

# HOW WILL CHANGING SEA- LEVEL AFFECT WORLD POPULATION?

ALEXANDER ROBSON

SPRING 2014

# TABLE OF CONTENTS

INTRODUCTION	3
DATA EVALUATION	4
<b>What was needed?</b>	4
<b>Choosing Population Data</b>	5
<b>Choosing Elevation Data</b>	7
<b>Choosing City Data</b>	9
<b>Choosing an Outline</b>	10
DATA ANALYSIS	11
<b>Refocusing the Project</b>	11
<b>Selected Data</b>	12
ADDING DATA	13
DATA PREPARATION	14
<b>Mosaicking the ASTER files</b>	14
<b>Extracting the Outline</b>	16
<b>Trimming the Data</b>	21
<b>Presentation</b>	26
<b>Combining the City Layers</b>	32
<b>Adjusting City Data Tables</b>	34
METHOD	36
MAP CREATION	37

<b>Increasing Sea Level</b>	<b>37</b>
<b>Generating Statistics</b>	<b>40</b>
<b>Correcting for Misalignment</b>	<b>41</b>
<b>Generating Statistics Continued</b>	<b>45</b>
<b>Results</b>	<b>47</b>
<b>Producing the Map</b>	<b>48</b>
<b>FUTURE STUDY AND SCALING</b>	<b>49</b>
<b>CONCLUSIONS</b>	<b>50</b>
<b>Potential Sources of Error for Extrapolation:</b>	<b>50</b>
<b>Scaling and Future Study</b>	<b>50</b>

# INTRODUCTION

## Problem

Due to climate change, global sea levels are rapidly rising. Coastlines around the world will change, causing large-scale economic disruption as cities are abandoned. It is important to establish a method to simulate what cities and how many people will be displaced as this occurs.

## Objective

This project attempts to establish a quantifiable estimate for how changing sea levels will affect the world's population. It will initially focus on the British Isles but may be refocused later as processing time and data restraints become more apparent. The principal method is to use the "Raster Calculator" tool to adjust an elevation file to represent a new sea level. This can then be used to create a new coastline, which in turn, is used to query the containment of city data. Those cities that were originally contained by the coastline but are not any longer will then be and their total population estimated.

## DATA EVALUATION

### What was needed?

(Things to be considered when picking data in bullet points)

A file containing *population data* for the British Isles.

- Resolution
- Density or Absolute values?

A raster file containing *elevation data* for the British Isles.

- Resolution
- Time of collection
- Accuracy

A file containing *data on cities* in the British Isles.

- Names
- Locations

An *outline of the British Isles*.

- As well matching other the raster files limits as possible

## Choosing Population Data

Population data proved to be hard to come by for the British Isles. The two best sources seemed to be either ERSI's database in the form of a disk or from the UK Data Service.

### ERSI NUTS3 Data

The ERSI NUTS3 data came in the form of polygons representing *population density* (persons per square kilometer). Unfortunately the *polygons represented a large ranges of values* (i.e. 351-1,000). These would have *needed to be converted in to discrete values* for the purpose of population displacement calculations. To do this, the value of each polygon would need to be replaced by the median value of its range, which would introduce *significant error* to the results. Even more error would be introduced for the unbounded 1,000+ persons per sq. km polygons. The data is also not in a raster format. As a result, the change in area of each polygon would need to be calculated independently for each increment in sea level. This would make the *calculations extremely time consuming*.

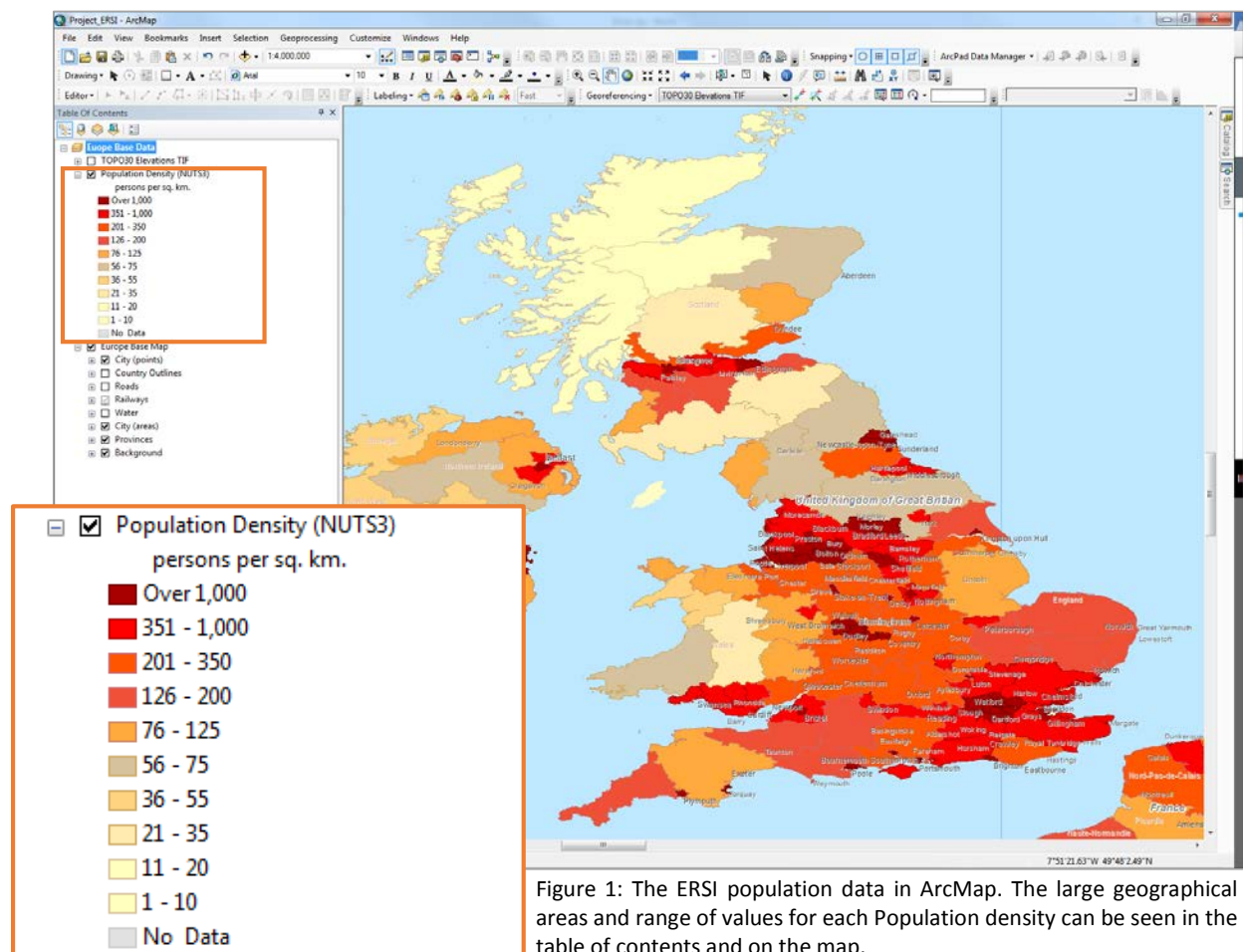


Figure 1: The ERSI population data in ArcMap. The large geographical areas and range of values for each Population density can be seen in the table of contents and on the map.

## UK Data Service Data

The UK data service had data in the form of *population per district* that was available for download in data tables. There was also corresponding district outline *shapefiles available separately*. It was possible that the shape files could have been loaded and the data tables joined to them. However, the size of these *districts where very large*, this meant that the resolution and accuracy of calculations would be poor.

## ERSI City Populations

After exploring the ERSI city data it became apparent that all *urban areas were grouped by population* (Figure 2). Although the ranges of these populations varied it seemed that this data would make for more accurate results than any of the other population data. Especially since the project is particularly concerned with urban areas. Though, it is worth noting that if better population data could be found such as that which is available for the US, accuracy would likely be improved by a significant factor.

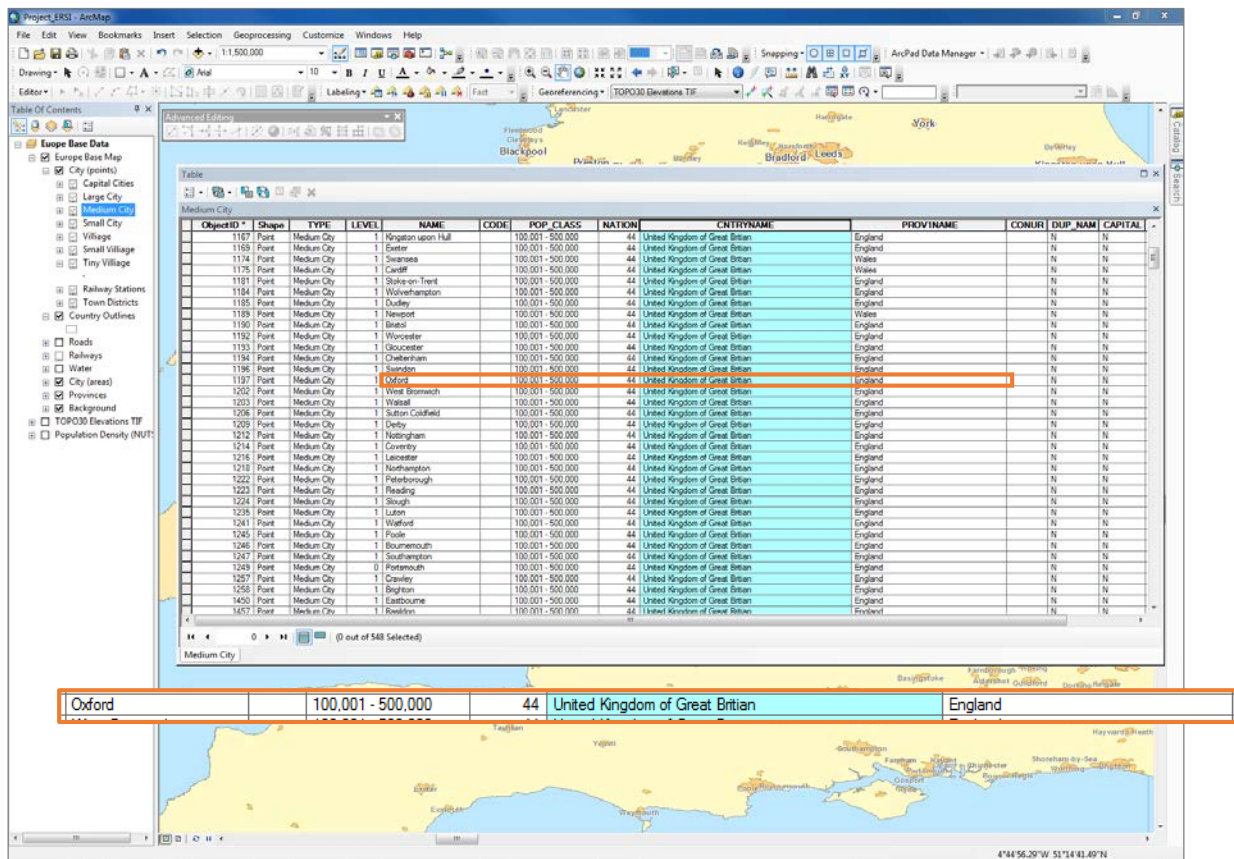


Figure 2: The attribute table for “Medium Cities” in Europe focusing on some of those that fall within the UK. Highlighted in orange is an example, Oxford, showing that the data table contains a “POP\_CLASS” column with the value 100,001 – 500,000 people (Defining a “Medium City”)

# Choosing Elevation Data

## USGS Earth Explorer

The best resolution that could be feasibly obtained for such a project was *60x60m* cells using *ASTER Global DEM* data. Additionally this data had vertical (root-mean-squared-error) accuracies generally between 10- and 25-meters. However, *GTOPO 30* data with a grid spacing of *30 arc seconds* (~1km) is much easier to work with, since the file sizes are smaller and you can obtain the coverage needed using fewer files. Both types of data could be obtained from the USGS EarthExplorer website (Figure 3).

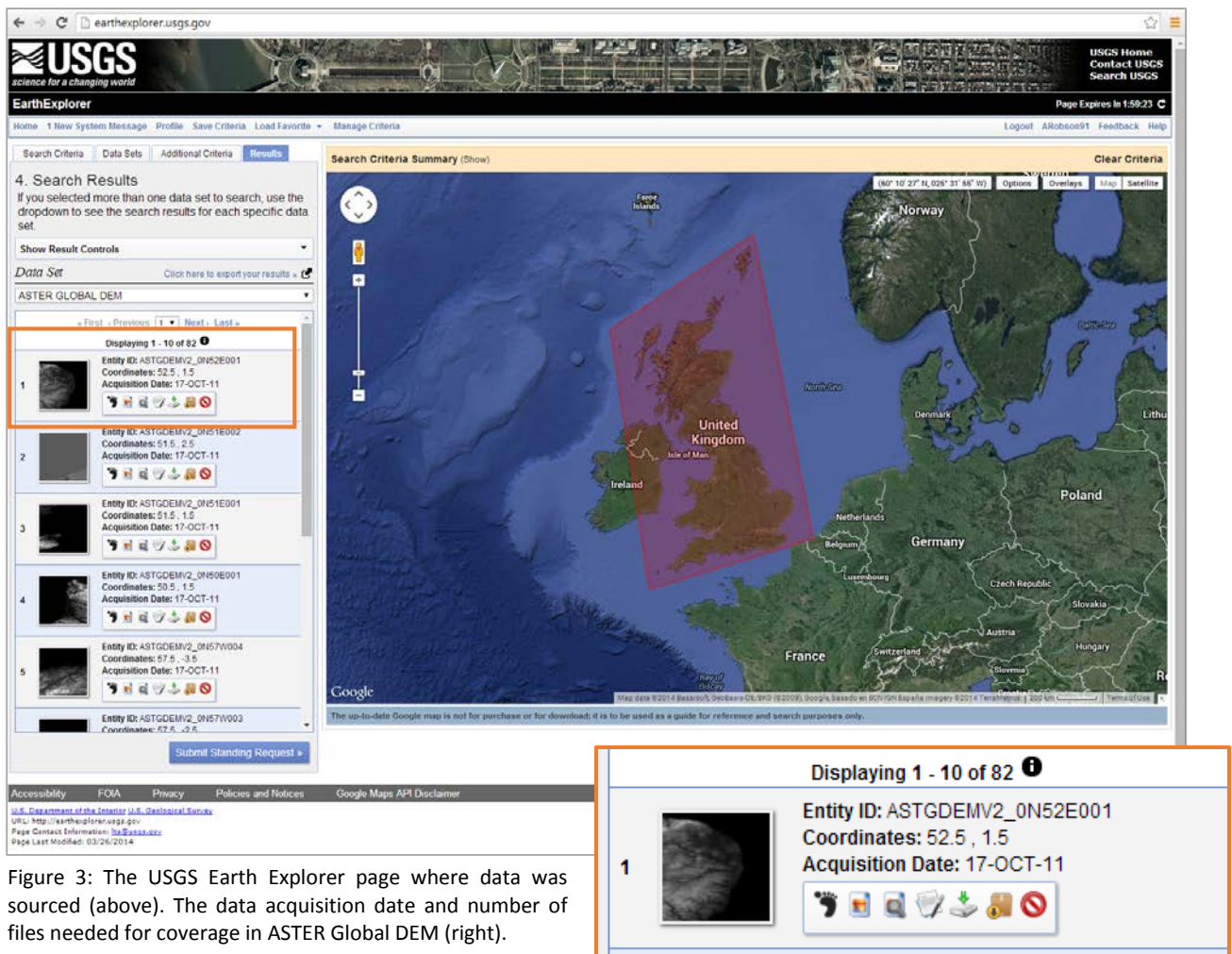


Figure 3: The USGS Earth Explorer page where data was sourced (above). The data acquisition date and number of files needed for coverage in ASTER Global DEM (right).

The ASTER data required many more files than GTOPO30; 82 compared to 1 respectively (Figure 3). For this reason the GTOPO 30 file was initially used. However, there was clear resolution issue. When the GTOPO 30 raster was viewed above the population density raster there were significant populated areas that showed as being outside the coverage of the raster (Figure 4). This meant that the calculations would show some amount of the population had been displaced by the ocean prior to any sea level change. Though, it is



possible to correct for this by adding cells to the raster (i.e. adding cells such that there is a cell over all parts of the ERSI outline and giving them a value of 0.1). This would introduce further errors, by assuming that the values do not change abruptly at the coast, such as is associated with cliffs.

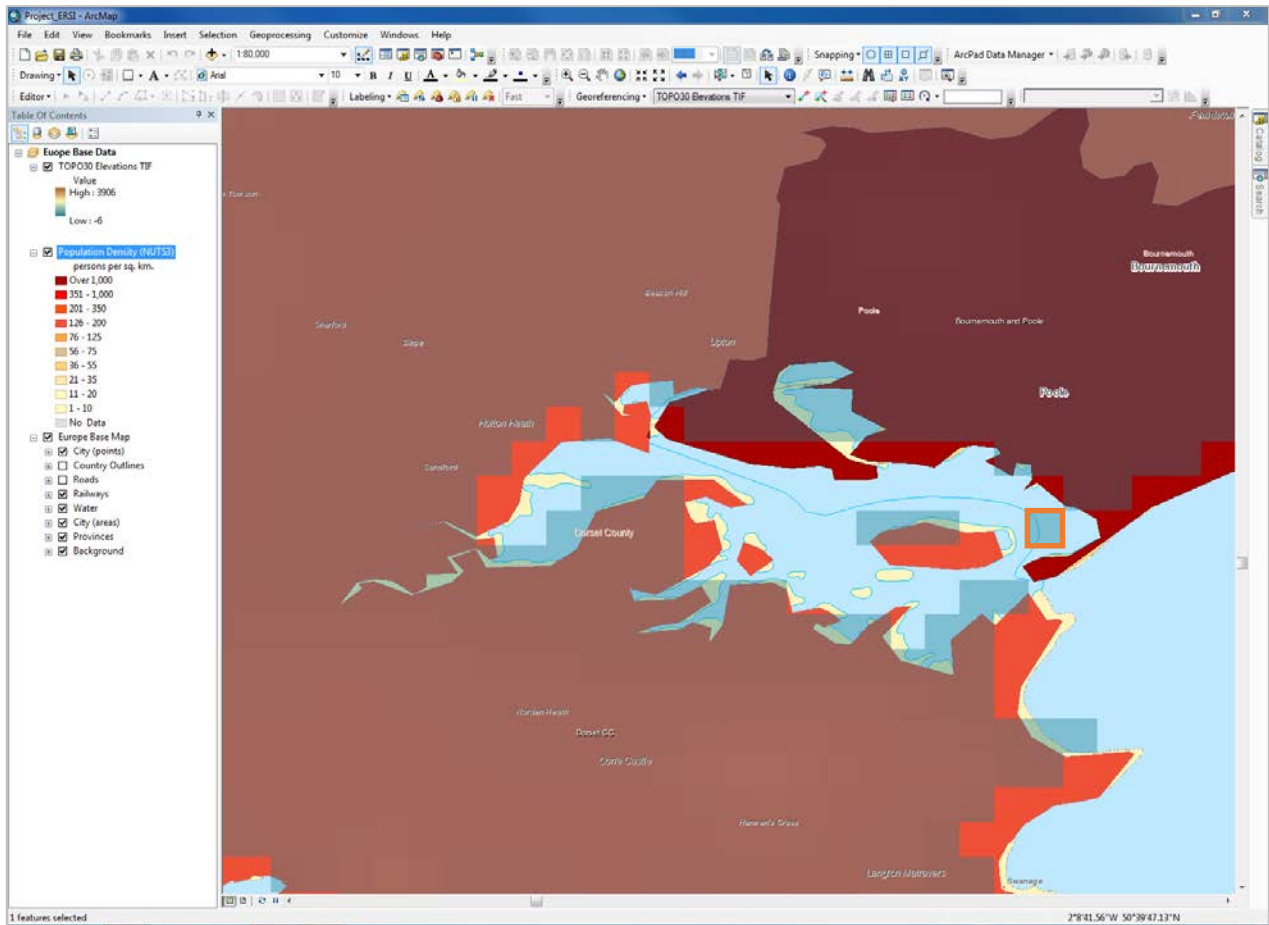


Figure 4: A screenshot of the south coast showing the resolution of the GTOPO30 raster (the grey cells). The colored polygons represent the ERSI population data and the yellow polygon represents the British Isles (ERSI Data). In some places, significant populations (consider the orange square is a square kilometer) would already be considered at sea level, since areas without a cell representing them are considered as such in this dataset.

Due to these reasons the ASTER data was used despite the additional data acquisition and preparation time.

## Choosing City Data

### ERSI

The ERSI data mentioned earlier in “choosing population data”, also contained city data (Figure 5 and 6). It was from a reputable source and contained *names and positions of cities* in the British Isles. For the purpose of using cities for reference points this data was more than sufficient.

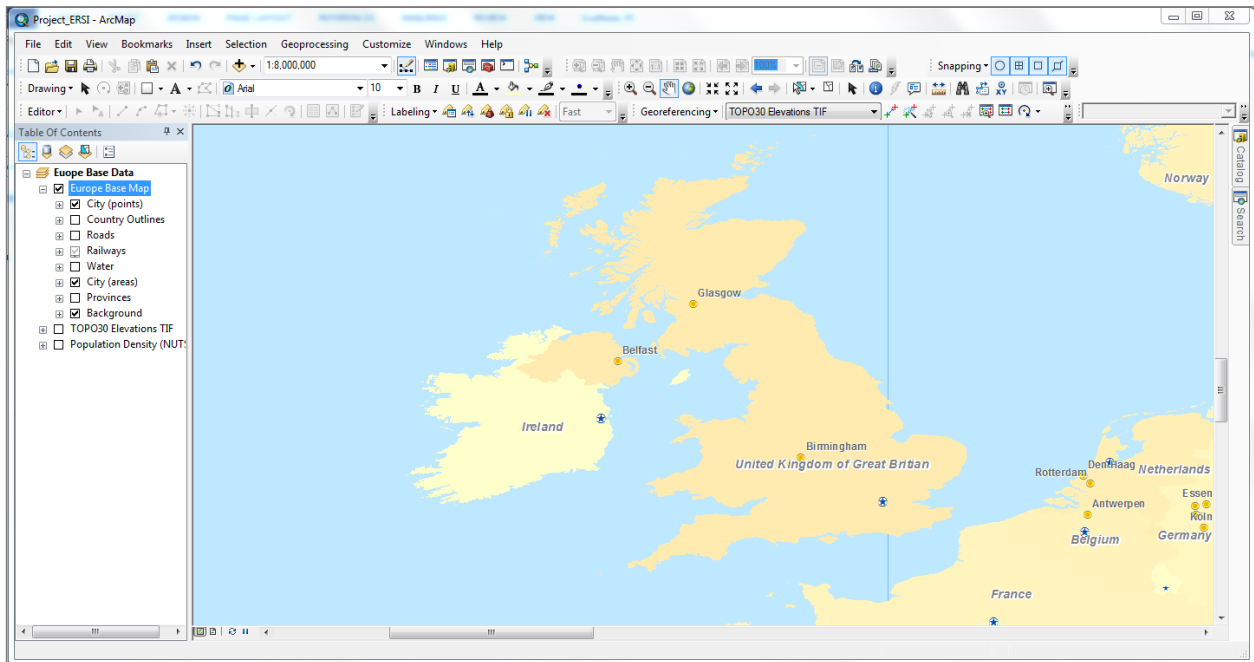


Figure 5: A screenshot of the ERSI data showing the British Isles. As you zoom in and out of the image various cities and towns become visible. These are also categorized by size as shown in Figure 6.

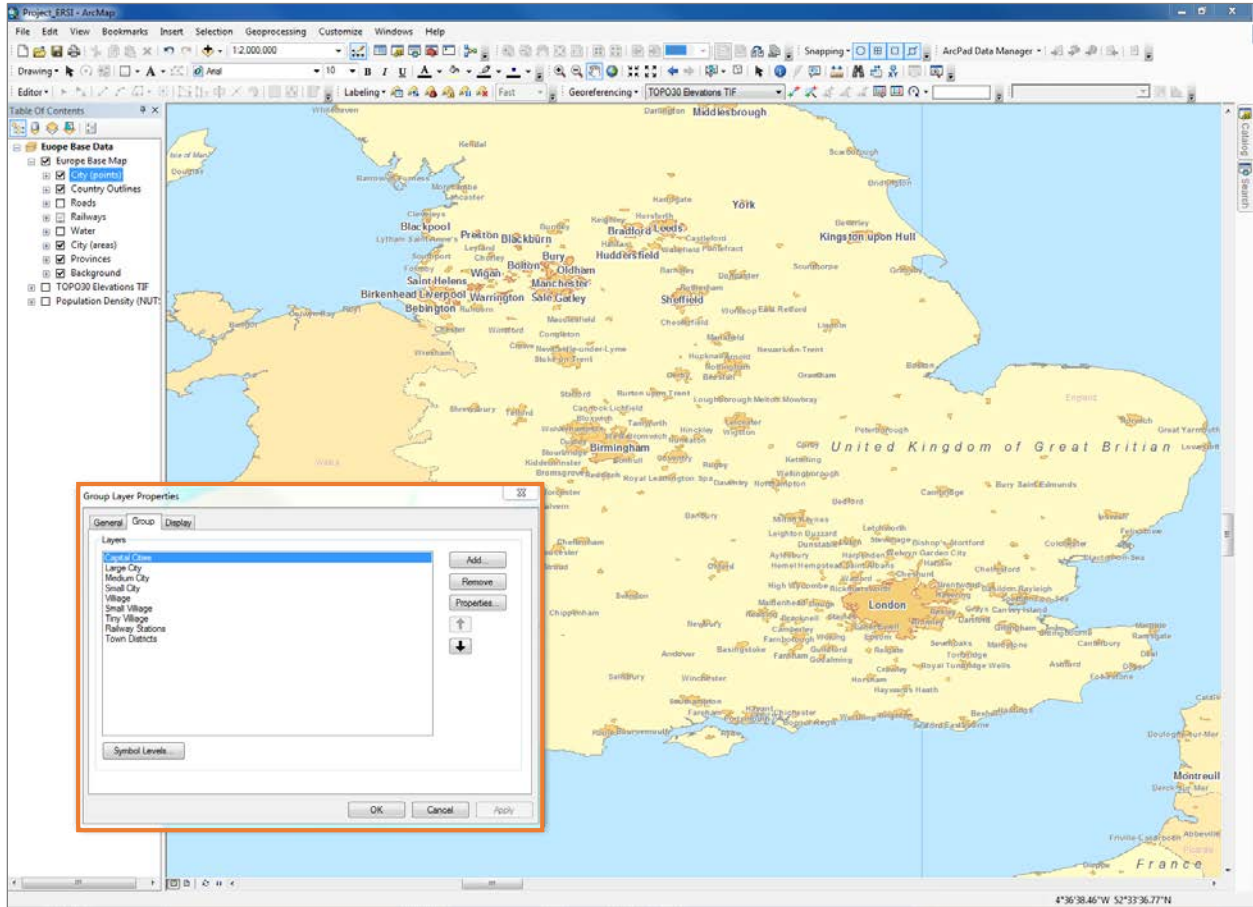


Figure 6: A zoomed-in screenshot of the ERSI data showing more cities yet still nowhere near the full extent of city/town data. Included is also the areas covered by these cities rather than just points. This means that as the coastline changes it will be possible to see the extent to which a city has been submerged as opposed to considering it a point. Also included, outlined in orange, is a window showing how the urban areas are grouped. This may be useful later when trying to display the data selectively.

## Choosing an Outline

The outline can be extracted from the “Country Outlines” layer which contains an outline titled “United Kingdom of Great Britain” (Figure 7).

Figure 7: A screenshot showing the “United Kingdom” within the attribute table for “Country Outlines” in the TOC. From here this data could be extracted to create a new layer file of the UK outline.

ObjectID	Shape	COUNTRYNAME	COUNTRYABB	NATION	SQKM	COLORMA
1	Polygon	Albania	ALB	365	28919.51	9
2	Polygon	Andorra	AND	376	468.22	4
3	Polygon	Armenia	ARM	374	29649.48	2
4	Polygon	Austria	AUT	43	83235.55	10
5	Polygon	Azerbaijan	AZE	994	168073.36	9
6	Polygon	Belgium	BEL	32	30291.55	4
7	Polygon	Bulgaria	BGR	369	110998.05	6
8	Polygon	Bosnia and Herzegovina	BIH	387	51157.62	1
9	Polygon	Belarus	BLR	375	204793.39	3
10	Polygon	Channel Islands	CHA	830	197.96	3
11	Polygon	Switzerland	CHE	41	40900.25	1
12	Polygon	Cyprus	CYP	357	9441.29	4
13	Polygon	Czech Republic	CZE	420	77953.87	7
14	Polygon	Denmark	DNK	431	43094.46	6
15	Polygon	Estonia	EST	393	45114.39	2
16	Polygon	Finland	FIN	358	340367.52	5
17	Polygon	France	FRA	33	545567.24	5
18	Polygon	Faeroe Islands	FRO	298	1403.95	1
19	Polygon	Germany	DEU	40	357022.75	10
20	Polygon	Greece	GRC	71	131990.86	10
21	Polygon	United Kingdom of Great Britain	GBR	44	242091.51	1
22	Polygon	Georgia	GEO	995	69802.6	10
23	Polygon	Gibraltar	GIB	260	6.76	7

# DATA ANALYSIS

## Refocusing the Project

Having collected all the data it has become apparent that within the given time constraints it is not feasible to perform this task for the entire British Isles. Instead, the same data files will be applied to a smaller scale region of interest, The Isle of Wight (Figure 8).



Figure 8: An image showing the location of the Isle of Wight with respect to the British Isles.

To implement this change in area of interest an outline for the Isle of Wight needs to be sourced. This can be done by exploding the “Country Outline” for the “United Kingdom of Great Britain” (Figure 7) using the “Explode Multipart Feature” tool (🗑️) (Page 17). This will then be used to create a mask to trim the Raster files and to clip the shape files. As such no new data is required.

## Selected Data

Data	Source	Type	Description
Population	ERSI	Point Features/Attribute Table	Number of People in a City
Elevation	USGS EarthExplorer	Raster	ASTER
City	ERSI	Point Features/Attribute Table	Points with Attributes
Outline	ERSI	Shapefile	Within UK outline

## ADDING DATA

Firstly the European base map data from the ERSI disk was added to the directory in ArcMaps. The add data button (📍) was then used to add it to a blank map document. This included the raw data needed for city positions, population calculations and the outline of the Isle of Wight. It projected in GCS WGS 1984 (Figure 9).

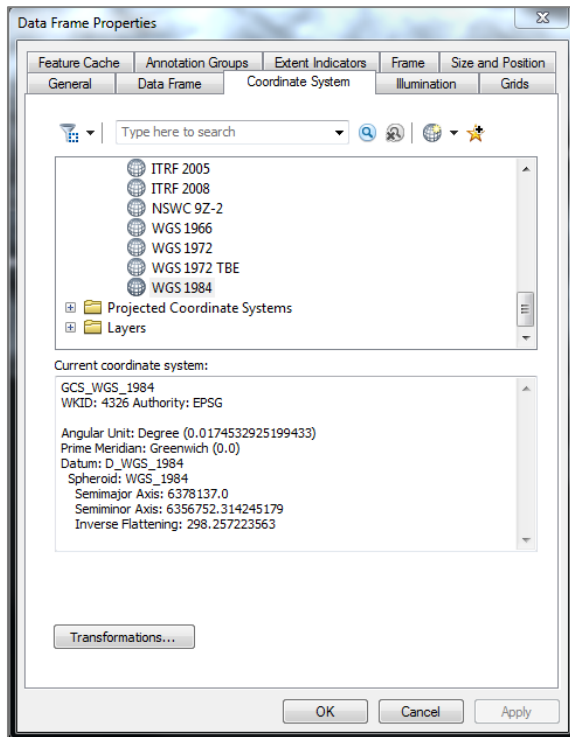


Figure 9: The data frame properties after loading the ERSI base data.

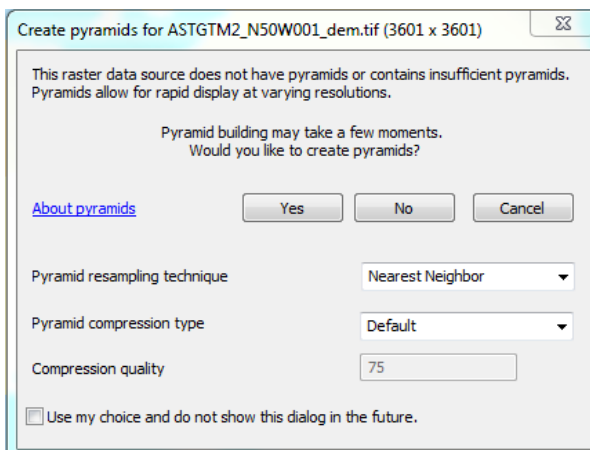


Figure 10: Pop up window asking if “Would like to create pyramids?”

Secondly the two Aster .tif elevation files needed to give coverage over the area of interest were added. This was done by the same procedure listed above. When the data was added a window popped up (Figure 10) all default values were left and the pyramids were generated. This was done for both files. The data was the projected on the fly. To see if this was done correctly the project raster tool was used to project the .tif into GCS WGS 1984, it projected identically to the on the fly projection. The alignment of the coastlines was manually checked when zoomed in to a great extent and was deemed satisfactory (Figure 11).

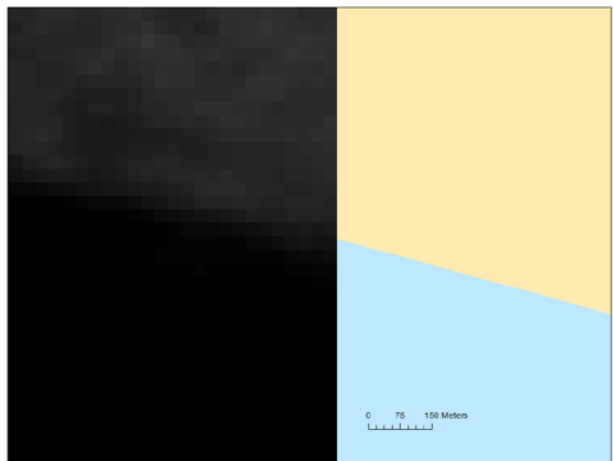


Figure 11: A layout view giving a sense of the alignment of the two projected data files.

## DATA PREPARATION

### Mosaicking the ASTER files

First the “Mosaic to New Raster” tool was selected (Left of Figure 12). Then within the “Mosaic to New Raster” window the two .tif files were chosen as the input rasters. The rest of the window was filled out as shown in Figure 12. For all the sections in the “Mosaic to New Raster” window, the values for the input rasters (which had all the same values for this purpose) were looked up and entered (top right of Figure 12). After this tool was run the original two tiles were removed, as they were no longer needed.

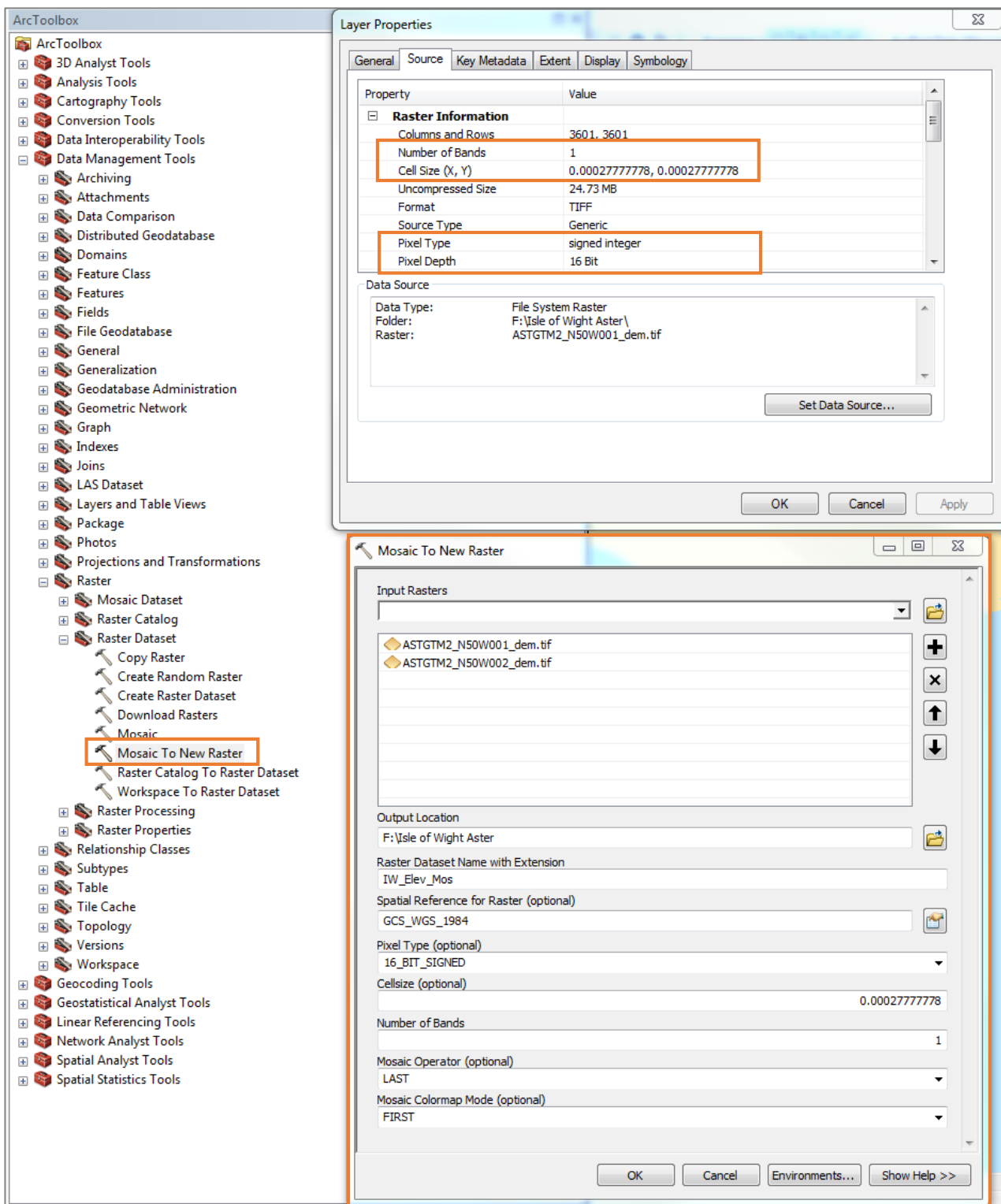


Figure 12: The windows used to Mosaic the two ASTER Elevation files together.



## Extracting the Outline

Before anything else was performed it was important to extract the outline so that everything else could be cropped with respect to it. Firstly the Attribute Table was opened for “Country Outlines” and the United Kingdom of Great Britain polygon was selected (Figure 13).

Shape	CNTRYNAME	CNTRYABB	NATION	SQKM	COLORMA
Polygon	Aland Islands	ALA	247	1477.29	1
Polygon	Albania	ALB	355	28919.51	9
Polygon	Andorra	AND	376	468.22	4
Polygon	Armenia	ARM	374	29949.48	2
Polygon	Austria	AUT	43	83235.55	10
Polygon	Azerbaijan	AZE	994	168073.36	9
Polygon	Belgium	BEL	32	30291.55	4
Polygon	Bulgaria	BGR	359	110998.05	6
Polygon	Bosnia and Herzegovina	BIH	387	51157.62	1
Polygon	Belarus	BLR	375	204793.39	3
Polygon	Channel Islands	CHA	830	197.96	3
Polygon	Switzerland	CHE	41	40900.25	1
Polygon	Cyprus	CYP	357	9441.29	4
Polygon	Czech Republic	CZE	420	77953.87	7
Polygon	Germany	DEU	49	353522.34	6
Polygon	Denmark	DNK	45	44707	2
Polygon	Spain	ESP	34	510512.15	6
Polygon	Estonia	EST	372	44948.48	10
Polygon	Finland	FIN	358	340367.52	5
Polygon	France	FRA	33	545567.24	5
Polygon	Faeroe Islands	FRO	298	1403.95	1
Polygon	United Kingdom of Great Britain	GBR	44	242091.51	1
Polygon	Georgia	GEO	995	69802.6	10
Polygon	Gibraltar	GIB	350	6.76	7
Polygon	Greece	GRC	30	133755.32	2
Polygon	Croatia	HRV	385	56279.85	9
Polygon	Hungary	HUN	36	92241.49	7
Polygon	Isle of Man	IOM	833	566.94	9
Polygon	Ireland	IRL	353	69342.41	10
Polygon	Iceland	ISL	354	104597.47	3
Polygon	Italy	ITA	39	302081.5	3
Polygon	Liechtenstein	LIE	423	158.12	9
Polygon	Lithuania	LTU	370	64045.72	8
Polygon	Luxembourg	LUX	352	2564.11	9
Polygon	Latvia	LVA	371	63908.49	9
Polygon	Monaco	MCO	377	1.47	5
Polygon	Republic of Moldova	MDA	373	33627.85	1
Polygon	The former Yugoslav Republic of Macedonia	MKD	389	25398.54	4
Polygon	Malta	MLT	356	323.33	3
Polygon	Netherlands	NLD	31	34985.26	3
Polygon	Norway	NOR	47	328191.31	4
Polygon	Poland	POL	48	307698.35	5
Polygon	Portugal	PRT	351	92982.46	8
Polygon	Romania	ROU	40	236276.33	5
Polygon	Russian Federation	RUS	7	4021154.96	7

Figure 13: The table of contents for “Country Outlines” showing the selected United Kingdom of Great Britain polygon.

This was then exported as a new shapefile (Figure 14, 15 and 16) and displayed in the table of contents. The result was a shapefile containing the outlines of all part of the UK. The exported data was then added to the map by responding “Yes” when asked “Do you want to add the exported data to the map as a layer?”.

The next step was to extract the outline of the Isle of Wight from this new shapefile.

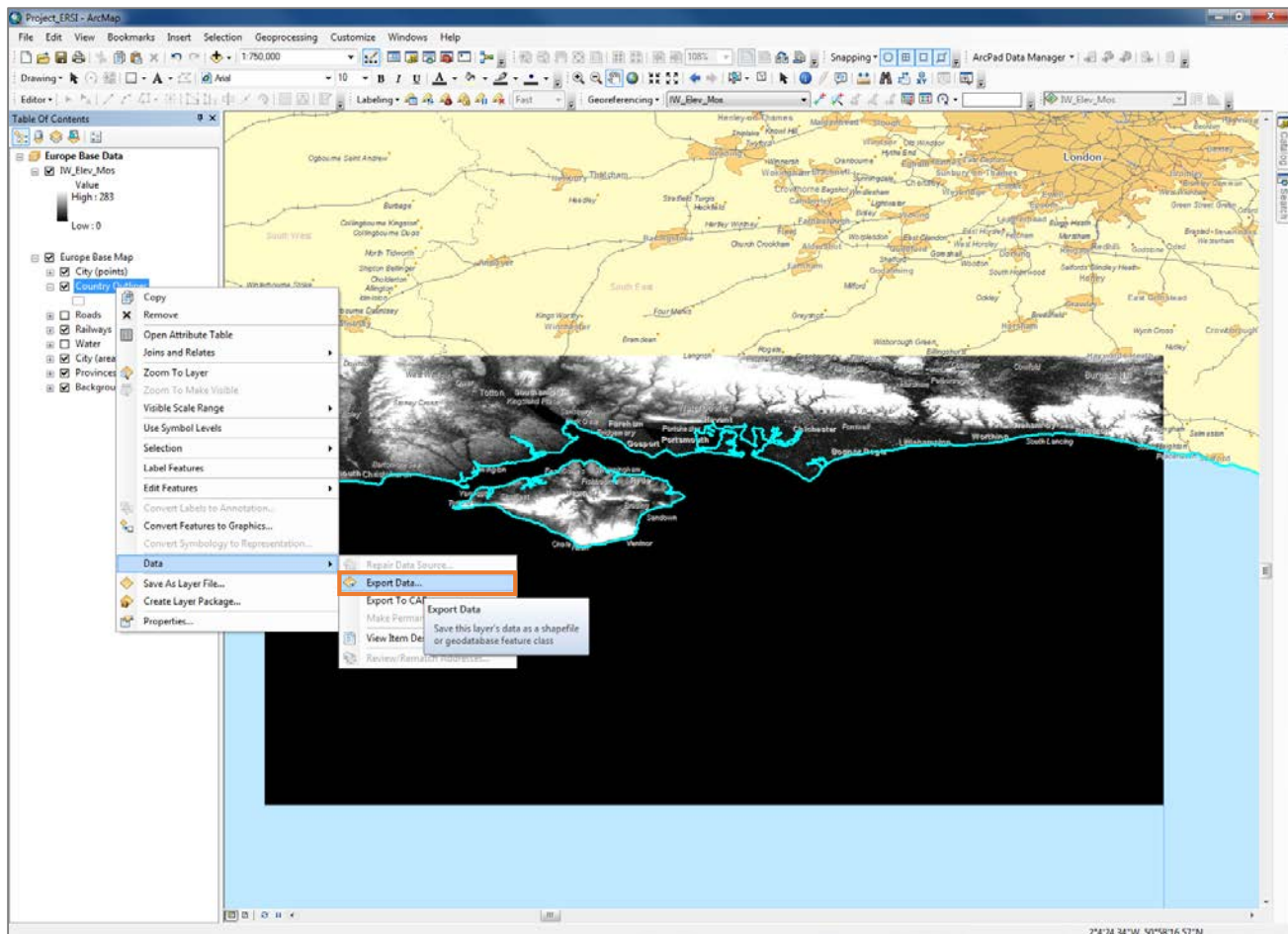


Figure 14: A screenshot in Data View showing the how to open the “Export Data” window in figure 15 to export the UK Outline from the “Country Outlines” file.

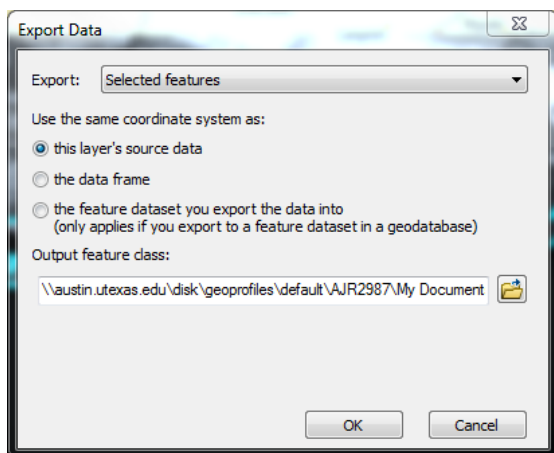


Figure 15: The “Export Data” window. “Export: Selected features” (the United Kingdom outline) was chosen. It could have been exported in the same coordinate system as either “the layer’s source data” or “the data frame” since they were the same but “the layer’s source data” was used. Choosing the “Output feature class” is shown in Figure 16.

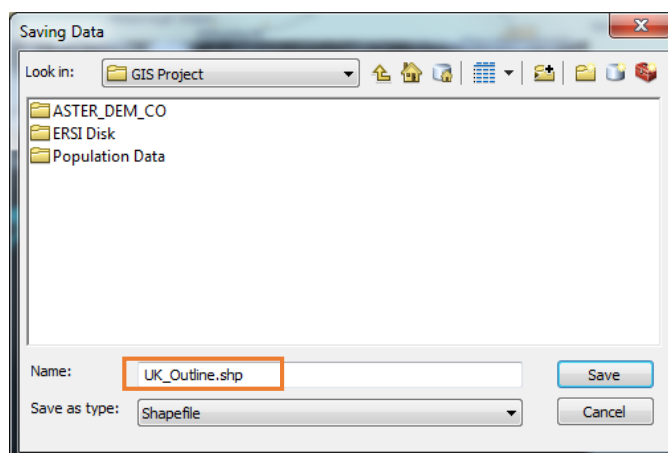


Figure 16: The “Saving Data” window showing the data was saved in the GIS project folder as UK\_Outline.shp. It was saved as a shapefile since it is only needed to define containment.

First the polygon in the “UK\_Outline” layer was selected. This was done by right-clicking on it in the Table of Contents and opening the “Attribute Table” and clicking to the very left hand side of the polygon (Figure 17).

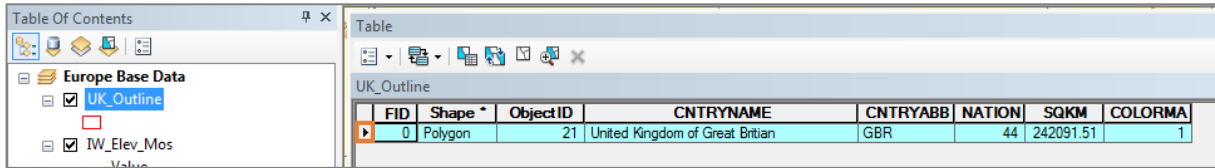


Figure 17: The selected polygon in the Attribute Table. The orange box marks where was clicked to select this polygon.

It is necessary to separate this polygon into its more basic components, including the Isle of Wight outline. This is done via the editing, and advanced editing toolbars. These toolbars were opened via Customize > Toolbars > Advanced Editing and Customize > Toolbars > Editing. Editing was then started by going to the “Editing” drop down in the “Editing” toolbar and selecting “Start Editing” (Figure 18).

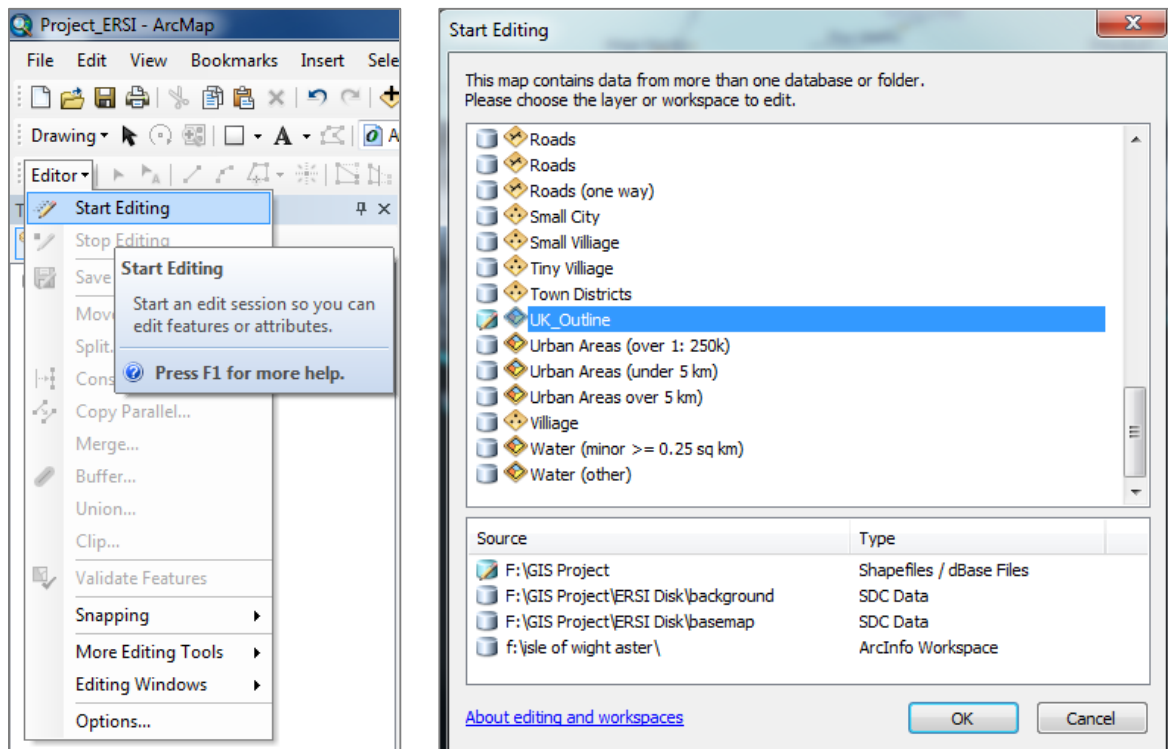


Figure 18: A screenshot showing how to “Start Editing”. Firstly follow the steps illustrated on the left. Then as shown on the right select “UK\_Outline” and press “OK” to start editing that layer.

Once “Start Editing” had been applied to the “UK\_Outline” it was checked that the “UK\_Outline” polygon was selected, if it was not the steps in Figure 17 were followed to select it. Once this was done “Explode Multipart Feature” (🔗) was selected from the “Advanced Editing” toolbar. Then edits were saved by returning to the “Editing” drop-down and selecting “Save Edits” (Figure 19). The Attributes Table for “UK\_Outline” was then

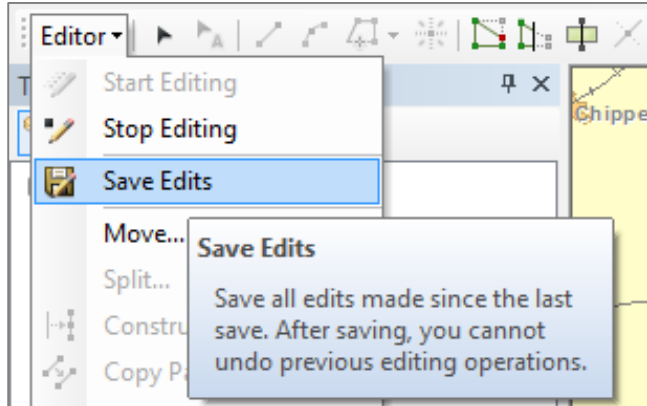


Figure 19: How to “Save Edits”

revisited to check there were now 1518 polygons. The attributes table was then closed “Select Features Tool” (🔍) was selected. It was then used to select the polygon representing the Isle of Wight’s coastline by clicking near the outline of the Isle of White (to make this visible the “UK\_Outline” layer was dragged to the top of the Table of Contents. The result is shown in Figure 20.

The same steps shown in Figures 14, 15 and 16 were then followed to export the Isle of Wight outline as a new shapefile. The resulting layer was saved as “IOW\_Outline”.

When asked “Do you want to add the exported data to the map as a layer?” “Yes” was the response.

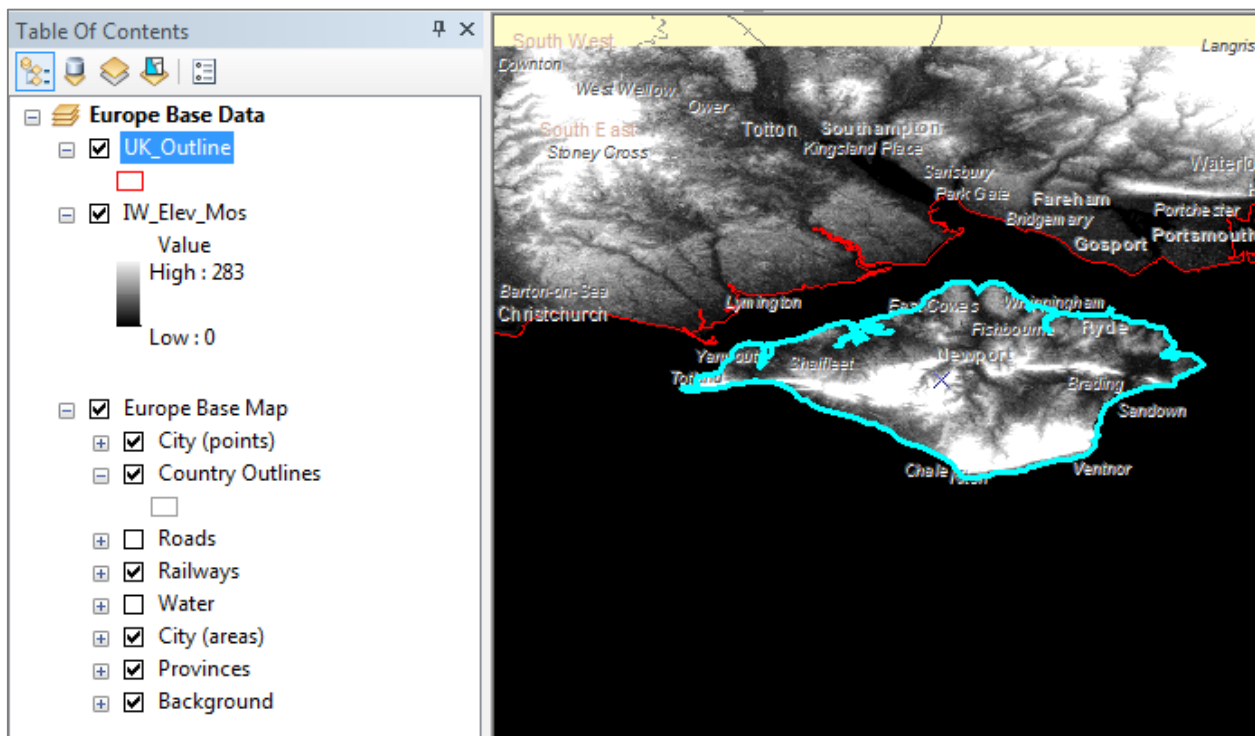


Figure 20: A screenshot showing the result of selecting the Isle of Wight outline in the newly “Exploded” “UK\_Outline” layer.

## Keeping Data Organized

The “Country Outlines” or “UK\_Outline” layers were no longer needed since they were intermediate files to obtain the Isle of Wight Outline shapefile. They were removed by right-clicking on the layer in the Table of Contents and clicking “Remove”.

The “IOW\_Outline” was then renamed by double clicking on the layer in the Table of Contents to open the “Layer Properties” window and selecting the “General Tab” then by editing the text in the “Layer Name” field to “Isle of Wight Coastline”.

At this point a new data frame was opened (Insert > Data Frame) and was named “Isle of Wight Today”. The “Isle of Wight Coastline” Layer was then dragged and dropped from the original data frame into the new data frame (“Isle of Wight Today”) in the Table of Contents as was “Europe Base Map” and “IW\_Elev\_Mos”. The old data frame was removed by right clicking on it in the Table of Contents and pressing “Remove”. The result is shown in Figure 21.

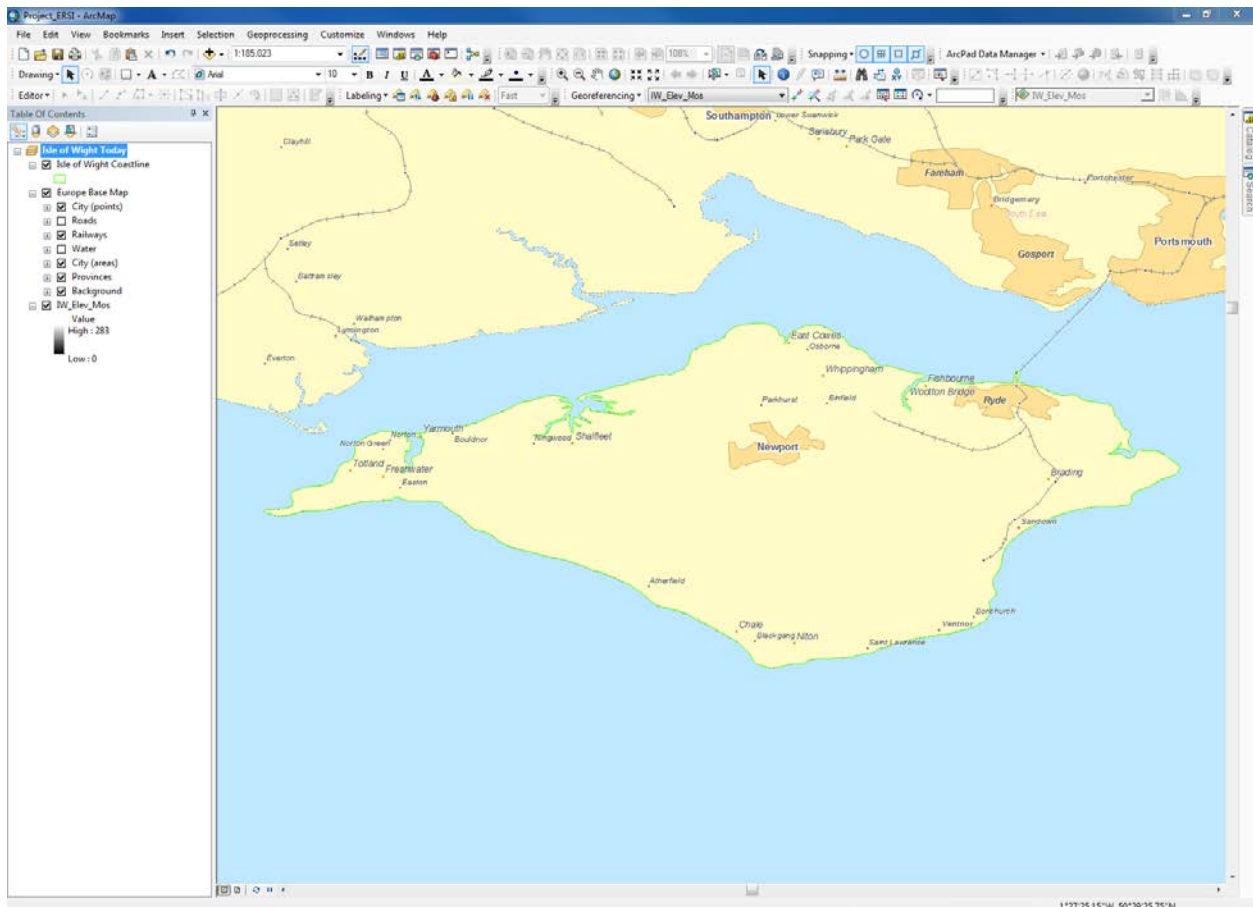



Figure 21: The new Data Frame active containing the outline of the Isle of Wight, the locations of cities and their populations for the whole of Europe and the untrimmed elevation raster. Also showing the old “Europe Base Data” data frame minimized.

## Trimming the Data

The data now needed to be trimmed to the outline. This helps the program run faster during operations since you can remove huge amounts of unrequired data. This will be done via processes called clipping extracting by a mask.

### Trimming the Elevation Raster

Before any tools can be used the “3D Analyst” and “Spatial Analyst” extensions needed to be turned on. This was done via Customize > Extensions and then ticking the boxes accordingly.

Next the “Extract by Mask” tool was applied to the IW\_Elev\_Mosaic (Mosaicked Elevation Rasters). This was found via ArcToolbox (  ) > Spatial Analyst Tools > Extraction > Extract by Mask. The fields were filled out as shown in Figure 22.

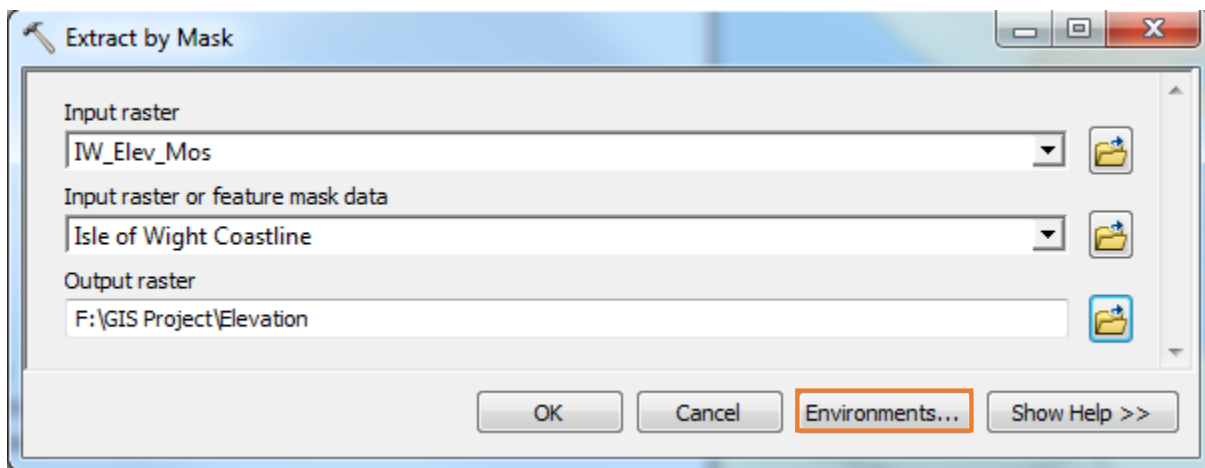


Figure 22: The “Extract by Mask” window. The output was called Elevation and saved to an appropriate location. The orange box marks where to open the “Environment Settings” window in Figure 23.

It was also necessary to change the Environments settings to those shown in Figure 23. Since the unclipped elevation data is no longer needed this is removed from the Table of Contents. The result is shown in Figure 24.

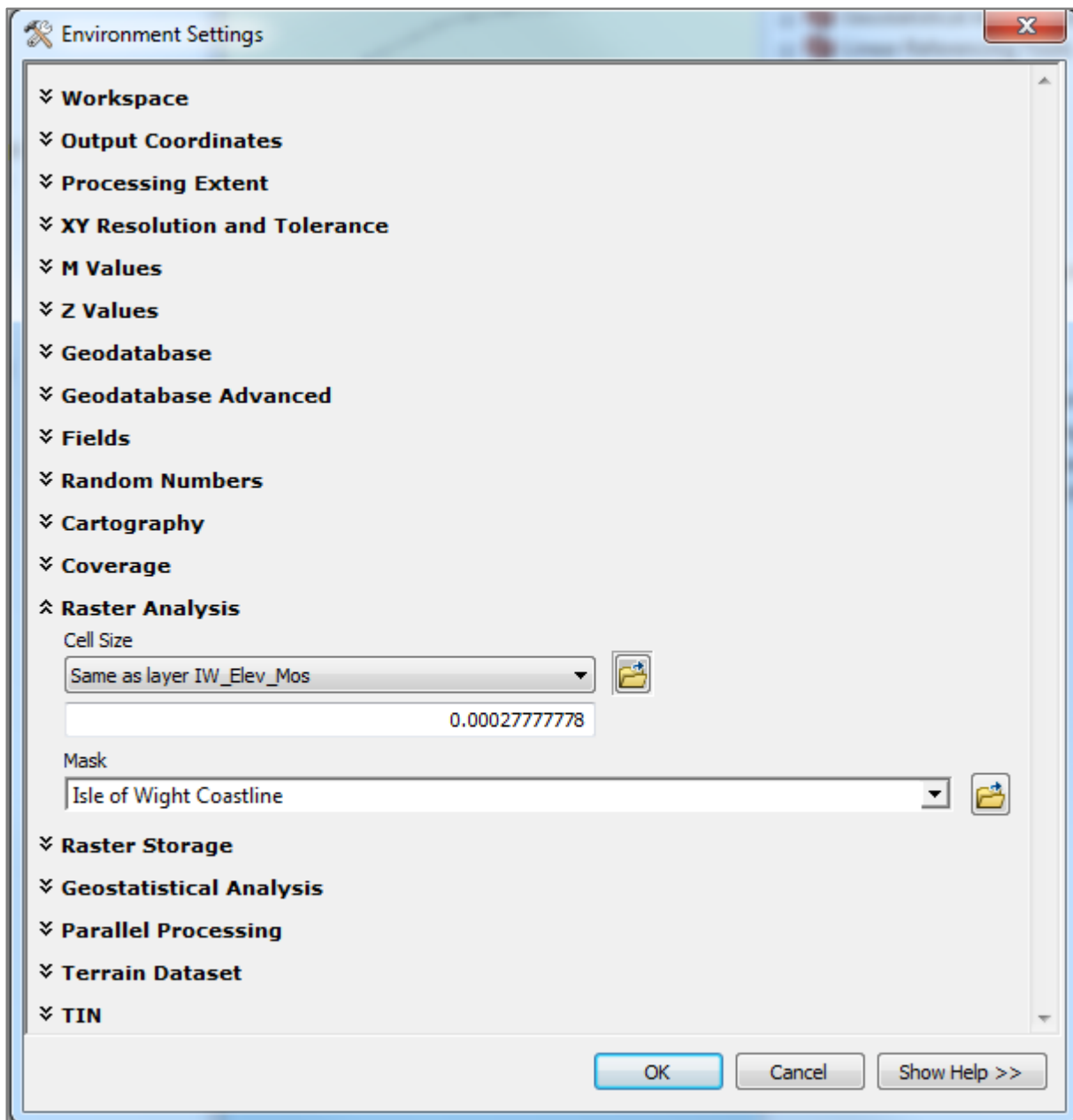


Figure 23: The “Environment Settings” window. The mask was set to Isle of Wight Coastline and the cell size was kept consistent with the input data.

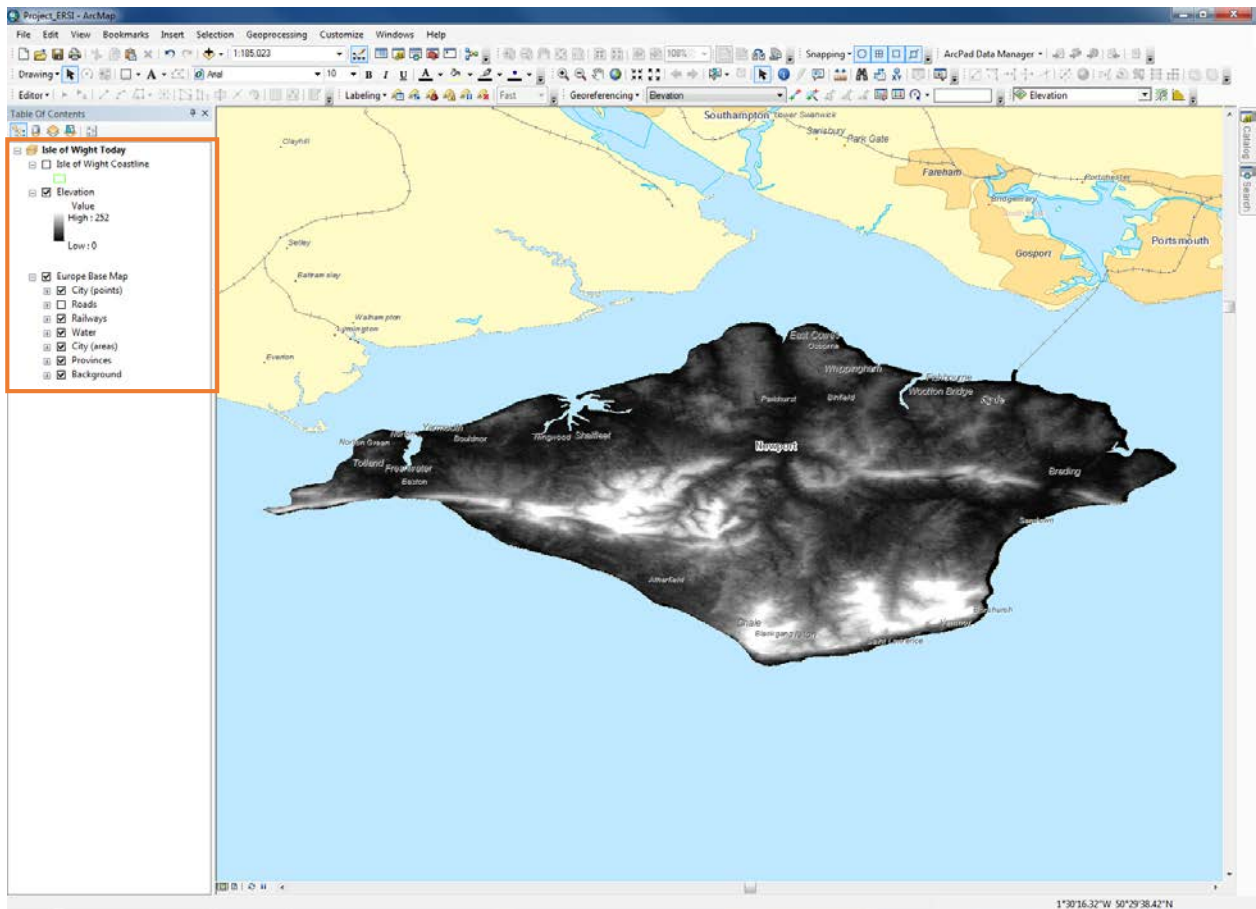


Figure 24: A screenshot showing the result of the “Extract by Mask” tool. Notice the orange box showing how the Table of Contents has lost the now removed “IW\_Elev\_Mos” and gained “Elevation”.



## Trimming the City Data

First the “City Points” and “City Areas” layers were taken from being subsections of “Europe Base Map” and placed independently in the “Isle of Wight Today” data frame, as was the “Background” layer since this will be needed later (See Page 26) (Figure 25). “Europe Base Map” was then minimized since it was not needed.

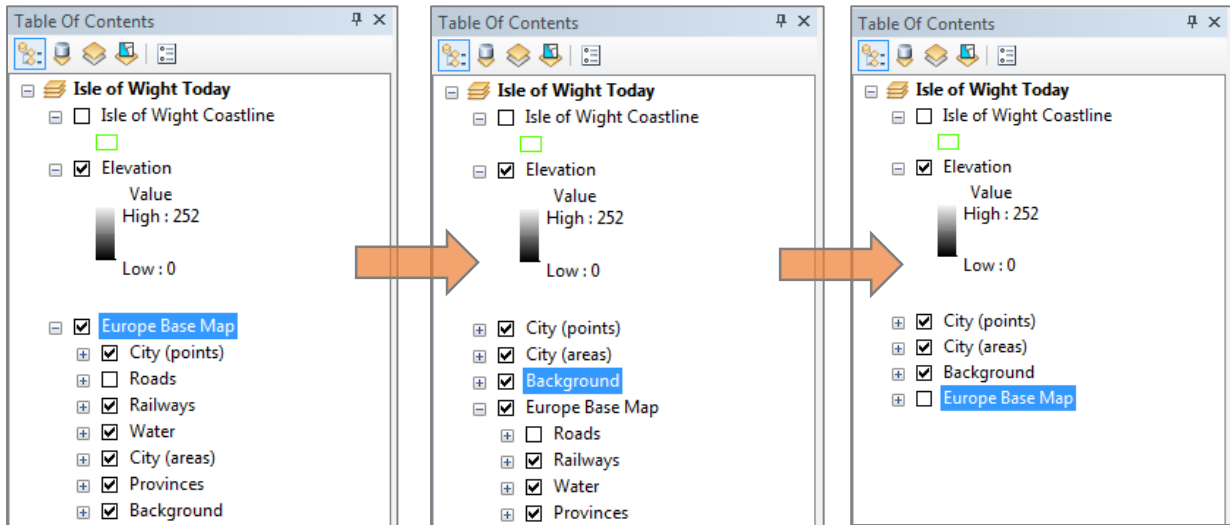


Figure 25: A series of screenshots showing the reorganization of the Table of Contents from Left (Before) to Right (After).

Next the “Clip (Coverage)” tool was used on “City (points)”. This can be found via ArcToolbox (🔧) > Analysis Tools > Extract > Clip. As shown in Figure 26 the two cities coverages are made up of layers. Each of these layers was clipped individually (Figure 27). This process was repeated for each layer in both city coverages.

- City (points)
  - Capital Cities
  - Large City
  - Medium City
  - Small City
  - Villiage
  - Small Villiage
  - Tiny Villiage
  - Railway Stations
  - Town Districts
- City (areas)
  - Urban Areas over 5 km)
  - Urban Areas (under 5 km)
  - Urban Areas (over 1: 250k)

Figure 27: A screenshot of the Table of Contents showing the sublayers within each city Layer.

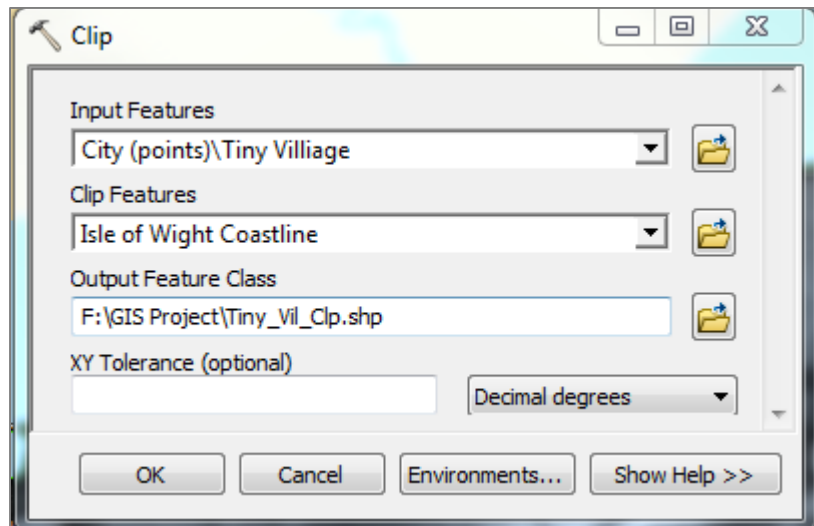


Figure 27: The “Clip” window. Showing how the “Tiny Villiage” layer was clipped with respect to the “Isle of Wight Coastline”

During this process some of the layers being clipped returned an output containing zero values. This meant that there were no cities of that type within the outline. As a result that layer is not of interest for this project and can be removed (i.e. “Small City”, “Medium City”, “Large City”, “Capital City”, “Urban Areas (under 5 km)” and “Urban Areas over 5 km”). The newly generated layers were then moved below their parent layers in the Table of Contents, they were then renamed as were the coverages and the old layers removed. (Figures 28).

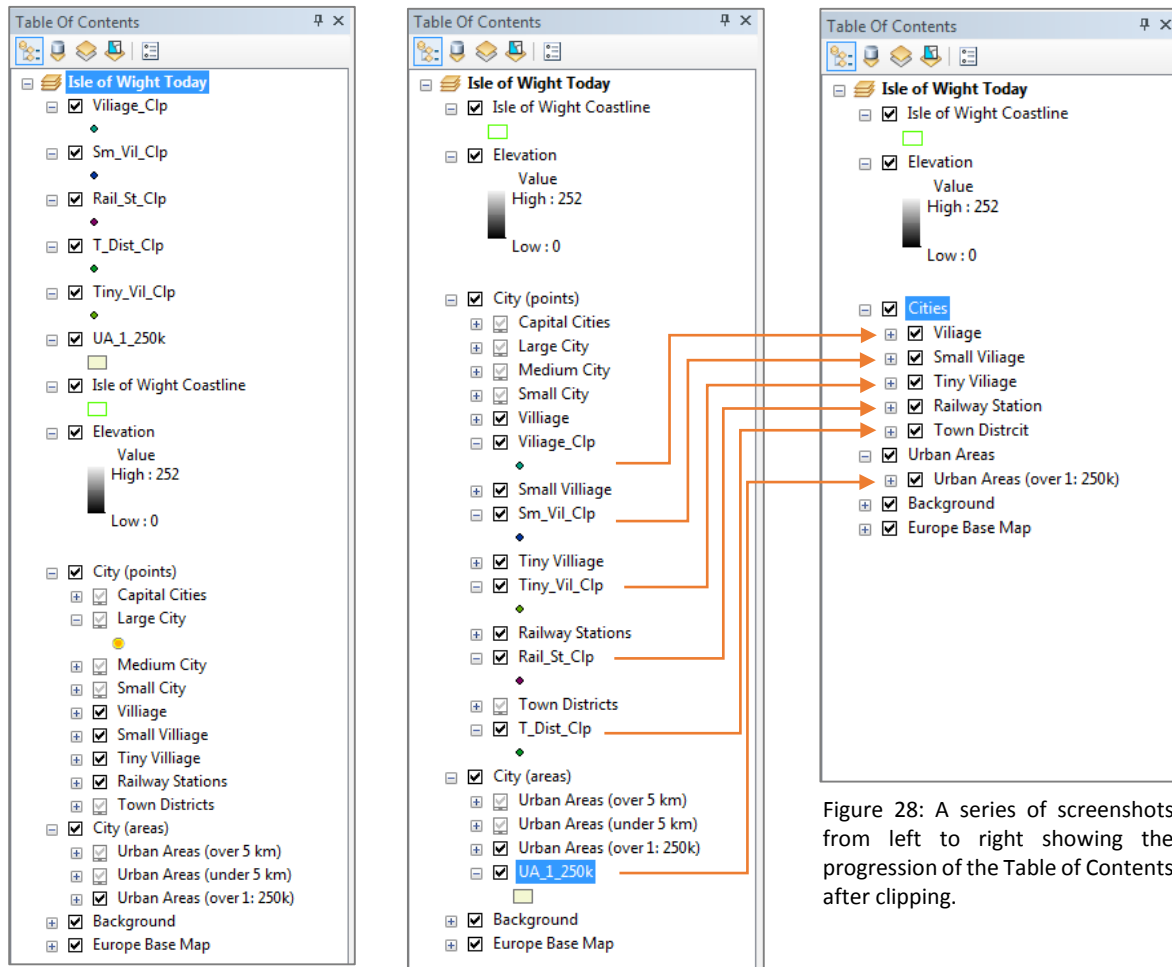


Figure 28: A series of screenshots from left to right showing the progression of the Table of Contents after clipping.

N.B. All the files that have been removed still exist in well-organized folders. They are simply no longer being displayed in the Table of Contents.

## Presentation

Before any more processing of the data was performed it was useful to resymbolize the data. Since this had to be done eventually and it makes the data more pleasant to work with.

First the “Europe Base Map” data can be turned off (  →  ) since it is no longer of interest. This was also done with the “Background” coverage. The “Ocean Background” layer was then moved from within the “Background” coverage to be an independent layer in the Table of Contents and renamed “Sea” (Figure 29).

At this point the “Railway Station” layer was removed from the TOC since it contained no population data and was therefore irrelevant.

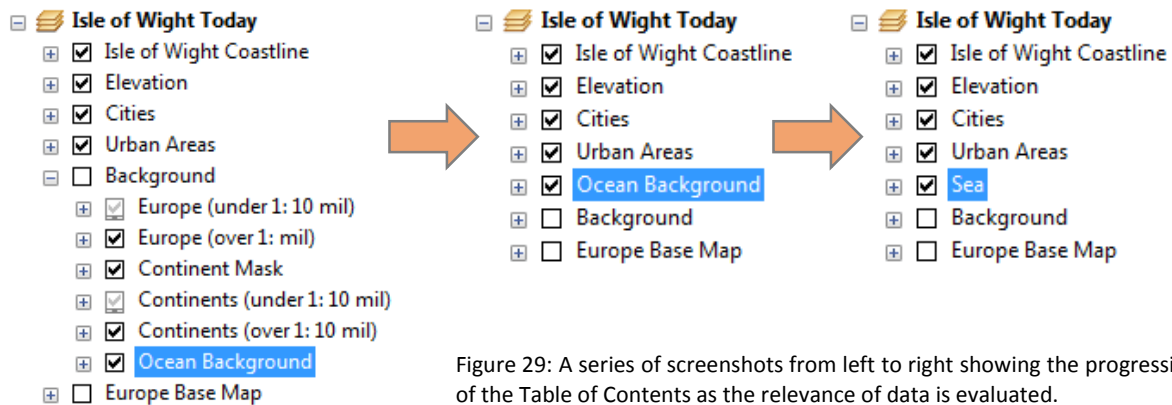


Figure 29: A series of screenshots from left to right showing the progression of the Table of Contents as the relevance of data is evaluated.

## Symbology

Symbology of layers was changed by double clicking on a layer in the TOC and navigating to the “Symbology” tab. From here the Point, Line and Polygon features (The “Cities”, “Urban Areas”, “Sea” and “Isle of Wight Coastline” layers) can be changed via the symbol section (Figure 30). The results are shown in Figure 31. A reference scale was then set for the “Isle of Wight Today” data frame (1:150,000).

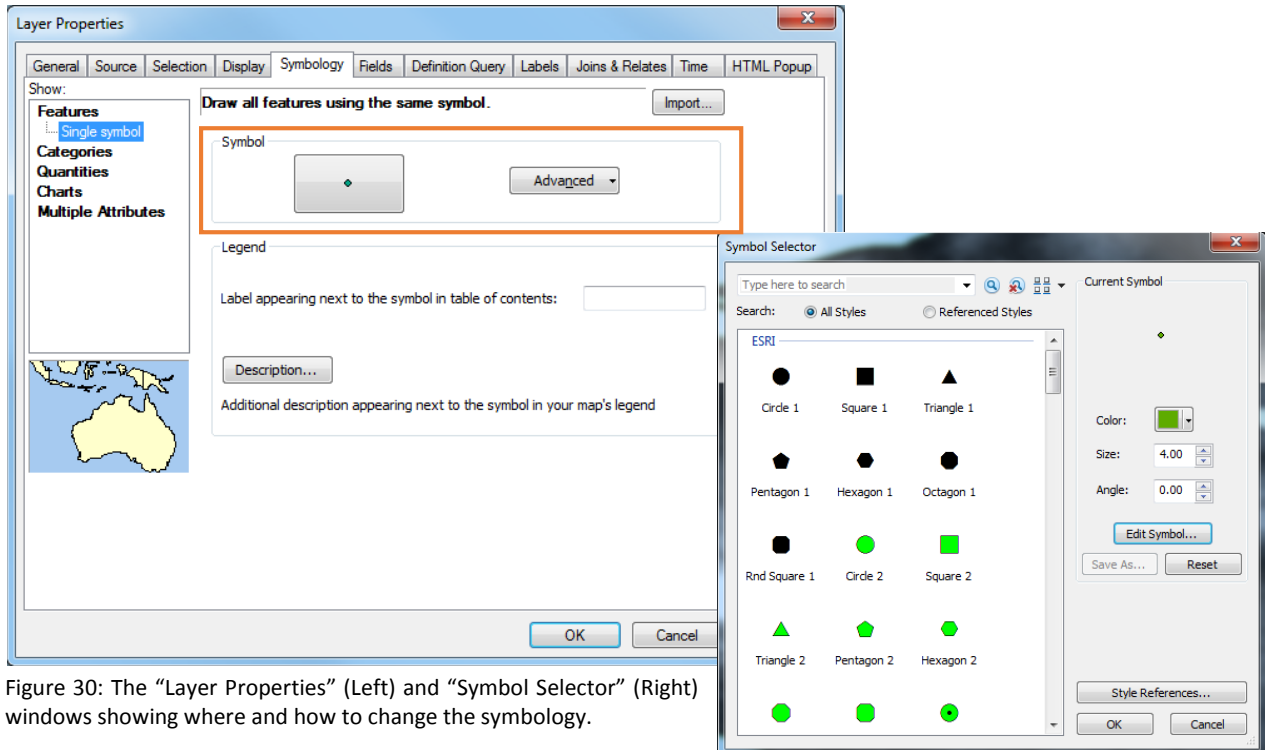


Figure 30: The “Layer Properties” (Left) and “Symbol Selector” (Right) windows showing where and how to change the symbology.

It was then necessary to change the symbology of the “Elevation” layer. Then as in the previous step the layers were double clicked and the “Symbology” tab selected. From here to make the elevation an attractive and informative background for the landmass it was resymbolized to the “Elevation #2” Color Ramp (Figure 32).

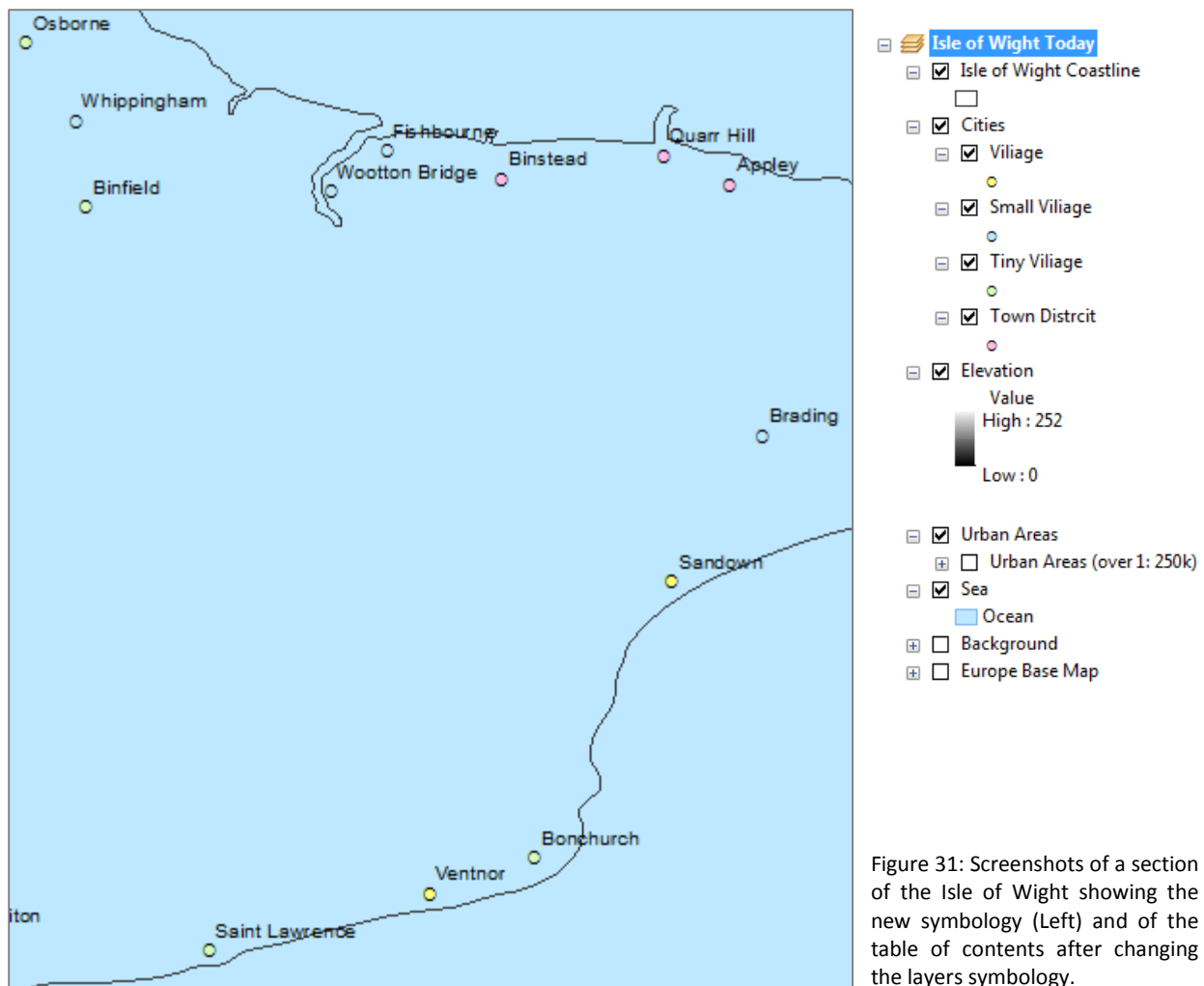


Figure 31: Screenshots of a section of the Isle of Wight showing the new symbology (Left) and of the table of contents after changing the layers symbology.

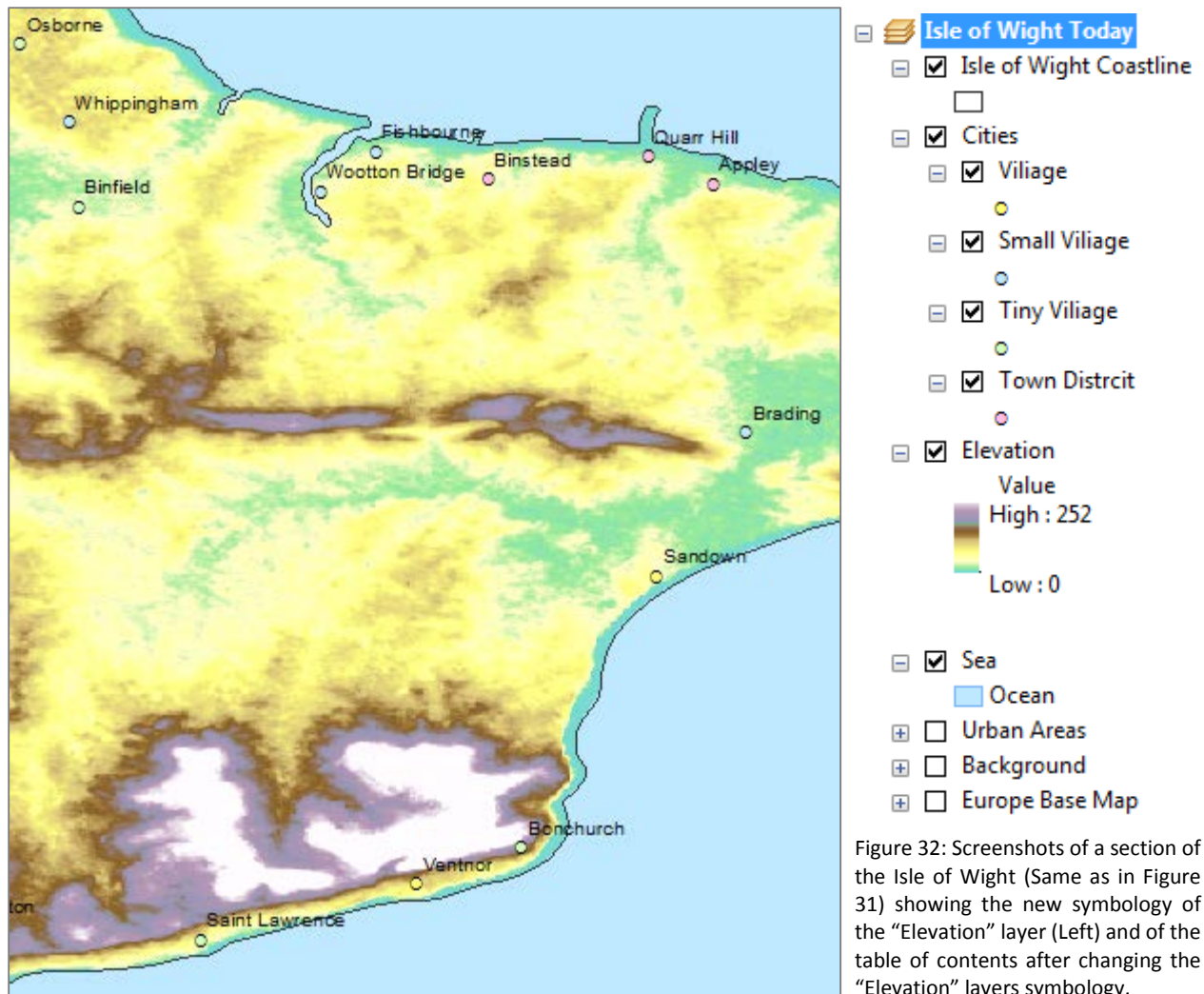


Figure 32: Screenshots of a section of the Isle of Wight (Same as in Figure 31) showing the new symbology of the “Elevation” layer (Left) and of the table of contents after changing the “Elevation” layers symbology.

The “Urban Areas” Layer was later resymbolised to be 50% Transparent (Adjusted via the “Display” tab after double clicking the layer) and the outline and fill colors changed (Figure 33)

### Labels

Although the labels were not ideal at this stage it was decided to leave them as they were; anticipating that later the labels would need to be changed again. In adjusting them they would need to be changed to “Annotations”, when the city layers were later split in to those above/below sea level these annotations would not be linked to these groups.

## Creating a Hillshade

The final step in improving data presentation was to create a hillshade using the “Elevation” layer. This was done via the “Hillshade” tool (again here it was important to check the relevant extensions were active as in “Trimming the Data” – “Trimming the Elevation Raster”). The “Hillshade” tool was located by ArcToolbox > Spatial Analyst Tools > Surface > Hillshade. The parameters entered to do this are shown in Figure 33.

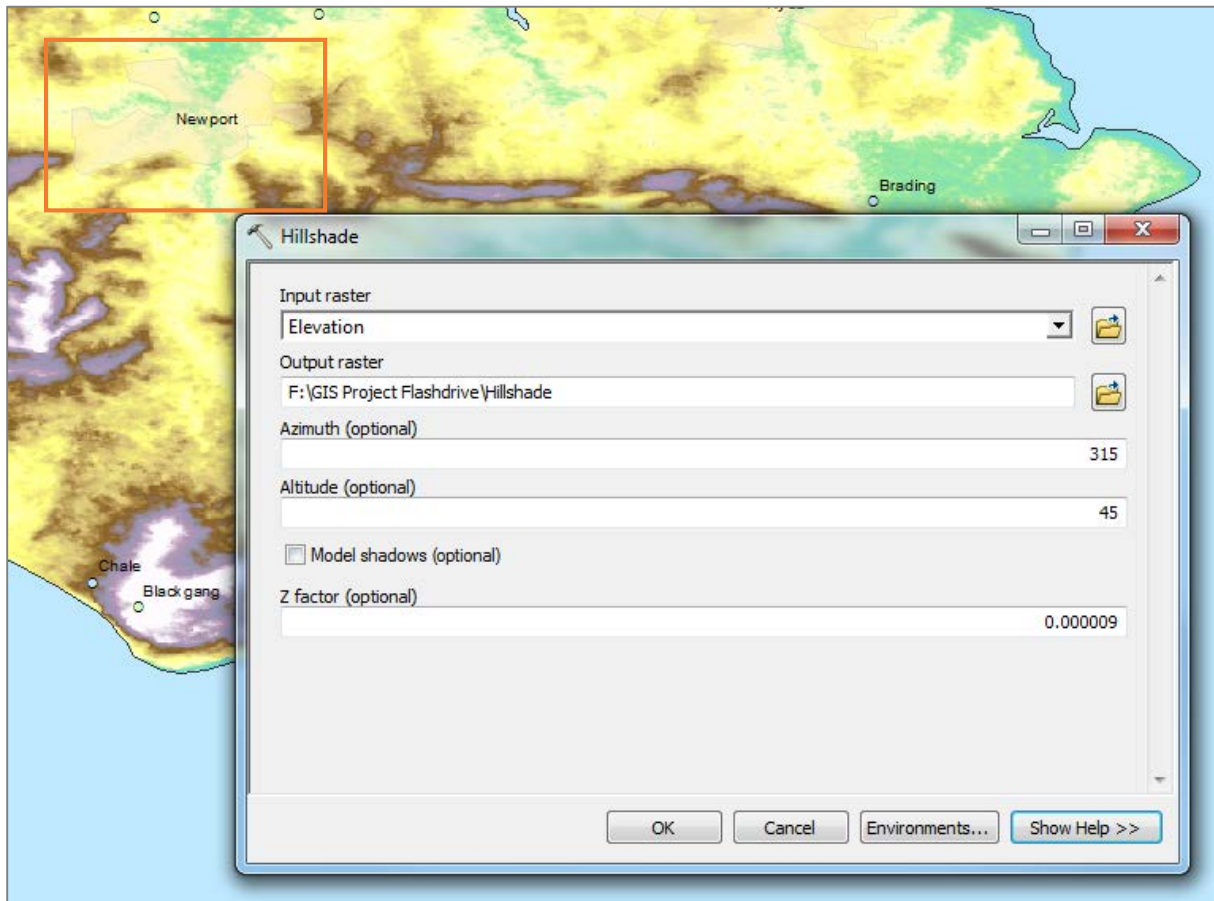


Figure 33: The new “Urban Areas” symbology (orange box) and the “Hillshade” window and the parameters entered to create the hillshade. Z factor 0.000009 was used to convert from the X-Y units (Decimal Degrees) to the Z units (Meters).

This “Hillshade” layer was then moved above “Elevation” in the Table of Contents. It’s symbology was then changed as before, but with Color Ramp to “Pink to YellowGreen Diverging, Bright” and transparency to 50%. The result is shown in Figure 34.

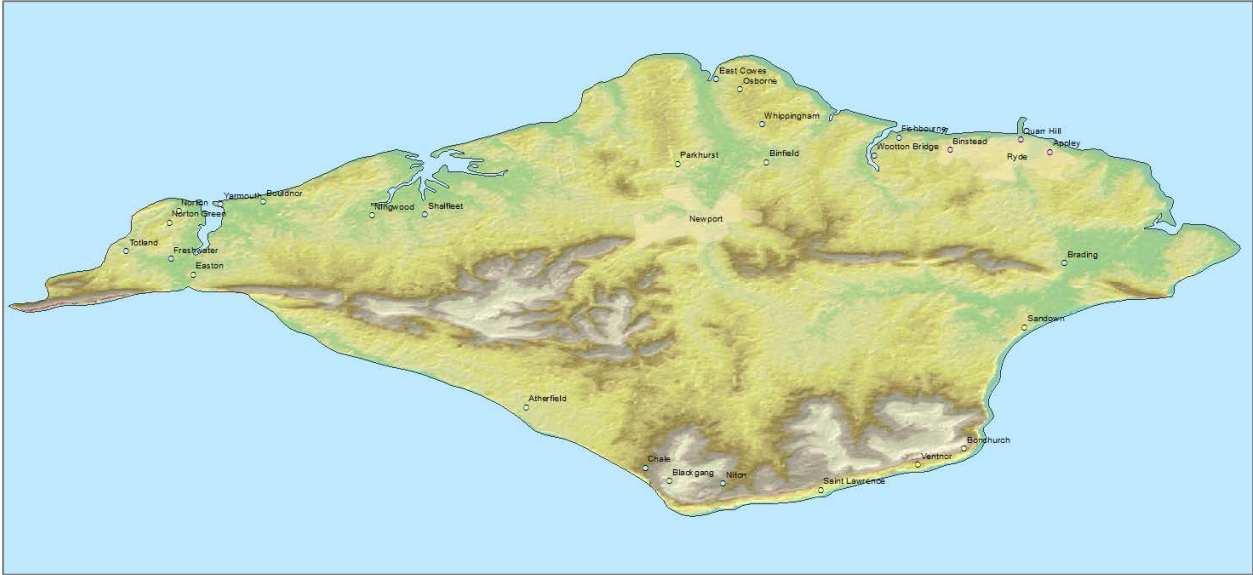


Figure 34: A screenshot showing the new appearance after the hillshade has been applied.



## Combining the City Layers

Before adjusting sea level and calculating population displacement it is important to place all the Urban Points (those under the Cities section) into one layer. This was done using the “Append” tool (ArcToolbox > Data Management Tools > General > Append). As shown in Figure 35. The old layers were then removed and the new appended dataset renamed “Places” The result is shown in Figure 36.

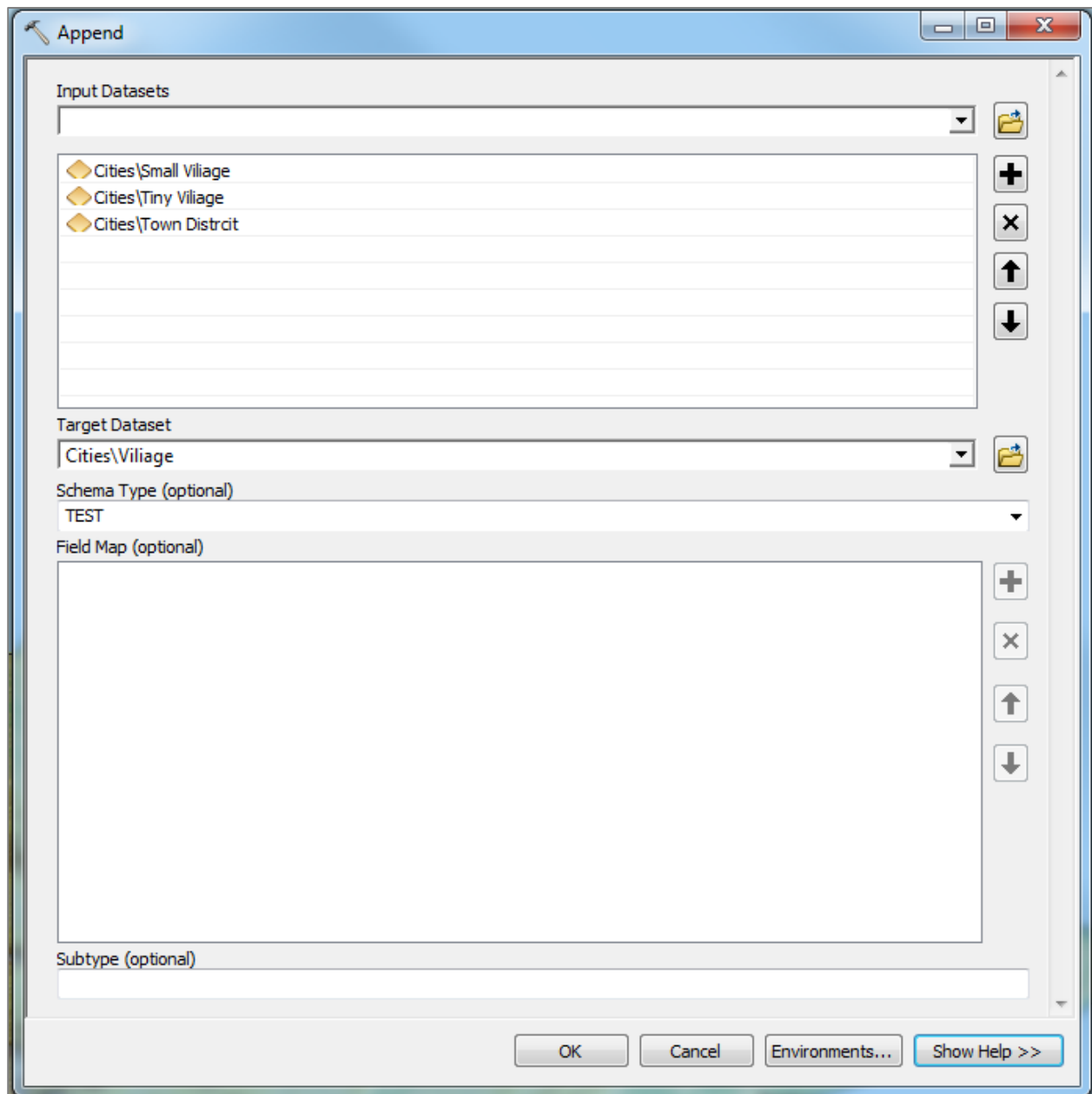


Figure 35: The “Append” window which was used to append the “Small Village”, “Tiny Village” and “Town District” datasets to the “Village” layer.



Table Of Contents

- Isle of Wight Today
  - Isle of Wight Coastline
  - Places
    - TYPE
    - Small Village
    - Tiny Village
    - Town District
    - Village
  - Urban Areas
    - Urban Areas (over 1: 250k)
  - Hillshade
    - Value
    - High : 247
    - Low : 0
  - Elevation
    - Value
    - High : 252
    - Low : 0
  - Sea
  - Background
  - Europe Base Map

Figure 36: Screenshots of a section of the Isle of Wight (Left) and of the table of contents after changing the “Appending” the urban point layers together.

# Adjusting City Data Tables

## A Note on Project Scaling


When calculating the total populations under sea after adjusting the sea level each city needs a discrete population. For the purpose of this exercise this will be performed by manually creating a new field in the “Places” Attribute Table as outline below. To perform this on a larger scale you would enter the Attribute Table right click on the new field (AVG\_POP) and select field calculator. This could then be used to automatically fill the new field as the median value of the existing POP\_CLASS field.

## Creating a New Field

Each place has a corresponding population range (Figure 37).

FID	Shape	TYPE	LEVEL	NAME	CODE	POP_CLASS	DATUM	CENTRYNAME	PROV1NAM	CONUR	DUP_NAM	CAPITAL	LABEL_FLAG
0	Point	Town District	1	Quarr Hill		< 1,000	44	United Kingdom of Great Britian	England	Ryde	N	N	0
1	Point	Town District	2	Appley		< 1,000	44	United Kingdom of Great Britian	England	Ryde	N	N	0
2	Point	Town District	1	Binstead		< 1,000	44	United Kingdom of Great Britian	England	Ryde	N	N	0
3	Point	Village	2	Ventnor		5,001 - 20,000	44	United Kingdom of Great Britian	England		N	N	0
4	Point	Village	2	Sandown		5,001 - 20,000	44	United Kingdom of Great Britian	England		Y	N	0
5	Point	Small Village	2	Shaffleet		1,001 - 5,000	44	United Kingdom of Great Britian	England		N	N	0
6	Point	Small Village	2	Yamouth		1,001 - 5,000	44	United Kingdom of Great Britian	England		N	N	0
7	Point	Small Village	1	East Cowes		1,001 - 5,000	44	United Kingdom of Great Britian	England		N	N	0
8	Point	Small Village	1	Wootton Brid		1,001 - 5,000	44	United Kingdom of Great Britian	England		N	N	0
9	Point	Small Village	1	Whippingha		1,001 - 5,000	44	United Kingdom of Great Britian	England		N	N	0
10	Point	Small Village	1	Fishbourne		1,001 - 5,000	44	United Kingdom of Great Britian	England		N	N	0
11	Point	Small Village	2	Freshwater		1,001 - 5,000	44	United Kingdom of Great Britian	England		N	N	0
12	Point	Small Village	2	Brading		1,001 - 5,000	44	United Kingdom of Great Britian	England		N	N	0
13	Point	Small Village	2	Niton		1,001 - 5,000	44	United Kingdom of Great Britian	England		N	N	0
14	Point	Small Village	2	Chale		1,001 - 5,000	44	United Kingdom of Great Britian	England		N	N	0
15	Point	Small Village	2	Totland		1,001 - 5,000	44	United Kingdom of Great Britian	England		Y	N	0
16	Point	Tiny Village	2	Ningwood		< 1,000	44	United Kingdom of Great Britian	England		N	N	0
17	Point	Tiny Village	2	Norton Green		< 1,000	44	United Kingdom of Great Britian	England		N	N	0
18	Point	Tiny Village	2	Norton		< 1,000	44	United Kingdom of Great Britian	England		Y	N	0
19	Point	Tiny Village	2	Bouldnor		< 1,000	44	United Kingdom of Great Britian	England		N	N	0
20	Point	Tiny Village	1	Parkhurst		< 1,000	44	United Kingdom of Great Britian	England		N	N	0
21	Point	Tiny Village	1	Osborne		< 1,000	44	United Kingdom of Great Britian	England		N	N	0
22	Point	Tiny Village	1	Birfield		< 1,000	44	United Kingdom of Great Britian	England		N	N	0
23	Point	Tiny Village	2	Bonchurch		< 1,000	44	United Kingdom of Great Britian	England		N	N	0
24	Point	Tiny Village	2	Blackgang		< 1,000	44	United Kingdom of Great Britian	England		N	N	0
25	Point	Tiny Village	2	Easton		< 1,000	44	United Kingdom of Great Britian	England		N	N	0
26	Point	Tiny Village	2	Saint Lawren		< 1,000	44	United Kingdom of Great Britian	England		Y	N	0
27	Point	Tiny Village	2	Barfield		> 1,000	44	United Kingdom of Great Britian	England		N	N	0

Figure 37: The Attribute Table for the “Places” layer before adding the new field. Highlighted in orange is the “POP\_CLASS” field.

To allow for later data analysis it was necessary to create a new field containing the median of the population range. This was done by clicking “Table Options” (  ) from within the “Table” window (Figure 37) and selecting “Add Field..”. From the “Add Field..” window a new “Long Integer” (Short integer limits the field to 4 figures this was not sufficient) field was created called “AVG\_POP” (Figure 38).

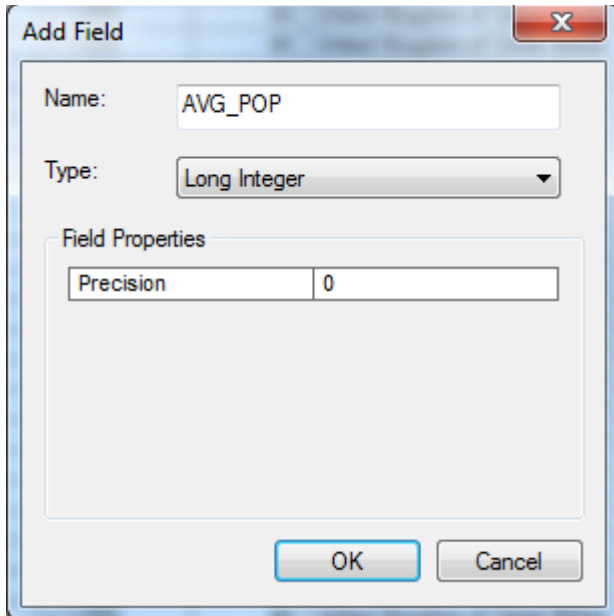


Figure 38: The “Add Field” window, showing the creation of the AVG\_POP field for the “Places” layer.

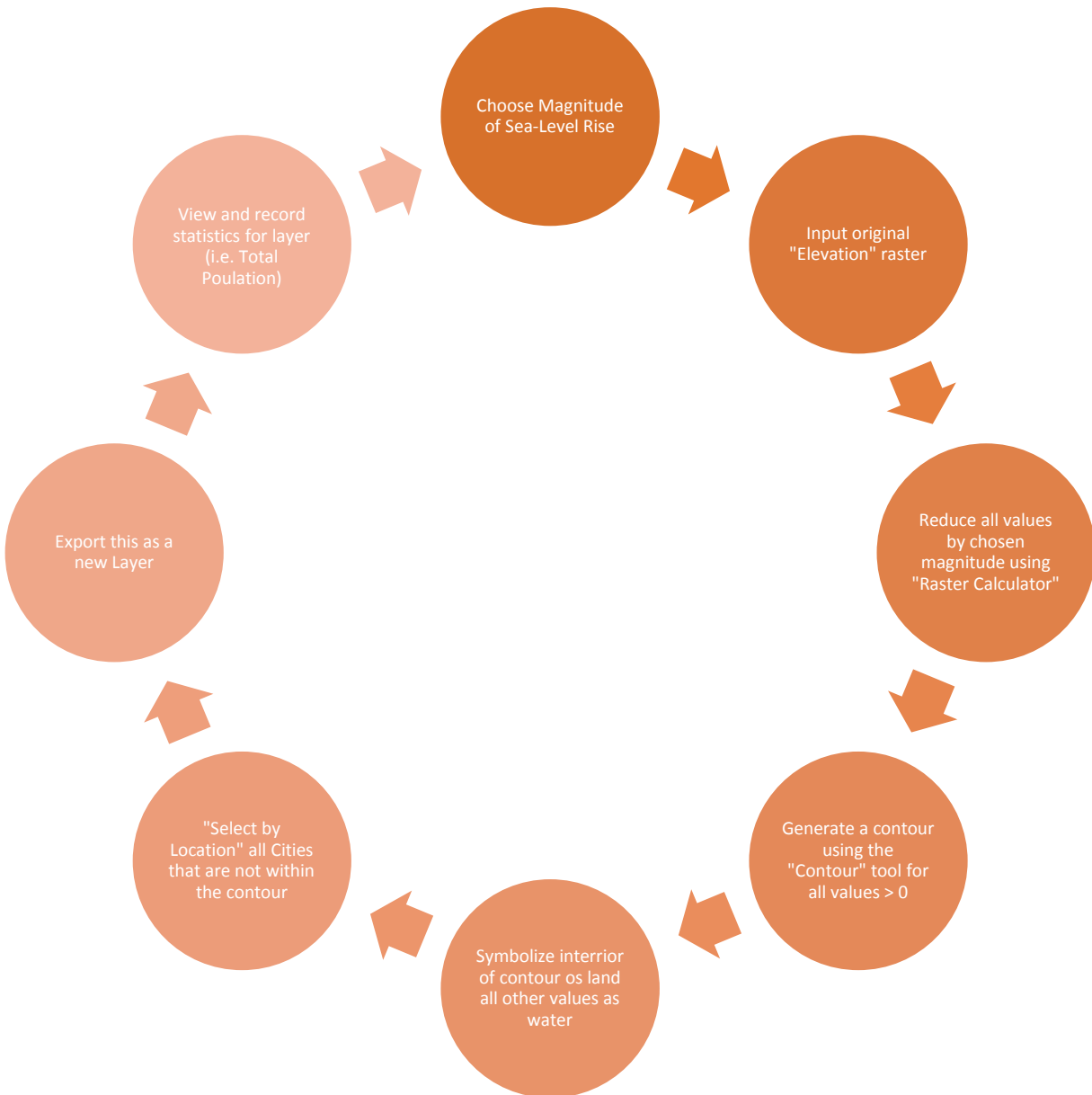
Next editing of the “Places” layer was initiated. (Editor Toolbar > Start Editing and select the “Places” layer). Then within the Attribute Table the “AVG\_POP” field values were manually changed to the median values of the “POP\_CLASS” field (Figure 39). Edits saved and Stopped (Editor Toolbar > Dropdown > Save Edits/Stop Edits).

FID	Shape	TYPE	LEVEL	NAME	CODE	POP_CLASS	NATION	CENTRYNAME	PROV1NAM	CONUR	DUP_NAM	CAPITAL	LABEL_FLAG	AVG_PO
0	Point	Town District	1	Quarr Hill		< 1,000	44	United Kingdom of Great Britain	England	Ryde	N	N	0	500
1	Point	Town District	2	Appley		< 1,000	44	United Kingdom of Great Britain	England	Ryde	N	N	0	500
2	Point	Town District	1	Binstead		< 1,000	44	United Kingdom of Great Britain	England	Ryde	N	N	0	500
3	Point	Village	2	Ventnor		5,001 - 20,000	44	United Kingdom of Great Britain	England		N	N	0	12500
4	Point	Village	2	Sandown		5,001 - 20,000	44	United Kingdom of Great Britain	England		Y	N	0	12500
5	Point	Small Village	2	Shalfleet		1,001 - 5,000	44	United Kingdom of Great Britain	England		N	N	0	3000
6	Point	Small Village	2	Yamouth		1,001 - 5,000	44	United Kingdom of Great Britain	England		N	N	0	3000
7	Point	Small Village	1	East Cowes		1,001 - 5,000	44	United Kingdom of Great Britain	England		N	N	0	3000
8	Point	Small Village	1	Wootton Bld		1,001 - 5,000	44	United Kingdom of Great Britain	England		N	N	0	3000
9	Point	Small Village	1	Whippingha		1,001 - 5,000	44	United Kingdom of Great Britain	England		N	N	0	3000
10	Point	Small Village	1	Fishbourne		1,001 - 5,000	44	United Kingdom of Great Britain	England		N	N	0	3000
11	Point	Small Village	2	Freshwater		1,001 - 5,000	44	United Kingdom of Great Britain	England		N	N	0	3000
12	Point	Small Village	2	Brading		1,001 - 5,000	44	United Kingdom of Great Britain	England		N	N	0	3000
13	Point	Small Village	2	Niton		1,001 - 5,000	44	United Kingdom of Great Britain	England		N	N	0	3000
14	Point	Small Village	2	Chale		1,001 - 5,000	44	United Kingdom of Great Britain	England		N	N	0	3000
15	Point	Small Village	2	Totland		1,001 - 5,000	44	United Kingdom of Great Britain	England		Y	N	0	3000
16	Point	Tiny Village	2	Ningwood		< 1,000	44	United Kingdom of Great Britain	England		N	N	0	500
17	Point	Tiny Village	2	Norton Green		< 1,000	44	United Kingdom of Great Britain	England		N	N	0	500
18	Point	Tiny Village	2	Norton		< 1,000	44	United Kingdom of Great Britain	England		Y	N	0	500
19	Point	Tiny Village	2	Bouldnor		< 1,000	44	United Kingdom of Great Britain	England		N	N	0	500
20	Point	Tiny Village	1	Parkhurst		< 1,000	44	United Kingdom of Great Britain	England		N	N	0	500
21	Point	Tiny Village	1	Osborne		< 1,000	44	United Kingdom of Great Britain	England		N	N	0	500
22	Point	Tiny Village	1	Birfield		< 1,000	44	United Kingdom of Great Britain	England		N	N	0	500
23	Point	Tiny Village	2	Bonchurch		< 1,000	44	United Kingdom of Great Britain	England		N	N	0	500
24	Point	Tiny Village	2	Blackgang		< 1,000	44	United Kingdom of Great Britain	England		N	N	0	500
25	Point	Tiny Village	2	Easton		< 1,000	44	United Kingdom of Great Britain	England		N	N	0	500
26	Point	Tiny Village	2	Saint Lawren		< 1,000	44	United Kingdom of Great Britain	England		Y	N	0	500
27	Point	Tiny Village	2	Atherfield		< 1,000	44	United Kingdom of Great Britain	England		N	N	0	500

Figure 39: The “Places” Attribute Table after the new field had been created and filled (orange box).

## METHOD

General Method:



For this project a series of figures and accompanying statistics were produced for various changes in sea level. Outlined in this section is the method for producing one for a 15 increase, it is worth noting this can be followed near exactly for the other values.

## MAP CREATION

### Increasing Sea Level

For each sea level change a new data frame was created (Insert > Data Frame) and named X<sub>m</sub> where X is the rise in sea level to be calculated. All the files from the “Isle of Wight Today” were then copied across and the “Isle of Wight Today” data frame was minimized for convenience.

This was done via the “Raster Calculator” tool (ArcToolbox > Spatial Analyst Tools > Map Algebra > Raster Calculator). The tool was used to reduce all values of the “Elevation” raster, effectively raising sea level by 15 meters (Figure 40).

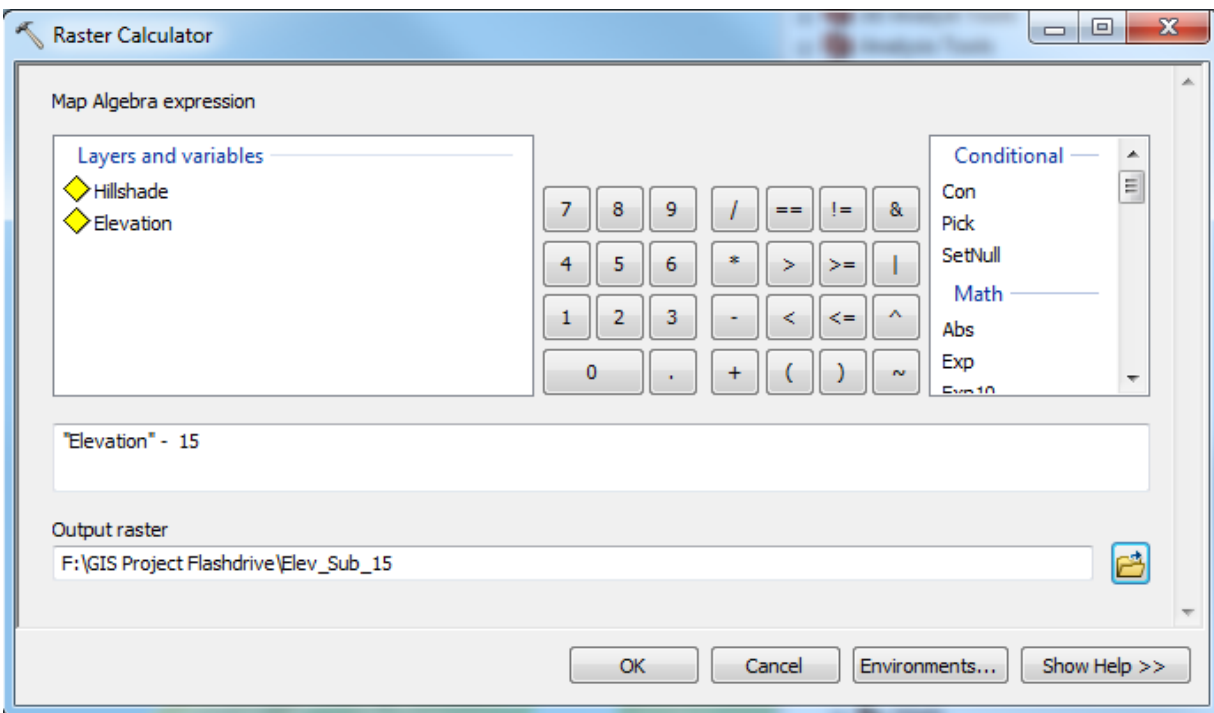


Figure 40: The “Raster Calculator” window showing how it is used to generate a new elevation raster in which sea level has risen 15m. This new file was saved as Elev\_Sub\_15 (For each increment the Elev\_Sub\_X format was conserved)

Having created this new raster it was necessary to represent all values now below zero as sea. To do this the “Raster Calculator” was again used. This time a conditional statement was input (Figure 41) which created a new binary raster with all values greater than zero (land) able to be symbolized separately from those equal to or less than zero (the sea).

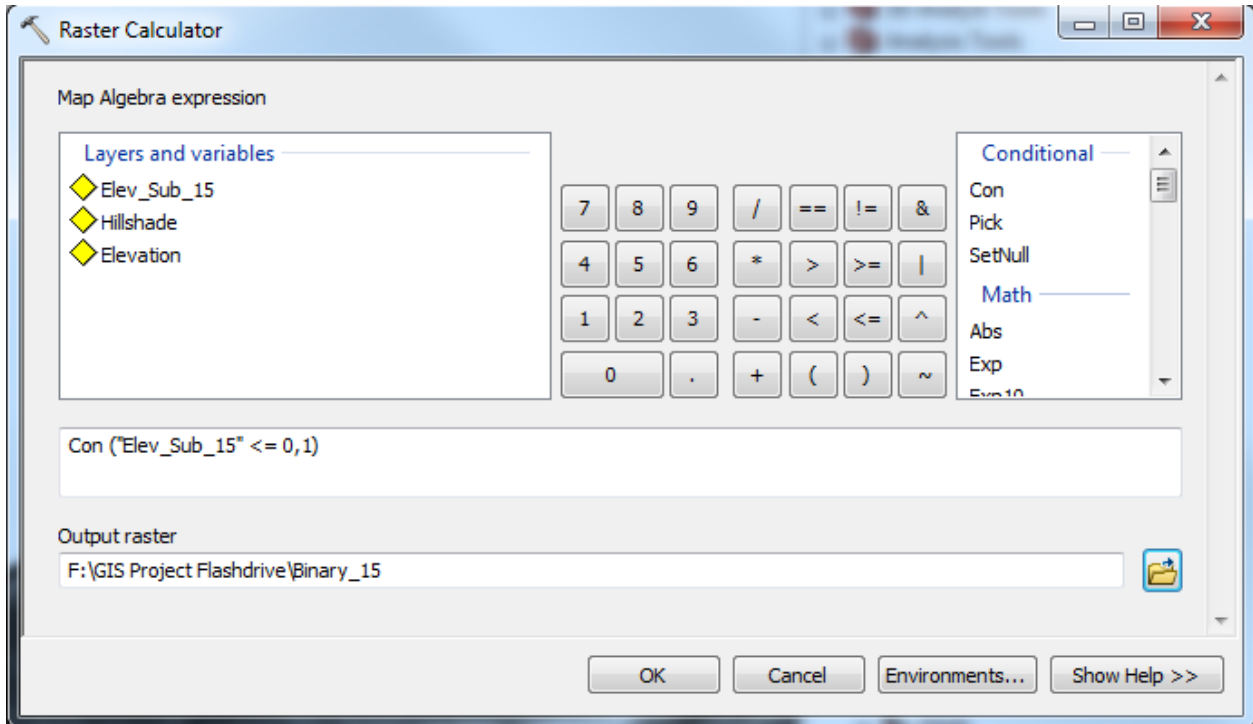


Figure 41: The “Raster Calculator” window showing how it is used to generate a new binary raster in which any cells corresponding to values of less than or equal to zero in the “Elev\_Sub\_15” raster will be assigned the value, 1 (Sea) and all other cells assigned the value, 0 (Land). For each increment the Binary\_X format was conserved.

## Aesthetics

The 15m data frame then had “Elevation”, “Hillshade”, “Background” and “Europe Base Map” removed. A new hillshade (Hillshade\_15) was generated as outlined earlier (Data Preparation – Presentation – Creating a Hillshade p. 30-31). Both “Hillshade\_15” and “Elev\_Sub\_15” were then resymbolized as before (Data Preparation – Presentation – Creating a Hillshade/Symbology p. 26-31). Binary\_15 was then resymbolized such that the new 1 values are represented by the same blue as “Sea”. These new rasters were renamed appropriately and the Table of Contents reorganized (Figure 42). The resulting Table of Contents and Map are visible in Figure 43.

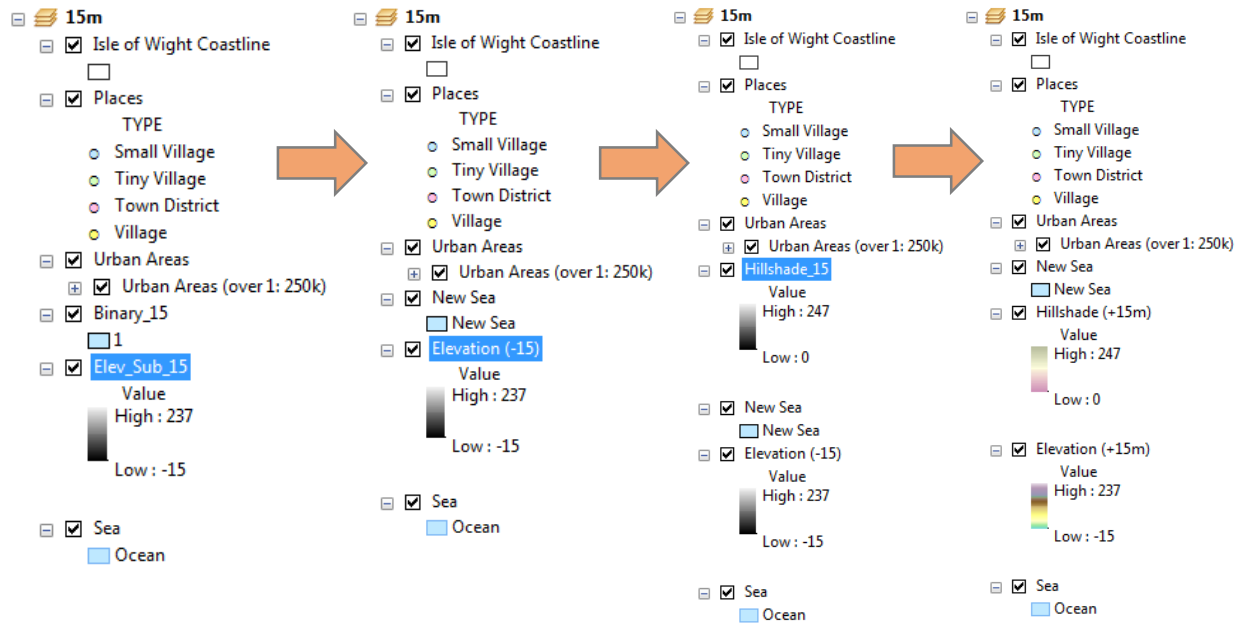


Figure 42: The evolution of the Table of Contents for the 15m rise data frame.

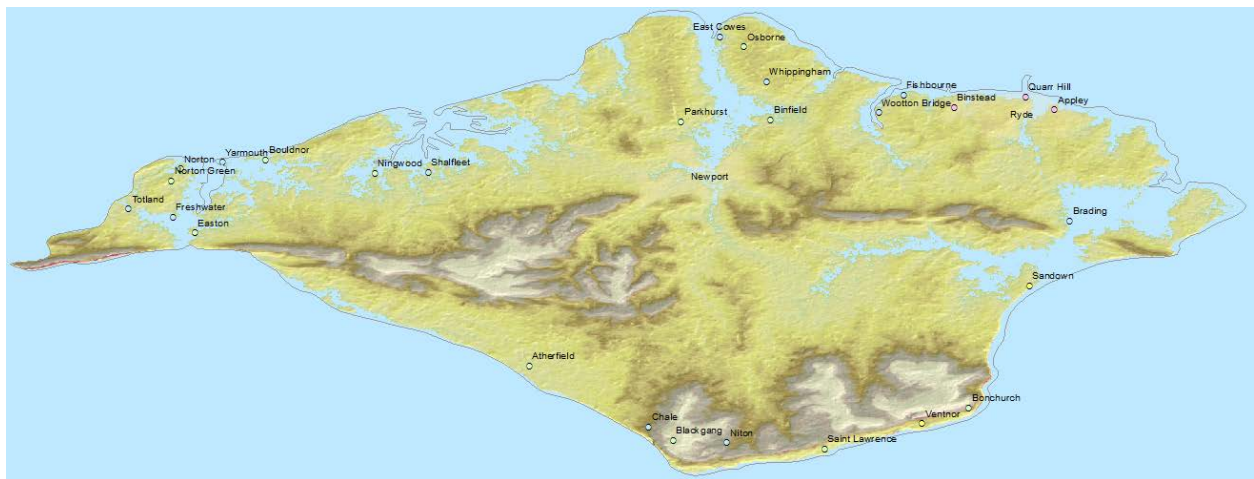


Figure 43: How the map looked after raising sea level 15m.



## Generating Statistics

First it was necessary to separate the “Places” that were now below or at sea level from those that were not (Figure 44)



Figure 44: The method for separating places above and below sea level.

## Creating a Contour

The “Contour” tool was used (ArcToolbox > Spatial Analyst Tools > Surface > Contour) to generate a contour at elevation zero (Figure 45).

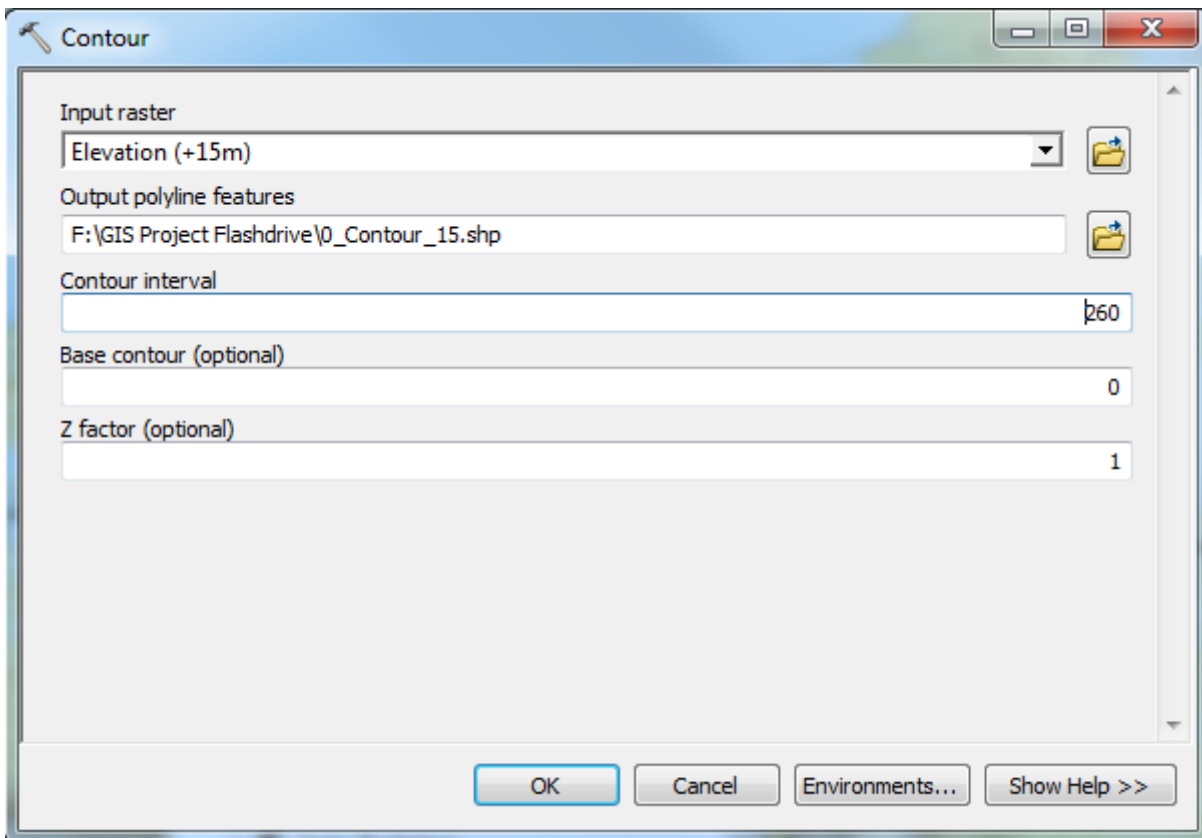


Figure 45: The “Contour” window. The base contour was chosen as 0 and an interval of greater than the range of the data. This was so that only the “Base contour” will be generated.

## Correcting for Misalignment

### The problem

It became clear at this point there was a problem with this method. The contour generated did not form a complete loop. This was because when the elevation data was trimmed to the Isle of Wight outline it trimmed some of the data that the elevation raster recorded was above sea level. As a result, along some of the cliffs where there were horizontal misalignments/accuracy issues between the outline and elevation raster the value at the edge of the raster is positive to a large extent. As a result of this even after subtracting 15m from the raster there are still regions on its edge that have a positive value. Due to this and containment analysis as is needed for the population calculation is impossible.

### The solution

To solve this problem all steps were repeated after generating a new outline. This outline was generated by trimming the raster to a polygon as explained below and then creating a zero elevation contour as explained above. As a result this outline by definition was perfectly aligned with the Elevation files coast. *From this point onwards all images and maps are generated using this outline.*

### Generating the Trimming Polygon

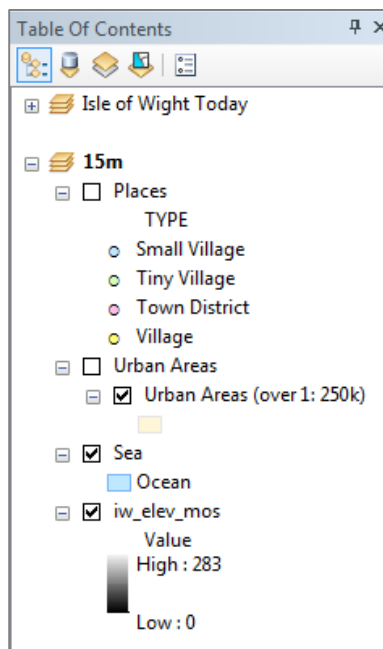




Figure 46: The new files table of contents. Notice that old obsolete files have been removed and the "iw\_elev\_mos" has been added.

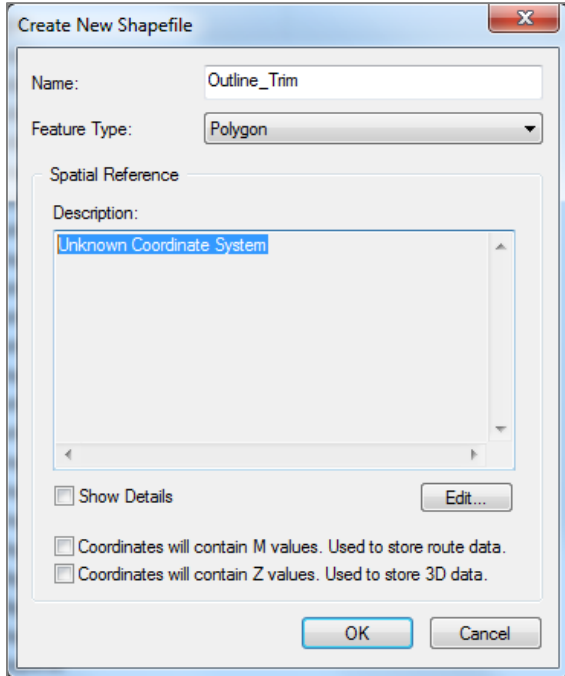
A new ArcMap file was started. The data was reloaded as shown in Figure 46. The "iw\_elev\_mos" file was added.

To trim this raster it was necessary to create a polygon that only encompassed positive values from the Isle of Wight but included all such positive values. This was done visually.

First ArcCatalogue was opened and File > New > Shapefile was used. The Shapefile was named "Outline\_Trim" and was created for the "Polygon" feature type (Figure 47).

This file was then added to the ArcMap data frame using the add data button (  ).

Editing was then started (As outline previously) on the new shapefile. "Create Features" (  ) was selected. Then from the "Create Features" window "Polygon" was selected (Figure 48). Points were then carefully manually picked such that all positive points on the Isle of Wight were included but no other positive points were (Figure 48). "Finish Sketch" was then selected (Right Click > Finish Sketch) (Figure 48).



This shapefile was then used to trim the “iw\_elev\_mos” raster as outlined previously (Data Preparation > Trimming the Data > Trimming the Elevation Data”). The only difference that the file it was trimmed to was not the “Isle of Wight Coastline” file but rather the new “Outline\_Trim” polygon. From here all previously procedures involving the outline or outline derived files were repeated.

Figure 47: The “Create New Shapefile” window used to create the new shapefile “Outline\_Trim”.

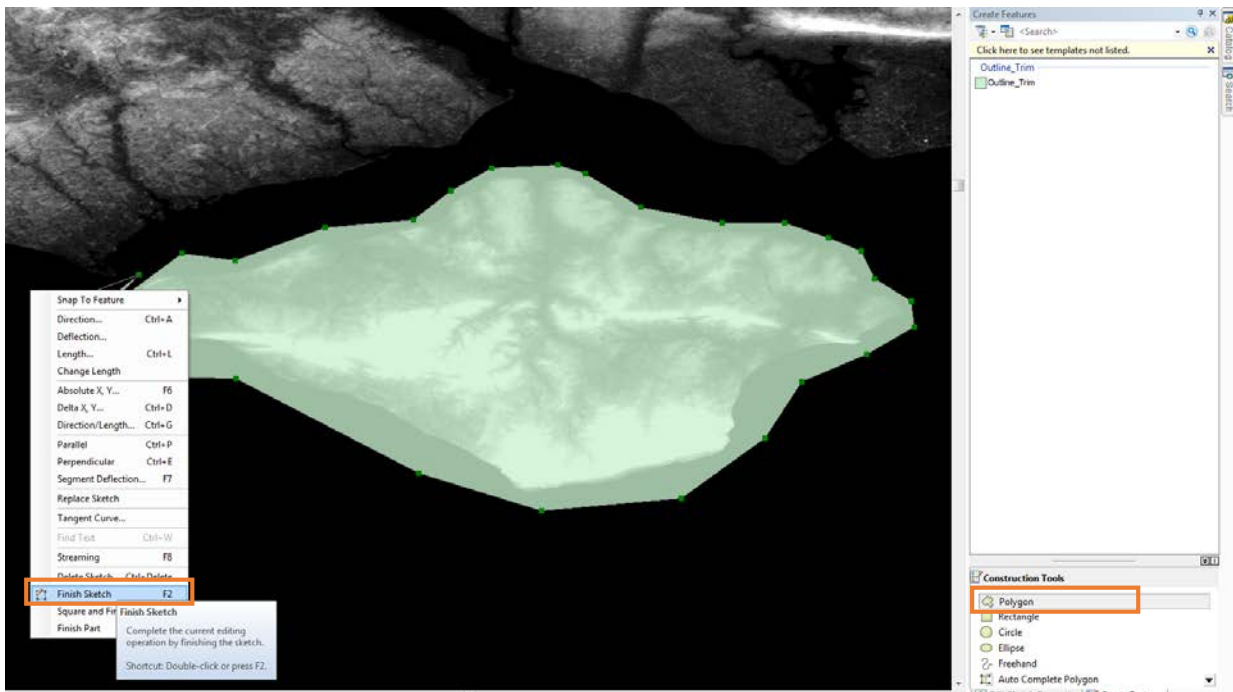
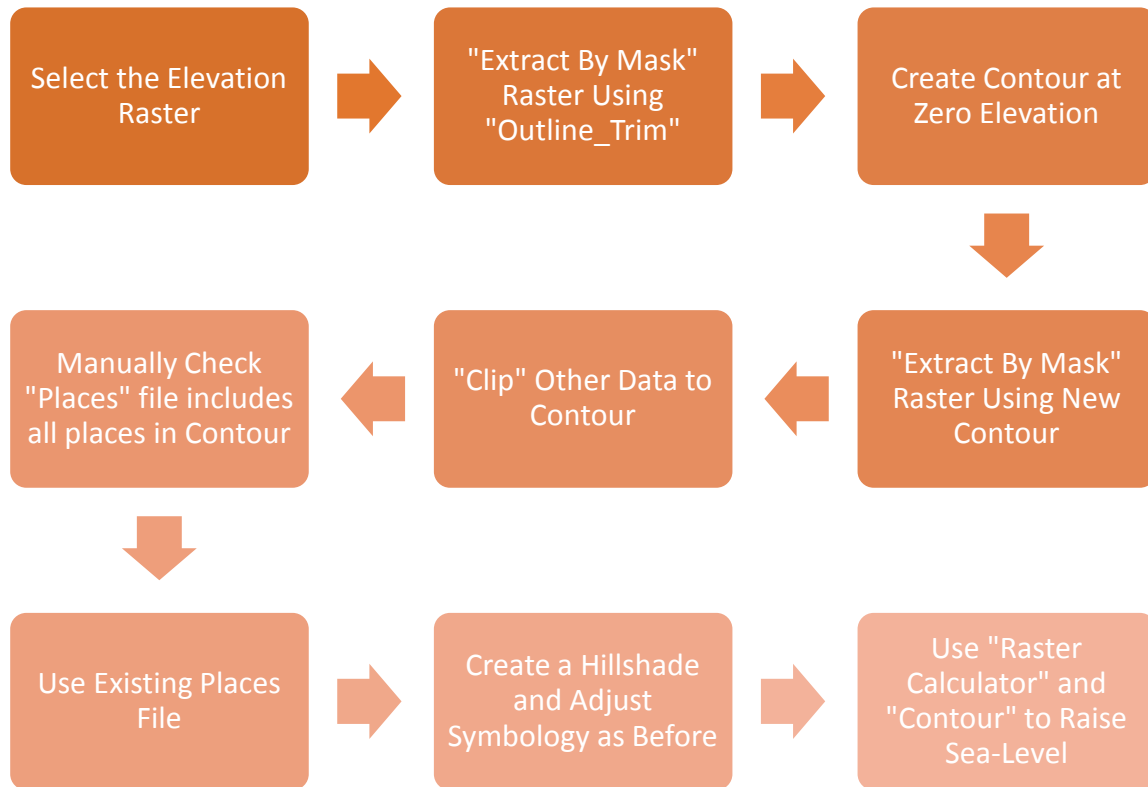


Figure 48: The creation of the “Outline\_Trim” polygon. “Create Features > Polygon” and “Finish Sketch” are both shown in orange boxes.

Steps:



Below are two figures showing the results before and after a 15m rise in sea level (Figure 49).

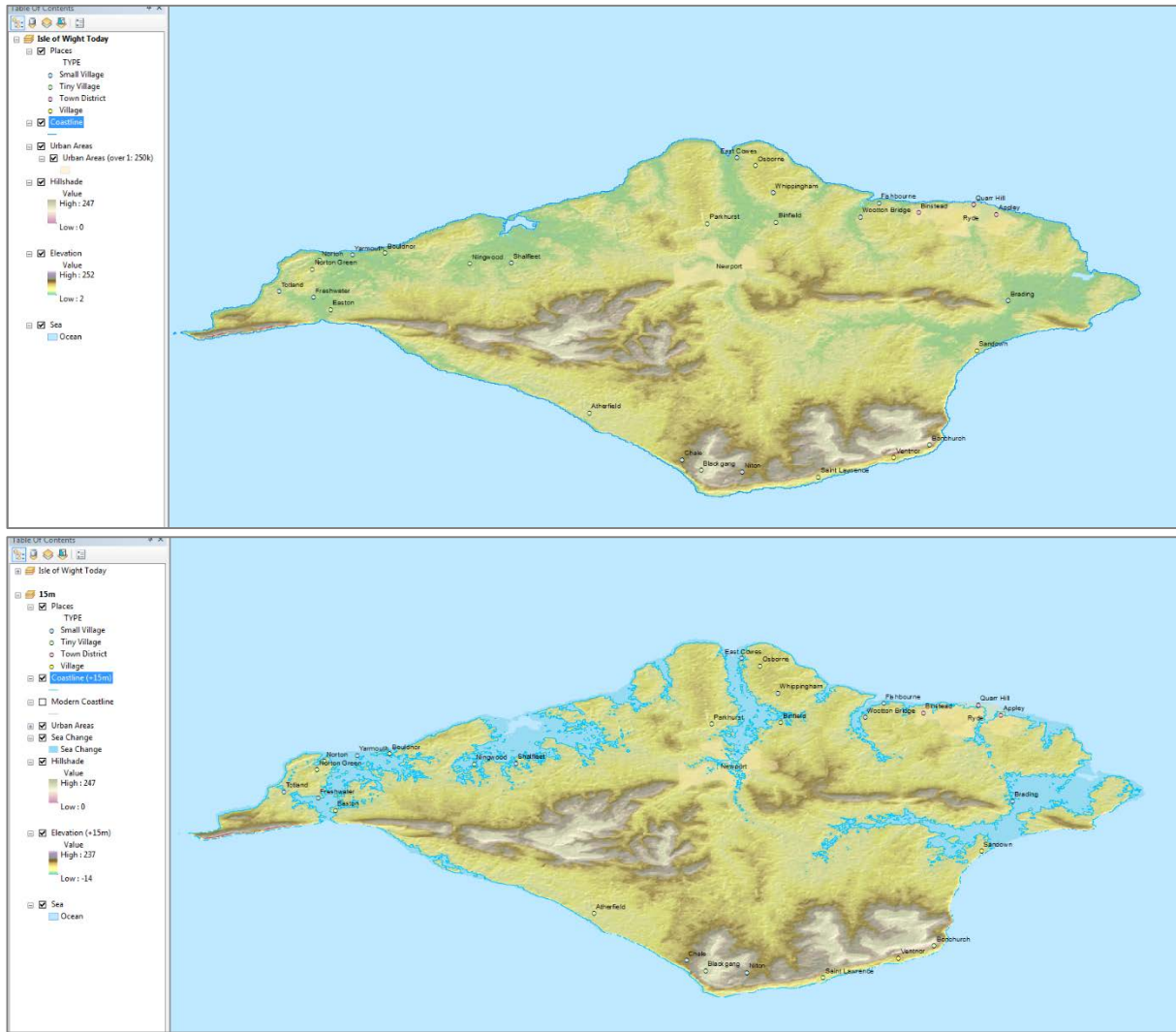


Figure 49: Top: Appearance before sea level rise. Bottom: Appearance after 15m rise in sea level. Please see final handouts for a better representation,

*At this point the project is back at the same stage as it was before it was decided that the outline needed to be recalculated.*

## Generating Statistics Continued

### Calculating Population Displacement

To calculate how many people's homes have become below sea after the rise it is necessary to select by location. First the "New Sea" binary raster (showing the difference in water extent) must be converted into a polygon. This is done using the "Raster to Polygon" tool (ArcToolbox > Conversion Tools > From Raster > Raster to Polygon) (Figure 50).

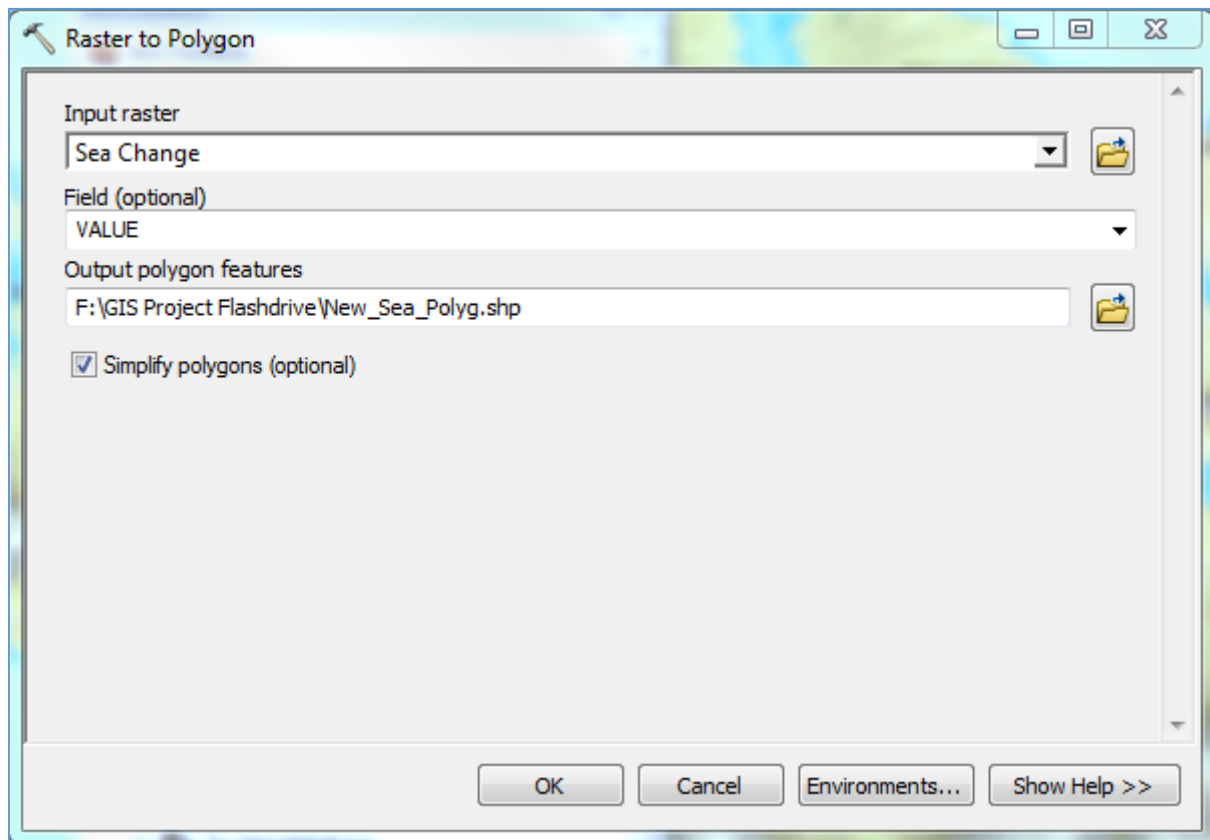


Figure 50: The "Raster to Polygon" window showing how the "New\_Sea\_Polg" polygon was created. This was then renamed "Containment Polygon" since it is used to establish which cities are now under sea.

"Select by Location" ( Selection > Select by Location) was then used to select all "Places" contained within the "Containment Polygon" (Figure 51) since it represents the parts of the Isle that are now under sea.

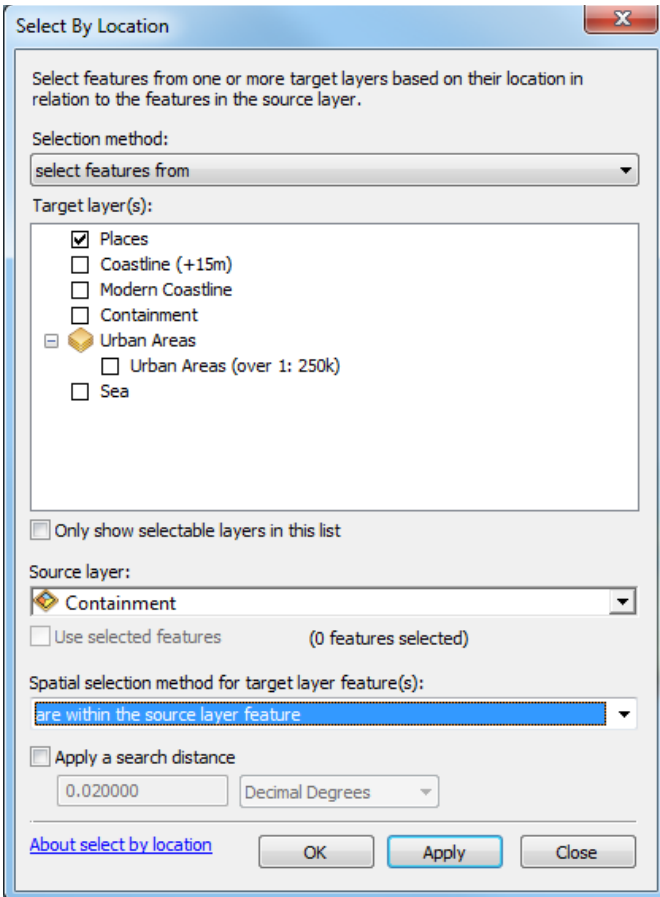


Figure 51: The “Select by Location” window, showing the parameters used to select all the “Places” now under water.

The Attribute Table was then opened for “Places” (Right Click > Attribute Table). The “Show selected records” tab was used to view the underwater places.

Then the “Statistics” window was then opened (Selection > Statistics). The “Places” layer was selected and the field was defined as “AVG\_POP” (Figure 52). The window then returned various statistics about the selected places (those under water). The “Sum” was then recorded since this represents an estimate for the total number of people displaced by the given sea level rise.

All data in the Attribute Table was then manually selected by returning to the “Show all records” tab and clicking the top records then holding shift and clicking the bottom record. Selection statistics was revisited and the “Sum” recorded.

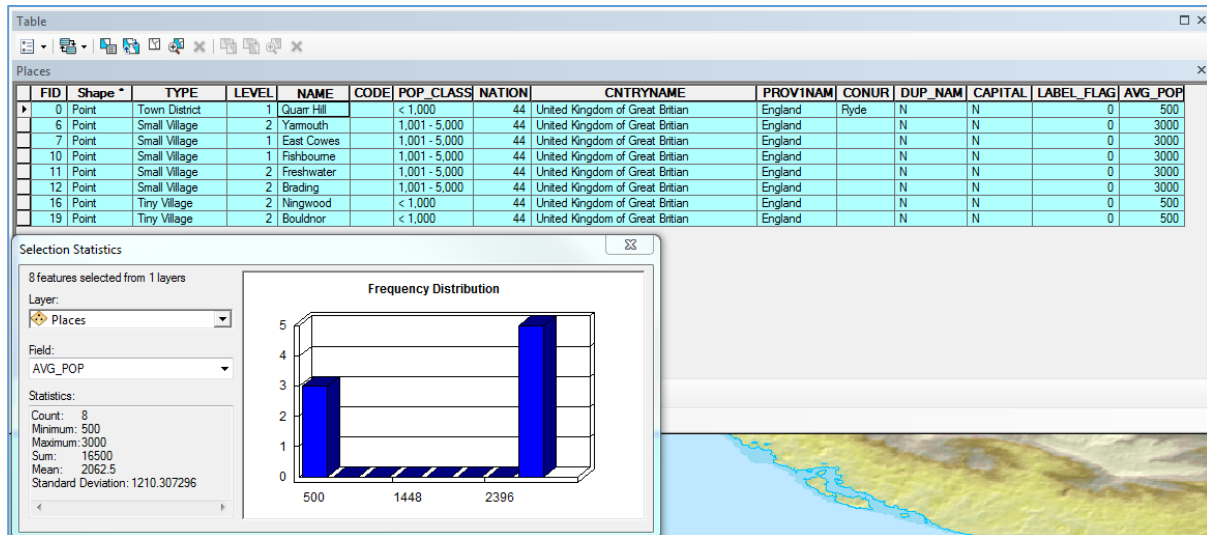


Figure 52: Top: The “Places” Attribute Table showing the newly selected underwater places. Bottom: The “Selection Statistics” window showing how statistics were obtained a given selection, in this case the places underwater after a 15m rise in sea level.

## Calculating Change of Area

To calculate the original area the Elevation rasters the attribute table was opened and all the data was selected. Selection > Statistics was then used to view the “Sum” of all the count values (The number of cells in each row). This gives the total number of cells. This can then be multiplied by the area of a cell (30m by 30m = 90 m<sup>2</sup>)

The result was:

Original Area of the Isle of Wight = 637666 x 90 = 57389940 m<sup>2</sup> = 57.38994 km<sup>2</sup>

The value after the raised sea level is simply this subtract the value of the “Sea Change” binomial raster. Which is calculated in the same way

Area after 15m Sea Level Rise = 57 389 940 – (83009 x 90) m<sup>2</sup> = 49.919130 km<sup>2</sup>

The percentage change was therefore: 13.02%

## Results

### Population

It is estimated by the method outlined above that due to a 15m sea level rise 16, 500 people would have been displaced. That is 25.19% of the original population (65,500).

### Land Area

It is estimated that 13.02% of land would be lost by a 15m sea level rise.



# Producing the Map

## Creating a New Field

The main notable step in producing the layout was the addition of a new field to the “Places” Attribute Table. This field was created as a “Text” field called “Underwater” field in which Y or N could be entered to represent Yes or No respectively (Figure 53). The underwater places were then selected as before (Map Creation – Generating Statistics Continued) and after turning on editing for this layer (Data Preparation – Extracting the Outline p.18-19) the values were manually entered and edits were saved and stopped. This then allowed the places to be symbolized by whether they were submerged or not.

## The Reference Image

A new data frame was created and the original “Europe Base Map” file loaded to create the reference image of the UK. The area of interest box was added manually by creating a new shapefile in ArcCatalogue and then Add Features > Polygon (Map Creation – Correcting for Misalignment – Generating the Trimming Polygon p. 41-42)

## General

Other than the new “Places” field some symbologies were adjusted as were a few names. Also some of the labels were converted to annotations (Right Click > Convert Labels to Annotations) If there are any parts of this process that you would like addressed further feel free to contact me at: [A.I.e.x\\_R@Hotmail.co.uk](mailto:A.I.e.x_R@Hotmail.co.uk)

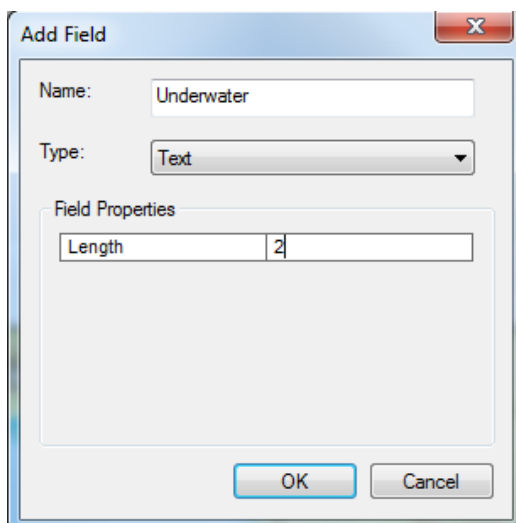


Figure 53: The “Add Field” window, showing the parameters used to generate the “Underwater” field which allowed for differential symbolizing of places above and below the sea.

## FUTURE STUDY AND SCALING

How to improve/further the study:

### *Population Data:*

- Acquire data with exact city populations or
- Acquire raster data with population coverage across total area of interest.

### *Contouring:*

- Include an additional step in processing that would only allow points below sea level and connected by other such tiles to the previous extent of the sea.

### *Erosion:*

- Include a method for estimating erosion since this will also effect populations, for example eroded cliff will likely not be overcome by the rising sea but might erode into it.

### *Population Growth:*

- Try and account for how populations may change during the time it takes for the given change in sea level.

## CONCLUSIONS

Roughly 25% of the population in cities were displaced by a 15m rise in sea level. However, due to the limitations of this study it is difficult to extrapolate the potential effects on world populations. The small sample size is a major factor. This will produce skewed results for a variety of reasons as listed below.

### Potential Sources of Error for Extrapolation:

- Island Area – This creates a larger coast to interior ratio, meaning a larger proportion of the population were located on the coast compared to global distributions.
- Elevations – Elevations in such a small area are unlikely to be representative of the world. For example the effect of this experiment on Bangladesh or the Netherlands would be significantly different due to their low relief.

### Scaling and Future Study

A future study could address this issue over a much larger area. This would give a larger sample giving more statistically valid results. There should be no issues with scaling this project other than creating some code to auto-fill the field in Data Preparation > Adjusting City Data Tables. Though, this is not necessary if a population raster can be found and used. In fact all data needed to scale this project to the whole of Europe is available from the sources listed.

