A common need in many GIS applications is accurate river locations. In many parts of the world, high quality, and human-checked GIS datasets already exist marking hydrography already exist, but in some places, this data is still missing or incomplete. In this lab, we'll go through a workflow to generate streamlines only using a digital elevation model as our input. To practice this, we'll use the Navarro River Watershed in California as a case study and generate streamlines within that region. For our data in this exercise, we'll prefix most outputs with *nav* to represent that they are for the Navarro River.

This process will give us a concrete use of an algorithm - a set of steps designed to get from our inputs to our outputs - and we'll need to chain together many different tools to get our streamlines from our digital terrain model. This isn't just a formula to memorize, it's a mental thought process. Consider how each tool gets us closer to our needed result of streamlines by providing the input for the next tool.

In addition to being its own lesson, this exercise sets up a few future exercises. First, we'll use the generated streamlines and the intermediate data products to run an analysis of salmon nests, called redds, and their relationship to the harvest of wood in the area. Then, in a future exercise, we'll look into how we can use automation to make the process of generating streamlines easier (more streamlined, you might say).

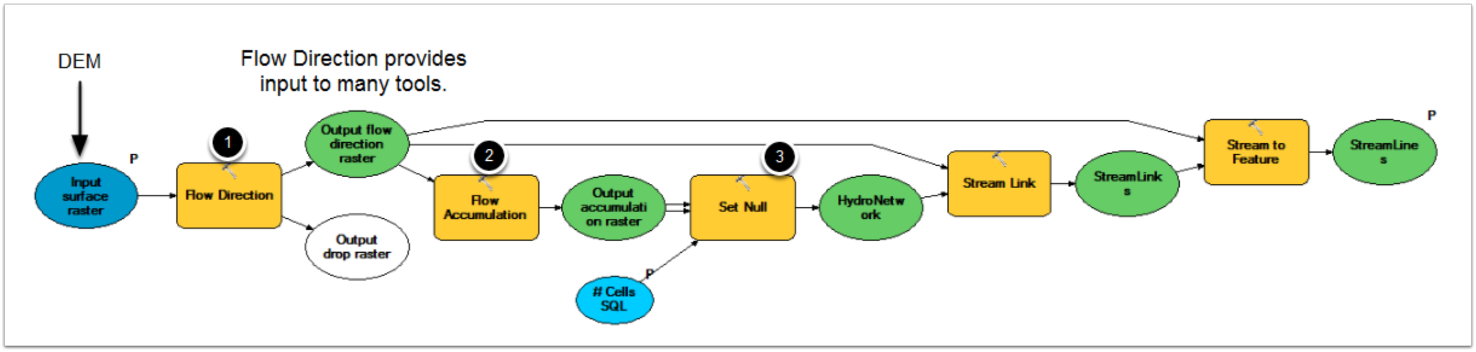
1. Summary of Steps

This graphic illustrates the approximate process we'll follow in this exercise. To generate streamlines (the green oval on the right), we'll need to start with our DEM (blue oval on the left).

1. First, we'll generate a flow direction raster, which has pixels indicating the direction water would flow off of the surface.
2. Then, we'll use that raster to generate a flow accumulation raster, whose values represent how many cells flow into each cell.
3. Then we'll run a series of tools that extract the highest areas of flow accumulation, which are effectively the streams, and turn those first into a raster stream network, then a set of streamlines.

You'll learn how to make diagrams like this that actually run the relevant tools, called models, in another exercise.

Note: All the following procedures are being performed on a depressionless DEM. Prior to initiating any of these algorithms, it is important to identify and fill any sinks - local low spots that interrupt flow in the DEM, but that likely aren't on the landscape. Read the documentation about the Sink and Fill tools in ArcGIS to get more information on this topic.

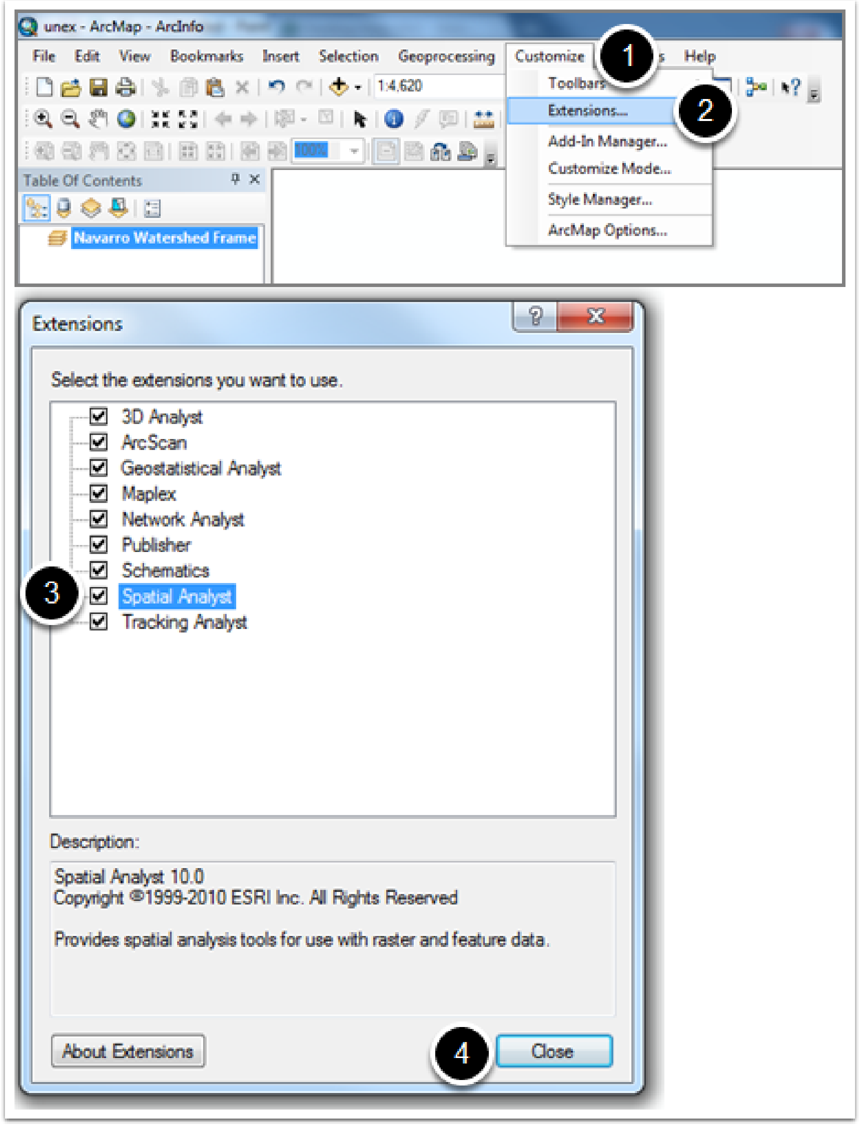


2. Getting Set Up - Add the Spatial Analyst extension

Note: If you already have spatial analyst enabled in ArcMap, you can skip to step 2.

Let's start by making sure Spatial Analyst is enabled. Spatial Analyst is a very powerful ArcGIS tool for raster processing, making it essential for working with DEMs. It has a built in hydrology toolset that forms the basis for stream generatiojn from a DEM. It is not enabled by default though, so we'll need to go through a few steps to enable it. Add the Spatial Analyst Extension by:

1. Select the *Customize* menu
2. Click Extensions…
3. Check the Spatial Analyst box
4. Select Close.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Schematics
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Spatial Analyst 10.0
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Provides spatial analysis tools for use with raster and feature data.
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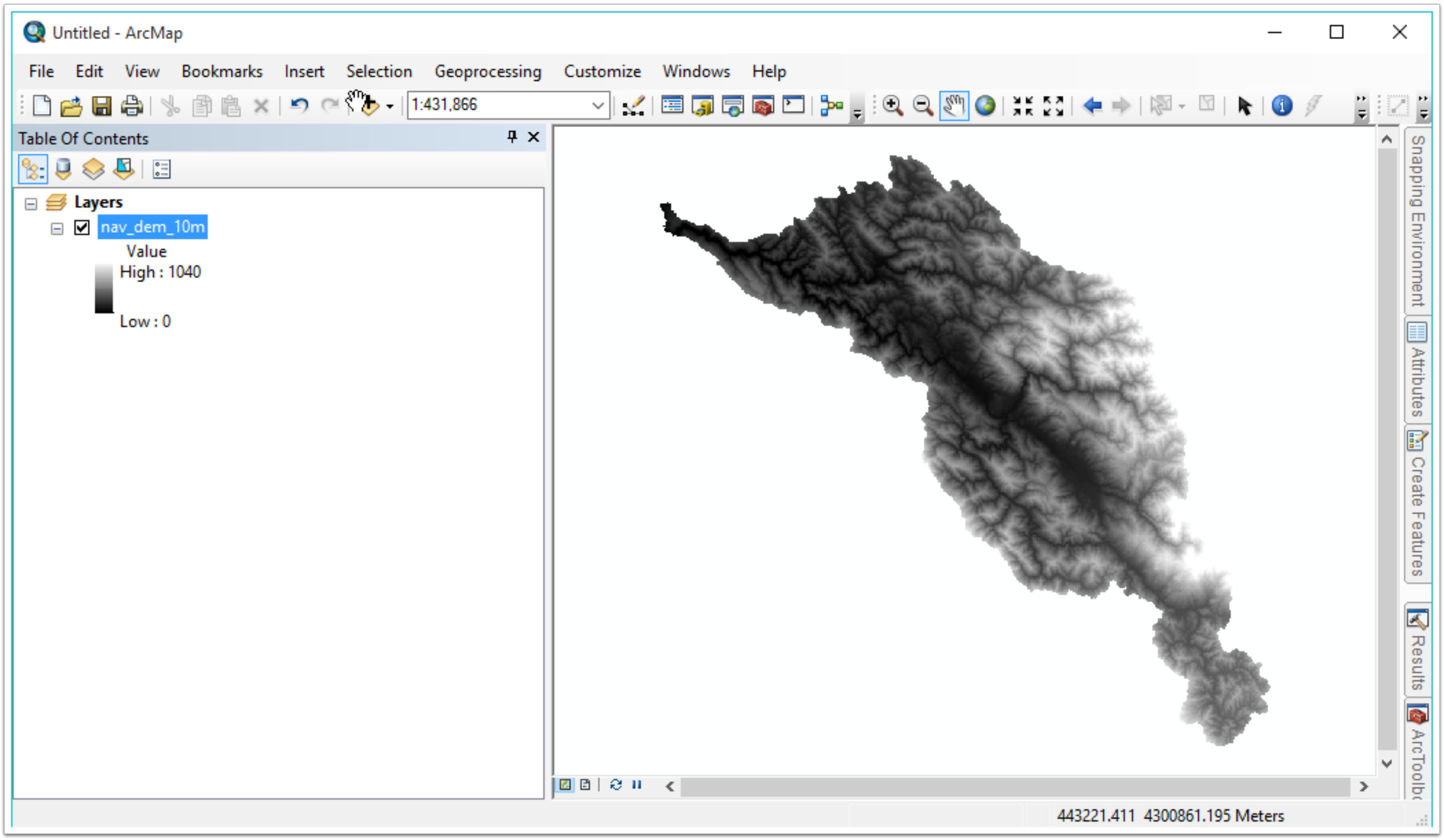
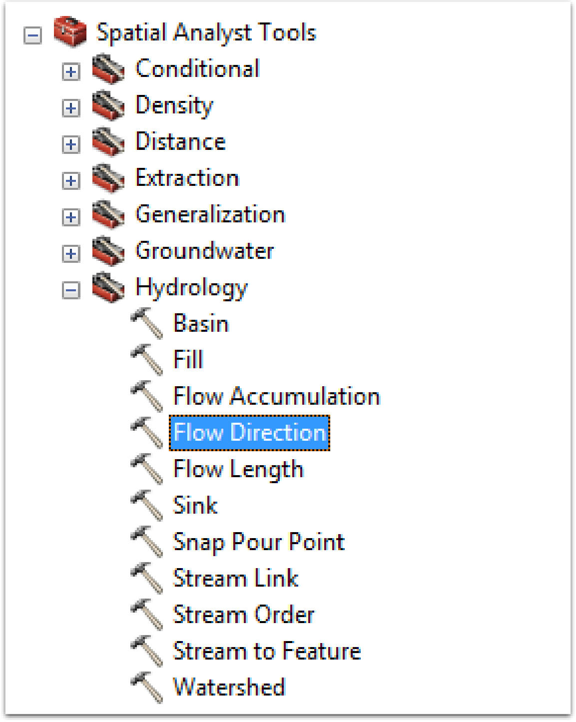
3. Part 1: Generating streamlines from a DEM

We'll start off with the digital elevation model - add it to your map document. It is a File Geodatabase raster named *nav_dem_10m* located in *analysis_data.gdb*.



4. Run Flow Direction

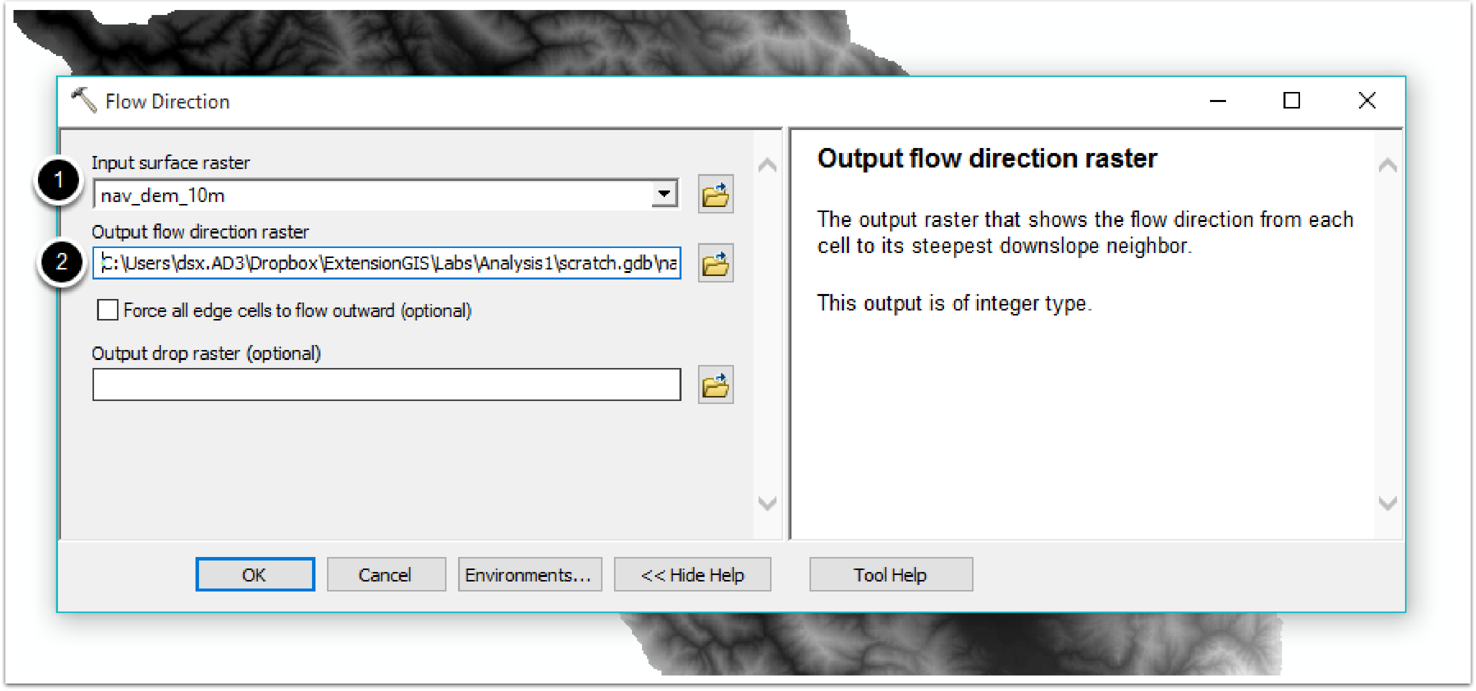
So, as the diagram showed, our first step to creating streamlines is to generate a *Flow Direction* raster. Luckily, there's a tool for this in the Spatial Analyst toolbox. Run the tool now.



4.1 Setting up Flow Direction

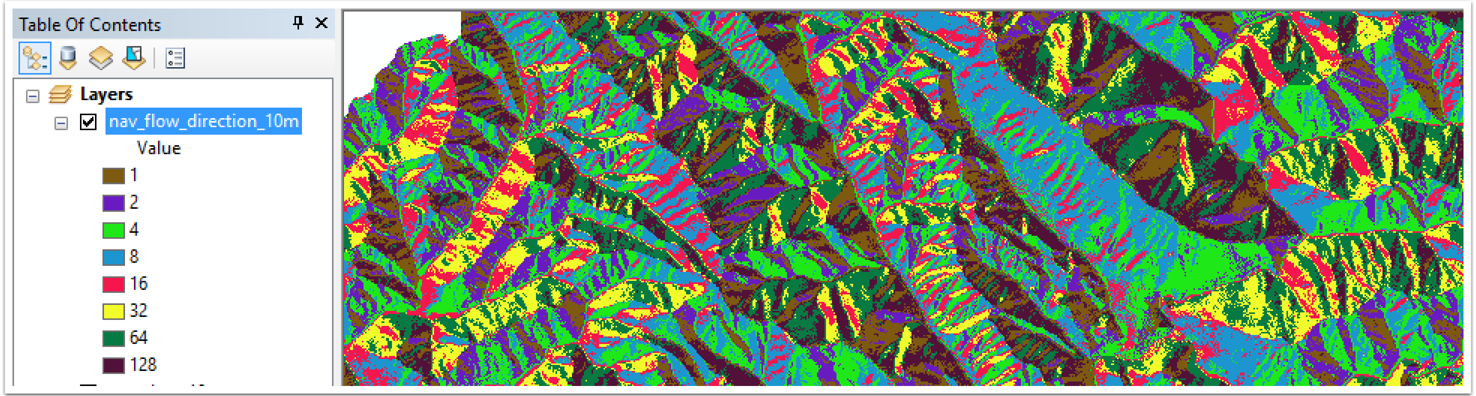
The flow direction tool opens. As was mentioned earlier, this is a raster that is derived from the digital elevation model where each value in the output represents a direction (North, North-East, etc). The values are integers, but each integer represents a compass direction. In assigning it colors, we can see at a glance which way it flows.

1. Right now, we only have one layer in our map document that we can use as input, so use that as the *Input surface raster* parameter. Think for a second about the general concept of creating a flow direction raster and how that can be done from a DEM. Look at the tool help if necessary and make sure you understand what we're creating here.
2. For the output, place it in your scratch geodatabase (make a geodatabase to fill this role if you don't have one already), and call it *nav_flow_direction_10m*



4.2 Technicolor Hillshade

The result of the flow direction tool is a new raster, as seen in the screenshot. I always like to think of it as a "technicolor hillshade" - the effect of coloring the different flow directions with unique colors is similar to a hillshade, and you'll probably see that sort of effect in the "shading" created by the color choice.

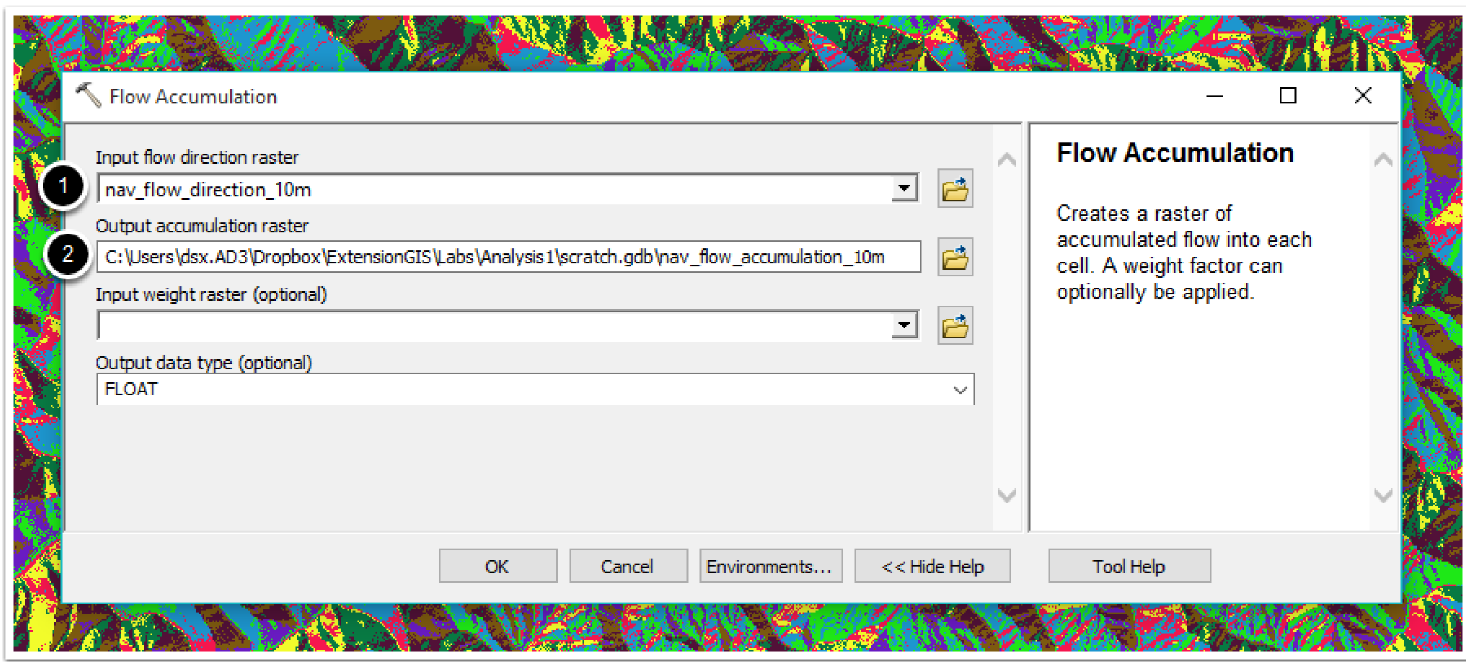


5. Run Flow Accumulation

The flow accumulation raster is just an intermediate product for us though - a step on our way to getting streamlines. We need it as input to the next tool, called *Flow Accumulation*. The Flow Accumulation tool takes the Flow Direction raster and traverses it like a network. For each cell, it counts up the number of cells that flow into it - the number of cells upstream - and puts that count in the output raster for that cell. This is the number of accumulated cells upstream!

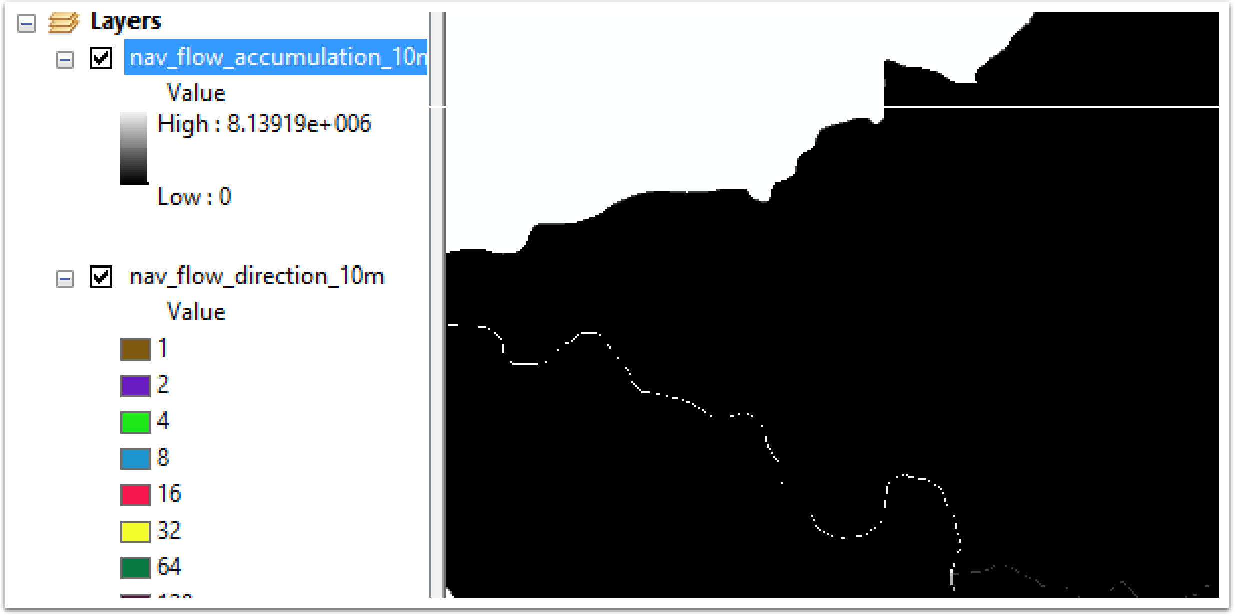
Provide the flow direction raster as the input (1), and name yhour output *nav_flow_accumulation_10m* (2). Then run the tool.

Thought experiment: How would you figure out the upstream *area* for a cell based on a flow accumulation raster?



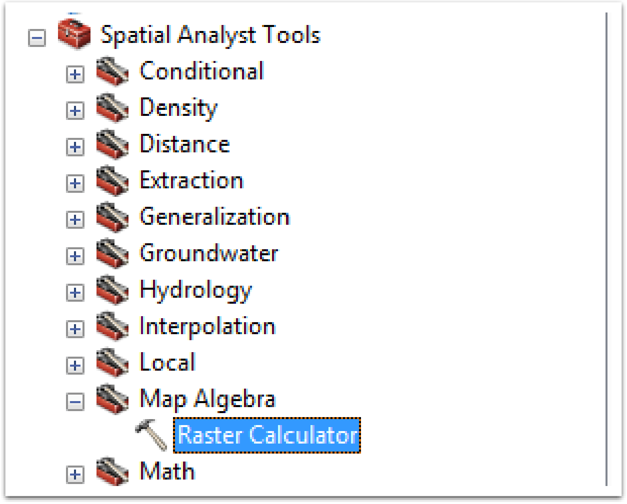
5.1 Looking at the flow accumulation raster

The flow accumulation raster is, by default, symbolized in a way that makes it hard to see most of it - its symbology is dark - the opposite of the bright colors of the flow direction raster. Think for a moment about why it's so dark - look at the low and high values in the color ramp and think about why so many values are so low in this kind of stream network (look again at the DEM to understand the high and low points).



6. Building a stream network

Now, let's extract the cells that will build the backbone of the stream network. If stream and rivers are places where enough water collects to turn into a single flowing unit (instead of just running across the surface or soaking into the ground), then these locations are represented by areas of higher flow accumulation. We'll use the Raster Calculator to extract these cells to a new raster for viewing.



6.1 Extracting the cells

Raster Calculator lets us run *expressions* against rasters to get a new raster back as a result. If we use *boolean logic* (true/false), then it gives us a new raster with cells containing values of 0 and 1, where 0 represents cells for which the expression wasn't true and 1 was a place where the expression *was* true.

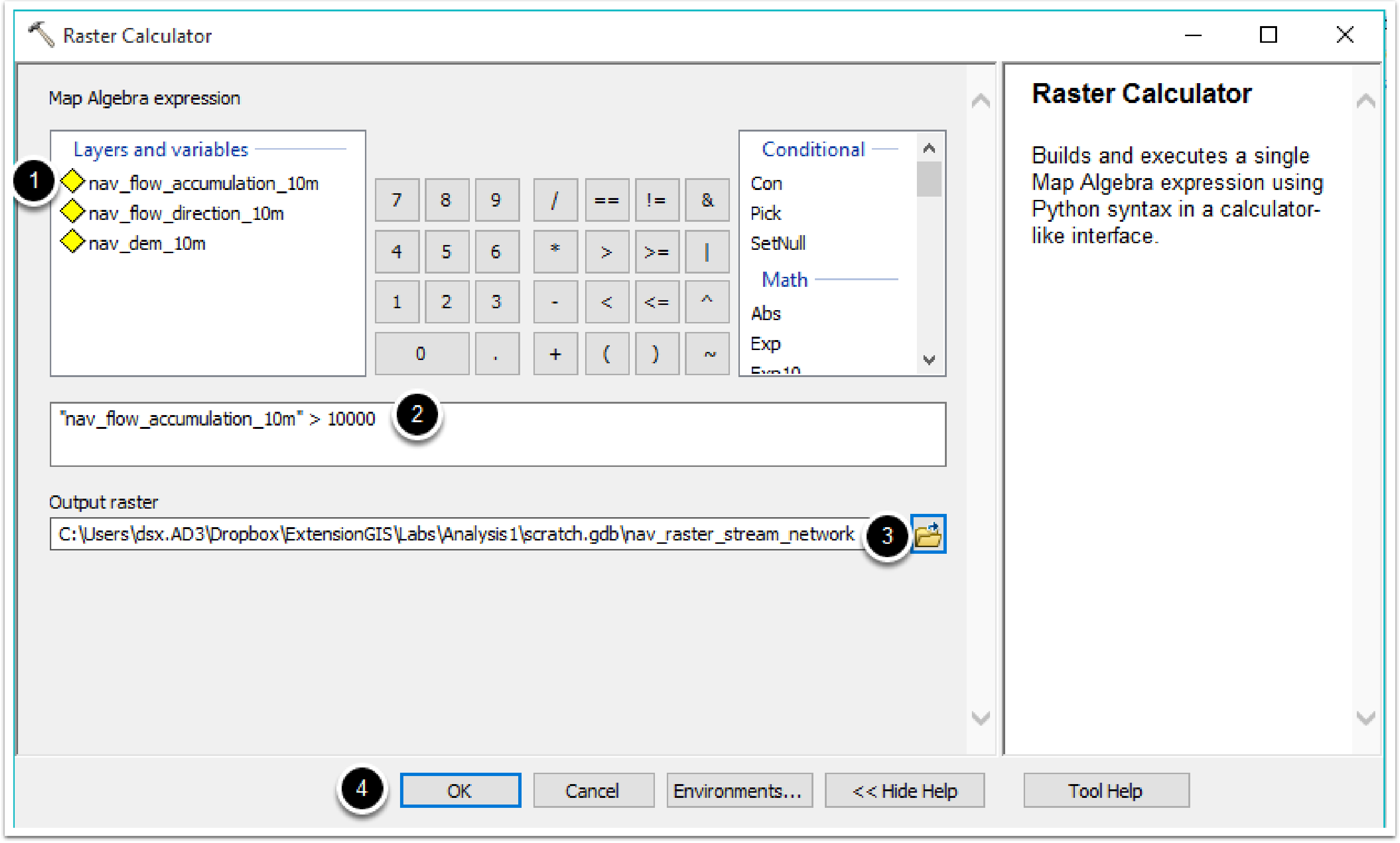
In this case, let's define a stream as any place that has an upstream area of 1 square kilometer. If our DEM has 10m cell sides, then each cell has an area of 100 m^2, so we need 10,000 cells in order to get 1,000,000 m^2, or 1 square kilometer. So, in raster calculator, this equates to:

```
"nav_flow_accumulation_10m" > 10000
```

ArcGIS evaluates this for each cell in nav_flow_accumulation_10m - if the cell's value is greater than 10000, then it evaluates to *true* and the output raster's value is 1. Otherwise, it's false and the output raster's value is 0 in that cell.

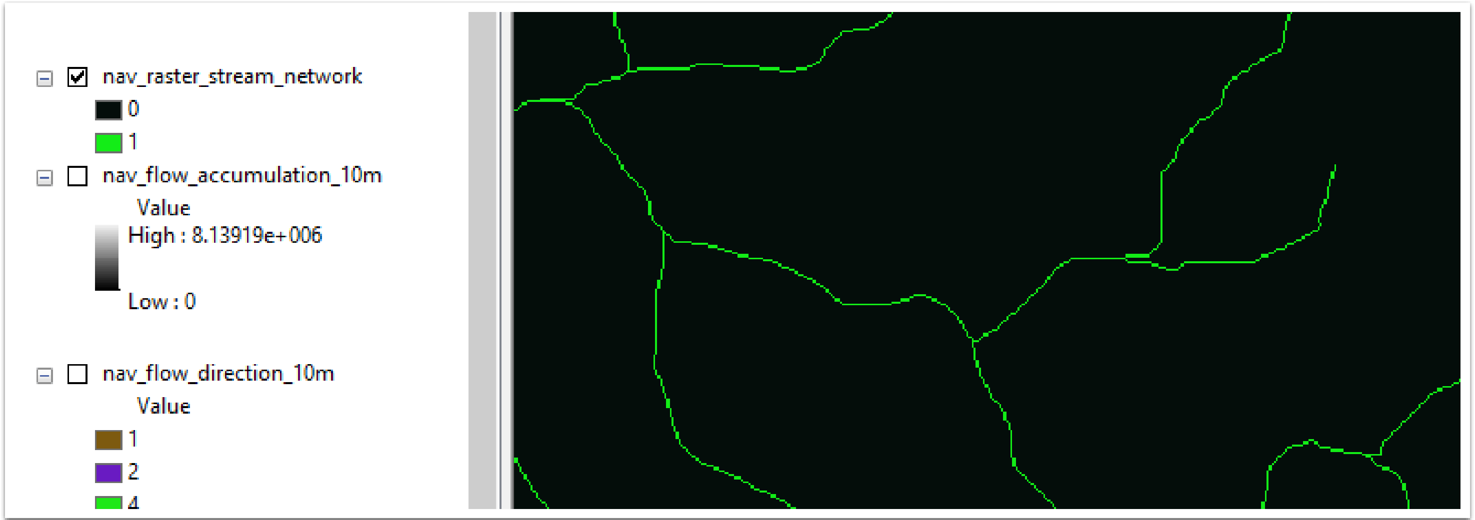
Let's build the query using the calculator:

1. Double click on *nav_flow_accumulation_10m* in the *Layers and variables* section to add it to the expression box.
2. In the expression box, add > *10000* to the end of the expression so that it reads like the expression written above.
3. Save the output raster in your scratch geodatabase and name it *nav_raster_stream_network*
4. Click *OK* to run the tool.



6.2 Look Familiar?

Do these results look familiar yet? While we might be able to convert this raster directly to lines, we'll continue on processing these data so that we can get streamlines that are nicely segmented for better future processing.



6.3 The Set Null Tool

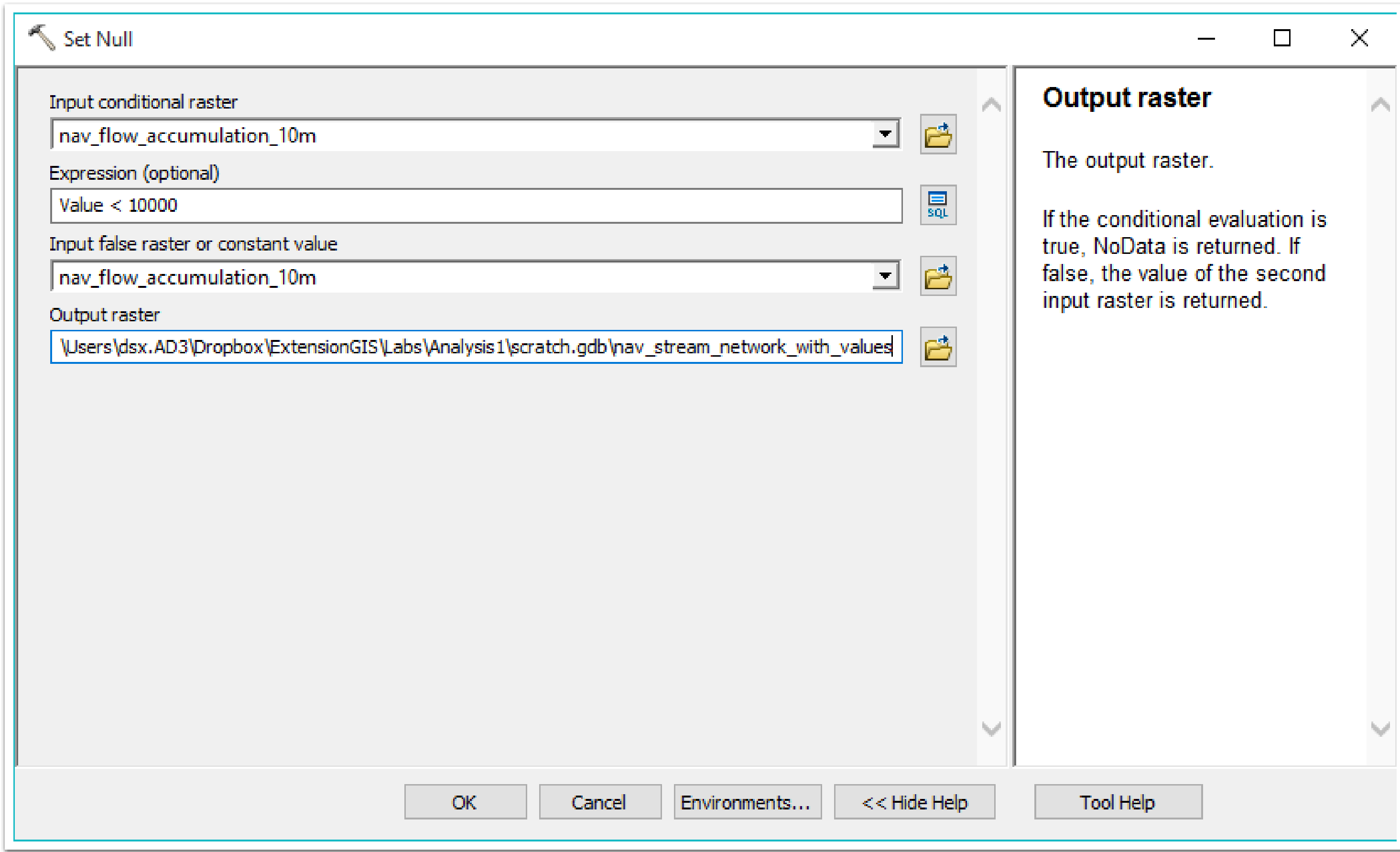
OK, so now, instead of making our streams with the raster calculator where we just get a yes/no response back, let's use the Set Null tool to get back a new raster that preserves the Flow Accumulation values but turns everything else to nulls so we can just process those values.

To do this, we'll use the *Set Null* tool (search for it if you don't know where to find it). Open the tool.

1. Put in *nav_flow_accumulation_10m* as your *Input conditional raster*.
2. Put *Value < 10000* as your *Expression.* (think about why the inequality is reversed here)
3. Put *nav_flow_accumulation_10m* as your *Input false raster or constant value*.
4. Put the output in your scratch geodatabase as *nav_stream_network_with_values*

Look at the tool description and help and see if you can figure out what we're doing here. What's the logic? Set Null works similarly to Raster Calculator. We can provide a *condition* - a logifcal statement that it evaluates to determine if it should set the values to Null. So, what we're doing is providing our flow accumulation raster as the raster to be evaluated - the *conditional* raster. Then, like Raster Calculator, it evaluates the expression for each cell, and for cells where the expression is *true* this tool sets the output value to Null. We then provide the *false raster* or a constant value (just a number) that is used when the expression is false. So the output raster has null values where the expression is true, and in our case preserves the original flow accumulation values when the expression is false (that's why we reversed the inequality - we want to keep all the values above 10000 and set the values below 10000 as null!).

Bonus Challenge: Can you repeat this step using just the raster calculator? *Hint:* Look in the right-hand box for functions you can use in the expression, and check out the tool help!



6.4 Making a new stream raster

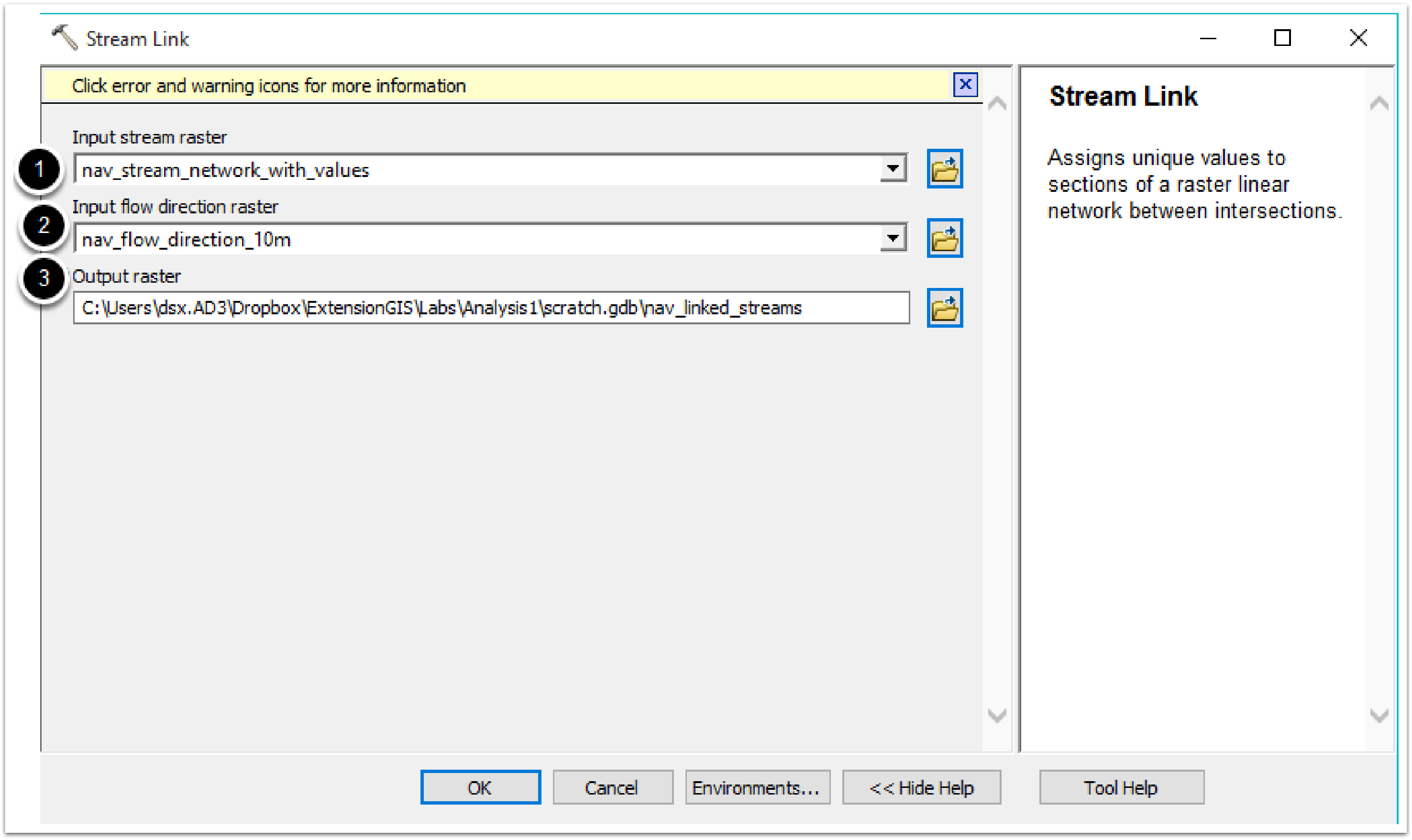
OK, now that we have a raster that's just the flow accumulation values that we think are streams, let's work on converting them to streams. First, we'll use the stream link tool, which will assign unique segments of stream between confluences (merging) of rivers all the same ID, so each unique raster value is a different stream segment.

Find and open the stream link tool.

1. Pass in the raster you just created, *nav_stream_network_with_values* as the *Input stream raster*
2. Provide *nav_flow_direction_10m* as the *Input flow direction raster*

3. Put your output in the scratch geodatabase and name it *nav_linked_streams*

Run the tool. Once it's done running, explore the result a little bit. We'll use this raster much more in the future labs, so make sure to keep it around!

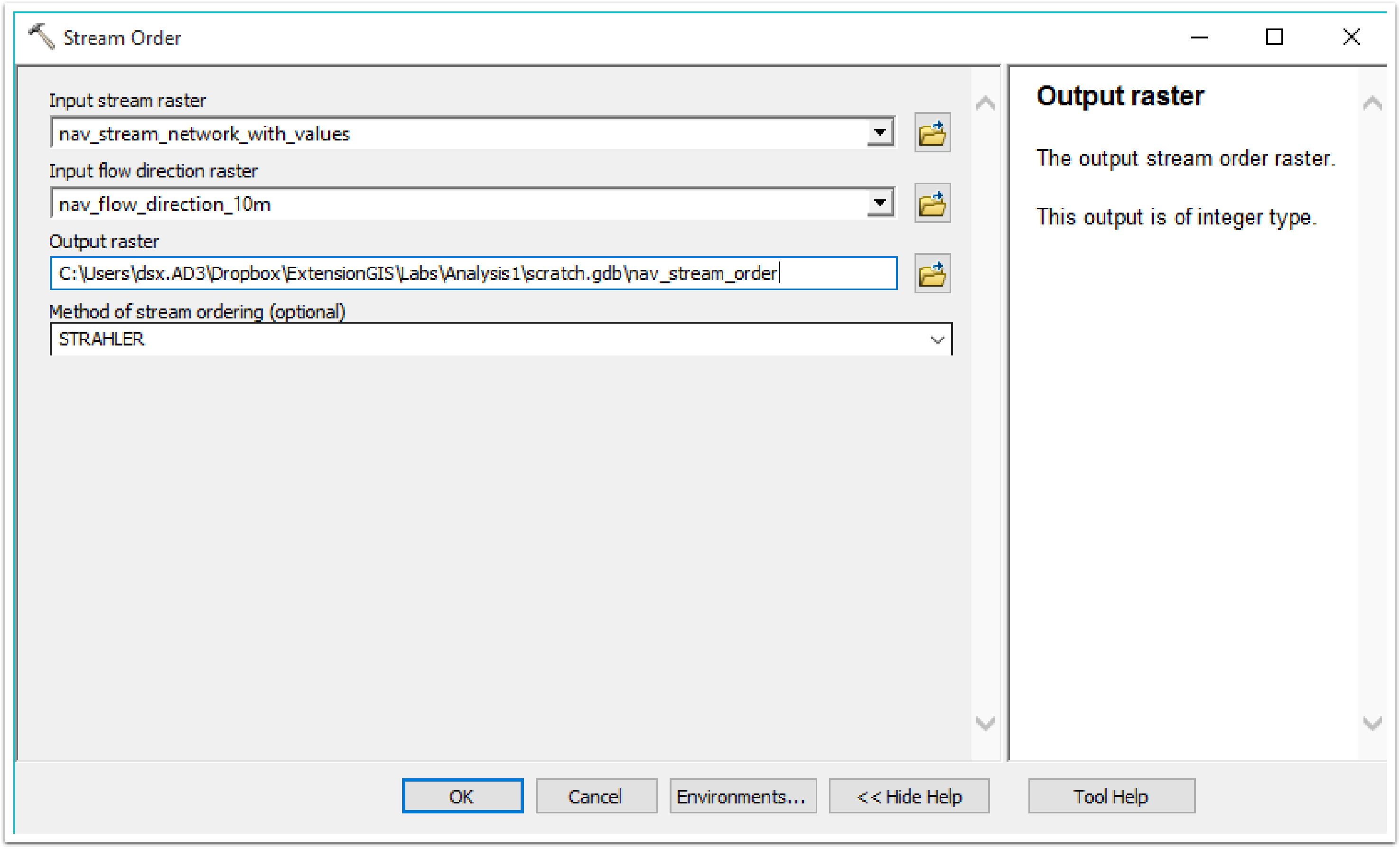


6.5 Convert to stream order

Now we'll make a *stream order* raster. Stream order is a measure of the size of a stream, usually based on the number of upstream confluences. Read the tool help for more information on how it's calculated. We'll finally use this to create our streamlines, and then the converted streamlines will have an attribute denoting the stream size since the raster value will be attached.

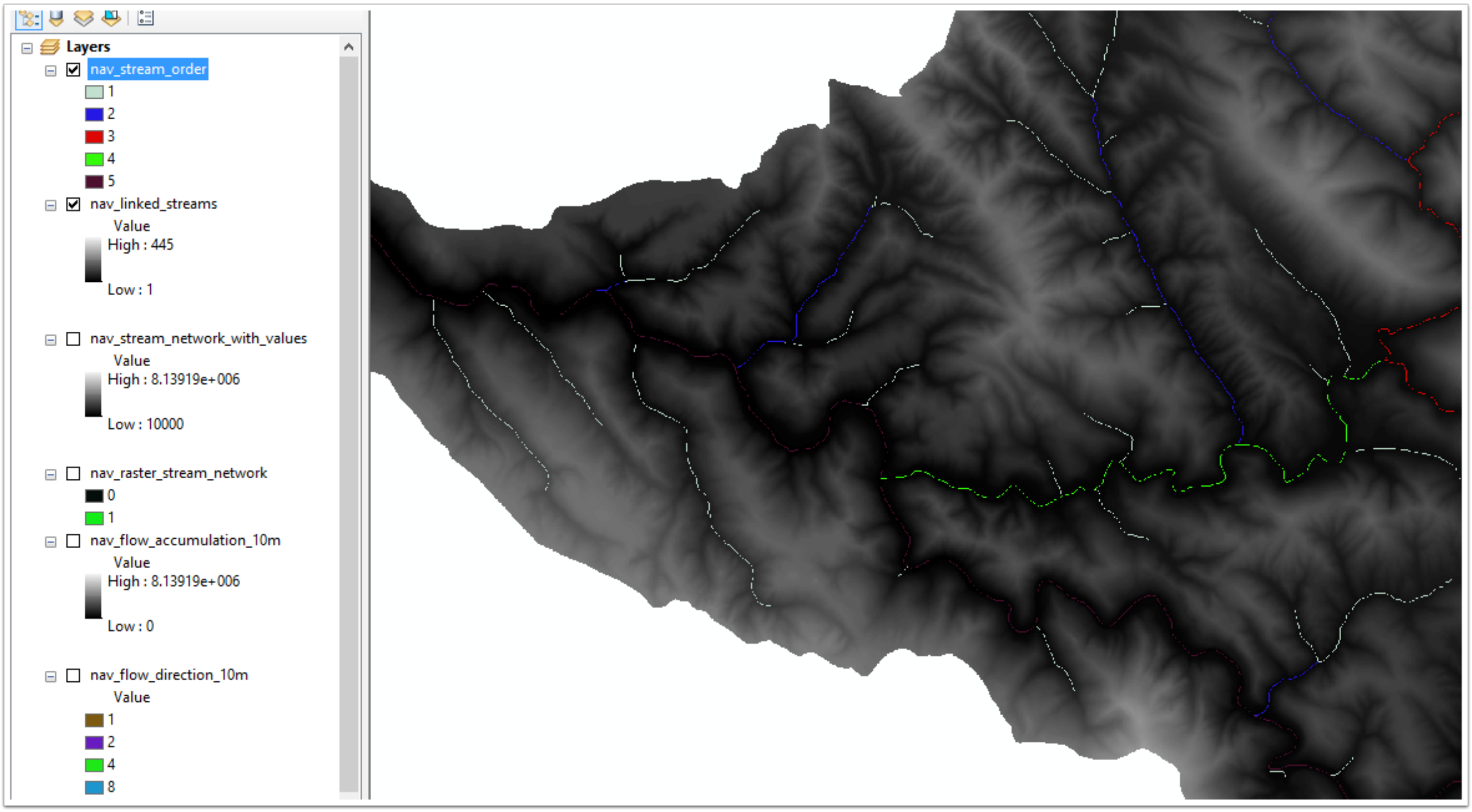
1. For *Input stream raster* pass in *nav_stream_network_with_values*
2. Provide your flow direction raster again for the second parameter
3. Put the output raster in your scratch geodatabase and name it *nav_stream_order*
4. Use the default *Method of stream ordering* (STRAHLER)

Run the tool.



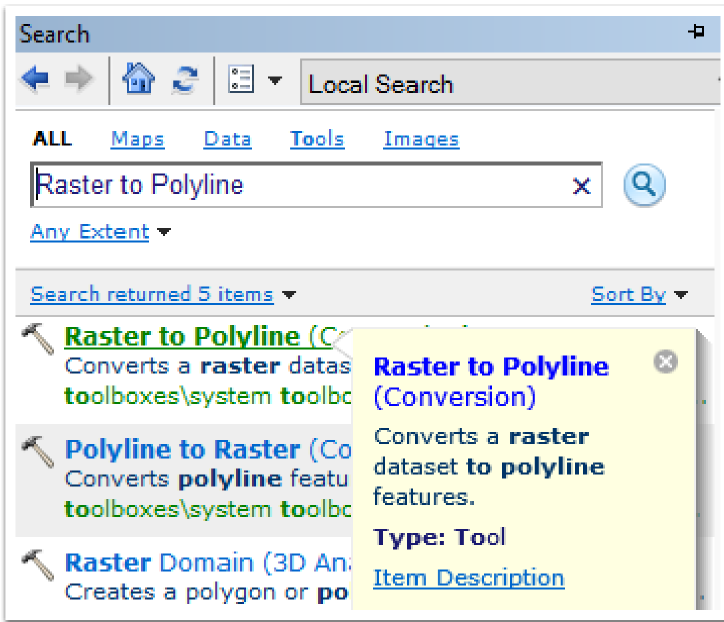
6.6 The Strahler Stream Order

Examine the results of the Stream Order tool. Where are higher values, and does there seem to be a method to how the values change? Look at the Stream Order tool help to find out more information on how stream orders are assigned.



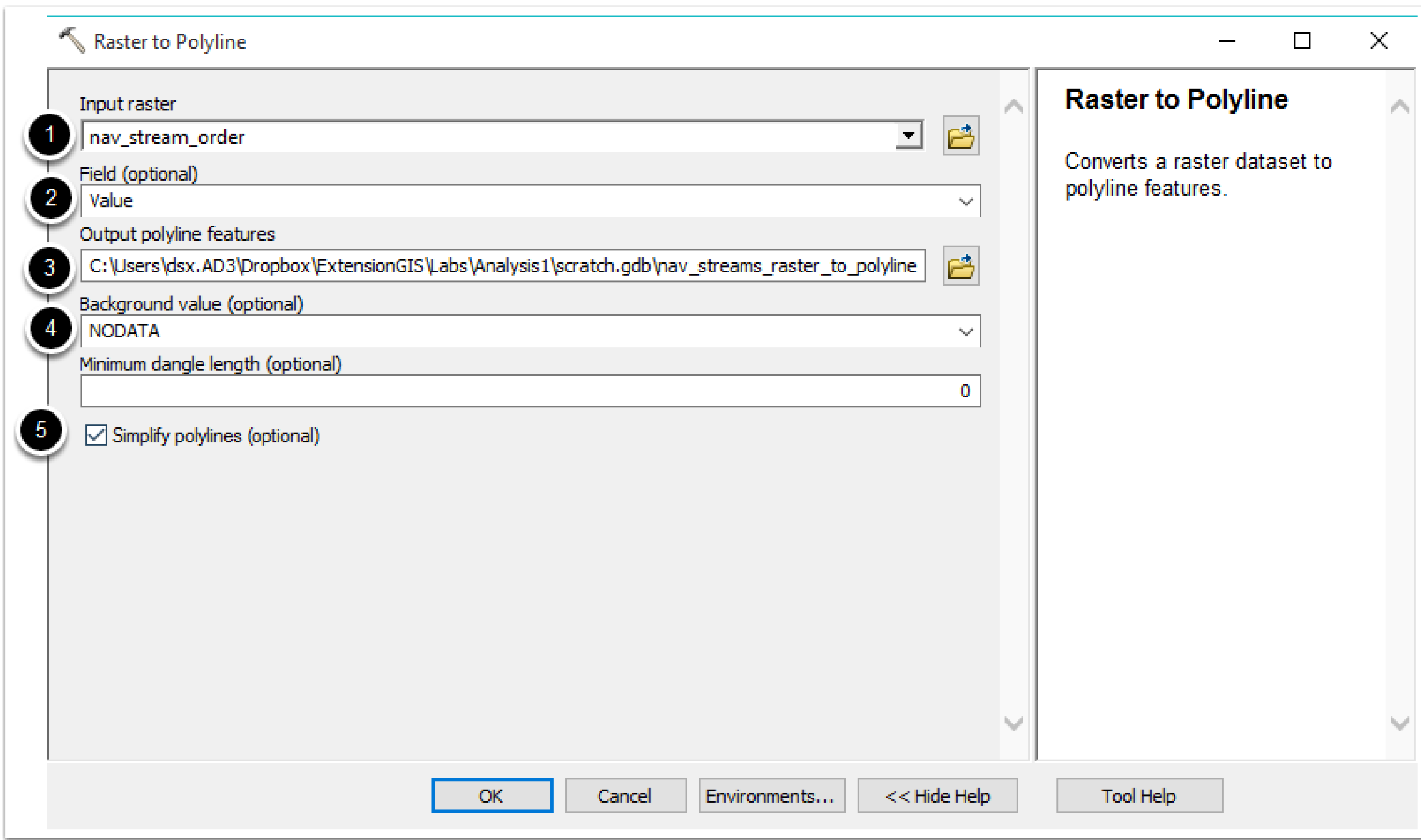
7. Converting to vector

OK! Now we've effectively generated the streamlines, but we're still stuck in raster data. Let's create vector hydrography by converting our raster to vectore. We'll look at two ways to do this. First, there's the R*aster to Polyline* tool, which handles the general case - converting any raster like this to lines. Then, we'll look at a tool specific to streams, called *Stream to Feature*. Find the Raster to Polyline tool and open it up.



7.1 Conversion

Raster to Polyline is a straightforward data conversion tool. Provide the input raster you want to convert - in this case *nav_stream_order* (1) - and then the field to use to convert it. We'll use the raster's value, which you can select as *Value* (2). Put the output in your scratch geodatabase as *nav_streams_raster_to_polyline* so that we can distinguish these streams from the others by conversion method (3). Choose *NODATA* as the *Background value* (4), and have it simplify polylines (5). Run the tool.



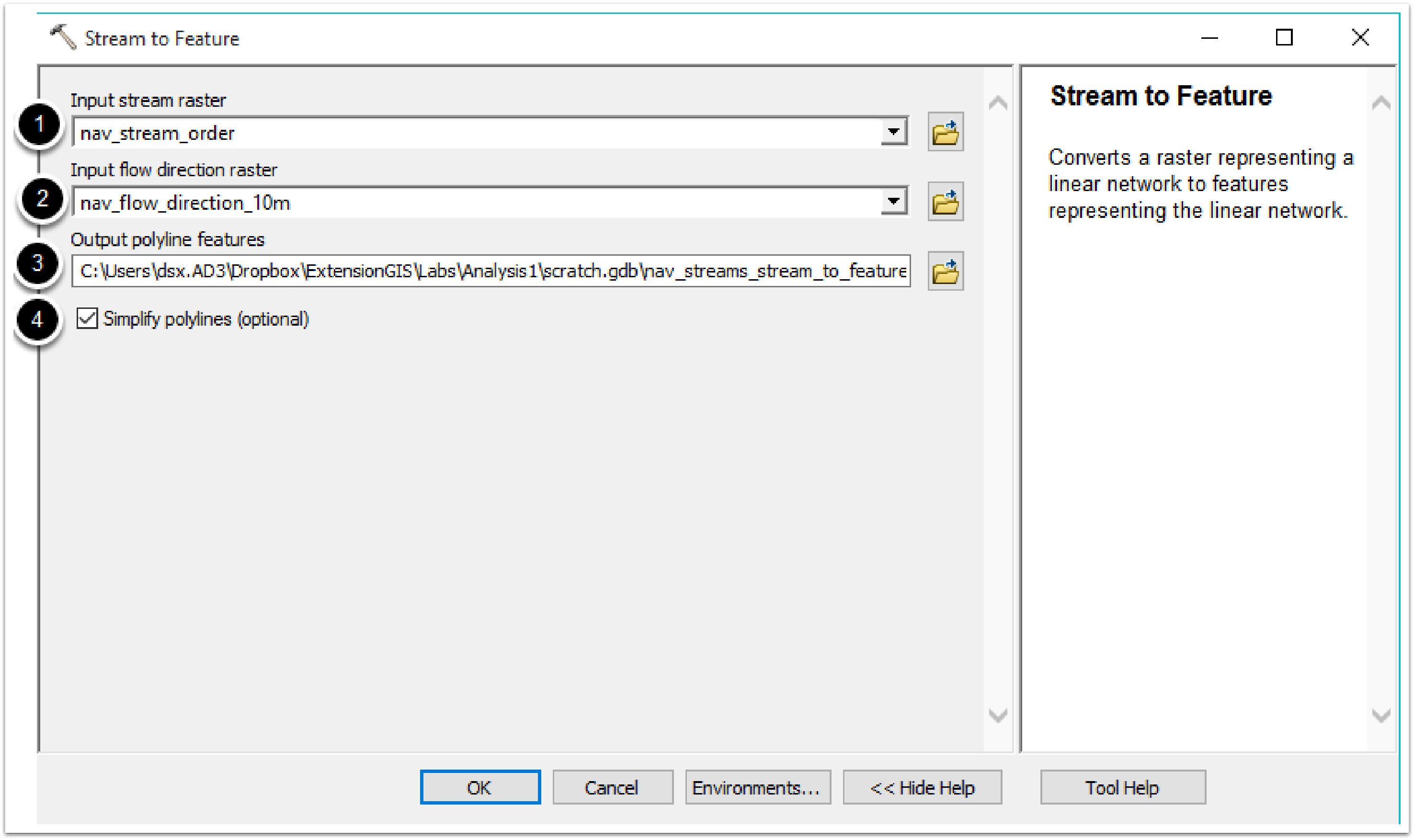
7.2 Stream to Feature

Before examining the output, let's convert the streams another way. Find and open the *Stream to Feature* tool. This tool has fewer parameters, in part because it's purpose built for converting raster streams generated using this method to a feature class.

1. Provide *nav_stream_order* again as your *Input stream raster*
2. Provide your flow direction raster in the second parameter
3. Put the output in your scratch geodatabase as *nav_streams_stream_to_feature*

4. Simplify polylines again

Run the tool.



7.3 Examine the output

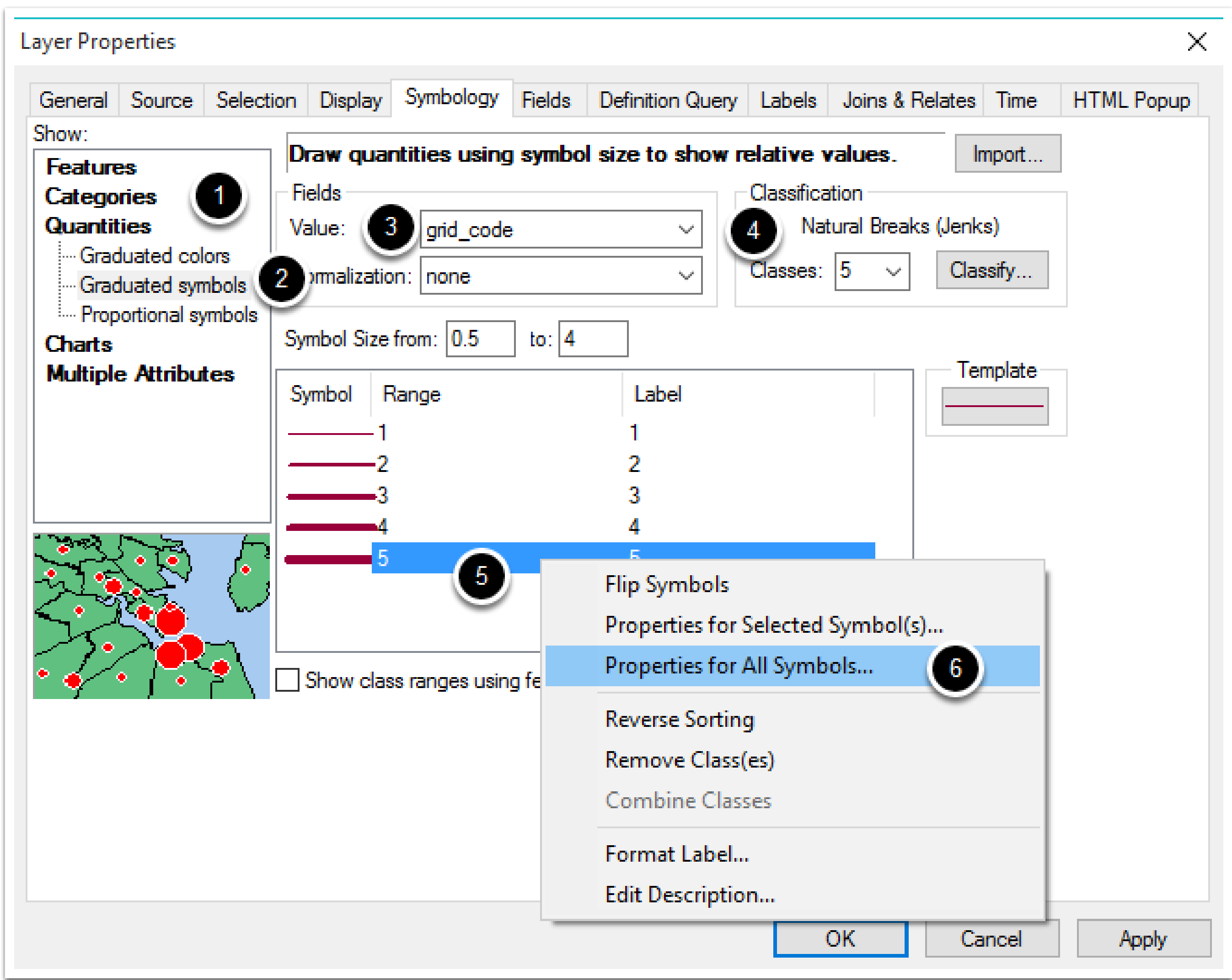
Take a look at the two stream layers you just generated, overlaid on your stream order raster. What is different about them? Any thought about what is causing them to be different (and related, why we provided the flow direction raster to Stream to Feature, but not to Raster to Polyline?)

8. Symbolizing our new streams

Open the Symbology properties for the stream layer generated from the Stream to Feature tool (*nav_streams_stream_to_feature).* Let's symbolize the streams by stream order in a way that reflects their size. To do so, we'll use the *Graduated symbols* symbology style, which increases the size of the symbol as the quantity increases, rather than changing the color ramp. By doing this, we'll show larger symbols for larger stream orders.

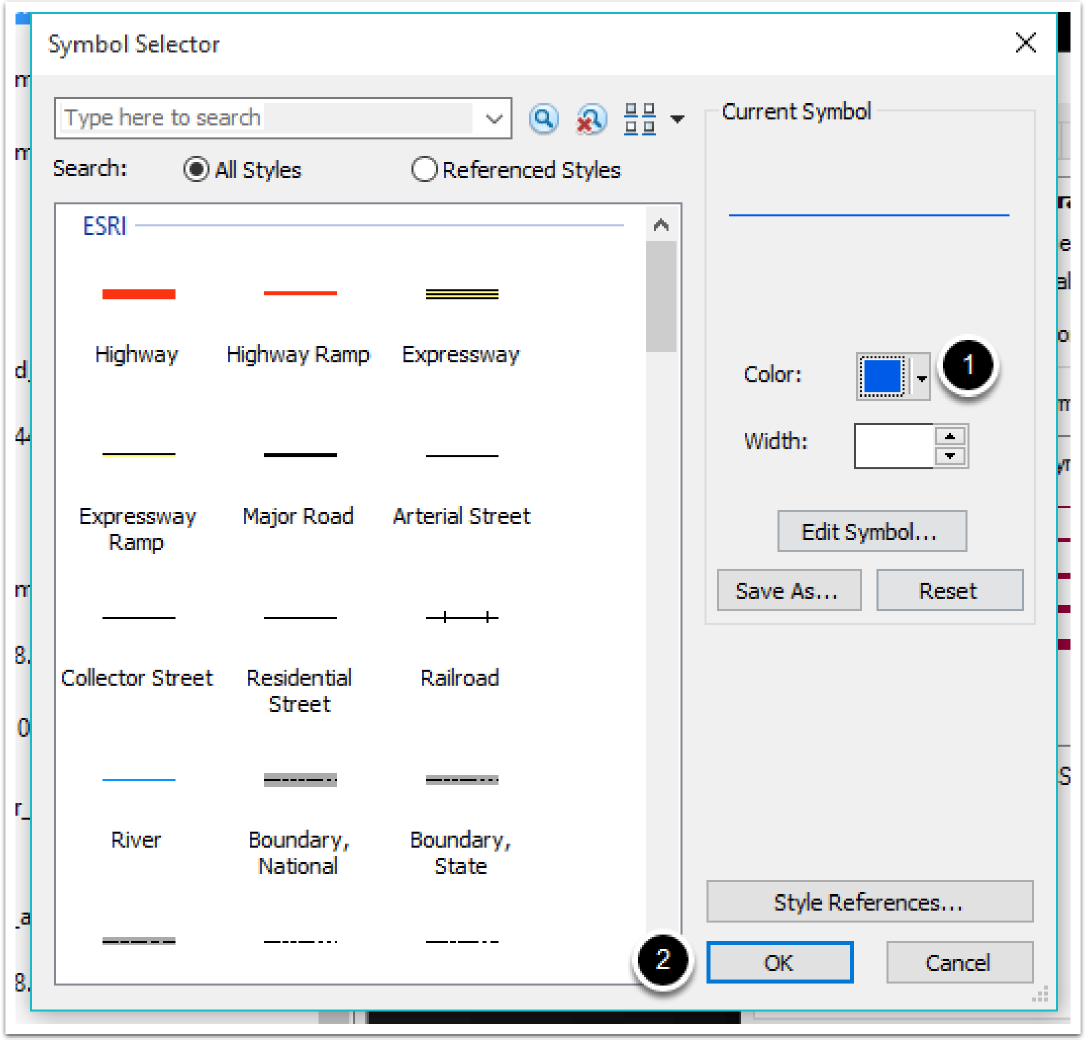
To do this, we'll do many small steps.

1. Switch to the *Quantities* symbology type.
2. Click *Graduated symbols*
3. Switch the field to symbolize on to *grid_code*. This is the value that the streams had in the raster, so it's the field that contains the stream order designation
4. Confirm that it's using 5 symbol classes. Note the increasing size of the symbols in the symbol box.
5. Right click on a symbol in the box, and select *Properties for All Symbols* (6) to bring up the dialog specifying what the symbols look like.



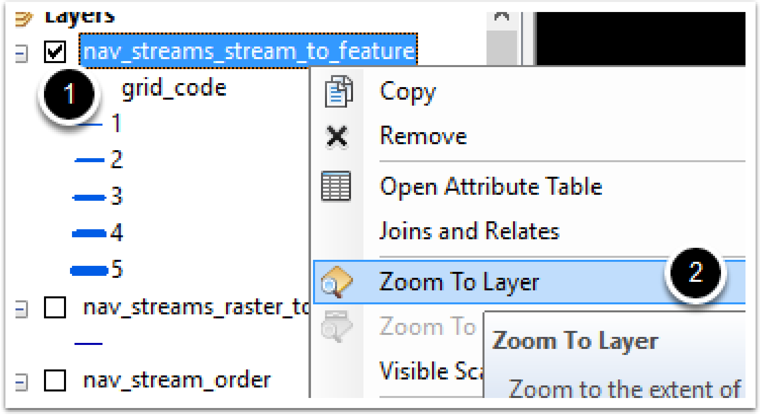
8.1 Make them look like rivers

Let's make these lines look more like rivers - change the color to a blue color (1). Then click OK (2) to return to the main symbology dialog. Then click OK again to close the main symbology dialog and save your settings.



9. Take a look at what you built

Let's zoom to the layer to take a look at it. Right click (1) on your new vector hydrography layer (*nav_streams_stream_to_feature)* and click *Zoom to Layer (2)*.



9.1 A complete stream network

Take a look at the streams you built. Do they look like you'd expect, in terms of which streams are larger and which ones are smaller. Do the lines travel in the places you would expect water to flow?

Congratulations on completing this exercise! Save your map document somewhere you can find it, as you'll use this data again in week 3!