Post-fire hillslope and watershed stabilization is typically tasked to Burned Area Emergency Response (BEAR) teams dispatched to active or recently contained wildfires. The objective of the response team is to prioritize emergency stabilization to prevent further damage to life, property, or natural resources on or adjacent to Forest Service lands. Most BAER teams include multiple resource specialists including hydrologists, soil scientists, engineers, biologists, vegetation specialists, and archeologists. However, not all specialists are present on all BAER teams. Historically BAER efforts have focused on hillslope stabilization to prevent erosion or hillslope failure upstream or upslope of critical resource areas such as T&E species habitat, reservoirs, housing developments, or other infrastructure. BAER's current "**go to"** tool for analyzing hillslope erosion is FS WEPP. FS WEPP was developed and is maintained by the Rocky Mountain Research Station and is largely based on decades of work conducted by Pete Robichaud. Although BAER assessments might include road infrastructure, much less emphasis has been placed on stabilizing or maintaining road infrastructure in burned areas to prevent erosion, sedimentation, and infrastructure failure. Failed infrastructure can create large and chronic sediment sources and become incredibly expensive to repair or replace. We know that most of the sediment delivered to waterbodies on NFS lands comes from our system and non-system roads. For that reason, road length density (miles of road / square mile of watershed) is one of the main indicators used to assess watershed conditions under the USFS Watershed Condition Framework. There are more than 380,000 miles of inventoried "system roads" within the NFS and an unknown number of non-system roads which are a legacy of days gone by. By and large the USFS maintains only a small fraction of system roads. The rest are in various stages of disrepair with plugged and undersized drainage structures

When drainage structures plug with woody debris, leaves, or sediment it is possible for high flows to overtop roadways or for roadways to become conduits for flow. Either scenario can result in large scale erosion, infrastructure failure, sedimentation, and cost (Figure 1). For this reason, it is important to know where system and non-system road infrastructure is located, and where critical infrastructure and problem points may occur. Many National Forests have partial inventories of road and drainage structures (culverts), but these inventories are often not complete. Recently the USGS released a data product of all potential road stream intersections in the US based on the NHD and Tiger Road products, however, this does not cover all USFS system roads nor non-system roads.

Figure 1. Left: Upstream end of a culvert plugged with woody debris and sediment following fire. Right: culvert plugging and failure results in overtopping of the road prism, flow capture on the road surface, and large-scale erosion.

An alternative approach to assess the potential for road interception of hillslope drainage is to conduct a flow accumulation analysis using a high-resolution DEM. Flow accumulation analysis utilizes a DEM to first develop a flow direction raster. This flow direction raster is then used to determine the contributing area above each grid cell in the DEM. This analysis provides an estimation of overland flow paths and their total contributing area. When overlaid on a high-resolution hill shade product, it is possible to determine where flow lines intersect system and non-system roads, and where flow is diverted or captured by this infrastructure. For this analysis scale matters. The current national scale 10m and 3m NED products are likely not of sufficient resolution to conduct this analysis as illustrated in the following figures.

Figure 2. Both hill shade products below were generated from a 3m DEM centered on the Fernow Experimental Forest in Parsons, WV. The figure on the left also depicts the National Forest System Roads available for download from the FSGeodata Clearinghouse. The figure on the right uses green arrows to depict where the 3m DEM accurately defines the road prism, and the red arrows depict where the 3m DEM fails to accurately define the road prism.

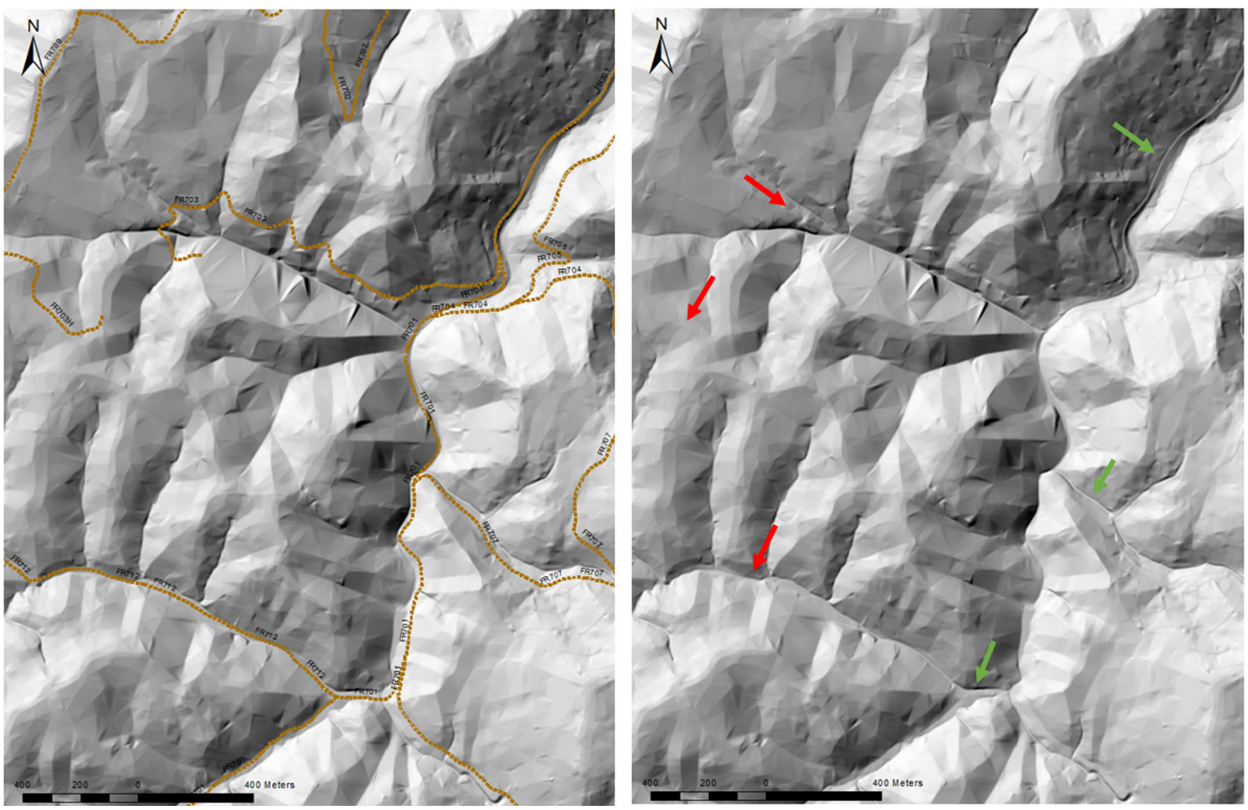


Figure 3. This figure is a close-up of the Northwest quadrat of Figure 2. The figure on the left is the 3m hill shade with the NFS roads overlay. The figure on the right is the same location, but the hill shade is derived from 1m LiDAR data. Note the additional non-system road prisms visible using the 1m resolution LiDAR.

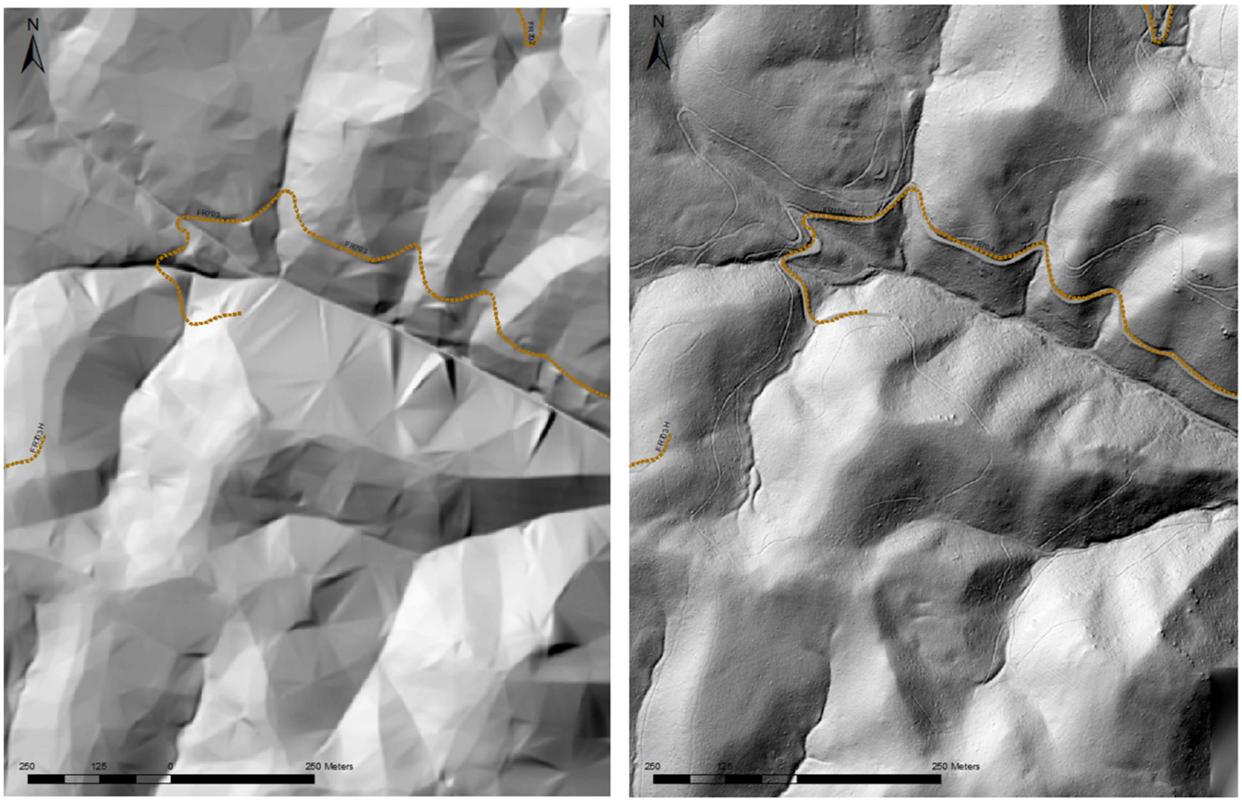
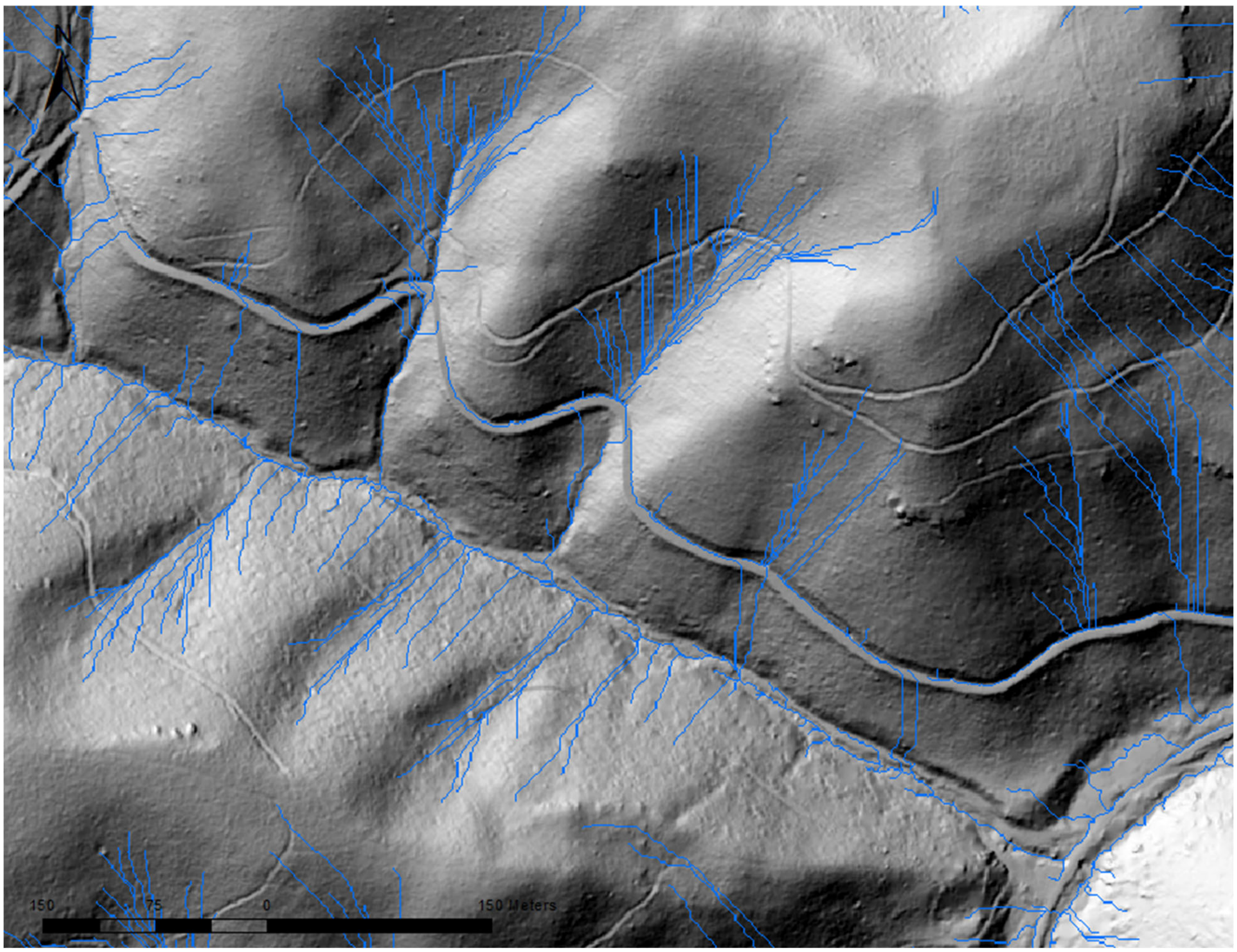


Figure 4. In this figure the 1m hill shade product is overlain with the output from a Flow Accumulation model derived from the same 1m LiDAR. The non-system roads are clear and it is possible to visualize where hillslope runoff is potentially intercepted and diverted by system and non-system roads. What is not shown in this figure is other infrastructure such as culverts. It is likely that culverts exist in most major drainages that intersect system roads. It is also possible that culverts exist on non-system roads, but it is more likely that these culverts are undersized and a high risk of plugging and failure. In both cases an analysis like this would be useful in alerting hydrologists and engineers that the failure of specific infrastructure could lead to flow diversion onto road prisms. Subsequent erosion or failure of these roads could lead to large increases in sediment production and increased cost for repairing infrastructure.



Developing the Flow Accumulation model is relatively straight forward using existing tools in ArcGIS. Best results are obtained when working at the watershed or catchments scale. The finest resolution watershed delineation for the conterminous US is the Hydrologic Unit Code 12 (HUC12). Each HUC12 watershed tends to be between 15,000 – 30,000 acres. Larger watersheds (HUC10) tend to be 90,000 - > 150,000 acres. Smaller sub-watershed can be delineated using standard analysis tools in ArcGIS.

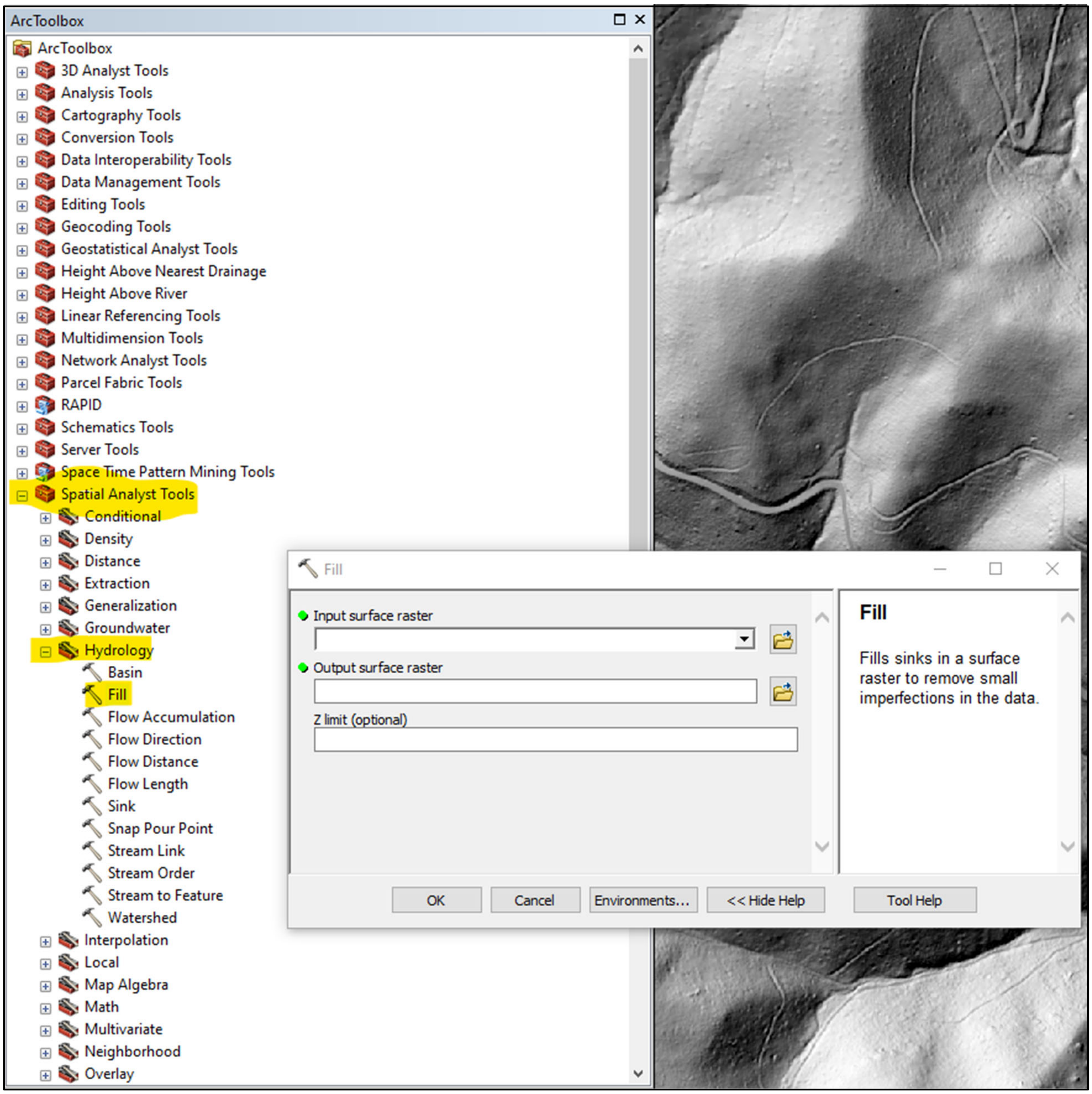
Once the area of interest has been identified, obtain the highest resolution DEMs possible (1m preferred).

Define the Environment Settings in ArcToolbox so that you are saving output to a desired workspace, the output coordinates are consistent, the processing extent matches the area of interest, and that raster cell size matches the input raster.

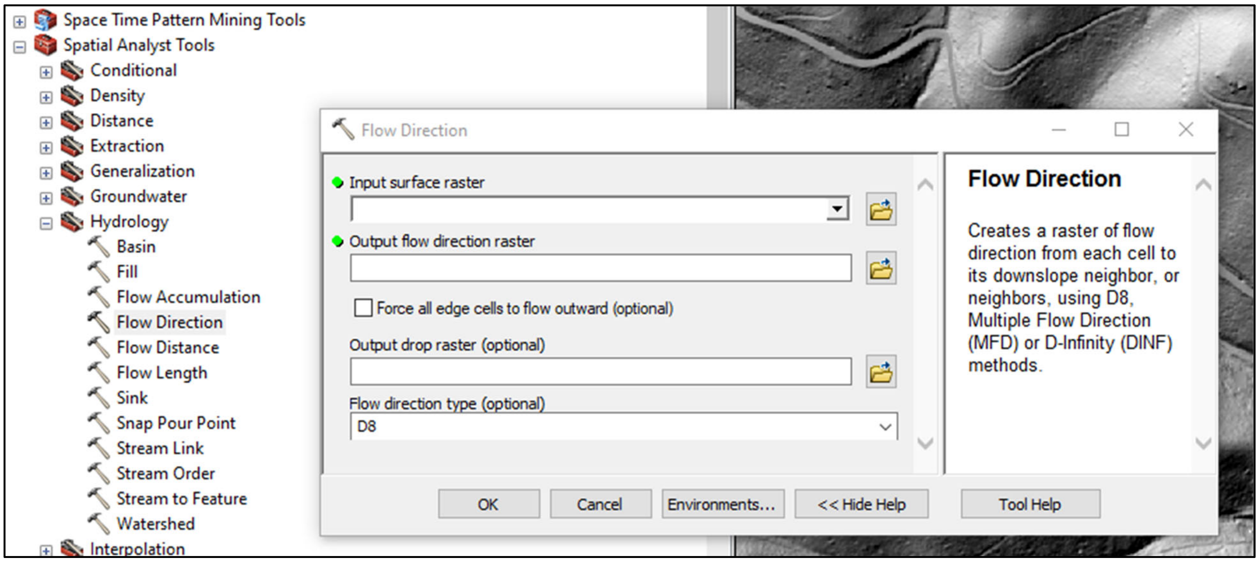
Mosaic the DEM tiles to create a seamless DEM that extends beyond the watershed boundary.

Open the Spatial Analyst Tools and find the Hydrology tool set.

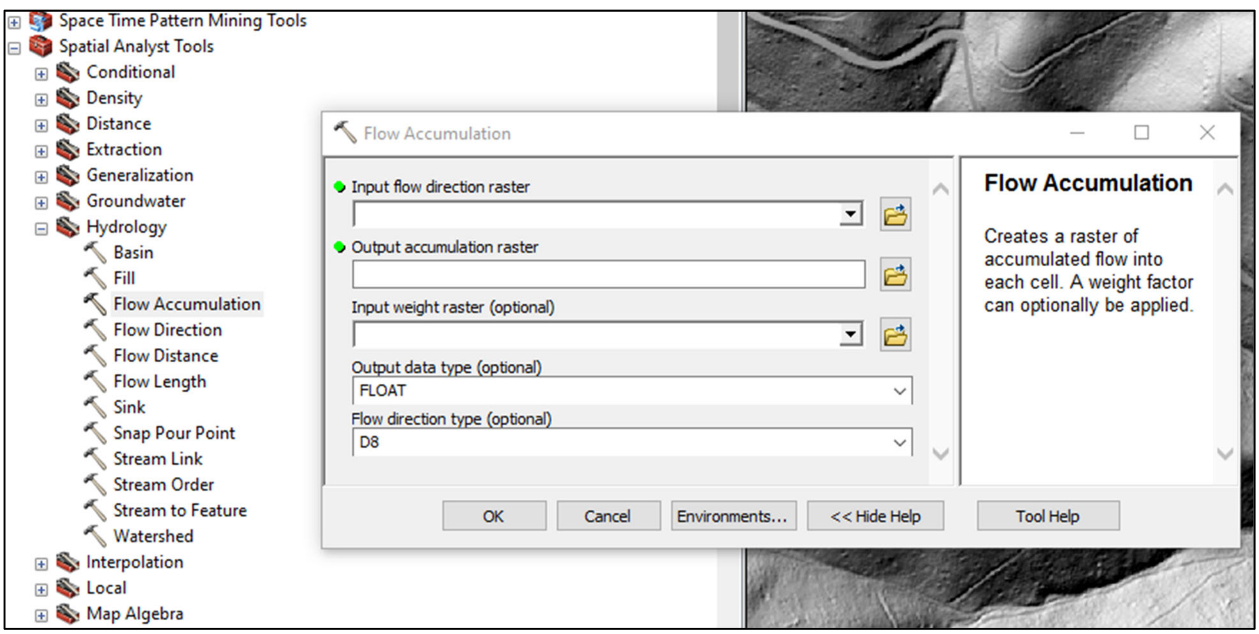
There is some debate about whether sinks in the DEM should be filled. In my humble opinion, a sink eventually fills, and water flows out. So I would fill the sinks in the DEM first. However, sinks in the DEM may identify culvert inlets.



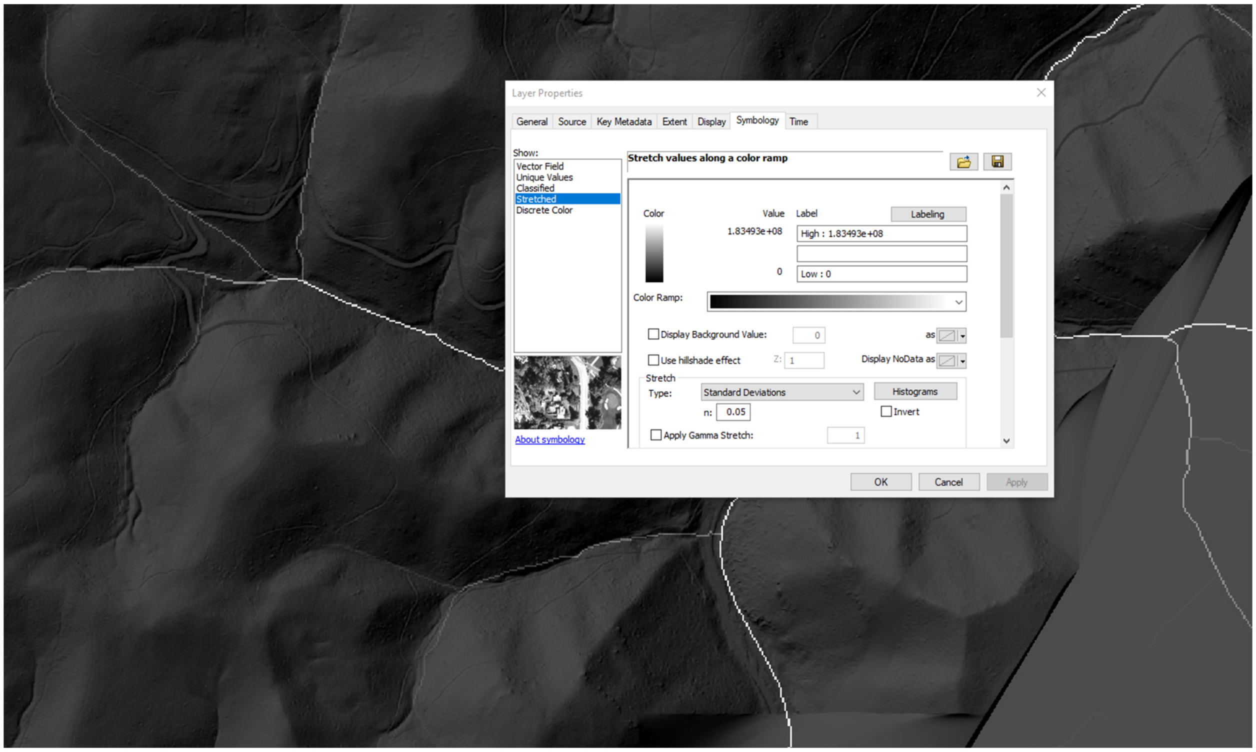
Once the sinks in the DEM have been filled. Open the Flow Direction Tool. The DEM with the filled sinks is the Input Surface Raster. The Flow Direction tool will assign the direction of downslope runoff based on 3 optional algorithms (See Flow direction type).

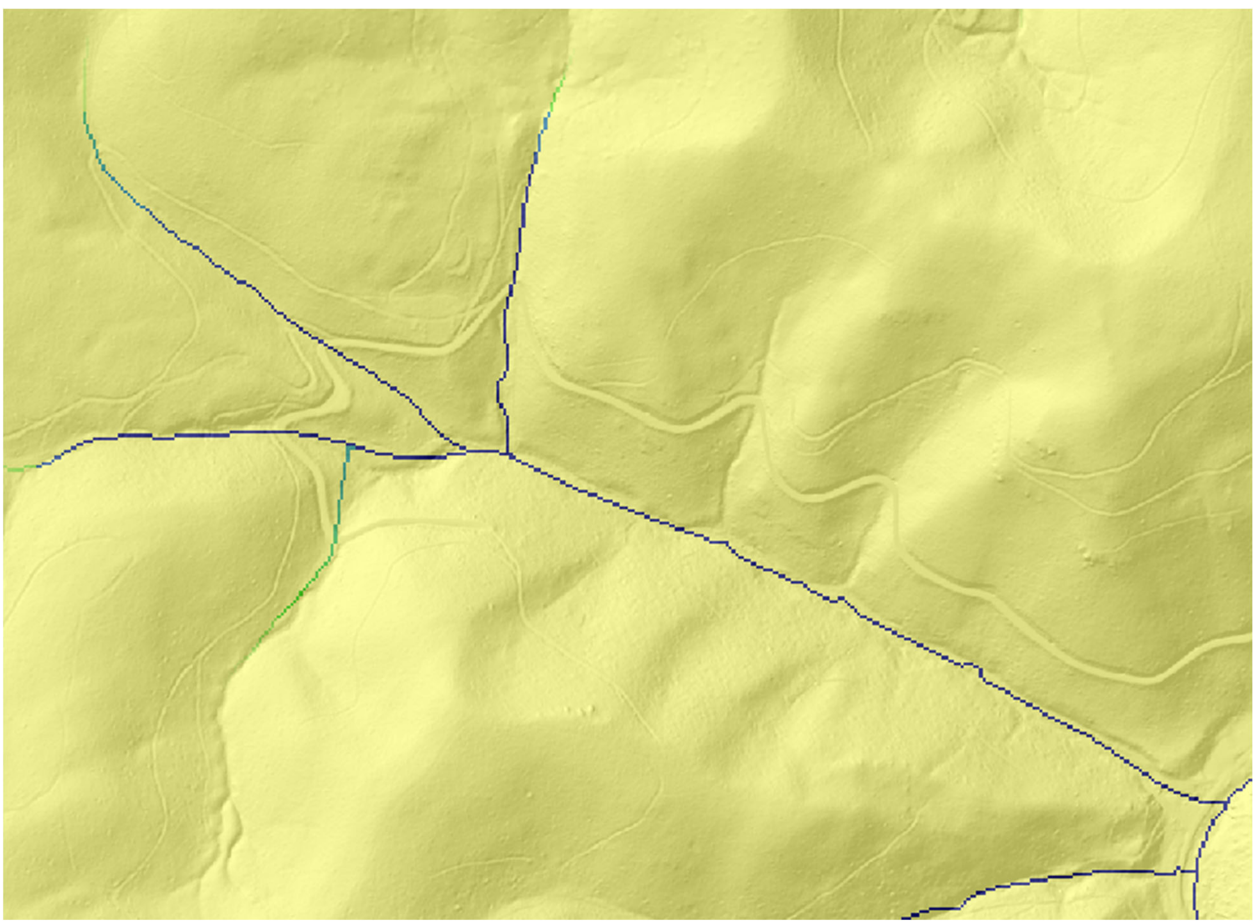


Once the Flow Direction raster has been created, use the Flow Direction Raster as Input for the Flow Accumulation Tool. The Flow Accumulation tool uses the Flow Direction Raster to count the number of upslope grid cells contributing runoff to each grid cell in the raster dataset. The units on the Flow Accumulation raster are number of gridcells. If the input resolution of the raster grid is 1m^2 than no Input weight is needed. If the input resolution on the raster grid is >1m than a conversion must be applied to convert to square meters.

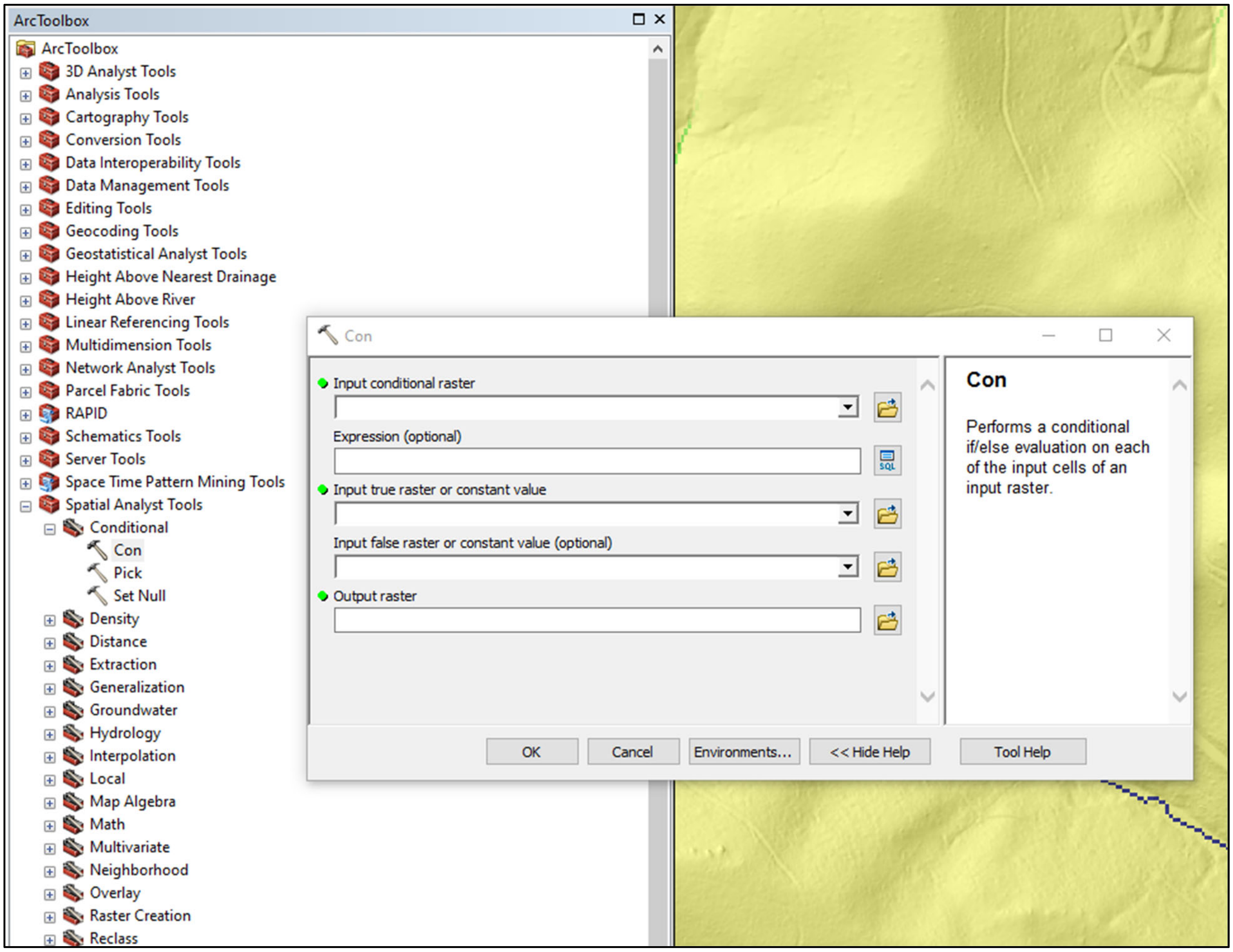


The output from the Flow Accumulation Raster will have many grid cells with low values. This will cause only the largest drainages to appear without modifying the symbology.


Layer Properties
General
Source
Key Metadata
Extent
Display
Symbology
Time
Show:
Vector Field
Unique Values
Classified
Stretched
Discrete Color
About symbology
Stretch values along a color ramp
Color
Value
Label
Labeling
1.83493e+08
High : 1.83493e+08
0
Low : 0
Color Ramp:
Display Background Value:
as
Use hillshade effect
Z:
Display NoData as
Stretch
Type:
Standard Deviations
Histograms
n:
0.05
Invert
Apply Gamma Stretch:
OK
Cancel
Apply

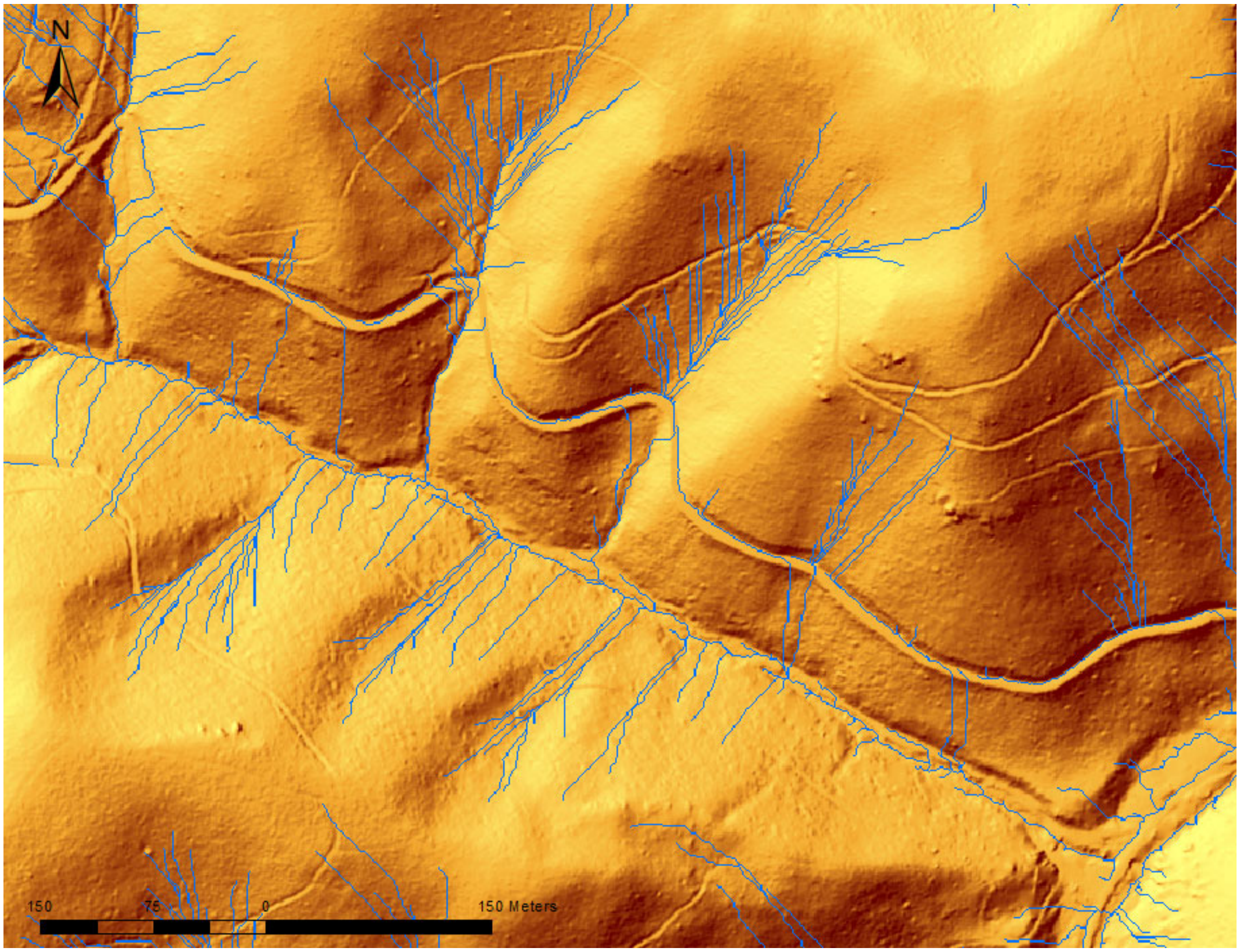


To better visualize the flow paths it may be necessary to utilize the Con tool within Spatial Analyst. The Con tool allows the user to define the threshold for cells displayed in a raster. The Flow Accumulation raster is the Input conditional raster. The expression can be used to define the threshold for classifying grid cells as true or false. For instance VALUE > 500 would select all cells with Flow Accumulation > 500 and classify them as true. The Input true raster can be either the Flow Accumulation raster or a constant value (1 or 500 for example). The input False raster can be assigned can be assigned a constant value (O or null).



The output Raster will contain only values determined to be True and be assigned a constant value or the Flow Accumulation Value depending on the option chosen.

Below, the output Con raster with a threshold of 500 square meter of contributing area is displayed over the 1m hill shade with an alternative color ramp. This view provides a decent visualization of how disruptive roads can be to hillslope hydrology.



The visualization may provide an indicator of locations where additional analysis or resources could be applied. Dense drainage networks with high flow accumulation above a road prism could be indicators that a culvert is at risk of plugging and failure. Flow lines running along road prisms for extended lengths are also indicators that if culverts fail or are lacking than serious erosion due to gully development or road prism failure are possible. These indicators could be used by BAER teams or Forest Engineers to prioritize areas for further reconnaissance, maintenance, hillslope stabilization, or infrastructure upgrades.

Some work has been done to develop a model for these purposes, but the current Geomorphic Road Analysis and Inventory Package (GRAIP) requires intensive, site-specific measurements. There is generalized version of the model available for preliminary analysis called GRAIP Lite that relies solely on geospatial datasets, but the output is produced at the HUC-6 scale, and it is not clear that individual road segments and crossing can be evaluated. It may be worthwhile to reach out to GRAIP Lite developers Tom Black and Charlie Luce for more information.