Exercise 5. Height above Nearest Drainage Flood Inundation Analysis

GIS in Water Resources, Fall 2017

Prepared by David G Tarboton

Purpose

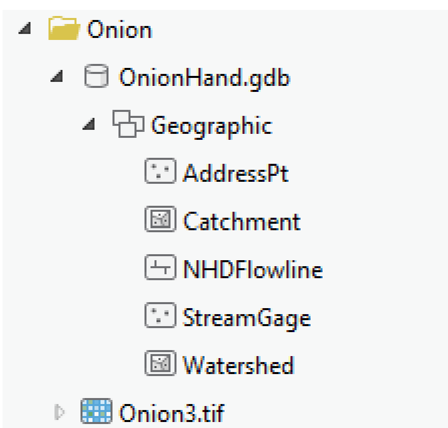
The purpose of this exercise is to illustrate the use of TauDEM for calculation of the height above the nearest drainage (HAND) from a digital elevation model, to use this HAND raster to derive stream reach hydraulic properties, flood inundation depth and a flood inundation map.

Computer and Data Requirements

To carry out this exercise, you need to have a computer which runs ArcGIS Pro. You will use the CyberGIS TauDEM App online from HydroShare to run TauDEM. This eliminates the need for you to install TauDEM.

The following data is provided in Ex5.zip (http://hydrology.usu.edu/dtarb/giswr/2017/Ex5.zip)

- OnionHand.gdb. A geodatabase containing NHDPlus flowlines and catchments for Onion Creek. This also contains address points that will be used in assessing addresses vulnerable to flooding.
- Onion3.tif. A 1/3 arc second digital elevation model from the National Elevation dataset. This DEM has already had a flow direction conditioning procedure applied to it to remove barriers along high resolution NHD flowlines.

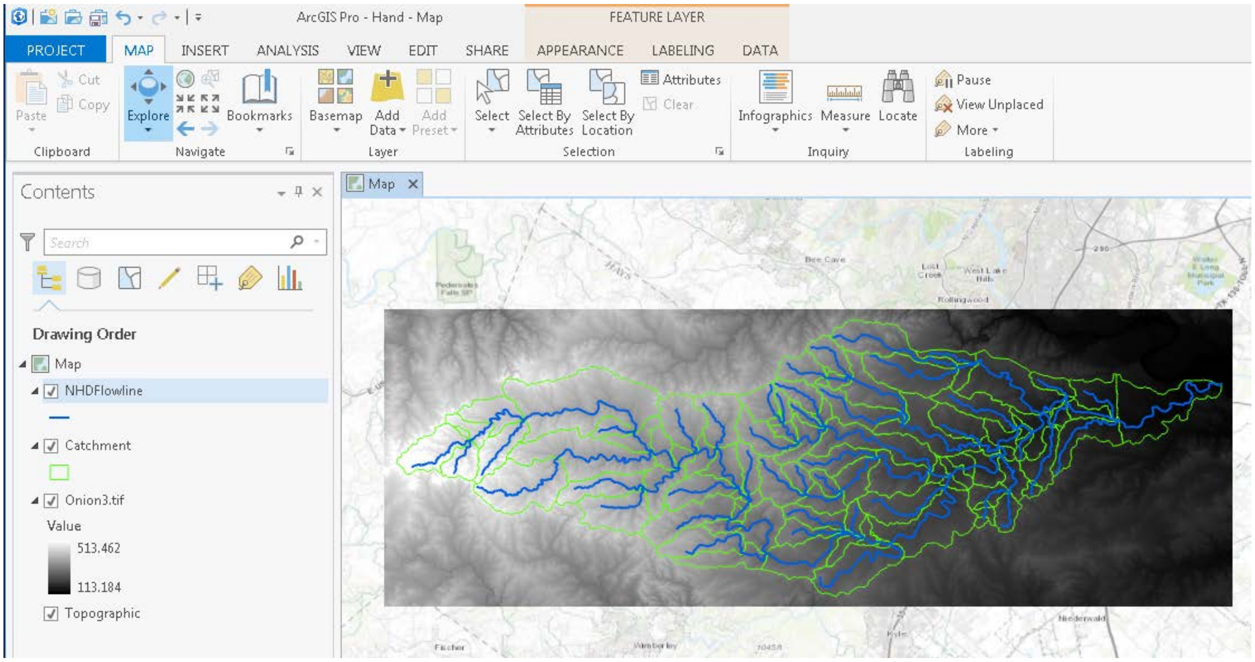


There is also a file Ex5Intermediate.zip (http://hydrology.usu.edu/dtarb/giswr/2017/Ex5Intermediate.zip) provided that includes intermediate results that you can use if you have trouble with CyberGIS or some of the other steps involved.

Computation of Height above the Nearest Drainage Raster

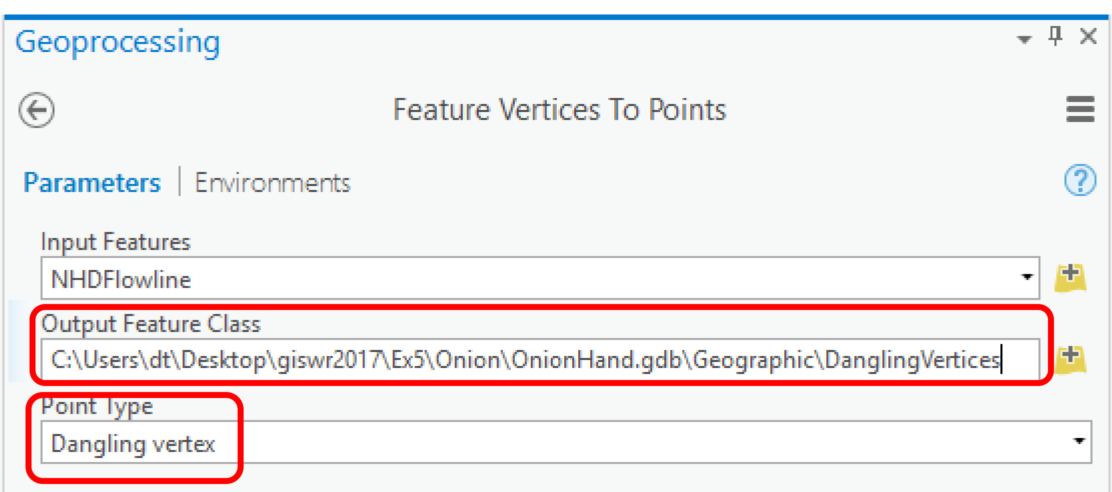
1. Preparing the inputs

Unzip the zip file and add the DEM and NHDFlowlines and Catchments to a Map in ArcGIS Pro.



To evaluate the height above the nearest neighbor raster we need a raster of stream grid cells consistent with NHDplus. While it is possible to directly convert the NHDFlowline dataset to a raster, it is preferable to have a stream raster consistent with DEM flow directions. We therefore use a procedure to identify dangling vertices of the NHD flowlines and use these as seed points to delineate a stream raster. Dangling vertices are points at the extreme "dangling" ends of a feature class.

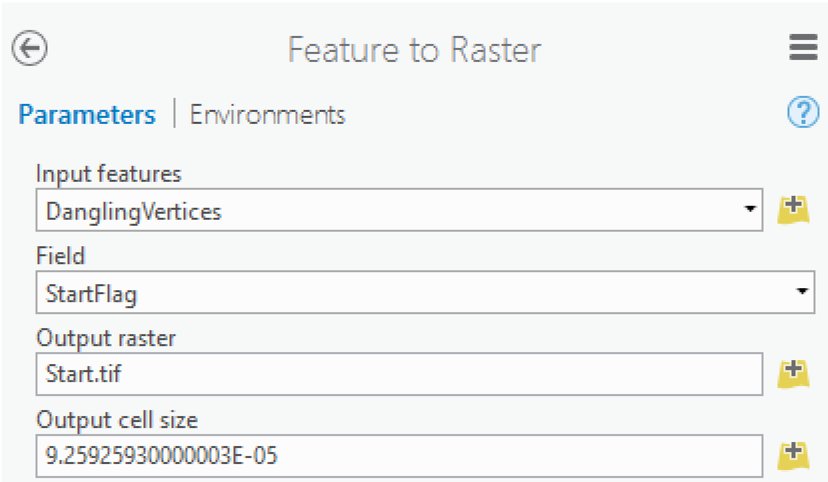
Open the geoprocessing panel and search for "dangle", then select the **Feature Vertices to Points** tool. Set the parameters as follows.



Add the output Feature Class DanglingVertices in the OnionHand.gdb Geographic feature class and run the tool.

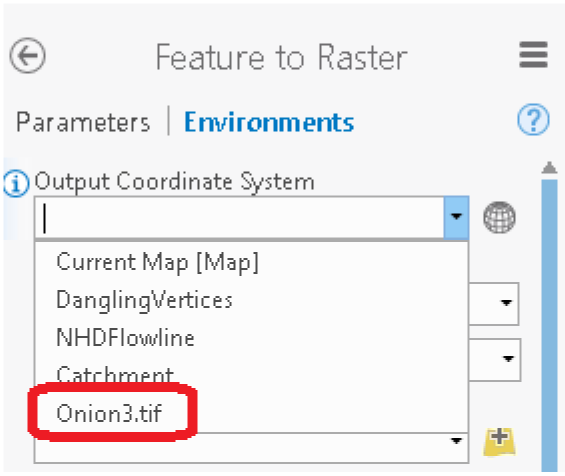
You should see a map with points at the end of each stream.

Next we need to convert these points to a raster to use in seeding the TauDEM stream network delineation. Locate the **Feature to Raster** Geoprocessing tool and set the following inputs.

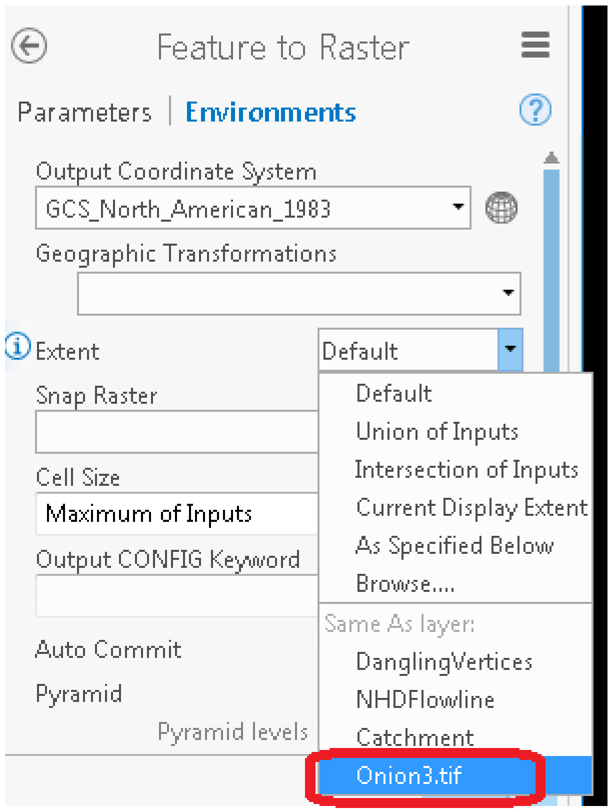


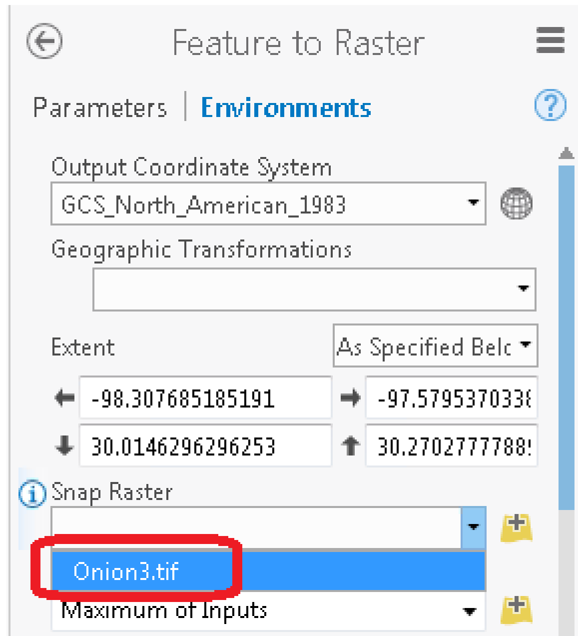
Set the field to StartFlag. This is a convenient field in the attribute table that has the value of 1. Save the output raster "Start.tif" in the same location as the DEM. I used a folder named "Onion" from the initial unzipping.

Do not press Run just yet. Click on **Environments**. Then for Output Coordinate System click on Onion3.tif.



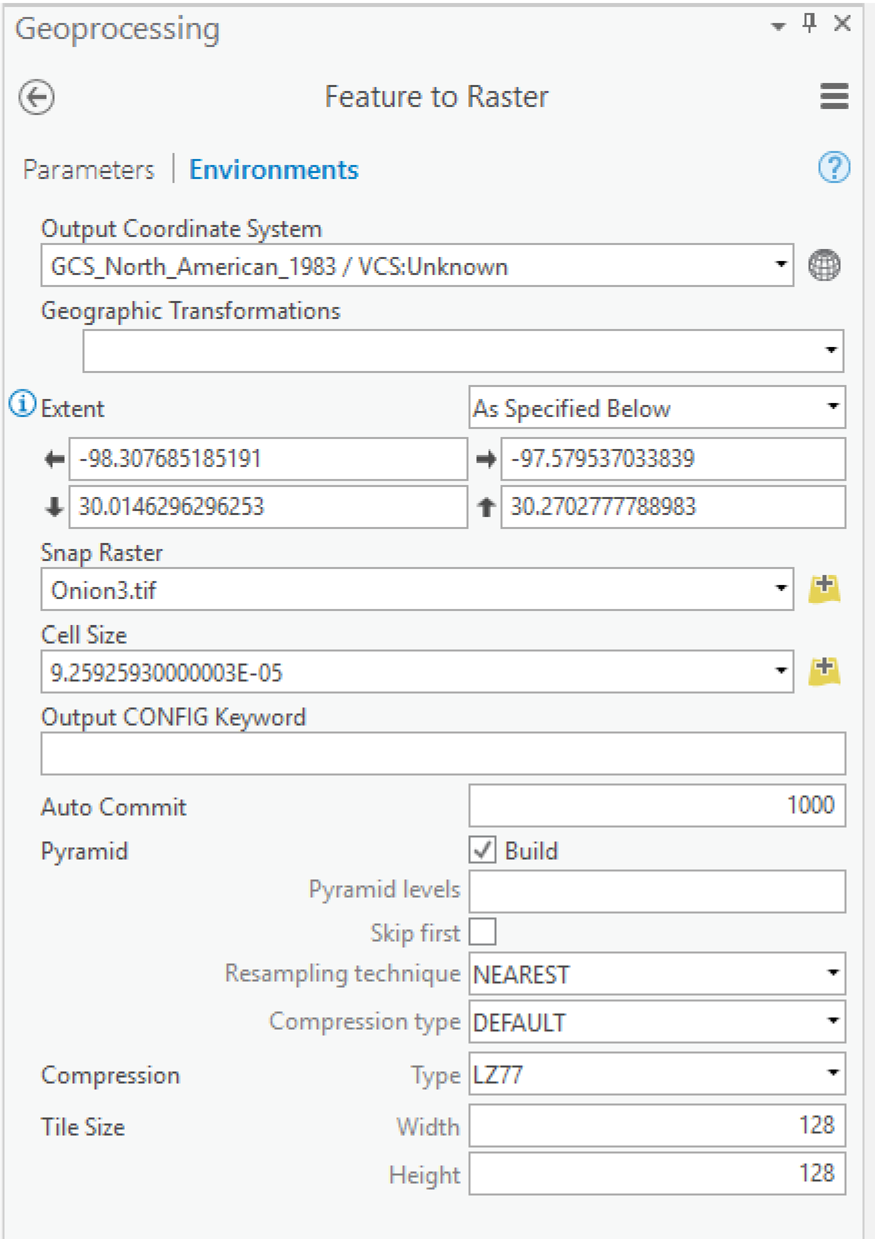
The display will switch to GCS_North_American_1983 / VCS:Unknown indicating that this coordinate system from the Onion3.tif file will be used. (Note that the Vertical coordinate system is not set for this data, hence the Unknown. Do not worry about this). This is important to get the resulting raster the same dimensions as the DEM. Next click on **Extent** and **Snap Raster** and in both cases pick Onion3.tif.



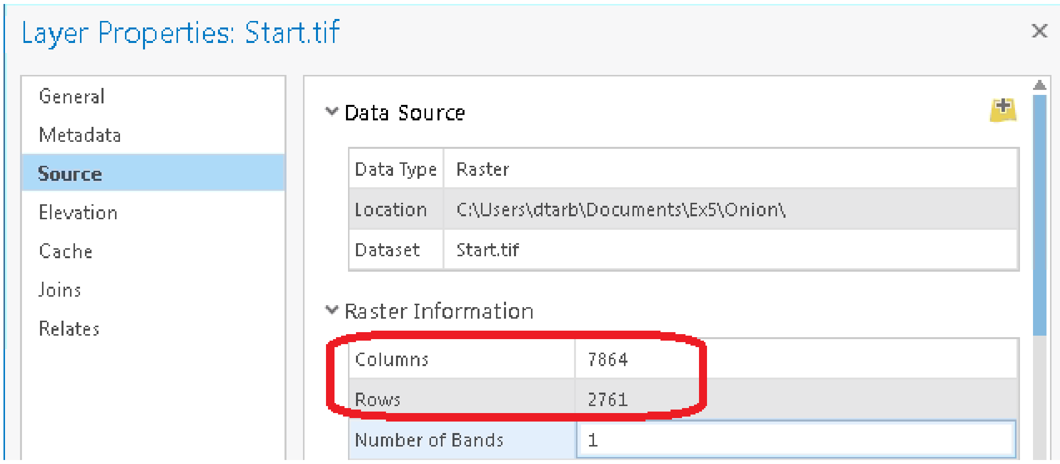


Lastly slick on Cell Size and again choose Same as layer Onion3.tif. These settings are all necessary so that the resulting Start.tif raster that is produced has the same dimensions (columns, rows, cell size, coordinate system, etc.) as the Onion3.tif DEM.

The environments parameter settings should be as follows. Then click run.

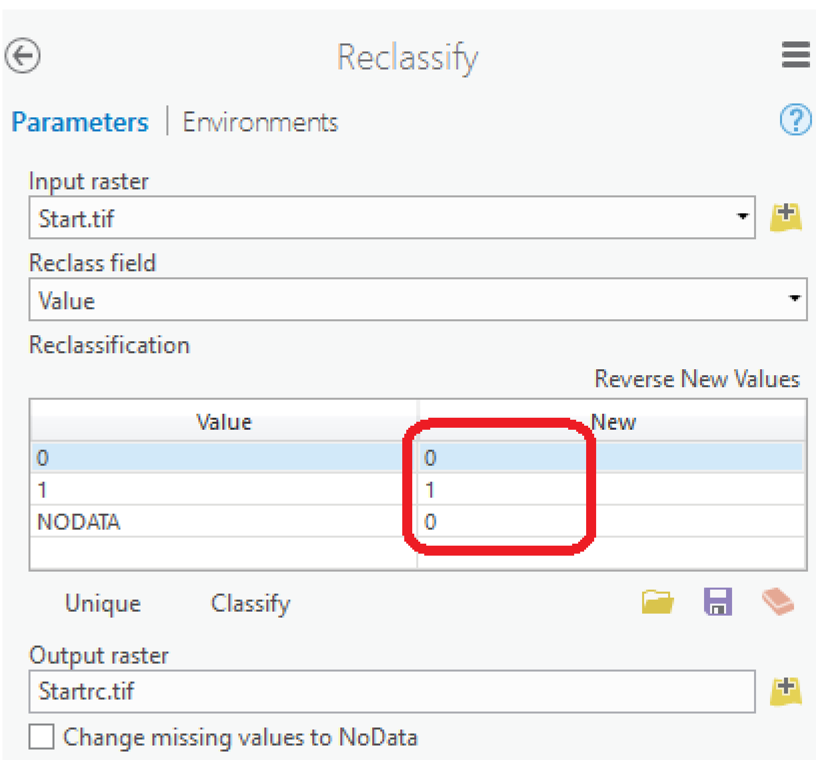


The result should be a new raster "start.tif" that has the same number of rows and columns as Onion3.tif DEM. Check this, as if this is not the case the stream delineation will not work.

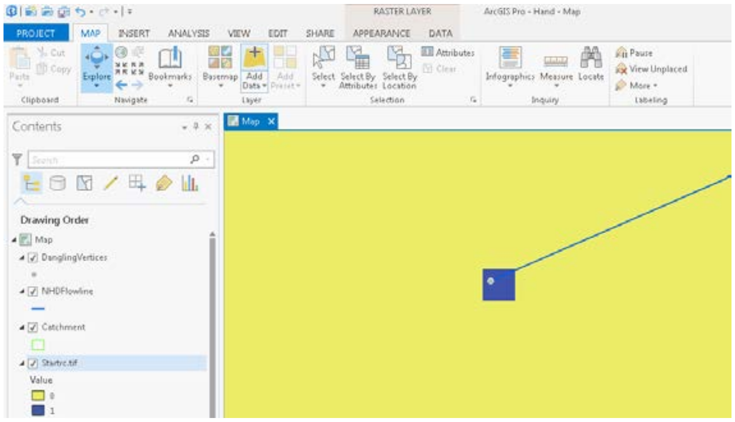


If you open the Attribute Table for Start.tif you will see there are 42 grid cells with the value of 1 and one with a grid value of 0. This is the single cell near the outlet. There are many more grid cells overall (7864 * 2761). The way we are going to use this raster in TauDEM requires non-nodata values everywhere, so let's reclassify nodata values to 0.

Locate the **Reclassify (Spatial Analyst)** Geoprocessing tool. Set the input raster as Start.tif and adjust the values as follows. Save the output as Startrc.tif (rc for reclassified) and Run.

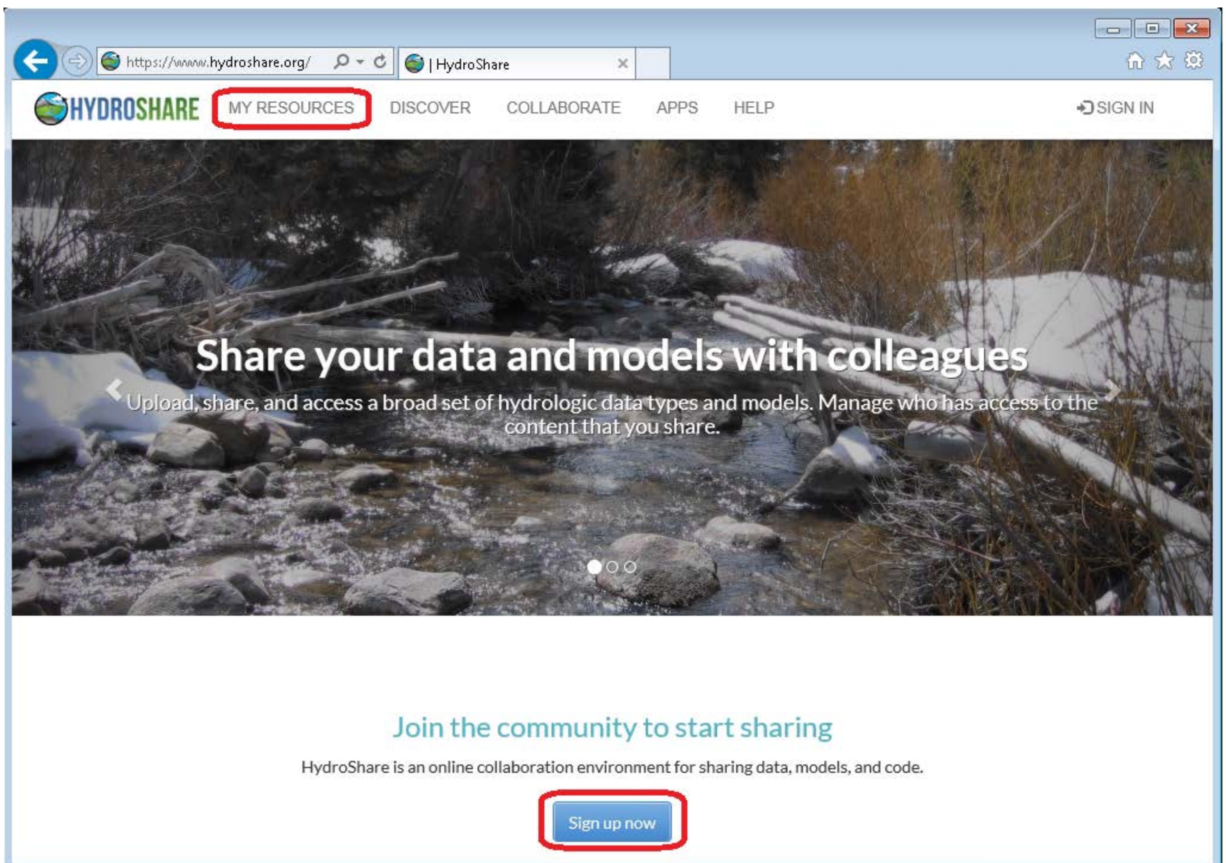


The result should be a raster with values 0 and 1, with no data values. If you zoom in over the sources of NHDFlowlines you will see that there is a single cell with a value of 1 at the source of each stream. The raster Startrc.tif will be used together with Onion3.tif in TauDEM to delineate a stream raster using CyberGIS.



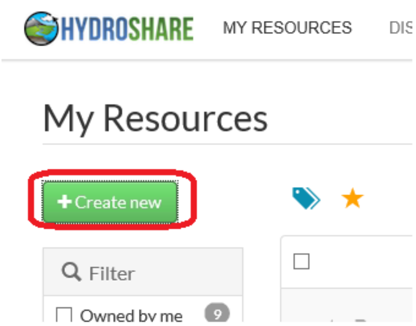
2. Load to HydroShare

Go to www.hydroshare.org.

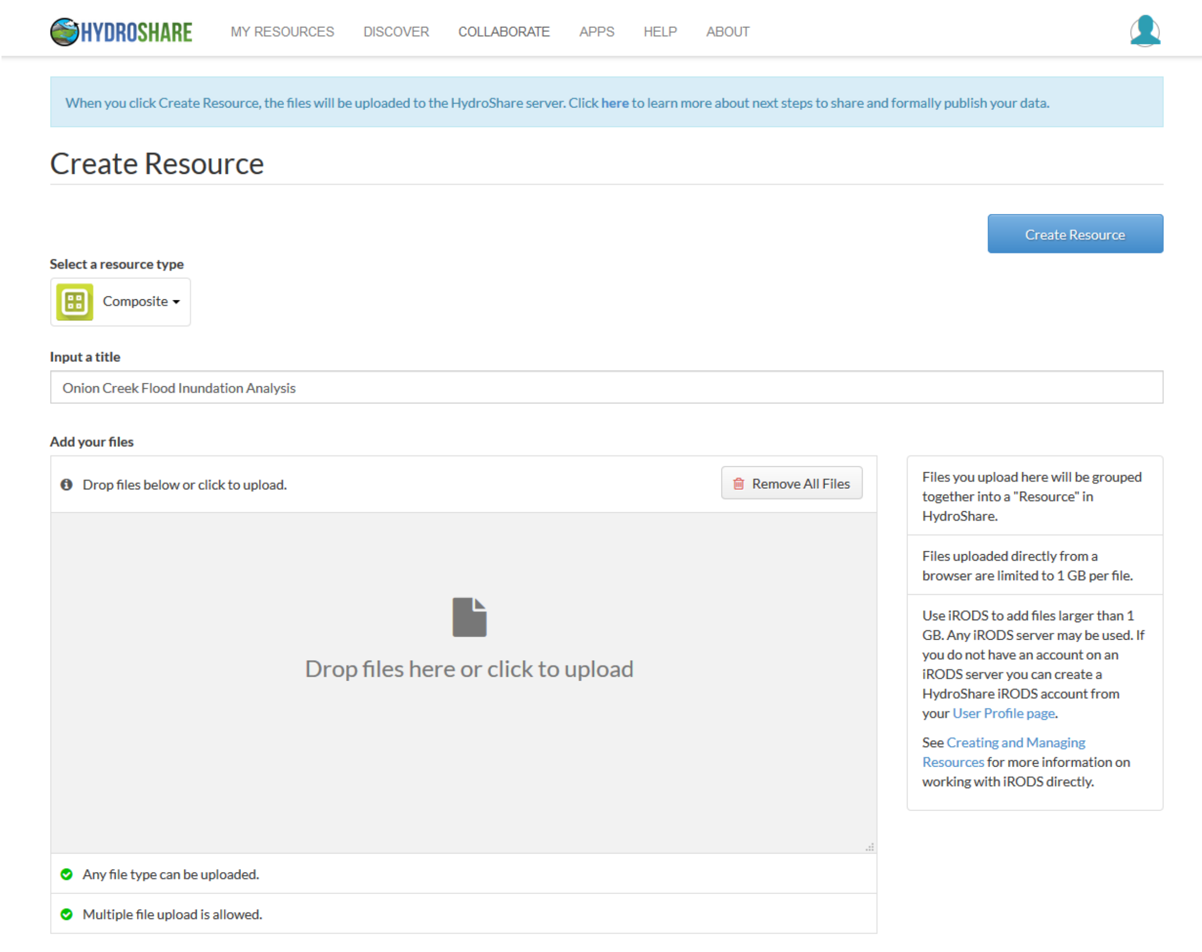


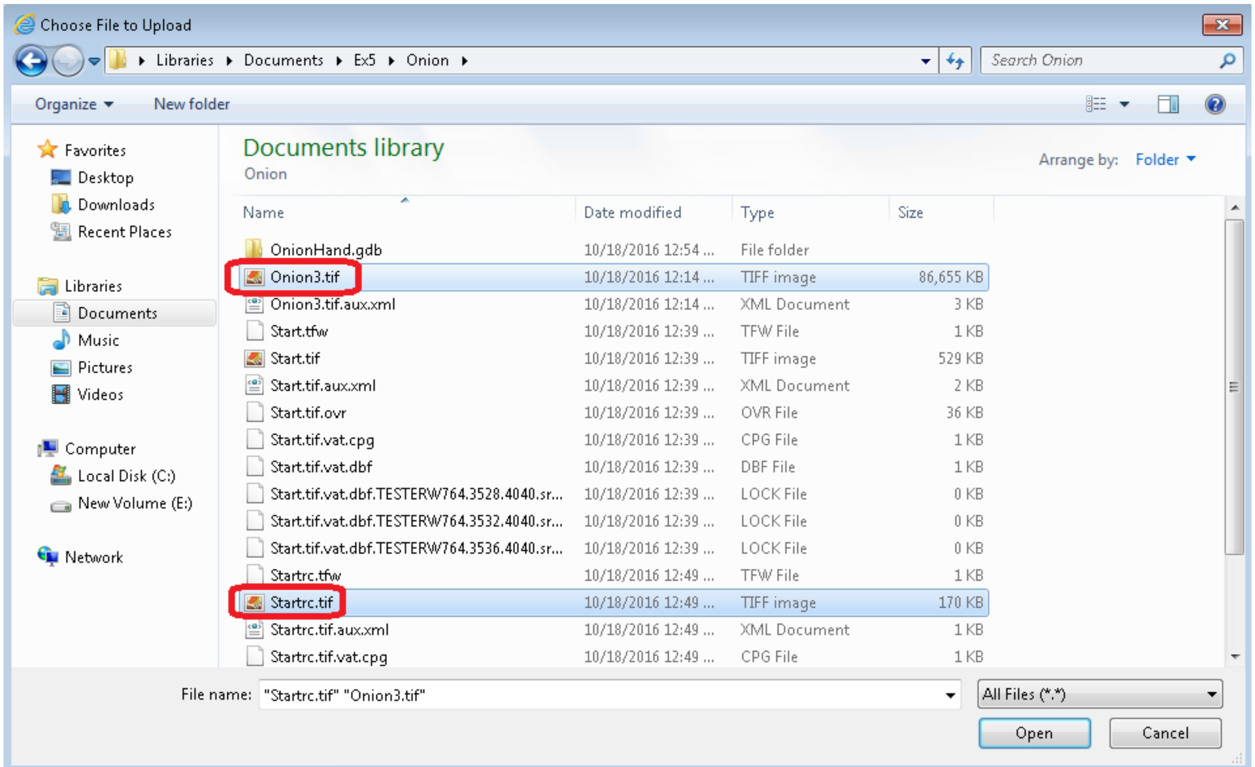
If you already have an account go to "My Resources", otherwise click sign up now and enter your name, email and other details to request an account. You will receive an email that requires you to validate your email (check your junk folder if you do not immediately receive this).

At My Resources click Create new.

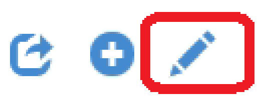


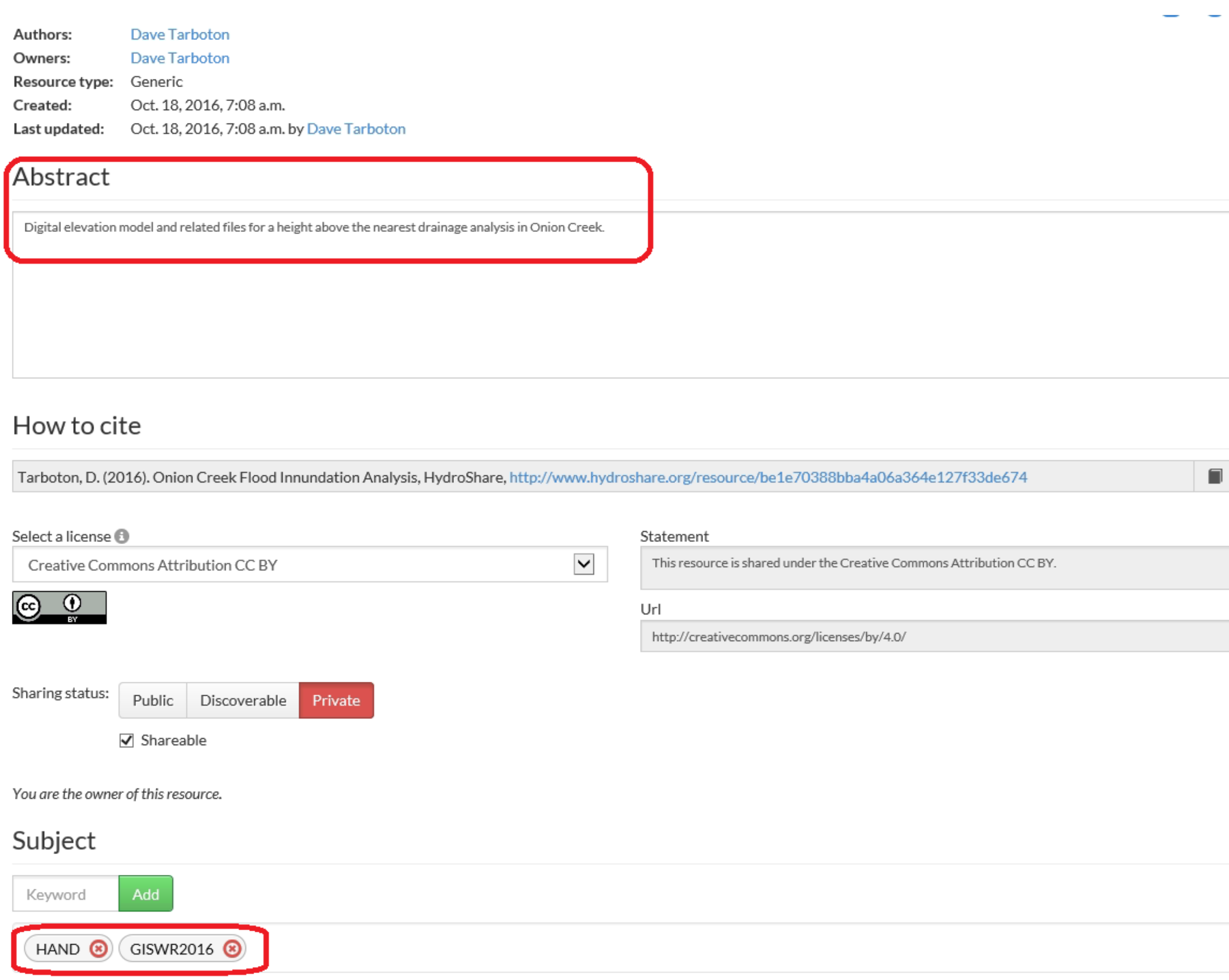
Use a Composite resource type (the default) and type in the Title "Onion Creek Flood Inundation Analysis". Browse or drag and drop to add files and select the two files "**Onion3.tif** and **Startrc.tif**" and click **Create Resource**. When you click Create Resource, you'll see a blue circle rotating as your files are uploaded to Hydroshare.





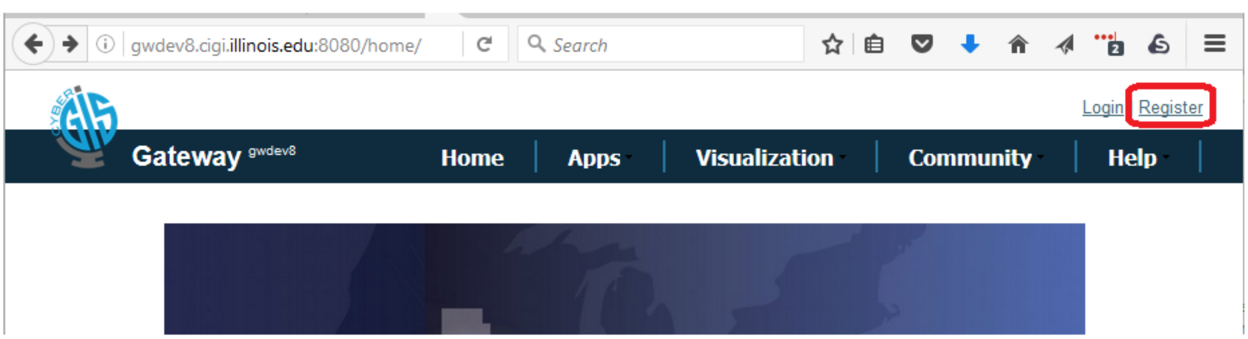
This may take a while as files are being uploaded into the HydroShare server at RENCI at the University of North Carolina in Chapel Hill. Eventually you will get to the HydroShare Landing Page for this resource where you have tools for adding metadata, such as an abstract, keywords, spatial coverage etc. You could also change the permissions setting to share with others and collaborate on this if you want. I suggest entering just a short abstract and keywords for this resource. Click on the Pencil icon to edit.



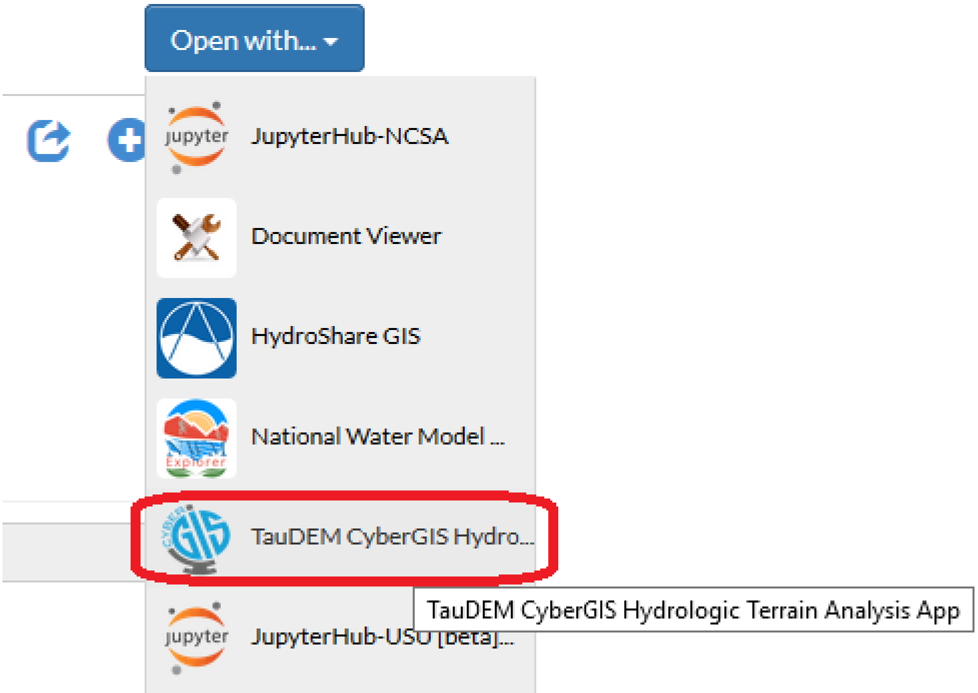


3. Use CyberGIS

Go to http://gwdev8.cigi.illinois.edu/home/. Note that this is a prototype CyberGIS Gateway App website as this functionality is still under development. Register for an account at CyberGIS by clicking on the Register link and entering the information requested.

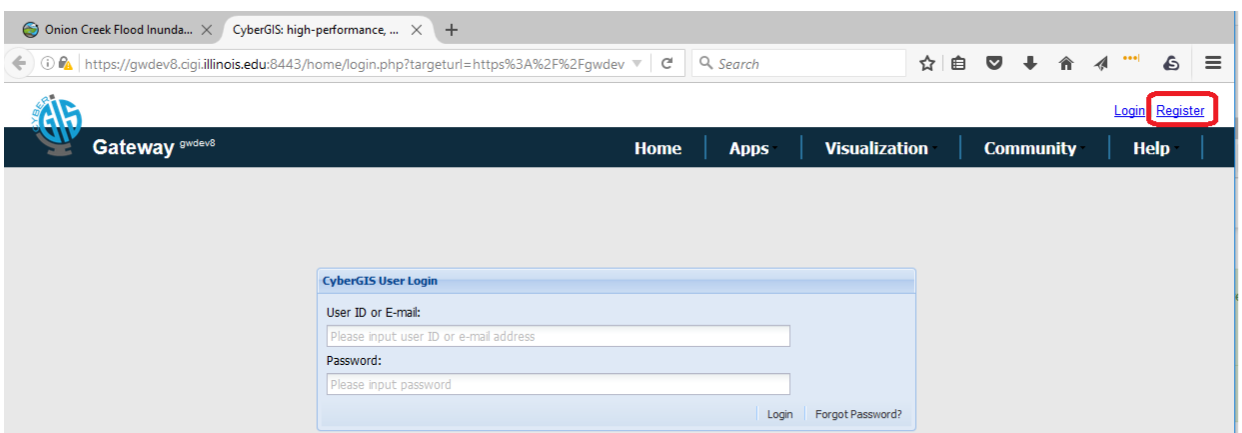


Once you have a **CyberGIS** account, return to **HydroShare** and at your **Onion Creek Resource** click Open with TauDEM CyberGIS Terrain Analysis App.

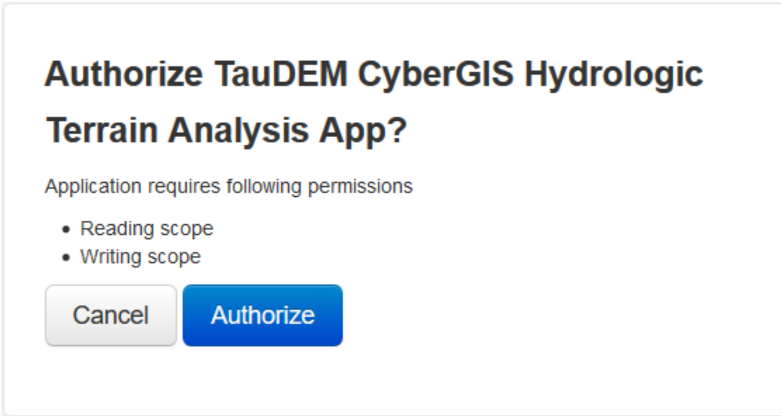


If you receive a security certificate warning click "Continue to this website". The configuration of certificates for secure web data transfer is not properly up to date.

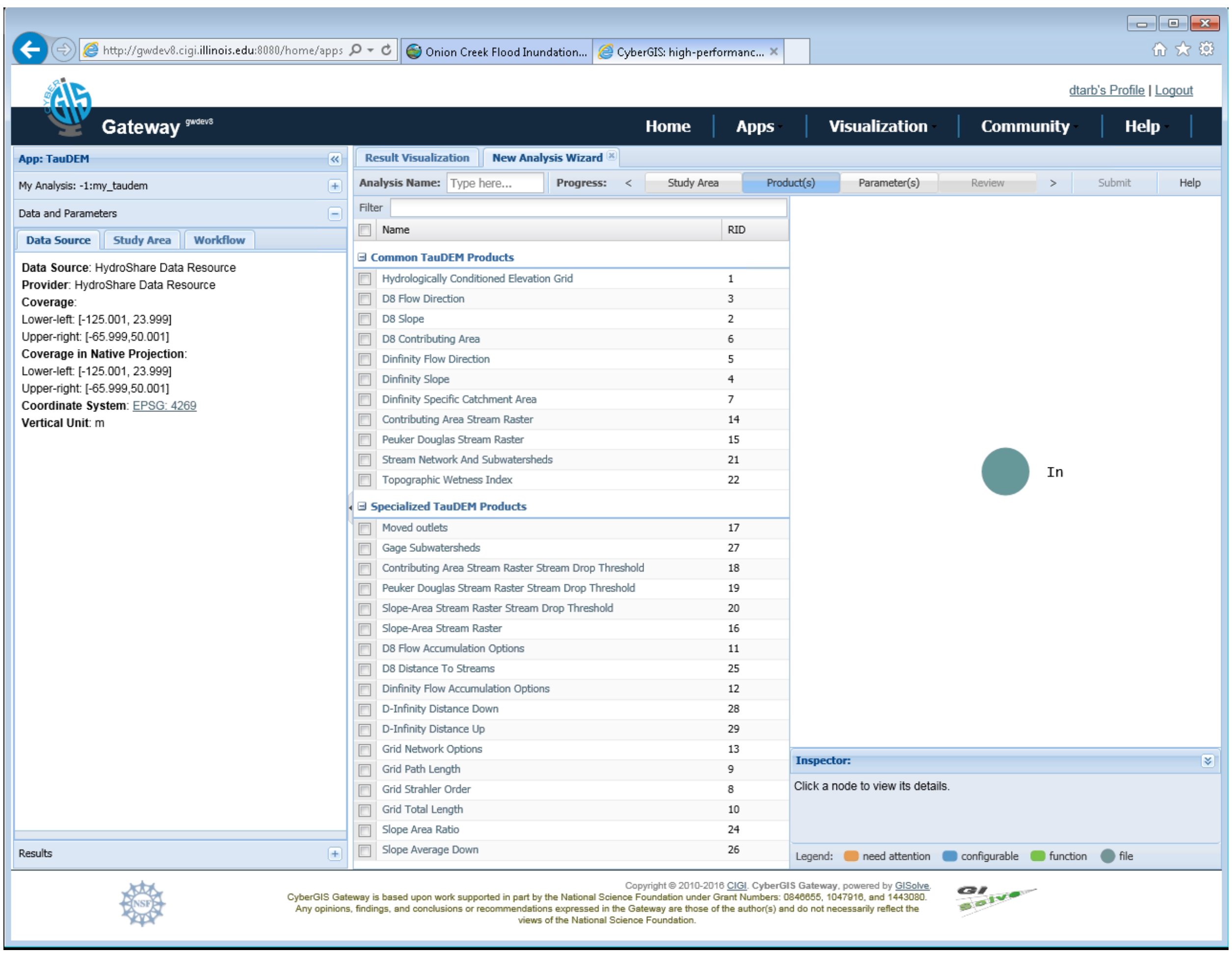
Log in using the account you just created.



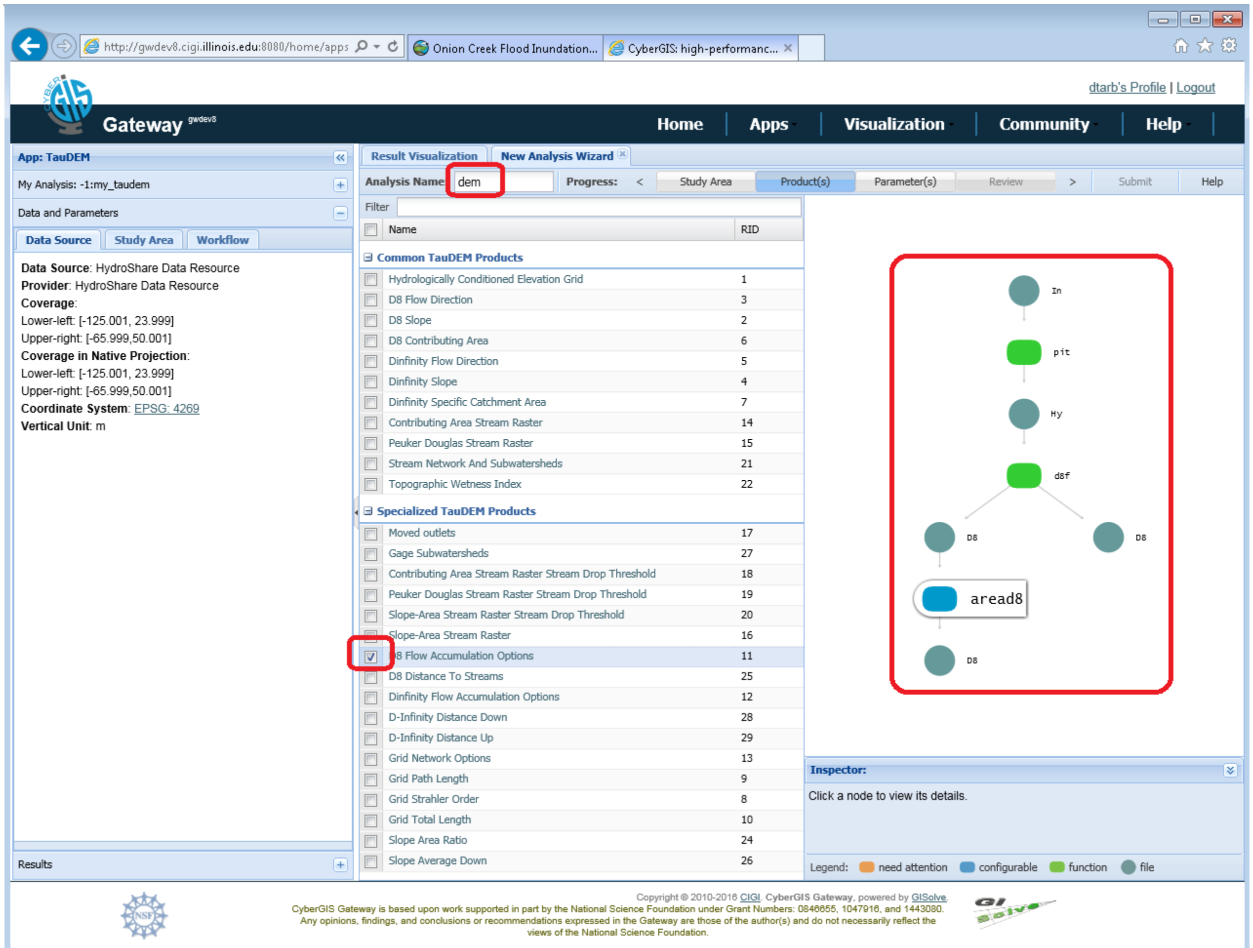
You will also need to Authorize the TauDEM App. This is similar to authorizing an app on a cell phone to access your data.



You should get to the TauDEM CyberGIS App page. This is designed for you to indicate the result that you want, then it will figure out what sequence of commands to run.



First you need to enter an Analysis name. Here I suggest using "**dem**" as this will be used as a prefix for the rasters produced. Then you can click on the check boxes for whatever TauDEM products you want. Here we first want to delineate streams from the start points of NHDPlus streams. This is a weighted contributing area calculation, so select the **D8 Flow Accumulation** Options product. Note that the system automatically fills in the sequence of functions to run. You can hover over each symbol to learn about it.



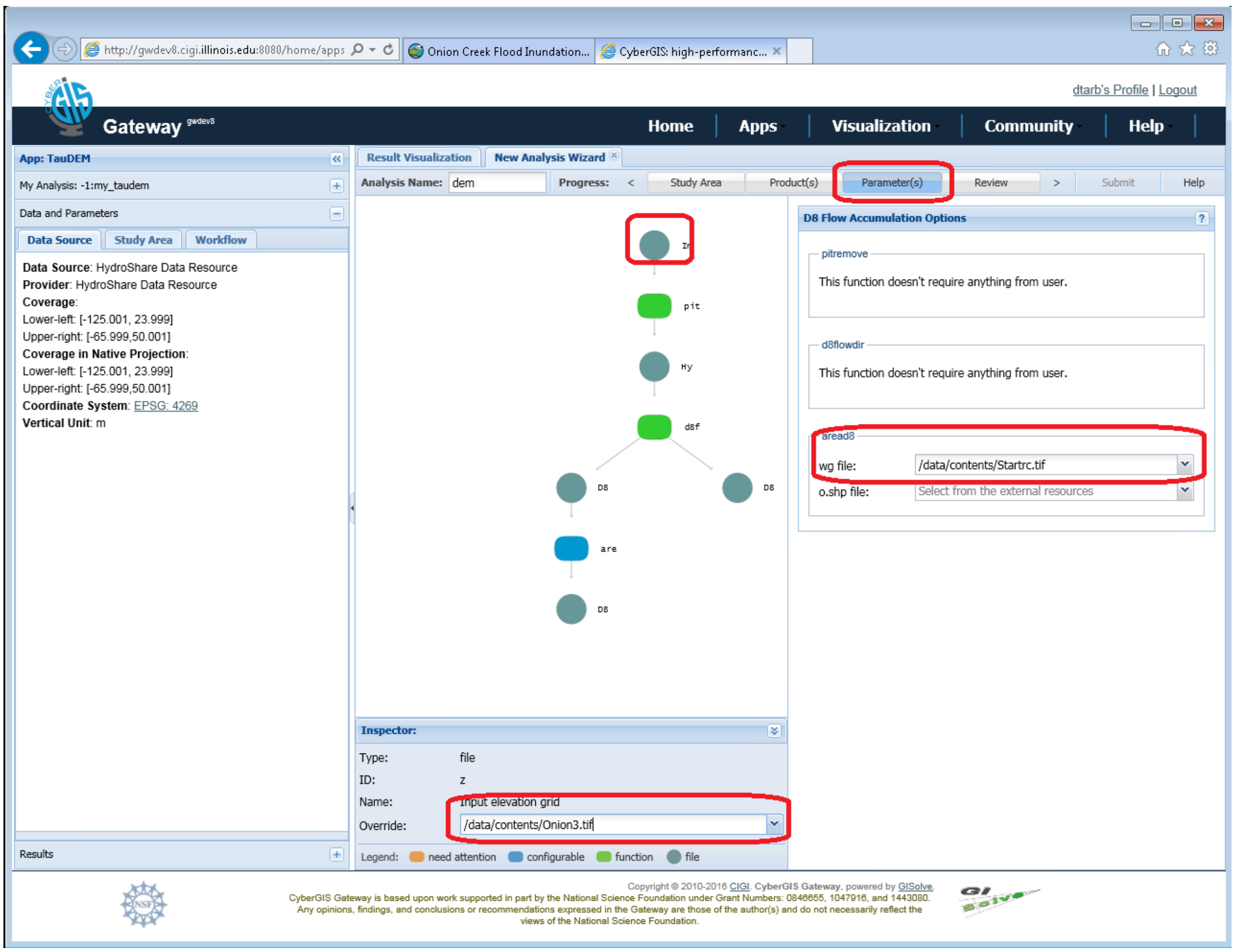
In the workflow above, the first grey circle at the top represents the input elevation grid file

The green rectangle below this depicts the Pit Remove function. Functions are green, files are grey and functions with settable parameters are blue. Pit Remove results in an output file "Hydrologically correct elevation grid"

This is similar to running Fill in ArcGIS. The next function moving down is d8flowdir that outputs two result files D8 Flow Direction and D8 Slope. This is similar to ArcGIS Flow Direction Tool where there is both a flow direction raster and drop raster output giving D8 slope. Only the Flow Direction raster (the one on the left) feeds into the next function AreaD8. The AreaD8 function produces as output the weighted D8 contributing area file that is the product requested and final result from this workflow. The fact that AreaD8 is blue indicates that we will need to specify parameters for it.

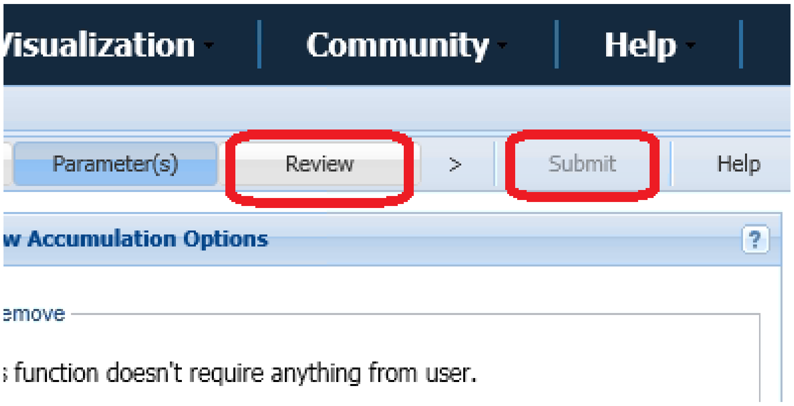
Next click **Parameters** at the top. Here you get to specify input parameters. For Aread8 set the weight file "wg" to Startrc.tif. You do not need to set an o.shp shapefile. This is only needed for cases where you want results upstream of an outlet. Here we are computing results for the entire DEM.

Next click on the grey/blue **In** circles at the top to set the Input elevation grid. Use the **Override** box to set **Onion3.tif** for the input elevation grid.

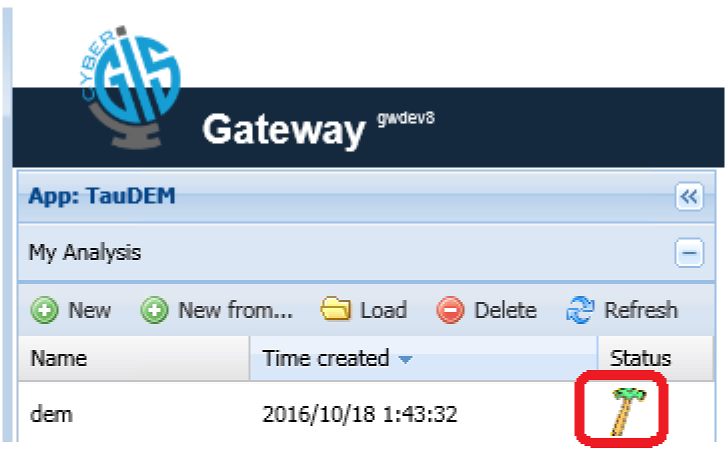


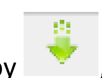
The diagram indicates that Onion3.tif will be used as input to a Pit Fill to produce "Hy" a hydrologically conditioned DEM. Then D8 flow directions will be run to produce D8 slope and D8 Flow Direction rasters. Then AreaD8 will be run to produce a weighted D8 contributing area. By using the start grid cells as weights we will effectively define a stream network starting only at the start points of NHD streams.

At the top click on Review then submit.



You should see an animated hammer indicating that the job is queued.



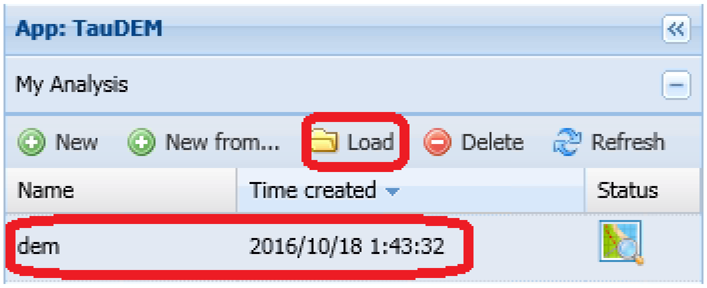
Eventually the hammer,  changes to a spinning globe  , followed by , then  that give a sense of where the job is in the processing. When you see the map icon the job is complete.

Since this takes a while use the time it is running to check out TauDEM and CyberGIS TauDEM App documentation.

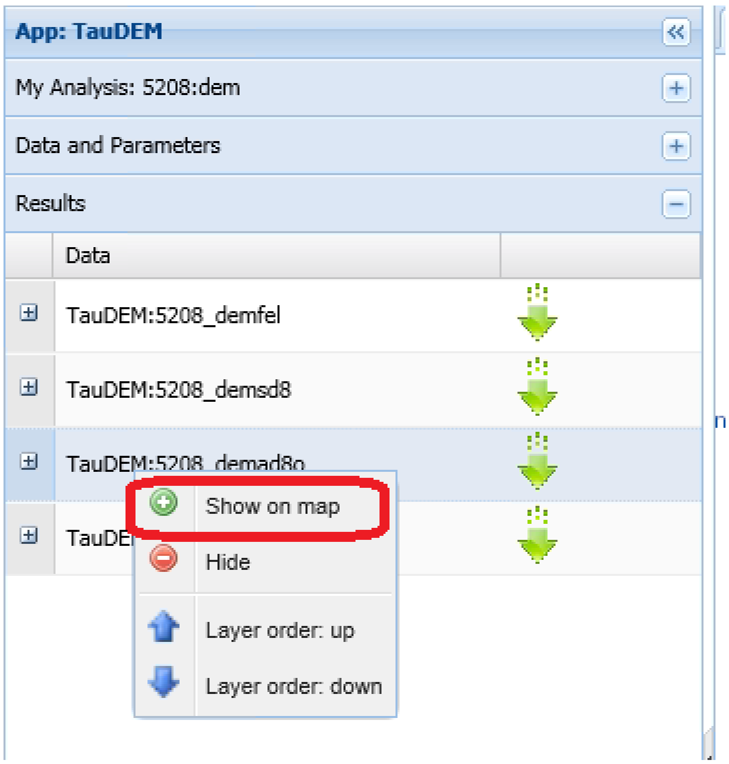
https://wiki.cigi.illinois.edu/display/DOC/TauDEM+User+Guide

http://hydrology.usu.edu/taudem/taudem5/documentation.html

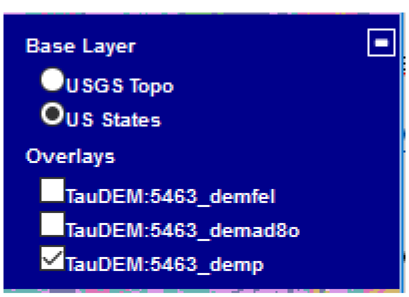
Once the CyberGIS processing completes, select your result row on the Analysis list and click **load** to see your results on the map.

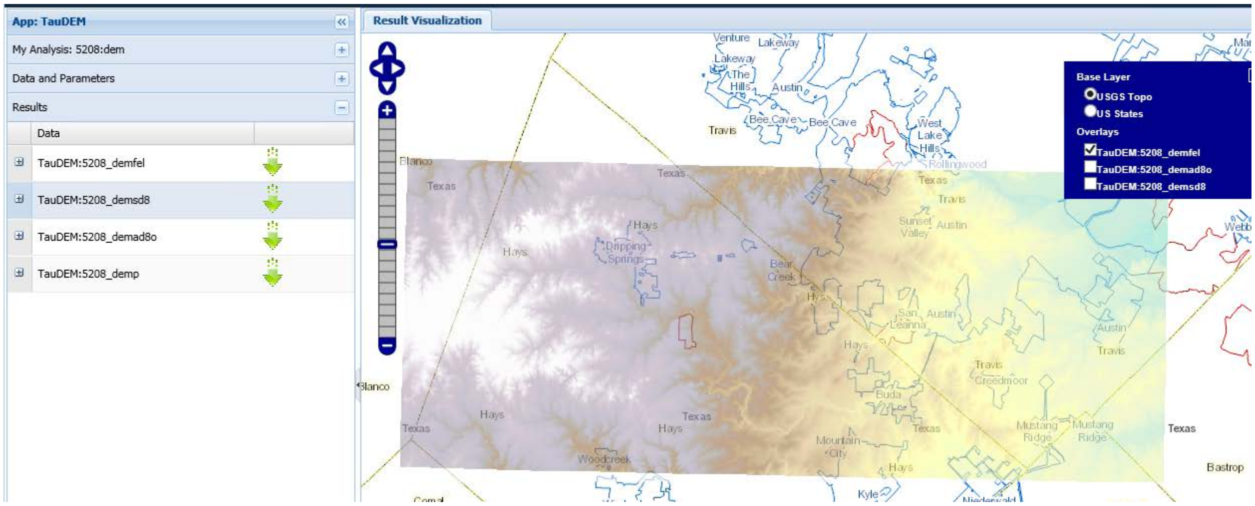


Then right click on layers that you want to show on the map.



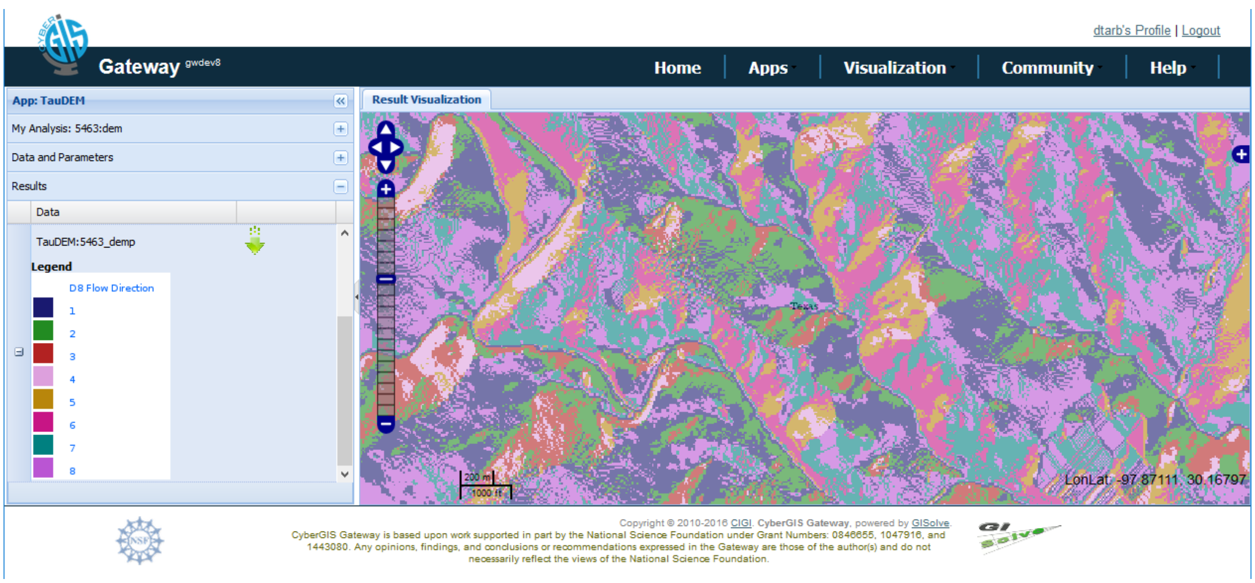
You can also expand the + on the right to turn layers on and off.





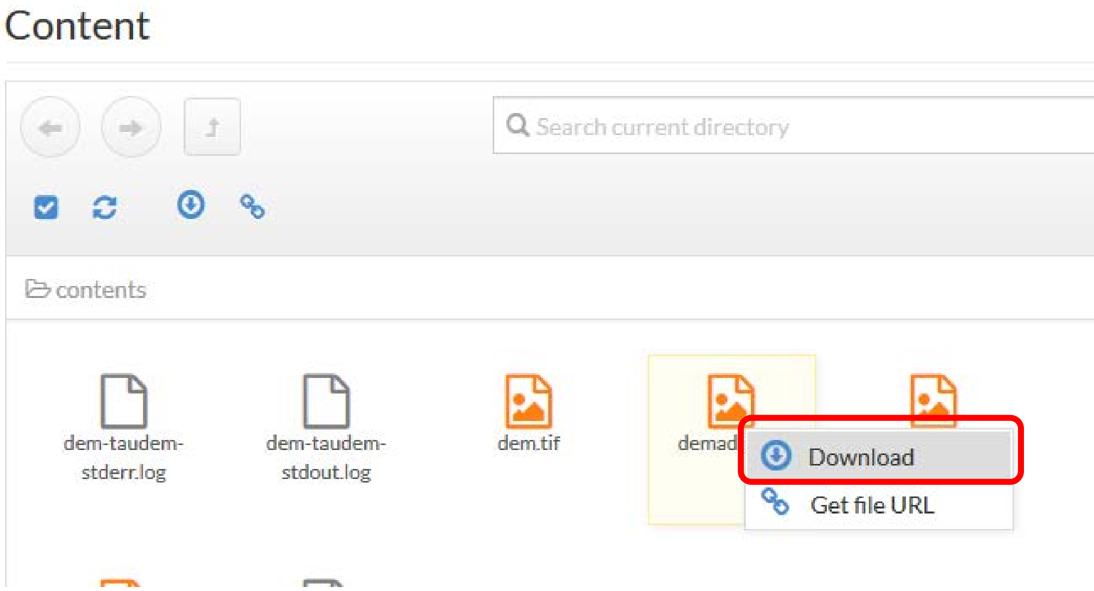
The four result layers produced are

- demfel. This is the filled digital elevation model raster.
- demsd8. This is the D8 slope raster.
- demad80. This is the result from weighted D8 Contributing area. The values of this particular grid range from 0 to the number of grid cells that were in the weight grid used as input. We will examine this in ArcGIS later, after downloading.
- demp. This is the D8 flow direction raster using 1 to 8 flow direction encoding that TauDEM uses, as illustrated below



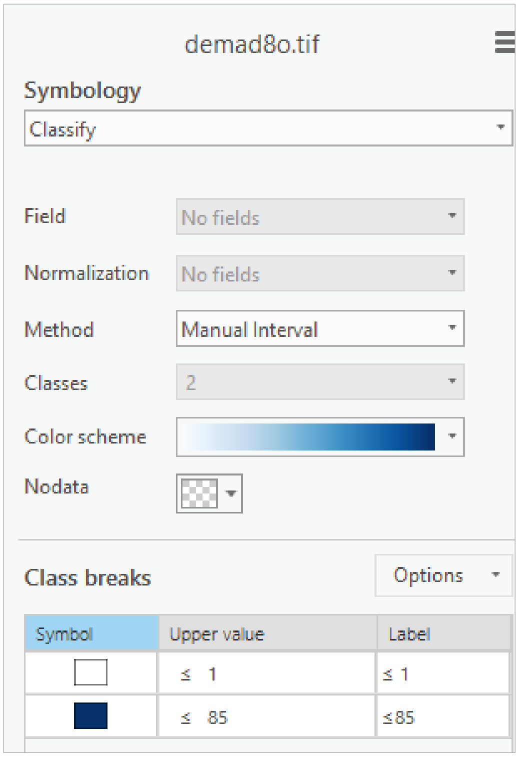
Once the job is complete go back to HydroShare and if necessary reload the HydroShare resource landing page that you started with and you will see that it contains additional files. These are the result of the processing that have been saved back to HydroShare for you to use.

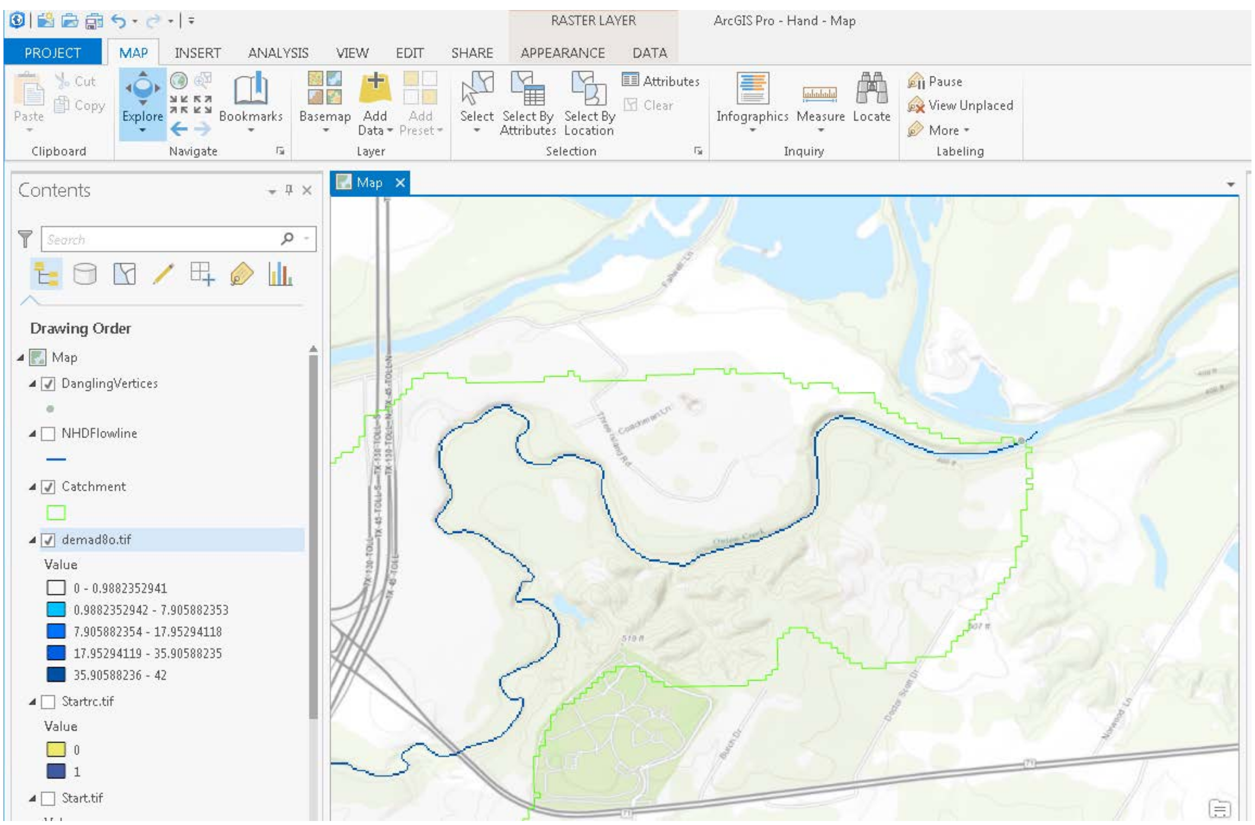
Download demad8o.tif by right clicking on the blue download arrow.



Put this file in your "**Onion**" folder and look at it in ArcGIS Pro. If you don't see it in ArcGIS Pro you may need to Refresh in the Add Data Window, or save your Project, Close ArcGIS Pro, and then open it up again. For some reason, ArcGIS Pro cannot immediately see files that are not already there when the project opens.

For **demad80.tif** use a **Classify** symbology and set as transparent values less than 1 and blue values greater than 1. To do this, use a Classification with two classes, of which the upper limit on the first class is 1. Set this class to have "No color" in the Symbology

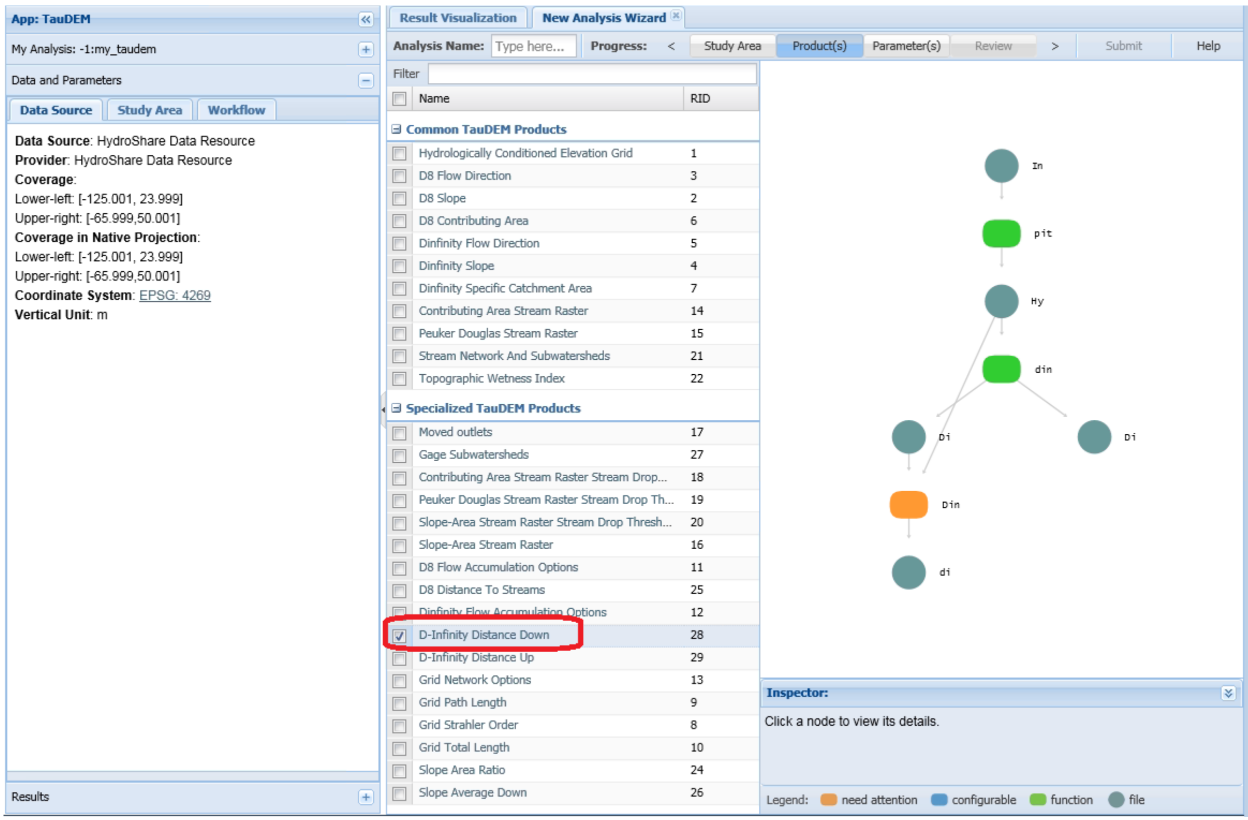




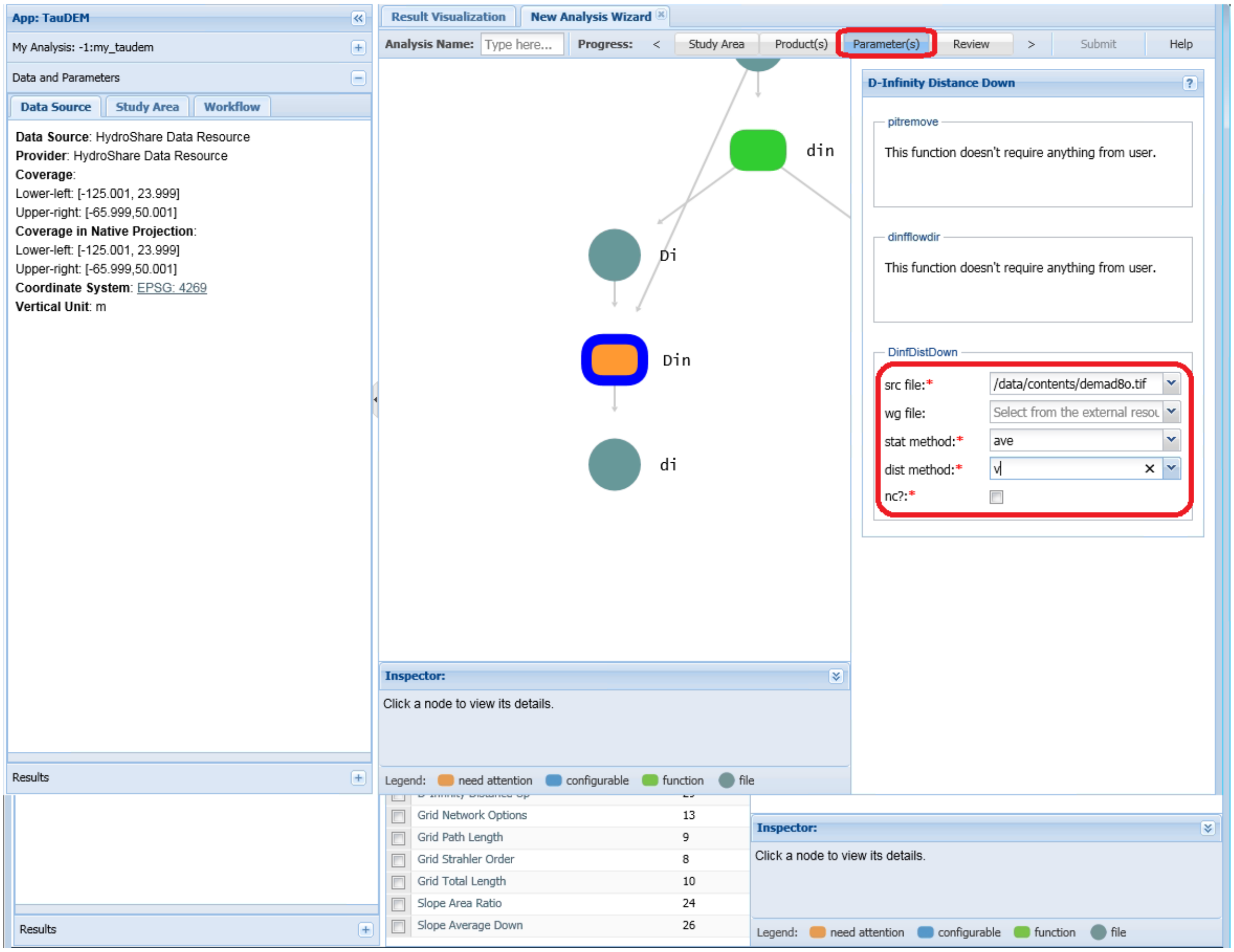
Zoomed in you see that this provides a raster that very closely follows stream NHDFlow lines. It also peters out right where it enters the Colorado River (of Texas). This is because the Colorado River enters from outside the map so its Flow Accumulation is unknown (based on the data in the map) and calculated as "no data". We will use a threshold value of 1 on this raster to define a stream network. We will also use this raster as the Height Above the Nearest Drainage target.

Go back to **HydroShare** and again on the **Onion Creek Flood Inundation Analysis** Resource Open With TauDEM CyberGIS App.

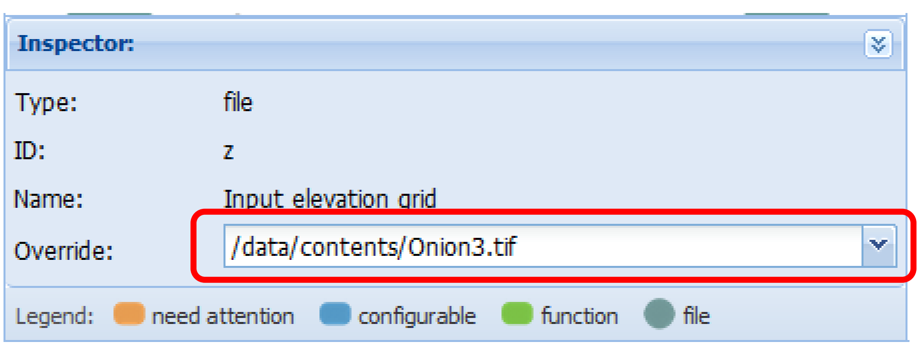
Provide an analysis name "dem2" to keep results separate from the previous ones. Select the product D-Infinity Distance Down. This will evaluate height above the nearest drainage (HAND). We will use the weighted flow accumulation to define the target source streams in this calculation.



Click on Parameters at the top and for src file select demad8o.tif. This specifies the target streams to which distance is computed. Select stat method "ave". This says to use average distance. Select dist method "v". This says to use vertical drop.

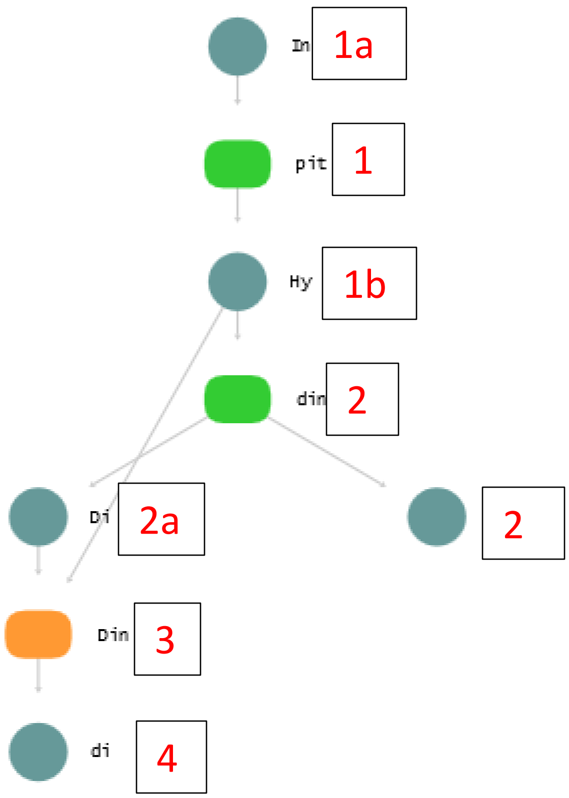


Click on the In Circle at the top and set the input elevation grid to Onion3.tif



This makes sure that the Input elevation grid used in the workflow is the correct one.

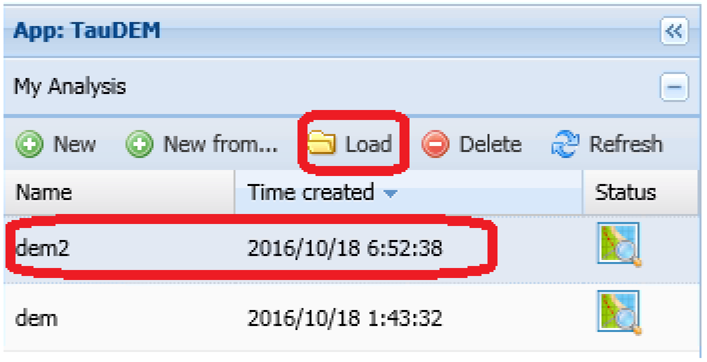
In the workflow depicted the sequence of steps is illustrated following the arrows from top to bottom.

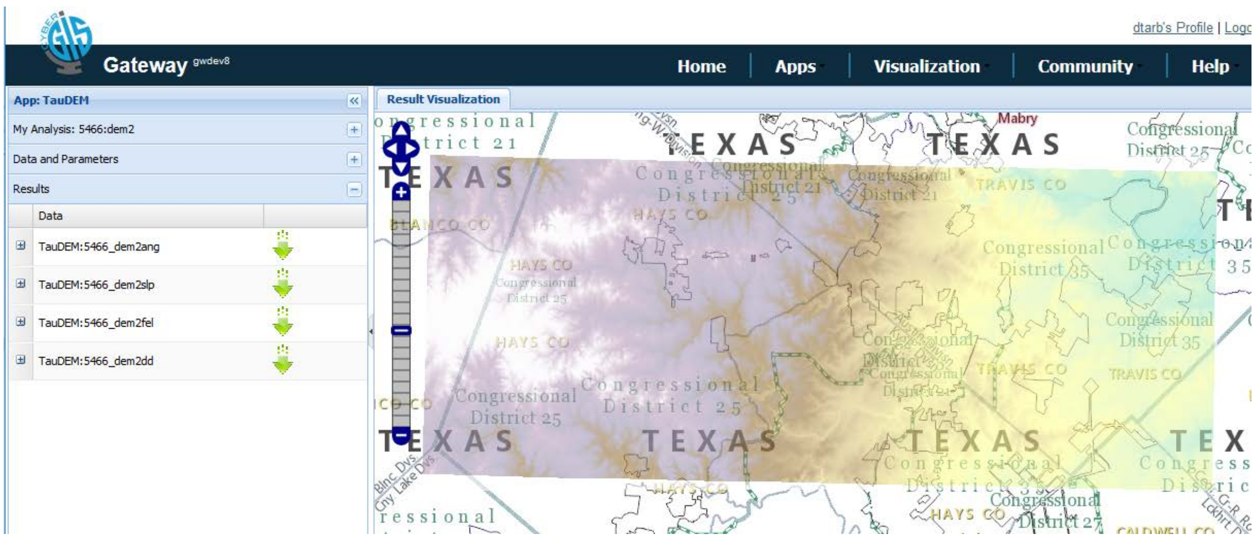


The functions executed are

1. Pitremove on Input DEM (1a) to produce Hydrologically Correct DEM (1b).
2. Dinfflowdir on Hydrologically Correct DEM to produce Dinfinity Slope (2a) and Dinfinity Flow Direction (2b)
3. DinfDistDown using as input Dinfinity flow directions and the demad8o.tif file that was set as src file as the target to which distance down is computed.
4. The result is the distdown grid that in this case is HAND.

Click Review and Submit. When you see the map icon the job is complete. Select dem2 on the Analysis list and click load to see your results on the map.

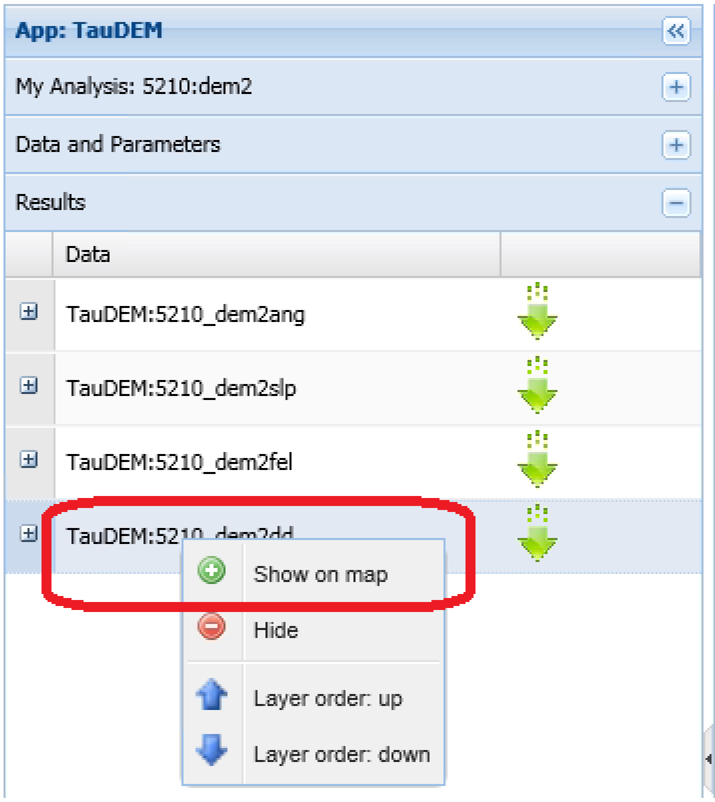




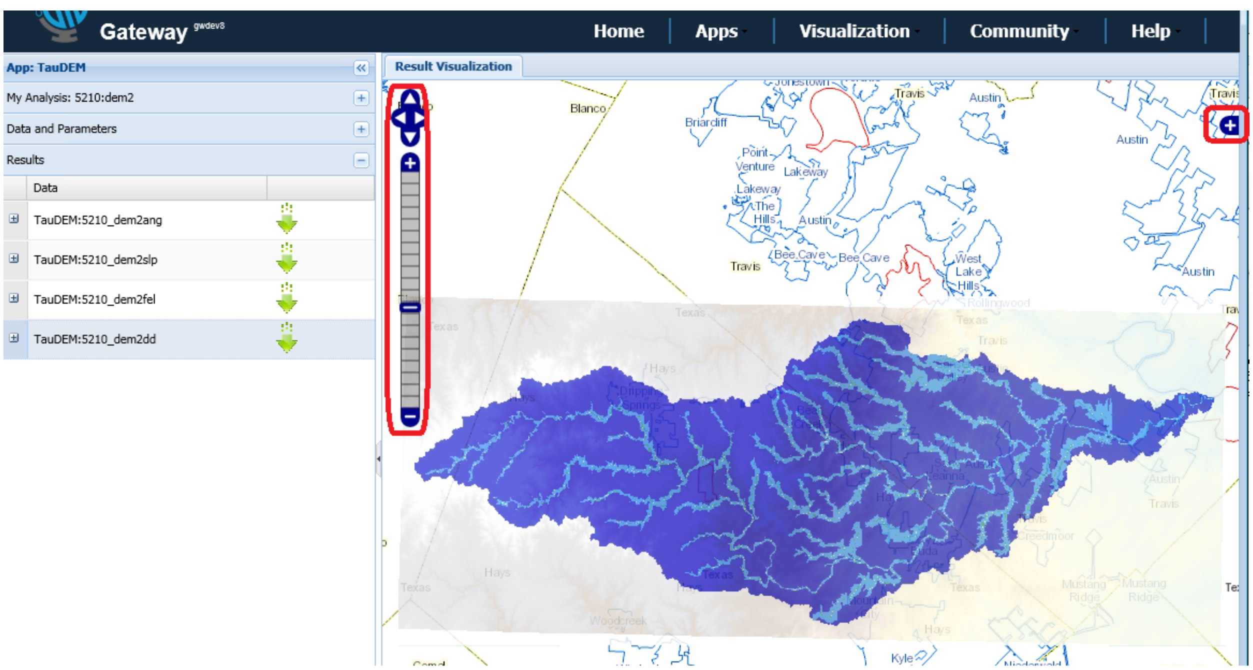
Four layers are included in the map.

- dem2fel. This is the pit filled DEM that is the result 1b on the workflow above
- dem2ang. This is the Dinfinity flow direction grid that is the result 2a on the workflow above that is output from the DinfFlowDir function
- dem2slp. This is the Dinfinity slope grid that is the result 2b on the workflow above that is output from the DinfFlowDir function
- dem2dd. This is the Dinfinity distance down grid that is the result 4 on the workflow above. This has been computed in a vertical direction using flow proportion averaging along all flow directions according to the settings above. This is the HAND result that we want.

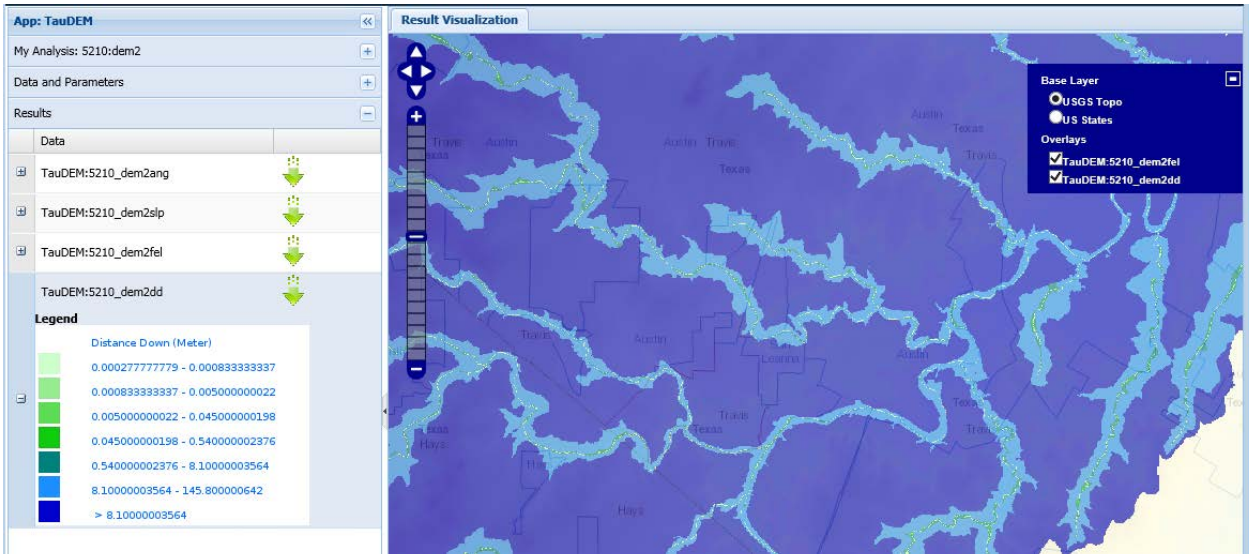
Right click on dem2dd to show on the map.



You should see a visualization of the HAND raster dem2dd.tif in the CyberGIS map display.



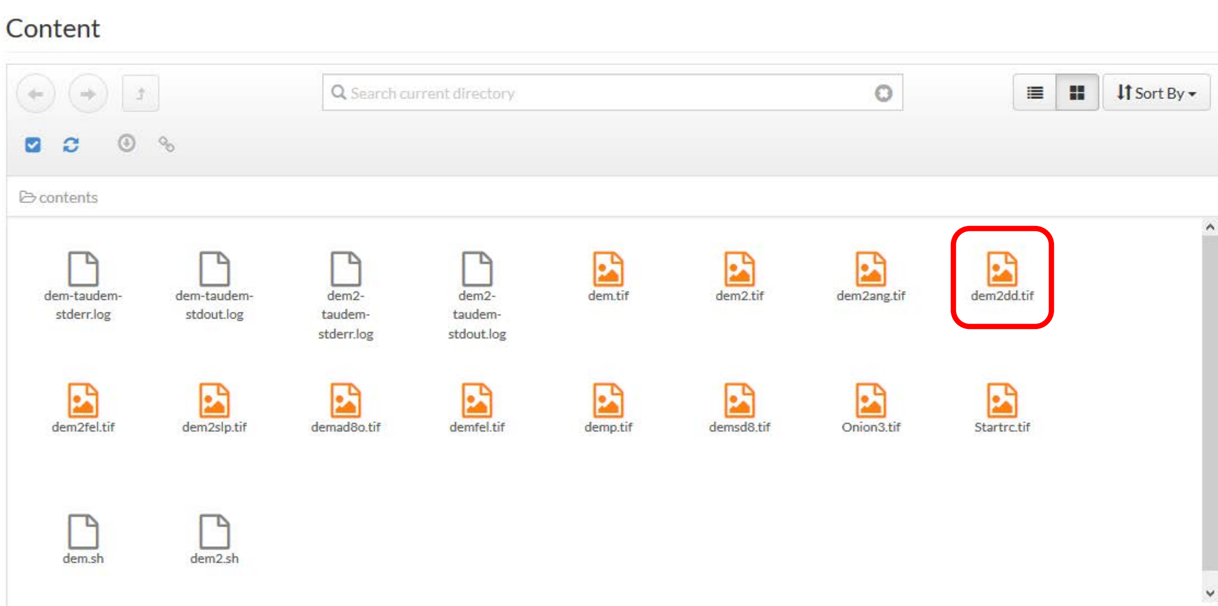
You can use the zoom and pan controls circled, and the layers control on the right to control what is displayed on the map. You can also expand the color legend on the left to see how to interpret the colors.



Wow! Here you performed quite an elaborate analysis with TauDEM completely on the web, or to use the computing cliché "in the cloud". You did not have to install or configure software. You did not have to figure out too much about the sequence of functions to run. This is one of the directions that GIS computing is moving to in the future.

To turn in. Make a screen shot of the CyberGIS map of HAND you produce zoomed out and zoomed in to an area of interest. Write a short explanation of the color symbology interpretation.

Go back to **HydroShare** and refresh the landing page for the Onion Creek Flood Inundation Analysis resource. You should see a new set of result files that have been added to this resource.



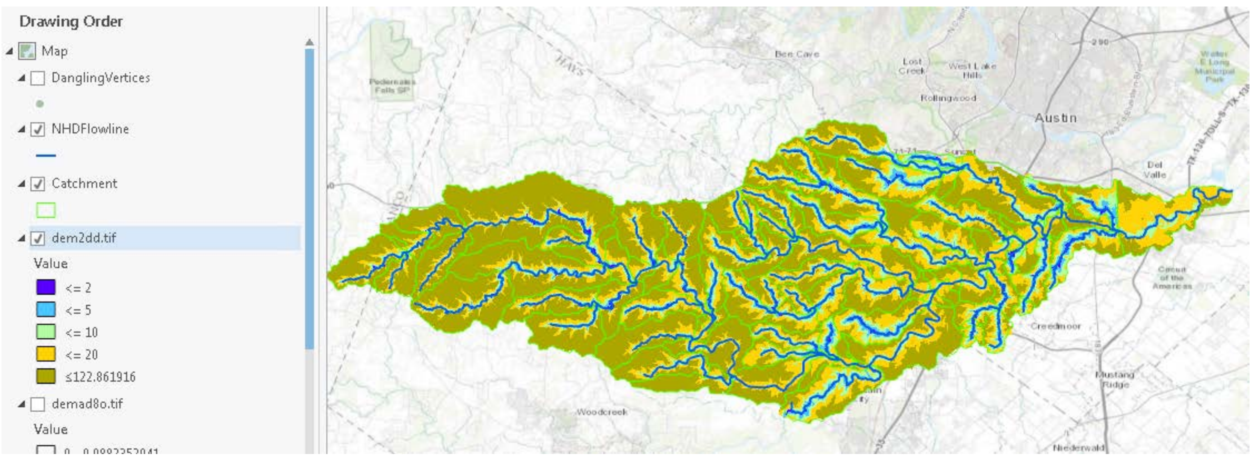
Right click on the file **dem2dd.tif** and download it. This is the HAND raster for this watershed. Also download **dem2slp.tif** that we will use later. You are now done with CyberGIS and HydroShare and can close the browser if you want.

In case you are unable to complete the CyberGIS processing you can get the result files dem2dd.tif and dem2slp.tif in http://hydrology.usu.edu/dtarb/giswr/2017/Ex5Intermediate.zip.

4. Hydraulic Properties

Add the HAND raster **dem2dd.tif** that you downloaded to your ArcGIS Pro map.

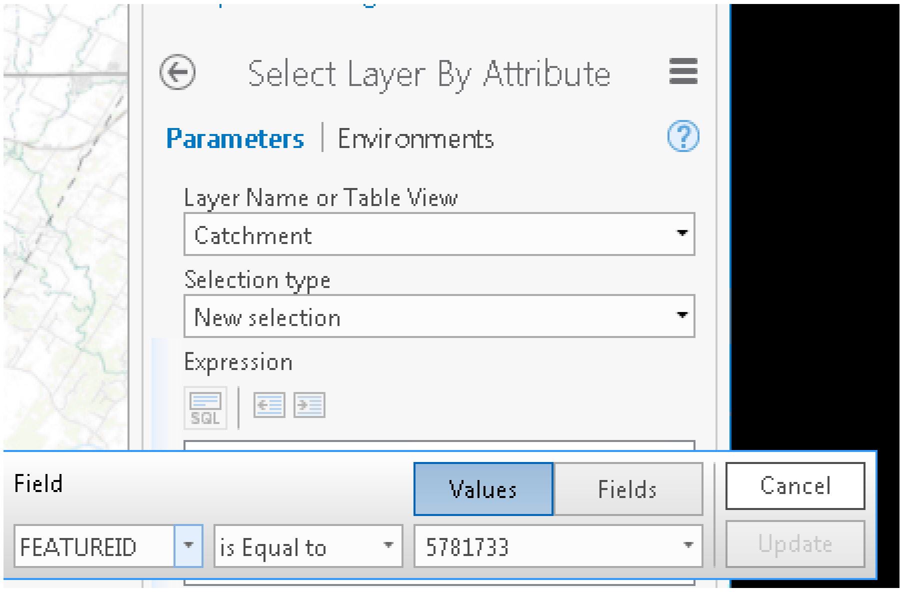
Adjust the symbology to illustrate the HAND raster nicely. In the below I used a Classify symbology with colors from dark blue where HAND is small to browns for large.



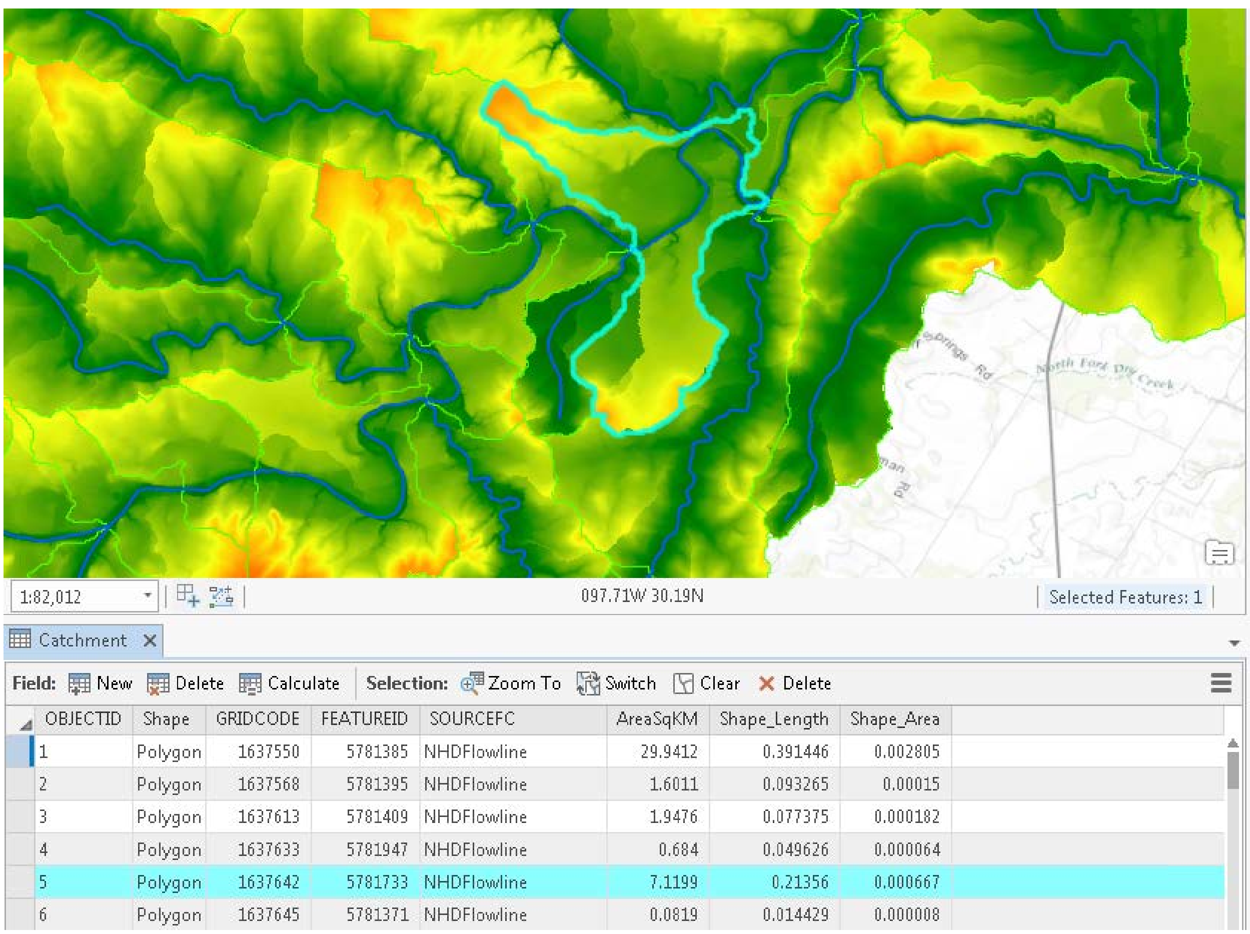
To turn in. Make a map layout of the HAND raster that illustrates it nicely. Include NHDFlowline and catchment feature classes in this map, together with a legend, title and scale bar.

Now lets determine hydraulic properties and potential flooding for one particular catchment. Lets pick FeatureID=5781733. This was one that was particularly affected by flooding a few years ago.

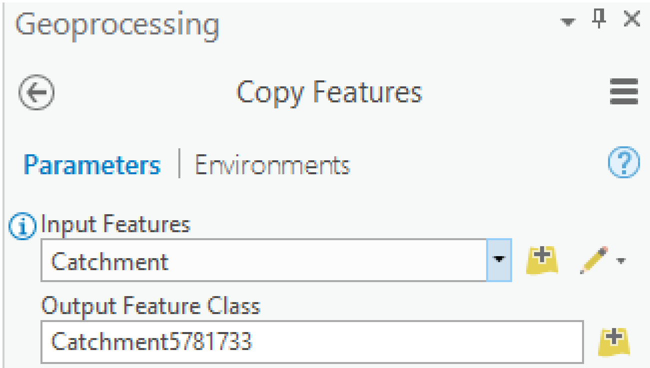
Open the attribute table of Catchments. Click on Select by attributes and add a clause FEATUREID is Equal to 5781733 and Run.



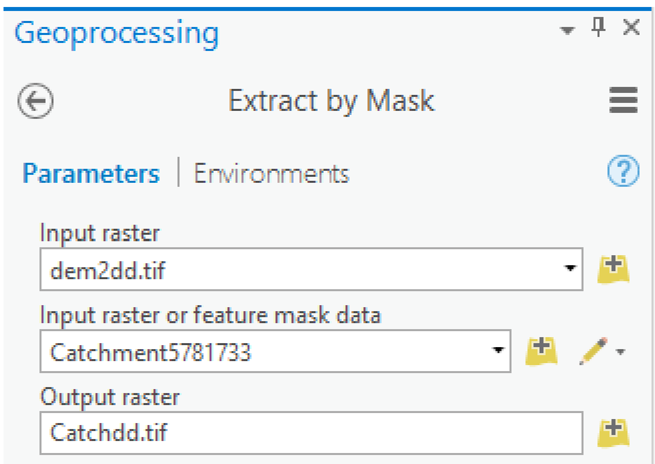
You should see a specific NHD plus catchment selected. Zoom to Selection to see it better.



Export this Catchment to your project geodatabase as a feature class named **Catchment5781733**.

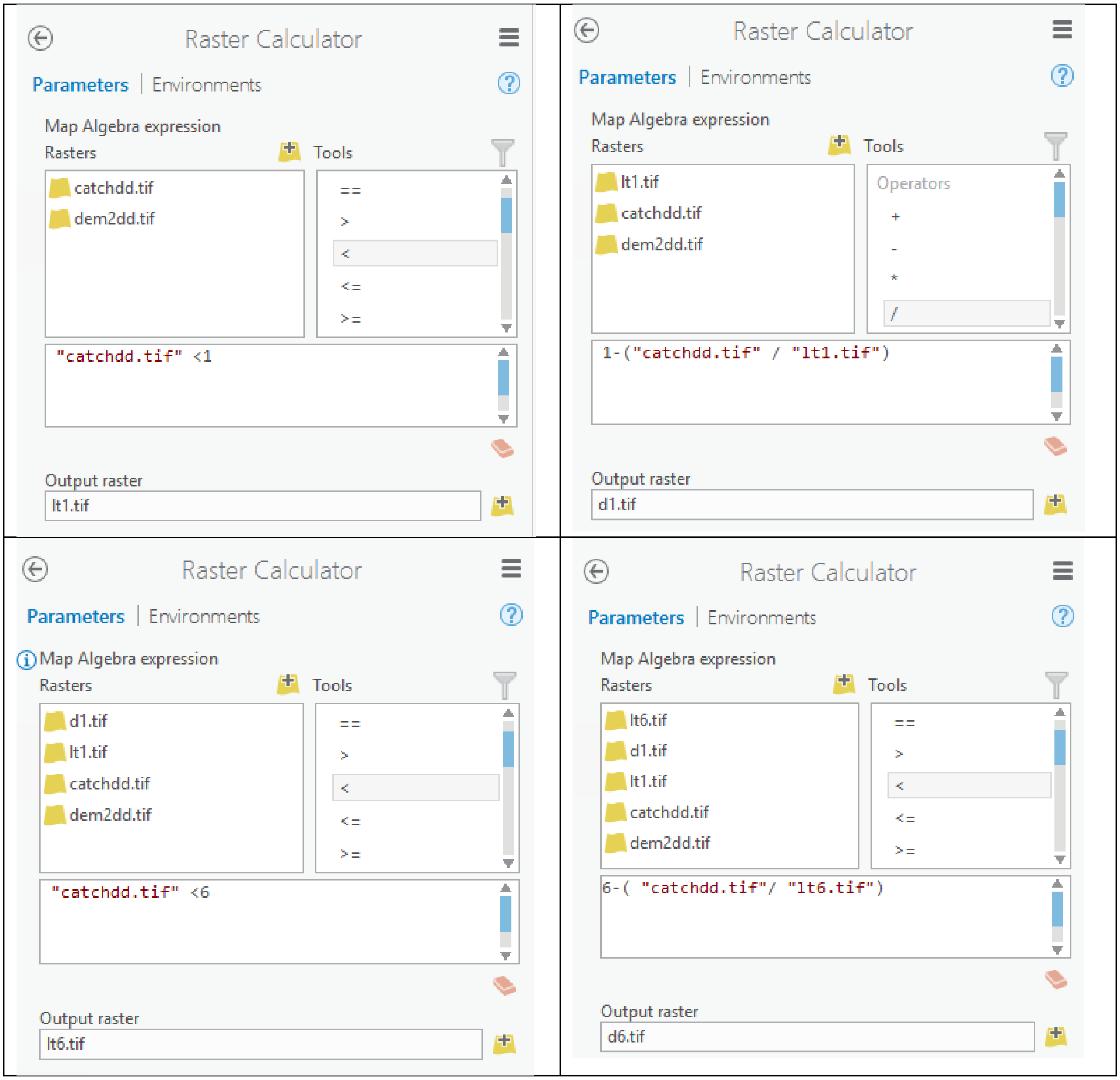


Locate the Geoprocessing tool **Extract by Mask**. Set the input raster as **dem2dd.tif**, input feature mask data as **Catchment5781733**, and output raster as **Catchdd.tif**. I put this in the "Onion" folder. Click Run. Note that this function extracts the HAND (dd) raster for only the selected catchment in the Catchment feature class.

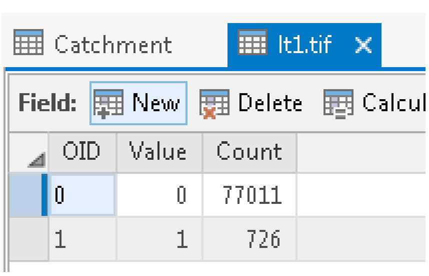


This results in a raster with values retained (masked out) just for the selected polygon. This allows us to examine the HAND layer for this polygon in detail.

Perform the following raster calculations



lt1.tif is a raster with all grid cells less than 1 m. If you look at it's attribute table you will see that there are 726 grid cells with a value less than 1.



OID	Value	Count
0	0	77011
1	1	726

If you look at its Raster Information in properties you will see that the cell size is 9.2 x 10^{-5} deg. The units are degrees in geographic coordinates.

Raster Information

Columns	7652
Rows	2566
Number of Bands	1
Cell Size X	9.25925930000012E-05
Cell Size Y	9.25925930000008E-05

The length and width of each cell (taking latitude as 30°) and earth radius as 6371 km

$$\Delta x = 6371000 \times 9.259 \times 10^{-5} \times \frac{\pi}{180} \times \cos(30) = 8.92\ m$$

$$\Delta y = 6371000 \times 9.259 \times 10^{-5} \times \frac{\pi}{180} = 10.3\ m$$

The cell area is thus 10.3 x 8.92 = 91.9 m^2.

The surface area at a stage of 1 m is thus 726 x 91.9 = 66719 m^2.

d1.tif is a raster with grid cells that give inundation depth for a stage height of 1 m. Look at its Statistics in Properties to see its mean value.

Statistics

Build Parameters: skipped columns: 1, rows: 1, ignored value(s): None

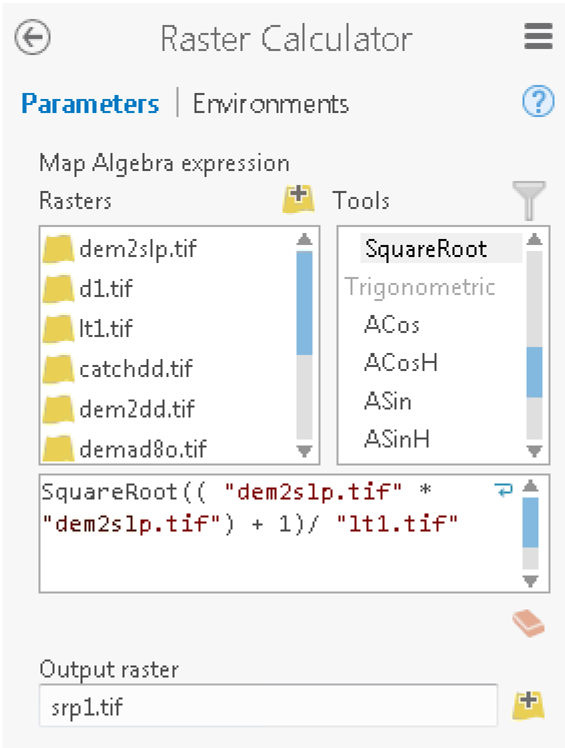
Band Name	Minimum	Maximum	Mean	Std. Deviation
Band_1	0.0069427490	1	0.7188906879	0.3517051763

This mean depth of 0.719 m represents a volume of

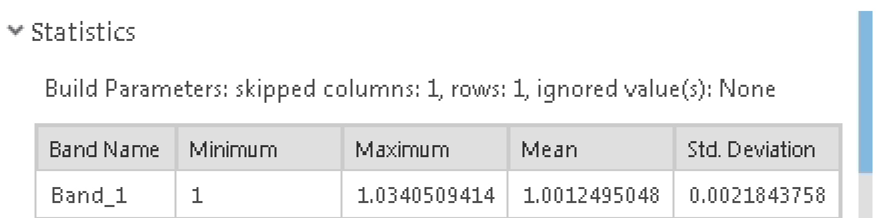
$$V = 0.719 \times 66719 = 47971\ m^3$$

To obtain the wetted bed area we need a slope raster. Use dem2slp.tif from the Onion Creek Flood Inundation resource in HydroShare downloaded earlier (or download now if you missed it). This is the slope computed by TauDEM. Add this to the ArcGIS Pro map.

Evaluate the following Raster Calculator expression



This evaluates for each grid cell $\sqrt{1+slp^2}$. By dividing by lt1.tif only grid cells within the area with stage less than 1 are evaluated. Statistics on this indicate a mean of 1.00125.


Statistics

Build Parameters: skipped columns: 1, rows: 1, ignored value(s): None

Band Name	Minimum	Maximum	Mean	Std. Deviation
Band_1	1	1.0340509414	1.0012495048	0.0021843758

The following formula gives bed area

$$A_b = \sum A_c \sqrt{1+slp^2}$$

Here this is 726 x 91.9 x 1.00125 = 66803 m^2

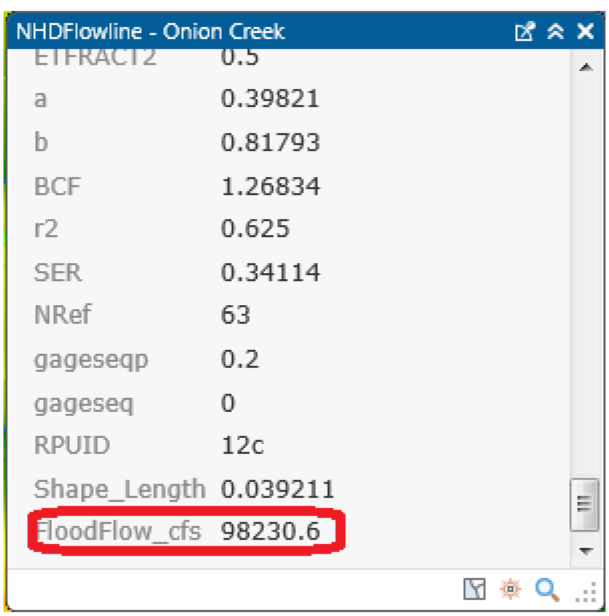
Use identify to determine the length and slope attributes of the NHDFlowline segment through this catchment (length = 4.072 km = 4072 m, slope = 0.001749). Assume mannings n = 0.05. With this information the hydraulic properties and uniform flow discharge needed for a rating curve can be calculated.

Stage h (m)	1	6	10	14
A_s (m^2)	66719			
A_b (m^2)	66803			
V (m^3)	47971			
L (m)	4072	4072	4072	4072
A = V/L (m^2)	11.8			
P=A_b/L (m)	16.4			
R=A/P (m)	0.719			
S_o	0.001749	0.001749	0.001749	0.001749
n	0.05	0.05	0.05	0.05
$Q = \frac{1}{n} A R^{\frac{2}{3}} S_o^{\frac{1}{2}}$ (m^3/s)	7.92			
Q (ft^3/s) = Q (m^3/s) x 35.3	279.6			

Follow the procedure above to determine the discharge associated with stage heights of 6, 10 and 14 m and fill in the table above.

To turn in. Table giving hydraulic properties and discharge associated with stage heights of 6, 10 and 14 m. Plot a rating curve with discharge on the x axis and stage height on the y axis (convert to ft) that has four points corresponding to depths of 1, 6, 10 and 14 m.

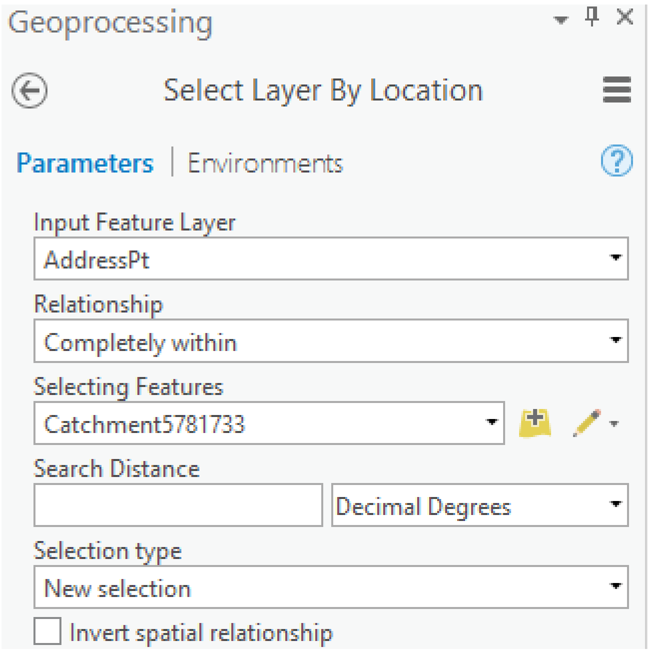
The NHDFlowline feature class provided for this exercise has an attribute FloodFlow_cfs. This is the last column. This was calculated taking the October 31, 2013 Onion Creek flood discharge of 120,000 ft^3/s and scaling by Q00001A to obtain an estimate that is roughly based on contributing area for each reach. The FloodFlow_cfs for this reach is indicated as 98231 ft^3/s.



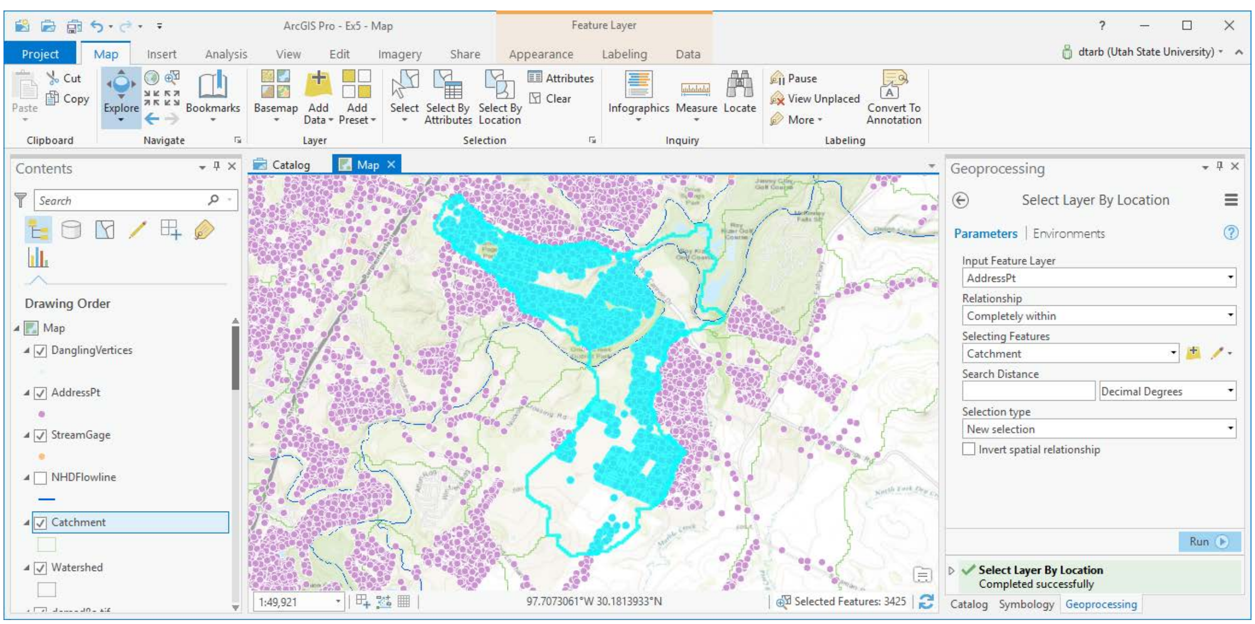
Interpolate based on the results above a stage height that corresponds to this discharge. If you are unable to succeed with the calculations above pick a stage height of 6 m.

To turn in. Report the stage associated with a potential flood discharge of 98231 ft^3/s in Catchment with COMID = 5781733.

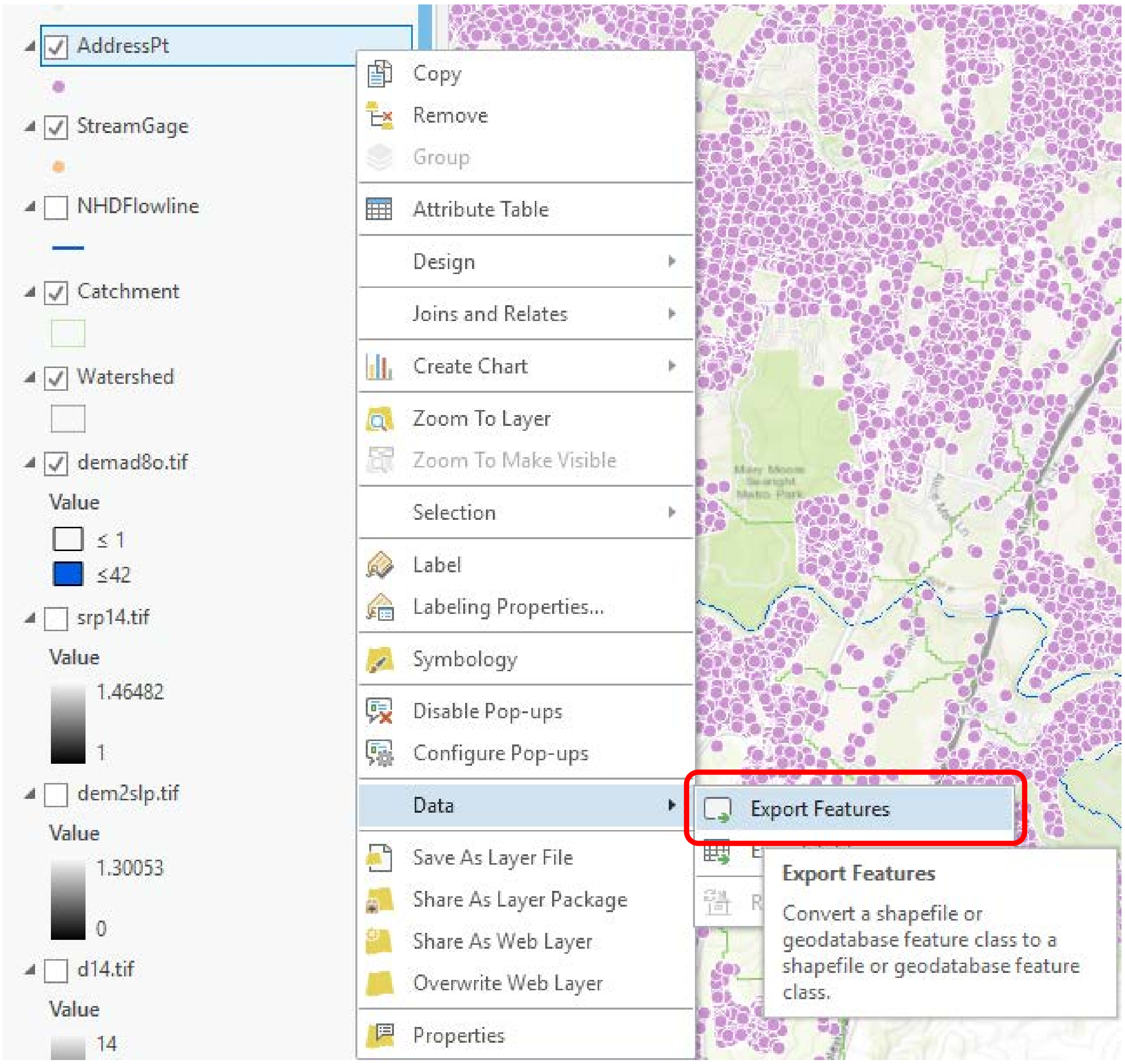
Use Raster Calculator functions to determine the Inundation depth in this catchment for the stage height you calculated. Add the **AddressPt** Feature class to your map. Use **Select by Location** to Create a new feature class that is just address points in **Catchment 5781733**.

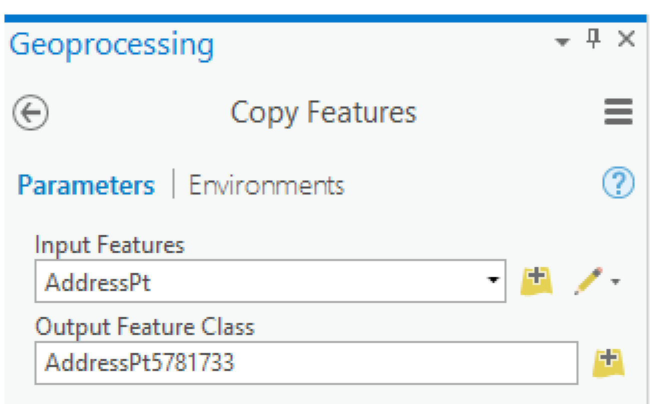


You should see the following with just address points in Catchment 5781733 selected.

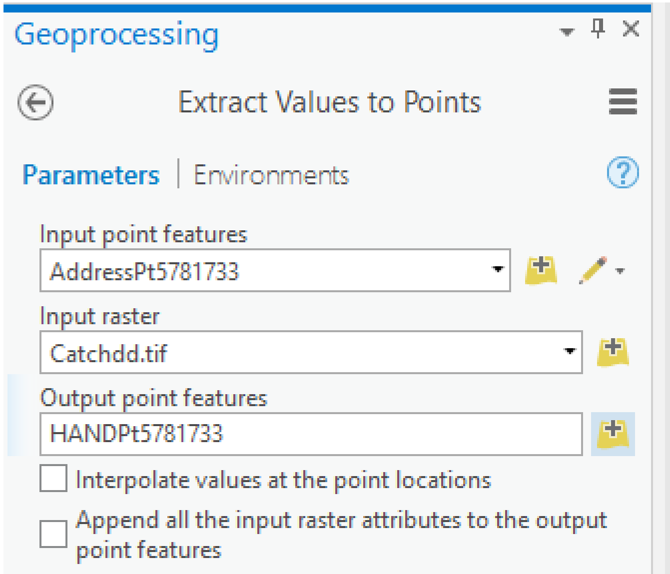


Export the selected AddressPt dataset as a feature class **AddressPt5781733.**

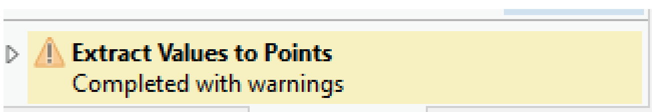




Use **Extract Values to Points** to determine HAND from catchdd.tif for addresses in this catchment. What you are doing is to overlay the AddressPts on the HAND raster and determine for each AddressPt what the HAND value is for that Address location.



I ignored the warning I received.



I think it is inconsequential and as a result of a small datum difference.

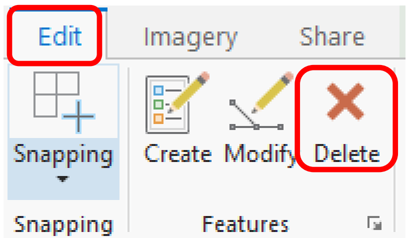
Open the attribute table for HANDPt5781733. RASTERVU gives the raster value (HAND) for each address point. Sort Ascending on the RASTERVU column. You will see that the water depth in Onion Creek has to rise to about 8m before many address points start getting flooded in this area.

HANDPt5781733

OBJECTID	Shape	ElevationM	ElevationFT	COMID	RASTERVALU
2419	Point	174.383	572.123	5781733	<Null>
2477	Point	199.434	654.311	5781733	<Null>
2554	Point	170.731	560.141	5781733	<Null>
2747	Point	171.838	563.773	5781733	<Null>
3003	Point	179.287	588.212	5781733	<Null>
3324	Point	176.567	579.288	5781733	<Null>
3097	Point	153.754	504.442	5781733	2.262756
454	Point	163.192	535.407	5781733	3.556214
746	Point	159.639	523.75	5781733	7.541763
2877	Point	174.387	572.136	5781733	8.04714
2878	Point	174.389	572.142	5781733	8.075903
2870	Point	174.486	572.461	5781733	8.133614

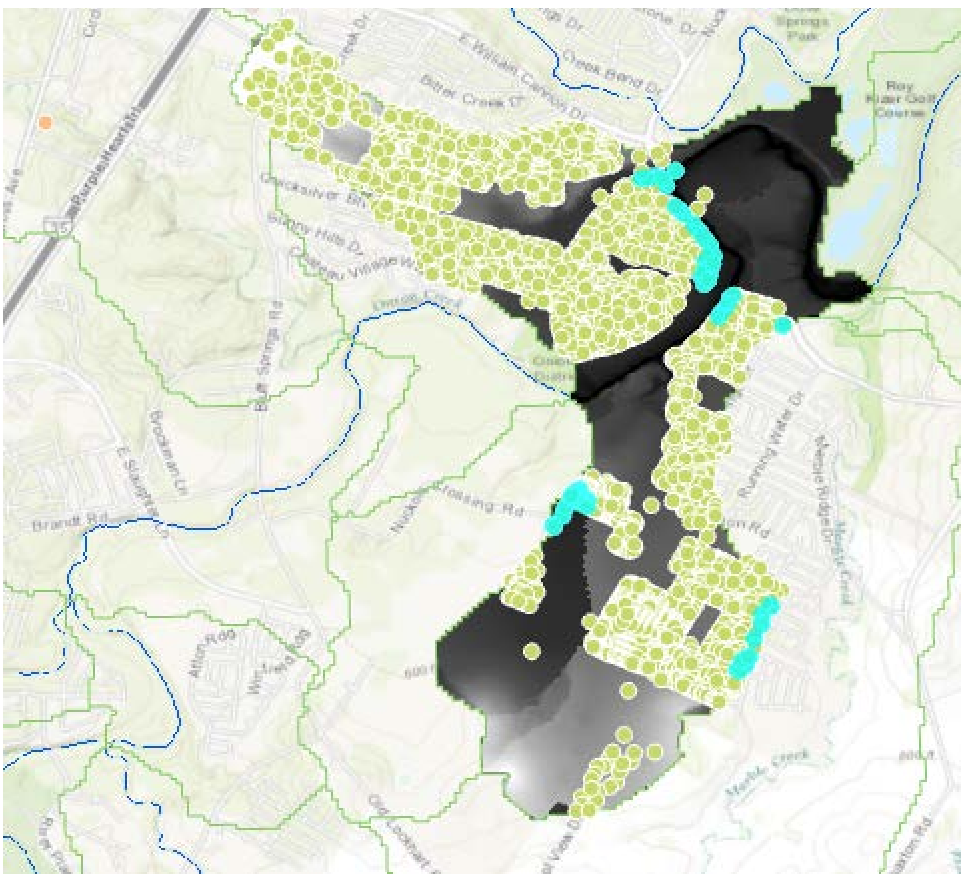
Note that there are also Null values in this table. If you zoom in close on these points you will see that they fall within Catchment5781733 but outside the Catchdd.tif raster that has HAND values for this Catchment.

Select these HANDPT5781733 features with Null RASTERVU and delete them from the feature class.



Select all address points with RASTERVU less thanthe flood stage height you determined to show the addresses subject to flooding for this discharge.

Following are address points with HAND value less than 9 m.



Note that some of these address points are incorrect and not adjacent to the stream. This occurs due to inconsistencies between the high resolution (10 m) DEM we used for HAND and NHDPlus catchments that were delineated using a 30 m DEM which along the edges may include area that drains to another stream. This underscores the importance of having consistent catchments and DEM in this process.

Prepare a map that shows addresses where the HAND value is less than the flood stage height you determined. These are addresses subject to flooding for this discharge. Prepare a plot that shows the distribution of inundation depths (as a histogram) for address points within this catchment.

To turn in. A layout showing the catchment with COMID= 5781733. On this layout include HAND, potential flood inundation depth based on your calculate flood stage. Include address points using a separate symbol for address points subject to flooding in this potential flood. Your plot that shows the distribution of inundation depths for address points potentially subject to flooding in this catchment at this discharge.

OK. You are done!

Summary of Items to turn in.

1. *Make a screen shot of the CyberGIS map of HAND you produce zoomed out and zoomed in to an area of interest. Write a short explanation of the color symbology interpretation.*
2. *Make a map layout of the HAND raster that illustrates it nicely. Include NHDFlowline and catchment feature classes in this map, together with a legend, title and scale bar.*
3. *Table giving hydraulic properties and discharge associated with stage heights of 6, 10 and 14 m. Plot a rating curve with discharge on the x axis and stage height on the y axis (convert to ft) that has four points corresponding to depths of 1, 6, 10 and 14 m.*
4. *Report the stage associated with a potential flood discharge of 98231 ft^3/s in Catchment with COMID = 5781733.*
5. *A layout showing the catchment with COMID= 5781733. On this layout include HAND, potential flood inundation depth based on your calculate flood stage. Include address points using a separate symbol for address points subject to flooding in this potential flood. Your plot that shows the distribution of inundation depths for address points potentially subject to flooding in this catchment at this discharge.*