USING ARCGIS TO CONSTRUCT & MANIPULATE DEMS

Tutorial[1] Produced by Joe Wheaton

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PURPOSE

This exercise is intended to teach you how to a) build a digital elevation model (DEM) from raw topogarphic point (x,y,z) data, and b) construct a DEM for a design. A small reach of the Provo River outside of Heber City, UT is used as an example.

BACKGROUND

There are many programs you can use to construct and manipulate digital elevation models (DEMs) in. Most of these fall under GIS (e.g. ArcGIS, MapInfo, MapWindow), CAD (e.g. AutoCAD) or scientific visualization software (e.g. Surfer, Matlab). In this exercise, we use one of the most common GIS programs, ArcGIS, to illustrate the workflow. In general, CAD programs tend to be much more powerful for drawing and design work, but limited for analyses. By contrast, drawing (referred to as editing in GIS) is rather cumbersome in GIS software, but analysis and display options are much richer.

There are many uses of DEMs in restoration design including:

- Planning Maps
- Grading Plans (calculation of earthwork volumes)
- Monitoring (repeat surveys for change detection and morphological sediment budgeting)
- Boundary conditions to hydraulic and morphodynamic models
- Visualization tool
- Derive habitat maps, and geomorphic maps from
- Morphometric Analyses

For more information, see lecture slides. This tutorial is intended as a reference to remind you how to undertake these basic tasks, with step-by-step instructions and screen shots.

[1] For color version of this handout, with active hyperlinks, see: http://www.gis.usu.edu/~jwheaton/ICRRR/2010/Part_II/ICRRR_D2_Topo_Excercise.pdf

PREREQUISITES

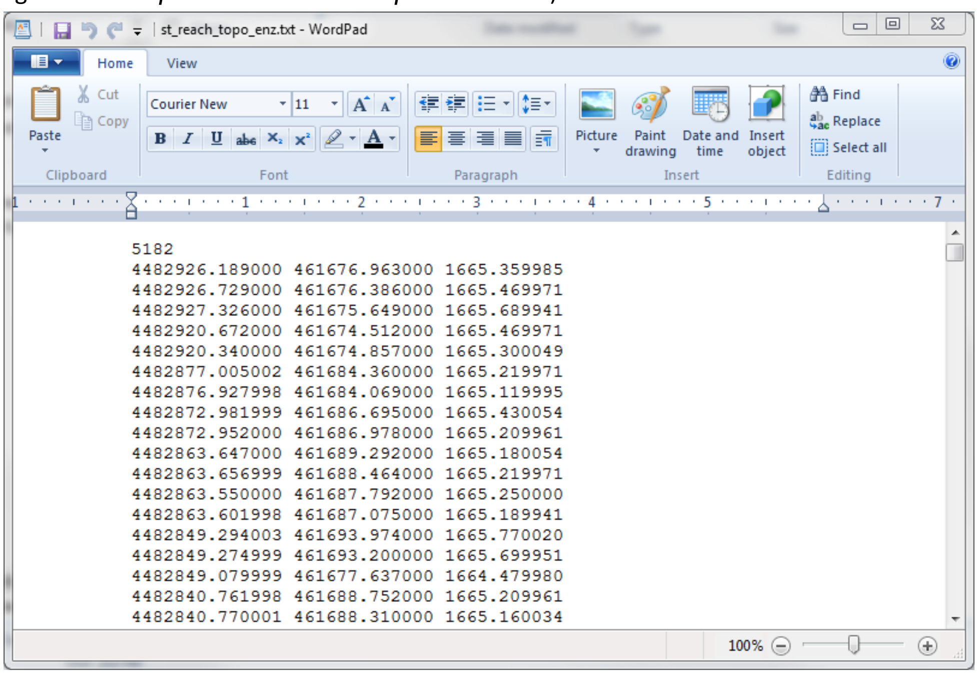
- You will need the data from D2_DEM.zip[2] unzipped to a known location (using foldernames).
- You will need ArcGIS 9.3.1 with the *Spatial Analyst & 3D Analyst Extensions* installed and enabled (T*ools -> Extension*) and the toolbars turned on (Student Version of Software available for free from instructors, but may not be used for business purposes).

PART I – BUILD DEM

The first part of this exercise focuses on how to build a digital elevation model (DEM) from raw survey data.

LOOK AT AND PREPARE RAW X-Y-Z SURVEY DATA

1. Navigate to the folder with your raw survey data in it and open the file in any text editor (e.g. wordpad or notepad). For our example, look at `st_reach_topo_nez.txt` (You can use the right-click -> *Open With… -> Wordpad* to do this).

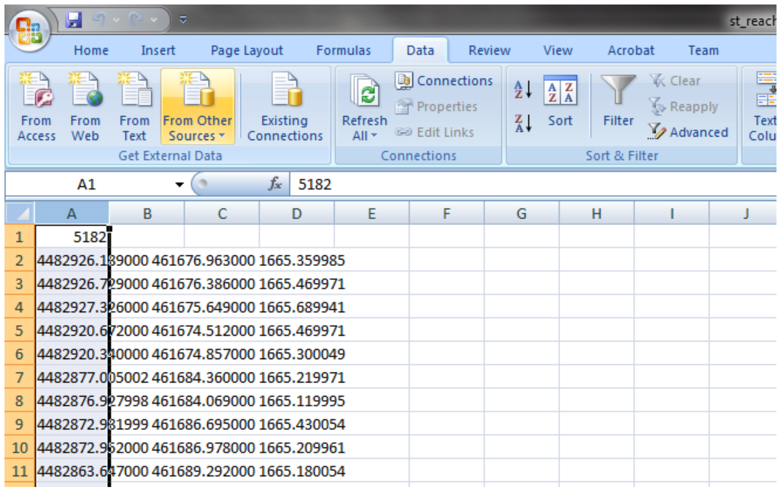


2. Notice that in this example, there appears to be a one line header (indicating here the number of points in the data file). Each point in the data file gives the coordinates of the point as a triplet. Ideally, you have some sort of metadata associated with the file to tell you what the format is,

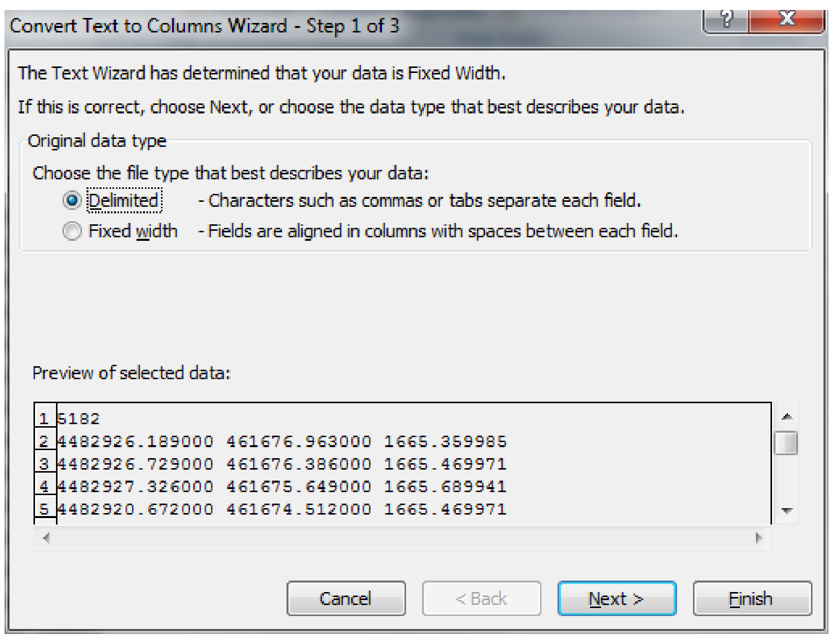
[2] Tutorial data (including raw topography and aerial imagery) can be downloaded from: http://www.gis.usu.edu/~jwheaton/ICRRR/2010/Part_II/ProvoTopoData.zip

where it came from, when it was collected, by what technique and by whom, as well as information on the coordinate system/projection. For this example, we know the file is in a nez format (easting, northing, elevation). Other common formats include pnezd, penzd, enz, xyz, etc. (where p refers to point, d refers to description, etc.). In order to import the data into ArcGIS the headerline is essential. Close the wordpad document and reopen the file in Excel.

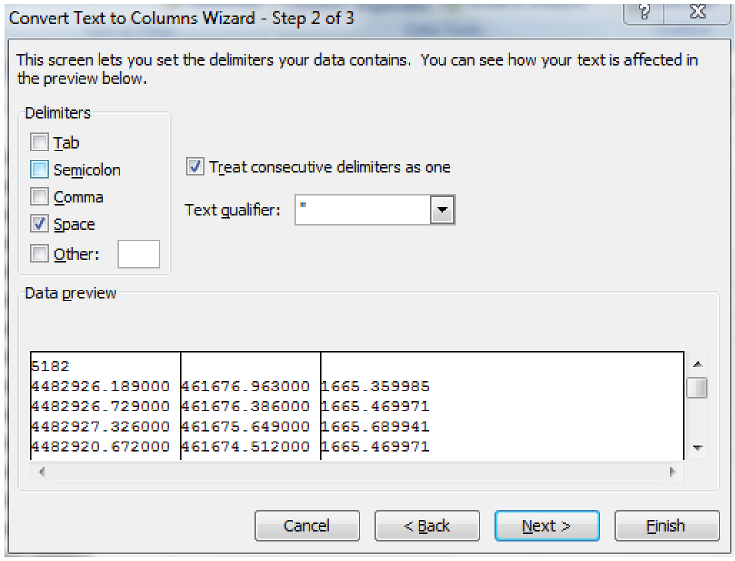
3. In excel, all the data will be in one column. Highlight column A, by clicking on it, and then go to *the Data menu*:



4. Use the *Text to Columns* command:

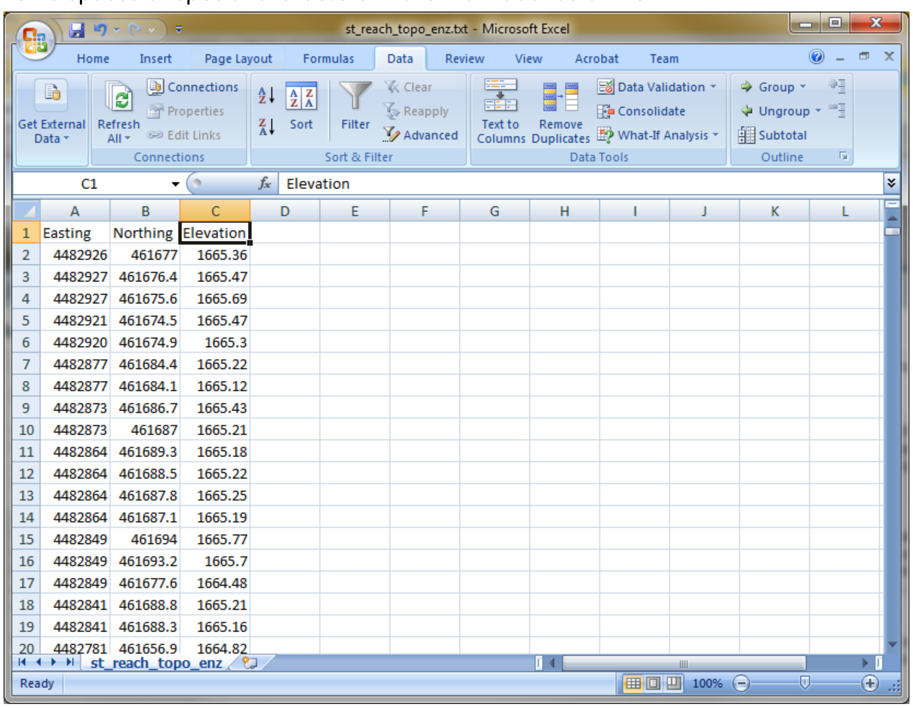


Select, *delimited* in the first step,



Select, *space* in the next step, then Finish. This sorts the data into separate columns.

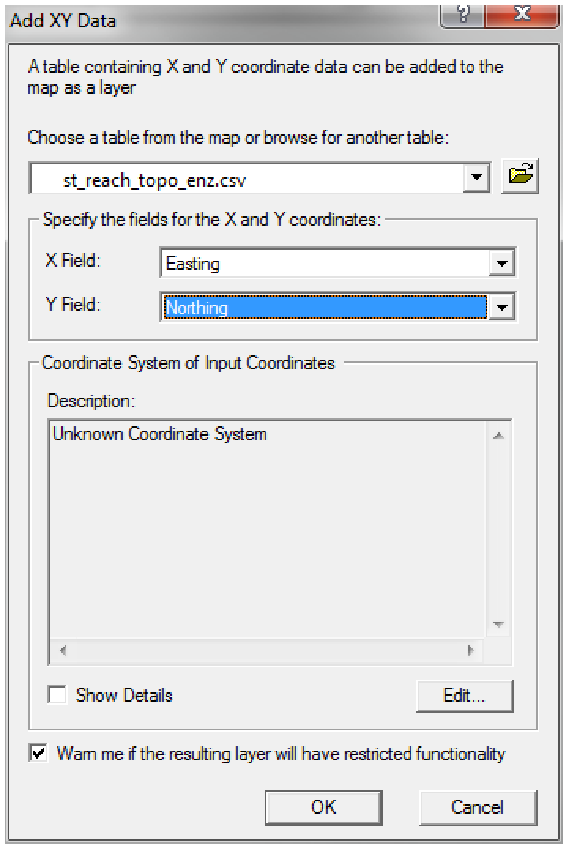
5. Next replace the first row with easting for column A, northing for column B, and elevation for column C. A header is necessary to facilitate the import of the data into ArcGIS. It is critical that there are no spaces or special characters in the individual columns:



6. Finally, using the *Save As* command, save the file as *CSV (Comma delimited) (*.csv)* file in the same folder (i.e. `st_reach_topo_nez.csv`). Click *Yes* when asked about the format warning. Quit Excel (click No to save the file as you've already done this).

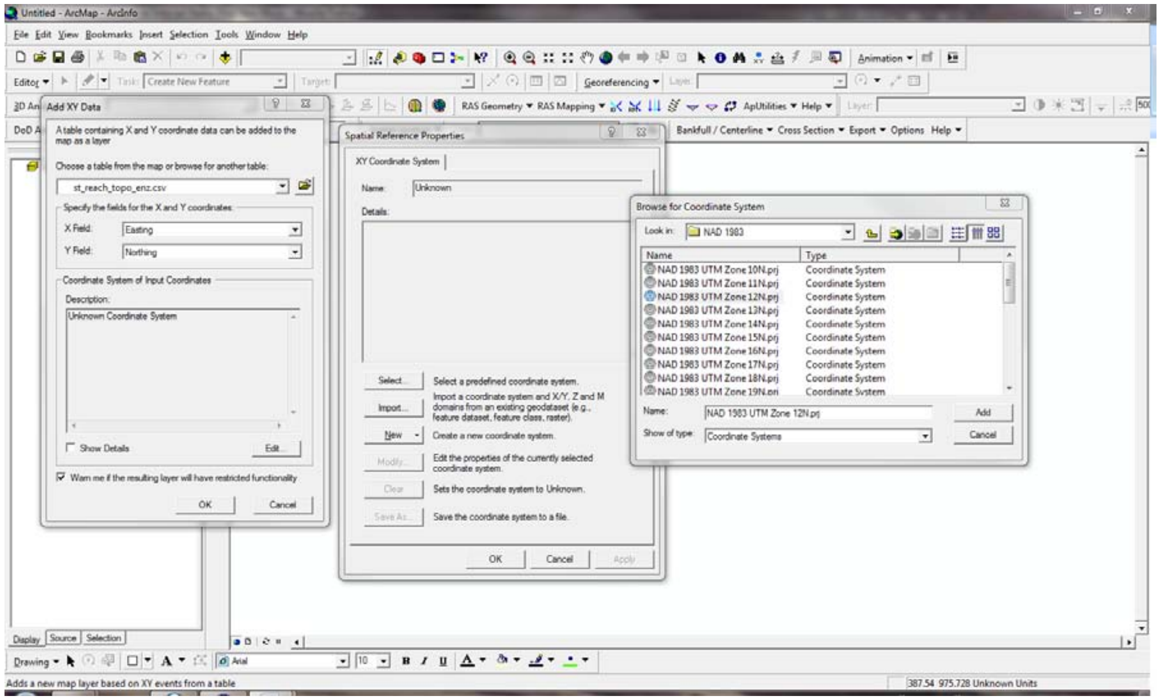
IMPORT X-Y-Z DATA

1. *Open* a blank new Map Document in ArcGIS[3].
2. Use the *Tools-> Add X-Y Data* command to add the `st_reach_topo_nez.csv` file. In the Add XY Data dialog, use the open folder button to bring up the `st_reach_topo_nez.csv`. Then choose the Easting field for the X-Field and Northing for the Y-Field.

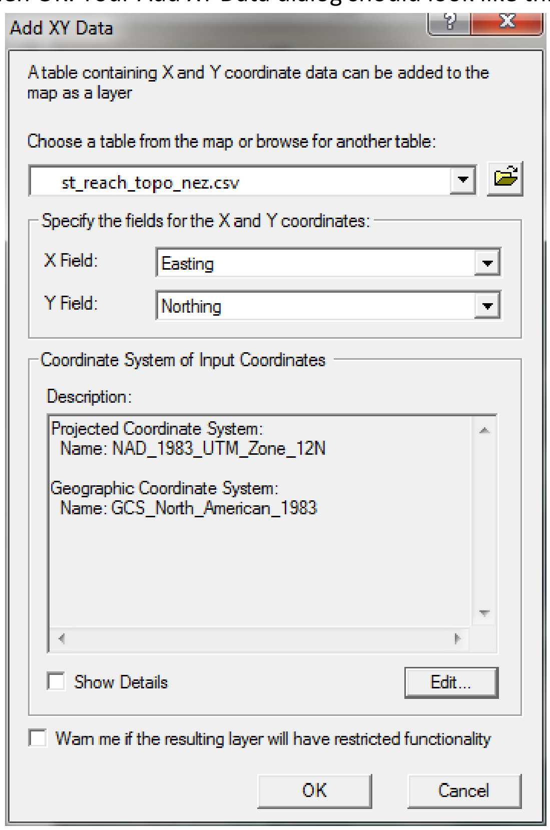


For the Coordinate System, we know this is in UTM Zone 12, NAD 1983. Click on *Edit…* and then in the *Spatial Reference Properties Dialog*, click on *Select* to Browse for the Coordinate System. Browse to `Coordinate Systems -> Projected Coordinate Systems -> UTM -> NAD 1983` and then select `NAD 1983 UTM Zone 12N.prj`.

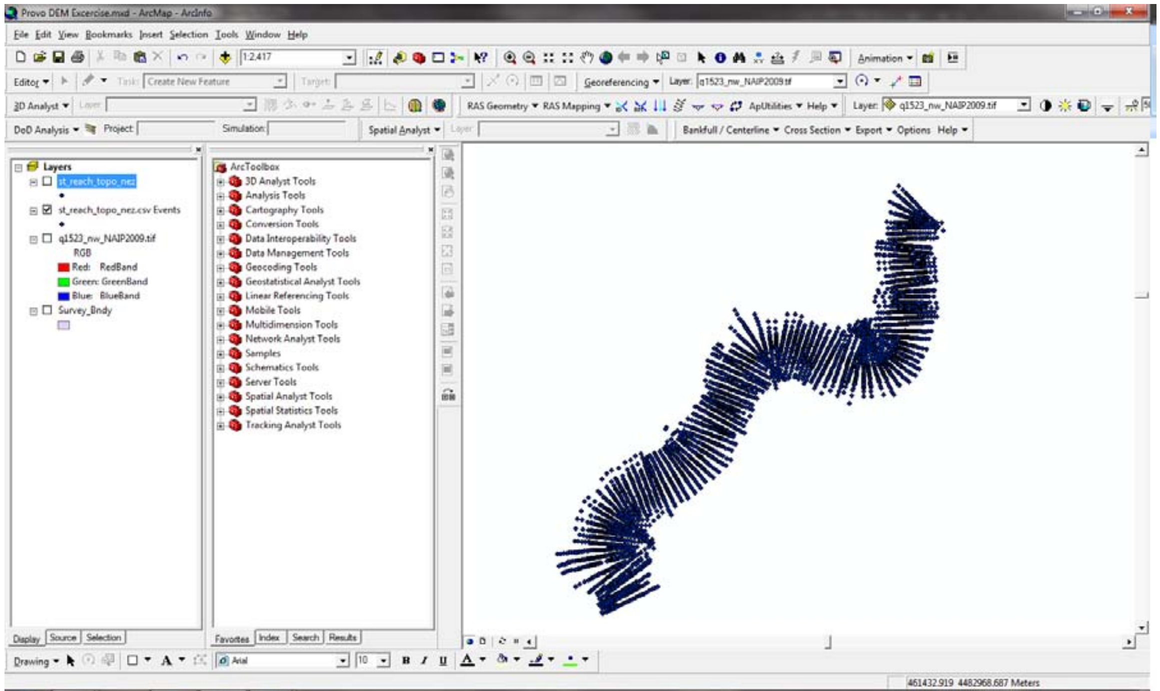
[3] This tutorial was written based on ArcGIS 9.3.1. Instructions will be similar for ArcGIS 9.1 and 9.2, with some minor differences. Instructions for ArcGIS 10 follow a conceptually similar workflow, but some of the menus, command windows, and where things are accessed has changed.



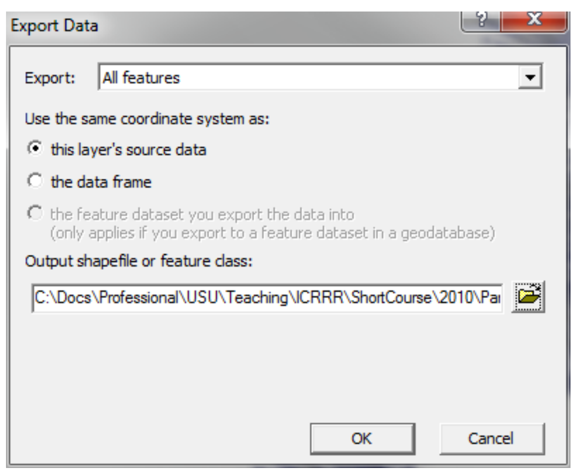
Click on OK, then OK, then OK. Your Add XY Data dialog should look like this before clicking OK:



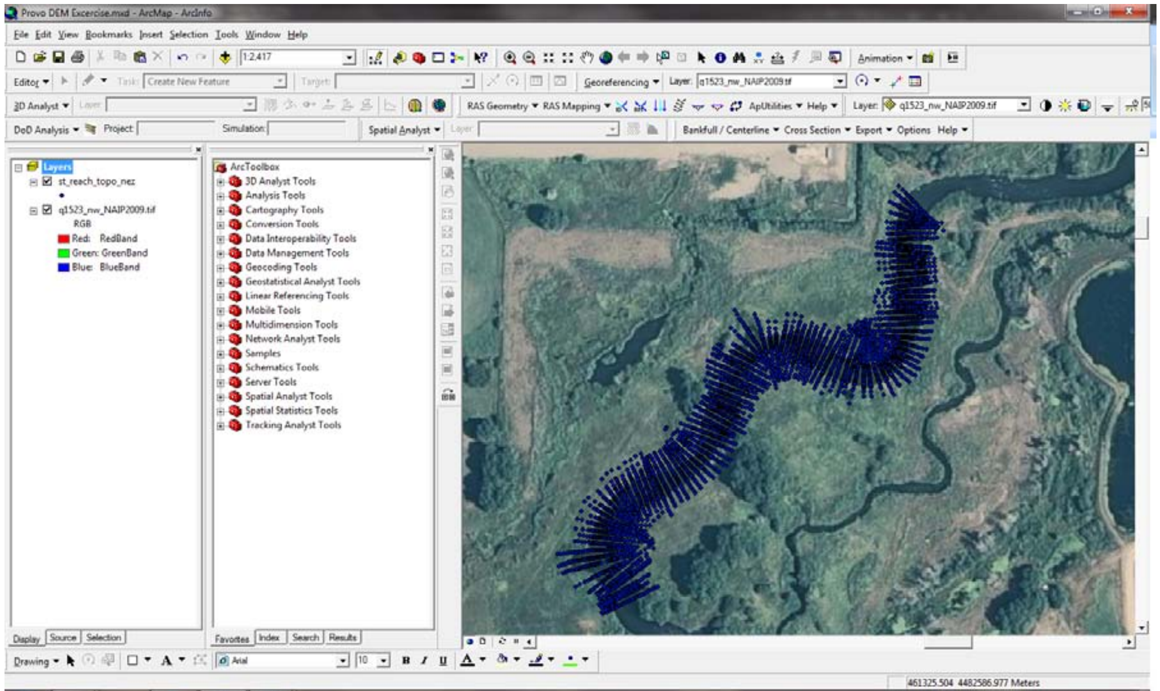
3. This will add the raw point survey data to the map's data frame:



4. Next, convert the *.csv file to a shapefile by right clicking on the `st_reach_topo_nez.csv Events` layer and going to *Data -> Export Data*. Navigate using the open folder button to your working folder and save the shape file as `st_reach_topo_nez.shp`. Click Yes, when asked if you want to add the exported data to the map as a layer.



5. Remove the `st_reach_topo_nez.csv Events` layer from the data frame by right-clicking on it and selecting *Remove*.
6. For context, it is sometimes helpful to see where these points reside with an aerial photo (if available). One was provided for you in the zip file (`q1523_nw_NAIP2009.tif`) as well as its associated files that define its projection, its position, resolution, etc. Add `q1523_nw_NAIP2009.tif` to the data frame using the Add Data  button. Make sure it is below the `st_reach_topo_nez` layer so you can see the points over the aerial photo:



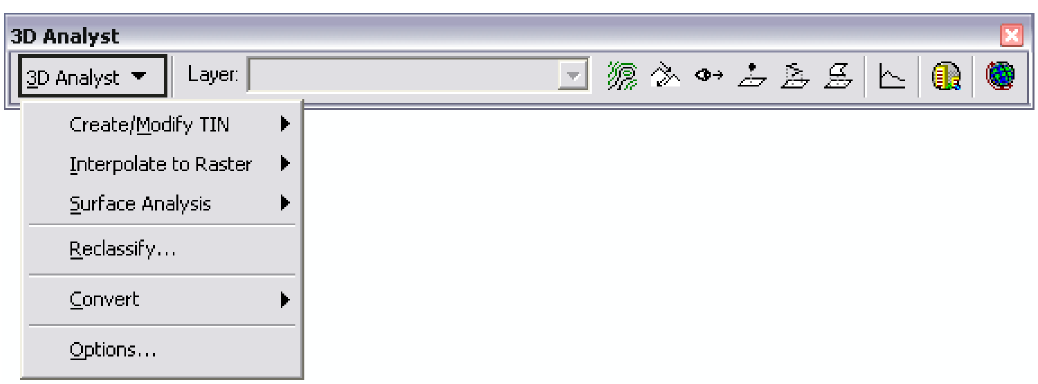
You can turn the layer off if you don't want to view it.

7. Next save the Map Document by using the File -> Save As command. I would suggest saving the map document in the same folder you are working in as something logical (e.g. `Provo DEM Exercise`).

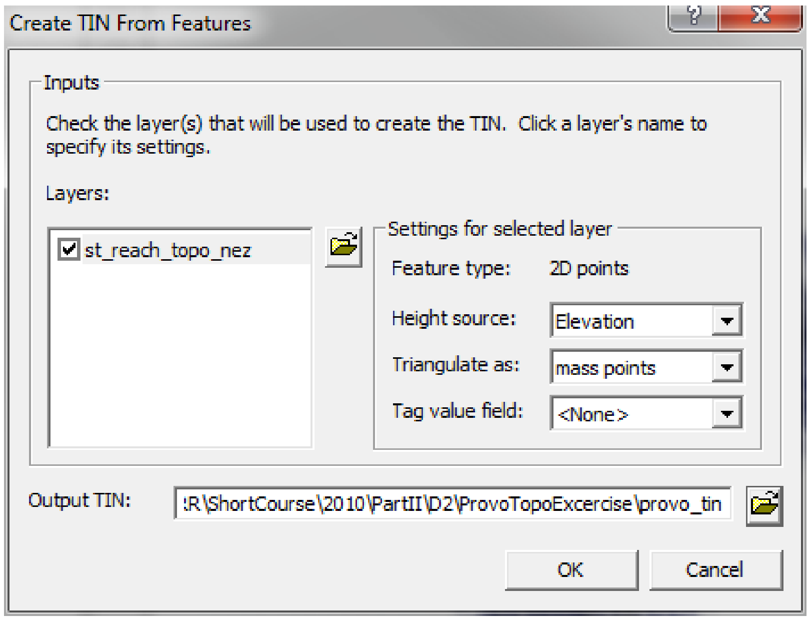
CREATE TIN FROM DATA

NOTE: Before creating a TIN, you need to make sure your *3D Analyst Extension* is installed, enabled and the toolbar on. Check that the extension is enabled by using the *Tools -> Extensions* and verifying it is checked. Check that the toolbar is loaded by right-clicking in a blank space on the toolbar and checking that 3D Analyst is checked.

1. Go the the 3D Analyst Menu in the 3D Analyst Toolbar and *Create/Modify TIN -> Create TIN from Features*.

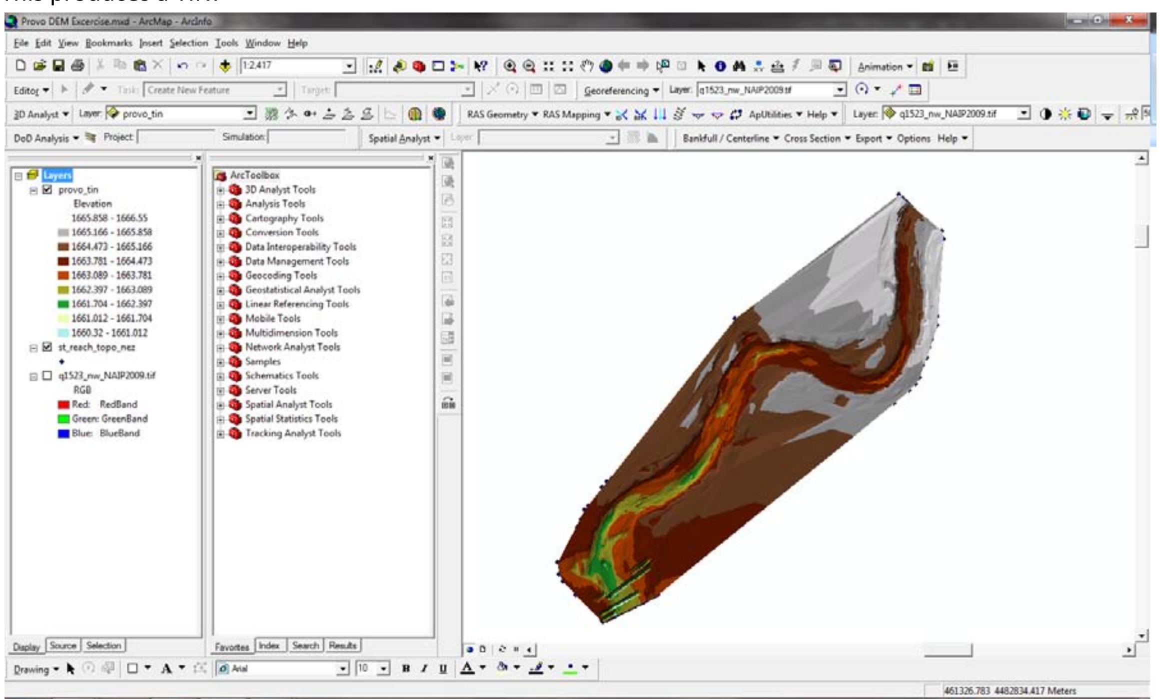


This brings up a Crate TIN From Features dialog:



Check the `st_reach_topo_nez layer` and make sure the *Height Source* is specified as *Elevation* and *Trinagulate as*: is specified as *Mass Points*. Save the Output TIN to your working directory as `Provo_TIN`. Click *OK*.

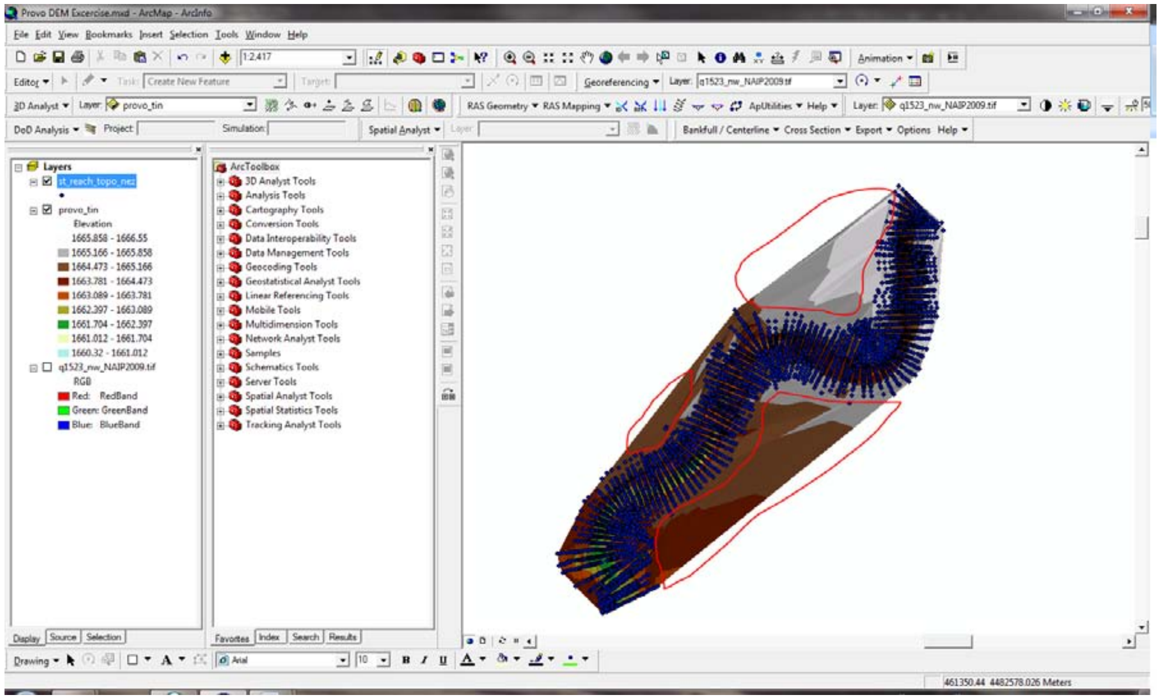
2. This produces a TIN:



CHECK TIN FOR ERRORS

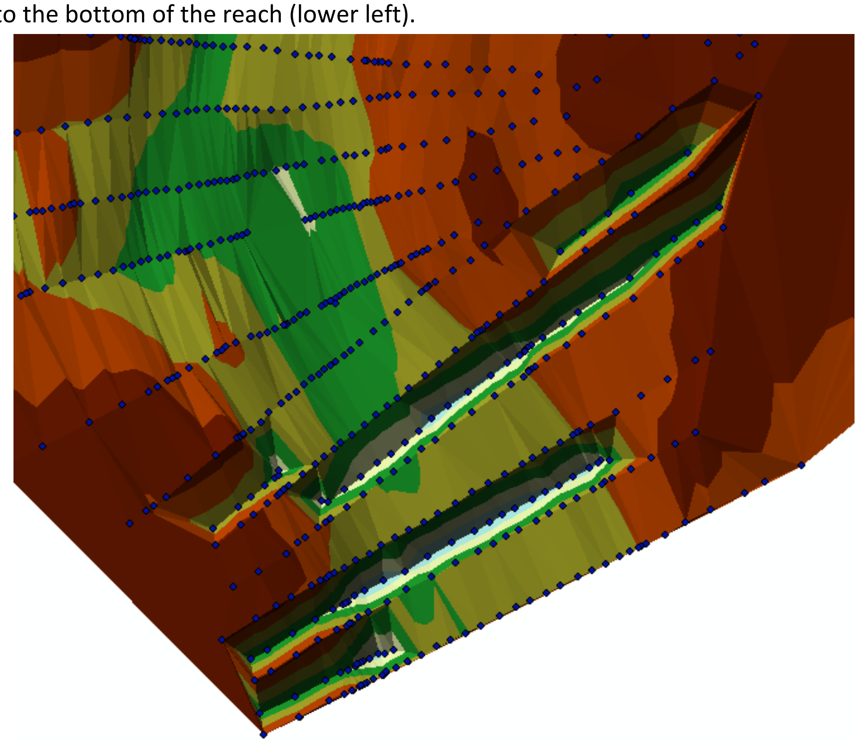
Although building a TIN is easy, it is also easy to build a TIN that misrepresents your data and or has busts in the data. In this example the flow direction is southwest (from the upper right to lower left). Accordingly, the highest bed elevations are at the top of the reach and lowest are at the bottom of the reach.

1. To inspect the TIN to see if represents your data appropriately, drag your points on top of the TIN in the Display dock to change the display order.



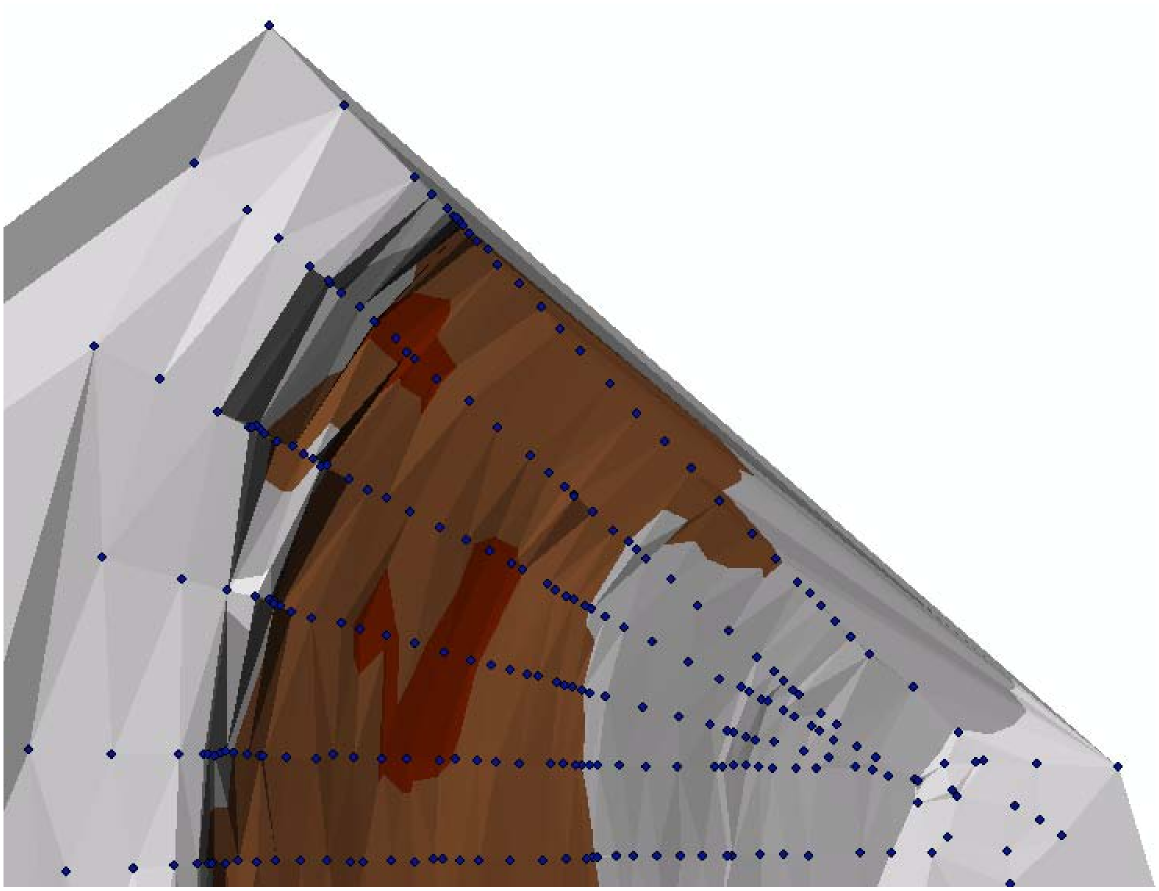
Notice the areas circled in red above (not shown in your display). The TIN algorithm has interpolated across these areas of the floodplain where no survey data was collected, by simply connecting the dots between the closest points. Although this may be a crude approximation of the floodplain surface in flat areas, it is NOT an accurate or honest representation of the survey data. This typically occurs with TINing in areas that represent planform concavities.

2. Zoom into the bottom of the reach (lower left).



Notice the five trenches in the data. Although it is plausible that the river really does look like this (i.e. if a backhoe dug trenches parallel to each other and perpendicular to the river), the fact that these transects line up perfectly with the second, fourth, seventh, and ninth cross section transects in this tightly spaced cross sectional topographic survey is highly suspect.

3. Zoom into the top of the reach (upper right).

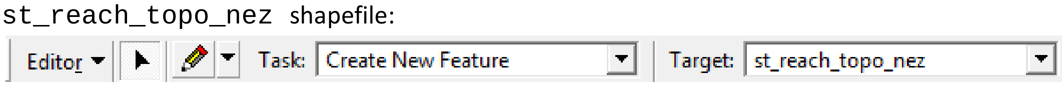


Notice that there is a wall or dam of topography preventing entry into the top of the reach. This is due to the two outermost points being linearly interpolated across. This is not only incorrect, this could seriously impact a hydraulic model's results.

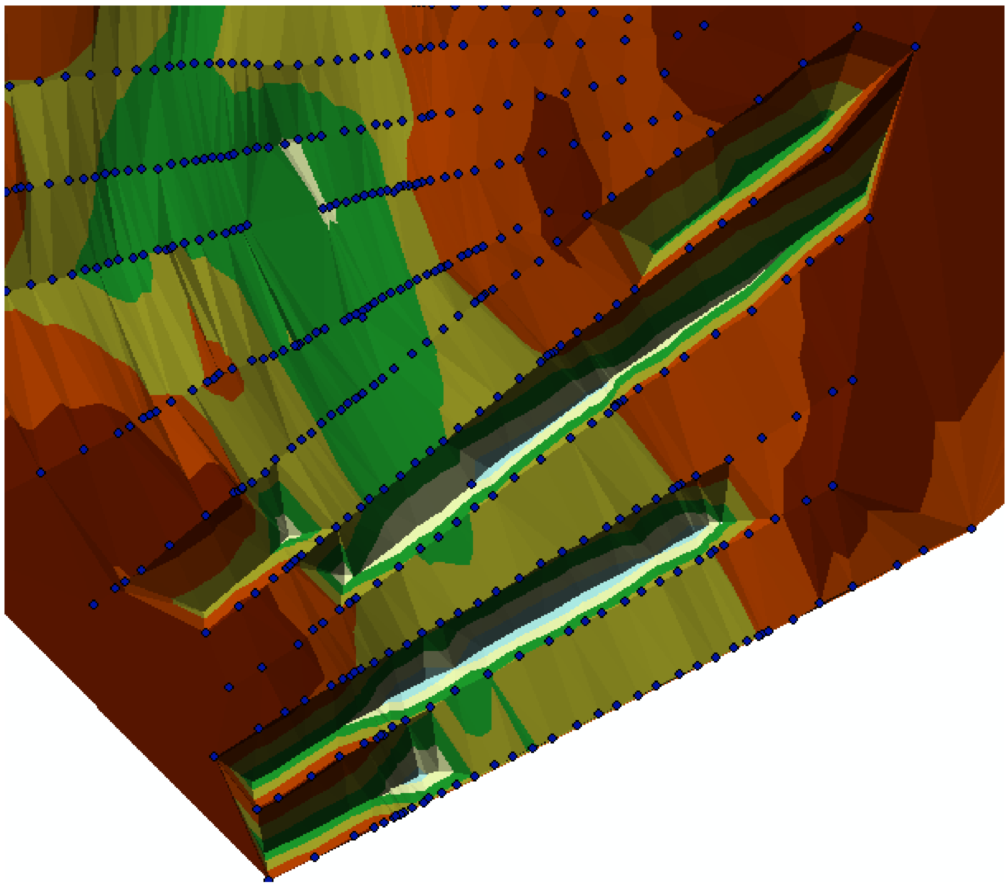
4. We should modify the TIN to not interpolate across areas of the floodplain without data, and to remove these apparent busts.

MODIFY TIN

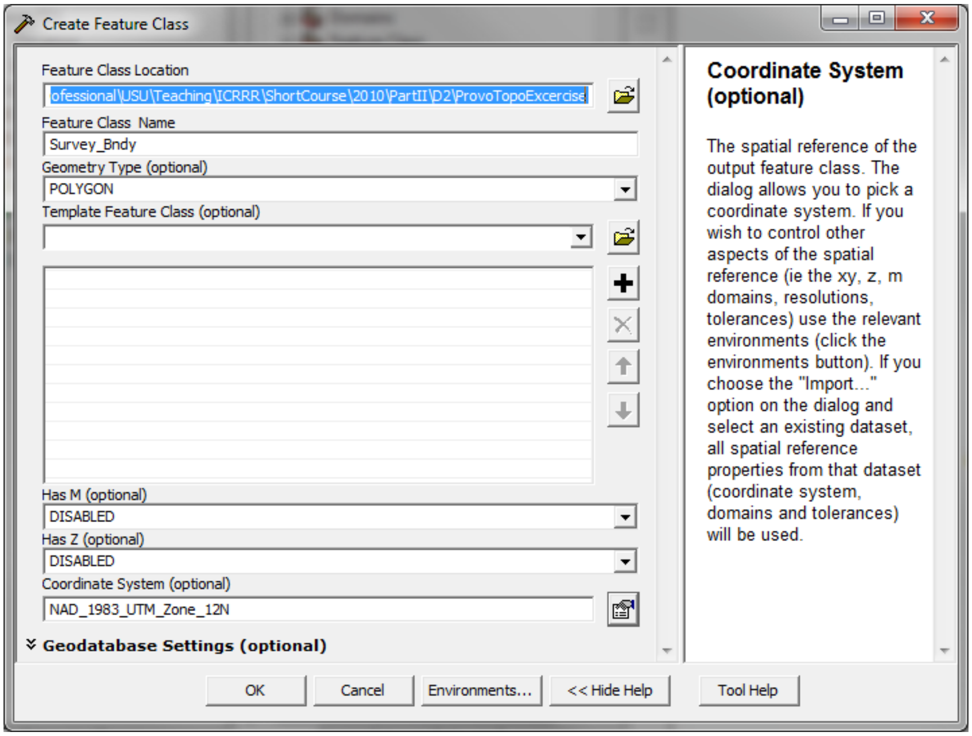
1. First, edit the `st_reach_topo_nez` shapefile to remove the points comprising the trench busts in the second, fourth, seventh and ninth cross sections from the left. To do this, load the Editor toolbar by right clicking on an empty toolbar space and checking *Editor*. Go to the *Editor menu* and select *Start Editing*. Make sure that the Target in the editor toolbar is the `st_reach_topo_nez` shapefile:



2. Using the *edit tool* (selected in screen shot above), *zoom in* and *select* ONLY the points in the suspect transects (you can use the shift key to select multiple points at once as well as dragging a window box over the points you wish to select). As you select points you, you can right click on the selection at any time and use the *delete* command to delete them. When you are done deleting all the suspect points, navigate back to the editor menu and click on *Stop Editing*, and select *YES* when asked *Do you want to save your edits*. Your modified shape file should look something like this in the area of the downstream reach after editing:

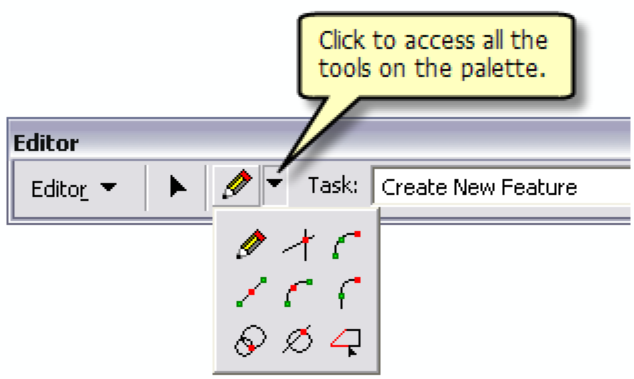


3. Next, we will draw a polygon around the survey data to use in the TIN construction to prevent interpolation outside the survey area. To do this, we first need to create a new shapefile of type polygon first. From *the Window Menu* Select the ArcToolBox if it is not already loaded. Navigate in the toolbox to *Data Management Tools -> Feature Class -> Create Feature Class*:



For *Feature Class Location*, select the same working folder you've been using all along. For *Feature Class Name*, use `Survey_Bndy`. For the *Geometry Type*, slect *Polygon*. Scroll down and specify *NAD_19883_UTM_Zone_12N* as the *Coordinate System* (you can use the import feature and import the coordinate system from your other shapefile if you wish). Click OK and this will create a blank shapefile.

4. *Remove* the Provo_TIN from the data frame by right-clicking on it and using the *Remove* command. This will make it easier to see the survey points and enable us to overwrite the TIN later. Right click on the `st_reach_topo_enz` file and use the *Zoom to Layer* command.
5. Begin an edit session for the Survey_Bndy shapefile by using the Editor -> Start Edit command and selecting Survey_Bndy as the target in the toolbar. Make sure the task is set to Create New Feature[4].



Using the pencil  (*Sketch Tool*) in the *Editor toobar* draw a polygon around the survey points such that all the points are inside the polygon. Make sure that you draw the polygon for the upstream boundary to prevent it from interpolated between the two outermost points and building a dam:

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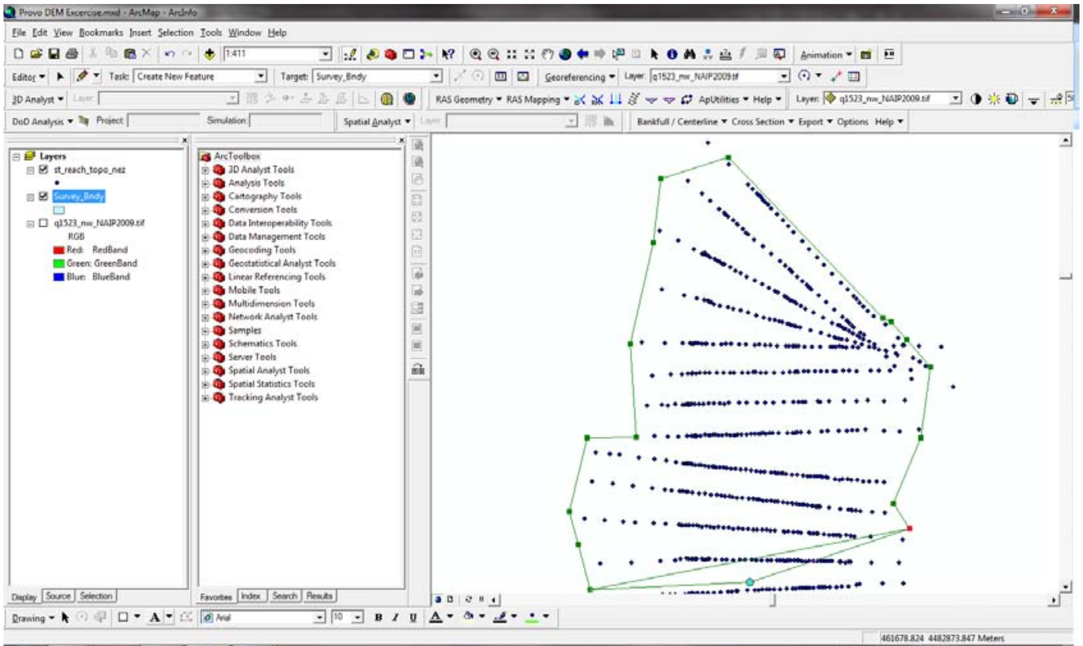
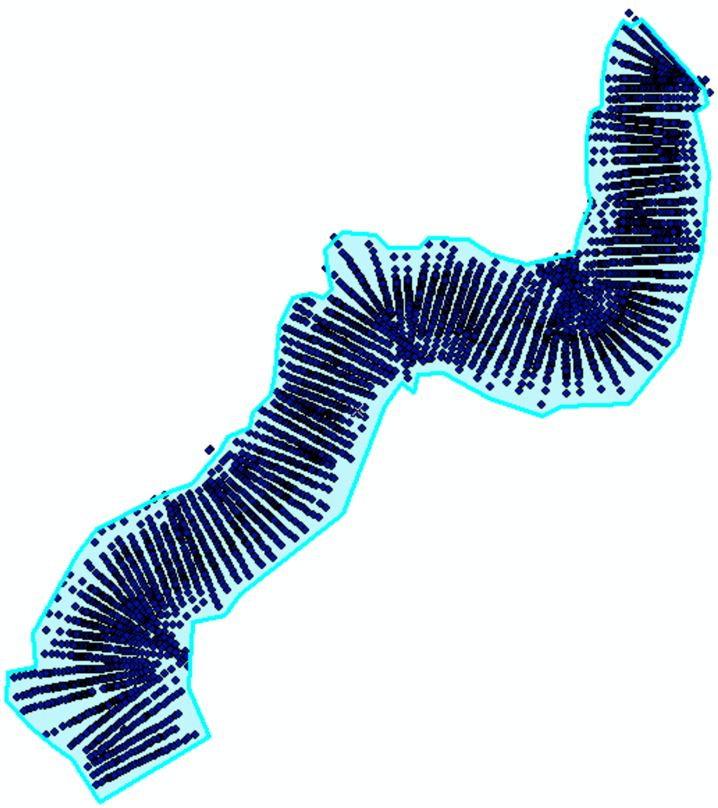
[4] Note, if the tools are grayed out it typically means that you either not in an active edit session (i.e. you need to *Start Editing*) or that the Task is not on *Create New Feature* (e.g. switched to *Modify Existing Features*).

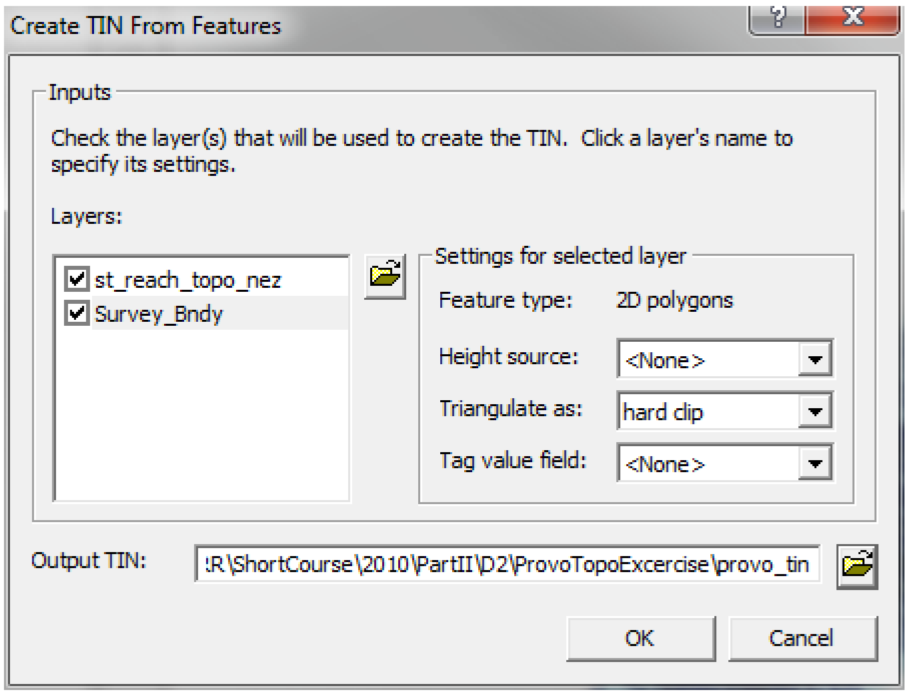


My polygon had between 25-30 vertices, use F2 to Finish the Sketch:



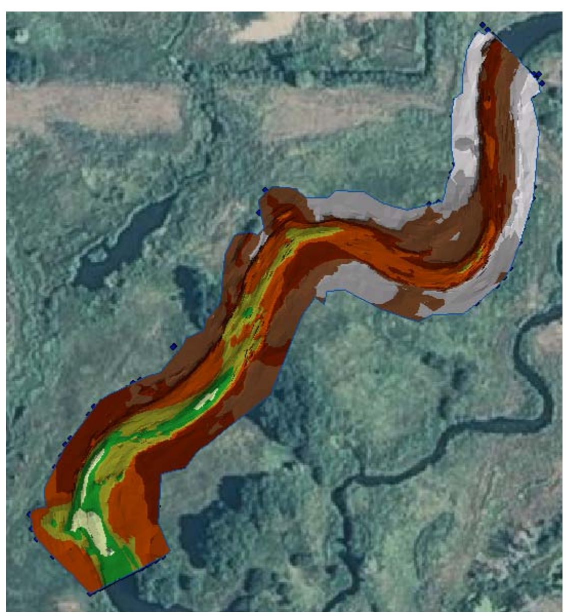
6. To finish editing your polygon, Use the *Editor -> Stop Editing* command and save your changes. We are now ready to build a new TIN using our modified point file (`st_reach_topo_enz`) and our new boundary polygon (`Survey_Bndy`).

7. Go the the *3D Analyst Menu* in the 3D Analyst Toolbar and *Create/Modify TIN -> Create TIN from Features*. This brings up a *Create TIN From Features* dialog:



Again check the `st_reach_topo_nez layer` and make sure the *Height Source* is specified as *Elevation* and *Trinagulate as*: is specified as *Mass Points*. Then click on the `Survey_Bndy` and click it too. For this one, make sure the the *Height Source* is specified as *<None>* and *Trinagulate as*: is specified as *hard clip*. Save the Output TIN to your working directory as `Provo_TIN` to overwrite the original TIN. Click *OK*. Then click *Yes* to overwrite the original output.

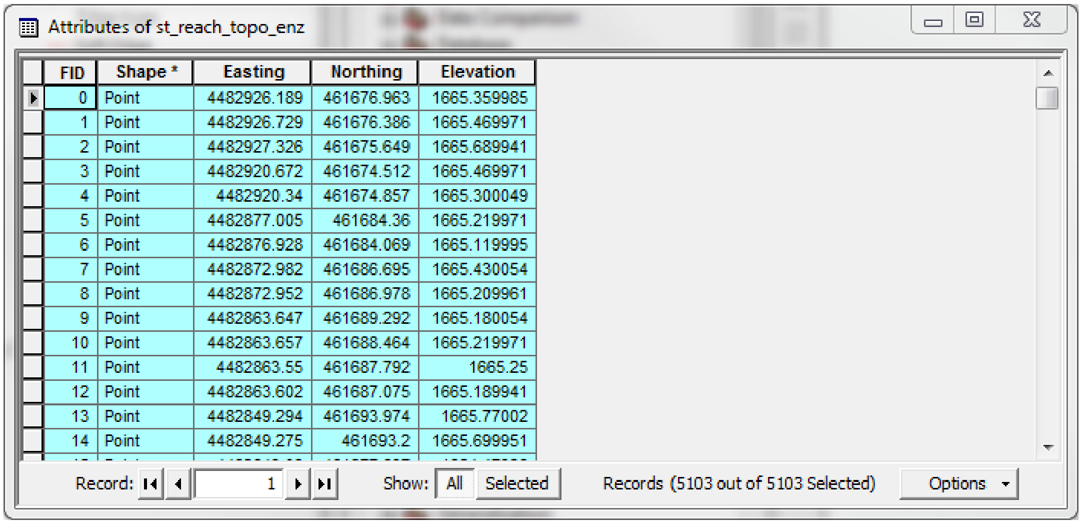
8. This TIN looks like a much better representation of the data and does not have the obvious busts (trenches).



EXPORT UPDATED TOPOGRAPHIC POINT DATA (OPTIONAL)

You may wish to export the modified point data[5] we ended up with in the `st_reach_topo_nez` shapefile. There are various ways to do this. One option is:

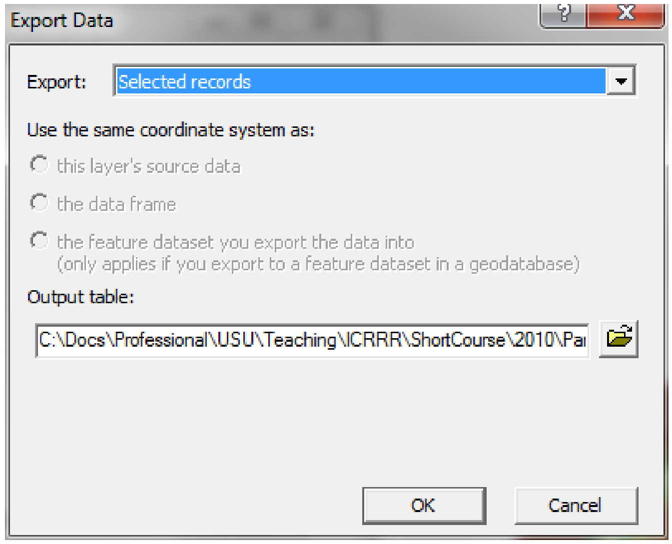
1. Right click on the `st_reach_topo_nez` and select Open Attribute Table.
2. Click on *Options -> Select All*



FID	Shape *	Easting	Northing	Elevation
0	Point	4482926.189	461676.963	1665.359985
1	Point	4482926.729	461676.386	1665.469971
2	Point	4482927.326	461675.649	1665.689941
3	Point	4482920.672	461674.512	1665.469971
4	Point	4482920.34	461674.857	1665.300049
5	Point	4482877.005	461684.36	1665.219971
6	Point	4482876.928	461684.069	1665.119995
7	Point	4482872.982	461686.695	1665.430054
8	Point	4482872.952	461686.978	1665.209961
9	Point	4482863.647	461689.292	1665.180054
10	Point	4482863.657	461688.464	1665.219971
11	Point	4482863.55	461687.792	1665.25
12	Point	4482863.602	461687.075	1665.189941
13	Point	4482849.294	461693.974	1665.77002
14	Point	4482849.275	461693.2	1665.699951

3. Click on *Options -> Export…*

[5] Note, that although this method of exporting data to a table will work for any shapefile, not all shapefiles have coordinate fields in them (which is what we want). Look at how to create fields (http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=Adding_and_deleting_fields) and calculate geometry (http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?id=750&pid=745&topicname=Making_field_calculations) in ArcGIS Help.

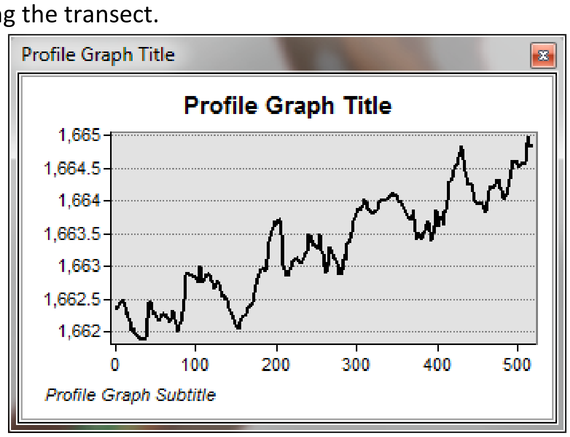


This will allow you to *export* the data to a table (saved as a database file `*.dbf`). The `*.dbf` can be opened in excel and saved to any file format you wish (for example for use in a hydraulic model).

DERIVING CROSS SECTIONS OR PROFILES FROM TIN - OPTIONAL

One very useful feature of having a digital elevation model or TIN is to be able to derive cross sections or longitudinal profiles from it.

1. In the 3D Analyst toolbar, select the TIN as the Layer and then click on the *Interpolate Line* button. Draw a line across the channel as a cross section or along the thalweg (double click to end the line).
2. Once you're happy with your line, click on the *Create Profile Graph* *button*. This brings up a profile dialog showing the transect.



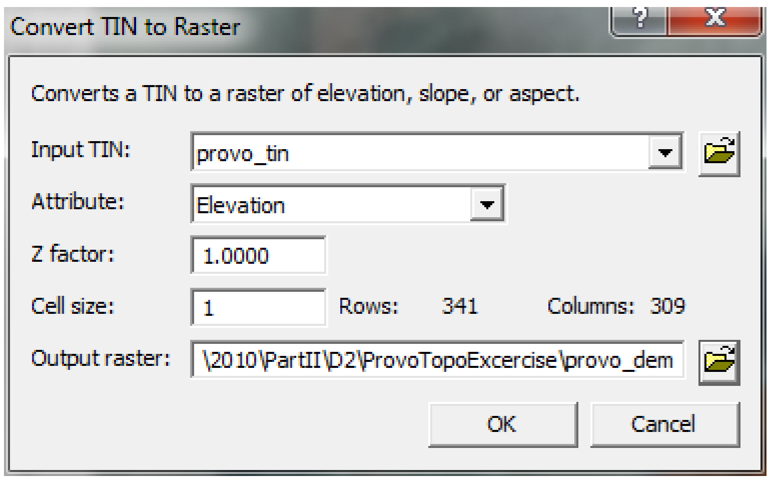
You can modify its appearance, or export the data, or save an image of this by right-clicking on the graph. Refer to: http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?id=3583&pid=3577&topicname=Creating_profile_graphs for more information. You can overlay two profiles by using the shift key before making the profile.

There are other useful profile and cross section tools available as plug-ins to ArcGIS. For example River Bathymetry Toolkit (http://www.fs.fed.us/rm/boise/AWAE/projects/river_bathymetry_toolkit.shtml) and HEC-Geo-RAS (http://www.hec.usace.army.mil/software/hec-ras/hec-georas.html) both have a wide array of more powerful profiling tools.

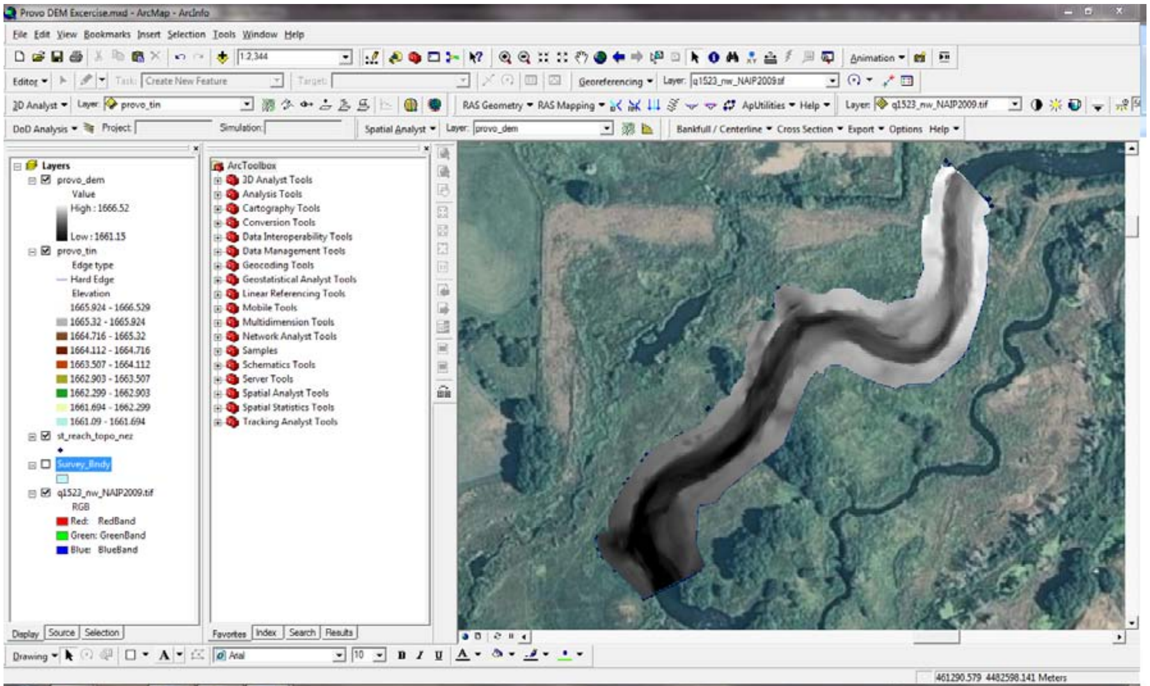
CONVERT TIN TO DEM

A TIN is a triangular irregular network, and is one way to digitally represent 2.5D surfaces. Many programs require terrain to be represented in a raster format, which is a uniformly gridded representation of the data at some particular resolution. Since it easier to write algorithms and codes for doing analyses of raster data, you will find many more tools available for analyzing DEMs then TINs.

To convert your TIN to a DEM, simply go *the 3D Analyst* menu -> *Conversion -> TIN to Raster…*



Make sure the *Input Tin* is `provo_tin`, the *attribute* is *Elevation*, the *Z Factor* is *1.000* and the *Cell Size* is *1* meter. Save this as provo_dem in your working directory. This produces a one meter resolution raster:



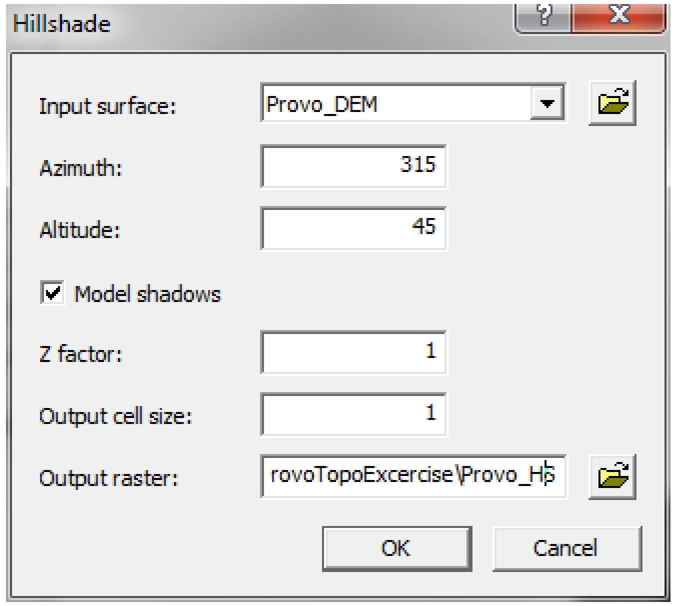
DERIVE OTHER SURFACES FROM DEM

As mentioned above, there are many commands and tools available to analyze and visualize DEMs. Here are some of the more common tools available to you in 3D Analyst.

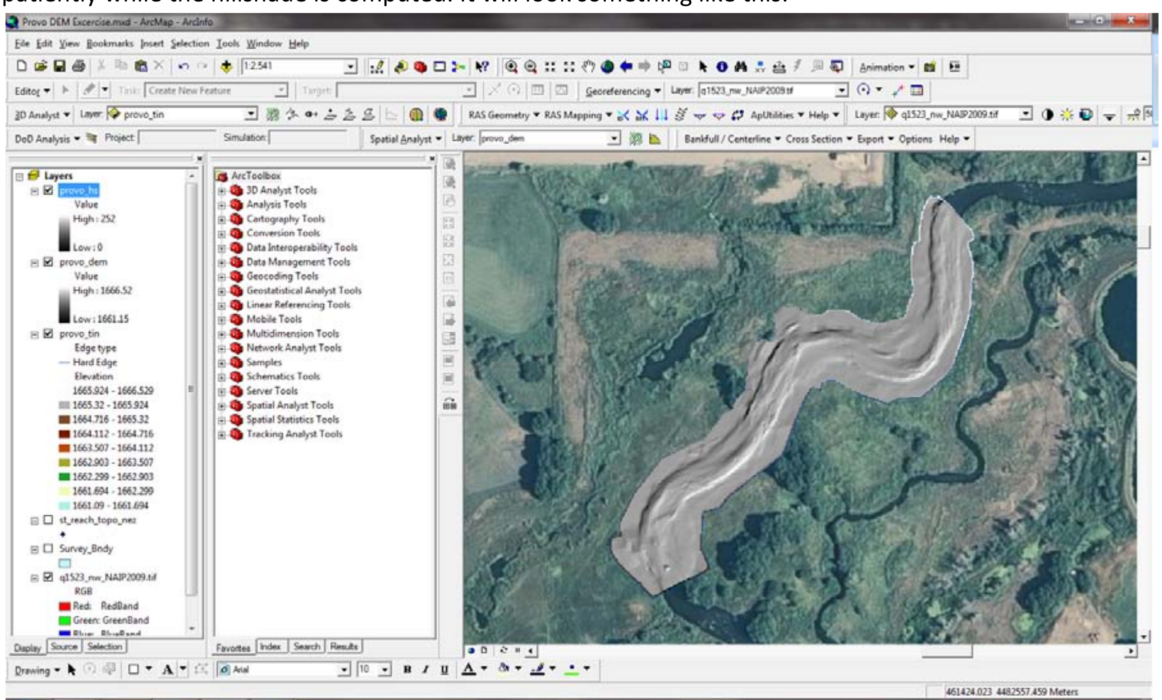
HILLSHADE

A hillshade is the illumination of a surface based on the topography and a hypothetical light source. Hillshades are commonly used to visualize topography and terrain. Hillshades are often used as a contextual backdrop.

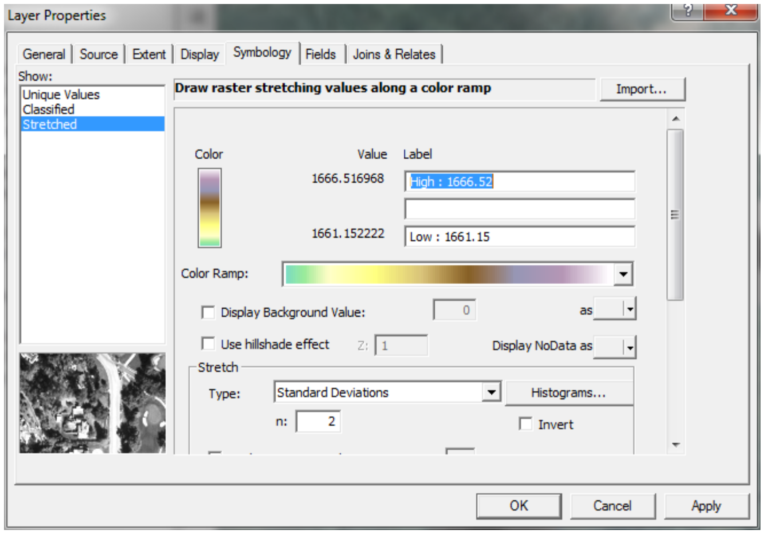
1. To create a Hillshade of the DEM, access the Hillshade tool from *3D Analyst -> Surface Analysis -> Hillshade*



Make the *Input Surface* the `Provo_DEM`, use the default *Azimuth* and *Altitude*, click on the *Model Shadows* box, and leave the *Z Factor* as 1 and the *Output Cell Size* the same as the input raster (1 meter in our example). Click on the *open folder* button to specify the output hillshade raster name (call it `Provo_HS` and put it in your working directory). Click *OK* and wait patiently while the hillshade is computed. It will look something like this:

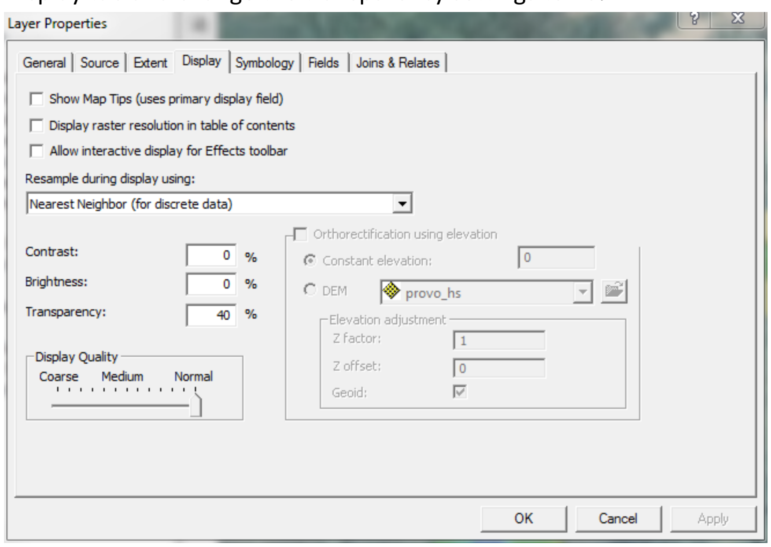


2. To visualize the DEM and the hillshade together, move the `Provo_HS` layer beneath the `Provo_DEM` layer in the Display Dock for the data frame. Right Click on the *properties* of the DEM (`Provo_DEM`) and go to the symbology tab:

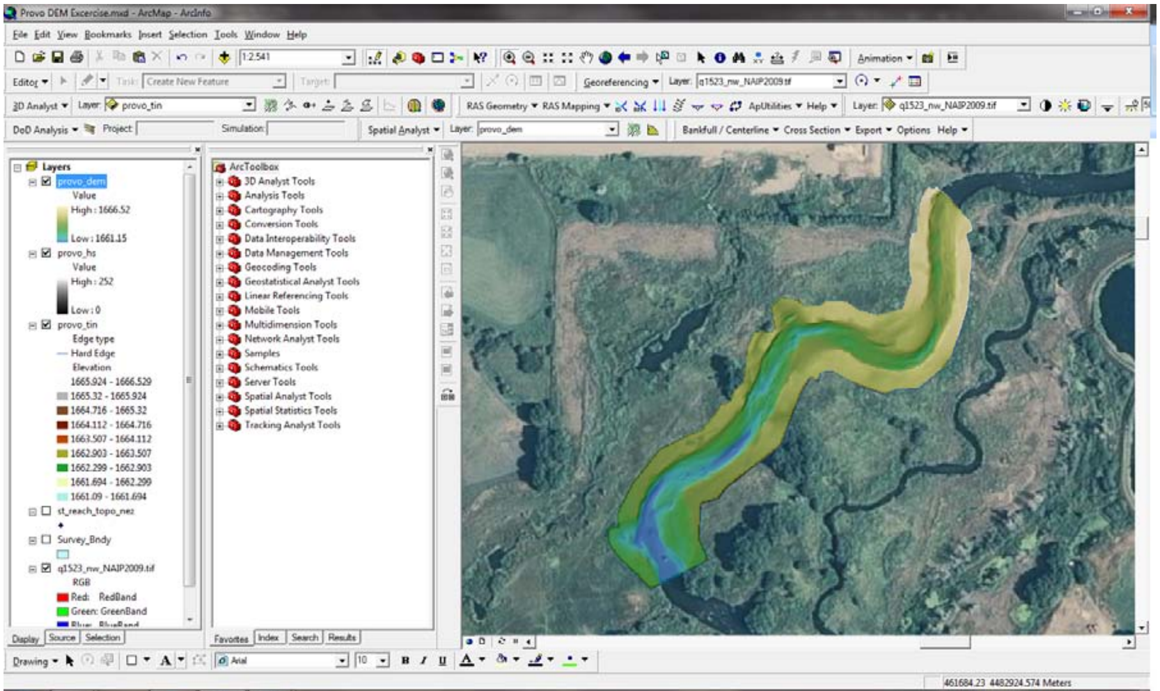


Change the symbology color ramp to something that appeals to you.

3. Switch to the Display tab and change the transparency settings to 40%:



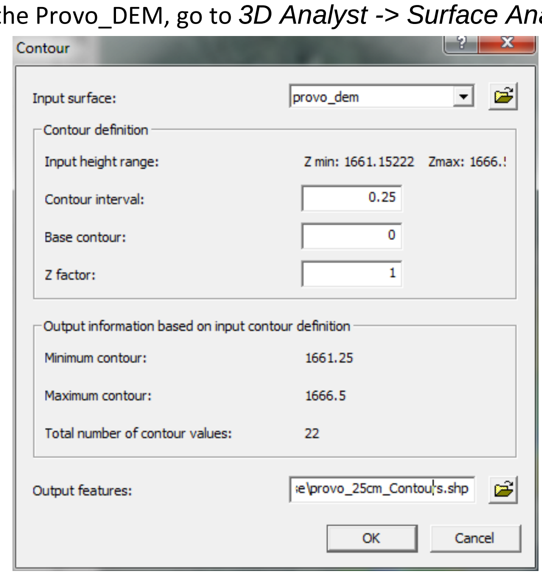
Click OK. You can now see the hillshade beneath the DEM:



CONTOURS

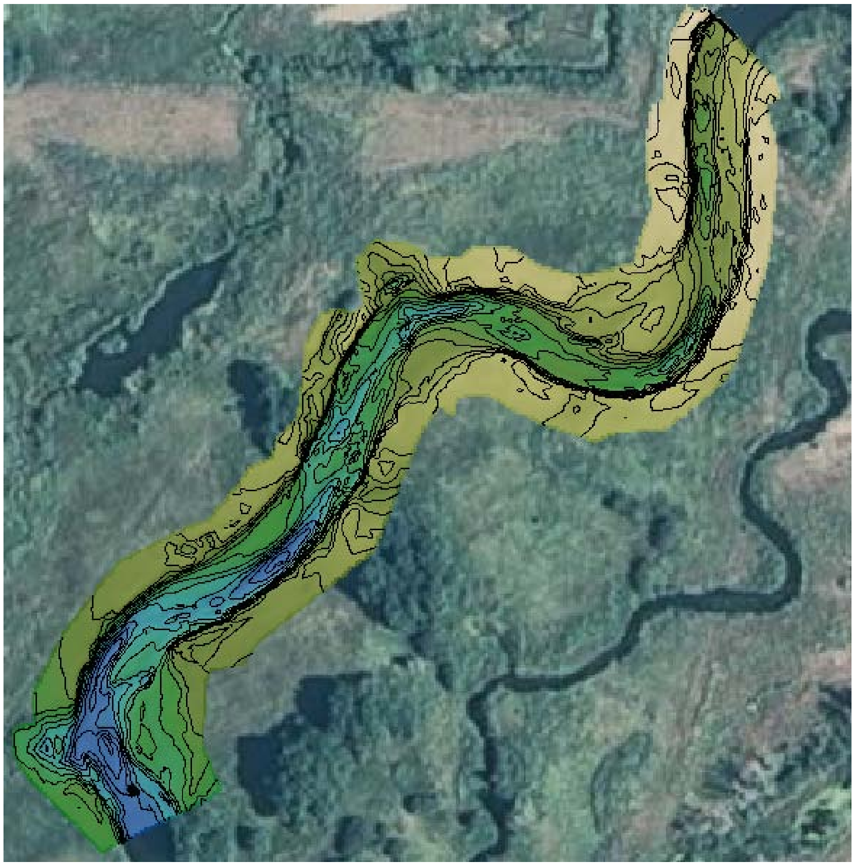
Contours are a useful way of visualizing topography. Contours can be derived from TINs or DEMs. See http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?id=3579&pid=3577&topicname=Creating_contours for more information on creating contours.

1. To derive contours for the Provo_DEM, go to *3D Analyst -> Surface Analysis -> Contour..:*



   Specify `Provo_DEM` as the *Input Surface*, choose a *Contour Interval* (0.25 for 25 cm), leave the *Base Contour* at 0 and the *Z Factor* at 1, then specify where to save the output shapefile in your working directory and what to call it (e.g. `Provo_25cm_Contours.shp`).

2. This will produce a vector shapefile of type polyline, where the polylines represent the individual contours:



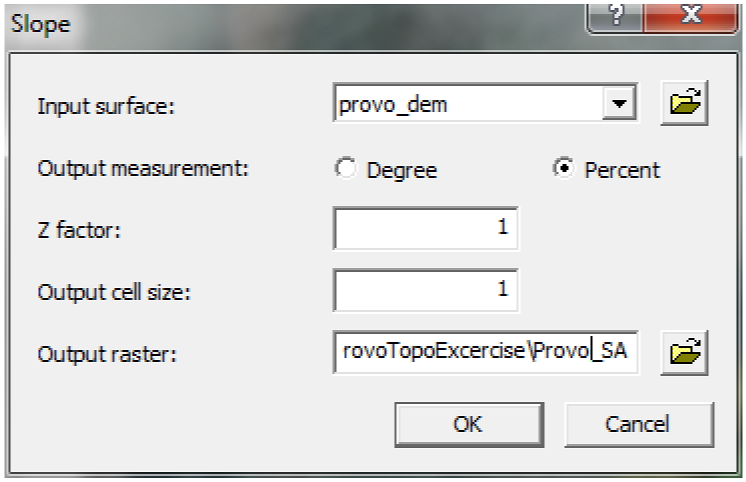
3. If you wish to check the elevation of a particular contour use the *Identify tool*  to see its elevation. If you want to label the contours, right click on the contour layer and in the Properties Dialog go to the Labels tab and adjust the settings.

SLOPE ANALYSIS (OPTIONAL)

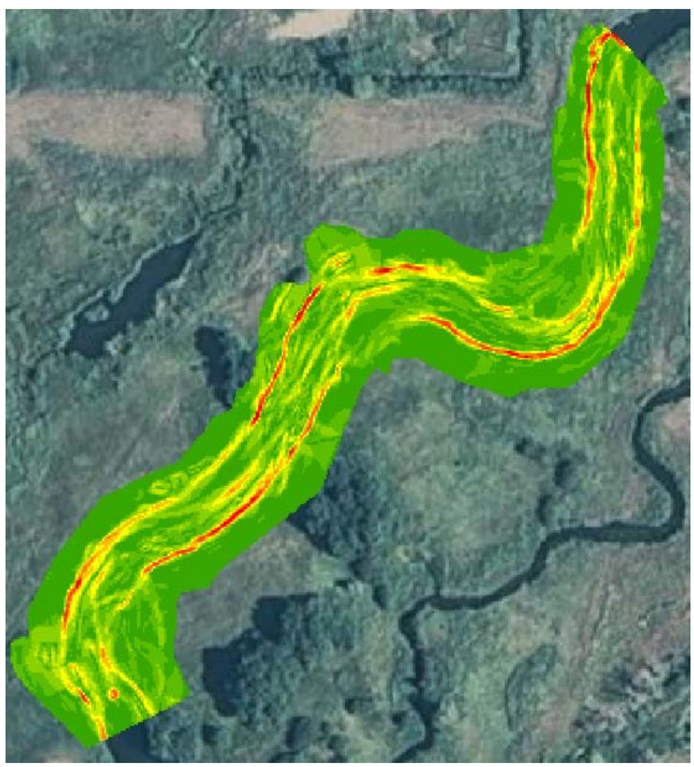
A slope analysis is a useful tool for showing local[6] slopes.

1. To perform a slope analysis of the DEM, go to *3D Analyst -> Surface Analysis -> Slope Analysis:*

[6] Since local slopes are calculated on a cell-by-cell basis relative to neighboring cells, they are not a good approximation of reach slopes.



As with the other commands, specify the Input Surface as the `Provo_DEM`, choose whether you prefer to see *slope values in degrees or percent*, keep the *Z Factor* at 1, keep the *Output Cell Size* the same as your input surface (1 meter in our example), and specify where to save the output raster. Upon clicking *OK* you will see something like the below:

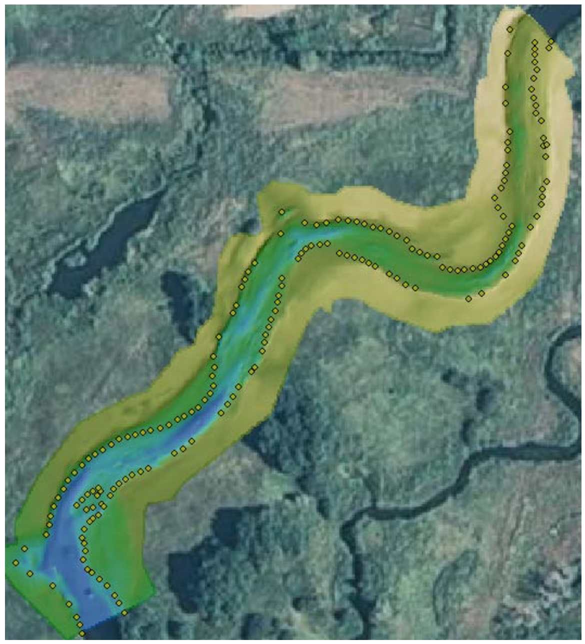


Notice that the banks pop out very clearly in red.

DERIVE WATER DEPTHS (OPTIONAL)

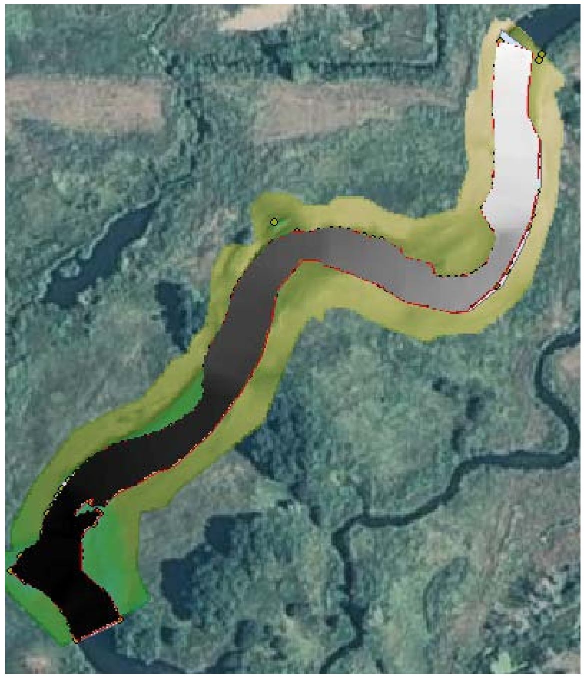
A map of water depth (at time of survey) can be very helpful for context, visualization, instream habitat mapping, as well as depth validation of hydraulic model results. If you have a DEM of bathymetry, and a water surface edge survey, you can derive water depths.

1. First import the water surface edge survey `st_reach_wse_nez.csv` (refer to instructions above if you need help).



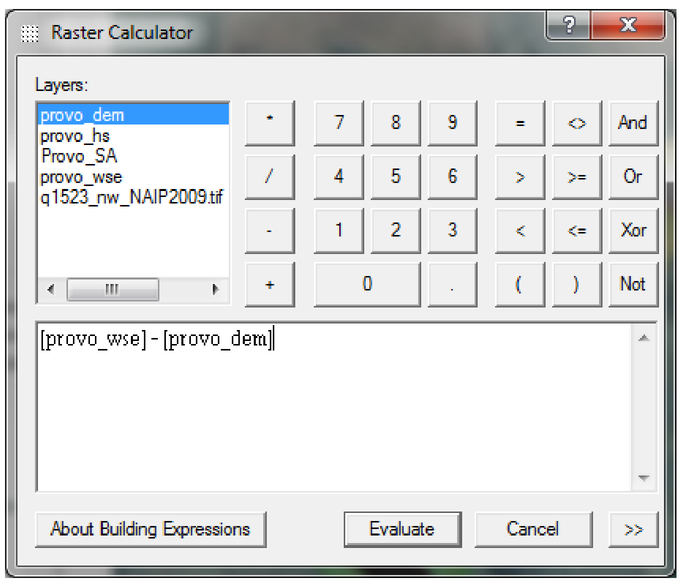
   The points should appear as an outline of the waters edge.
2. Next create a shapefile[7] and edit it to draw a polygon around the waters edge survey.
3. Next derive a water surface TIN using the waters edge polygon as a hard clip boundary and the `st_reach_wse_nez.csv` dataset.
4. Next, convert your water surface TIN to a water surface DEM (using the *Tin to Raster* tool).

[7] Refer back to instructions on creating a shapefile if you need help (i.e. *Create Feature Class* tool).



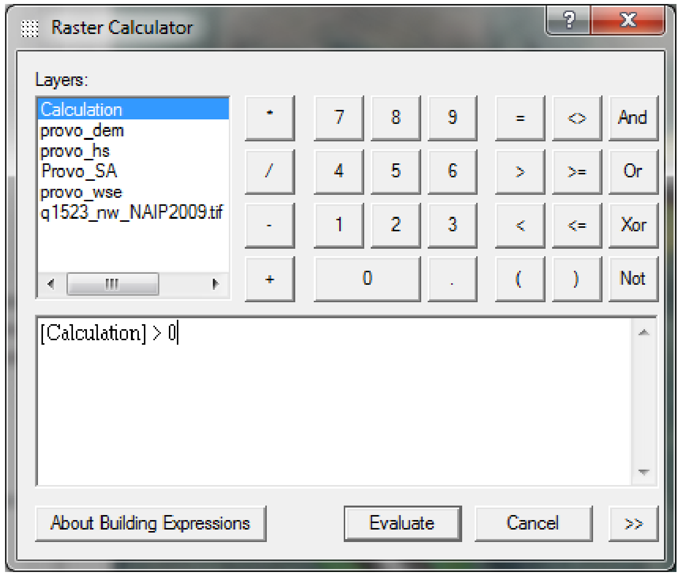
Your water surface raster should look something like the above.

5. To derive a water depth, we simply need to subtract the DEM bathymetry elevations from the water surface elevations. To do this, we can use the *Raster Calculator* found in the *Spatial Analyst* Toolbar:



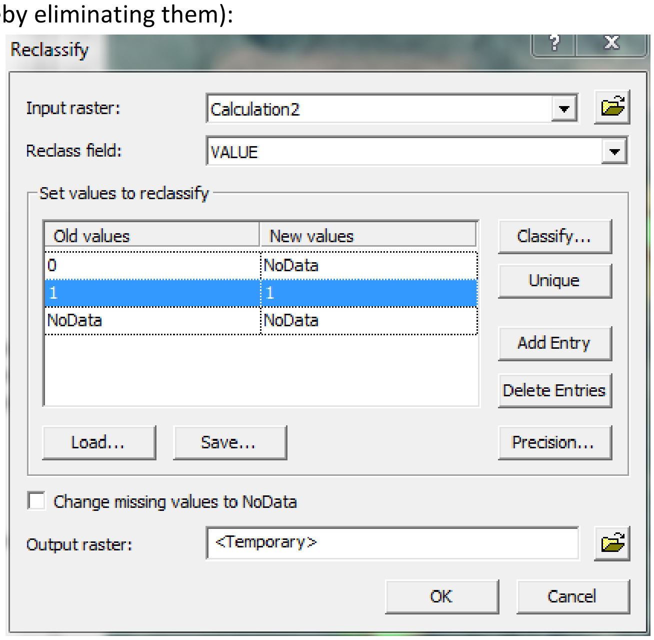
In our example, this produces a raster with both negative and positive values in the `Calculation layer`.

6. The negative values need to be filtered out from the `Calculation`. We can use the *Raster Calculator* to do this with a logical operator:



By checking for all cells in which the [`Calculation`] > 0, the raster calculator will return a `Calculation2` layer with 0s where the argument is false (i.e. the cells we want to remove) and 1s where the argument is true.

7. Wecan then use a *Reclassify* command in the *Spatial Analyst toolbar* menu to turn the zeros into NoData (thereby eliminating them):



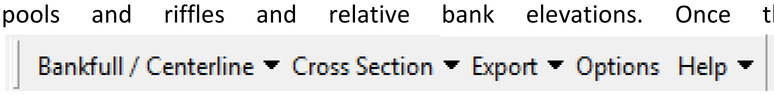
For 0 change the *New Values* to NoData, and for 1 leave the *New Values* as 1 (or *delete entry*). Click *OK* to evaluate.

8. We can then use the *Raster Calculator* one last time to get our water depth layer (`Calculation3`) by multiplying our *Reclassified Layer* by the original *Calculation* layer.
9. We can now make this layer permanent by right clicking on it and saving it in our working directory as *`Provo_WD`*, for example. If we change the display properties of the layer to a blue color ramp, we now have a nice water depth map.

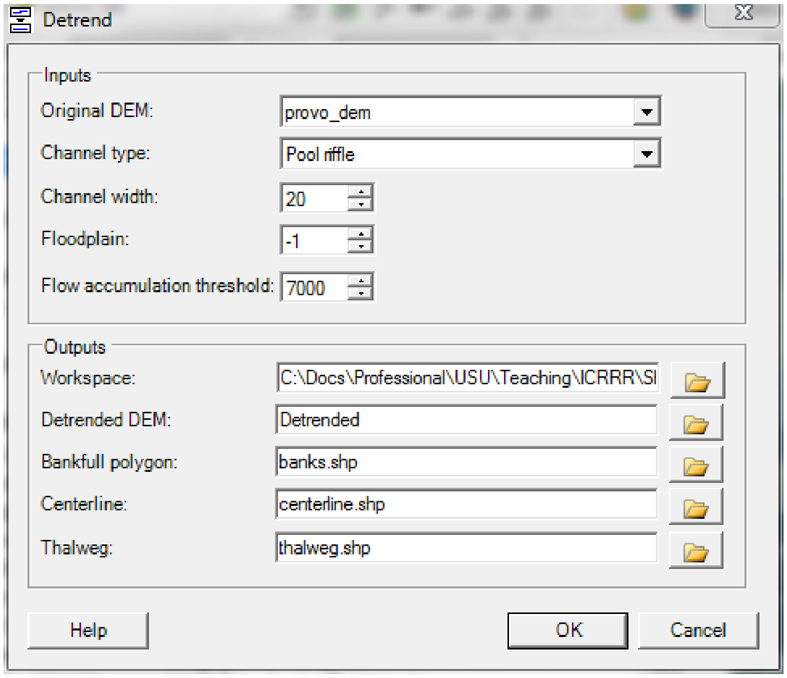
RIVER BATHYMETRY TOOLKIT (OPTIONAL)

The River Bathymetry Toolkit is a free plug-in that can be installed for doing a number of common tasks to DEMs of rivers, which include bathymetry (under water elevations). These tasks include, detrending the DEM, deriving a bankfull stage, deriving channel thawlegs, channel centerlines, extracting longitudinal profiles, extracting cross sections and hydraulic geometry. Here we highlight the first two of the tools (see RBT Documentation for details, example data, tutorials and instructions).

Detrending of DEMs is the process of removing the valley slope trend in the DEM such that elevations relative to the channel itself our displayed. This helps bring out the topography of the river and highlight pools and riffles and relative bank elevations. Once the RBT toolbar is installed



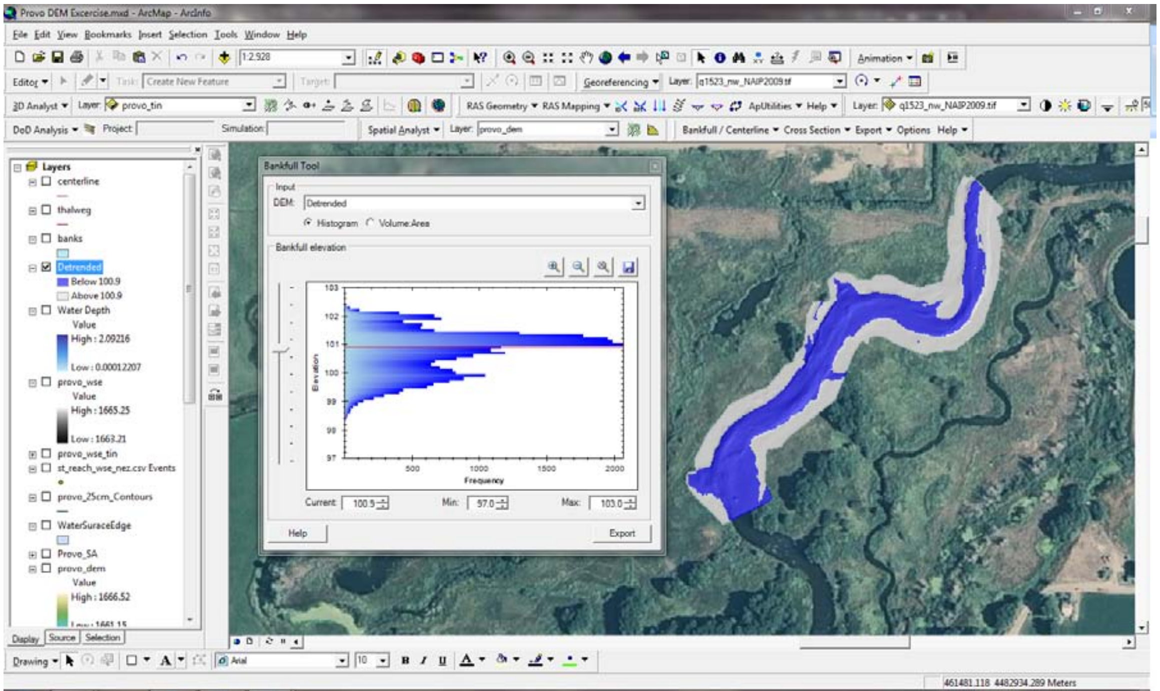
, you can access the *Detrend* command from the *Bankfull/Centerline* menu:



There are a number of parameters (see RBT Documentation), but if you specify your DEM (`Provo_DEM` for our example), you can click OK, wait patiently and you will ultimately derive a detrended DEM:

As compared with the regular DEM, this detrended DEM does a nice job of highlighting the pools, bars and floodplain.

In RBT, if you have a detrended DEM, you can use it to derive approximations of flood inundation paterns with their *Bankfull Tool*. The *Bankfull Tool* shows you a distribution of detrended elevations and has an interactive slider bar you can adjust and see how inundation patterns adjust accordingly (in RBT, they use this to establish an approximate bank full elevation).



See below for more information on RBT.

MORE INFORMATION

For more information on some of the tools described above as well as other tools for working with DEMs in rivers, you may find some of the following resources useful:

- For ArcGIS 3D Analyst: http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=An_overview_of_the_3D_Analyst_toolbox
- For River Bathymetry Toolkit, go to: http://www.fs.fed.us/rm/boise/AWAE/projects/river_bathymetry_toolkit.shtml and refer to McKean et al. (2009).
- For HEC-Geo-RAS: (http://www.hec.usace.army.mil/software/hec-ras/hec-georas.html)
- For morphological sediment budgeting using repeat topographic surveys, see the DoD Uncertainty Analysis Software at: http://www.joewheaton.org/Home/research/software/dod-uncertainty-analysis-software and refer to Wheaton et al. (2010).

PART II - CREATE DESIGN DEM

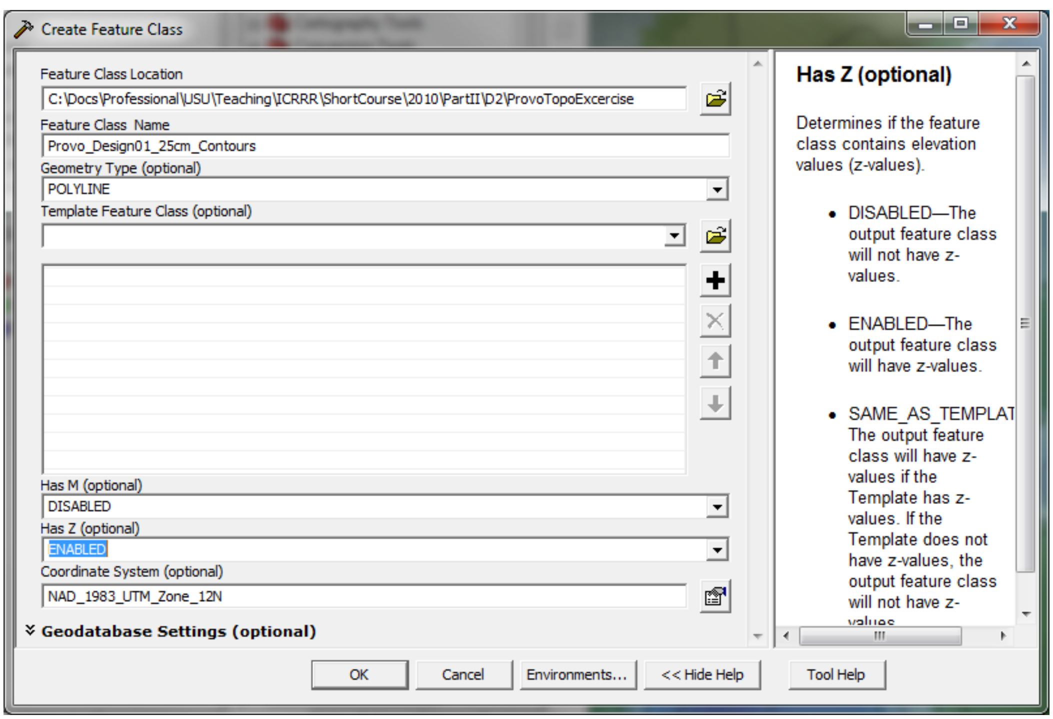
A design DEM is one that shows the topography of the design merged with the existing topography. A design DEM is ultimately a digital version of a grading plan that might be handed to a contractor. Design DEMs are useful for doing earthwork calculations to estimate volumes of cut and fill and assess whether or not there is a balance or whether or not material will need to be imported or exported. Depending on the nature of the grading, some contractors can use a design DEM for machine control construction (with survey grade GPS or total stations) to control graders, scrapers and dozers. Design DEMs can also be used to compare against as-built surveys to assess how well the constructed project matches the design project. Finally, design DEMs are also useful to act as topographic boundary conditions in hydraulic and/or morphodynamic models to test design conditions and/or test specific design hypotheses.

In this exercise, we will very briefly go through one workflow using GIS to create a simple grading plan and covert it to a design DEM for potential use in the

CREATE GRADING PLAN LAYERS

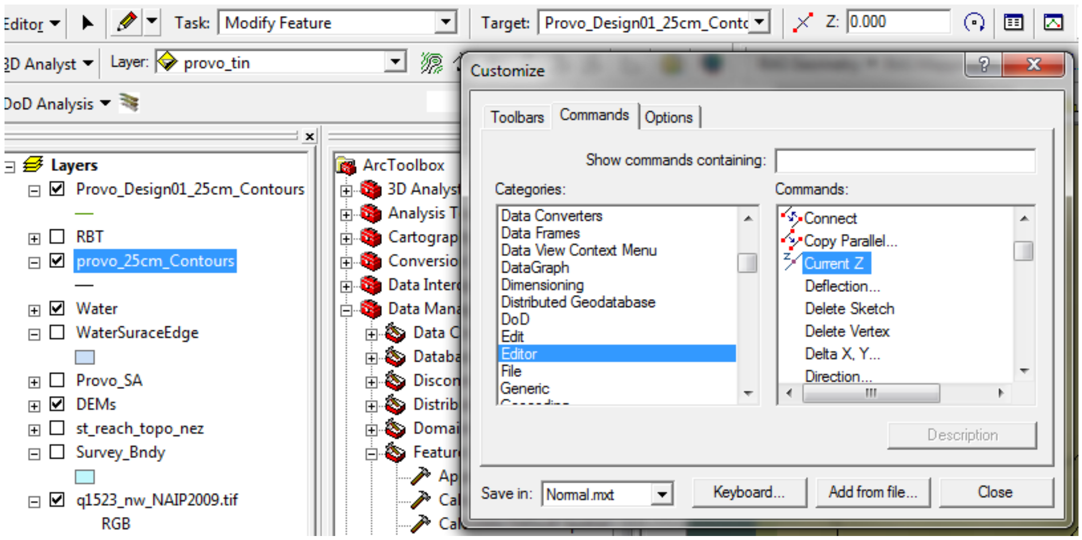
The first step to create a grading plan is to draw some contours in a feature class or shapefile of type polyline.

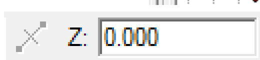
1. Navigate to the ArcToolBox and down to *Data Management Tools -> Feature Class -> Create Feature Class*:



Fill out the dialog as with before (see Modify TIN), but this time make sure that the *Geometry Type* is *POLYLINE* and that *Has Z* is *ENABLED*. This will allow you to assign contour elevations to the polylines and make them three dimensional.

2. To easily assign elevations to each vertice in the polylines, we will use the *Current Z tool*[8]. To do this, right-click on a blank part of the toolbar in ArcGIS and switch to the *Commands tab* and navigate to the Editor commands under Categories and locate the *Current Z* command. Drag the command up on to the Editor toolbar as shown below:



This puts the  command in the toolbar and allows you to specify an elevation in an edit session for any feature class that has Z values enabled.

MAKE GRADING PLAN WITH CONTOURS & FINISH GRADE POINTS

CONTOURS

In this example we will grade in (with cutting) a side channel. Decide the area you wish to regrade, locate the contours and if necessary use the Identify tool  to check the contour elevations of existing contours. Your grading plan contours should almost always start at an existing contour and finish further along the same elevation contour. The only exception to this is for peaks or troughs, where you can use a closed circle contour inside the boundaries of neighboring grading contours. It is easy to accidently connect a grading contour to two different elevation contours. Such an error will create an abrupt step in your topography as opposed to smooth transitions.

To draw contours, you simply need to Start Editing for the target layer with your contours (`Provo_Design01_25cm_Contours` in our case). Then use the sketch tool  to draw your contours, baring in mind the rules outlined above. When you start your contour, make sure you have

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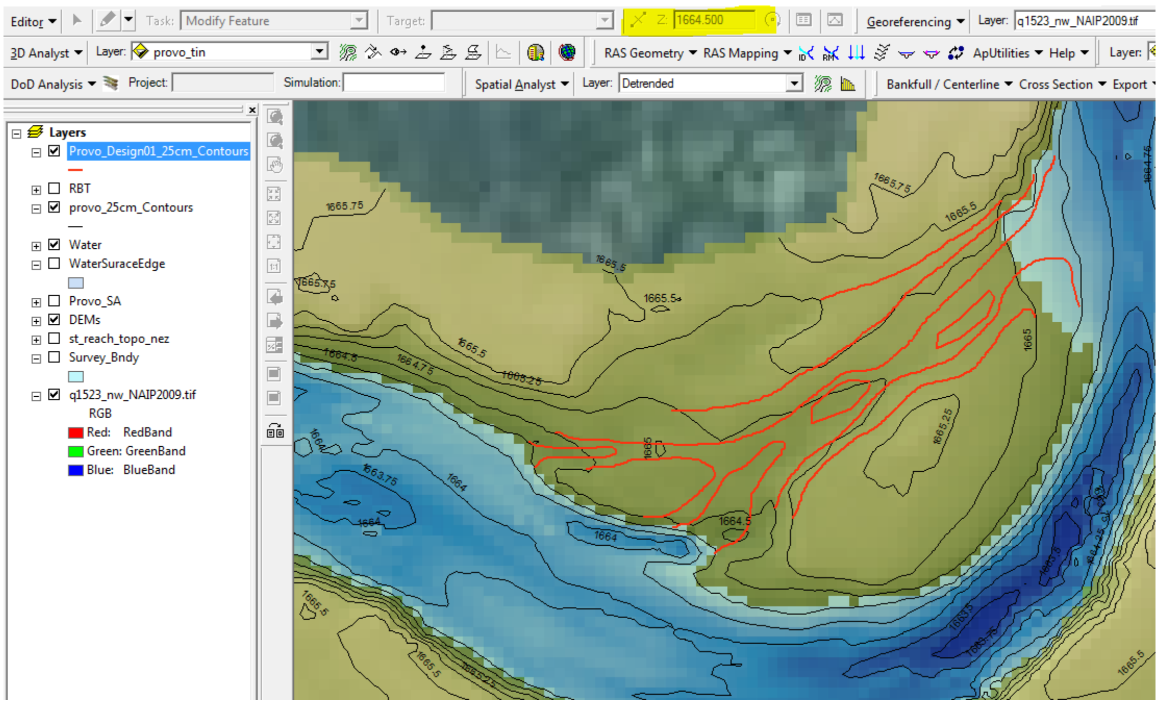
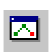
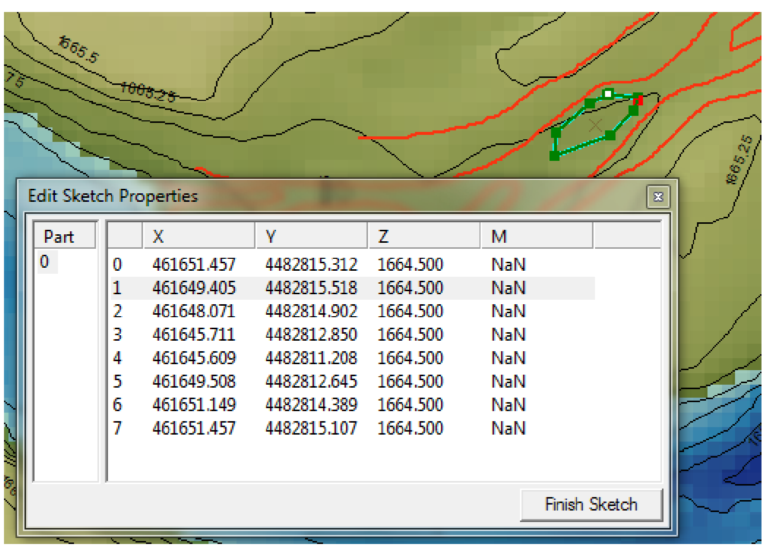
[8] See http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?id=4764&pid=4762&topicname=Defining_z-values_for_features for more information on defining z-values for features.

specified the elevations to use in the *Current Z* box 

. The example below shows a grading plan depicting a side channel to be cut into the inside bend (using red contours). The closed red circles represent two pools in the side channel. The side channel bifurcates at the downstream end, such that the side channel rejoins the main channel at two places.



To make sure the contour you drew has the correct elevation values, you can check or modify its elevations by clicking the *Edit Tool*  and then double-click the contour with the z-values you want to check or edit. Once selected (it will be a different color and vertices will show), use the *Sketch Properties* button  on the editor toolbar to make sure the Z values are what you expect them to be:



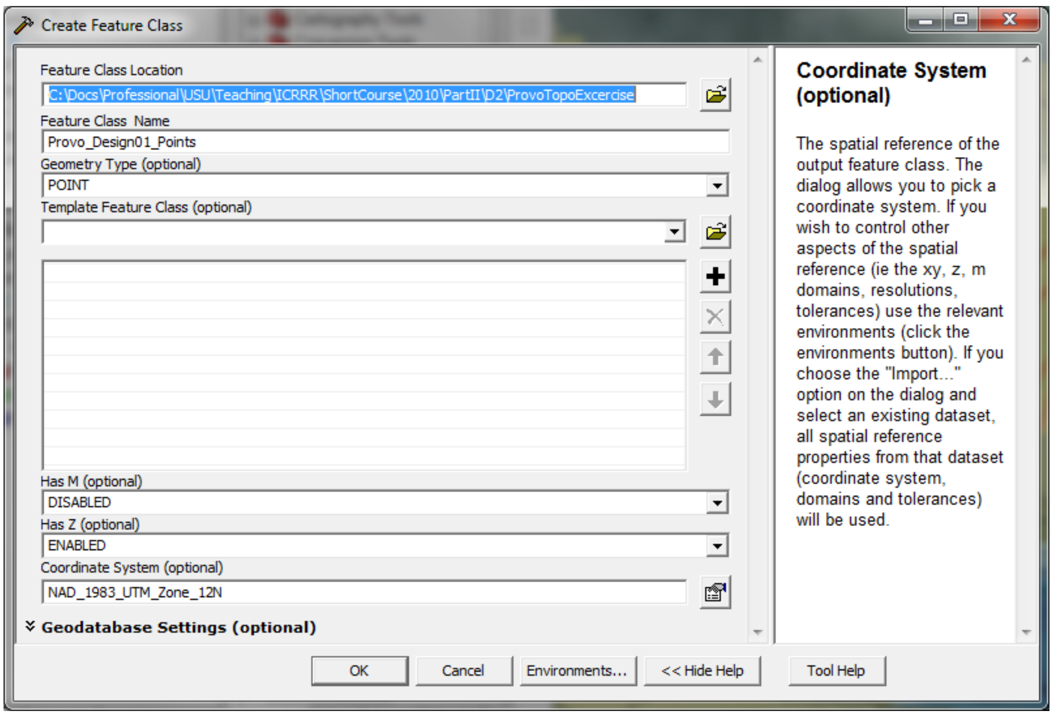
	X	Y	Z	M
0	461651.457	4482815.312	1664.500	NaN
1	461649.405	4482815.518	1664.500	NaN
2	461648.071	4482814.902	1664.500	NaN
3	461645.711	4482812.850	1664.500	NaN
4	461645.609	4482811.208	1664.500	NaN
5	461649.508	4482812.645	1664.500	NaN
6	461651.149	4482814.389	1664.500	NaN
7	461651.457	4482815.107	1664.500	NaN

When you're happy with the contours, Stop Editing and save your changes.

FINISH GRADE POINTS

Creating finish grade points is especially useful for Design DEMs that will be used in hydraulic modeling to define critical low points and crest elevations that have a large influence on controlling hydraulic patterns and topographically steering the flow. Because the contours can only specify the topography to within a plus or minus range of the contour interval, spot elevations (or finish grade points) can be used to fill in between.

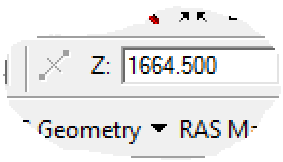
1. Again, create a feature class for the new points:



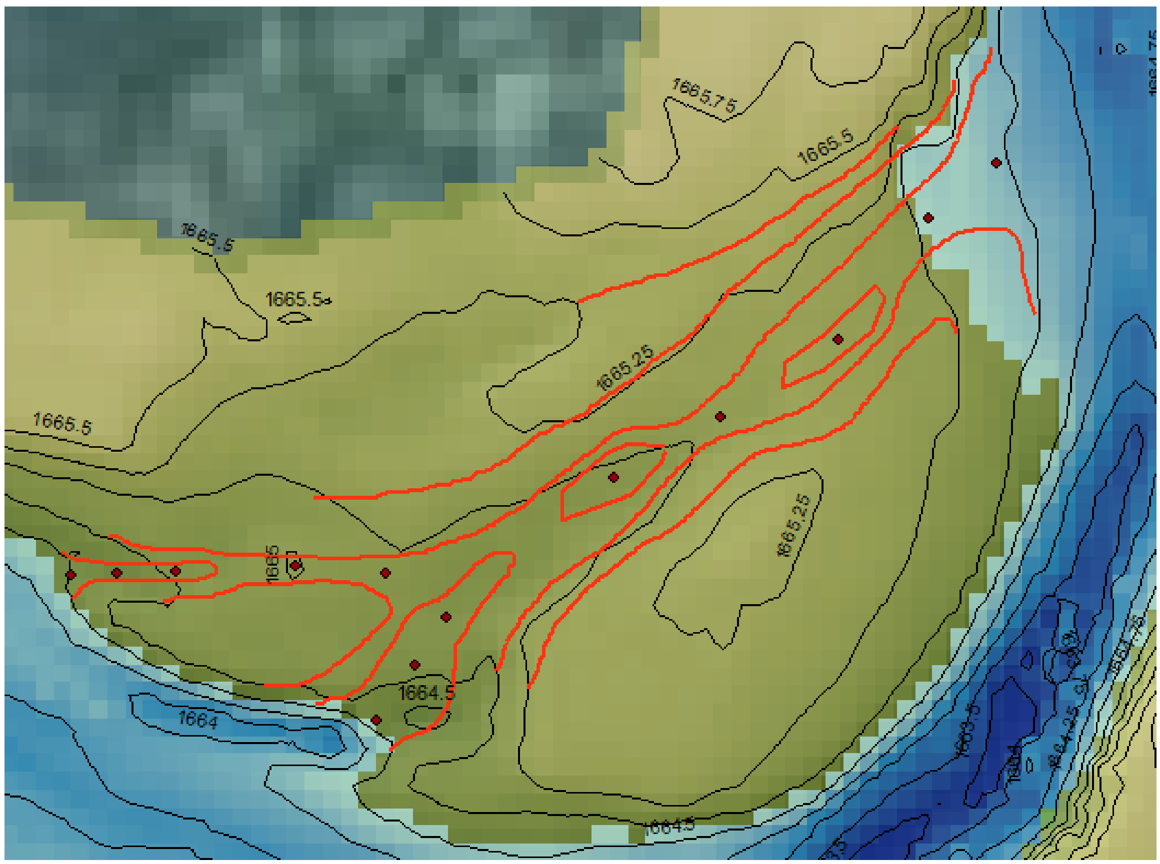
   Fill out the dialog as with before (see Modify TIN), but this time make sure that the *Geometry Type* is *POINT* and that *Has Z* is *ENABLED*. This will allow you to assign point elevations to and make them three dimensional.[9]

2. To create finish grade points, use the sketch tool and click where you want points. There are various ways to specify your finish elevations. I suggest using the current Z tool

[9] NOTE: If you want to export these points out to a *.dbf table and use the points elsewhere, you may wish to also create an Elevation field and manually populate it with elevation values as you create your points. This is not necessary for modeling within ArcGIS as the 3D z value is stored in the Geometry of the point, but that information is not as easy to extract and export.



in the editor toolbar and change the values as you go. Alternatively, you can use the *Edit Tool* and double-click on the point you wish to modify, and use the *Sketch Properties* button on the editor toolbar to then edit the Z value. The points should generally be in between the contour intervals (otherwise, just draw another contour). Points should be placed to define critical crest elevations and low points:

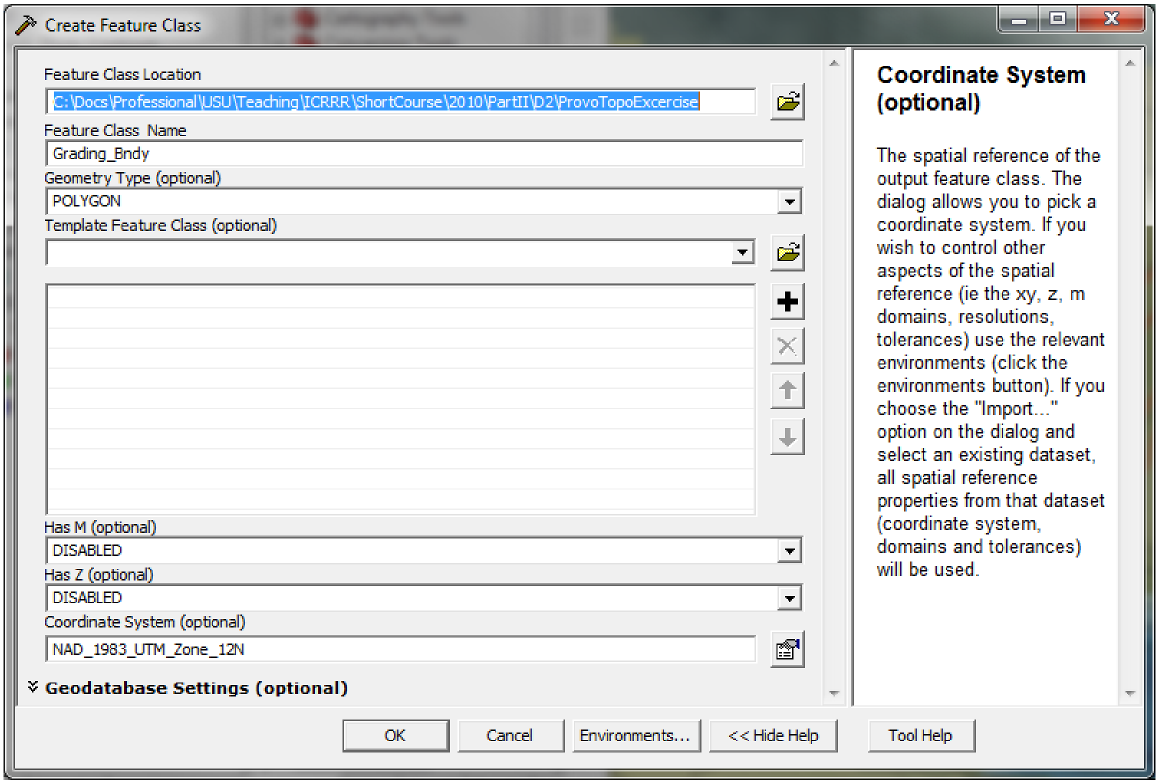


3. Once you're done with creating points, stop the edit session and save the changes. Remember, saving the Map Document does not actually save edits. Only saving edits from the Editor menu saves edits to a feature class or shape file.

DELINEATE GRADING BOUNDARIES

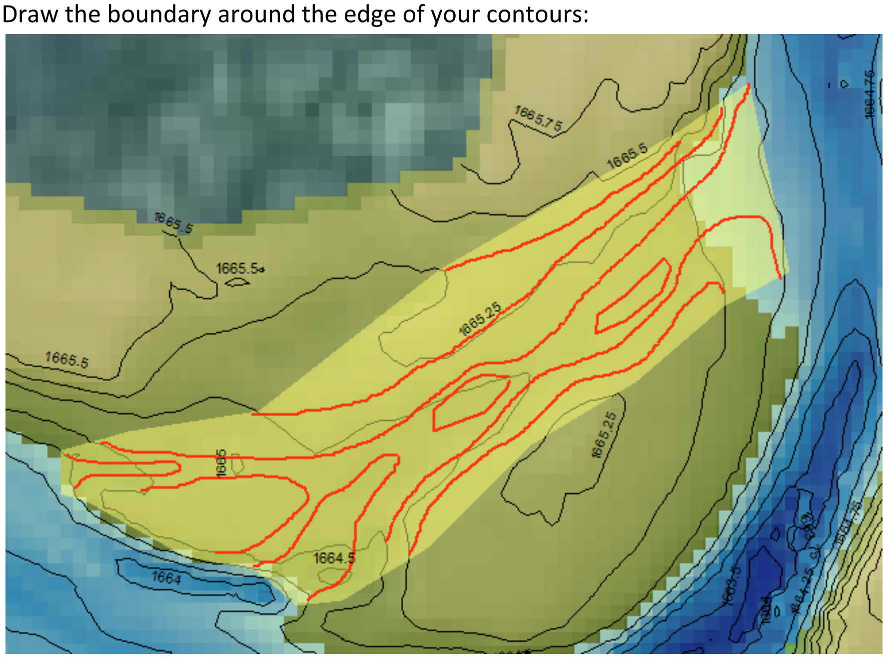
After you've created your grading plan with contours and spot elevations, we want to create a new DEM of the study site that includes the original elevations everywhere no grading will take place, and the new elevations where you have specified them. One way to do this is by using a polygon grading boundary.

1. First we need to create a polygon shape file:



Fill out the dialog as with before (see Modify TIN), but this time make sure that the *Geometry Type* is *POLYGON*.

2. Draw the boundary around the edge of your contours:

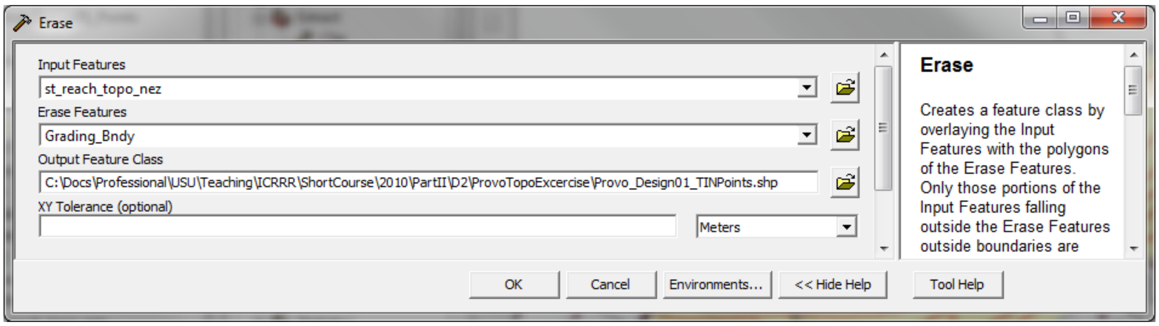


The polygon should not extend too far into the non-graded area as you want to be able to use as many of those original points as possible.

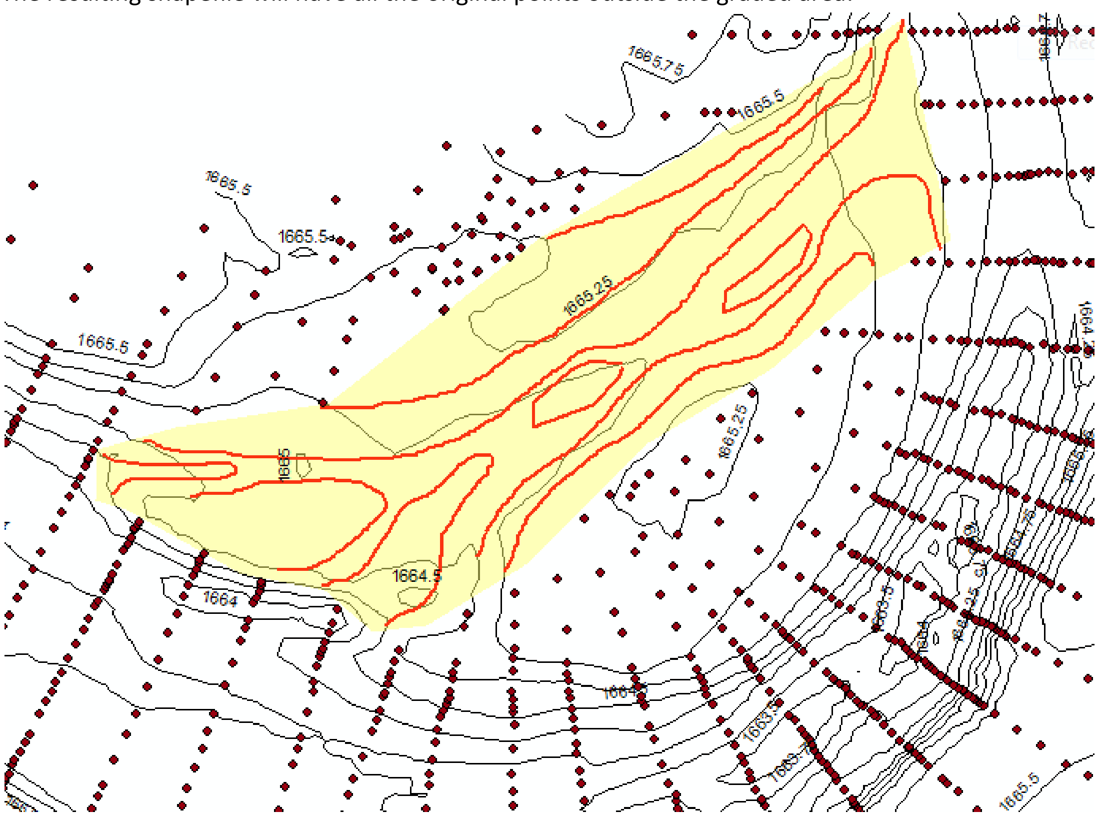
GET TOPOGRAPHIC DATA FOR DESIGN DEM ALL TOGETHER

Now we want to use all of the original survey points outside the grading polygon, and use only the contours and the design points inside the polygon. To build this file requires multiple steps.

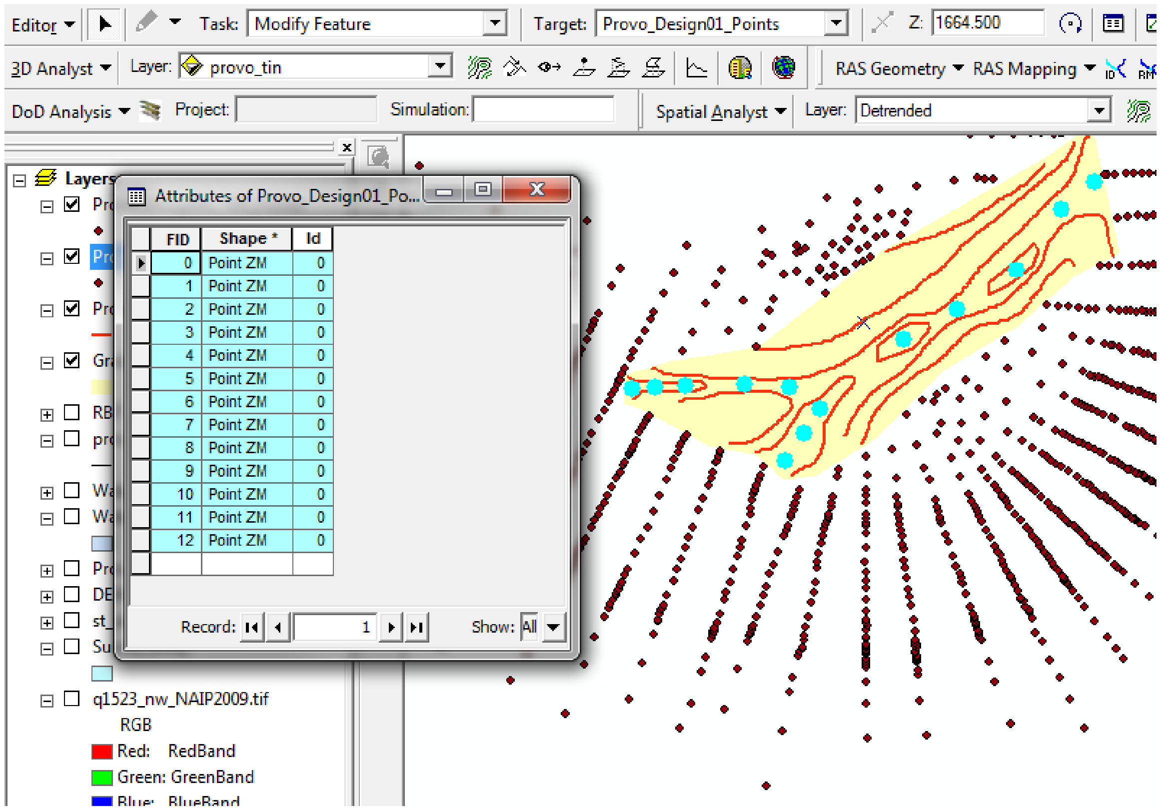
1. First, use the Erase command in the *ArcToolbox -> Analysis Tools -> Overlay -> Erase*:



   Select the original topography point data (`st_reach_topo_nez`) for the Input Features, select the Grading_Bndy for the Erase Features, and specify the Output Feature Class as a name you will recognize in your working directory (e.g. `Provo_Design01_TIN_Points.shp`). The resulting shapefile will have all the original points outside the graded area:

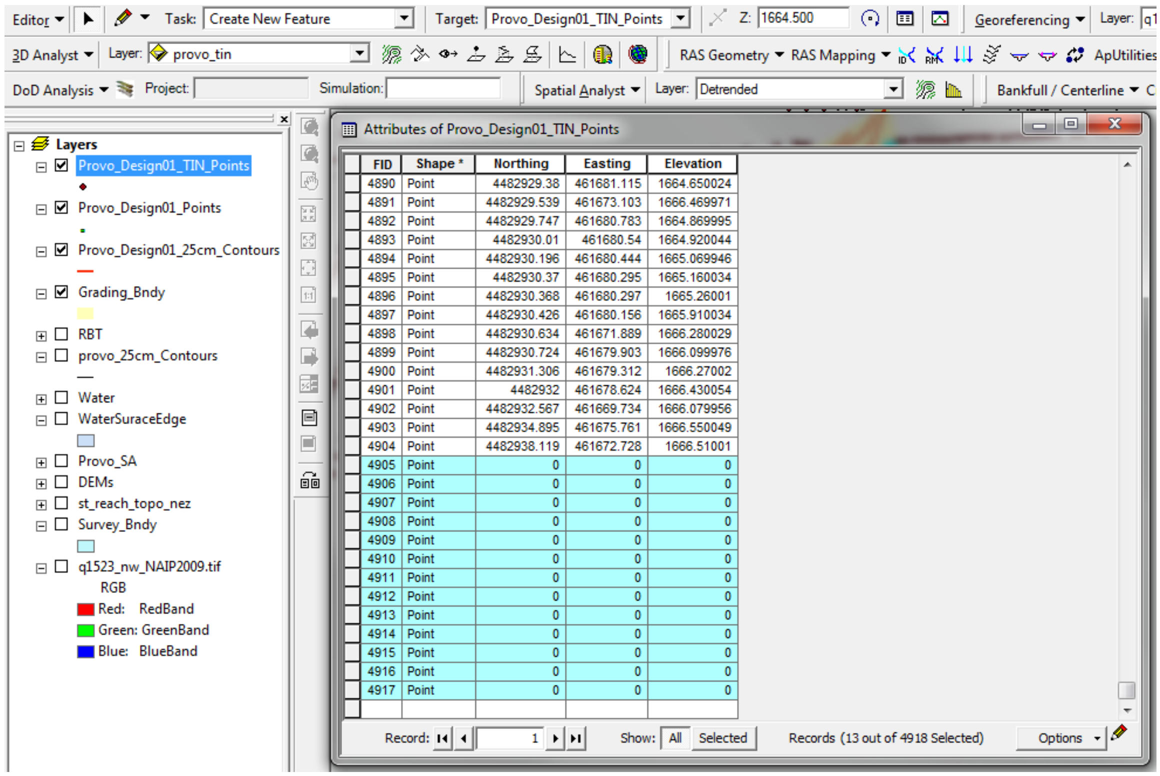


2. Next we will use some basic editing commands to copy the points from the `Provo_Design01_Points` layer to the `Provo_Design01_TIN_Points` layer. Start an edit session for the `Provo_Design01_Points` layer.
3. Open the Attribute Table for `Provo_Design01_Points` layer and select all the points:



After you've selected all the points, copy them (e.g. Edit -> Copy). Now turn off the `Provo_Design01_Points` layer in the Display dock and close the attribute table.

4. Next, open the attribute table for `Provo_Design01_TIN_Points` layer and change Target in the editor toolbar to this. Also make sure that the Task: is set to Create New Feature. Now you can paste (using Edit -> Paste or control V) the points from the `Provo_Design01_Points` layer into the `Provo_Design01_TIN_Points` layer:

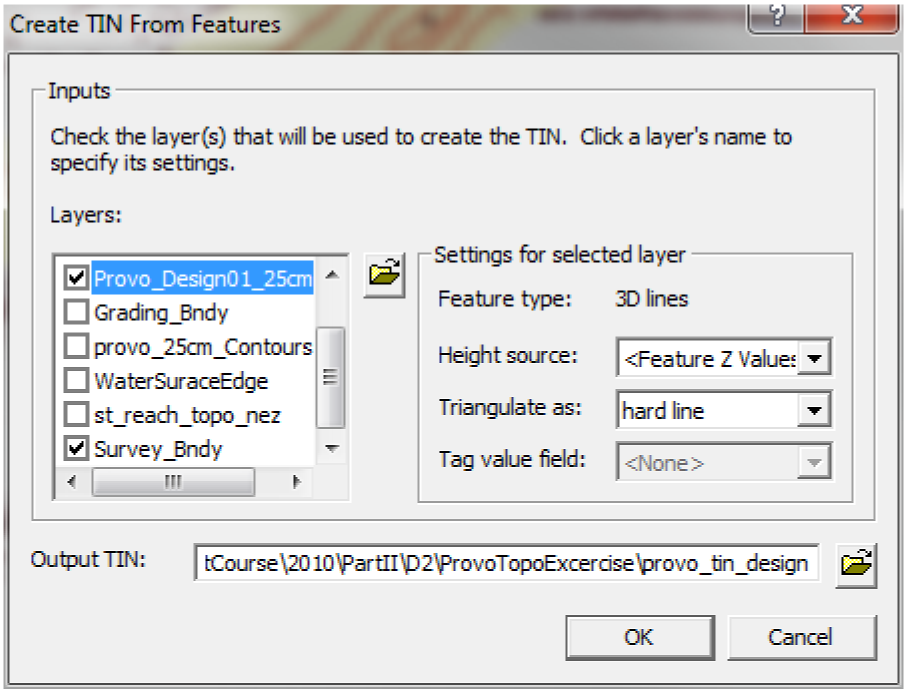


Notice that the copied points all have 0 listed for the northing, easting and elevation. The point coordinates are correctly preserved in the Shape geometry for the feature class. However, the attribute fields are not populated.

5. OPTIONAL -> (skip to 6 if not exporting points). If you plan on exporting your points for use elsewhere, you will want to populate the northing, easting and elevation values. The Northing and Easting columns can be recalculated by simply highlighting the top of the column, right-clicking and selecting the Calculate Geometry command (choose X for Easting, Y for Northing). However, the elevation field has to manually edited.
6. *Stop* the Edit session and save your changes.

BUILD NEW DESIGN DEM

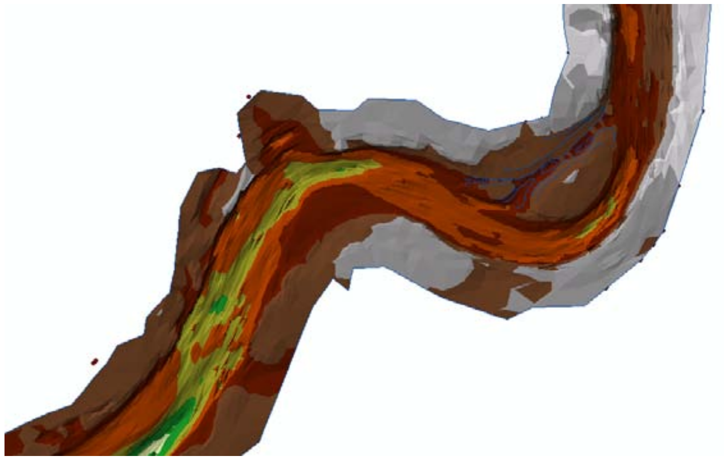
1. To build the design DEM, we will create a TIN (refer to previous Create TIN from Data section for more detailed instructions). Bring up the Create TIN… dialog:



This time we will use three inputs:

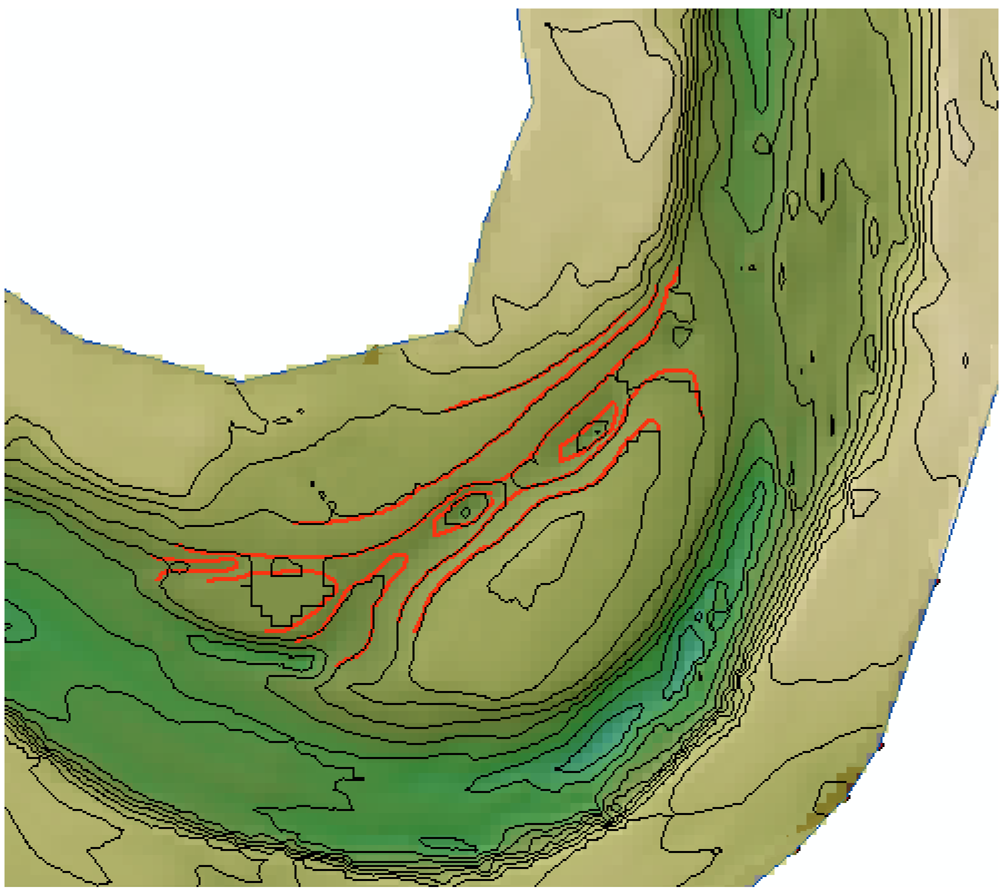
- `Survey Bndy` with <None> as the height source, and triangulate as hard clip
- `Provo_Design01_TIN_Points` with <Elevation> as the height source and triangulate as Mass Points
- `Provo_Design01_25cm_Conturs` with <Feature Z Values> as the height source and triangulate as <hard line>

Save this as Provo_TIN_Design in your working directory and click OK.



Notice the side channel now shows up in the TIN.

2. As with before, it may be useful to visualize this with 25 cm contours, and convert it to a DEM and Hillshade.



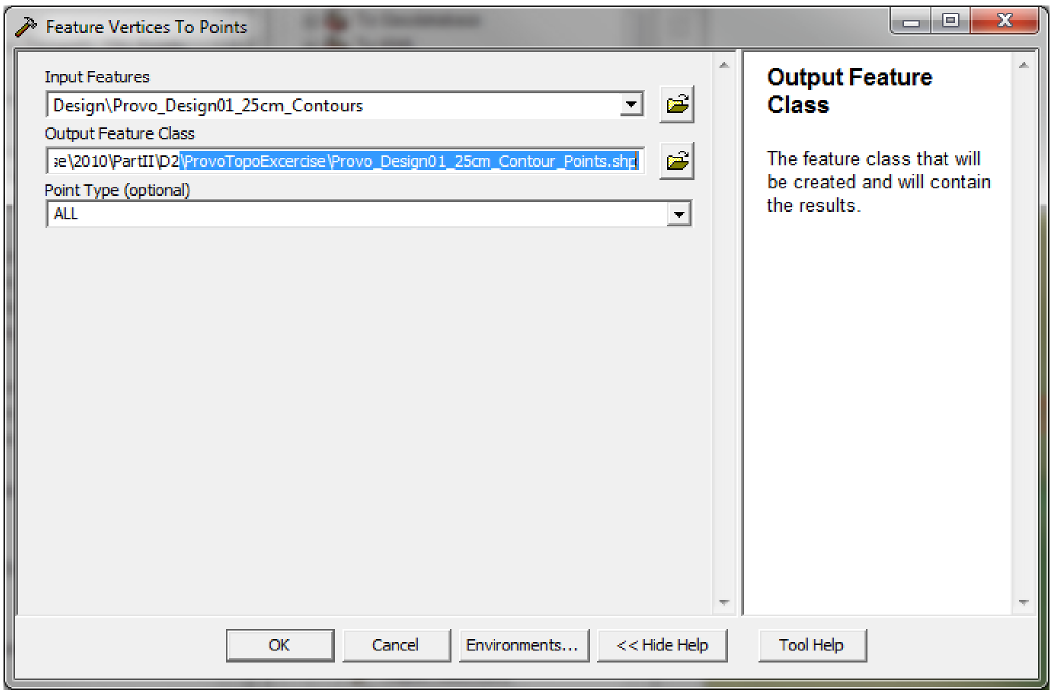
Above, the Design DEM contours are shown in black and the original design polygon contours are shown in red. You can iterate on the specification of individual points to improve the match or accept the result as is. Once you are satisfied, you are done. Congratulations.

It should be noted that this process is straightforward to implement to compare multiple design scenarios.

EXPORTING POINT DATA (OPTIONAL)

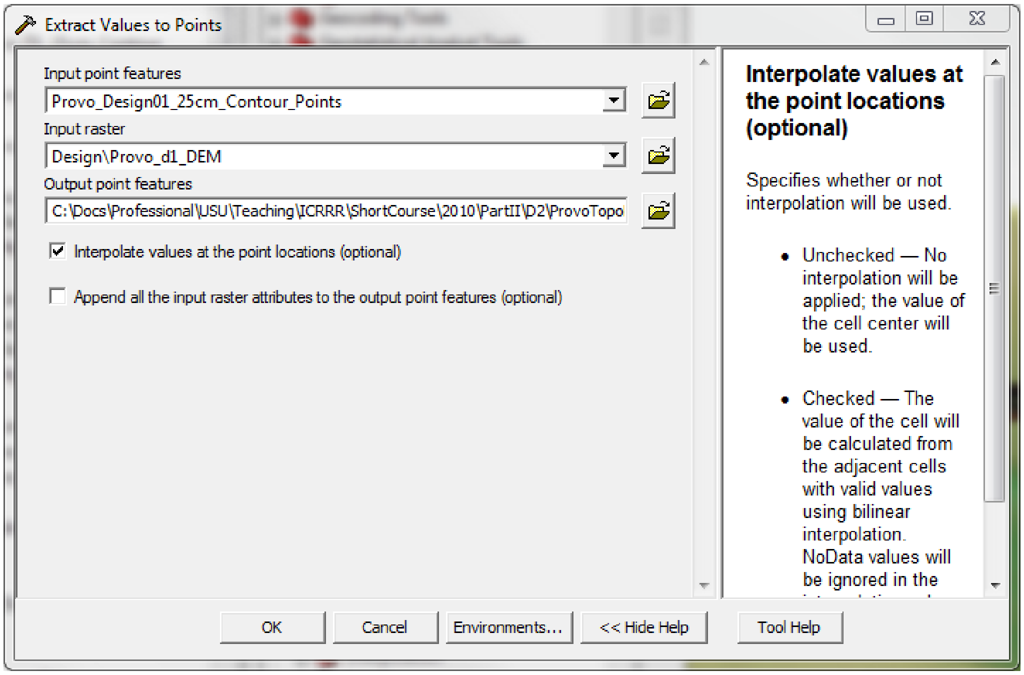
If you wish to export the point data for use externally, you can easily export the original point data and design points to a *.dbf file using the Export tool from the attribute table of `Provo_Design01_TIN_Points layer.` However, you need to export the design contours as well. Some programs will accept a shape file. You can also use *the File Management Conversion tools* to convert this to various CAD formats (e.g. `*.`DXF file). However, if you need to get the points off here is a simple workflow that extracts the point values from the DEM at the contour vertices:

1. In ArcToolbox, go to *Data Management Tools -> Features -> Feature Vertices To Points*:



   Specify `the Provo_Design01_25cm_Contours layer` as your *Input Features*, specify a *Output Feature Class* to save the points to, and then select *ALL* for *Point Type*.

2. Next, navigate in ArcToolbox to *Spatial Analyst Tools -> Extraction -> Extract Values to Points*:



This will create a point file with an elevation field from the DEM.

3. You will need to create two new fields in the shapefile for the Norhting and Easting and populate them with the Calculate Geometry tool to get those coordinates. Then, you can export the points to a *.dbf file and use them as described previously.

SUMMARY

This tutorial walked you through two simple tasks: building a DEM from raw topographic data, and building a desigin DEM using your own imagination. With the screen shots, step-by-step instructions, and optional sections, this 44 page document could give the impression that this is a lengthy and tedious task. In reality, the first task typically takes 5-30 minutes, and the second task is a simple workflow, in which the amount of time required depends on the complexity and scope of your design.

References were provided throughout and a few papers on RBT and DoD work are listed below. If you get really stuck, feel free to contact me at Joe.Wheaton@usu.edu and I'll attempt to help you.

REFERENCES

McKean J, Nagel D, Tonina D, Bailey P, Wright CW, Bohn C and Nayegandhi A. 2009. Remote Sensing of Channels and Riparian Zones with a Narrow-Beam Aquatic-Terrestrial LIDAR. *Remote Sensing.* **1**(4): 1065-1096. DOI: 10.3390/rs1041065.

Wheaton JM, Brasington J, Darby SE and Sear D. 2010. Accounting for uncertainty in DEMs from repeat topographic surveys: Improved sediment budgets *Earth Surface Processes and Landforms.* **35**(2): 136-156. DOI: 10.1002/esp.1886.