HOW TO CREATE AN INUNDATION/FLOOD HAZARD MAP

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Please read the instructions CAREFULLY, as each step in this tutorial is dependent on the previous step. A voice over of the tutorial is also available. Please take your time in running the tutorial. Please note that this tutorial was written under ArcMAP version 10.3.1.

Introduction

Inundation maps can be an important part of understanding coastal inundation issues, assessing flood adaptation strategies, and floodplain management. Today, the Federal Emergency Management Agency (FEMA) creates inundation maps called FIRMS (Flood insurance rate maps). These maps can be used in decision-making. For example FIRMS were used in the proposal of the Big U being built at the Battery in New York City after the damage of Hurricane Sandy. In this tutorial you will learn how to analyze flood extent and create flood risk maps in ArcGIS.

Following this tutorial you will create an inundation map for the San Francisco Bay area in California. To do this you will obtain Digital Elevation Models (DEMs) for the San Francisco Bay area and use previously calculated water levels. In the tutorial you should:

- Identify the flood hazard area with a 100-yr storm surge;
- Identify the flood hazard area with a 100-yr storm surge plus the mean 2100 sea-level rise projection;
- Identify the flood hazard area with a 100-yr storm surge plus accounting for uncertainty in the 2100 sea-level rise projection.

The process will require you to:

- Integrate raster and vector data layers
- Calculate the area inundated by the different flood levels for a county

Procedure

Obtaining the data files

The some of the data files needed for this tutorial have been previously downloaded and are located in the tutorial's folder. However, updated data and DEM files can be (re-)downloaded following these steps.

DEMs are used to record the earth's physical terrain surface. Each grid cell in a DEM has elevation values. The elevation data serve as the base data layer for mapping inundation. In this case, mapping coastal inundation. To understand more about available types of elevation data and requirements see https://coast.noaa.gov/digitalcoast/_/pdf/guidebook.pdf.

In this tutorial, you will use the 1/9 arc-second (3-meter) topobathy (merged topographic and bathymetric surface) DEMs from the U.S. Geological Survey National Elevation Dataset. To download the data,

Navigate to the USGS NED product searcher:
http://viewer.nationalmap.gov/basic/?basemap=b1&category=ned,nedsrc&title=3DEP%20View

In the Product Search Filter click on the subfilter: 1/9 arc-second DEM, zoom into the San Francisco area, click Find Products, and download the following DEMs.

- Ned19_n37x75_w122x25_ca_sanfrancisco_topobathy_2010
- Ned19_n37x75_w122x50_ca_sanfrancisco_topobathy_2010
- Ned19_n37x75_w122x75_ca_sanfrancisco_topobathy_2010
- Ned19_n38x00_w122x25_ca_sanfrancisco_topobathy_2010
- Ned19_n38x00_w122x50_ca_sanfrancisco_topobathy_2010
- Ned19_n38x00_w122x75_ca_sanfrancisco_topobathy_2010

In order to assess the area inundated for different counties navigate to the U.S Census Bureau TIGER/Line Shapefiles:
https://www.census.gov/geo/maps-data/data/tiger-line.html

Go to *Download* > *Web Interface* > Select year: *2015 or current year* > Select a layer type: *Counties (and equivalent).* Click submit and download the national file.

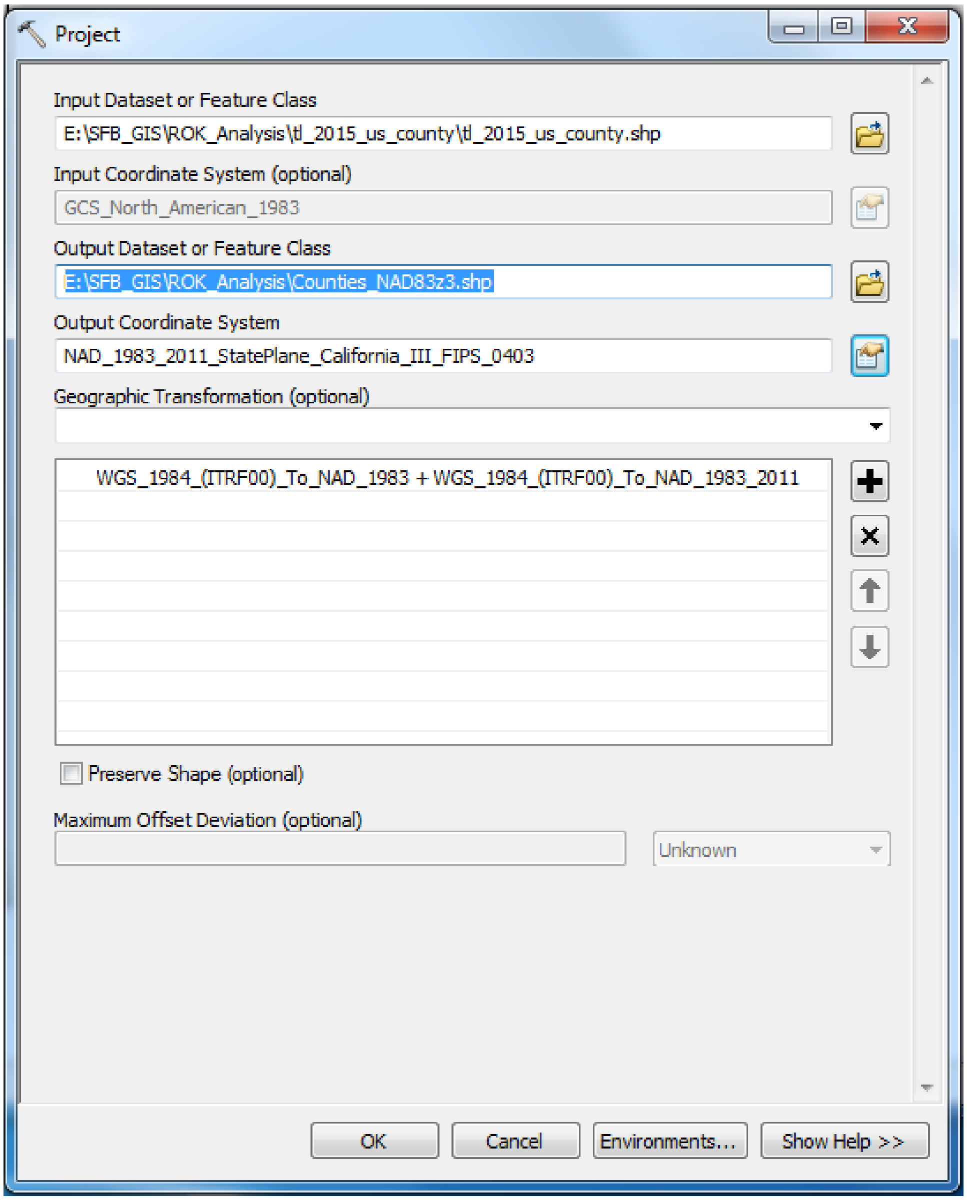
Additionally, download; Select a layer type: *States (and equivalent)*.

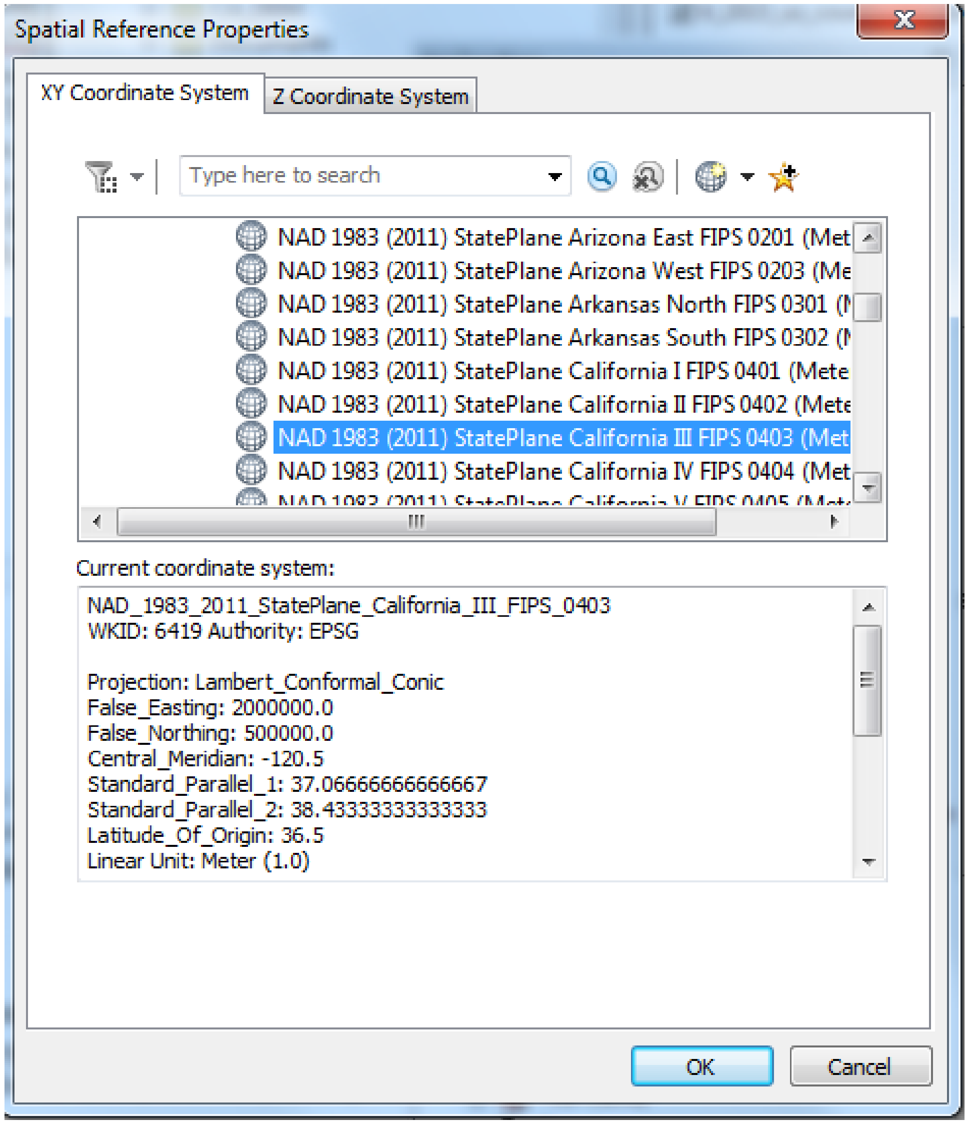
Download water data; Select a layer type: *Water* >*Area Hydrography* >*California* >and select the following counties:

- Alameda
- Contra Costa
- Marin County
- San Francisco County
- San Mateo County

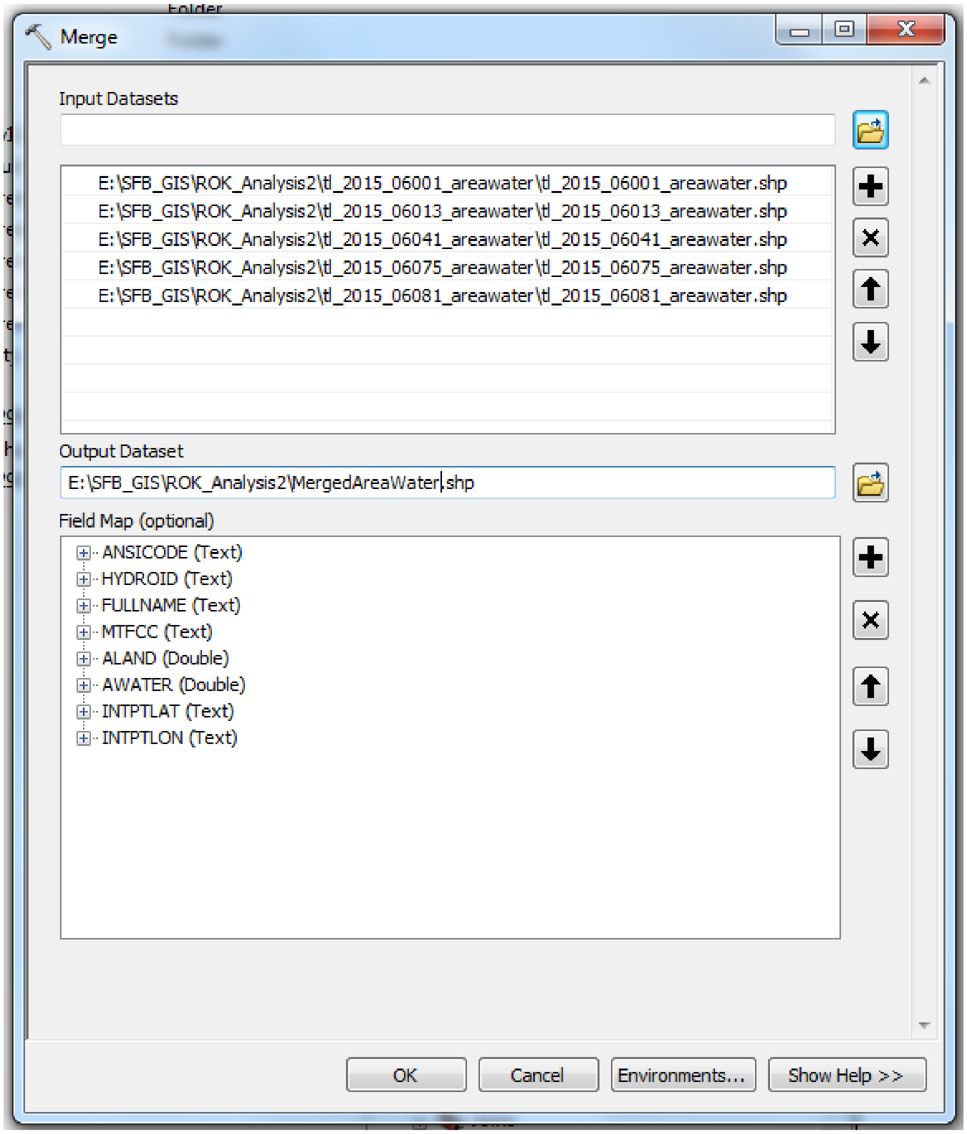
Before you begin, check your workspace settings

The point of this tutorial is to create an inundation map. In order to do this effectively, the data must be in an appropriate coordinate system. We want to use a projection that preserves area in the location of interest. For the example of San Francisco Bay, NAD 83 California Zone 3 is appropriate. Open up ArcCatalog. In ArcCatalog, open ArcToolbox and navigate to the project tool, *Data Management Tools > Projections and Transformations > Project*. In the tool select the county shapefile as the Input Dataset or Feature Class. The Input Coordinate System should fill in automatically. Under Output Dataset of Feature Class, click the yellow folder icon, navigate to the folder if needed, and give the feature class a different name from the input (Counties_NAD83z3). Under Output Coordinate System, click the icon to the right and select *Projected Coordinate Systems > State Plane > NAD 1983 (2011) (Meters) > NAD 1983 StatePlane California III FIPS 0403 (Meters*). Run the Project tool and repeat this step for the states shapefile.





We also want to merge all of the water shapefiles into one single shapefile. Still in ArcCatalog, use the merge tool to combine the shapefiles. Navigate to *Data Management Tools > General > Merge*. In the tool, select the county water shapefiles as the Input Datasets and under Output Dataset name the file MergedAreaWater. Once the shapefile is merged we can change the projection. As above, run the Project tool and name the resulting shapefile as Water_NAD83z3.



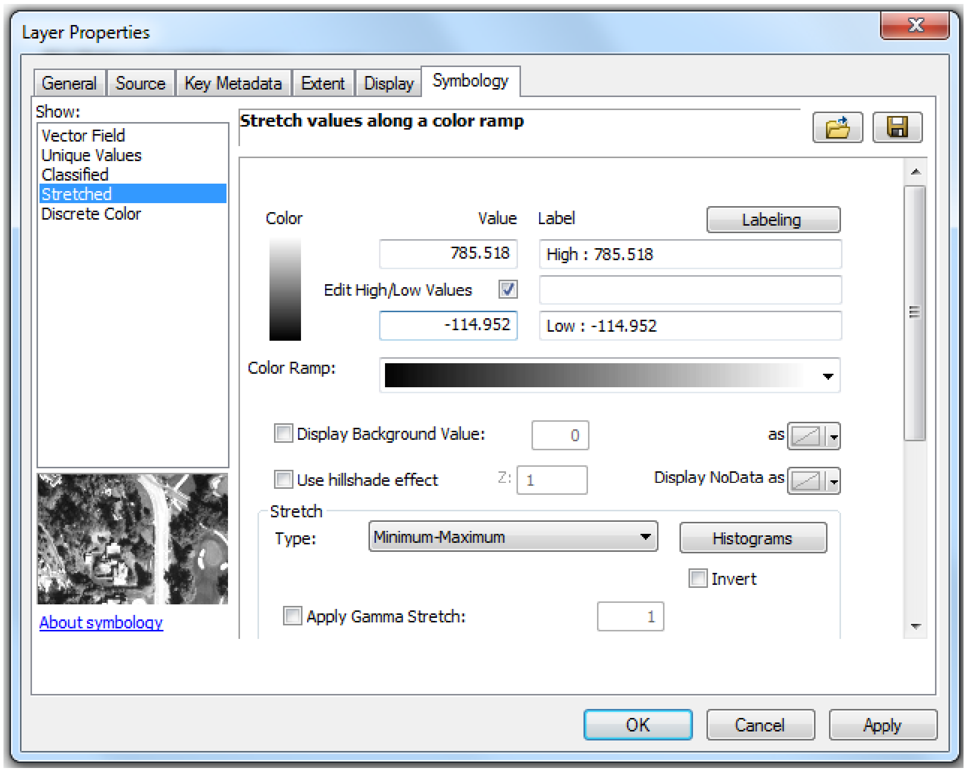
Once that is done, open ArcMap under ArcGIS and choose *New > Blank Map*. This will give you an empty ArcMap screen. Go to *Geoprocessing > Environments* and click on Workspace. Make sure that both the current workspace and scratch workspace are set to the same location as the DEM and shapefiles.

We will also change the workspace projection. In the current workspace go to *View > Data Frame Properties*. In the coordinate System tab expand *Projected Coordinate Systems > State Plane > NAD 1983 (2011) (Meters) > NAD 1983 StatePlane California III FIPS 0403 (Meters)*. Click apply and then ok. Now add in the DEM layer images. A window may appear about transformations. This will be resolved later so click 'ok'. If prompted choose cubic conversion instead of nearest neighbor.

Combine the DEMs into one layer

Before we combine the DEMs into one layer we first want each layer to have the same elevation range. Look at the elevation ranges for each DEM in the table of contents. Note the highest elevation and the lowest elevation. In the table of contents left click on one of the DEM layers, click on properties, and click on the symbology tab.

We will reset the elevations manually. Under Stretch Type: choose Minimum-Maximum. Check the Edit High/low Values and change the high and low values to the highest and lowest elevation of the DEM layers. Click Apply, ok, and repeat for all DEM layers.



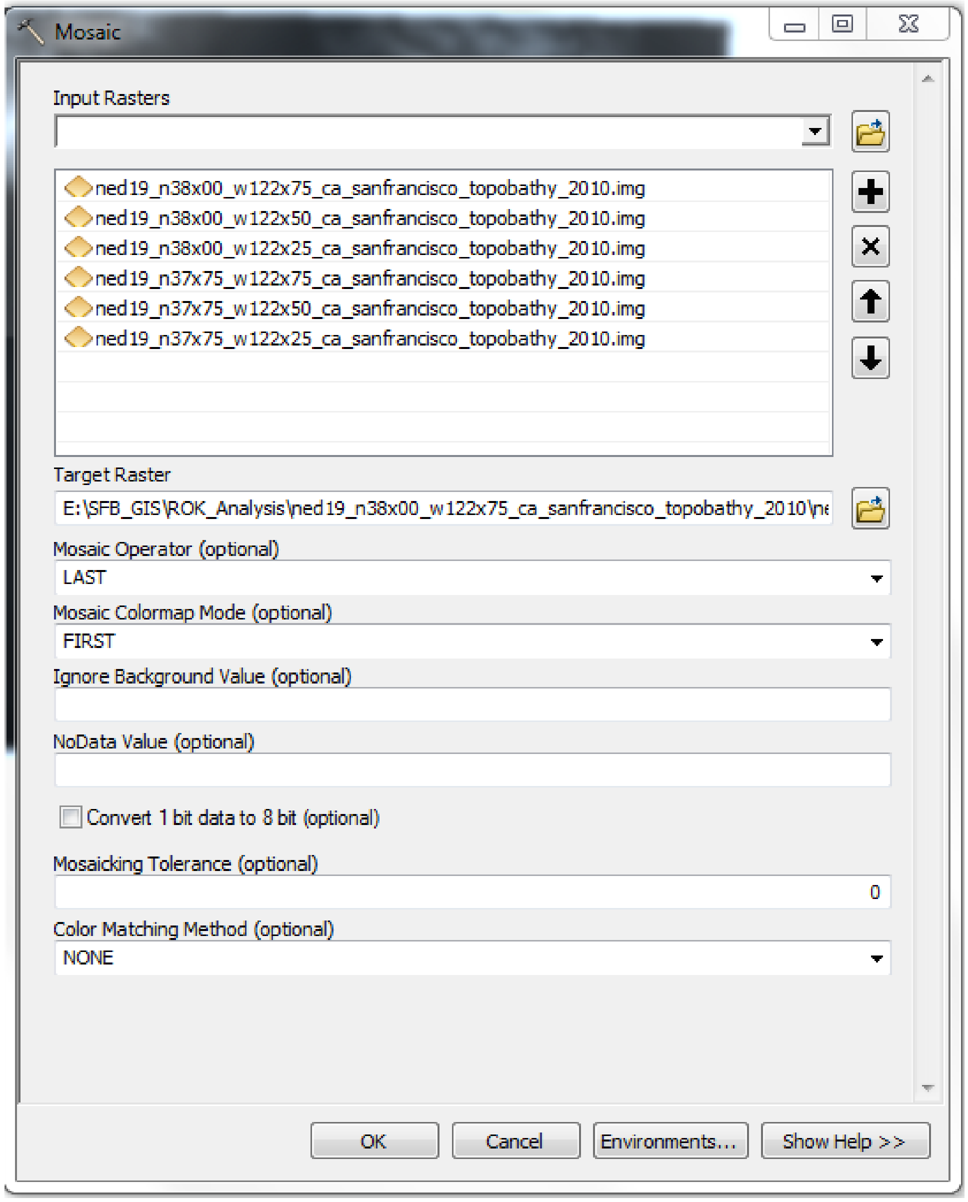
Mosaic

To do the analysis it will be easier to work with one layer rather than 6 DEMs. We can merge the multiple raster datasets into one using the Mosaic tool. However, this tool must output to an existing raster dataset (either an empty dataset or one already containing data). The default is to set the "Target Raster" as the first raster in the list of input rasters.

It is possible to create an empty raster for the "Target Raster". This is done with the Create Raster Dataset tool (*Data Management Tools> Raster Toolset> Raster Dataset Toolset> Create Raster Dataset)*. For simplicity we will just use the default and set the "Target Raster" as the first raster in the list. This will overwrite the original DEM, so save all original DEMs (as copies) to a subfolder called DEM_archive.

Navigate in the ArcToolbox to *Data Management Tools> Raster> Raster Dataset> Mosaic*. For the inputs add all the DEM layers to merge together. Then set the target to the first file in the list.

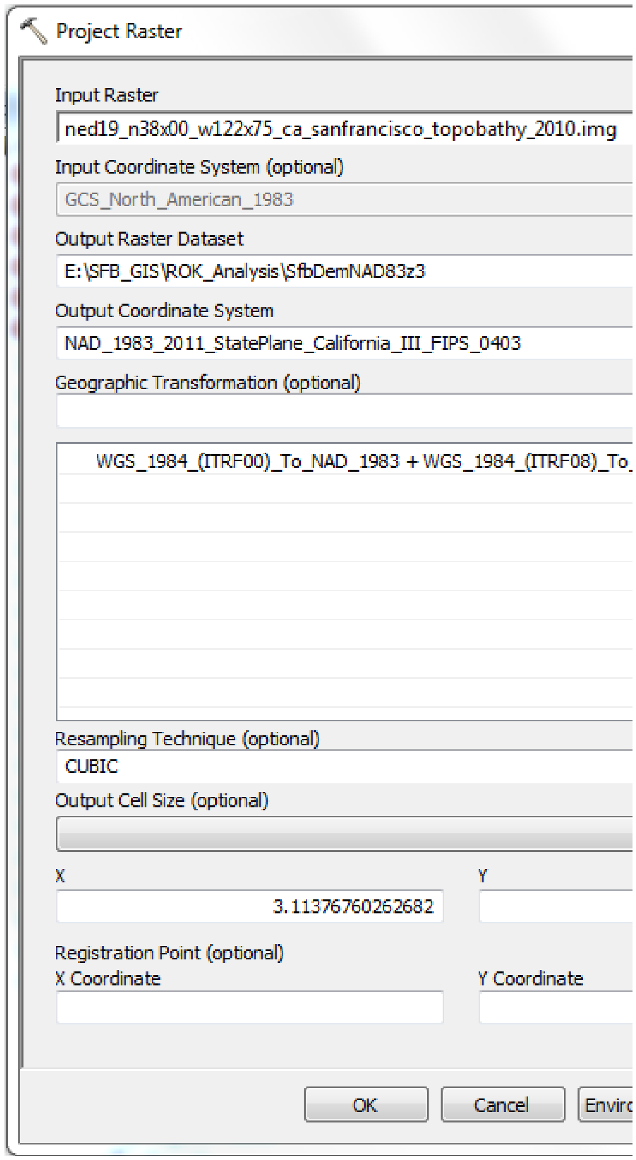
Leave everything else as is, click 'ok', and remove the individual DEMs from your project except for your new mosaicked raster. This may take a few minutes.



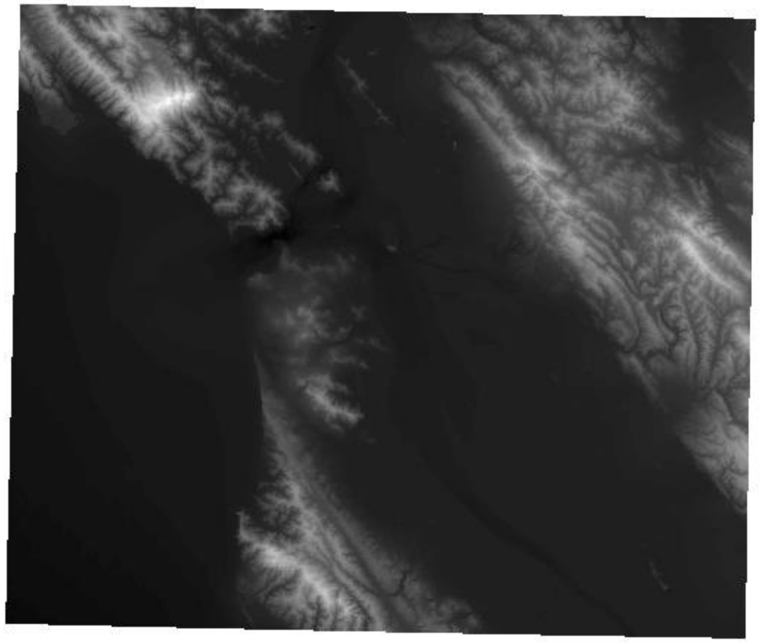
Reproject the DEM

We want the layers that we create to be in the same coordinate system and be able to work with the other layers. Therefore we need to reproject the DEM into the same coordinate system as our other layers.

Navigate in the ArcToolbox to *Data Management Tools > Projections and Transformations > Raster > Project Raster*. For the "Input Raster" select the merged DEM (the second field will fill in automatically). In the Output raster Dataset field, navigate to your folder and save your new raster with a logical name (Dem_NAD83z3; ArcGIS does better with raster datasets that have short names, i.e., less than 13 characters). In the Output coordinate system click the button to the right of the field and choose NAD 1983 StatePlane California III FIPS 0403 (Meters). Choose 'CUBIC' convolution for the resampling technique (click on Show Help to read more about this resampling technique). Leave the output size at the default. Click 'ok' and remove the unprojected DEM layer from your project.



Your mosaicked file should now look like this…



Adjusting the Elevation to Mean Sea-level

The DEMs from the USGS NED are referenced to the North American Datum of 1988 (NAVD 88). For our flood maps, it is preferred to reference mean sea-level as 0 m rather than NAVD88. According to the San Francisco tide gauge (#9414290) the NAVD88 is at 1.804 m while mean sea-level occurs at 2.773 m. To adjust the mosaic DEM to mean sea-level, the raster has to be subtracted by the difference between mean sea-level and NAVD88 (0.981). Navigate in the ArcToolbox to *Data Management Tools* > *Spatial Analyst* > *Map Algebra* > *Raster Calculator*. For input raster add the Mosaiked DEM, select the subtraction operator, and type 0.981. Save the output with a sufficient name (i.e., NED_msl) and click ok.

Applying the Elevation Data

We are interested in the area that is prone to flooding from certain storm surge values. To find these areas, we have to analyze the elevation data and output the results.

The first step is to identify which parts of the elevation data that are between mean sea-level and the storm surge level. Here we will use the storm surge values estimated in Ruckert et al. (in prep.).

- 100-yr storm surge = 1.59 m
- 100-yr storm surge plus mean 2100 sea-level rise = 2.76 m

- 100-yr storm surge plus accounting for uncertainty in 2100 sea-level rise = 3.26 m

Reclassify the Elevation Data

By reclassifying the elevation data we are turning ranges of elevations into categories or ranks. First we will create a surface layer that has a ranking for sea-level, the current 100-yr storm surge, the area between the current storm surge and storm surge plus mean sea-level, and between the storm surge plus mean sea-level and the storm surge plus uncertain sea-level. We will assume everything below an elevation of 0 m is current standing water.

Navigate to *Spatial Analyst Tools > Reclass> Reclassify*. Ensure that the input raster is set to the mosaicked layer and set the Reclass field to Value. Name the output raster as NED_reclass. You will have to manually edit the values in the Reclassification dialog box. See the table below on how to change the values. NOTE: The ranges have to typed in as number then a space, then a hyphen, followed by another space, and then the number. Selecting each row and clicking the "Delete Entries" button can remove the extra rows. Leave the "NoData" row. Run the tool and then study the resulting layer. Remember what each value stands for before clicking apply.

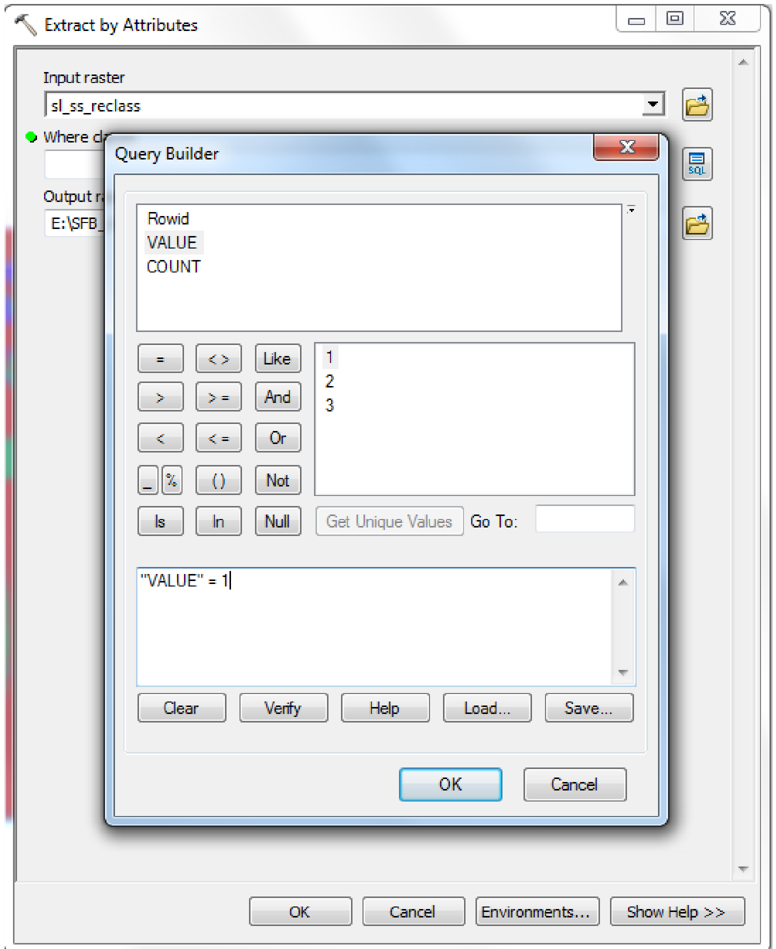
Old values	New values
-115.932782 - 0	1
0 – 1.59	2
1.59 – 2.76	3
2.76 – 3.26	4
3.26 – 784.549	5
NoData	NoData

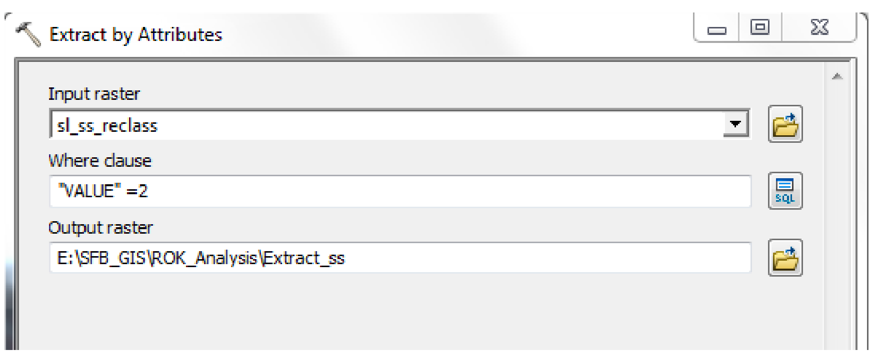
Your output raster should now have five rankings.

Extract the elevation ranges

To turn the new datasets into workable forms, we first want to extract the appropriate elevation ranges. For ease you may want to turn off the reclass layer.

Navigate to the *Spatial Analyst Tools> Extraction> Extract by Attributes*. First we will extract the elevation range signifying standing water. Select the output raster named NED_reclass. Click on the small SQL query builder button to the right of the second field to build a query. Select from 'Value' where "Value"=1 (remember the standing water was ranked as 1). Name the extracted dataset as Extract_sl and click ok.



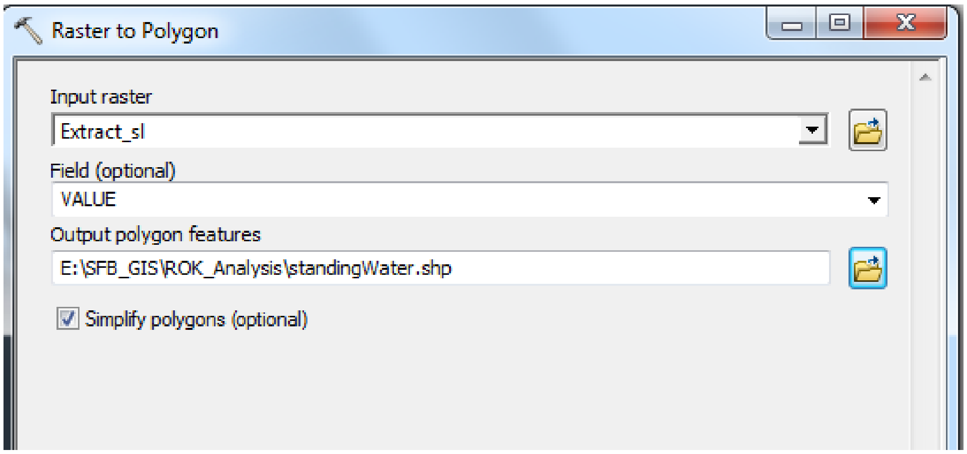


Again navigate to the Extract by attributes tool and select the output raster called NED_reclass. This time select from 'Value' where "Value"=2 (the storm surge value was ranked 2). Name the extracted dataset as Extract_ss and click ok. We will repeat this step for the other elevation ranges; Extract_sstomslr (value =3) and Extract_mslrtouslr (value = 4).

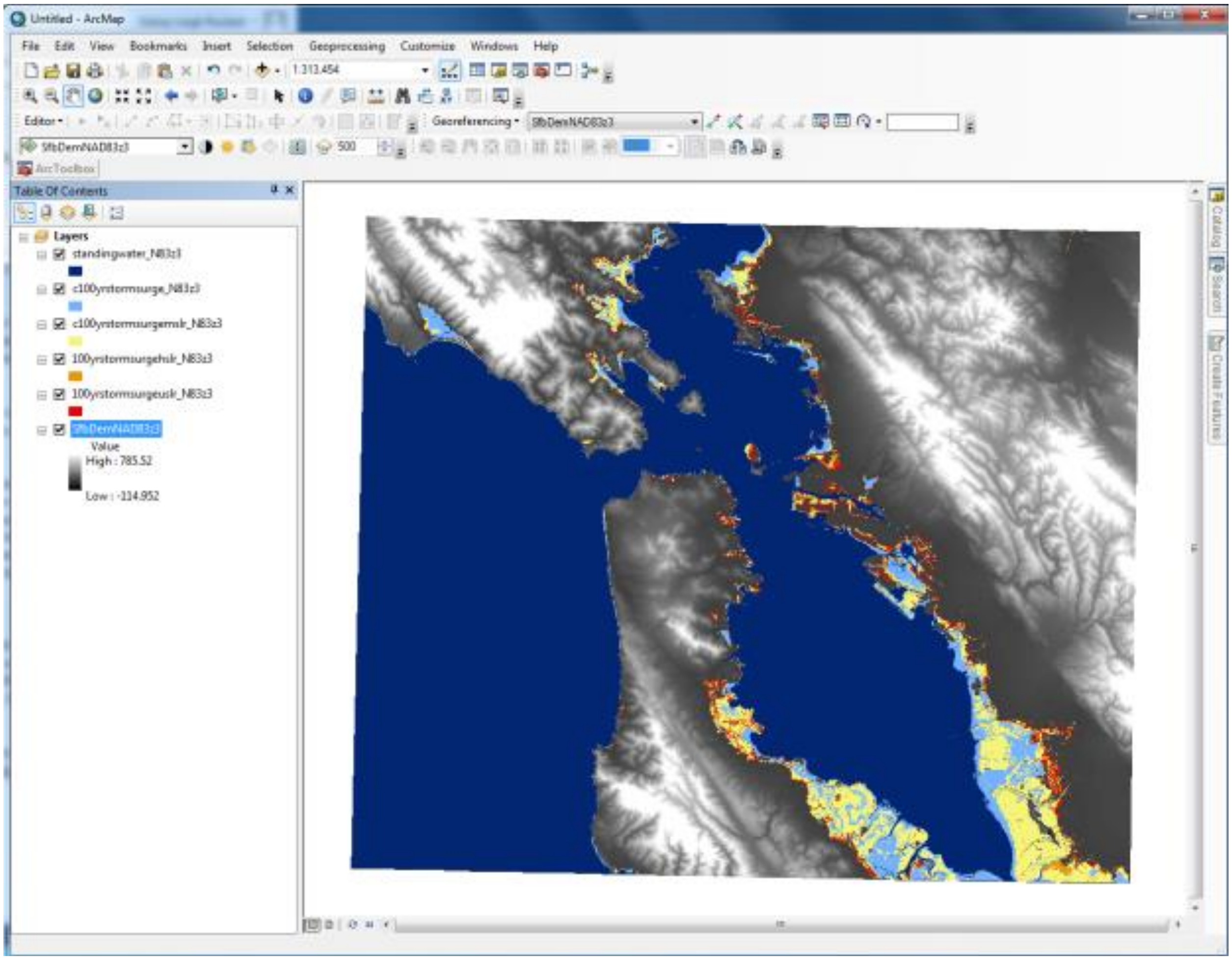
Converting the results from raster to vector format

To enable further analysis we want to convert the results from the extracted raster to a vector polygon. Navigate the Toolbox to *Conversion Tools > from Raster > Raster to Polygon*.

Select extract_sl as the input and set the 'Field' to 'Value'. Name your new vector as NED_Water, leave the 'Simplify polygons (optional)' option checked, and run the tool. Repeat this step for the other extracted files and give them appropriate names (e.g., NED_stormsurge, NED_sstomslr, and NED_mslrtouslr).



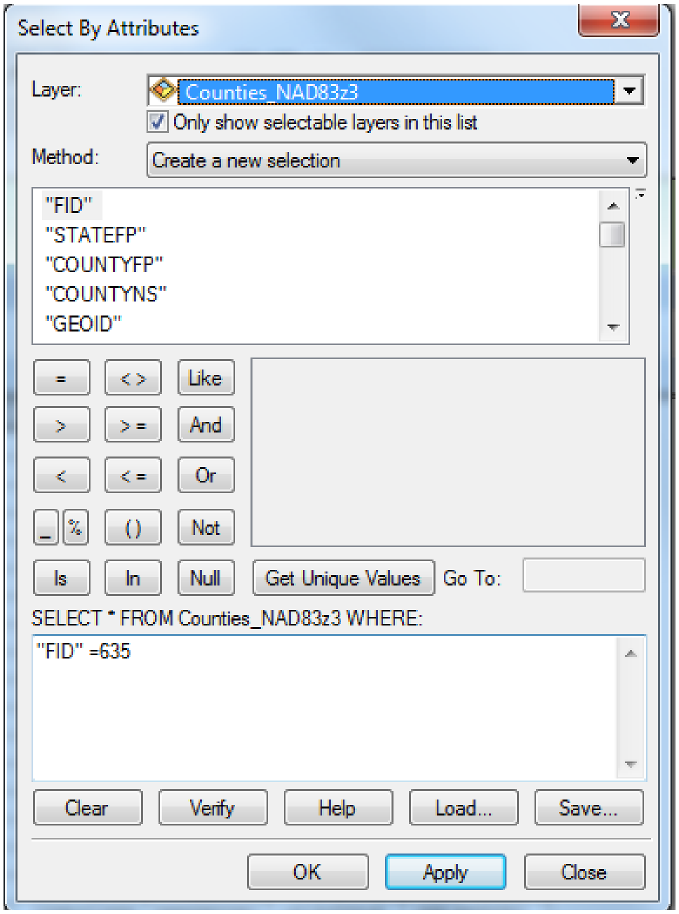
Remember that we still have to create the shapefiles for the storm surge plus mean sea-level and the storm surge plus uncertain sea-level. We will use the union tool to merge the storm surge and storm surge to mean sea-level rise shapefiles. Navigate the Toolbox to *Analysis tools > Overlay > Union*. Select the NED_stormsurge and NED_sstomslr as the inputs and name the ouput feature as "NED_mslr". Repeat this step to merge the storm surge and storm surge to uncertain sea-level rise shapefiles and name appropriately ("NED_uslr"). Once all the flood layers have been produced, reproject the shapefiles to NAD 1983 StatePlane California III FIPS 0403 (Meters). See above on how to do this. At this time you may remove the raster layers from the table of contents and the nonprojected shapefiles. Lastly, we want to get rid of the flood risk area that is currently underwater (i.e. in the bay, ocean, rivers, or lakes). To do this we will erase the known water area from the flood risk areas. Navigate in the toolbox to *Analysis tools> Overlay > Erase*. Select the input file as one of the flood shapefiles, select the erased feature as Water_NAD83z3, and give the file a good output name.



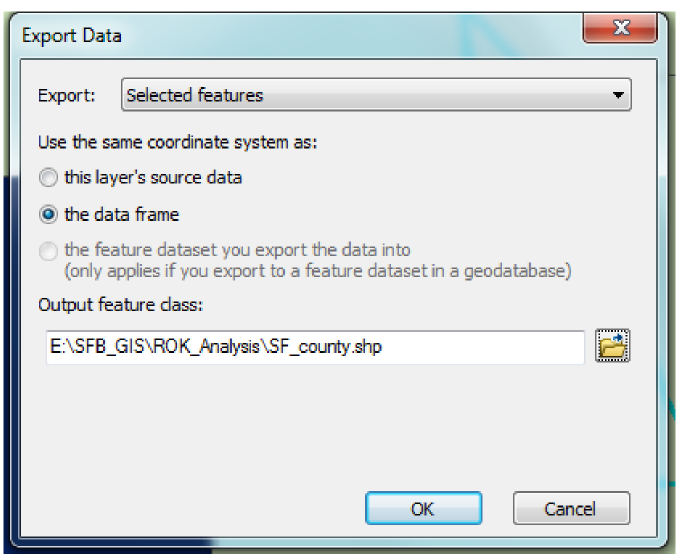
Find how much area is at risk

At this point it seems reasonable to want to know how much land is at risk of flooding in San Francisco County. Additionally, we want to know how each 100-yr flood impacts San Francisco.

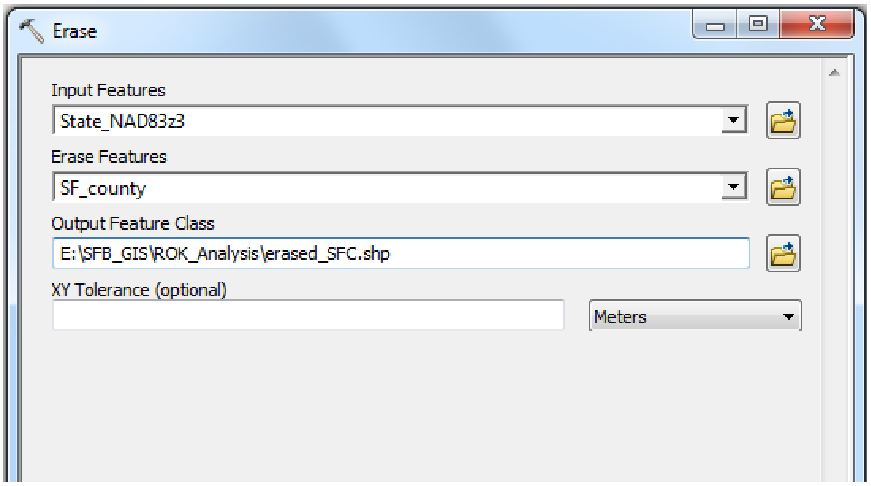
First you will need to know the boundary of San Francisco County. Add the county layer (in the same projection) to your map. This layer includes all the counties in the United States. Since we only care about San Francisco County we will extract it from the rest (San Francisco's FID is 635, but double check in the attributes). Navigate to *Selection > Select by attribute*. Select the county layer as the layer. In the WHERE clause select "FID" = 635. Click verify and ok.



Once San Francisco County is selected, left click the county layer in the table of contents and navigate to *Data* > *Export Data*. Make sure the 'Field' is selected and select projection as data layer. Name the resulting shapefile as SF_county.



Now that we have the boundary of San Francisco County we can find the flood area in the county, but to do this we have to get rid of the area outside of the county. First we will create a layer with the entire extent of the United States excluding San Francisco County. Navigate in the toolbox to *Analysis tools> Overlay > Erase*. Select the county layer as the input, the SF_county as the erase feature, and name the output feature as "erased_SFC".



Using "erased_SFC.sh" as a mask, a shapefile can be created with only the flood risk area in San Francisco County. Again navigate in the toolbox to *Analysis tools> Overlay > Erase*. This time select one of the flood risk shapefiles (Ned_ss_nad83z3, NED_mslr_nad83z3, and NED_uslr_nad83z3) as the input, select erased_SFB as the erase feature, and give the output an appropriate name. Viola, we have the area at risk for San Francisco County. Do this for all of the 100-yr storm surges. In the end you should have 6 shapefiles with names similar to the following:

- SanFrancisco_SS_100Flood
- SanFrancisco_SS_MSLR_100Flood
- SanFrancisco_SS_USLR_100Flood
- 100yr_SS_FloodRisk
- 100yr_SS_MSLR_FloodRisk
- 100yr_SS_USLR_FloodRisk

Now that we have a shapefile of the area, we can calculate the area at risk. Open *attribute table > add field* > put name as AREASQKM and select type as double > OK. Now in the attribute table right click the field you just created and click on calculate geometry > click square kilometers and ok. If you right click on the field again and go to statistics you can see the sum of the total area at risk for the county. Again do this for each San Francisco storm surge.

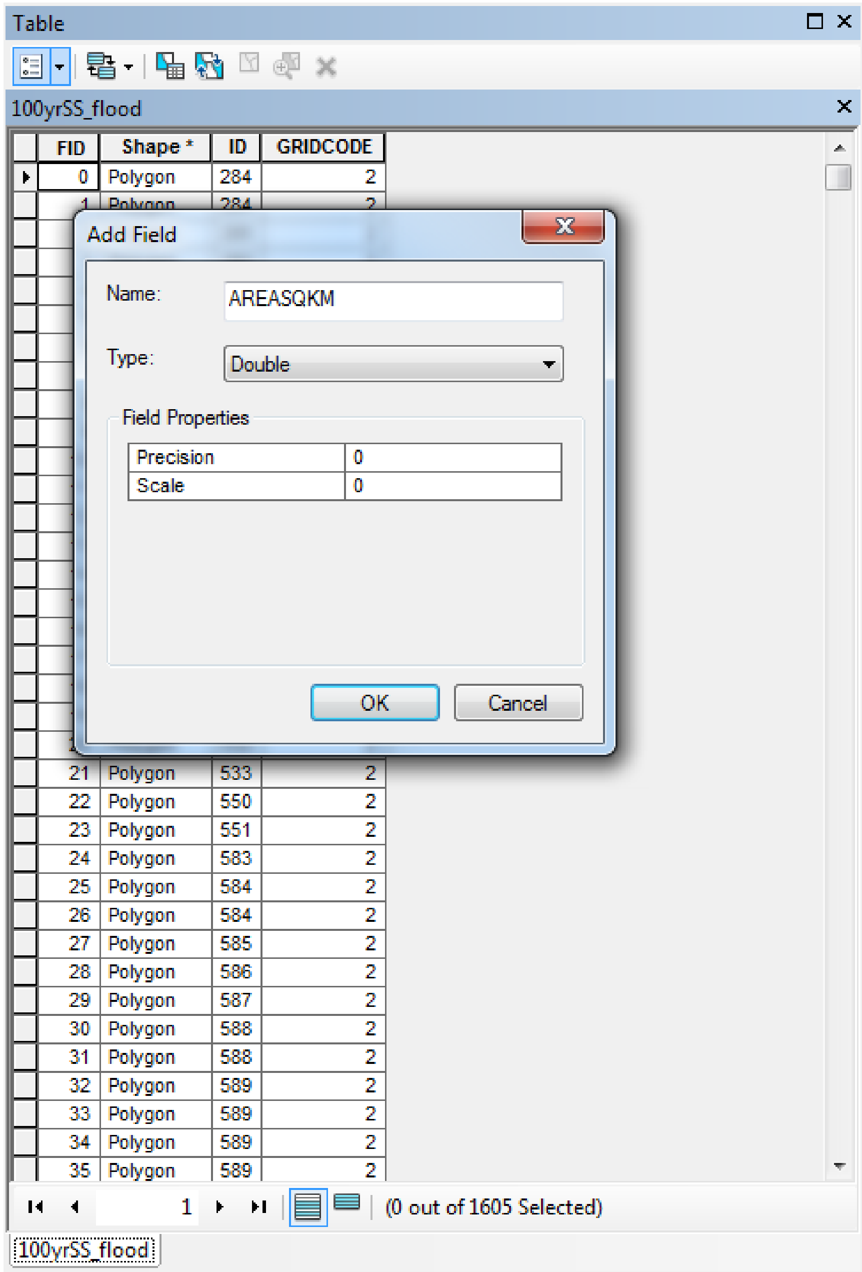
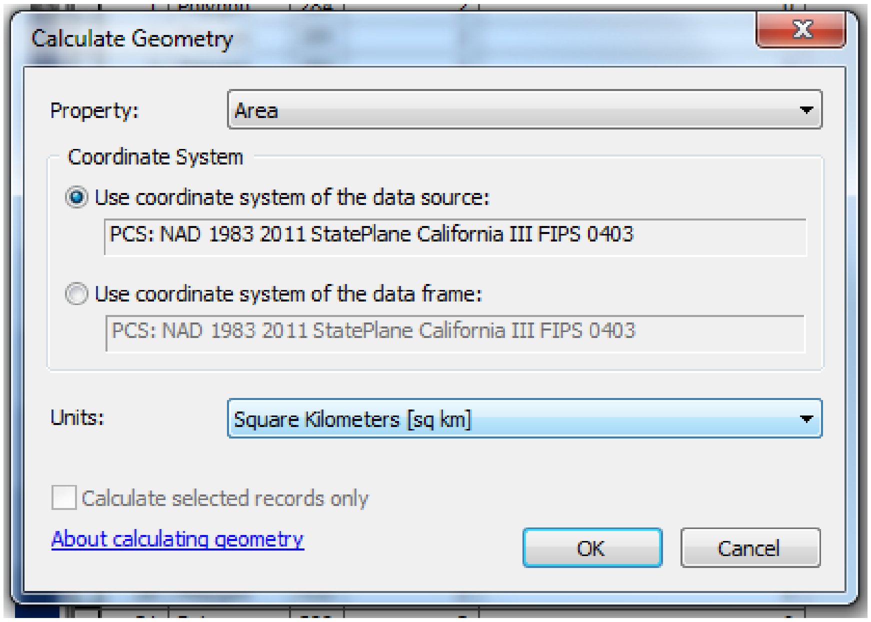
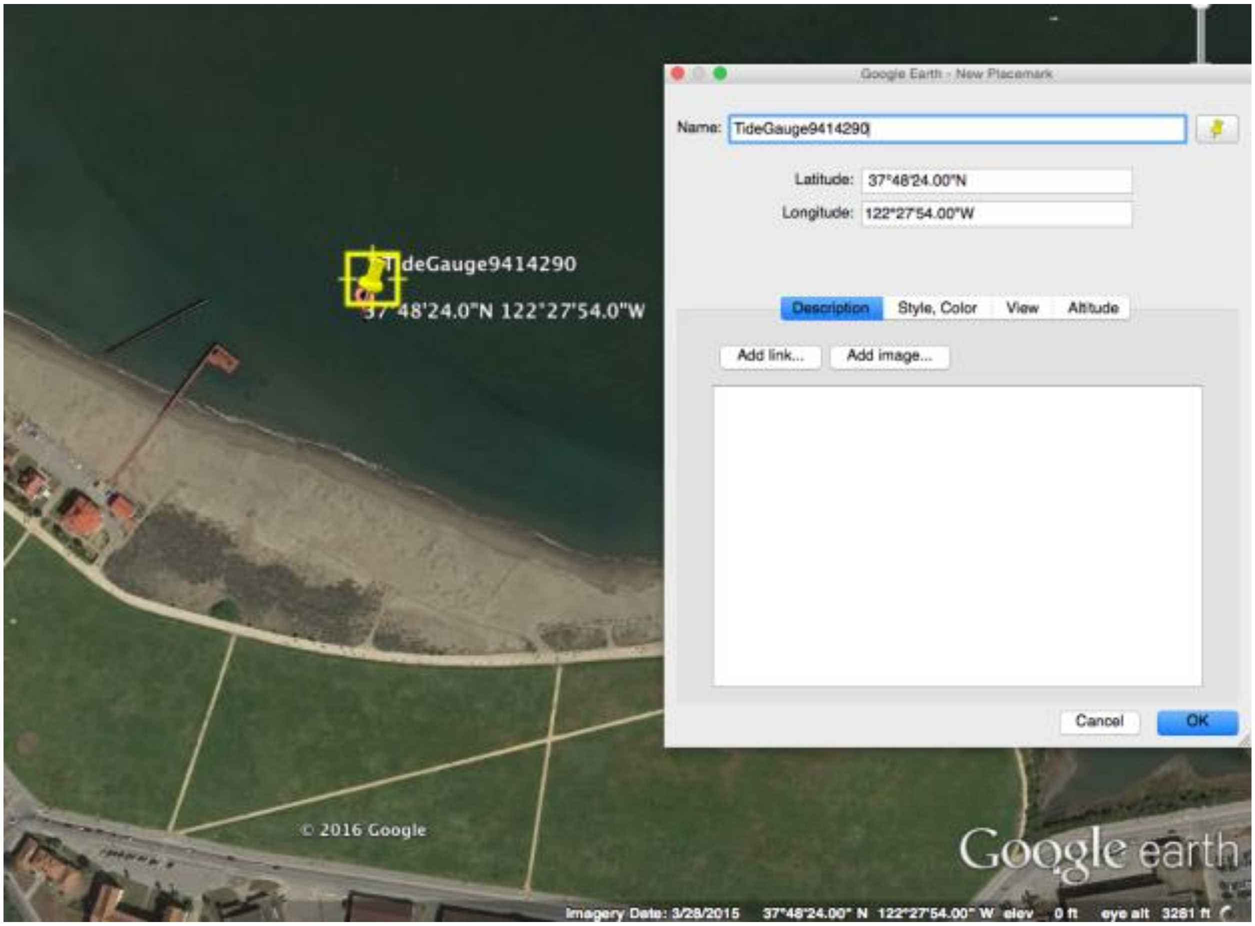


Table
100yrSS_flood
FID
Shape *
ID
GRIDCODE
Add Field
Name:
AREASQKM
Type:
Double
Field Properties
Precision
0
Scale
0
OK
Cancel
(0 out of 1605 Selected)
100yrSS_flood

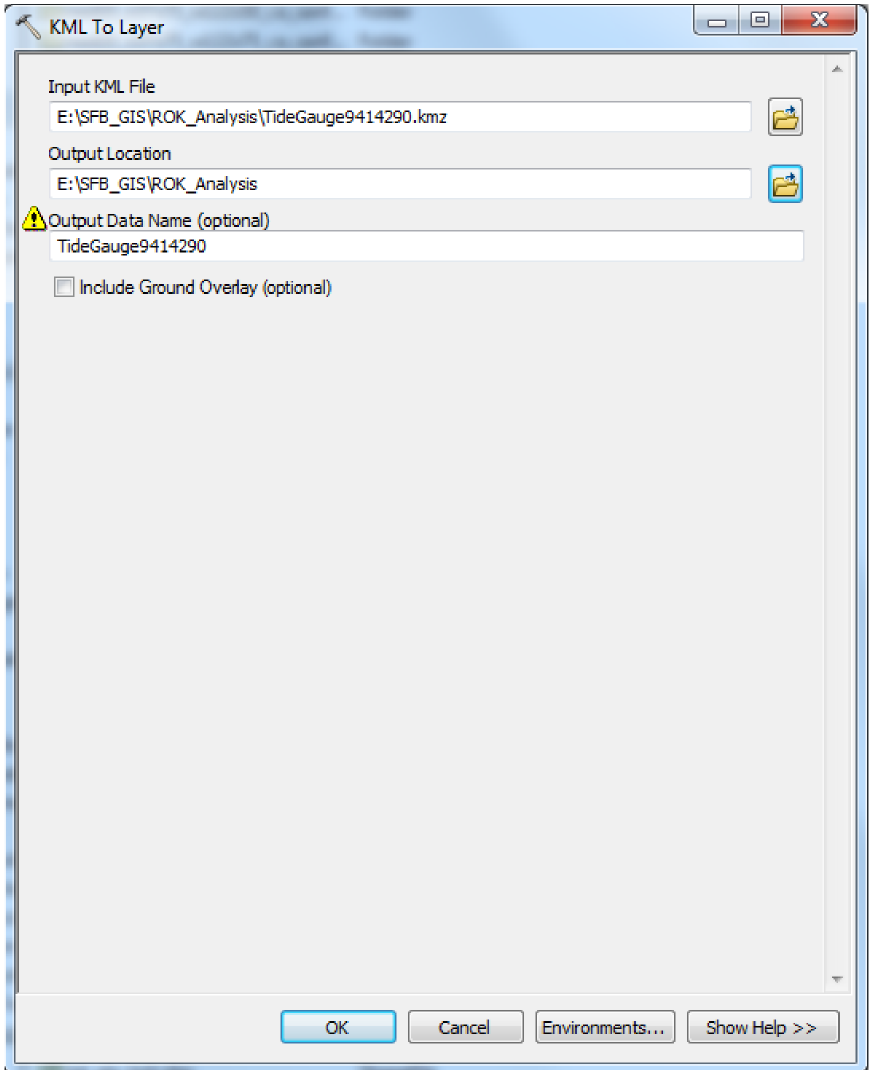


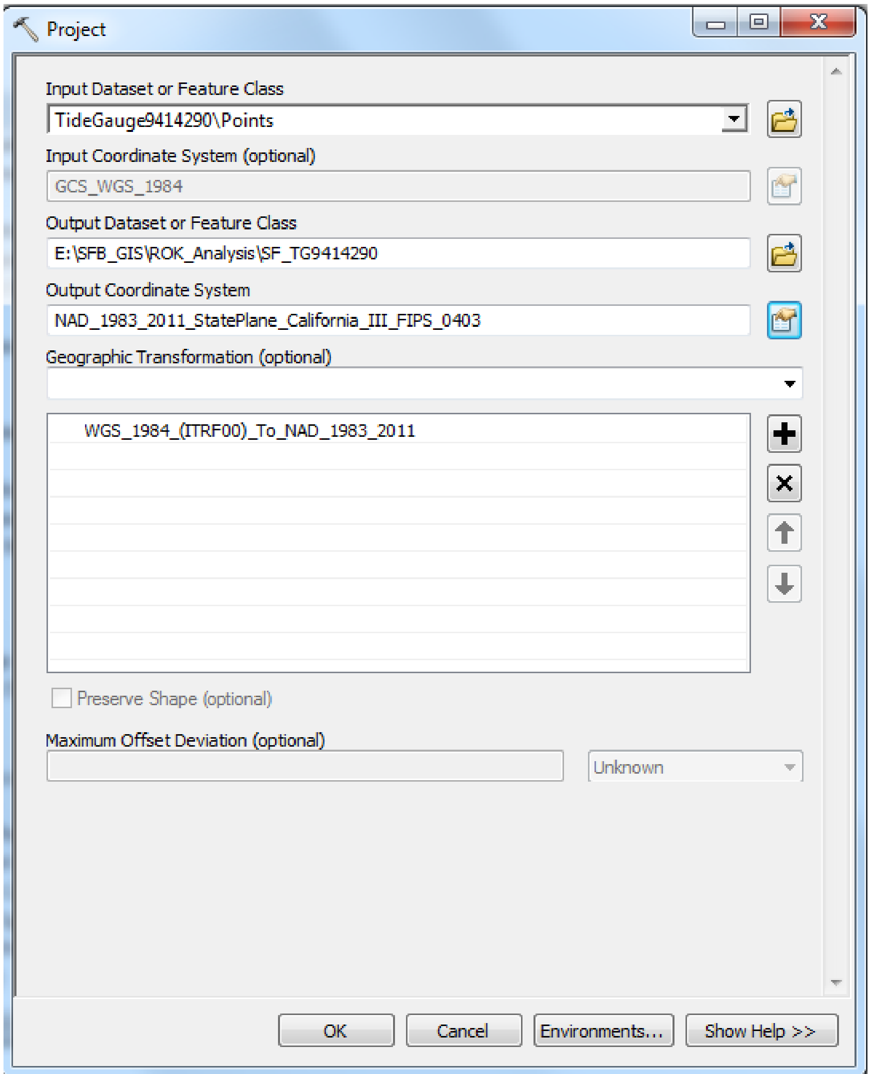
Adding the tide gauge location

The study (Ruckert et al., in prep) generates the storm surge levels using historical tides from the San Francisco Bay tide gauge (station ID: 9414290). In your map, it may be important to show where this tide gauge is located. The latitude and longitude of the tide gauge can be found on the NOAA tides and currents web page (https://tidesandcurrents.noaa.gov/stationhome.html?id=9414290). According to the station information, the tide gauge is located at 37° 48.4'N and 122° 27.9'W. Open up Google Earth (if you do not have this application, I highly recommend downloading; it's free). In the search bar enter in the coordinates as: *37° 48.4'N, 122° 27.9'W*, and click search. Google Earth will take you to the area where the tide gauge is located (actually in the image, the tide gauge is located slightly to the south east). In the toolbar on the top click on *Add Placemark,* give the point a logical name (TideGauge9414290), and click 'ok'. If you want to move the point to the location of the tide gauge in the image right click on the name in places or right click on the point and go to *get info*. The point can now be moved either by changing the coordinate information or by clicking on the point and dropping it at a new location. Once satisfied with the location of the point, right click the name or point and go to *save place as,* give the point a logical name, save it in the folder with your other ArcGIS data, and save the file as a kmz file. At this point you can exit out of Google Earth.



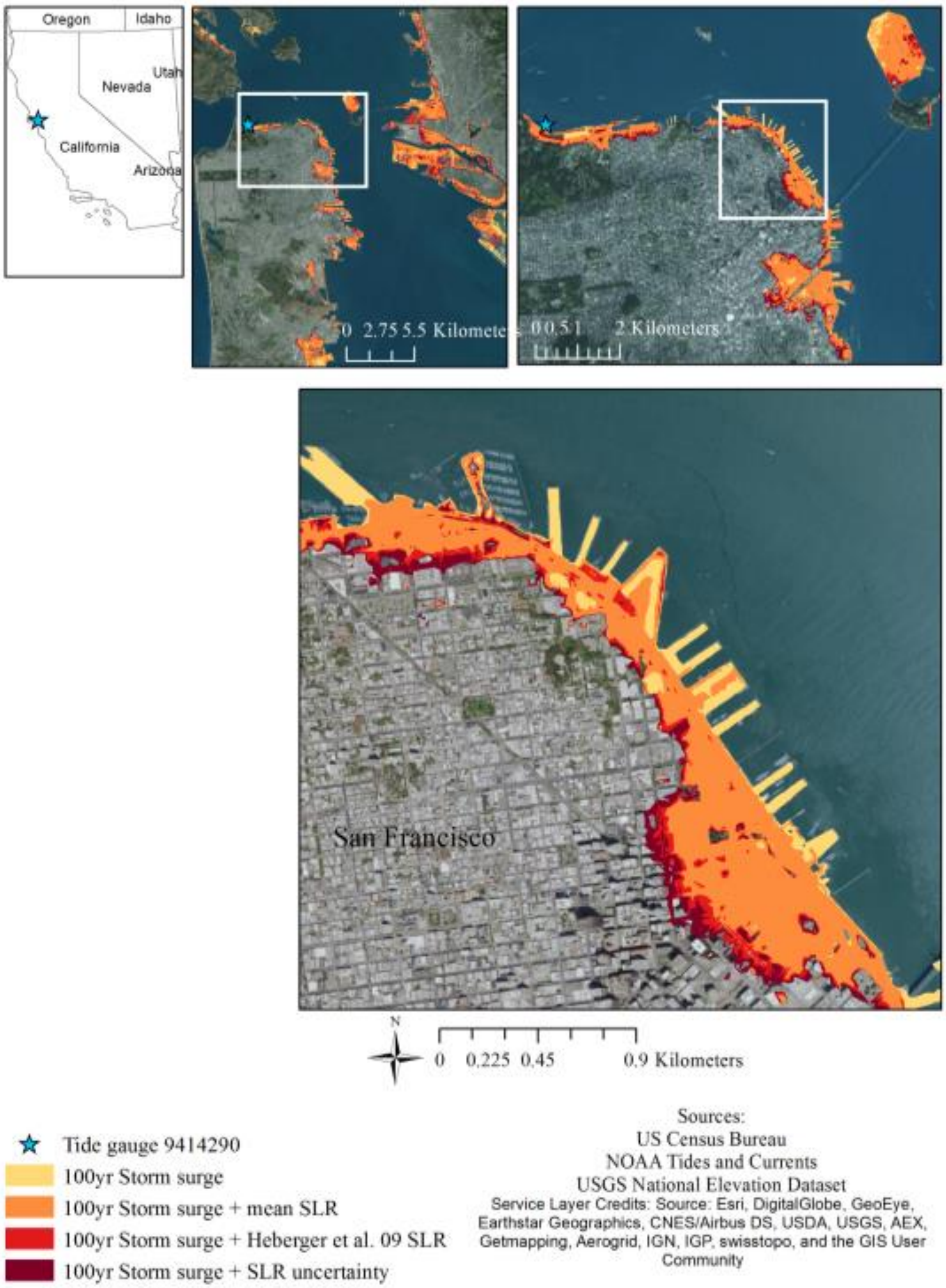
Now open back up ArcCatalog. In ArcCatalog, open up the ArcToolbox and navigate to *Conversion tools > from KML > KML to layer*. This tool converts kml or kmz files into feature classes and layer files. In the pop-up box select TideGauge9414290 as the input file. In the output folder select the folder with the other ArcGIS data. The output file name should automatically default to the name of the input file and run the tool. The output is generated in the WGS84 coordinate system. Since we are using a different coordinate system, reproject it in *NAD 1983 StatePlane California III FIPS 0403 (Meters)* and save it in your current folder (Check the above sections on how to navigate to the project tool).


KML To Layer
Input KML File
E:\SFB_GIS\ROK_Analysis\TideGauge9414290.kmz
Output Location
E:\SFB_GIS\ROK_Analysis
Output Data Name (optional)
TideGauge9414290
Include Ground Overlay (optional)
OK
Cancel
Environments...
Show Help >>



Create a visual map

Make a map of the results of your analysis. Be sure that the map includes: a title, scale bar, legend, north arrow, and acknowledgement of the sources (for all layers of data) (these additions can be found by clicking Insert). You can change the name of the layer by clicking on the name in the table of contents. You can also consider using a 'base map' service, available from Esri over the internet (click the down arrow beside Add Data, select Add Basemap). You can consider using the elevation raster as the background and can make the storm surge polygons semi-transparent. Multiple screens can be add by adding a Data Frame (click Insert and select Data Frame) For an example, the following figure is Fig 4 from Ruckert et al. (in prep)…



Citation:

Ruckert, KL, Oddo, PC, Keller, K. Accounting for sea-level rise uncertainty increases flood risk area: An example from San Francisco Bay, (in prep).