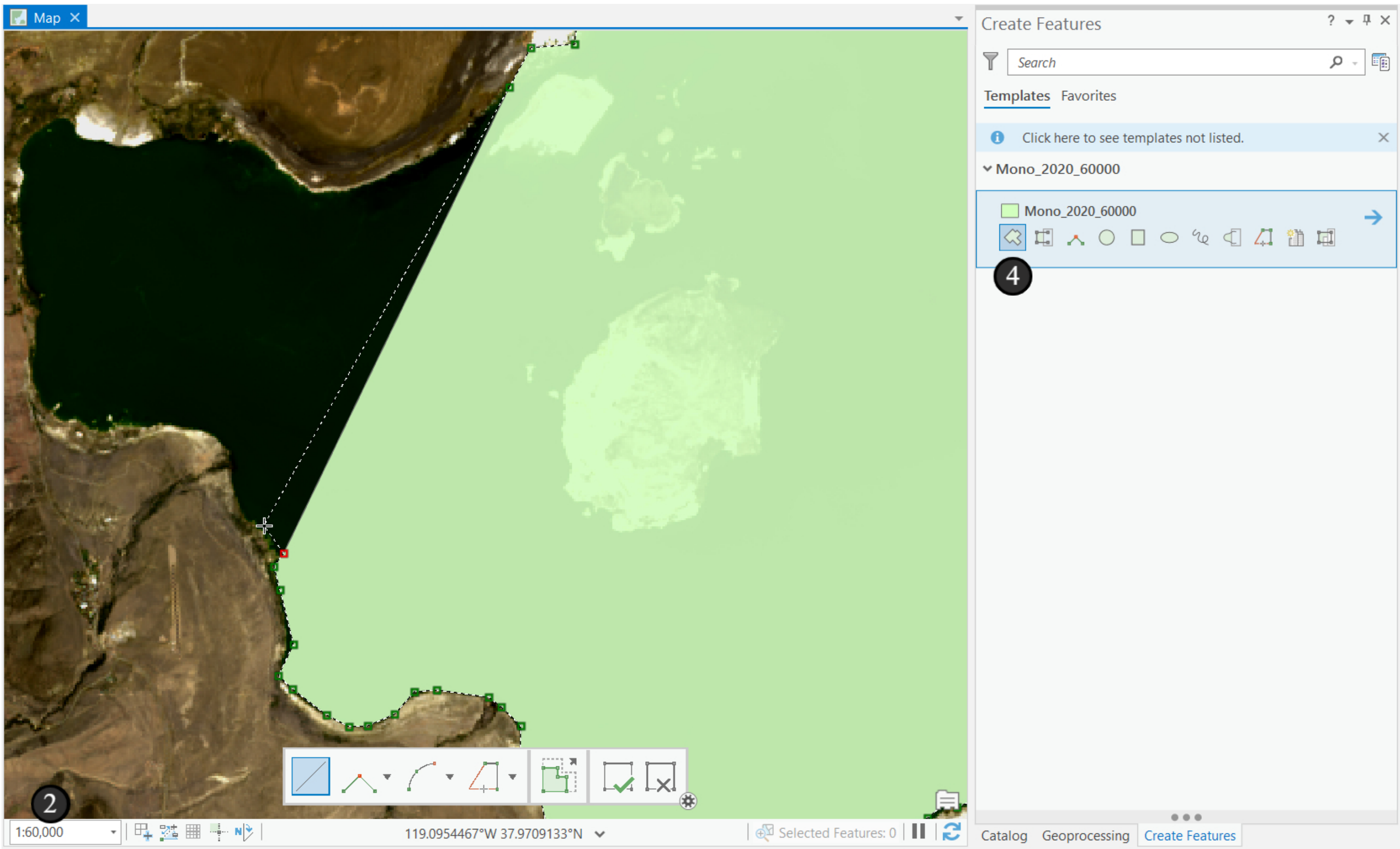
5. Lather, Rinse, Repeat

As you traced the polygon, you may have been tempted to zoom in to see the shoreline better. We're going to create a new polygon and do just that.

Repeat the steps from before:

1. (not shown) Create a new *Feature Class* following the same steps we did earlier (step 3.1). Keep everything the same, but name this one *Mono_2020_60000*.
2. Set the map scale to 1:60000 by typing 1:60000 in the scale bar at the bottom of the map and pressing enter.
3. (not shown) Then pan the map to the edge of the lakeshore. If the *Create Features* tab is still in the right-hand pane, click on that; otherwise open it again from the Edit ribbon. Make sure that the box next to the new Feature Class is checked in the Contents pane on the left; un-check the first Feature Class so you can see the lake short in the image again.
4. Click on the new Feature Class in the Templates tab and begin to digitize the new polygon. At this scale, you will need to pan the map to keep the shoreline in view. Because you cannot click and drag to pan the map in editing mode, you can use the arrow keys to move around, or use a keyboard shortcut (hold down C and drag). Again, keep the scale at 1:60000!

As you go around corners or come close to the end of the polygon, sometimes the polygon will make it difficult to see the shoreline--if you're running into this issue, you can go over to the Contents pane and change the color of the polygon by right-clicking on the color swatch and selecting *No Color* at the top of the dropdown menu. Changing the transparency on the Appearance ribbon can also help.



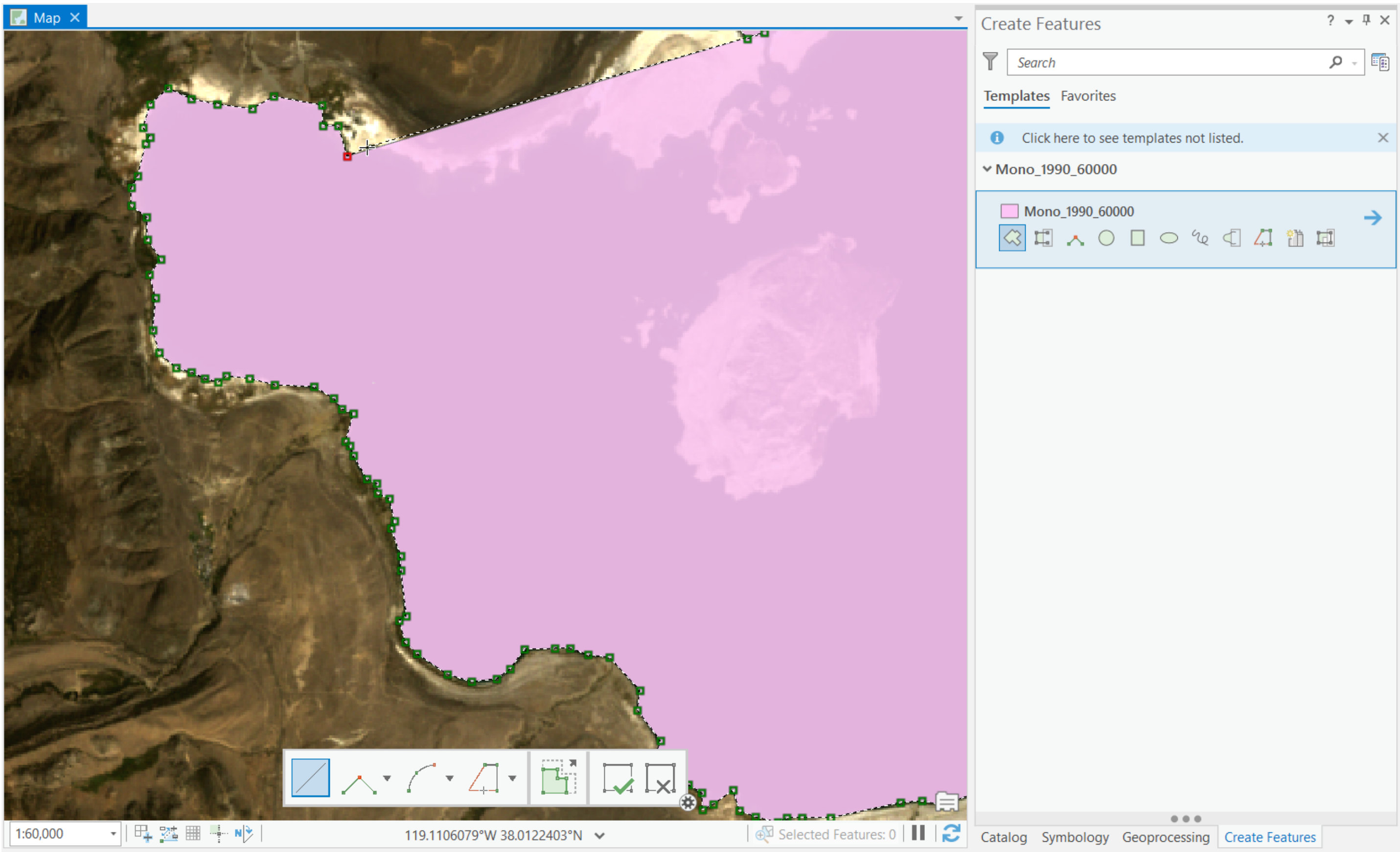
6. Compare Results from Different Scales

Once you've completed the process at 1:60,000, set the symbology of the two polygons so that they have transparent fills and you can see both of them, and zoom in on an edge. What differences do you notice? Which one seems more accurate?

As a bonus, consider how we might have been able to do both of these within the same file.

7. Digitize Mono Lake in 1990

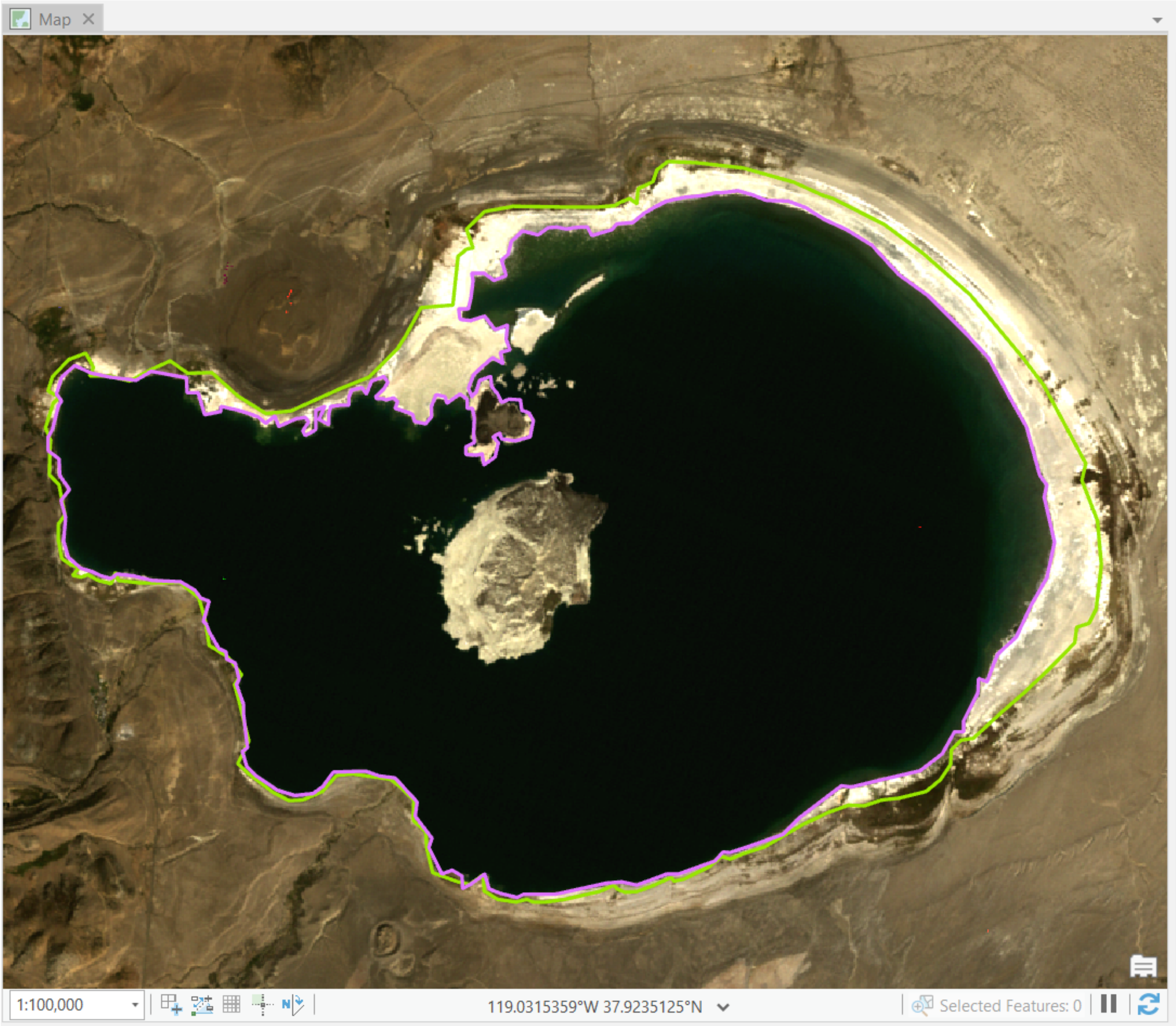
Now that you've had some practice digitizing and have explored scale issues, we're going to create another polygon that captures the shoreline of Mono Lake in 1990, before the restoration efforts began. Go ahead and create a third Feature Class layer called *Mono_1990_60000*, click on the checkbox next to *Mono1990_WGS.tif* in the Contents pane, and digitize the new polygon at 1:60,000 scale using the 1990 image of the lake. (Don't worry, this is the last one we'll do).



8. Comparing 1990 vs 2020

Now, let's compare the shoreline of Mono Lake in 1990 vs 2020. Zoom back out to a scale that lets you view the entire shoreline, and change the symbology of the 1:60,000 polygons so that both are visible with transparent fills again.

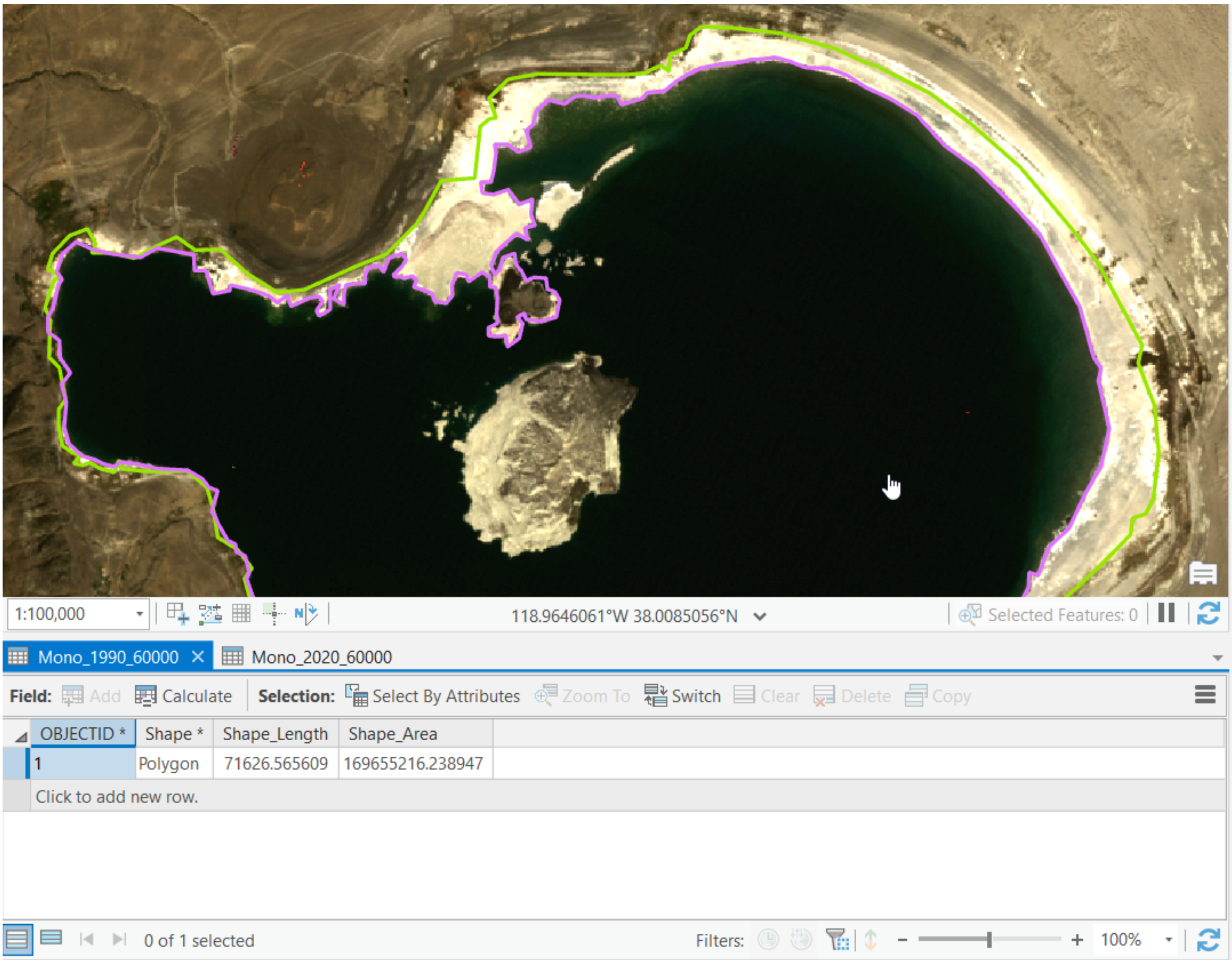
Visually, we can see that the surface area of Mono Lake is significantly larger, particularly on the north and east shores where the shoreline slopes more gradually.



8.1 Comparing Surface Area Change

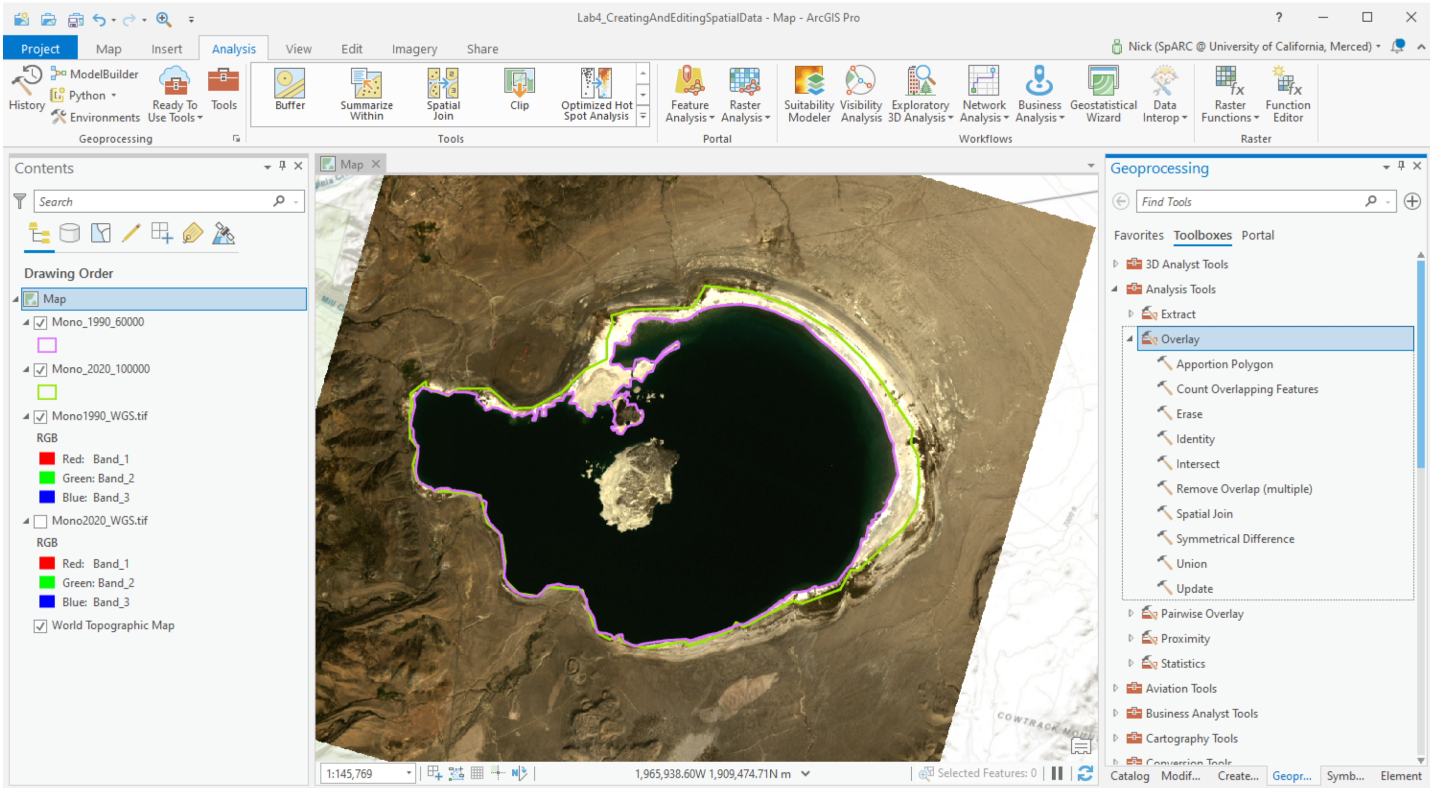
Now let's put some numbers to the change. Open up the attribute tables for Mono_1990_60000 and Mono_2020_60000. ArcGIS has pre-calculated the polygons' length (perimeter) and area for us. But what do these numbers mean? At the very beginning, we set our *Coordinate System to* NAD83 UTM Zone 11N, which, like all projected coordinate systems, has units associated with them. In this case, those units are meters, so lengths will be in meters and areas will be in square meters. If you want to see the areas in square km, divide by 1,000,000 (1 km = 1000 m, 1 sq km = 1000 m * 1000 m). What's the difference between the lake's surface area in 1990 and 2020 in square kilometers?

Your values may be slightly different depending on decisions that you made about what to include or not include as part of the shoreline in either year, and that's okay! If you are working on a project in which you are digitizing many features (lakes, streamlines, wetlands, etc), you will often need to make decisions on exactly where to draw the boundaries. In these types of projects, the key is consistency: pick your scale, decide how you will treat edge cases, and then stick to those decisions. A good strategy is to digitize several features in different areas to get a feel for the types of decisions you will have to make, and then go back and make changes to the early features if you decide to make changes to your workflow.



8.2 Overlaying the two

We can now see the difference between the lake level on the two different dates, but what if we wanted a polygon that represented the difference in surface area, as opposed to two polygons that show the area itself? Take a look in the geoprocessing tools on the toolboxes tab. In the *Analysis Tools toolbox* there is a *toolset* named *Overlay* that has tools for these kinds of comparisons - we've used one before - the Spatial Join. Which tool do you think could help us get a polygon for the difference in areas here? Open up some tools and hover your mouse icon over the help icon in the upper right corner for a graphic of how the tool behaves.

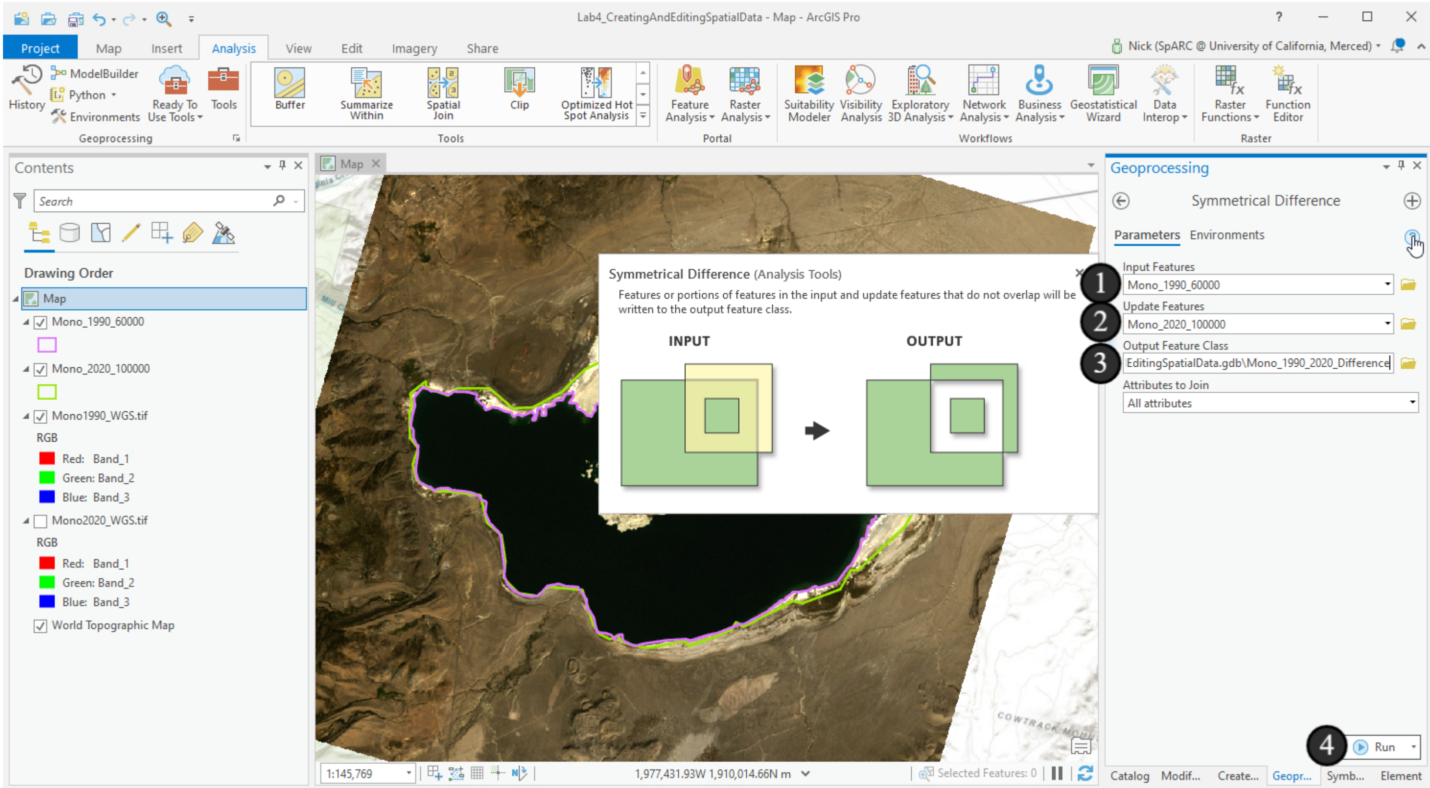


8.3 Getting the difference

I guess we sort of gave away the answer in asking you for the "difference" didn't we. Open symmetrical difference tool - hovering the mouse over the help icon in the top right shows that it gets rid of areas where polygons overlap between two datasets and keeps areas where only one of the datasets has a polygon. This is what we want!

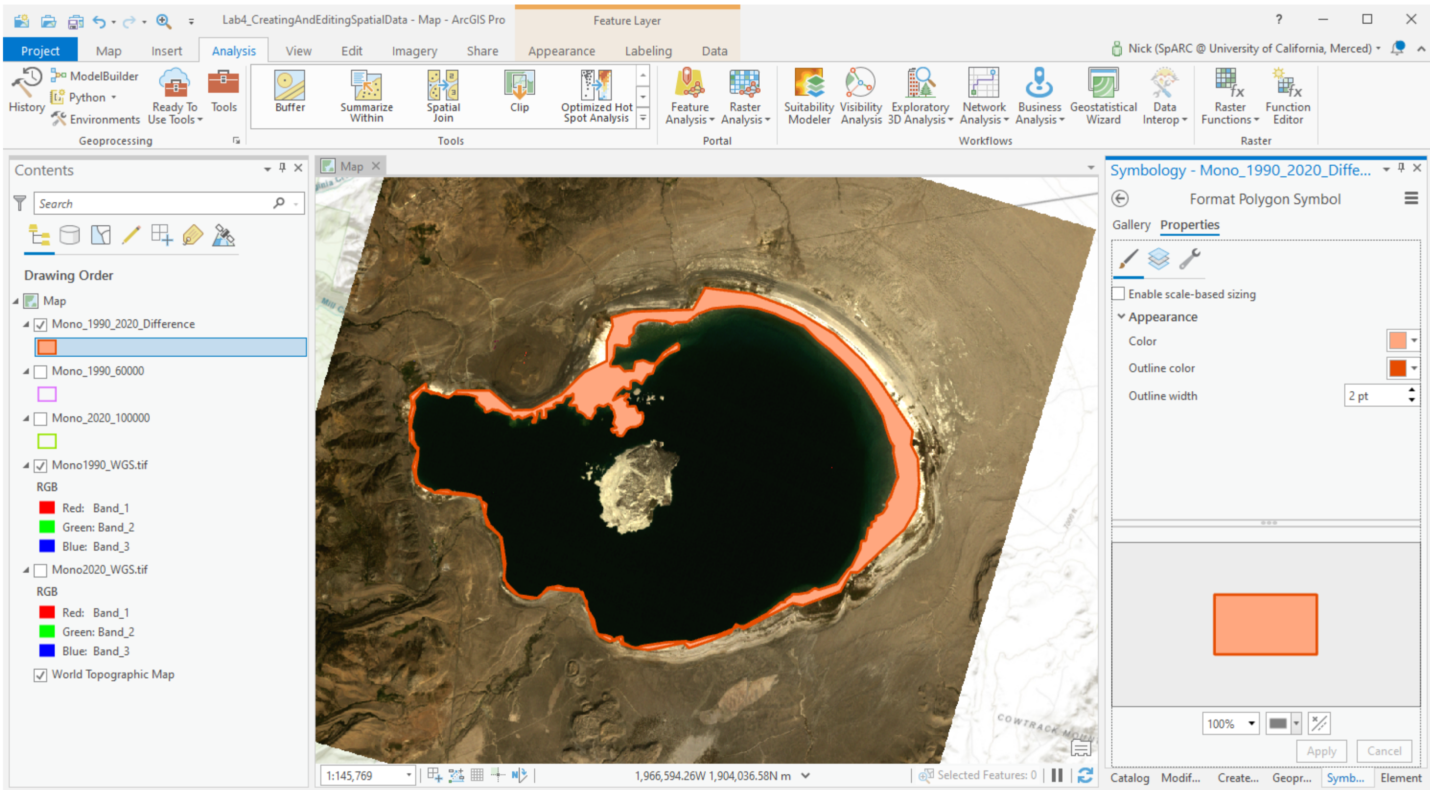
We could also have potentially used the *Erase* tool on lake data, since theoretically the lake only goes down, but it might not show us the true difference between our polygons on the southwestern edge of the lake where the slope is steep. Either one would be fine.

1. Use your 1990 data as the *Input Features*
2. Use your 2020 data as your *Update* features
3. Name your output features *Mono_1990_2020_Difference* in your default geodatabase.
4. Click Run.



8.4 Looking at the difference

At first, the differenced features might look similar to what you were already seeing. Just lines on a map, since it'll copy symbology from the input layers. Change the color and add a new outline color and some fill in the symbology to see the results. You could then use this spatially differenced data in further geoprocessing.

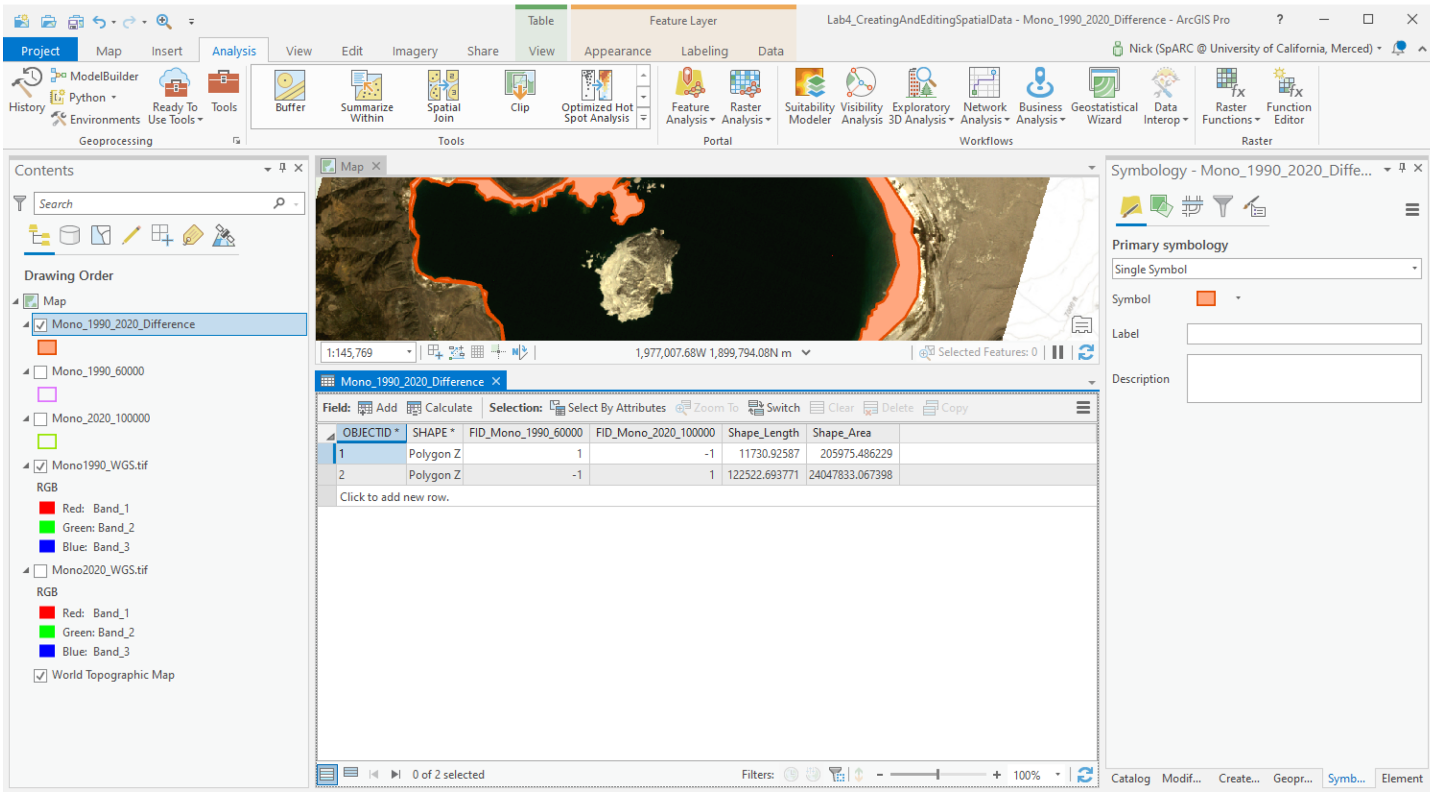


8.5 Getting the area difference another way

Finally, look at the attribute table for your differenced layer. It has two records. Select them each and see what's going on. It seems ArcGIS separated the polygons in my case, but yours may be different. If I wanted to calculate the total area difference in square kilometers, I'd need to sum the values in the *Shape_Area* field for the total area in square meters and divide by 1,000,000 to get the area in square kilometers. Looks like the difference in area is about 24 square kilometers - substantial! We can confirm this is a reasonable estimate by using the measure tool on the more gently sloping northeastern short to see that the lake had receded more than a kilometer linearly in some places!

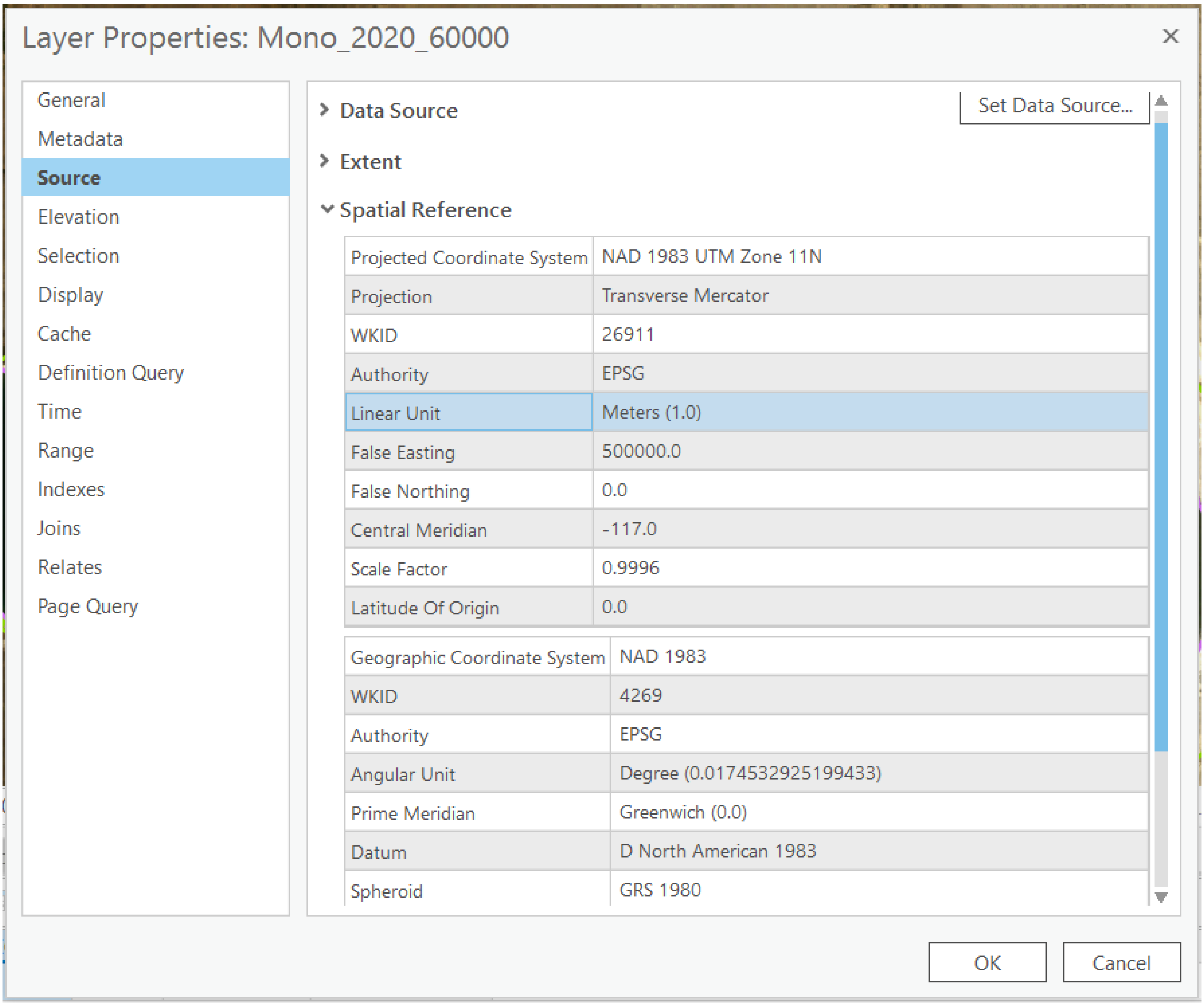
Bonus: If we had bathymetric data, how could we go about understanding the *volume* of change of the lake?

Double Bonus: If you had more features, doing this manually would be a pain. Can you figure out how to calculate this value within the attribute table itself?



9. Projected Coordinate Systems and Linear Units

As a final note, if you're ever unsure about what the unit is for the coordinate system that you are using, you can right-click the layer of interest and select *Properties* to open the Layer Properties dialog. The Linear Unit is listed in the *Spatial Reference* section under *Source*. You can also check the units of a particular projection using your favorite search engine or a website like https://spatialreference.org/.



10. Additional Bonus Question and Bonus Answer

Bonus: how would you go about comparing the percent overlap of the two features? Hint: think about other geoprocessing tools that you may have used in the past. (answer below)

How would you make the surface area more accurate (and improve the accuracy of the percent overlap calculation) for Mono Lake in particular? What else would you want to digitize? (answer below)

Bonus Answer: Lake Volume Change

Generally speaking, we'd determine the elevation of the lake shore at each time period, then difference them with the DEM to determine each one's volume. ArcGIS has a tool called Cut Fill that helps with this. See https://pro.arcgis.com/en/pro-app/latest/tool-reference/3d-analyst/how-cut-fill-works.htm

Bonus Answer: Calculating area in the attribute table

You could calculate area a few different ways - you'd start, in either case, by adding a new field that can accept decimal values (type float or double), then you could

1. Use the field calculator to have it divide the current Shape_Area field by 1,000,000
2. Use the Calculate Geometry tool to calculate the area of each polygon in square kilometers into that field. This tool has the bonus that it doesn't require your data already be in a specific coordinate system, so you can calculate the value even if your Shape_Area field isn't already in meters.

Percent Overlap

Percent overlap is the intersection of two geometries / the union of the two geometries. We have geoprocessing tools for each, so you can run the *Intersect* tool with both features as inputs and then run the *Union* tool, then divide the resulting values from their shape area fields.

More Accurate Surface Area

We mentioned this earlier, but you'd want to remove the islands too. Polygons with so-called *donut-holes* are complex so we skipped it here. If you want to learn more, Esri has a help article with details at https://pro.arcgis.com/en/pro-app/latest/help/editing/cut-a-hole-in-a-polygon-feature.htm