

Tuvalu – 2100

Effects of sea level rise on shallow atolls in the South Pacific



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INTRODUCTION

Residents of the tiny island nation of Tuvalu, with a maximum elevation of 5 meters above sea level, are understandably concerned about climate change. Even a small rise in sea level could inundate the coral atolls. The purpose of this project is to model the possible effects of sea level rise on the islands by calculating the area of land that will be submerged.

The first step will be to gather digital elevation model (DEM) data for Tuvalu. Using minimum and maximum estimates for sea level rise, new elevation rasters will be created based on the original raster. The properties of these rasters will be used to calculate the area of land that will be lost to sea level rise.

DATA COLLECTION

- Digital Elevation Model (DEM) of Tuvalu
 - <http://www2.jpl.nasa.gov/srtm/>
 - S06E176
 - S07E176
 - S07E177
 - S08E177
 - S08E178
 - S09E178
 - S09E179
 - S10E179
 - S11E179

DATA PREPROCESSING

The highest resolution DEM data available for the region is the three arc-second DEM files from the Shuttle Radar Topography Mission (SRTM) homepage. Version 2.1 of this data was downloaded in 1x1 degree tiles. The data was collected by a radar system on board the space shuttle Endeavor in February 2000. The spatial reference for SRTM DEMs is Geographic Projection, Horizontal Datum World Geodetic System 1984. Elevations are in meters. Error for horizontal location is as high as 50 meters and elevation has error up to 30 meters. Since Tuvalu is not supposed to rise more than five meters from the sea 30 meters of error can be very significant—unfortunately, this was the only DEM data of this resolution that was available.

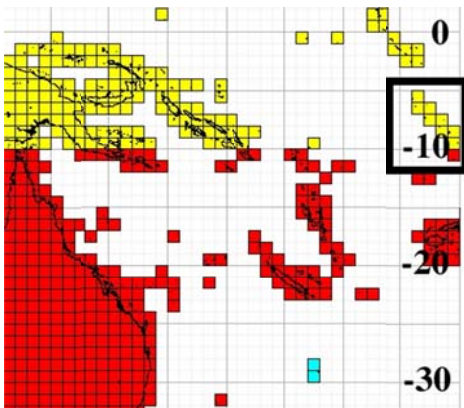


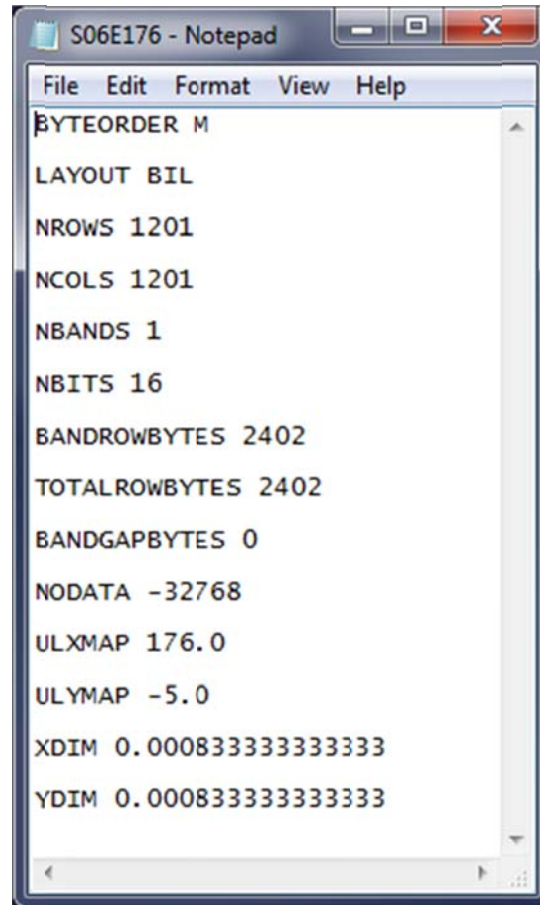
Figure 1: Definition of tiles for SRTM version 2.1. Tuvalu is outlined. Different colors denote different folders in which data is stored.

Figure 2: Sorting through the tiles

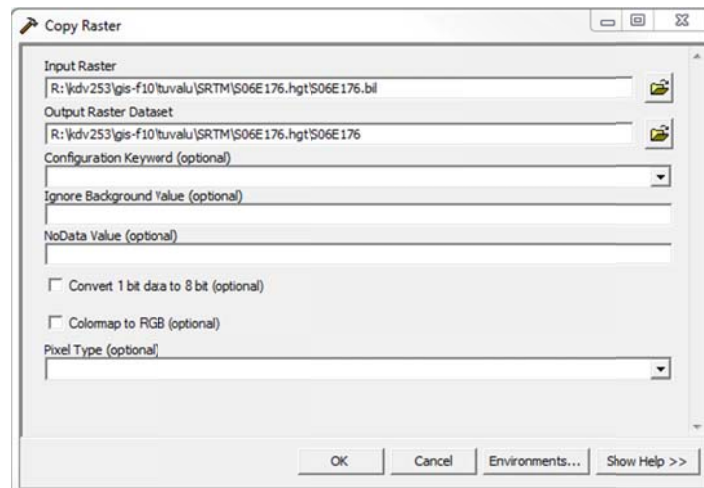
- [S06E144.hgt.zip](#)
- [S06E145.hgt.zip](#)
- [S06E146.hgt.zip](#)
- [S06E147.hgt.zip](#)
- [S06E148.hgt.zip](#)
- [S06E149.hgt.zip](#)
- [S06E150.hgt.zip](#)
- [S06E151.hgt.zip](#)
- [S06E152.hgt.zip](#)
- [S06E154.hgt.zip](#)
- [S06E155.hgt.zip](#)
- [S06E159.hgt.zip](#)
- [S06E176.hgt.zip](#)
- [S06W156.hgt.zip](#)
- [S07E071.hgt.zip](#)
- [S07E105.hgt.zip](#)
- [S07E106.hgt.zip](#)
- [S07E107.hgt.zip](#)
- [S07E108.hgt.zip](#)
- [S07E109.hgt.zip](#)
- [S07E110.hgt.zip](#)
- [S07E111.hgt.zip](#)
- [S07E112.hgt.zip](#)
- [S07E113.hgt.zip](#)
- [S07E114.hgt.zip](#)
- [S07E115.hgt.zip](#)

When the files were unzipped, it was discovered that they were in .hgt format, which ArcGIS cannot use. The files had to be converted to a raster using the following process:

- Header files were created for each of the .hgt files based on the template given on the course website. Figure 3, below, shows the header file for the S06E176 tile.



- Once the header files were created, the .hgt files were renamed as .bil files in Windows Explorer.
- ArcCatalog was used to convert the .bil files to GRID files. This was done by right-clicking on the .bil files in the catalog tree, selecting “Export”, then “Raster To Different Format...” and filling out the window as shown below in Figure 4.



- When the newly created raster was opened in ArcMap, it was evident that cells below sea level were improperly represented. This was fixed by using the Raster Calculator on the Spatial Analyst toolbar to derive a new raster with the correct values.

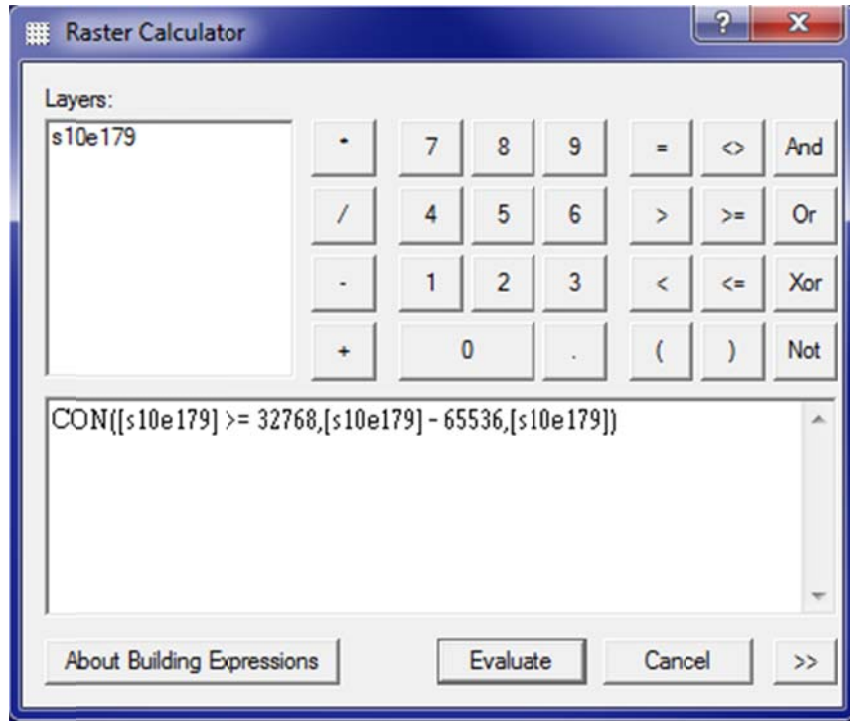


Figure 5: Expression used to recalculate negative values

- In order for the data to be projected properly the spatial reference of the rasters had to be defined by modifying the raster properties in ArcCatalog.

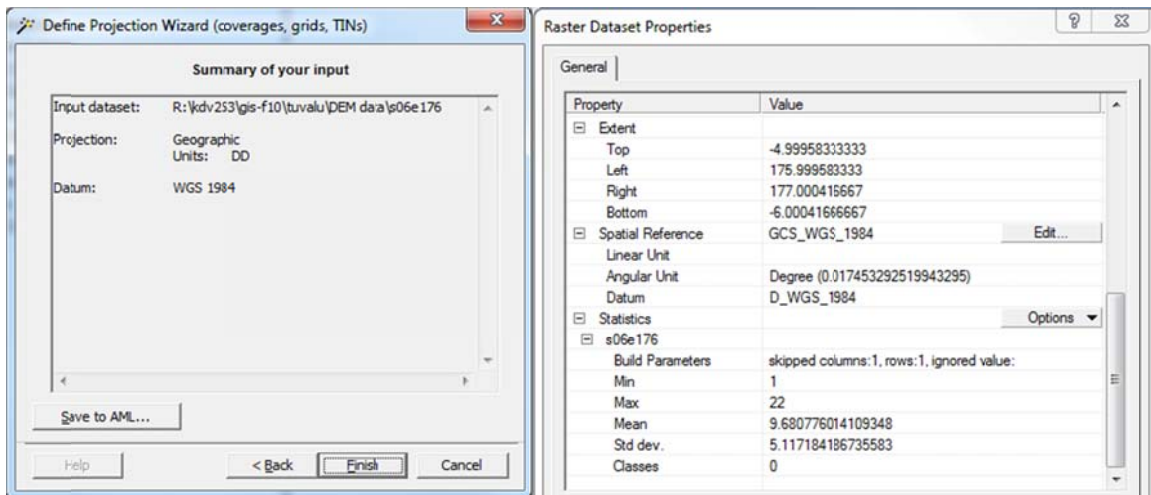


Figure 6: Defining projection in ArcCatalog

- The World_borders files, located in the class folder under Project_Data, is a polygon shapefile with every country in the world. It was loaded into ArcMap with the raster tiles to as an extra check on the correct placement of the atolls.

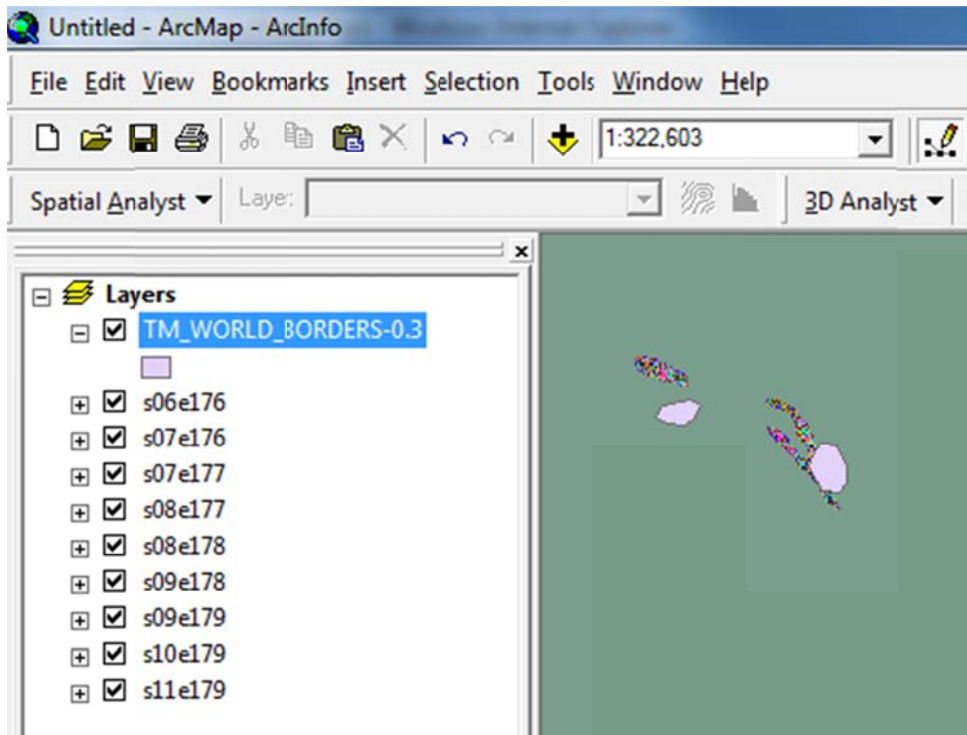


Figure 7: Nanumea's location is seen to coordinate well with its position in the shapefile.

- The nine atolls are to be analyzed together, which cannot be done accurately unless the DEM symbology is the same for all the rasters. Symbology can be coordinated by using the Mosaic to New Raster Tool, which can be found in ArcToolbox under Data Management Tools > Raster > Raster Dataset.

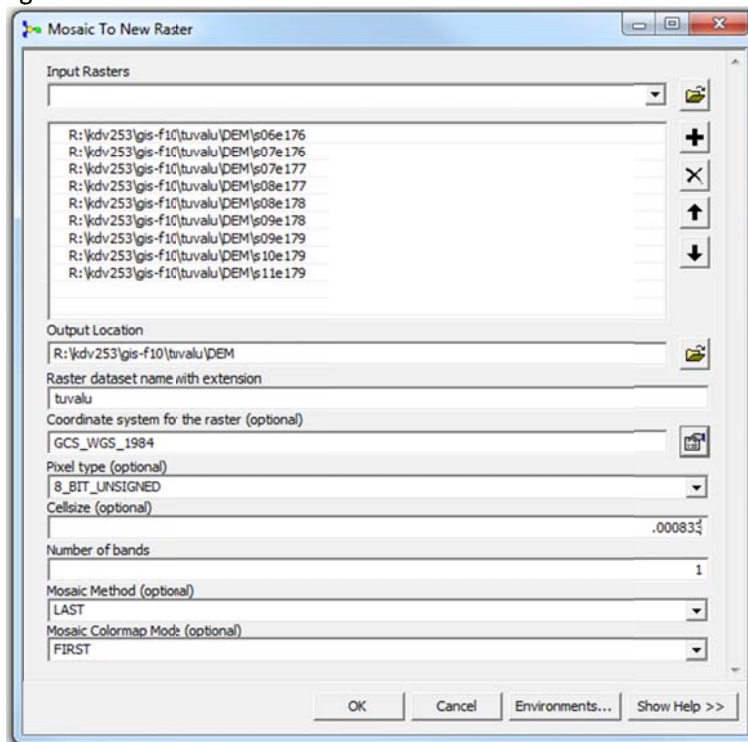


Figure 8: Mosaic to New Raster window

- The new mosaic raster had a maximum extent hundredth of a degree beyond 180 degrees longitude, causing it to fill the entire world between 5 and 11 degrees south with NoData cells. The new file was too large for analysis and had to be clipped using ArcToolbox's Clip tool under Data Management Tools > Raster > Raster Processing > Clip. This operation must be performed in ArcCatalog on a GRID file and the X maximum must not extend beyond 180 degrees or it will not work.

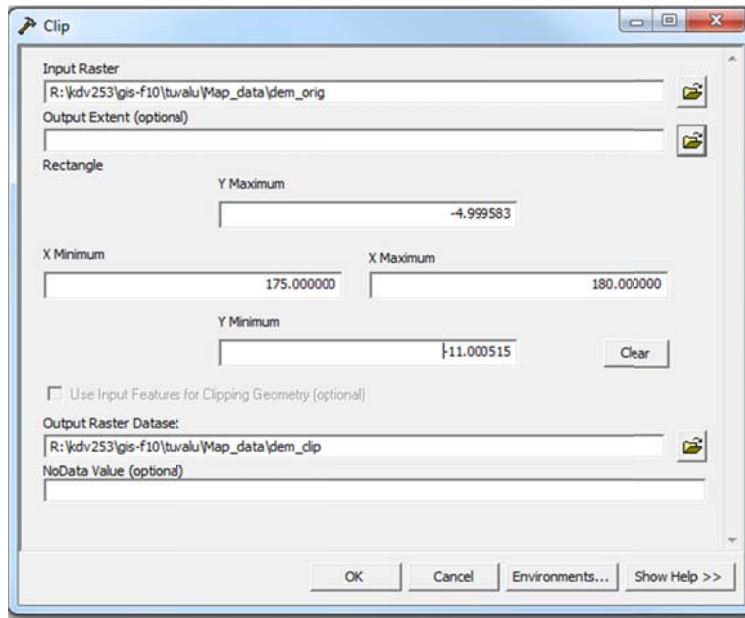


Figure 9: Clip window with proper inputs

- At last there is a single DEM file prepared for analysis.

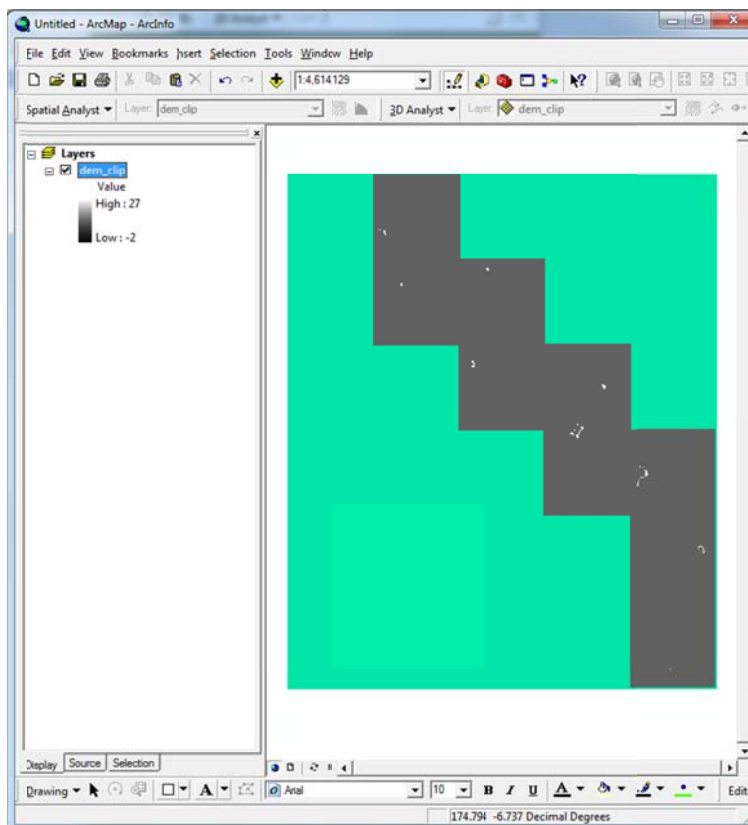
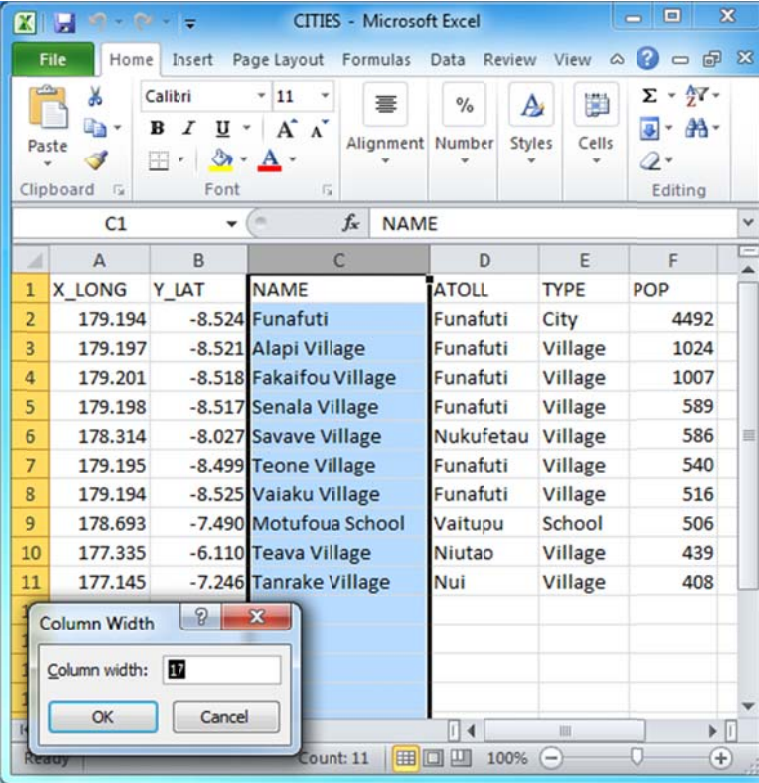


Figure 10: Success. NoData cells are represented in green.

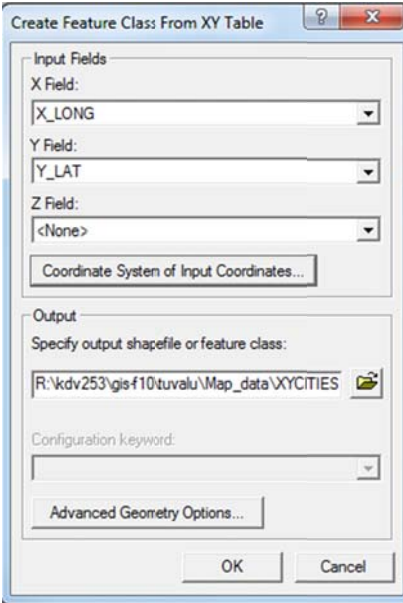
It would be useful to have a file with features overlaying the DEM file to determine what is being flooded. Since there are no such files to be found for Tuvalu they must be created.

- After doing some research, a website (<http://www.geonames.org/TV/largest-cities-in-tuvalu.html>) with coordinates, names, and populations of the largest cities in Tuvalu was found
- Based on this data, a table was created in Excel and modified so it could be saved as a CSV file, as shown below in Figure 11.



	A	B	C	D	E	F
1	X_LONG	Y_LAT	NAME	ATOLL	TYPE	POP
2	179.194	-8.524	Funafuti	Funafuti	City	4492
3	179.197	-8.521	Alapi Village	Funafuti	Village	1024
4	179.201	-8.518	Fakaifou Village	Funafuti	Village	1007
5	179.198	-8.517	Senala Village	Funafuti	Village	589
6	178.314	-8.027	Savave Village	Nukufetau	Village	586
7	179.195	-8.499	Teone Village	Funafuti	Village	540
8	179.194	-8.525	Vaiaku Village	Funafuti	Village	516
9	178.693	-7.490	Motufoua School	Vaitupu	School	506
10	177.335	-6.110	Teava Village	Niutao	Village	439
11	177.145	-7.246	Tanrake Village	Nui	Village	408

- Right-clicking on the CSV file in the ArcCatalog tree gives the option to make a feature class from XY data. The dialog box for this process is shown in Figure 12 below.



Input Fields

X Field: X_LONG

Y Field: Y_LAT

Z Field: <None>

Coordinate System of Input Coordinates...

Output

Specify output shapefile or feature class:

R:\kdv253\gis-f10\tuvalu\Map_data\XYCITIES

Configuration keyword:

Advanced Geometry Options...

OK Cancel

- The locations of cities in the completed shapefile match up very nicely with the DEM raster.

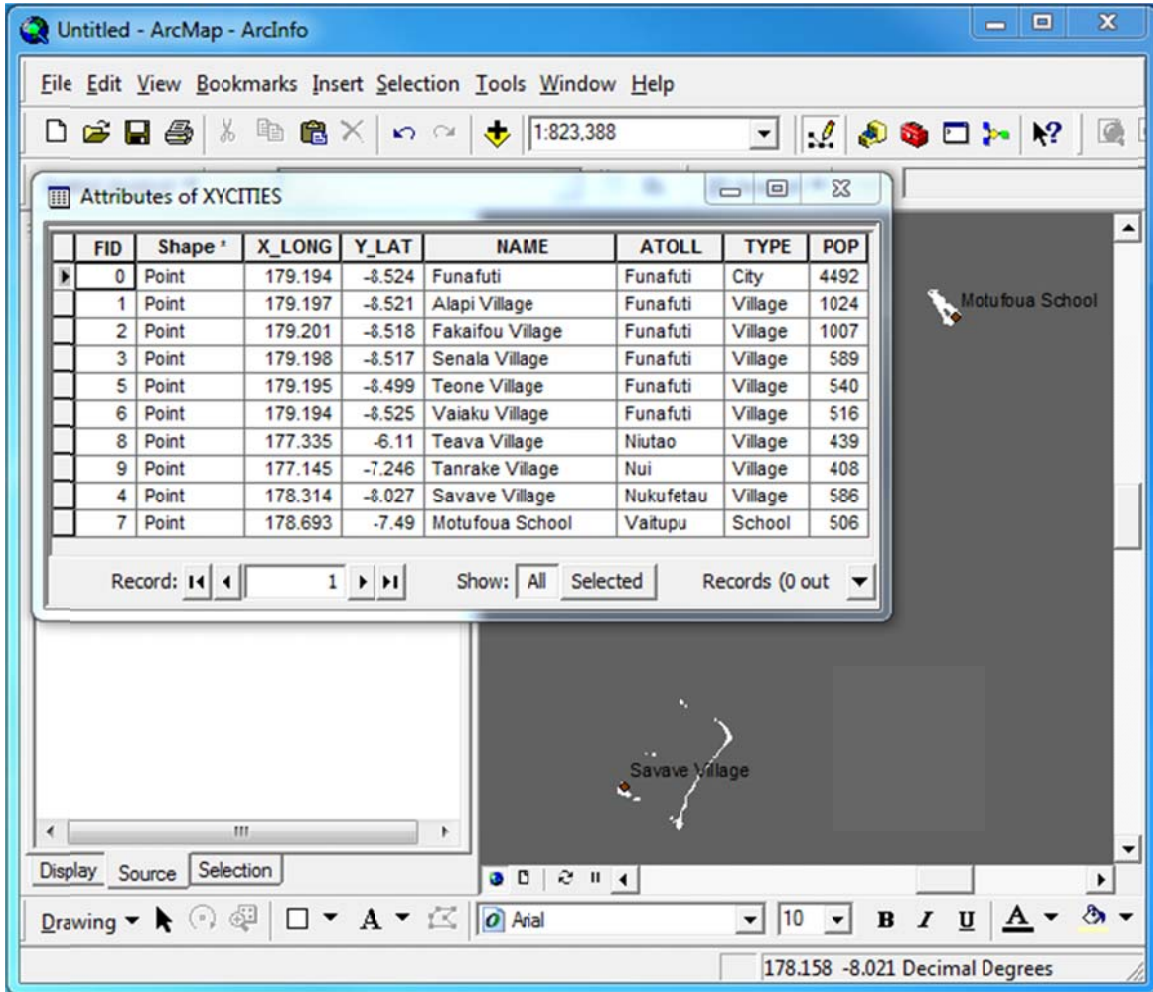


Figure 13: Vaitupu and Nukufetau are shown with the appropriate population centers.

ArcGIS PROCESSING

Because the islands are small, they will need to be viewed separately. This will be confusing without a map to reference their locations. Polygons of the present-day boundaries of Tuvalu were digitized from the raster file to create this reference map.

- A Personal Geodatabase named “Tuvalu” was created by right-clicking on the Map_data folder in ArcCatalog and selecting New > Personal Geodatabase...
- Right-clicking on the new geodatabase and selecting New > Feature Class... and filling out the field properly creates a new polygon feature class. The spatial reference was set to be the same as the raster from which the polygon is to be created. Creating a text field called “Name” will help with labeling the polygons.

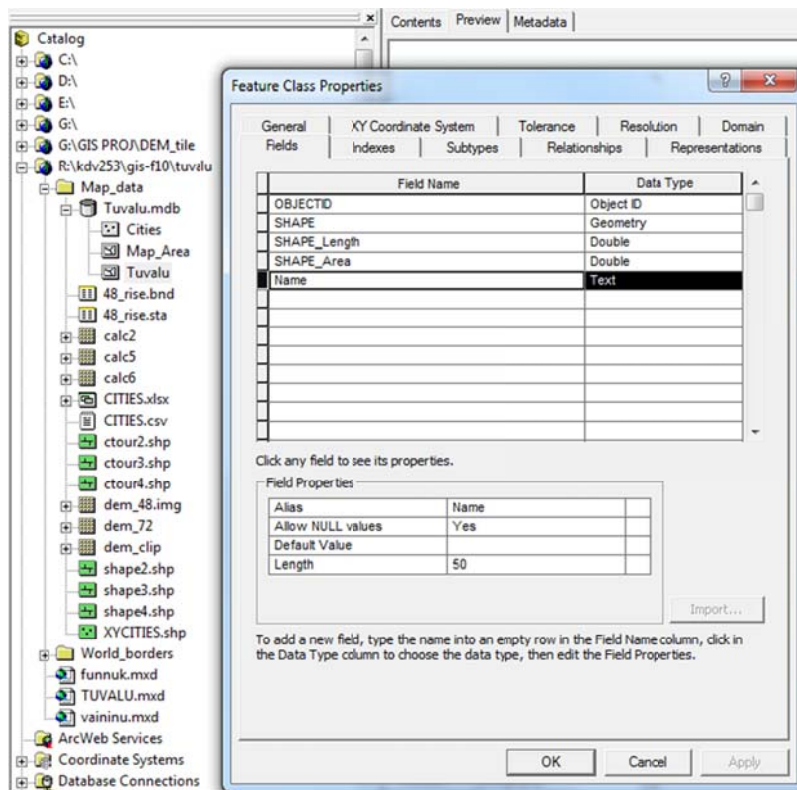


Figure 14: Feature Class properties for Tuvalu file shows Name field created for that file.

- Digitizing in ArcMap is done through the editing toolbar.

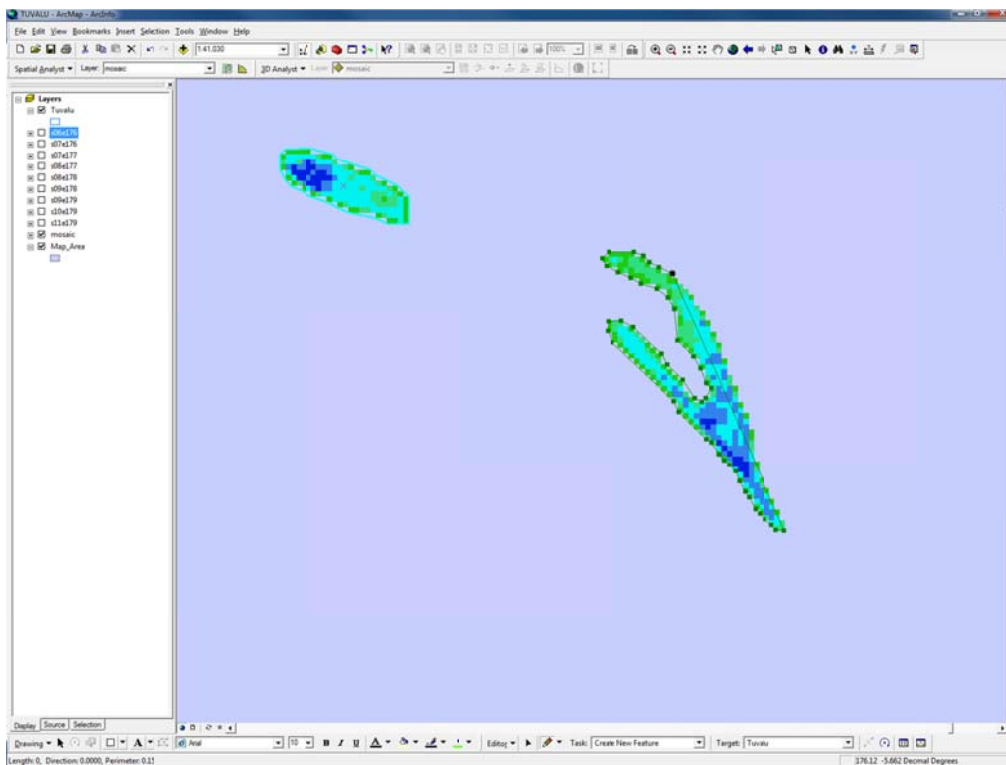


Figure 15: Polygons being digitized for Nanumea

- The name field can be filled out by clicking the attribute table button on the Editing toolbar.

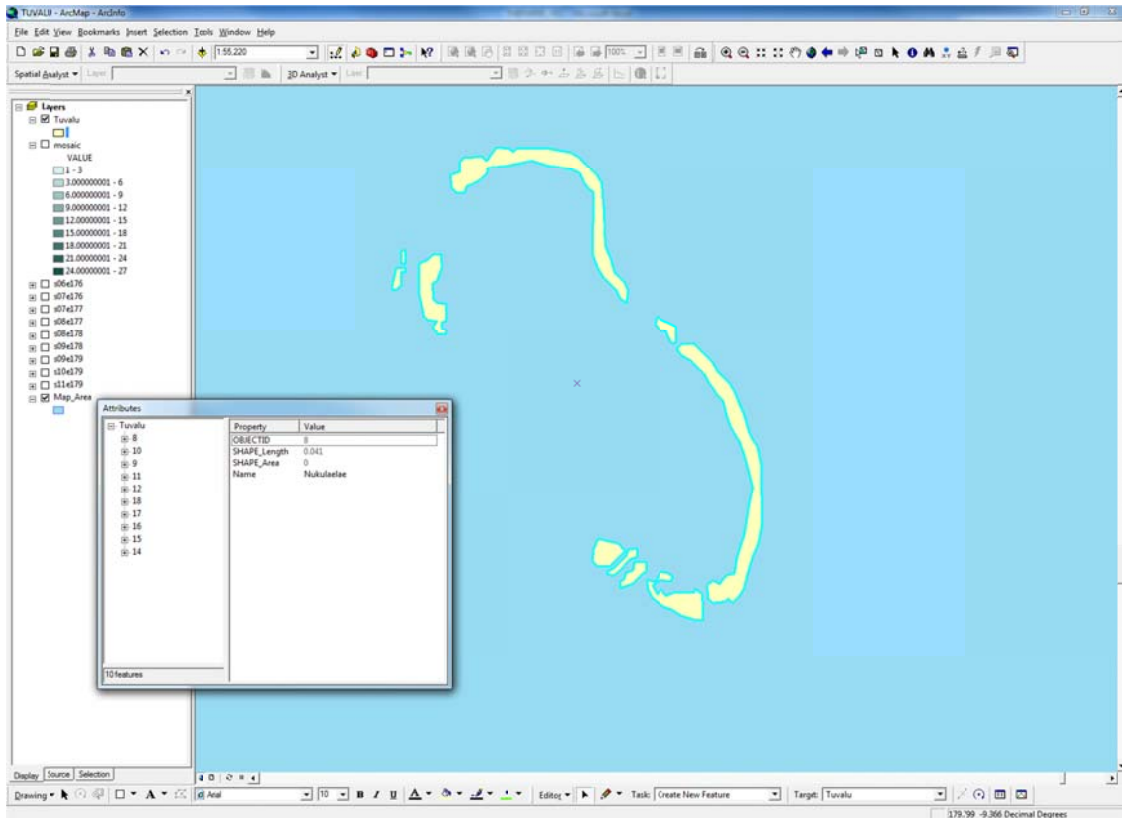
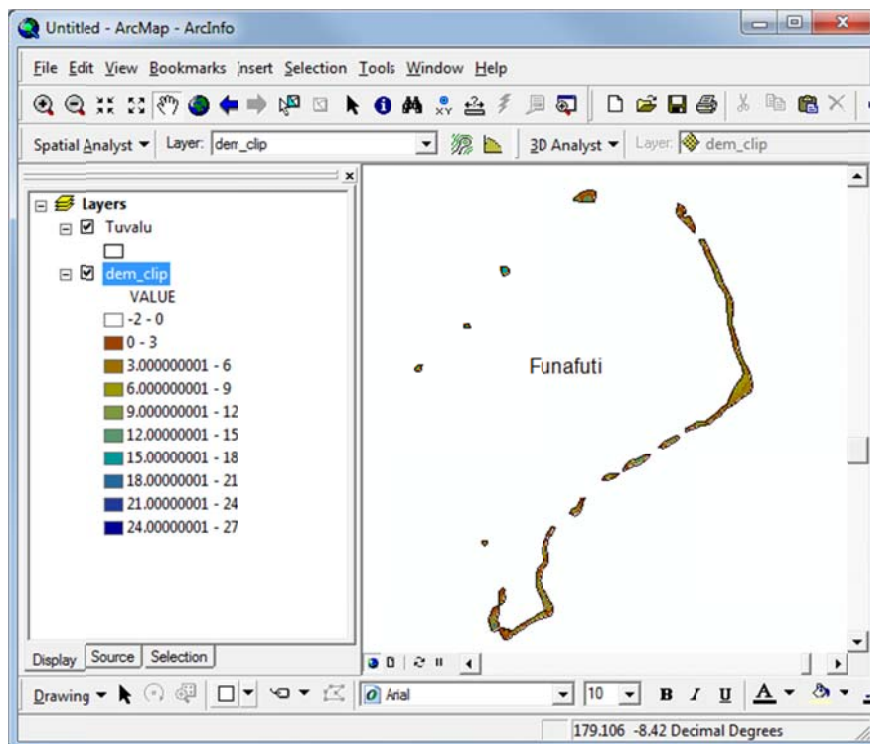


Figure 16: Naming Nakufetau polygons

- The result is a polygon that fits closely to the original raster data, seen in Figure 17 below.



Now that the data has been properly pre-processed, analysis of sea level rise can begin. This analysis will mostly be performed using the Spatial Analyst extension. The EPA estimates of a sea level rise of 0.48 to 0.79 meters by 2100 (<http://epa.gov/climatechange/science/futureslc.html>). New raster files and contour shapefiles will be created that reflect these minimum and maximum estimated changes in sea level.

- A shapefile of the present-day coastline was created by going to the Spatial Analyst Toolbar > Surface Analysis > Contour... and filling in the window as shown below.

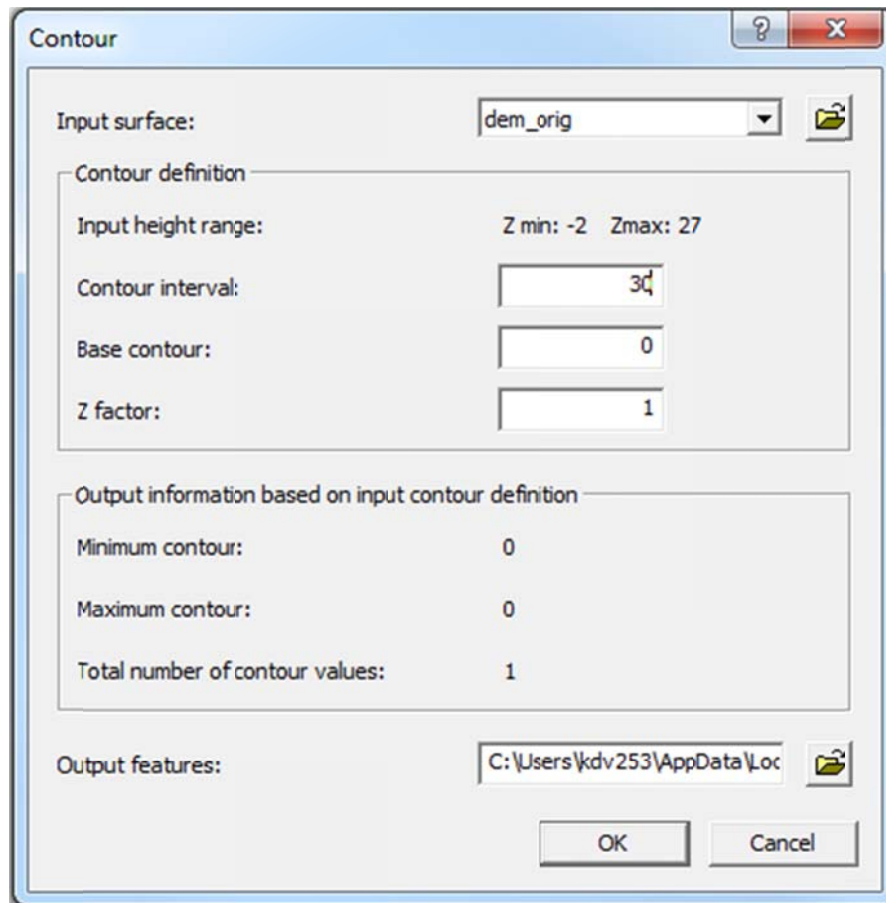


Figure 18: Setting the contour interval greater than the maximum height results in one contour for zero elevation, equivalent to the coastline for the given raster.

- To create a new raster based on 0.48 meters of sea level rise, go to the Raster Calculator on the Spatial Analyst toolbar and fill out the window as shown in Figure 19. A zero elevation contour can be created for this raster using the same method as the original raster.

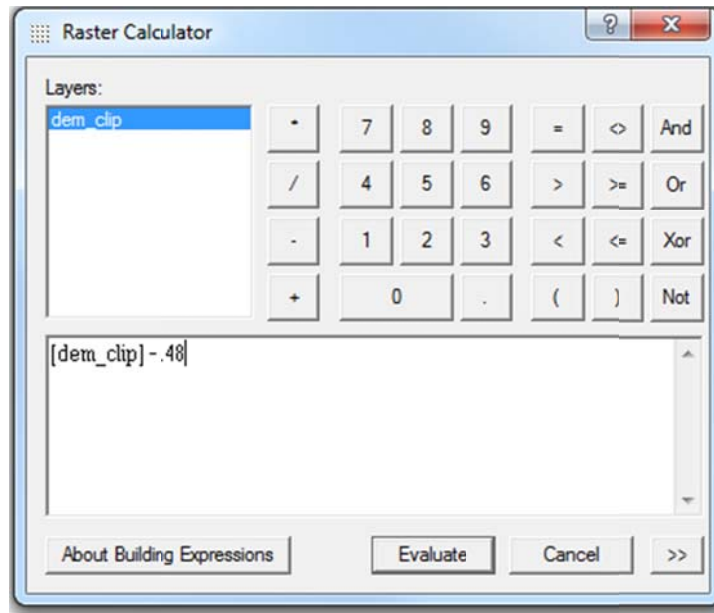


Figure 19: Calculating a new raster based on the old raster minus 0.48 m of elevation.

- The same steps were performed to create a DEM and coastline for 0.72 m of sea level rise.

Creating binary rasters from the DEM files, then reclassifying cells below sea level as no data cells allows for analysis of the different areas of the rasters.

- Binary rasters were created for the three DEM files by right-clicking on the layer, going to Properties, clicking on Symbology tab, and showing Classified values. Clicking the Classify... button allows classification of the raster into two classes.

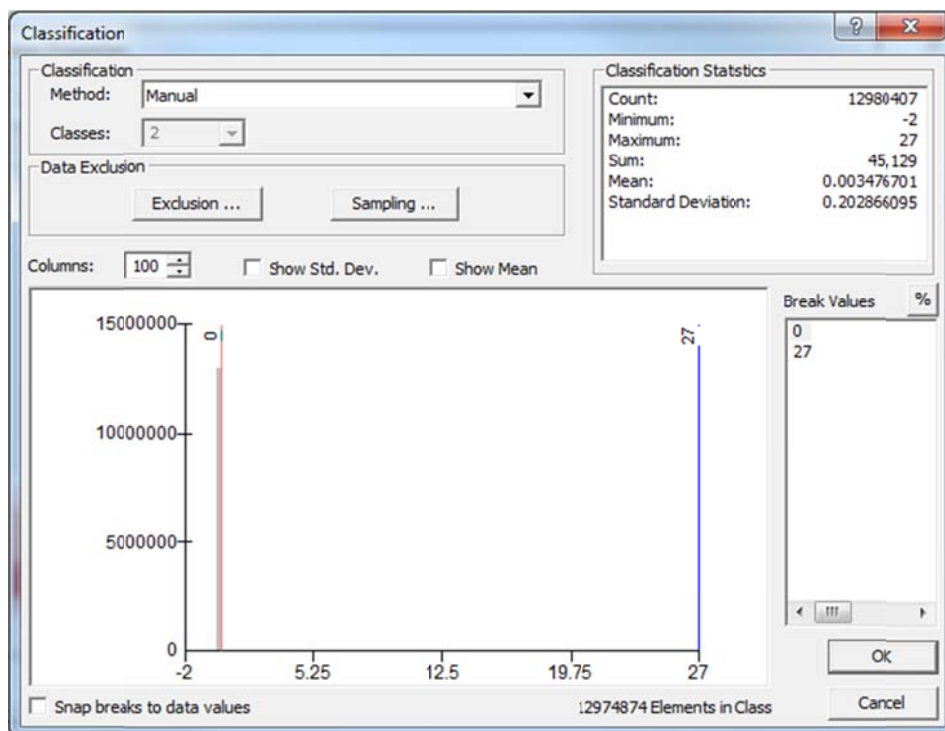


Figure 20: Creating binary raster for original DEM

- The binary rasters make reclassifying the areas below sea level simple. Reclassifying the levels below sea level as NoData creates a new raster where the number of cells represents the area above sea level.

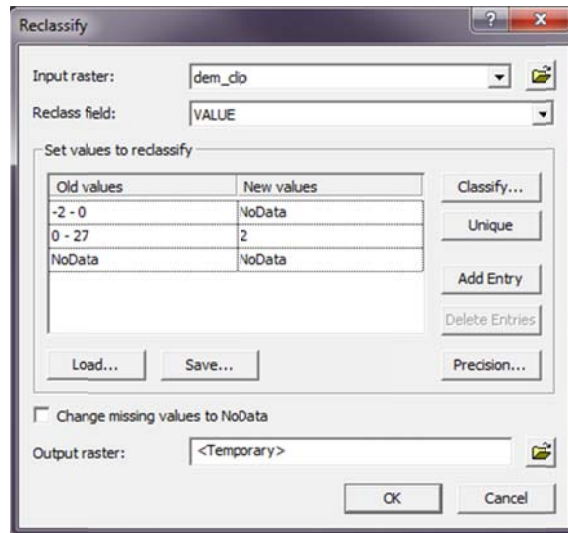


Figure 21: Reclassifying cells below sea level as no data cells for original DEM

- The area of the reclassified rasters can be calculated by determining the cell size and number of cells for each raster.
 - The cell size can be found by right-clicking on the file in the ArcMap Table of Contents, looking at the source for the layer properties, and noting the cell size. The cell size for all the data is 0.000833 by 0.000833 degrees (3 arc seconds = 0.000833 degrees). Since the data is in a geographic projection we can assume that one degree longitude = one degree latitude = 111 km, so the area of cell size can be calculated as $(111 \times 0.000833) \times (111 \times 0.000833) = .008549 \text{ km}^2$ for all of the data.

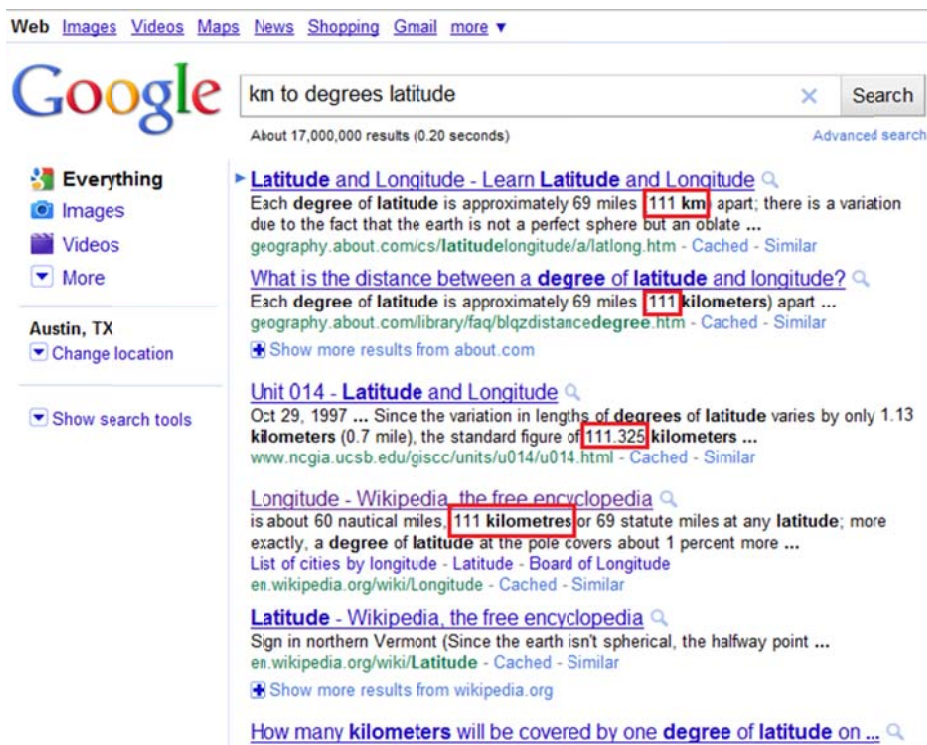


Figure 22: One degree of latitude is equal to 111 km.

- The number of cells can be found by right-clicking on the file and checking out the attribute table, then looking at the COUNT column.

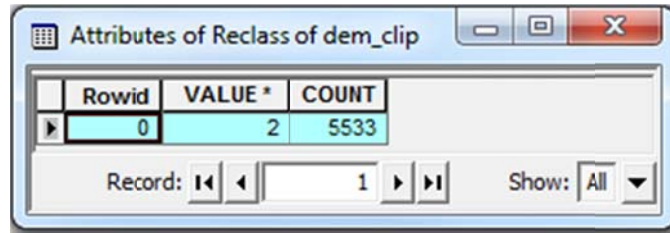


Fig 23: The number of cells for the original binary raster

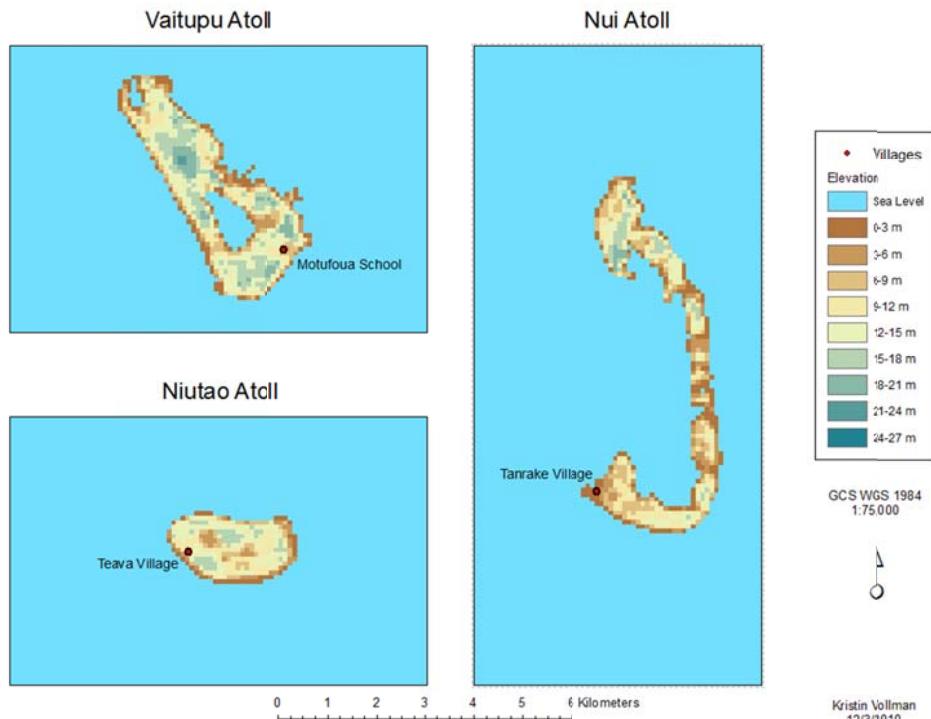
- The area of land above sea level before and after sea level rise is calculated by multiplying the number of cells times the cell size. The data for the different layers is summarized in Table 1 below.

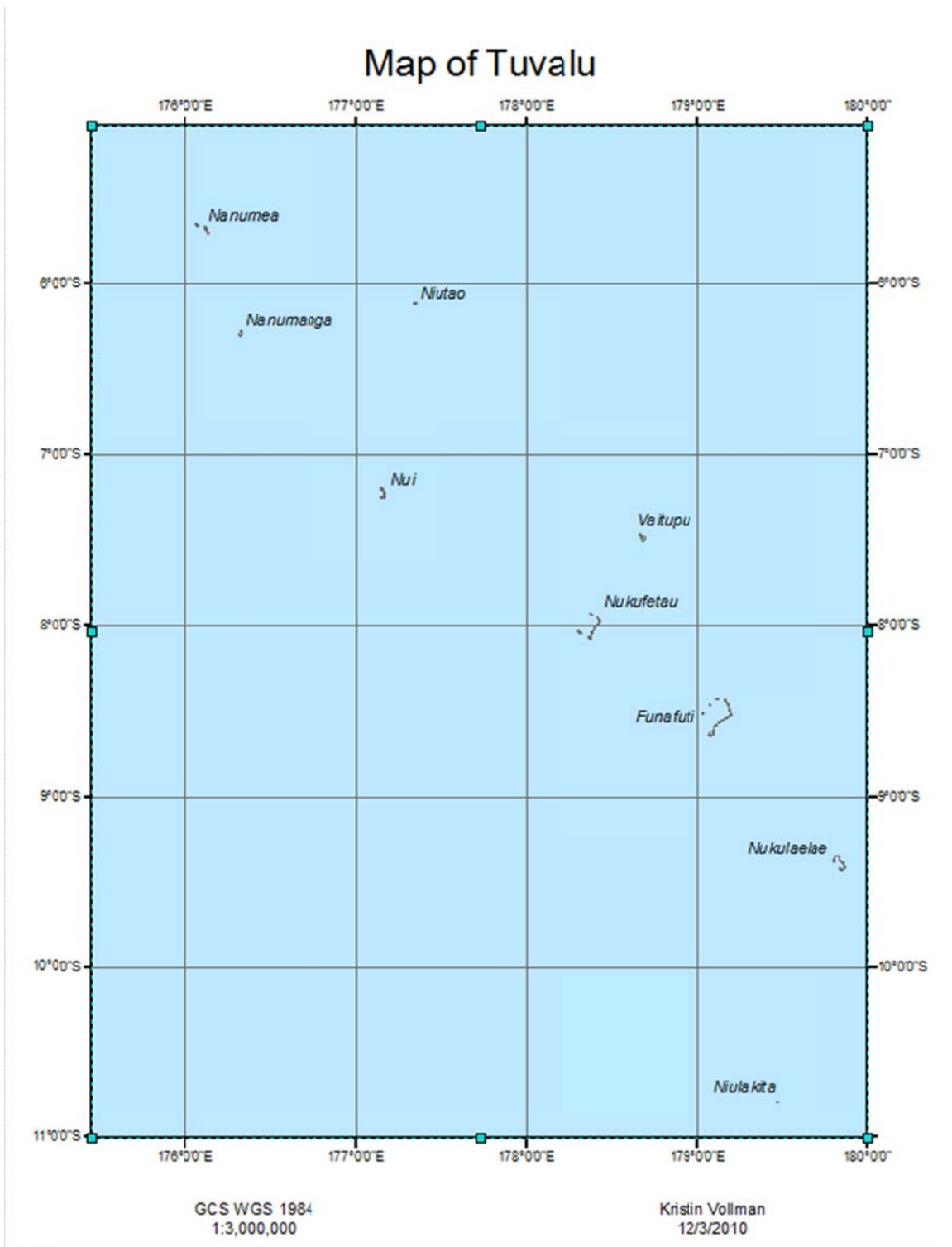
Raster Layer	Number of cells	Cell size	Area
Original sea level	5533	.008549 km ²	47.3 km ²
0.48m rise	5533	.008549 km ²	47.3 km ²
0.72m rise	5533	.008549 km ²	47.3 km ²

According to this analysis, despite the sea level rise, the area of land above sea level does not change at all and no land is lost to inundation.

CONCLUSION

What will happen to Tuvalu?





According to binary raster analysis, Tuvalu is completely unaffected by sea level rise. This analysis is wrong. A glance at the change in coastline shows that some land is lost to inundation. There were issues with the data, namely that every source available notes that Tuvalu has a maximum elevation of roughly five meters—however, the raster data gave elevations of up to 27 meters. The vertical elevation error of 30 meters caused severe problems in analysis. It is a shame that the parts of the world that most need accurate data to determine the effects of climate change have the least of it.

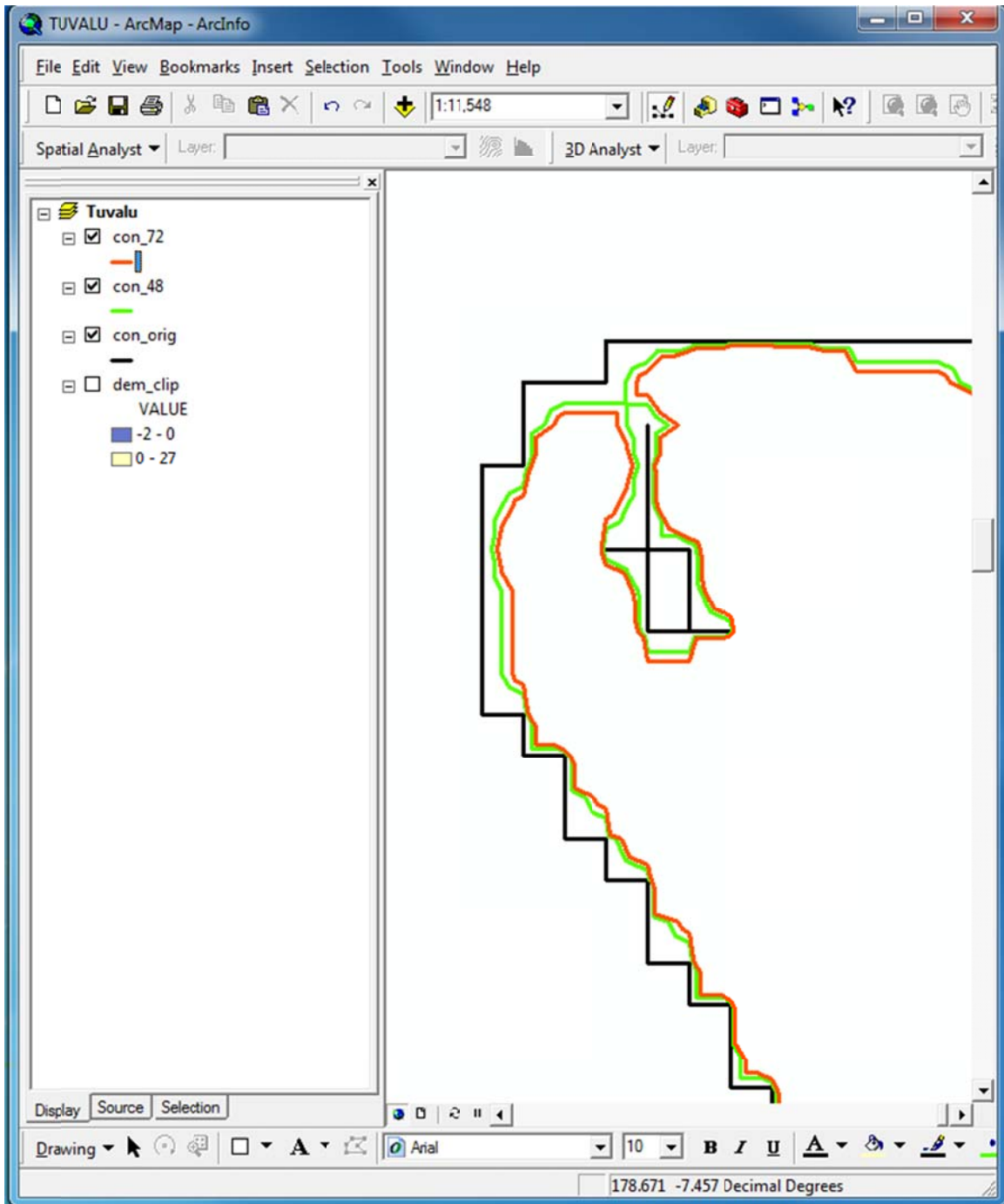


Figure 24: Change in coastline for Vaitupu. The original coast is represented in black, the coast after 0.48 meters of sea level rise in green, and the coast after 0.72 meters of sea level rise in red.

REFERENCES

- Maximum elevation of Tuvalu
 - http://www.indexmundi.com/tuvalu/elevation_extremes.html
- Estimation of sea level rise by 2100
 - <http://epa.gov/climatechange/science/futureslc.html>
- Names of atolls
 - <http://www.state.gov/r/pa/ei/bgn/16479.htm>
- Names, locations, and populations of population centers
 - <http://www.geonames.org/TV/largest-cities-in-tuvalu.html>
- Picture of Funafuti Atoll
 - http://de.wikipedia.org/wiki/Datei:Tuvalu_Funafuti_Atoll.JPG