# 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 (<u>http://hydrology.usu.edu/dtarb/giswr/2017/Ex5.zip</u>)

- 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

(<u>http://hydrology.usu.edu/dtarb/giswr/2017/Ex5Intermediate.zip</u>) 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.

Geoprocessing		≁ Ū ×					
	Feature Vertices To Points	≡					
Parameters   Environments		?					
Input Features							
NHDFlowline		- 🖻					
Output Feature Class C:\Users\dt\Desktop\giswr201	Output Feature Class C:\Users\dt\Desktop\giswr2017\Ex5\Onion\OnionHand.gdb\Geographic\DanglingVertices						
Point Type Dangling vertex		•					

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.

$\odot$	Feature to Raster	≡
Parameters   Environ	ments	?
Input features		
DanglingVertices		- 💾
Field		
StartFlag		•
Output raster		
Start.tif		<u></u>
Output cell size		
9.2592593000003E-05		<u>+</u>

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.

Geoprocessing				*	ά×
${}^{}$		≡			
Parameters   Env	ironments				?
Output Coordinate	e System				-
GCS_North_Amer	ican_1983 / VCS:Unkn	owi	n	•	۲
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(i) Extent		As	Specified Below		•
-98.3076851851	91	<b>→</b>	-97.579537033839		
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Snap Raster		1			
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Output CONFIG Ke	eyword				
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	Skip first				
F	Resampling technique	NE	AREST		•
	Compression type	DE	FAULT		•
Compression	Туре	LZ	77		•
Tile Size	Width				128
	Height				128

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.

General Metadata	∼ Data Sour	ce			<u></u>
Source	Data Type	Raster			
Elevation	Location	C:\Users\dtarb	o\Documents\E	x5\Onion\	
Cache	Dataset	Start.tif			
Joins Relates	❤ Raster Info	ormation			
	Columns		7864		
	Rows		2761		
	Number of	Bands	1		

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.

¢	Reclassify			
Parameters   Environme	nts	?		
Input raster				
Start.tif		- 💾		
Reclass field				
Value		•		
Reclassification		Reverse New Values		
Value		New		
0	0			
1	1			
NODATA	0			
Unique Classify		🗃 🔒 🔌		
Output raster				
Startrc.tif		<b>*</b>		
Change missing values	to NoData			

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.



<i>e</i> Choose File to Upload					
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ጵ Favorites 📃 Desktop	Documents library				Arrange by: Folder -
Downloads	Name	Date modified	Туре	Size	<u>^</u>
🕍 Recent Places	<u> OnionHand</u> .gdb	10/18/2016 12:54	File folder		
🥽 Libraries	🔜 Onion3.tif	10/18/2016 12:14	TIFF image	86,655 KB	
Documents	🖭 Onion3.tif.aux.xml	10/18/2016 12:14	XML Document	3 KB	
A Music	Start.tfw	10/18/2016 12:39	TFW File	1 KB	
Pictures	😹 Start.tif	10/18/2016 12:39	TIFF image	529 KB	
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1	Start.tif.ovr	10/18/2016 12:39	OVR File	36 KB	
💷 Computer	Start.tif.vat.cpg	10/18/2016 12:39	CPG File	1 KB	
a Local Disk (C:)	Start.tif.vat.dbf	10/18/2016 12:39	DBF File	1 KB	
New Volume (E:)	Start.tif.vat.dbf.TESTERW764.3528.4040.sr	10/18/2016 12:39	LOCK File	0 KB	
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File na	me: "Startrc.tif" "Onion3.tif"			✓ All Files	(*.*) -
				Ομ	en Cancel

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.



Authors: Owners: Resource type: Created: Last updated:	Dave Tarboton Dave Tarboton Generic Oct. 18, 2016, 7:08 a.m. Oct. 18, 2016, 7:08 a.m. by Dave Tarboton	
Abstract		
Digital elevation	model and related files for a height above the nearest drainage analysis in Onion Creek.	
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#### 3. Use CyberGIS

Go to <u>http://gwdev8.cigi.illinois.edu/home/</u>. 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.

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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.

$\bigcirc$ Onion Creek Flood Inunda $ imes$ CyberGIS: high-	performance, × +								
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AIS								<u>Logir</u>	Register
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	CyberG15 User Login								
	User ID or E-mail:								
	Please input user ID or e-mail address								
	Password:								
	Please input password								
			Login	Forgot Password?					

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

Authorize TauDEM CyberGIS Hydrologic							
Terrain /	Analysis Ap	p?					
Application req	uires following permi	sions					
<ul> <li>Reading sc</li> <li>Writing sco</li> </ul>	ope pe						
Cancel	Authorize						

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.

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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.

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http://gwdev8.cigi.illinois.edu:8080/home/apps	s 🔎 👻 🌍 Onion Creek Flood Inundation 🥖 Cyl	perGIS: high-performanc 🗙		金衣袋
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App: TauDEM 《	Result Visualization New Analysis Wizard 🛞			
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Data and Parameters	Filter	1		
Data Source Study Area Workflow	Name	RID		
Data Source: HydroShare Data Resource	Common TauDEM Products			
Provider: HydroShare Data Resource	Hydrologically Conditioned Elevation Grid	1		
Coverage:	D8 Flow Direction	3	11	
Lower-left: [-125.001, 23.999]	D8 Slope	2		
Upper-right: [-65.999,50.001]	D8 Contributing Area	6		
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Results +	Slope Average Down	26	Legend: 🛑 need attention 🛑 configurable 🥮 function 🌘	file
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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.

< 🔿 🏉 http://gwdev8.cigi.illinois.edu:8080/home/app	s 🔎 🛫 😋 Onion Creek Flood Inundation 🥖 CyberGIS: high-performanc 🗙 💮 🏠 😳
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Gateway <sup>gwdev3</sup>	Home Apps Visualization Community Help
App: TauDEM	Result Visualization New Analysis Wizard 🖲
My Analysis: -1:my_taudem	Analysis Name:         dem         Progress:         <         Study Area         Product(s)         Parameter(s)         Review         >         Submit         Help
Data and Parameters	D8 Flow Accumulation Options ?
Data Source Study Area Workflow	
Data Source: HydroShare Data Resource Provider: HydroShare Data Resource Coverage: Lower-left: [+25.001, 23.999] Upper-right: [-65.999,50.001] Coverage in Native Projection: Lower-left: [-125.001, 23.999] Upper-right: [-65.999,50.001] Coordinate System: <u>EPSG: 4269</u> Vertical Unit: m	pit influe       pit       Hy       dsf
	Ds   Ds   are   Ds     Inspector:   Type:   file   D:     Z
	Name: Input elevation grid
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CyberGIS G Any opinio	Copyright © 2010-2010 CIGL CyberGIS Gateway, powered by CISolve ateway is based upon work supported in part by the National Science Foundation under Grant Numbers: 0840655, 1047916, and 1443080, ns, findings, and conclusions or recommendations expressed in the Sateway are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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.

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Parameter(s)	Review	>	Submit	Help
w Accumulation Opti	ons			?
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; function doesn't requ	uire anything from	m user.		

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

<u></u>	Gateway gwdevs				
App: TauDEM		<b>«</b>			
My Analysis		=			
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dem	2016/10/18 1:43:32	7			
Eventually the I give a sense of	nammer, changes to a s where the job is in the processi	pinning globe ng. When you	, followed by see the map icon th	he job is comple	that te.

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.

App: TauDEM		*
My Analysis		-
🗿 New 🕜 New fro	🍣 Refresh	
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Then right click on layers that you want to show on the map.

App	o: TauDE	M	~
My	Analysis:	5208:dem	+
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Ŧ	TauDEN	1:5208_demfel	
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You can also expand the + on the right to turn layers on and off.

Base Layer	•
OUSGS Topo	
OUS States	
Overlays	
TauDEM:5463_demfel	
TauDEM:5463_demad8o	
✓TauDEM:5463_demp	



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.

# Content

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<b>2</b> 2 0	00		
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Γ	Γ		
dem-taudem-	dem-taudem-	dem.tif	demad ③ Download

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

	demad8o.tif	≡
Symbology		
Classify		*
Field	No fields	*
Normalization	No fields	Ŧ
Method	Manual Interval	•
Classes	2	*
Color scheme		Ŧ
Nodata	•	
Class breaks		Options *
Symbol	Upper value	Label
	≤ 1	≤ 1
	≤ 85	≤85



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.

App: TauDEM	Result Visualization New Analysis Wizard 🗵
My Analysis: -1:my_taudem +	Analysis Name:         Type here         Progress:         Study Area         Product(s)         Parameter(s)         Review         >         Submit         Help
App: TauDEM       K         My Analysis: -1:my_taudem       +         Data and Parameters       -         Data Source:       Study Area       Workflow         Data Source:       HydroShare Data Resource       Provider: HydroShare Data Resource         Provider:       HydroShare Data Resource       Coverage:         Lower-left:       [-125.001, 23.999]       Upper-right:         Upper-right:       F65.999.50.001]       Coverage in Native Projection:         Lower-left:       [-125.001, 23.999]       Upper-right:         Upper-right:       F65.999.50.001]       Coverage in Native Projection:         Lower-left:       [-125.001, 23.999]       Upper-right:         Vertical Unit:       m       Non1]	Result Visualization       New Analysis Wizard         Analysis Name:       Type here         Progress:       Study Area         Product(s)       Parameter(s)         Review       > Submit         Pitremove       This function doesn't require anything from user.         Dinfinity Distance Down       Pitremove         This function doesn't require anything from user.       Dinfinition doesn't require anything from user.         Din       Select from the external recover         stat method:*       ave
	di di list method: ave list we list we list list we list list we list we list we list list w
Results +	Legend: 🛑 need attention 🛑 configurable 💭 function 🌒 file
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Results +	Slope Average Down 26 Legend: enced attention configurable function file

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

Inspector:		۲
Type:	file	
ID:	Z	
Name:	Input elevation grid	
Override:	/data/contents/Onion3.tif	-
Legend: 🛑 need	attention 🔵 configurable 🛑 function 🌘 file	

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.

App: TauDEM		<b>*</b>
My Analysis		-
💿 New 💿 New	/ from 🔁 Load 🥥 D	)elete 🛛 Refresh
Name	Time created 👻	Status
dem2	2016/10/18 6:52:38	
dem	2016/10/18 1:43:32	

AIS				dtarl	o's Profile   Logo
Gateway <sup>gwdev8</sup>		Home App	s Visualization	Community	Help
App: TauDEM	Result Visualization				
My Analysis: 5466:dem2 +	orgressional "9	EVAC	J Showing the	Mabry Coff	gressional
Data and Parameters	WAG	Congression		A J Dist	inet 25 CC
Results	EXAS	District	21 District 21	AVIS CO	1 122
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	5	Harris Can	1) Distric	Congressional	DISCTIC
	ressional	and the	JAR CHAYS Q	District 27 CALDY	MELL CO

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.

App	App: TauDEM 《						
My	My Analysis: 5210:dem2 +						
Dat	a and Parame	eters					+
Res	ults						
	Data						
Ŧ	TauDEM:5210_dem2ang				÷		
ŧ	TauDEM:5210_dem2slp				÷		
ŧ	TauDEM:52	10_de	m2fel		÷		
÷	TauDEM:52	10 da	m2dd Show on map		+		
		1 1 1	Layer order: up Layer order: down				•

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.



Content

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 <u>http://hydrology.usu.edu/dtarb/giswr/2017/Ex5Intermediate.zip</u>.

#### 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.

R S							
24	Parameters   Environments (?)						
Rips	Layer Name or Table View						
AN S	Catchment 🝷						
1223	Selection type						
42/	New selection 👻						
2 23	Expression						
NS P	SQL E						
Field	Values Fields	]  _ C	ancel				
FEATUREID	▼ is Equal to ▼ 5781733 ▼	] [ U	pdate				

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**.

Geoprocessing			т ц ×
$\odot$	Copy Features		≡
Parameters   Environments			?
(i) Input Featu Catchmen	res t	- 📛	1-
Output Fea Catchmen	ture Class t5781733		<b>(</b>

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.

Geoprocessing	g	*	Ψ×
$\odot$	Extract by Mask		≡
Parameters   E	nvironments		?
Input raster			_
dem2dd.tif		•	÷
Input raster or fe	eature mask data		
Catchment578	1733	- 🖻	/-
Output raster			_
Catchdd.tif			÷
			-

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

€ Raster Calculator	■ 🕑 Raster Calculator ■
Parameters   Environments	Parameters         Environments         ?
Map Algebra expression	Map Algebra expression
Rasters 📇 Tools	Rasters 🖄 Tools
Catchdd.tif ==	Lt1.tif Operators
dem2dd.tif >	Catchdd.tif +
<	dem2dd.tif _
<=	*
>=	v / · · · · · · · · · · · · · · · · · ·
"catchdd.tif" <1	<pre>1-("catchdd.tif" / "lt1.tif") </pre>
Output earter	S Output racter
It1.tif	d1.tif
Raster Calculator     Parameters   Environments	■
(i) Map Algebra expression	Map Algebra expression
Rasters 🖄 Tools	Rasters 🖄 Tools
d1.tif ==	▲ <b>It6.tif</b> ==
↓ It1.tif >	d1.tif >
catchdd.tif	lt1.tif <
dem2dd.tif <=	catchdd.tif <=
>=	▼ dem2dd.tif >= ▼
"catchdd.tif" <6	6-( "catchdd.tif"/ "lt6.tif")
	S Output raster
Output raster	d6.tif

It1.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.

🎹 Cat	hment	📰 lt1	.tif 🗙
Field:	🚛 New	🕎 Delete	🕎 Calcul
	) 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<sup>-5</sup> 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  $10.3 \times 8.92 = 91.9 \text{ m}^2$ .

The surface area at a stage of 1 m is thus  $726 \times 91.9 = 66719 \text{ m}^2$ .

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

Raster Calculator				
Parameters   Environme	ents 🥐			
Map Algebra expression Rasters 🏄	Tools 👕			
dem2slp.tif	SquareRoot			
d1.tif	Trigonometric			
lt1.tif	ACos			
atchdd.tif	ACosH			
dem2dd.tif	ASin			
demad8o.tif	, ASinH 🖕			
SquareRoot(( "dem2s "dem2slp.tif") + 1)	lp.tif" *			
	<b></b>			
Output raster				
srp1.tif	<u>+</u>			

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  $726 \times 91.9 \times 1.00125 = 66803 \text{ m}^2$ 

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 <sub>s</sub> (m <sup>2</sup> )	66719			
A <sub>b</sub> (m <sup>2</sup> )	66803			
V (m <sup>3</sup> )	47971			
L (m)	4072	4072	4072	4072
$A = V/L (m^2)$	11.8			
P=A <sub>b</sub> /L (m)	16.4			
R=A/P (m)	0.719			
So	0.001749	0.001749	0.001749	0.001749
n	0.05	0.05	0.05	0.05
$Q = \frac{1}{n} A R^{\frac{2}{3}} S_o^{\frac{1}{2}}  (\text{m}^3/\text{s})$	7.92			
$Q (ft^3/s) = Q (m^3/s) \times 35.3$	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<sup>3</sup>/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<sup>3</sup>/s.

NHDFlowline - Onion Creek			×
ETFRACT2	0.5		~
а	0.39821		
b	0.81793		
BCF	1.26834		
r2	0.625		
SER	0.34114		
NRef	63		
gageseqp	0.2		
gageseq	0		
RPUID	12c		
Shape_Length	0.039211	-	-
FloodFlow_cfs	98230.6		-
		🖸 🕸 🔍 .	

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  $98231 \text{ ft}^3/\text{s}$  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**.

Geoprocessing	тц×						
Select Layer By Location	≡						
Parameters   Environments	?						
Input Feature Layer							
AddressPt	•						
Relationship							
Completely within	•						
Selecting Features							
Catchment5781733 🔹 🎽	± 🖊 -						
Search Distance							
Decimal Degrees	•						
Selection type							
New selection	•						
Invert spatial relationship							

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



Export the selected AddressPt dataset as a feature class AddressPt5781733.

A Address Dt		
Addlesset	Сору	
🔺 🔽 StreamGage	Remove	
	Group	
▲	Attribute Table	
	Design	
⊿ 🗸 Catchment	Joins and Relates	•
▲ 🗸 Watershed	1 Create Chart	
	Zoom To Layer	and the second
⊿ 🗸 demad8o.tif	Zoom To Make Visible	Mary Mary Road State State State
Value	Selection	· ·
≤ 1	Label	
▲ srp14.tif	Labeling Properties	
Value	Symbology	
1.46482	Disable Pop-ups	
1	Configure Pop-ups	
dem2slp.tif	Data	Export Features
Value	Save As Layer File	
1.30033	Share As Layer Package	Export Features
0	Share As Web Layer	geodatabase feature class to a
⊿ 🗌 d14.tif	Overwrite Web Layer	shapefile or geodatabase feature class.
Value	Properties	Big y garage
Geoprocessing	₩ ₽ ×	
Copy Feature		
Parameters   Environments	?	
Input Features		
AddressPt	• 🖄 🦯 •	
Output Feature Class		
AddressPt5781733	<u></u>	

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.

Geoprocessing -	ά×
Extract Values to Points	≡
Parameters   Environments	?
Input point features	
AddressPt5781733 🔹 📩	/-
Input raster	
Catchdd.tif •	+
Output point features	
HANDPt5781733	<b>(†</b>
Interpolate values at the point locations	
Append all the input raster attributes to the outp point features	out

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.

	III HANDPt5781733 ×							
Fie	e <b>ld:</b> 🚌 Add	🕎 Del	ete 🕎 Calcu	🖪 Calculate 🛛 Selection: 🕀 Zoom To 📲 Switch 📃 Cl			h 🗏 Clear	
⊿	OBJECTID	Shape	ElevationM	ElevationFT	COMID	RASTERVALU 🔺		
	2419	Point	174.383	572.123	5781733	<null></null>		
	2477	Point	199.434	654.311	5781733	<null></null>		
	2554	Point	170.731	560.141	5781733	<null></null>		
	2747	Point	171.838	563.773	5781733	<null></null>		
	3003	Point	179.287	588.212	5781733	<null></null>		
	3324	Point	176.567	579.288	5781733	<null></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  $98231 \text{ ft}^3/\text{s}$  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.