Creating a DEM for the Gorongosa National Park, Mozambique from contours and spot heights

Introduction:

Interpolation is the mathematic process of extrapolating values from known values to the surrounding unsampled locations. Interpolation is based on the idea that points that are close to one another in space have more similar values than ones further away. There are two types of interpolation: deterministic and stochastic. Deterministic techniques are based on mathematical functions to calculate the surface. Stochastic techniques determine the statistical relationship between sampled points and use this information to predict parameter values for unmeasured points.

Three commonly used interpolation techniques are inverse distance weighting (IDW), spline and kriging. There are many other techniques; some considered superior over others.

Interpolation can be used to visualise surfaces of elevation, temperature, pressure, light; in fact anything which can be modelled using a continuous surface. But just how good are they, especially when comparing different techniques?

Scenario:

You wish to investigate patterns of soil erosion caused by recent forest clearance around the Gorongosa National Park in Mozambique. Because there are no direct measurements of soil erosion, you plan to use the Universal Soil Loss Equation for Southern Africa to estimate soil loss. This equation can be calculated within a GIS, but to use it, you need to have slope data – and to obtain slope data, you need a Digital Elevation Model (DEM).

In this exercise, we will create a DEM using one interpolation technique and then explore the results. The objective of the exercise is therefore to understand how DEMs can be created from contour and spot height data.

Data:

You have been supplied with the following four shape files:

- **spothts**: spot heights for the study area in metres above sea level. Note that the elevation value is in the **data_value** field.
- **Contours_moz:** contours for study area in metres above sea level. Note that the elevation value is in the **data_value** field.

- **Contours_moz2:** ancillary contours for study area in metres above sea level. Note that the elevation value is in the **data_value** field.
- **Drainage_moz:** surface drainage features (rivers and streams) for the study area.

All of these map layers are in the UTM Zone 36 (North) projection and make use of the WGS 1984 datum.

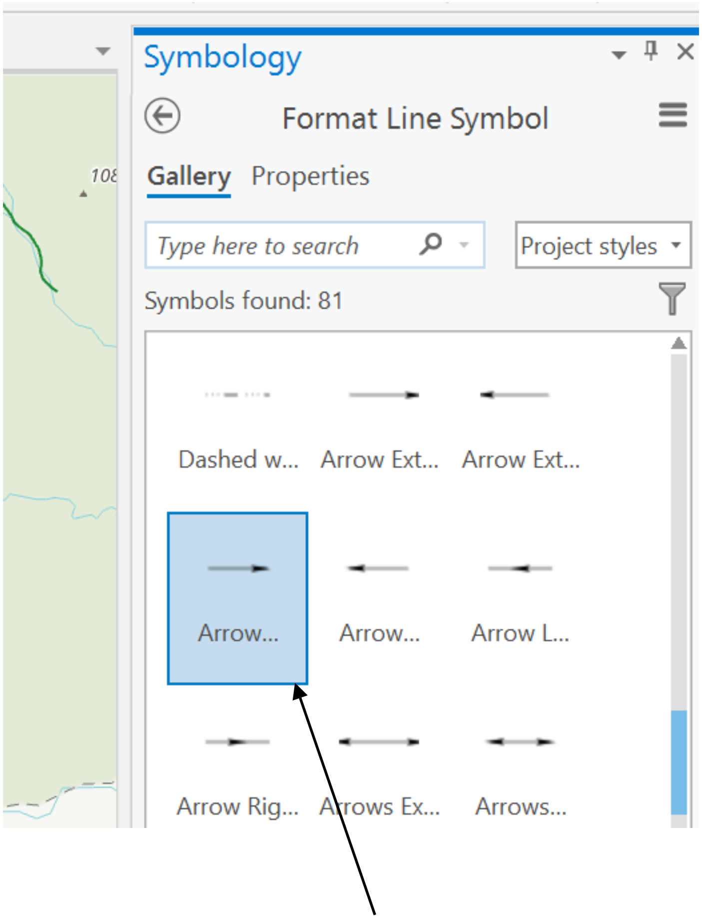
Pre-processing the data

The first technique that we will use is based on Hutchinson (1989)'s ANUDEM algorithm (an algorithm is an explicit step-by-step procedure for producing a solution to a given problem), implemented in ArcGIS Pro as the *topo to raster* tool. The key feature of this method of interpolating contours is that it also takes into account the location of surface drainage features. The method used to create the DEM ensures that rivers and streams always flow downhill.

For the algorithm to work, all the drainage lines need to have been digitised in a particular order, starting at the uphill end and finishing at the downstream end. We will start by checking that this is the case:

- open up all of the data in ArcMap and familiarise yourself with it;
- right-click on the **drainage_moz** shape file and choose *properties*, then click on the *symbology* tab.
- Click on the button next to *symbol* (see below) and then when the *symbol selector* window comes up, scroll down to the 'arrow at end' symbol and select it (see below).

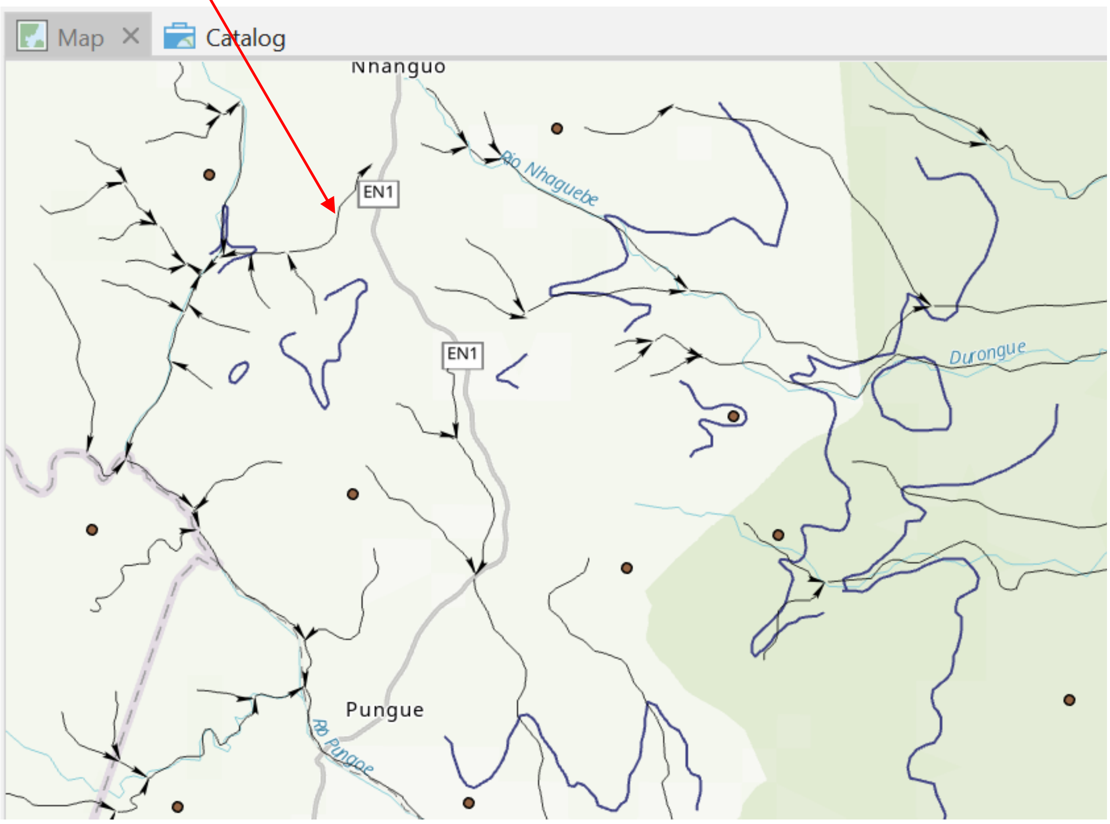
Click on the line symbol where it says 'symbol', below 'single symbol'. Scroll down through the available symbols if need be, until you find the arrow symbols (see below):



… choose this symbol

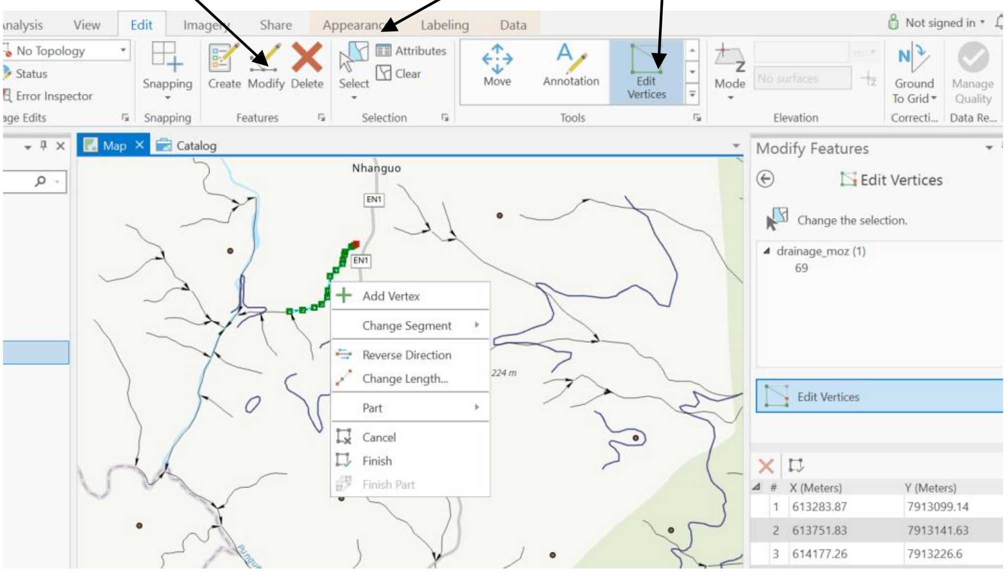
You should now be able to see the direction of flow of the various sections of stream and river. Most should be digitised starting at the uphill end and finishing at the downhill end – one, however, has not been. Before turning overleaf, can you identify which stream section has not been digitised in this way?

The stream section that has been digitised in the reverse direction (downhill to uphill) is this one.



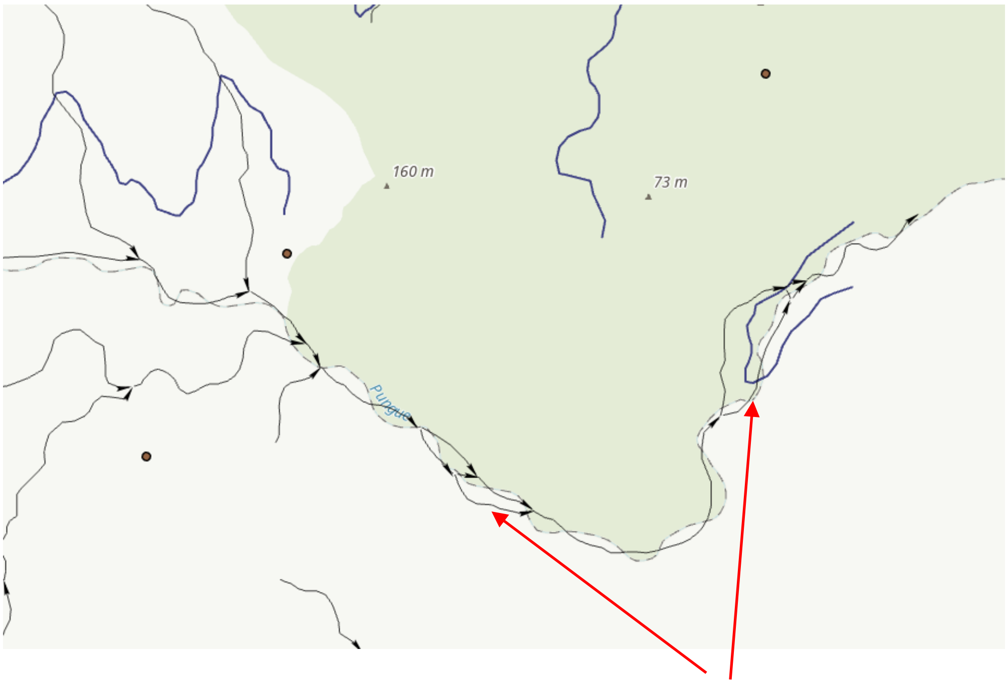
To fix this problem, we will need to reverse the direction of flow for this channel. To do this:

- Make sure you have the streams layer highlighted in the left-hand panel.
- Click on the *edit* menu then use the *Select* button to select the section of river channel with the incorrectly recorded direction of flow. Click the *modify* button on the ribbon. Click edit vertices.

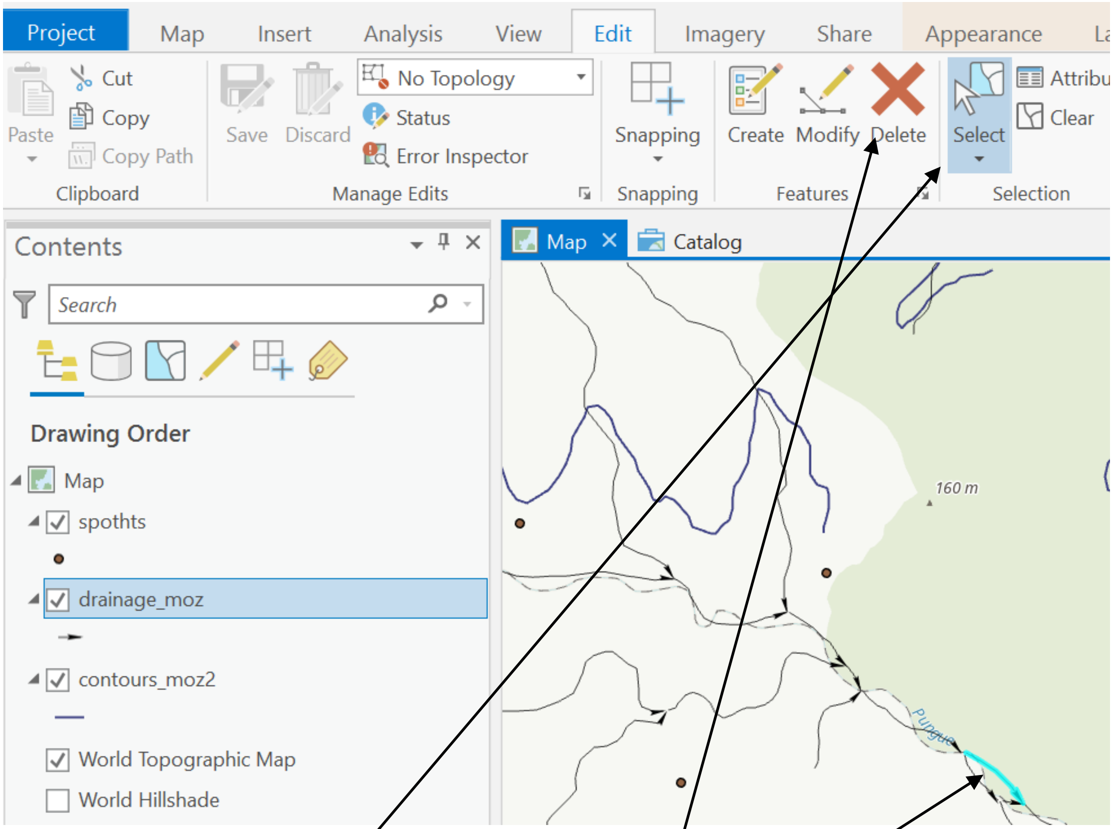


If you now right-click on your selected feature, you should be able to choose *reverse direction* from the pop-up menu to change the channel's direction of flow to match the rest of the network.

Note that when editing vertices, each vertex (i.e. x, y pair of coordinates defining the shape of a line) is shown in green, whilst the line's end point appears as a red dot. The red dot will change from one end to another as a result of you using this tool. Note also the panel on the right, which shows the coordinates for each vertex.

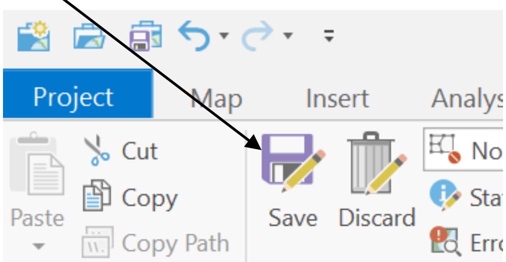


Note that in some places, there is also evidence of braiding in river channels. Braiding can also cause problems with the *topo to raster* algorithm, so we also need to delete these braided sections before going further (braiding means where a channel divides into two or more parts, which then rejoin).



To delete sections of braided river channel, first select one of the two braided channels with the select tool. Next, press delete. Repeat this until braided sections of river channel have been reduced to a single channel.

These edits to the river channel network should improve the quality of our interpolated raster elevation model. To save your edits, click on the *select* button on the ribbon again, click away from your feature, then click on the *save* button the ribbon:

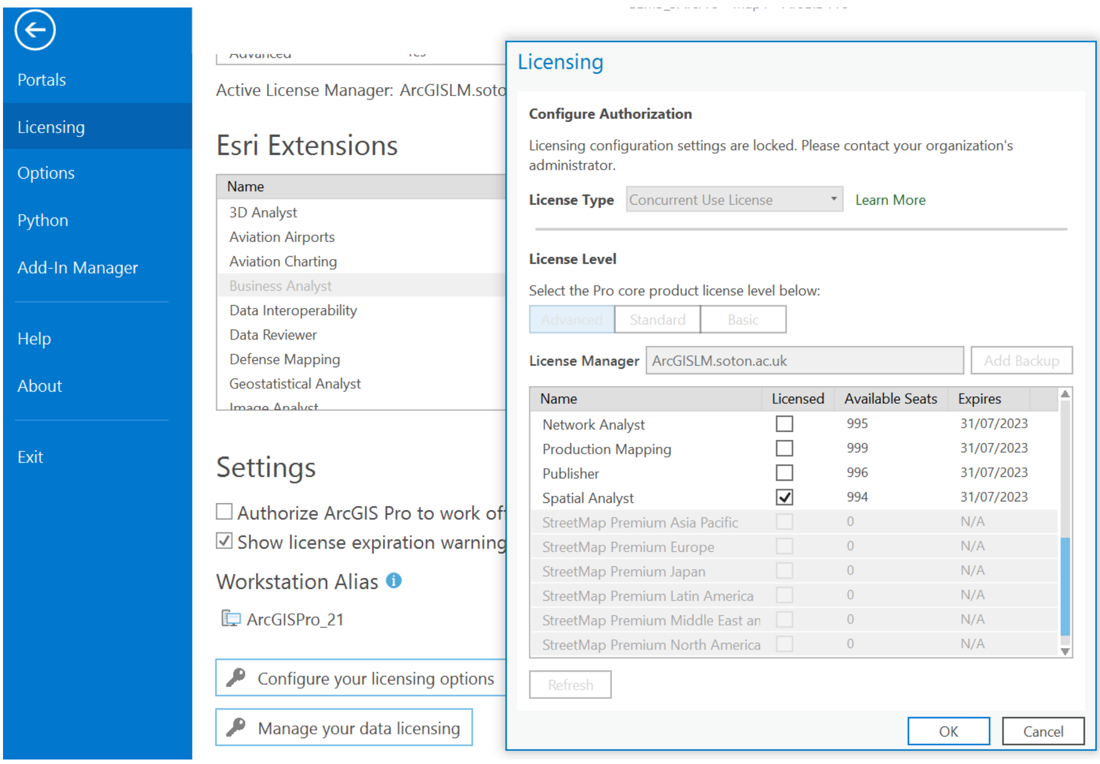


Save your edits when prompted in subsequent dialog boxes.

With these problems in our drainage network resolved, we are now in a position to interpolate a DEM using our contours, spot heights, and drainage lines.

Interpolating from contours, surface drainage lines and spot heights

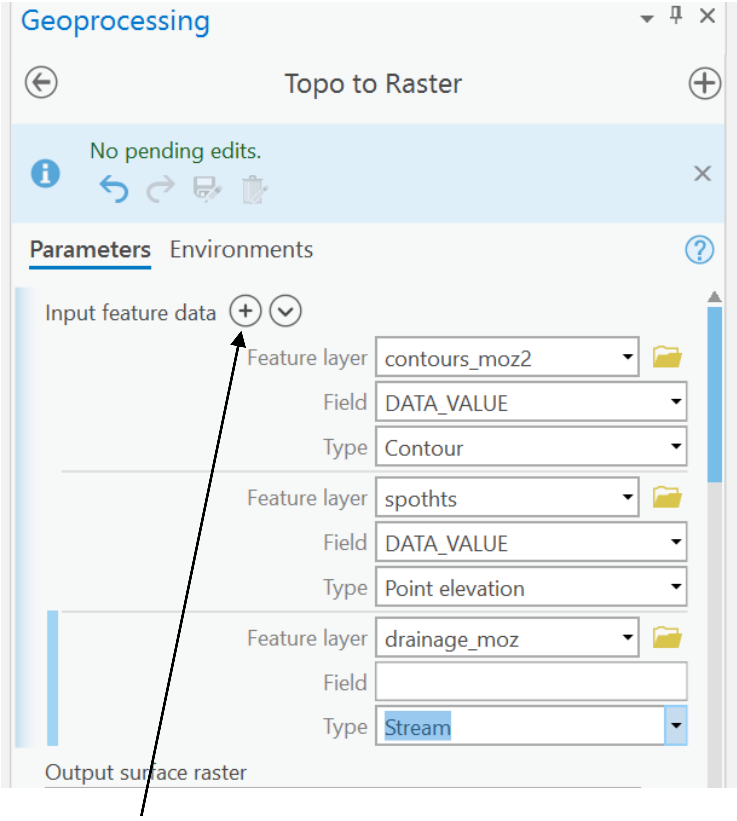
To enable the *topo to raster* tool, you will first need to activate the Spatial Analyst licence. To do this, head for the *project* menu and select *licencing.* Click on *configure your licencing options,* then make sure that the *spatial analyst* licence is checked to activate it:



Once you have done this, press the back button (arrow icon, top left) or press *[Esc]* and then head for the *Analysis* menu. Click on the *toolbox* icon in the ribbon below the menus to bring up the geoprocessing toolbox on the right. In the geoprocessing toolbox, search for 'topo' and then run *topo to raster* (Note: you may need to run the 'spatial analyst' rather than '3d analyst' version of the tool, if you only activated spatial analyst earlier under licencing).

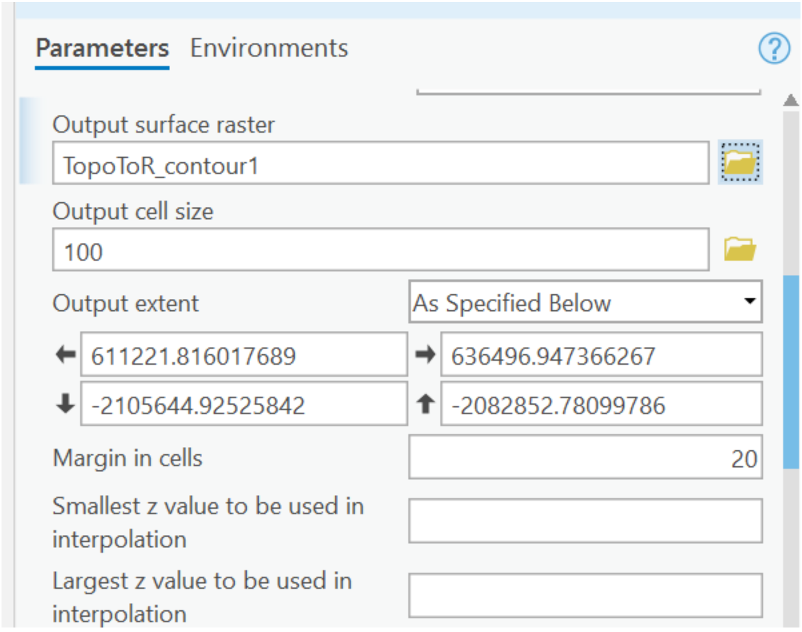
When running the tool, you can add in multiple input layers (see screenshot below):

- You can set **contours_moz** as a 'contours' input under 'type', being sure to set **data_value** (i.e. the field with the elevation values) as the *field*.
- You can set **contours_moz2** as a second input layer in the same way.
- You can add **spothts** as a *point elevation* layer, again being sure to set **data_value** as the *field.*
- Again under *input feature data*, select **drainage_moz**. Change the *type* here to *stream*. Because these are stream lines, there is no need to specify a field containing elevation values.

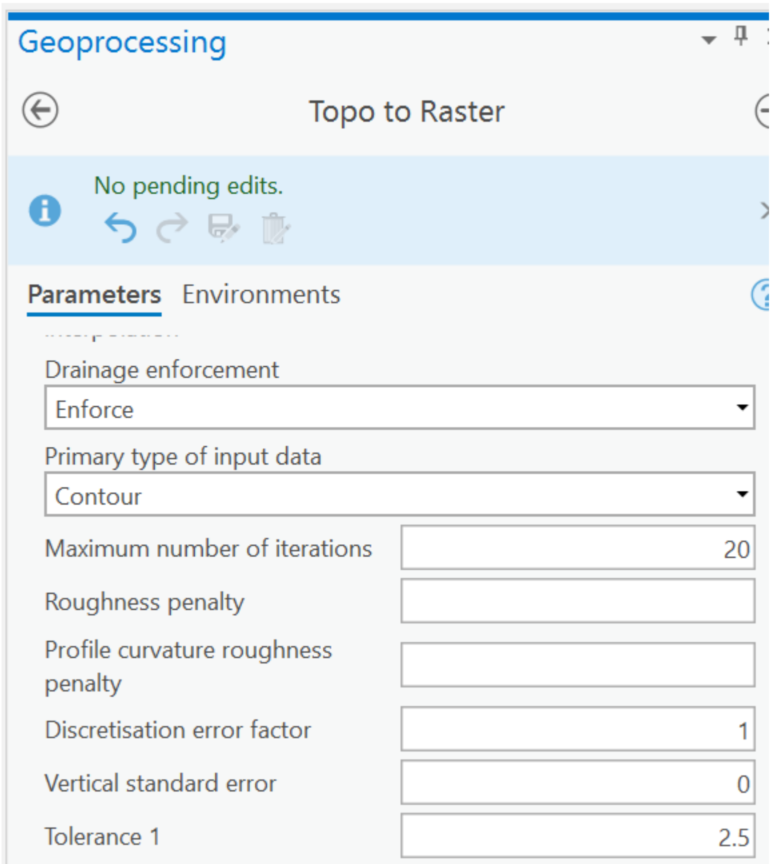


This button allows you to add multiple input layers. Note that although we will not use them here, we also have the option to upload a catchment boundary, the boundaries of lakes, and the locations of sinks. Sinks are depressions in the ground (i.e. low ground surrounded entirely by higher ground), which are usually rare in nature. They often represent problems in a DEM and can cause problems when carrying out hydrological processing, such as delineating streamlines or identifying catchment areas. Sinks are eliminated by the interpolation process, but under certain conditions (e.g. the presence of chalk or limestone sub-strata), sinks can occur naturally. Any sinks recorded in an input file here will not be removed during the interpolation (provided an appropriate option is specified).

You should also specify the name of an output raster file (tip: I often save raster files add a .tif to the file name, so that the raster is saved in geotiff format. ArcGIS Pro is less ‘fussy’ about issues such as spaces in file or folder names if you do this, but you do need to save such files in an ordinary folder, not in a geodatabase). You may also wish to change the *output cell size* to **100** metres for convenience:



You can leave the other settings at the default values.



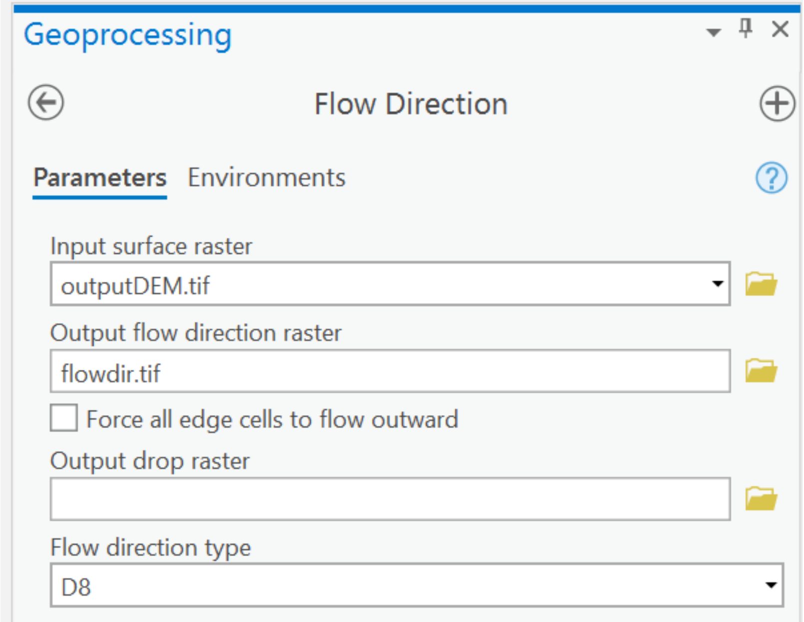
A few points to note here are as follows:

- The *drainage enforcement* option explains how sinks are treated. *Enforce* means sinks will be eliminated as far as is possible; *no_enforce* means sinks will be retained; and *enforce_with_sinks* means that only sinks not specified in an input file will be eliminated. Leave this set to *enforce*.

- Under *optional outputs*, you can ask ArcGIS Pro to store the locations of any sinks that it finds in a new map layer.
- ArcGIS Pro can also provide you with a detailed description of the algorithm's working (under *diagnostics*), and attempt to pick out surface drainage features from the resultant DEM automatically. The surface drainage lines can also optionally be stored in a new shape file.
- Click on *OK* to create your new DEM. It should look roughly something like this:

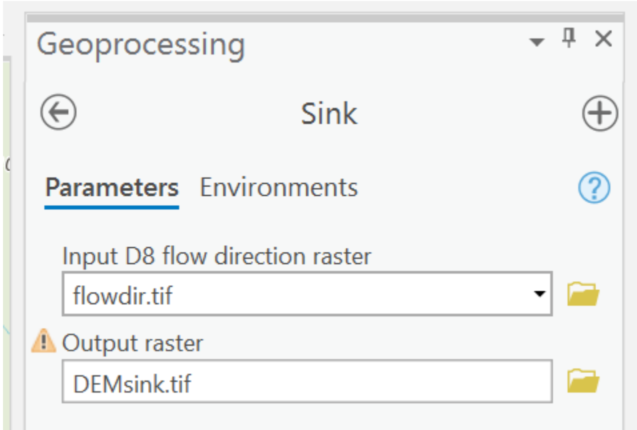
Optional extension activity

You can check for sinks in your DEM yourself using some of the tools in the geoprocessing toolbox. To do this, first head for the geoprocessing toolbox and type in 'flow' into the search box to find the *flow direction* tool. This tool will use direction of slope to work out how water flows between pixels in your DEM.



You need to specify the DEM you just created as your input, and then add a name for an *output flow direction raster* – then you can run the tool. Note that the **D8** algorithm is a simple type of flow direction, which works out the main direction of flow from each cell to one of its eight neighbours. Starting from the easternmost neighbouring cell and moving clockwise, the cells are coded 1, 2, 4, 8, 16,…up to 128 as explained here (https://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/flow-direction.htm).

Having worked out the direction of flow from each pixel in your DEM to each of its 8 neighbouring pixels via *flow direction*, you can now use the *sink* tool to identify any 'sinks'. Search for 'sink' in the geoprocessing toolbox, then run this tool, specifying your flow direction raster as the *input D8 flow direction raster* and choosing a suitable name for a raster output layer. The raster output layer will contain non-null codes for any pixels identified as sinks:



This should give you some indication as to how well your interpolation has worked – the fewer sinks, the better!

Task: How many other methods can you think of for assessing the quality of your new DEM?

[Some suggestions are given overleaf, but you should try and note down a few ideas here first before turning the page.]

Answers: Numerous methods are possible. Some of the more commonly used methods are:

- producing contours at twice the resolution of the input contour data set. To do this, find the *contour* within the *geoprocessing toolbox*. As our input data have a contouring interval of 20 metres (40 metres in some locations), choose a contouring interval of 10 metres. Specify your new **moz_dem** as the input and an appropriate name for the output (e.g. **dem_contours**). You can then see visually whether the contours in between the input contours look sensible.
- Optionally, we could set aside some of the input data (e.g. half of the spot heights) and not use them in the interpolation. The elevation values for these spot heights could then be compared to the interpolated DEM elevation values and a Root Mean Square error (RMSE) calculated for the DEM.
- Producing raster grids depicting slope and aspect (via the tools *slope / aspect* in the *geoprocessing toolbox*) can also help reveal problem areas in the DEM.
- Other methods are to look at the surface drainage lines that are generated for the DEM and see how sensible these seem, and to examine the output from the *topo to raster* algorithm in the *diagnostics* file in more detail.

Reference:

Note that you are not required to read this reference – it is provided here as the source of the technique used by ArcGIS Pro:

Hutchinson, M.F. (1989): ‘A new procedure for gridding elevation and stream line data with automatic removal of spurious pits’. *Journal of Hydrology* **106**: 211-232.