

# DSM, DTM, and watershed characteristics in OpenTopography

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GEOLOGICAL  
SURVEY



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THE UNIVERSITY OF UTAH

## *Tutorial notes*

*Applications of High Resolution Topography to Geologic Hazards in Utah  
September, 2017, Salt Lake City, Utah*



# OpenTopography

*High-Resolution Topography Data and Tools*

## **Overview**

Demonstrate the OpenTopography point cloud to raster workflow. Using predominantly the digital terrain model (“bare earth”) compute topographic metrics emphasizing the drainage network contributing area and topographic roughness using ArcGIS.

## **Outline**

1. Short lecture on watersheds and flow related terrain information
2. Compute DSM and DTM on selected data in OpenTopography.
3. Select data and run DTM computations including using TAUDDEM for watershed calculations in OpenTopography.
4. Compute topographic roughness in ArcMap
5. Manipulate and visualize drainage network in ArcMap and ArcScene

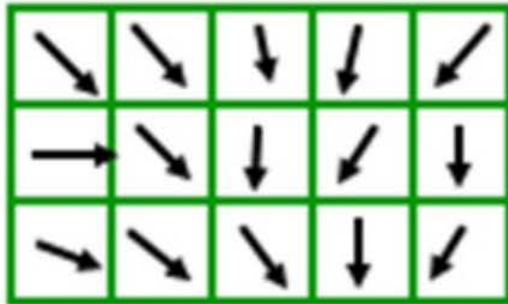
Raw DEM



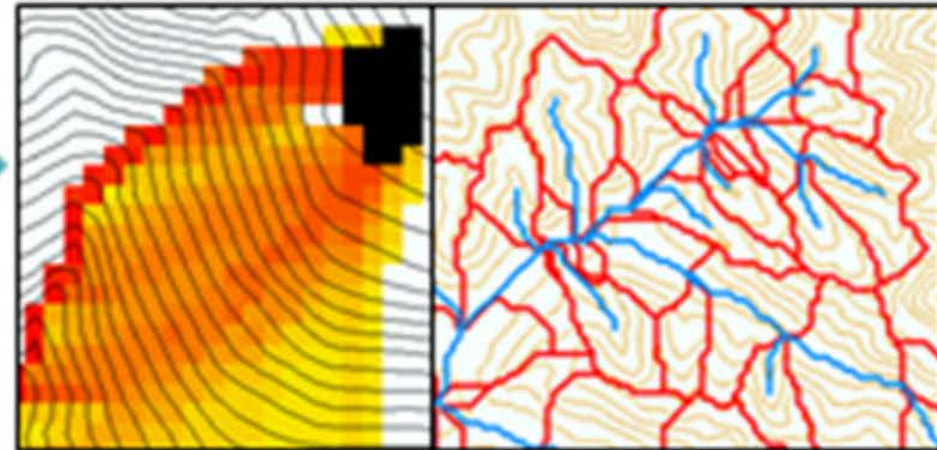
Pit Removal (Filling)



Flow Field



Flow Related Terrain Information



**TauDEM 5.0**

<http://hydrology.usu.edu/taudem/taudem5/>

## WATERSHED DELINEATION USING TAUEM

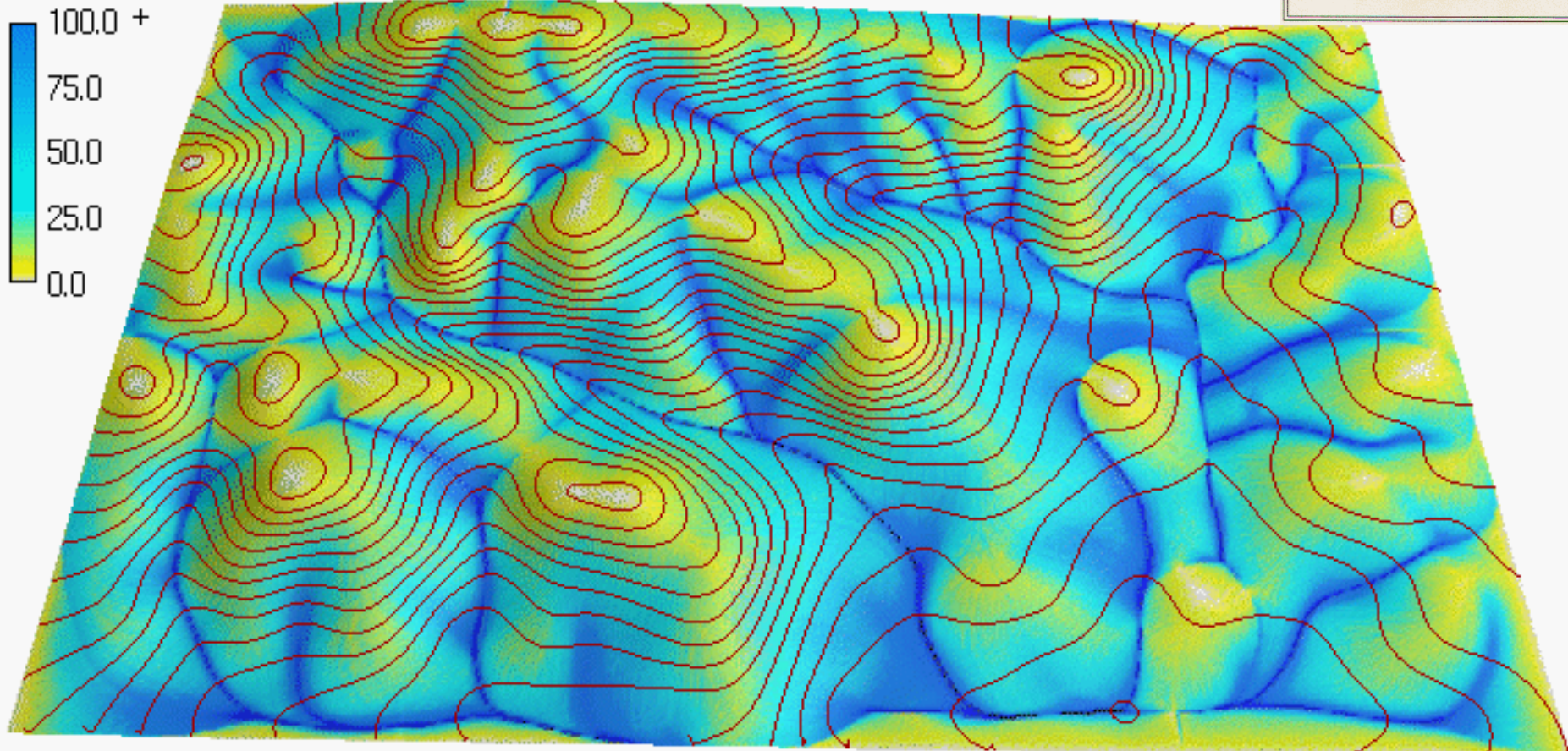
A tutorial for using TauDEM to delineate a single watershed





GRASS

UPSLOPE AREA

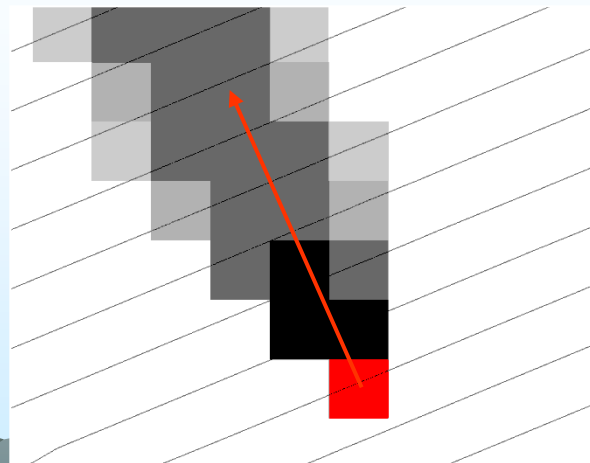
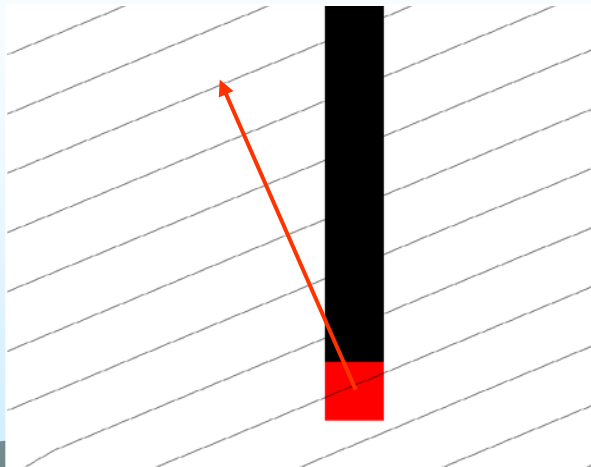
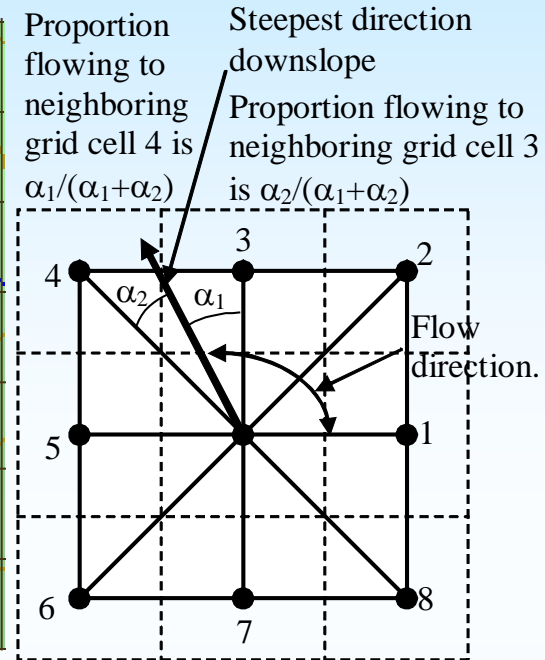
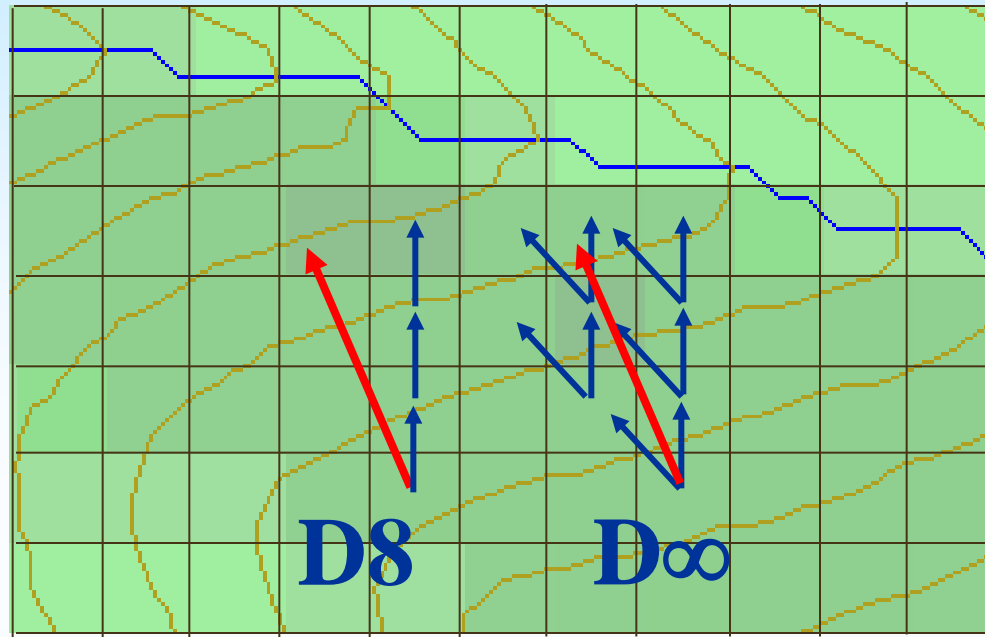


# Representation of Flow Field

Steepest single direction

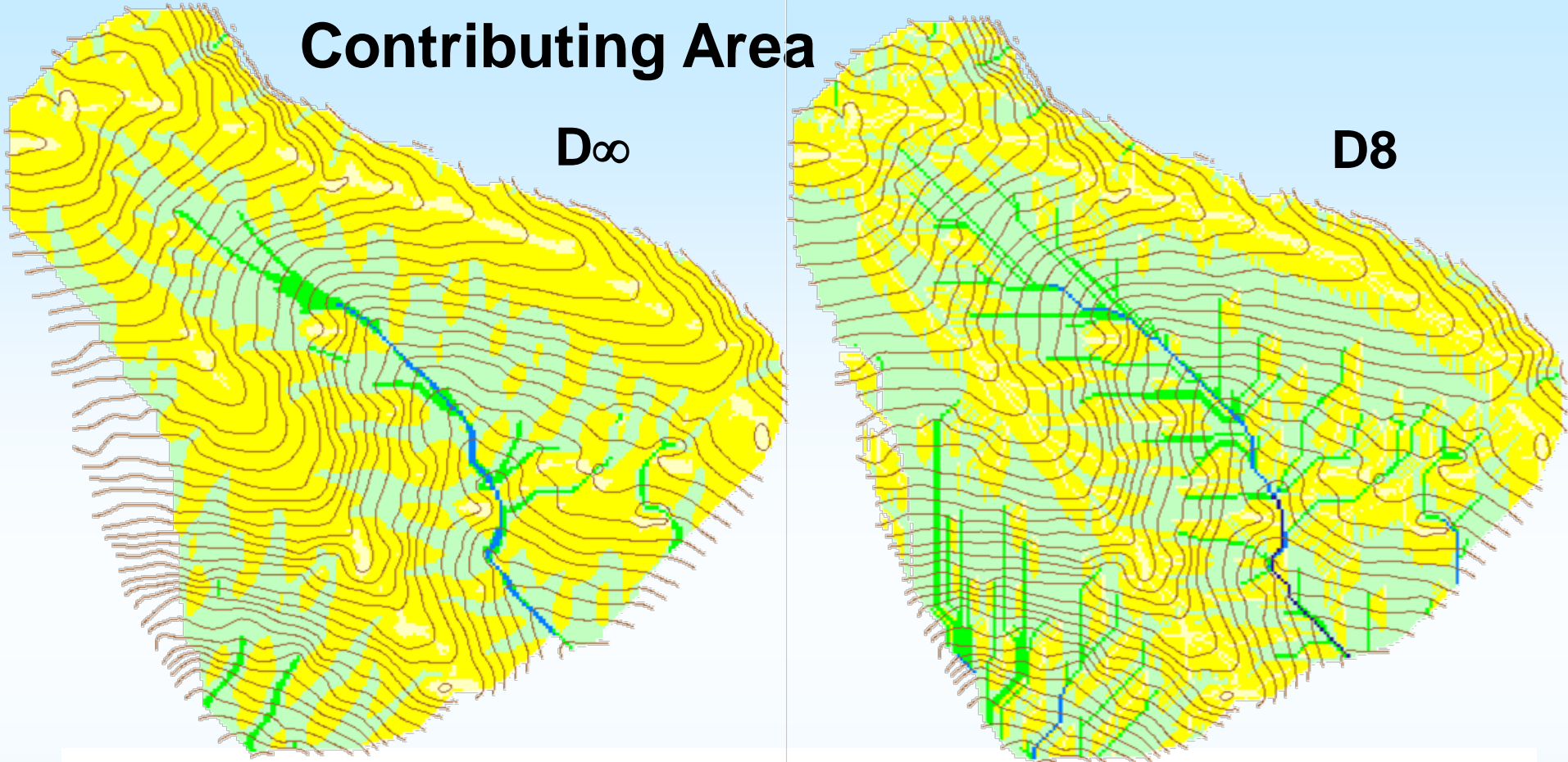
48	52
56	67

$$\frac{67 - 52}{30} = 0.50$$





# Contributing Area



**Table 2.** Differences Between Theoretical and DEM-Computed Upslope Area for Test Examples Expressed in Terms of the Mean Error and Mean Square Error

	Outward Cone		Inward Cone		Plane	
	Bias Mean $(A - \hat{A})$	MSE Mean $((A - \hat{A})^2)$	Bias Mean $(A - \hat{A})$	MSE Mean $((A - \hat{A})^2)$	Bias Mean $(A - \hat{A})$	MSE Mean $((A - \hat{A})^2)$
D8	-0.13	2.13	1.76	118.88	-0.17	0.065
MS	-0.81	0.69	-1.07	5.70	-1.37	2.065
Lea's [1992] method	-1.29	2.41	-4.05	44.00	-2.57	7.912
DEMON	-0.37	0.17	-0.37	19.23	-0.40	0.161
D $\infty$	-0.13	0.20	1.87	30.58	-0.17	0.065



# OpenTopography

High-Resolution Topography Data and Tools

## Log In

Log in to OpenTopography with your email and password.

Username (Email) \*

ramon.arrowsmith@asu.edu

Password \*

••••••••

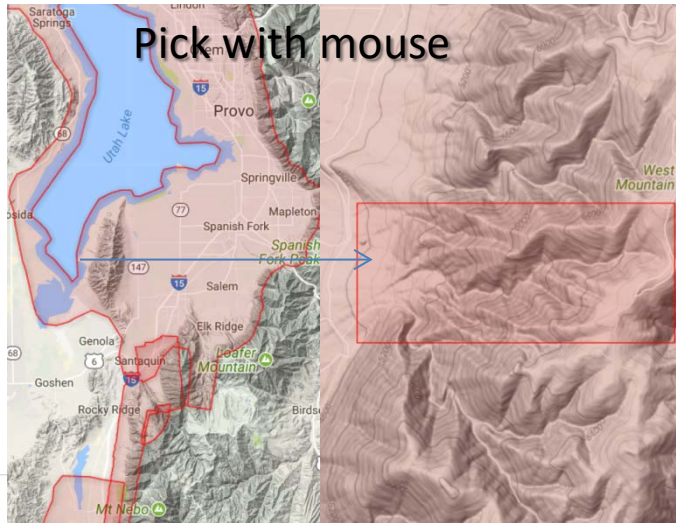
Remember my login

LOG IN

# State of Utah Acquired Lidar Data - Wasatch Front



- HOME
- ABOUT ▾
- DATA ▾
- TOOLS ▾
- LEARN ▾
- COMMUNITY ▾



## 4. Derivative products ⓘ

Generate hillshade and slope grids in grid format

GeoTiff ▾

## 5. Visualization ⓘ

Generate hillshade images from DEMs

Generate additional color-relief and colored hillshades

Generate additional Google Earth KMZ files

Altitude of the light, (in degrees)

Azimuth of the light, (in degrees)

Click for KMZ

Horizontal Coordinates: UTM Zone 12N, NAD83 (2011) [EPSG: 26912]  
Vertical Coordinates: NAVD88 (GEOID12A) [EPSG: 5703]

Data Selection Coordinates:  Manually enter selection coordinates (in the horizontal coordinate system listed above)

X<sub>min</sub> = 427611.125064    Y<sub>min</sub> = 4436738.937367  
X<sub>max</sub> = 429837.230033    Y<sub>max</sub> = 4437758.70925

The selection area contains approximately 34,455,000 points.

Choose Return Classification ⓘ

Ground     Unclassified

All points

## 2. Point Cloud Data Download

- Point cloud data in LAS format
- Point cloud data in LAZ format
- Point cloud data in ASCII format

## 3A. DEM Generation (Streaming TIN) ⓘ

Gridding Method

Calculate TIN

Gridding Parameters

Grid Resolution (Default = 1 meter)

Max. triangle size (Default 50 units)

Grid Format

GeoTiff ▾

## Description

options allow users to describe and keep track of their jobs. Information entered below is recorded along with other job parameters in your personal lidar job accessed via myOpenTopo (available only to registered OpenTopography users).

Title (up to 100 characters)

West Mountain

Meaningful name and submit

Description (up to 500 characters)

Job description

Your e-mail address

Ramon.arrowsmith@asu.edu

Notification upon completion of processing

Compute 1m DSM with slope map, hillshades and kmz in OpenTopography

1 m DSM from TIN



# Point Cloud Job Report

Modify and resubmit this job  
Full job metadata report

**Modify and resubmit: just a couple of changes for the DTM and tauDEM; can also find it in MyOpenTopo**

Job Id	Dataset	Title	Submission	Completion	Duration	Points	Format
pc1505706169406	UGS_Wasatch	West Mountain	2017-09-17 20:42:49	N/A	N/A	34,978,372	Streaming TIN

## 1. Coordinates & Classification

Horizontal Coordinates: UTM Zone 12N, NAD83 (2011) [EPSG: 26912]

Vertical Coordinates: NAVD88 (GEOID12A) [EPSG: 5703]

Data Selection Coordinates:  Manually enter selection coordinates (in the horizontal coordinate system listed above)

X<sub>min</sub> = 427601.376371    Y<sub>min</sub> = 4436717.985397    X<sub>max</sub> = 429846.630333    Y<sub>max</sub> = 4437779.667239

The selection area contains approximately 15,071,000 points.

Choose Return Classification

Ground     Unclassified

## Select Ground Only

## 6. Hydrologic Terrain Analysis Products (tauDEM)

### All tauDEM products

Hydrologically correct DEM with pits filled

D-Infinity Flow Direction  
 D8 Flow Direction:

D-Infinity Specific Catchment Area  
 D8 Contributing Area

Topographic Wetness Index

## Job Description

These options allow users to describe and keep track of their jobs. Information entered below is recorded along with other job parameters in your personal lidar Job archive accessed via [myOpenTopo](#) (available only to [registered](#) OpenTopography users).

Job title (up to 100 characters)

West Mountain TauDEM **Change job title**

Job description (up to 500 characters)

Job description

Enter your e-mail address

ramon.arrowsmith@asu.edu

for notification upon completion of processing



# myOpenTopo Workbench

Welcome Ramon Arrowsmith


Jobs currently running: 2  (Point Cloud jobs: 2)

 User

 Admin

Data

## User Point Cloud Jobs

	Job Id	Dataset	Title	Submission ↓	Status
1	<a href="#">pc1505706544249</a>	UGS_Wasatch	[E] West Mountain TauDEM	2017-09-17 20:49:04	Querying 
2	<a href="#">pc1505615743550</a>	UGS_Wasatch	[E] UGS Pearsons Canyon demo	2017-09-16 19:35:44	Done
3	<a href="#">pc1504304147938</a>	UGS_Wasatch	[E] weber test ground	2017-09-01 15:15:48	Done (Expired)
4	<a href="#">pc1504304037763</a>	UGS_Wasatch	[E] weber test	2017-09-01 15:13:57	Done (Expired)

1. [Point Cloud Jobs](#): View currently submitted and previous point cloud jobs.
2. [Raster Jobs](#): View currently submitted and previous raster jobs.
3. [User Jobs Statistics](#): Overview of your processing jobs statistics.

# Point Cloud Job Report

[Modify and resubmit this job](#)  
[Full job metadata report](#)

[Download Job Metadata](#)  
[View Job Configuration](#) 🔍

Job Id	Dataset	Title	Submission	Completion	Duration	Num points	Final Status
pc1505706169406	UGS_Wasatch	West Mountain	2017-09-17 20:42:49	2017-09-17 20:45:34	165 secs	34,978,372	Done ✓

## Download products and quick visualization in Google Earth

### Download Job Results

#### Point Cloud Results

- Download point cloud data in LAS format [points.las](#) (1.1 GB)

#### DEM Results

- Download DEM (TIN) [dems.tar.gz](#) (5.9 MB)

#### Derivative Products

- Download Hillshade & Slope Products (TIN) [viz.tar.gz](#) (9.4 MB)

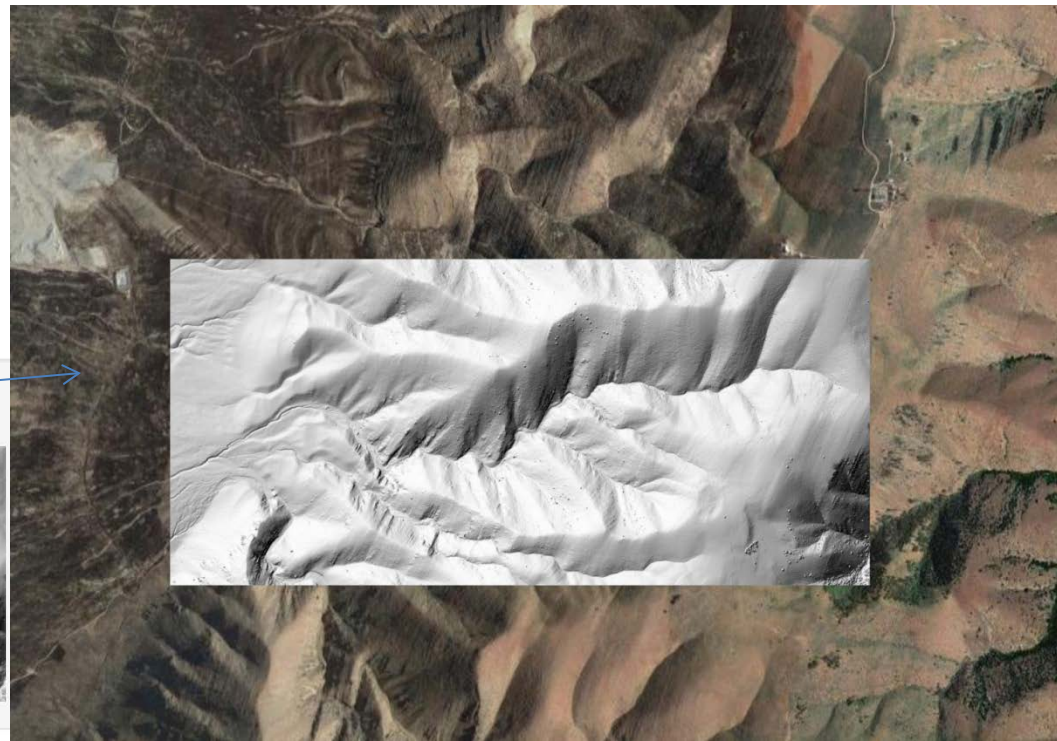
## Download dems as DSM

## View KMZ in Google Earth

### Visualization Products

#### Ztin DEM

- [View with Google Map](#)



# Point Cloud Job Report

[Modify and resubmit this job](#)  
[Full job metadata report](#)

[Download Job Metadata](#)  
[View Job Configuration](#) 🔍

Job Id	Dataset	Title	Submission	Completion	Duration	Num points	Final Status
pc1505706544249	UGS_Wasatch	West Mountain TauDEM	2017-09-17 20:49:04	2017-09-17 20:52:16	192 secs	17,715,525	Done ✓

## Download products and quick visualization in Google Earth

### Download Job Results

#### Point Cloud Results

- Download point cloud data in LAS format [points.las](#) (574.4 MB)

#### DEM Results

- Download DEM (TIN) [dems.tar.gz](#) (6.1 MB) **Download dems as DTM**

#### Derivative Products

- Download Hillshade & Slope Products (TIN) [viz.tar.gz](#) (9.8 MB) **Hillshades too**

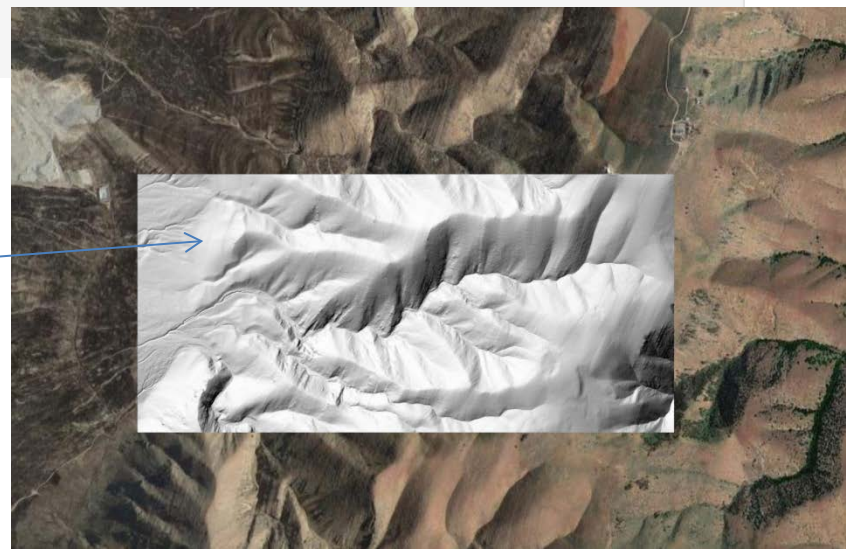
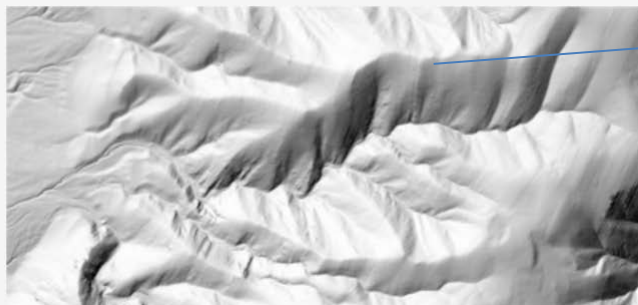
#### TauDEM Products

- Download PitRemove file [pitRemove.tar.gz](#) (5.9 MB)
- Download D-Infinity: Flow Direction file [dinfFlowDirection.tar.gz](#) (6.4 MB)
- Download D-Infinity: Slope file [dinfSlope.tar.gz](#) (5.9 MB)
- Download D-Infinity Specific Catchment Area file [Dinfarea.tar.gz](#) (7 MB)
- Download Topographic Wetness Index file [TWI.tar.gz](#) (6.7 MB)
- Download D8 - Flow Direction file [d8FlowDirection.tar.gz](#) (497.3 KB)
- Download D8: Slope file [d8Slope.tar.gz](#) (3.8 MB)
- Download D8 Contributing Area file [D8area.tar.gz](#) (2.5 MB)

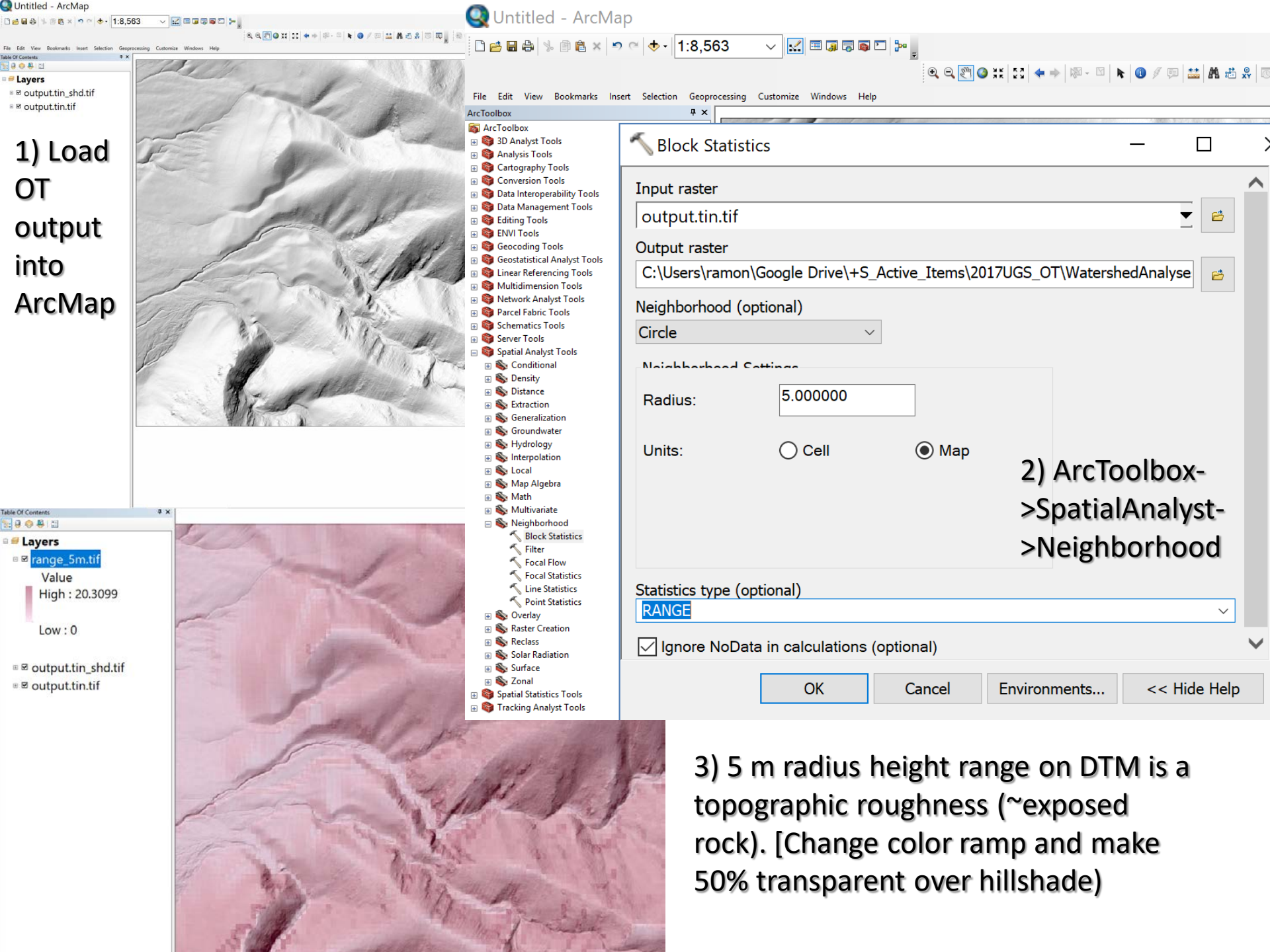
### Visualization Products

#### Ztin DEM

- [View with Google Map](#)








1) Load OT output into ArcMap

2) ArcToolbox->SpatialAnalyst->Neighborhood

3) 5 m radius height range on DTM is a topographic roughness (~exposed rock). [Change color ramp and make 50% transparent over hillshade]

Job Id	Dataset	Title	Submission	Completion	Duration	Num points	Final Status
pc1505706544249	UGS_Wasatch	West Mountain TauDEM	2017-09-17 20:49:04	2017-09-17 20:52:16	192 secs	17,715,525	Done 

## Download Job Results

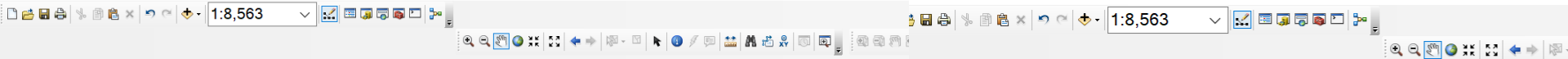
**Download products to a watershed folder and uncompress.**

- Point Cloud Results
  - Download point cloud data in LAS format [points.las](#) (574.4 MB)
- DEM Results
  - Download DEM (TIN) [dems.tar.gz](#) (6.1 MB)
- Derivative Products
  - Download Hillshade & Slope Products (TIN) [viz.tar.gz](#) (9.8 MB)
- TauDEM Products
  - Download PitRemove file [pitRemove.tar.gz](#) (5.9 MB)
  - Download D-Infinity: Flow Direction file [dinfFlowDirection.tar.gz](#) (6.4 MB)
  - Download D-Infinity: Slope file [dinfSlope.tar.gz](#) (5.9 MB)
  - DinfArea**  - Download D-Infinity Specific Catchment Area file [Dinfarea.tar.gz](#) (7 MB)
  - Download Topographic Wetness Index file [TWI.tar.gz](#) (6.7 MB)
  - Download D8 - Flow Direction file [d8FlowDirection.tar.gz](#) (497.3 KB)
  - Download D8: Slope file [d8Slope.tar.gz](#) (3.8 MB)
  - Download D8 Contributing Area file [D8area.tar.gz](#) (2.5 MB)

# Mosaic to new raster the output files

Untitled - ArcMap

Untitled - ArcMap



- ArcToolbox
  - 3D Analyst Tools
  - Analysis Tools
  - Cartography Tools
  - Conversion Tools
  - Data Interoperability Tools
  - Data Management Tools
  - Archiving
  - Attachments
  - Data Comparison
  - Distributed Geodatabase
  - Domains
  - Feature Class
  - Fields
  - File Geodatabase
  - General
  - Generalization
  - Geodatabase Administration
  - Geometric Network
  - Graph
  - Indexes
  - Joins
  - LAS Dataset
  - Layers and Table Views
  - Package
  - Photos
  - Projections and Transformations
  - Raster
    - Mosaic Dataset
    - Raster Catalog
    - Raster Dataset
      - Copy Raster
      - Create Random Raster
      - Create Raster Dataset
      - Download Rasters
      - Mosaic
      - Mosaic To New Raster
      - Raster Catalog To Raster Dataset
      - Workspace To Raster Dataset
  - Raster Processing
  - Raster Properties
  - Relationship Classes
  - Subtypes
  - Table
  - Tile Cache
  - Topology
  - Versions
  - Workspace
  - Editing Tools
  - ENVI Tools
  - Geocoding Tools
  - Geostatistical Analyst Tools
  - Linear Referencing Tools
  - Multidimension Tools
  - Network Analyst Tools
  - Parcel Fabric Tools
  - Schematics Tools
  - Server Tools
  - Spatial Analyst Tools
  - Conditional

### Mosaic To New Raster

**Input Rasters**

C:\Users\ramon\Google Drive\+S\_Active\_Items\2017UGS\_OT\WatershedAn...  
C:\Users\ramon\Google Drive\+S\_Active\_Items\2017UGS\_OT\WatershedAn...

**Output Location**

C:\Users\ramon\Google Drive\+S\_Active\_Items\2017UGS\_OT\WatershedAnalyse

**Raster Dataset Name with Extension**

dinf.tif

**Spatial Reference for Raster (optional)**

**Pixel Type (optional)**

32\_BIT\_FLOAT

**Cellsize (optional)**

**Number of Bands**

1

**Mosaic Operator (optional)**

LAST

**Mosaic Colormap Mode (optional)**

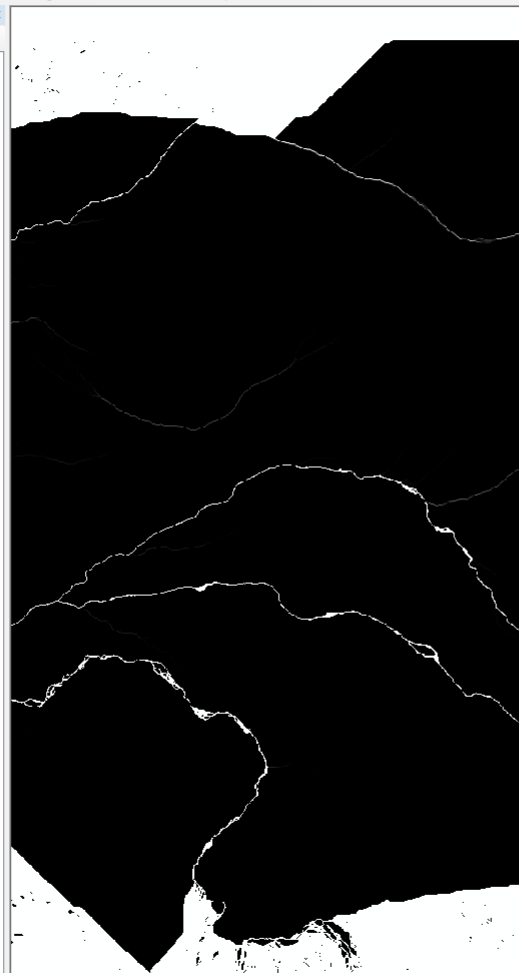
FIRST

OK Cancel Environments... << Hide Help

### Layers

- dinf.tif
  - Value
  - High : 146985
  - Low : 1
- range\_5m.tif
  - Value
  - High : 20.3099
  - Low : 0
- output.tin\_shd.tif
- output.tin.tif

Note that this is number of cells above a given point. Given resolution of 1m/pix this is in sq. m.



# Compute log10 of the area using Raster Calculator

Untitled - ArcMap

The screenshot shows the ArcMap interface with the Raster Calculator tool open. The 'Map Algebra expression' field contains the text `Log10("dinf.tif")`. The 'Output raster' field contains the path `C:\Users\ramon\Google Drive\+S_Active_Items\2017UGS`. The ArcToolbox on the left is visible, with the 'Raster Calculator' tool highlighted in a blue circle. The top menu bar includes File, Edit, View, Bookmarks, Insert, Selection, Geoprocessing, Customize, Windows, and Help. The top toolbar shows various navigation and tool icons.

Now we are getting a sense of the drainage network.

Untitled - ArcMap

This screenshot shows the ArcMap interface after the Raster Calculator operation. The 'Layers' panel on the left displays the output raster `log10_dinf.tif` with a value range from 0 to 5.16727. The main map area shows a drainage network visualization, where the network is represented by yellow and orange lines on a purple and blue background, indicating the flow paths of water across the terrain.



# Extract contributing areas greater than $10^3$ m<sup>2</sup> using Raster Calculator

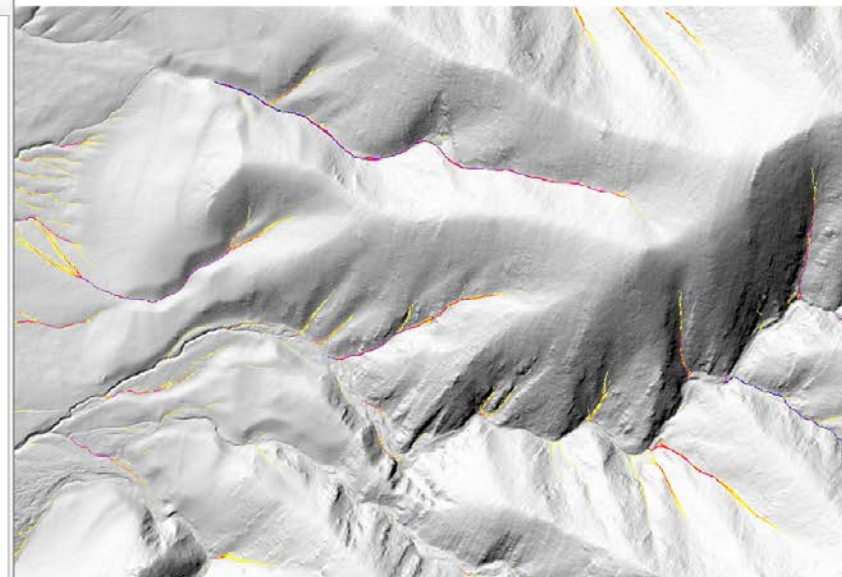
Untitled - ArcMap

The screenshot shows the ArcMap Raster Calculator window. The 'Map Algebra expression' field contains the formula: `Con("log10_dinf.tif" >= 3, "log10_dinf.tif")`. The 'Output raster' field contains the path: `C:\Users\ramon\Google Drive\+S_Active_Items\2`. The interface includes a toolbar with mathematical operators and a list of layers on the left.

Display stable drainage network over hillshade

Untitled - ArcMap

The screenshot shows the ArcMap Table of Contents window. The layer `log10_dinf_ge3.tif` is selected and highlighted in blue. Below the layer name, a legend indicates the value range: High: 5.16727 and Low: 3. The legend also shows other layers in the map: `log10_dinf.tif`, `dinf.tif`, `range_5m.tif`, `output.tin_shd.tif`, and `output.tin.tif`.



# Visualize DTM in ArcScene

Untitled - ArcScene

File Edit View Bookmarks Selection Geoprocessing Customize Windows Help

output.tin.tif

Table of Contents

Scene layers  
output.tin.tif  
Value  
High : 2068.9  
Low : 1450.14

1) Load DTM. Right click and select properties

Layer Properties

General Source Extent Display Symbology Base Heights Rendering

Elevation from surfaces

No elevation values from a surface

Floating on a custom surface:

C:\Users\ramon\Google Drive\+S\_Active\_Items\2017UGS\_OT\WatershedAnalyses\out\

Raster Resolution...

Elevation from features

No feature-based heights

Use elevation values in the layer's features

Factor to convert layer elevation values to scene units: custom 1.0000

Use a constant value or expression:

0

Layer offset

Add a constant elevation offset in scene units: 0

Floating on itself

2) Set it to float on itself and increase the base surface resolution to 1 m under the Base Heights tab

Raster Surface Resolution

This dialog is used to specify an approximate maximum resolution for the base surface.

	Base Surface	Original surface
Cellsize X:	1.000000	1.000000
Cellsize Y:	1.000000	1.000000
Rows:	1062	1062
Columns:	2246	2246

OK Cancel

Layer Properties

General Source Extent Display Symbology Base Heights Rendering

Show:

Unique Values  
Classified  
Stretched  
Discrete Color

Stretch values along a color ramp

Color	Value	Label
	2068.9	High : 2068.9
	1450.14	Low : 1450.14

Color Ramp:

Display Background Value: 0 as

Use hillshade effect Z: 1 Display NoData as

Stretch

Type: Percent Clip Histograms

min: 0.5 max: 0.5  Invert

4) Change color Ramp under the Symbology tab

Layer Properties

General Source Extent Display Symbology Base Heights Rendering

Visibility

Render layer at all times

Render layer only while navigation has stopped

Render layer only while navigating

Draw simpler level of detail if navigation refresh rate exceeds: 0.750 second(s)

Effects

Shade areal features relative to the scene's light position

Use smooth shading if possible

Select the drawing priority of areal features, related to other layers that may be at the same location. This helps to determine which feature gets drawn on top of the other. 1

Optimize

Render layer directly from data connection to conserve memory

Cache layer for fastest possible rendering speed

Enable Rendering with compressed textures

Quality enhancement for raster images Low High

Minimum transparency threshold Low High

Disable material textures

3) Set Shade areal features and maximize quality enhancement under the Rendering tab

# Change the background to black in ArcScene

The screenshot displays the ArcScene interface. The main window shows a 3D terrain model with a yellowish-brown color scheme. On the left, the 'Table of Contents' pane shows a layer named 'output.tin.tif' with a value range from 1450.14 to 2068.9. A blue arrow points from the 'Scene layers' header to the 'Scene Properties' dialog box. The dialog box is open to the 'Illumination' tab, where the 'Background color' is set to black. The 'Vertical Exaggeration' is set to 'None', and the 'Background color' dropdown is currently showing a black color swatch. The 'Enable Animated Rotation' checkbox is unchecked. The 'Description' field is empty. The 'OK', 'Cancel', and 'Apply' buttons are visible at the bottom of the dialog box.

File Edit View Bookmarks Selection Geoprocessing Customize Windows Help

output.tin.tif

Table of Contents

Scene layers

output.tin.tif

Value  
High : 2068.9  
Low : 1450.14

Scene Properties

General Coordinate System Extent Illumination

Description:

Vertical Exaggeration: None Calculate From Extent

Background color: Restore Default

Use as default in all new documents

Enable Animated Rotation

When you use the Navigation tool to rotate the scene, hold down the left mouse button, drag in the direction you want the scene to rotate, and release the mouse button while the scene is moving.

OK Cancel Apply

Right click  
on scene  
layers and  
change the  
background  
color to  
black

# Visualize drainage network in ArcScene

Untitled - ArcScene

File Edit View Bookmarks Selection Geoprocessing Customize Windows Help

output.tin.tif

Table of Contents

Scene layers

log10\_dinf\_ge3.tif  
Value  
High : 5.16727  
Low : 3

output.tin.tif  
Value  
High : 2068.9  
Low : 1450.14

Layer Properties

General Source Extent Display Symbology Base Heights Rendering

Elevation from surfaces

No elevation values from a surface  
 Floating on a custom surface:  
C:\Users\ramon\Google Drive\+S\_Active\_Items\2017UGS\_OT\Watershed  
Raster Resolution...

Elevation from features

No feature-based heights  
 Use elevation values in the layer's features  
Factor to convert layer elevation values to scene units: custom  
 Use a constant value or expression:  
0

Layer offset  
Add a constant elevation offset in scene units:

[About setting base heights](#)

Surface

Look in: WatershedAnalyses

- dinf.tif
- log10\_dinf.tif
- log10\_dinf\_ge3.tif
- output.tin.tif
- output.tin\_shd.tif
- range\_5m.tif
- scap0r0c0.tif
- scap1r0c0.tif

Floating on DTM

Name: output.tin.tif

Show of

2) Set it to float on the DTM, increase the base surface raster resolution to 1 m, and elevate it by 5 m to make it more visible under the Base Heights tab

1) Load drainage area. Right click and select properties

4) Change color Ramp under the Symbology tab

3) Set maximize quality enhancement under the Rendering tab (no need to shade it)



# Visualize drainage network in ArcScene (“skeleton of the landscape”)

Untitled - ArcScene

File Edit View Bookmarks Selection Geoprocessing Customize Windows Help



output.tin.tif

Table of Contents

Scene layers	
<input checked="" type="checkbox"/>	log10_dinf_ge3.tif Value High : 5.16727 Low : 3
<input type="checkbox"/>	output.tin.tif Value High : 2068.9 Low : 1450.14

