

# **New Orleans, Louisiana in 2100:**

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## **Effects of Subsidence, Sea-Level Rise, and Erosion**

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## I. Introduction

### A) Purpose:

The main purpose of this write-up is to describe data collection and data processing used to create maps that can help predict whether New Orleans will be underwater by 2100 and by how much. In order to tackle this problem, this project takes into account three major factors contributing to the potential submergence of New Orleans. These factors include subsidence, sea-level rise, and erosion.

### B) Problem Formulation:

#### Background

Continuing relief efforts for the damage caused by Hurricane Katrina in 2005 have increased debate over the long-term sustainability of New Orleans and other low-lying coastal areas of Louisiana. Certainly, flooding is not an uncommon problem in this city sitting in a bowl near the Louisiana coast [Fig. 1]. New Orleans actually rests at an average of two meters (six feet) below sea level. The city is basically surrounded by water: Lake Pontchartrain to the north (B), the great Mississippi River to the south (A), and wetlands to the east leading out to Lake Borgne.



Natural levees offer some protection to an area lying below sea level, but in an attempt to increase this protection, humans have created an extensive man-made levee system around New Orleans. While this may generally increase their flood control, it has disrupted a natural river system in which sediment would dump out over the area after a flood. As a result, not enough material is being deposited to make up for sinking due to subsidence. The city of New Orleans also pumps water out of the area to help keep it dry, which may intensify the effects of subsidence, causing the city to sink faster than it normally would.

Also, as demonstrated by the disaster of Hurricane Katrina in 2005, the levees only offer so much protection against flooding. In this case, the storm surge caused by the hurricane stressed the levees to the point of failure. The result of this breach was major flooding. According to CBS News and New Orleans Mayor Ray Nagin, 80 percent of the city was under water in August 2005 when Katrina and levee breaches flooded the city.

In addition, the growing concern of sea-level rise associated with climate change has worsened the long-term outlook for the city. Increasing temperatures could cause sea-level to rise by: “expanding ocean water, melting mountain glaciers and small ice caps, [and] causing portions of the coastal section of the Greenland and Antarctic ice sheets to melt or slide into the ocean” (Environmental Protection Agency). The Intergovernmental Panel on Climate Change (IPCC) estimates that the global average sea level will rise by 18-59 cm by 2100. In such a low-lying and low-relief city like New Orleans, even the small mean value of this estimate, 39 cm, would not go entirely unnoticed, especially in conjunction with the effect of subsidence.

A combination of coastal erosion (by wave processes, storm action, etc.), the effects of subsidence, and a rising sea-level spells trouble for New Orleans. What is the future for this city?

According to US environment correspondent Suzanne Goldenberg:

A vast swath of the coastal lands around New Orleans will be underwater by the dawn of the next century because the rate of sediment deposit in the Mississippi delta can not keep up with rising sea levels, according to a study published today.

Between 10,000 and 13,500 square kilometres of coastal lands will drown due to

rising sea levels and subsidence by 2100, a far greater loss than previous estimates.

[From the article: Climate change: Rising sea level to submerge Louisiana coastline by 2100, study warns] Found online at:

<http://www.guardian.co.uk/environment/2009/jun/29/rising-sea-level-new-orleans>

### The Problem

Will New Orleans be submerged by 2100, and by how much?

To determine whether this may be true, spatial and tabular data will be collected for the purpose of research and data manipulation using GIS software. These can then be presented as a map from which measurements can be taken to answer the question. The major factors contributing to potential submersion of New Orleans by 2100 included: subsidence, rise in sea-level, and coastal erosion.

In determining the effect of subsidence, data for soil types will be examined and ranked based on physical properties of the soil, consideration for the weight of buildings resting on top of the soil, and compared with previously measured subsidence rates for the area. The measured subsidence rates for the area may take in to account additional causes, such as pumping water from the soil. This project will not directly utilize pumping information for the Orleans Parish. A range of subsidence rates can then be assigned to these ranked soil groups.

As sea-level rise is also a rate, for the sake of simplicity, it will be combined with the subsidence rates. This rate for sea-level rise can be added on top of the rates for subsidence. The rate of sea-level rise from the year 2000 to 2100, a rate of ~ 40 cm/100 years is pulled from the mean value of the estimate from the IPCC, presented in the Background section above. Then, the combined values for 100 years of subsidence and sea-level rise can be subtracted from an elevation raster.

In considering coastal erosion, data for shoreline loss from 1932 to 1990 will be examined in the Digital Data Series DDS-79, Coastal Erosion and Wetland Change in Louisiana by the U.S. Geological Survey (USGS). Several transect measurements across the shoreline loss can be averaged to come up with a rough estimate of average coastal erosion. Then, this value will be plugged in as a buffer to subtract from land in contact with water to show an estimated loss of land.

## II. Data Collection

Data were collected from several online sources:

1. City of New Orleans Geographic Information Systems (CNOGIS) Portal site  
by The One New Orleans Community Recovery & Resources  
<http://gisweb.cityofno.com/cnogis/dataportal.aspx>
  - a) Parish Boundary
    - data download and html metadata  
(last update to website 12/23/2006)
  - b) Streets
    - data download and html metadata  
(last updated to website 02/29/2008)
  
2. The 2008 Louisiana Spatial Data Index (LSDX)  
by The Louisiana Geographic Information Center (LAGIC)  
[http://lagic.lsu.edu/geodata/downloads/LSDX\\_2008.pdf](http://lagic.lsu.edu/geodata/downloads/LSDX_2008.pdf)
  - a) Levees in Louisiana
    - data download: levees\_usace\_2006.zip
  - b) State Maintained Highways in Louisiana
    - data download: state\_highways\_ldotd\_2007.zip
  - c) Louisiana Land and Water Interface
    - data download: landwater\_interface\_losco\_1992.zip
  - d) NOAA Coastal Change Analysis Program (C-CAP) Land Cover and Change Data
    - data download: landcover\_la\_noaa\_2005.zip
  - e) Landsat Thematic Mapper Satellite Image 2005
    - data download: landsat5tm\_la\_lsu\_2005.zip
  
3. Atlas: The Louisiana Statewide GIS  
<http://atlas.lsu.edu/rasterdown.htm>
  - a) LIDAR Data
    - DEM for every  $\frac{1}{4}$  quad (by USGS) within or overlapping the area of Orleans Parish [31 total – see section A1 in the Procedure for a complete list]

## 4. Soil Data Mart

Natural Resources Conservation Service (NRCS)

<http://soildatamart.nrcs.usda.gov/>

- a) Soil data and metadata for Survey Area Symbol: LA071 with Survey Area Name: Orleans Parish, Louisiana
  - tabular and spatial data download (received as an export file via email, after submitting a request for information), spatial format: ArcView Shapefile, coordinate system: UTM Zone 15 Northern Hemisphere (NAD 83), MS Access Version: Access 2002, Template DB Version: 33.1, Template DB Name: soildb\_US\_2002, size: 1.7M
  - report on Physical Soil Properties for all soil map units, PDF format

## 5. Digital Data Series DDS-79, Coastal Erosion and Wetland Change in Louisiana by the U.S. Geological Survey (USGS)

<http://pubs.usgs.gov/dds/dds79/HTMLDOCS/catalog.htm>

- a) la\_morphology\_cewc (USGS Open-File Report 00-417)
  - metadata and files
- b) la\_process\_loss\_cewc (USGS Open-File Report 00-418)
  - metadata and files

### III. Procedure

**The procedure followed involves the following general steps:**

1. Creating an elevation raster from LIDAR data
2. Creating a ranked soil raster using reclassify, taking into account subsidence and sea-level rise
3. Subtracting rasters to create a new raster, showing the combined effects of subsidence and sea-level rise on elevation
4. Using the buffer tool to show the effect of erosion
5. Creating a binary raster to show land below sea-level, and comparing this for the year 2000 and the year 2100

#### A) Creating an Elevation Raster from LIDAR Data

This section greatly mirrored the process outlined in the PDF “Working With Elevation Data,” URPL 969 – Applied GIS Workshop: Rethinking New Orleans After Hurricane Katrina, Spring 2006. This pdf may be found online at:

<http://coastal.lic.wisc.edu/urpl969-katrina/urpl969-spring06-lab-elevation-data-roughdraft-10Feb06.pdf>

1. LIDAR data was downloaded from the Atlas LIDAR Downloader at <http://atlas.lsu.edu/lidar>. After selecting Orleans Parish, which is outlined in green when the cursor hovers over New Orleans on the map, the map zoomed into the area of interest. Clicking on  $\frac{1}{4}$  quads pulled up available downloads for each. For this project, DEM data was downloaded for each  $\frac{1}{4}$  quad of interest. After prompted with the File Download box, I navigated to an appropriate area to create a new folder titled no\_lidar in which to save the files.

DEM data was downloaded for all of the following areas, which are within or overlap the area of Orleans Parish:

- a) NEW ORLEANS WEST NW  $\frac{1}{4}$ , SW  $\frac{1}{4}$ , NE  $\frac{1}{4}$ , and SE  $\frac{1}{4}$  Quads
- b) SPANISH FORT SW  $\frac{1}{4}$  and SE  $\frac{1}{4}$  Quads
- c) NEW ORLEANS EAST NW  $\frac{1}{4}$ , SW  $\frac{1}{4}$ , NE  $\frac{1}{4}$ , and SE  $\frac{1}{4}$  Quads
- d) SOUTH POINT SE  $\frac{1}{4}$  Quad
- e) LITTLE WOODS NW  $\frac{1}{4}$ , SW  $\frac{1}{4}$ , NE  $\frac{1}{4}$ , and SE  $\frac{1}{4}$  Quads
- f) CHALMETTE NW  $\frac{1}{4}$ , SW  $\frac{1}{4}$ , NE  $\frac{1}{4}$ , and SE  $\frac{1}{4}$  Quads
- g) BELLE CHASE NE  $\frac{1}{4}$  Quad
- h) NORTH SHORE SW  $\frac{1}{4}$  and SE  $\frac{1}{4}$  Quads
- i) CHEF MENTEUR NW  $\frac{1}{4}$ , SW  $\frac{1}{4}$ , NE  $\frac{1}{4}$ , and SE  $\frac{1}{4}$  Quads
- j) RIGOLETS SW  $\frac{1}{4}$  and SE  $\frac{1}{4}$  Quads
- k) ALLIGATOR POINT NW  $\frac{1}{4}$ , SW  $\frac{1}{4}$ , and NE  $\frac{1}{4}$  Quads

Unfortunately, the MARTELLO CASTLE NE  $\frac{1}{4}$  Quad is unavailable, and was not found elsewhere online. So, this small piece of information is missing for Orleans Parish.

StuffIt (or WinZip) was used to extract the compressed files in the .zip files.

After opening ArcMap, all of the DEM data were loaded to a new map. When asked if you would like to create pyramids, I selected No.

To make sure no DEM information needed for the Orleans Parish was missing, the outline for Orleans Parish was also loaded (Parish\_boundary.shp), and then symbolized as hollow with a bright orange outline so it was easy to see on top of the DEM data [Fig. 2]. All of the DEM information for land areas within Orleans Parish filled the outline. Missing areas included the area represented by MARTELLO CASTLE NE  $\frac{1}{4}$  Quad and any area that would only be water.

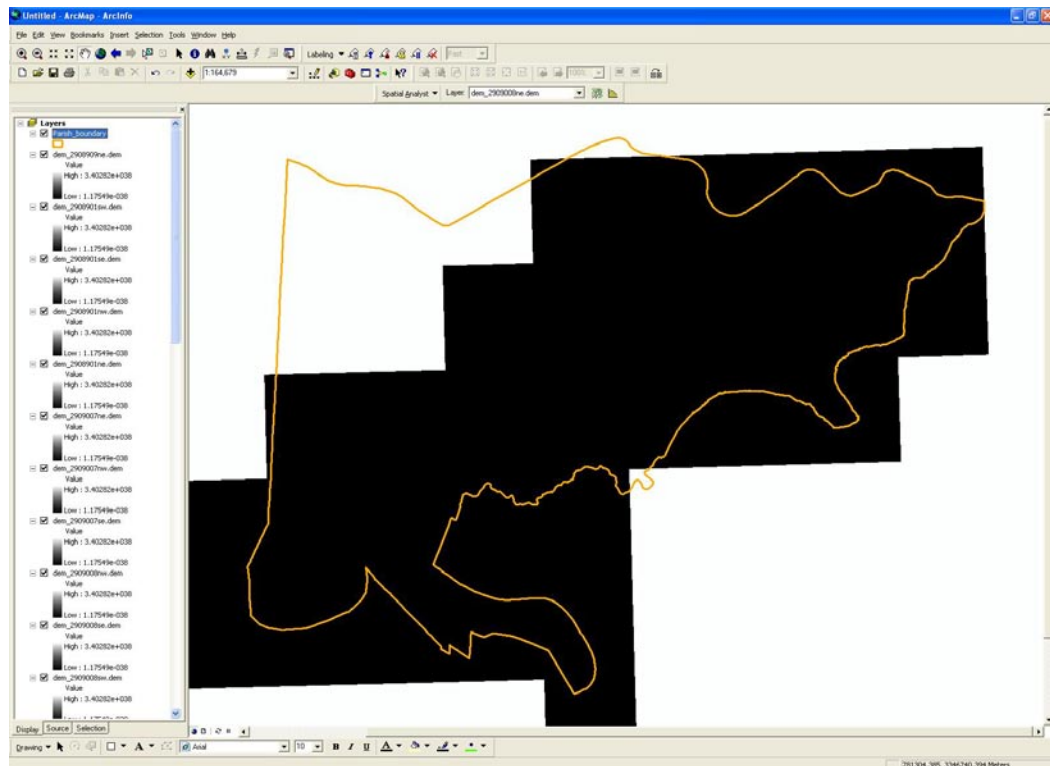


Figure 2

- The “DEM to Raster” tool was used to convert the LIDAR files into the GRID format. This is located in ArcToolbox > Conversion Tools > To Raster > DEM to Raster.

In the DEM to Raster box, the following choices were made [Fig. 3]:

Input USGS Dem file: dem\_2908901ne-dem

Output raster: c\_ne

Output data type: INTEGER

For convenience, the output raster was saved directly to the no\_lidar folder.

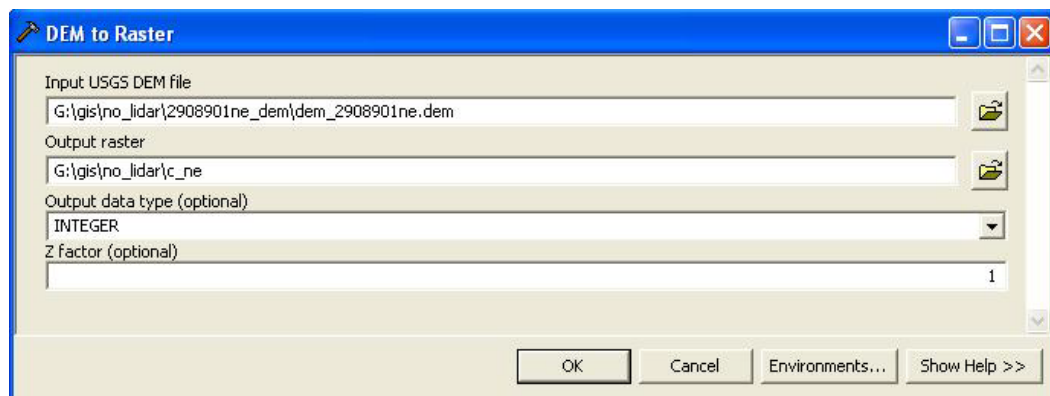


Figure 3



Output raster names were based on abbreviations of the “quad name\_¼ corner” (for example c\_ne is for CHALMETTE NE ¼ Quad, where CHALMETTE = c and NE ¼ = ne).

This process of converting DEM to raster was repeated for all DEM data.

- Then, the LIDAR files were merged using the “Mosaic to New Raster” tool. This is located in ArcToolbox > Data Management Tools > Raster > Raster Dataset > Mosaic to New Raster.

In the Mosaic to New Raster box, all of the LIDAR rasters were loaded as Input Rasters, the no\_lidar folder was chosen as the Output Location, and lidar\_msc was typed in as the Raster dataset name with extension. Just to be safe, no\_east\_se was imported as the Coordinate system for the raster, which should be NAD\_1983\_UTM\_Zone\_15N [Fig. 4]

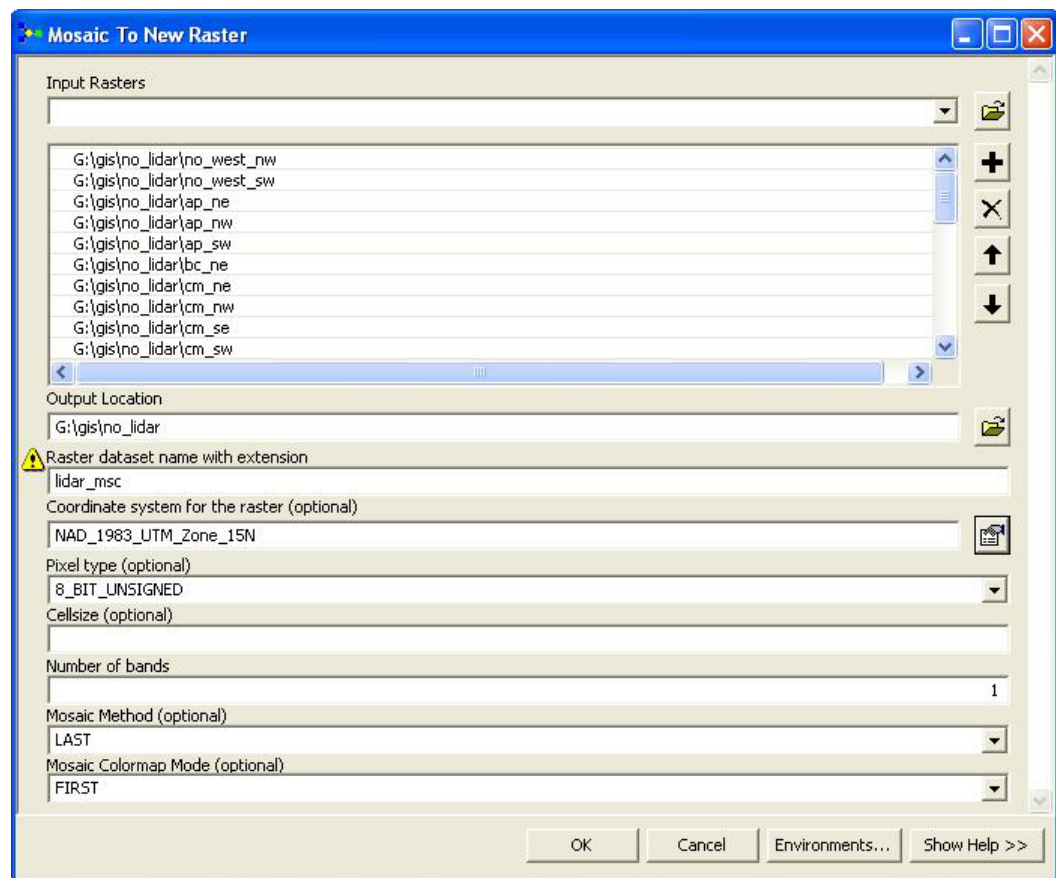


Figure 4

Note: There was a glitch of some sort that kept skewing the first two rasters I loaded in the list for the mosaic, while all others connected nicely. Therefore, I used no\_west\_sw and no\_west\_nw (the NEW ORLEANS WEST SW ¼ and NW ¼ Quads) as extra data for the program to mess up with the glitch, because those areas will not be included in the study area. Therefore, they were loaded first.

It won't matter that they are tilted, as they will be clipped out later. Note that they are tilted in figure 5. They are located within the red rectangle with an arrow pointing to it.

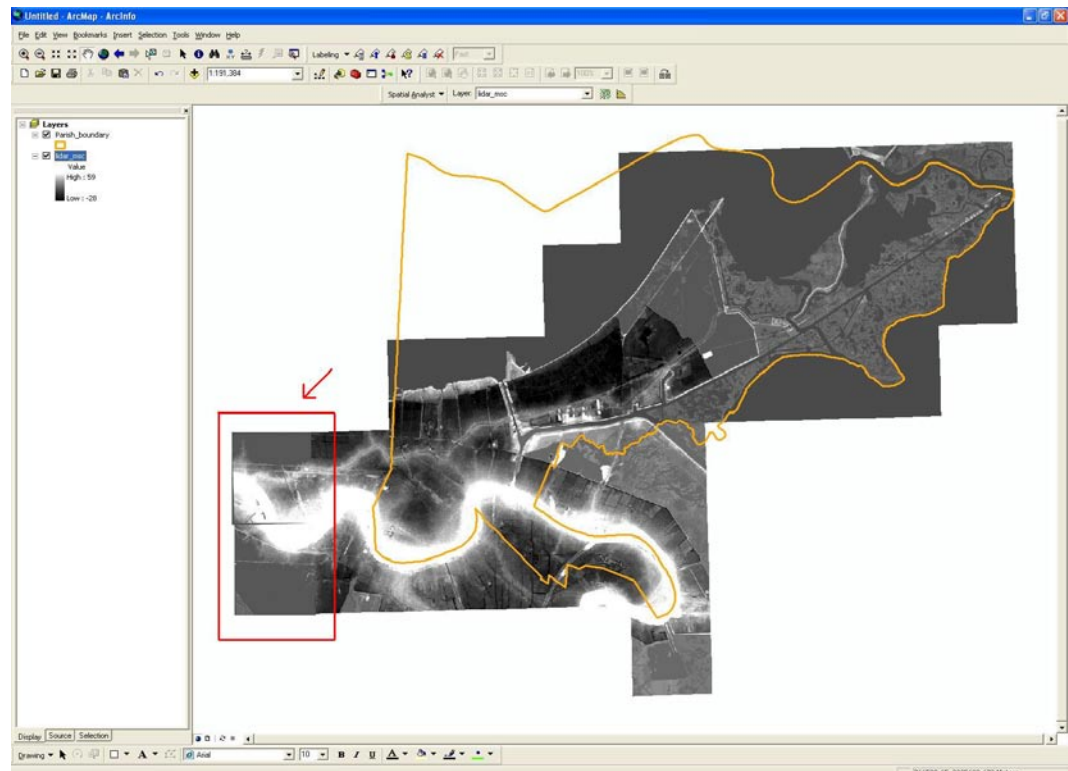


Figure 5

4. Lidar\_msc was then loaded in ArcMap. I took a moment to check its Source information in Layer Properties, including Raster Information, Extent, Spatial Reference, and Statistics.

Then, the raster was symbolized. Using Classify, the Classify Method was set to Defined Interval with an Interval Size of 1. The color ramp chosen to represent the data is Elevation #1.

5. The lidar raster is then clipped to the Orleans Parish boundary to remove information outside of this area.

Spatial Analysis should be turned on, along with its extension. Options needed to be set. This is found on the Spatial Analysis drop down menu. An appropriate Working directory was chosen, and the Analysis mask was set to Parish\_boundary. The analysis mask is the layer the lidar raster will clip to. Analysis Coordinate System was set to the second option so it will be the same as the active data frame [Fig 6].

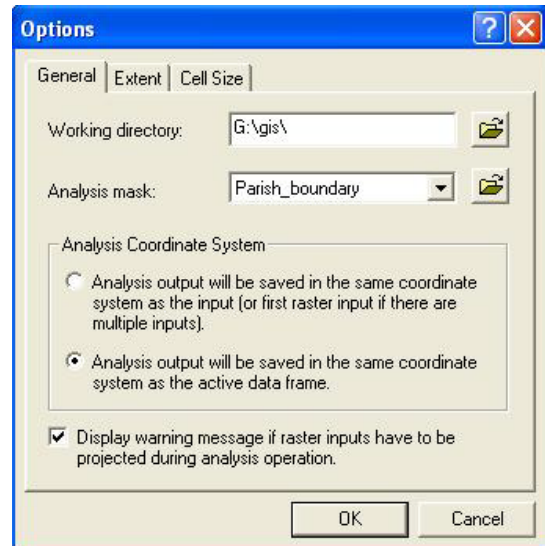


Figure 6

Extent was set to Same as Layer “Parish\_boundary” and Cell size was set to Same as Layer “lidar\_msc”

The Raster Calculator was when used to clip to lidar\_msc raster to the Parish\_boundary. This was done by loading lidar\_msc in Raster Calculator, then clicking “Evaluate”.

6. Reclassify was used to fill in the blank no data areas for the raster within the parish boundary.

First, the Calculation should be symbolized in the Symbology tab under Properties. Using Classify, the Classify Method was set to Defined Interval with an Interval Size of 1.

Then, from the Spatial Analysis drop-down menu, the Reclassify box was brought up and filled in accordingly. All new values should be filled in as -28, -27, etc. The new value for New Data was set to -1. [This was decided on the basis that the water area representing Lake Pontchartrain has a pixel value of -1, and the majority of the no data represents the rest of Lake Pontchartrain within the Orleans Parish boundary.] The option to Change missing values to no data should be selected and the Output raster set to save as lidar\_rc in the no\_lidar folder [Fig. 7].

The result should look similar to figure 8.

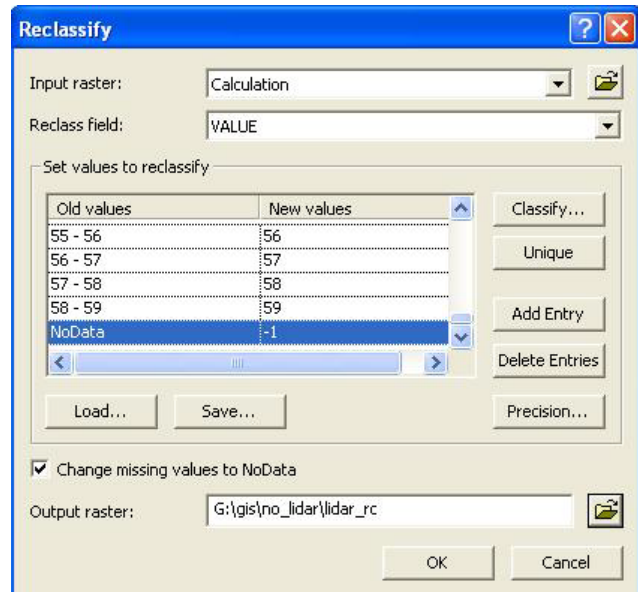


Figure 7

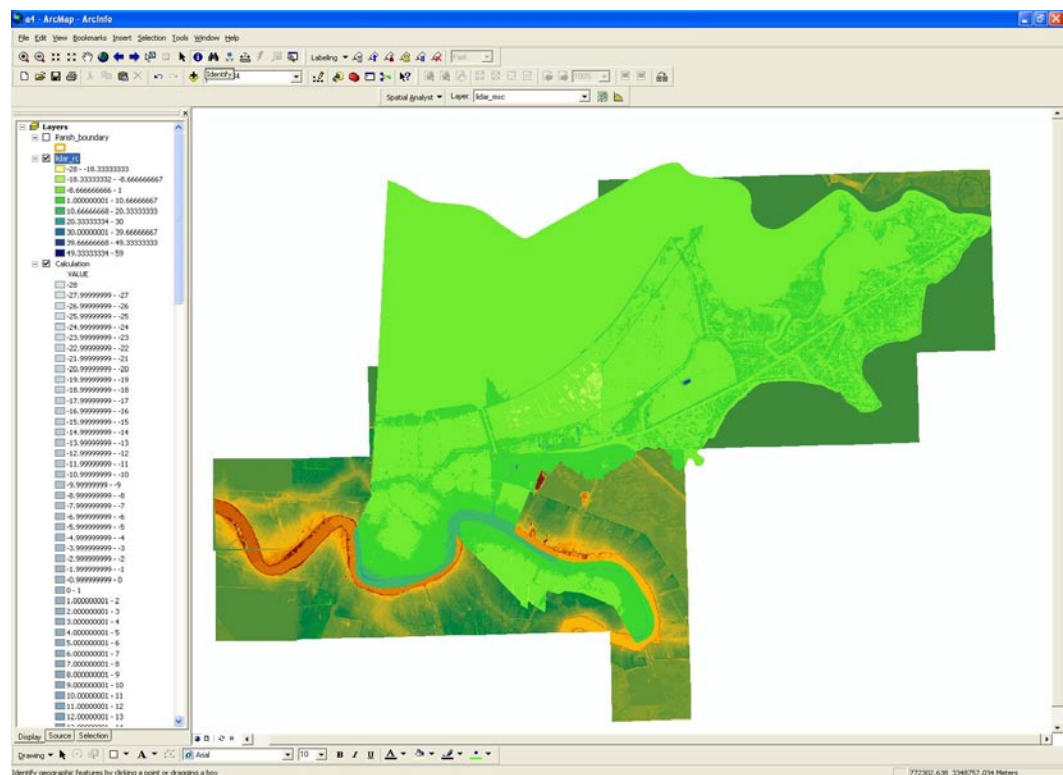


Figure 8

**B) Creating a Ranked Soil Raster Using Reclassify,  
Taking into Account Subsidence and Sea-level Rise**

1. Soil data was loaded into the map as the soilmu\_a\_la071.shp file. In the Symbology tab under Properties, all values for Value Field musym were added in

Categories, Unique values. Then, <all other values> was deselected. Random was left as the color ramp selection.

- To get started on determining a ranking system for subsidence rates, I examined a report on “Exploration of Subsidence and Elevation in Orleans Parish” by Prof. David Hart of the University of Wisconsin-Madison, which explores the relationship between subsidence and other factors such as geology, the location of pumping stations, land use, soil types, water wells, levees, and roads. This article can be found online at: <http://coastal.liv.wisc.edu/urpl969-katrina/urpl969-group2-paper-03May06.pdf>. The section on Subsidence and Soil Type was especially helpful.

From the information give in the report, I decided to rank the following soils by subsidence rate (on a ranking system where 7 = highest rate, 1 = lowest rate, and 0 = water):

#### Preliminary Ranking

Urban land (Ub) = 6  
 Allemands (Ae) = 5  
 Aquents (An, AT) = 5  
 Westwego Series (Ww) = 4  
 Harahan Series (Ha) = 3  
 Sharkey Series (Sk, Sh) = 2  
 Commerce/Cancienne Series (Cm, Co, CS) = 1  
 Water = 0

To guesstimate the ranks for the remaining soils, I mirrored decisions made in this report with information provided by the report on Physical Properties of the soils downloaded from the Soil Data Mart [See Appendix A]. In general, I decided that soils with high percent of organic matter would have higher subsidence rates than soils with high percent of clay. I also considered whether the soil was mostly covered by buildings, as the overlying weight of these would increase its subsidence rate. I then considered the general pattern for the other soils.

I determined that (GE) and (Dp) should have subsidence rates similar to (Ha), (CE) should be similar to (Ww), (LF) and (LV) should be similar with the (Ae, An, and AT) group. (Ke) seemed to fall somewhere between (Ww) and the (Ae, An, and AT) group. The new basic ranking was then the following:

#### New Basic Ranking

Urban land (Ub) = 7  
 Allemands (Ae) = 6  
 Aquents (An, AT) = 6  
 Arents and Aquents (LV) = 6  
 Lafitte (LF) = 6  
 Kenner (Ke) = 5

Westwego Series (Ww) = 4  
 Clovelly (CE) = 4  
 Harahan Series (Ha) = 3  
 Gentilly (GE) = 3  
 Dump (Dp) = 3  
 Sharkey Series (Sk, Sh) = 2  
 Commerce/Cancienne Series (Cm, Co, CS) = 1  
 Water = 0

However, numbers representing subsidence rates need to be assigned to this ranking system. The relationship between this basic ranking system and subsidence rates was based on the information in the “Exploration of Subsidence and Elevation in Orleans Parish” report. (Ub) has the highest subsidence rate at - 1.9 ft per 50 years. For the purpose of this project, feet was converted into meters, and the value then multiplied by 2 for a value of about 1.2 m per 100 years. I broke down the 0 to 1.2 range into sections to assign to the ranked soil groups.

I then decided to convert this into centimeters to make calculations using Raster Calculator easier later on, because it doesn’t handle decimal places well.

#### Final Ranking

Urban land (Ub) = 120  
 Allemands (Ae) = 100  
 Aquents (An, AT) = 100  
 Arents and Aquents (LV) = 100  
 Lafitte (LF) = 100  
 Kenner (Ke) = 80  
 Westwego Series (Ww) = 70  
 Clovelly (CE) = 70  
 Harahan Series (Ha) = 50  
 Gentilly (GE) = 50  
 Dump (Dp) = 50  
 Sharkey Series (Sk, Sh) = 30  
 Commerce/Cancienne Series (Cm, Co, CS) = 20  
 Water = 0

3. Soil data was then reclassified with this ranking system.

In order to reclassify, the soil shapefile must be converted to a raster. This is done through the Spatial Analysis drop-down menu option Convert > Features to Raster.

In the Features to Raster box, the following choices were made [Fig. 9]:

Input features: soilmu\_a\_la071

Field: musym

Output cell size: 5

Output raster: soil\_rstr saved to an appropriate location



Figure 9

The cell size must be set to 5 because the lidar raster has a cell size of 5. This is important because the cell size for rasters must be the same in order to perform calculations in Raster Calculator, which will be used later in the project.

Now the soil data can be reclassified.

In the Reclassify box, the Input raster was set to soil\_rstr and the Reclass field was set to MUSYM. The New values should be filled in according to the Final Ranking (section B2). I decided the value for NoData should be set equal to that of water (W), so NoData = 0. The option to Change missing values to NoData was also selected. The Output raster was saved to an appropriate location as soil\_rc2 [Fig. 10].

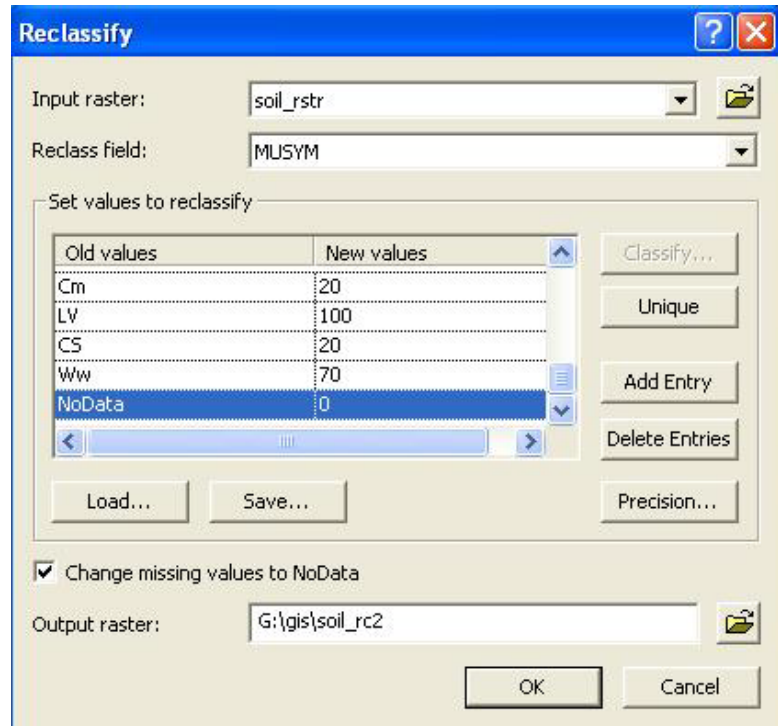


Figure 10

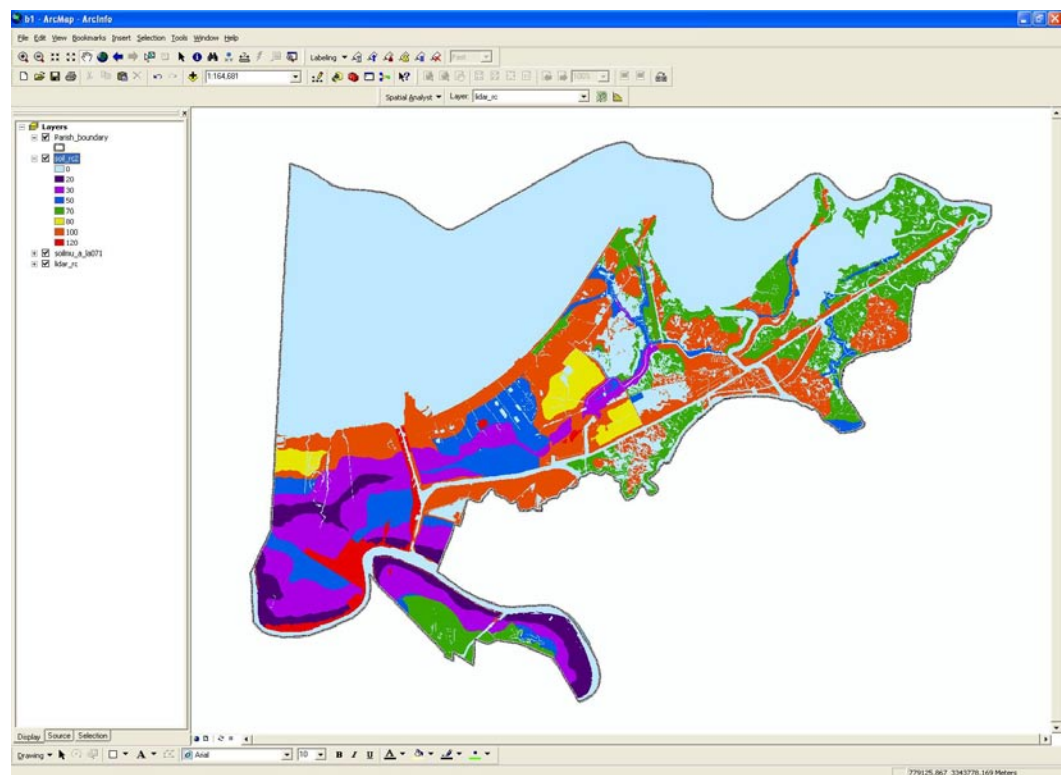


Figure 11



4. Sea-level rise is also a rate, so I decided I should add the effect of sea-level rise to this same raster because I can just subtract the combined elevation changes due to subsidence and rising sea-level from the lidar raster when I make calculations using Raster Calculator.

To do this, a rate of 40 cm per 100 years was simply added on top of the values in the Final Ranking. The soil\_rc2 raster was reclassified, now using the combined subsidence and sea-level rise values (40, 60, 70, 90, 110, 120, 140, 160). The new reclassified subsidence/sea-level raster was saved as soil\_rc3.

C) Subtracting Rasters to Create a New Raster,  
Showing the Combined Effects of Subsidence and Sea-level Rise on Elevation

1. The soil raster is now in centimeters, but the lidar raster is still in meters. Therefore, the lidar raster must also be converted into centimeters.

This can actually be done using the Raster Calculator.

In Raster Calculator, lidar\_rc was loaded, then multiplied by 100. This equation had the form [lidar\_rc] \* 100.

Then, the raster Calculation was symbolized. Using Classify, the Classify Method was set to Defined Interval with an Interval Size of 100. The color ramp chosen to represent the data is Elevation #1.

2. To show the combined effects of subsidence and sea-level rise on elevation, the soil raster was subtracted from the lidar raster in Raster Calculator. This equation had the form [Calculation] – [soil\_rc3].

Then, the raster Calculation2 was symbolized. Using Classify, the Classify Method was set to Defined Interval with an Interval Size of 100. The color ramp chosen to represent the data is Elevation #1.

3. With Calculation2 above Calculation, Calculation2 was hidden and unhidden to get an idea of the difference between the two. I noticed that the marsh areas to the northeast seemed to blend in more with Lake Pontchartrain after the change. Compare figures 12 and 13.



Elevation before effects of subsidence and sea-level rise

Figure 12



Elevation after effects of subsidence and sea-level rise

Figure 13

D) Using the Buffer Tool to Show the Effect of Erosion

1. Data pertaining to erosion was loaded to ArcMap and symbolized.

This included the la\_process\_change\_cewc.shp file and the landwater\_interface\_LOSCO\_1992.shp file

The landwater\_interface was symbolized with Value field = CLASS under the Categories > Unique Values in the Symbology tab of Properties. All values for CLASS were added, which only includes Land and Water. Land was symbolized with a light tan, and water was symbolized with the Lake option in Symbol Selector. <all other values> was deselected.

The la\_process\_change was symbolized Value field = CLASS under the Categories > Unique Values in the Symbology tab of Properties. All values for CLASS were added, which should include Direct Removal, Erosion, Land, and submergence. I accepted the default random colors. <all other values> was deselected.

2. The la\_process\_change was more closely examined in order to determine a rough average erosion value along the coast.

After zooming into a coastal area at a scale of 1:20,000, the measure tool was used to measure transects across the erosion along the coast [Fig. 14]. I measured 20 different transects from various coastal areas around Orleans Parish. The average was found to be about 120 meters. Metadata for the layer notes that this erosion is from 1932 to 1990, which is a difference of 58 years. By combining this information, I obtained a rate of 120 meters per 58 years.

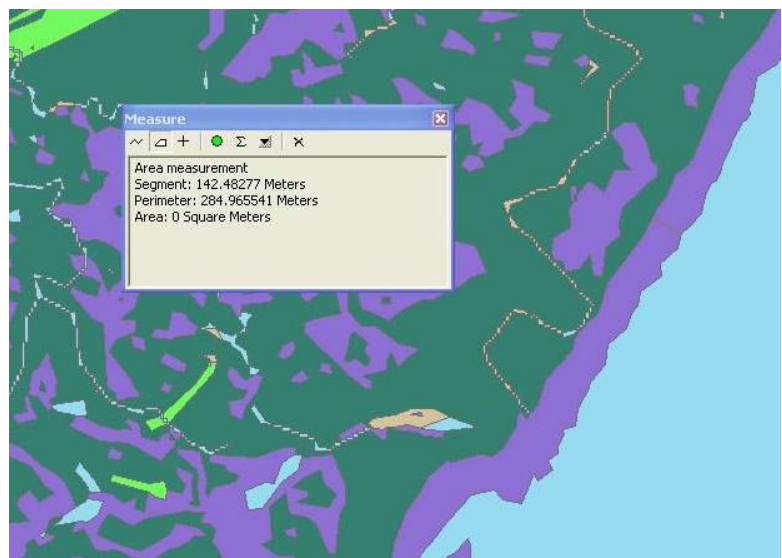


Figure 14

This project is interested in the year 2100 in comparison with the landwater\_interface, which is information from 1992. So, 1992 was subtracted from 2100 for a difference of 108 years. By setting  $120\text{m}/58\text{yrs} = x/108\text{yrs}$ , x was solved and found to equal about 223 m. So, by the year 2100, 223 meters will be eroded away from the land. This will be done later using the buffer tool, but first layers for land and water need to be set up.

3. The water and land were selected by attributes and made into two separate layers.

This was done by Select by Attributes from (Selection > Select by Attributes).

The following choices were made [Fig. 15]:

Layer: landwater\_interface\_LOSCO\_1992

Method: Create a new selection

The following equation was built: "CLASS" = 'Land'

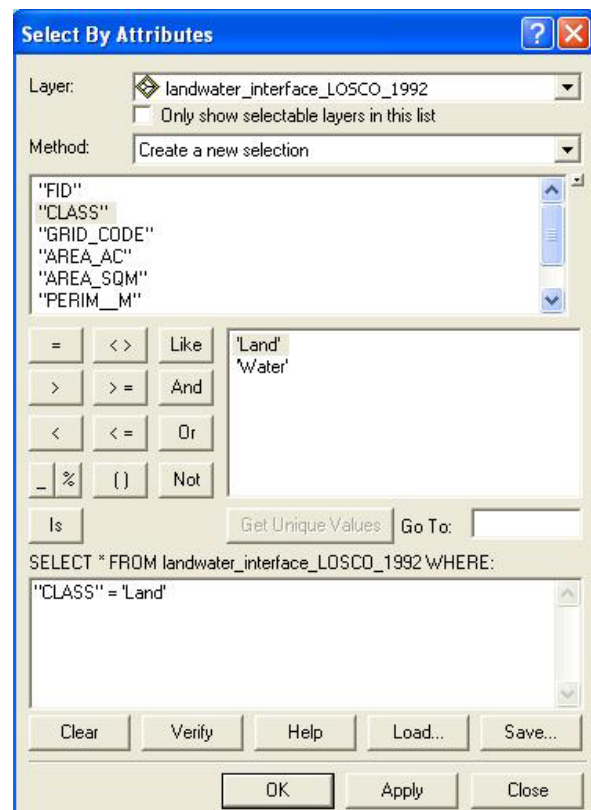


Figure 15

After selecting Land, the layer was right clicked and Data > Export Data. . . was selected to bring up the Export Data box. Selected features were exported as a new shapefile named land\_1. This was added to the map as a new layer.

This process was repeated for 'Water' and saved as a new shapefile named water\_1.

- To show the elevation information bounded by land around the year 2000, the calculation for elevation was sandwiched between water\_1 and land\_1, which represent the land-water interface at that time. To show only land area from our original lidar calculation (named Calculation), water\_1 was placed above Calculation and land\_1 was placed below Calculation. The land can be symbolized with a light tan, and the water can be symbolized with Lake from the Symbol Selector. The result should look similar to Figure 16.

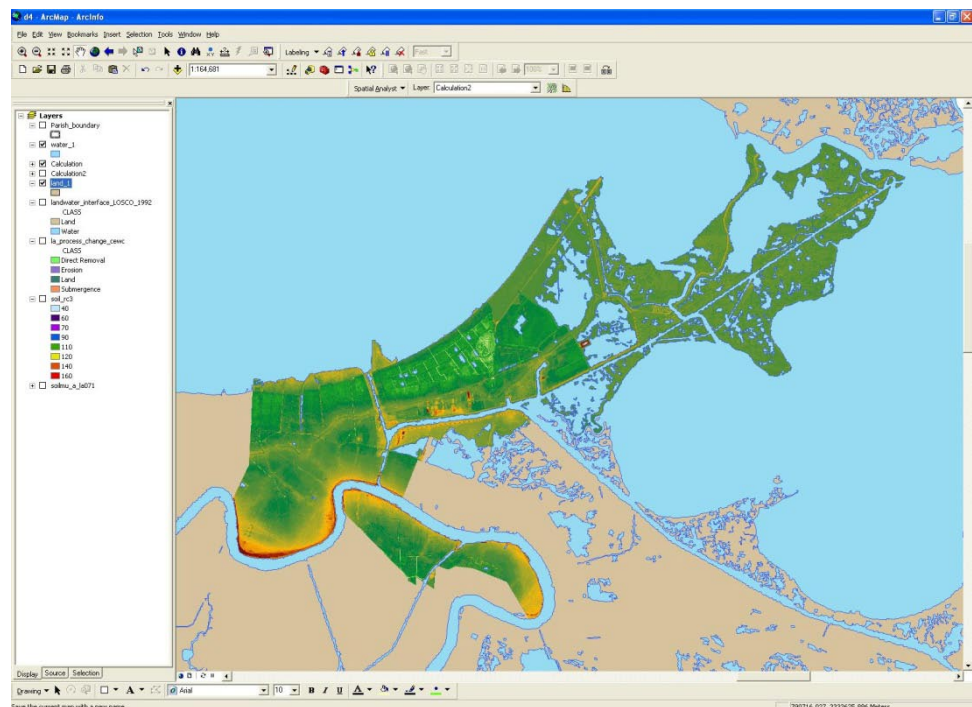


Figure 16

- Then, the buffer tool was used to show the effect of erosion, which is a difference of 223 meters from the year 2000 to 2100. The buffer tool is located in ArcToolbox > Analysis Tools > Proximity > Buffer.

To show the effect of erosion on the land, the following choices were made in the Buffer box [Figure 17]:

Input Features: land\_1

Output Feature Class was named land\_2

Linear unit: -223 Meters

Side Type: FULL

Dissolve Type: ALL

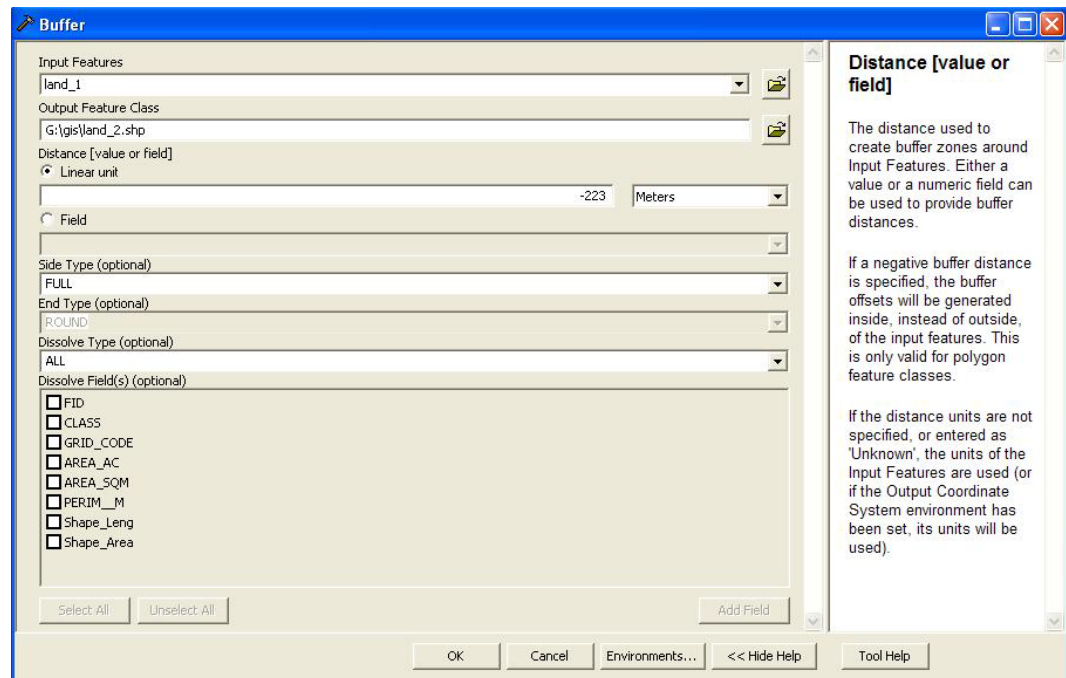


Figure 17

This buffer process was mirrored for water, except that the Linear unit should be set to 223 Meters (as a positive value). The Output Feature Class was named water\_2.

(The buffering for the water was taking too long, so I made a side step to reduce the amount of information being processed. I did this by creating a new shapefile (which I named water\_box), drawing a large rectangle around the area of interest with the editor to create a new polygon, and then setting it as the analysis mask in spatial analysis so I could clip water\_1 to this new polygon. This involved converting features to a raster for the clipping, and then converting it back into features in order to perform the buffer.)

To show the elevation information bounded by land around the year 2100, the second calculation for elevation (Calculation2) was sandwiched between water\_2 and land\_2, which represent the land-water interface at that time. This step mirrored step 4 above. The result should look similar to Figure 18.

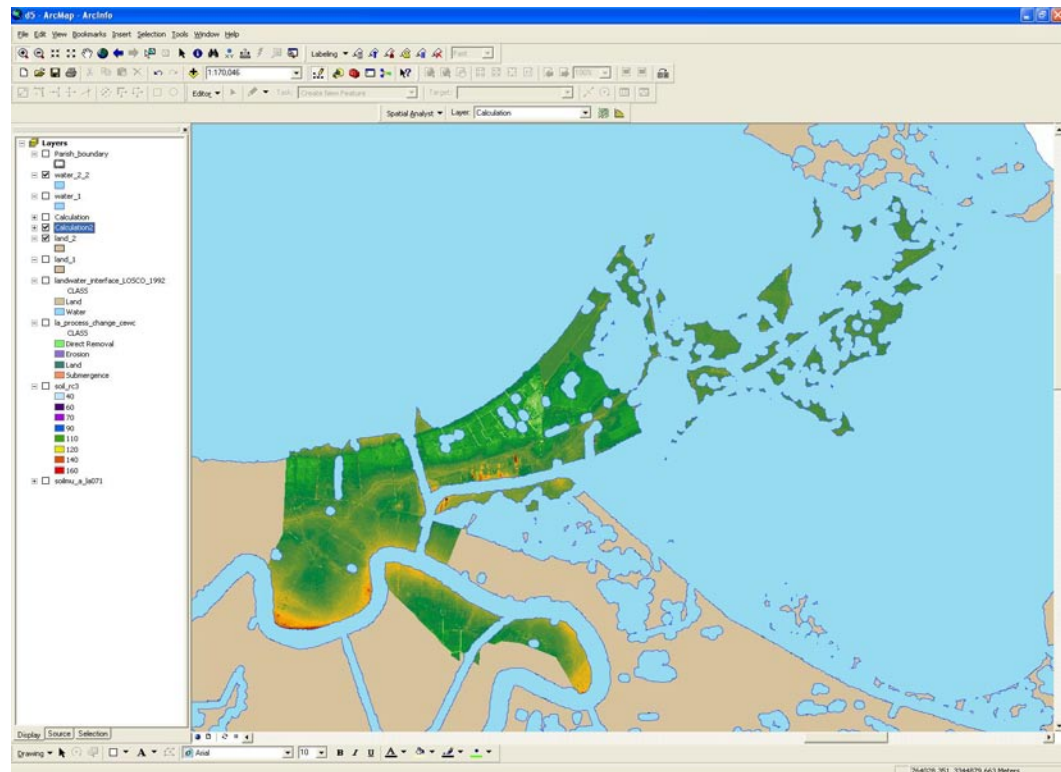


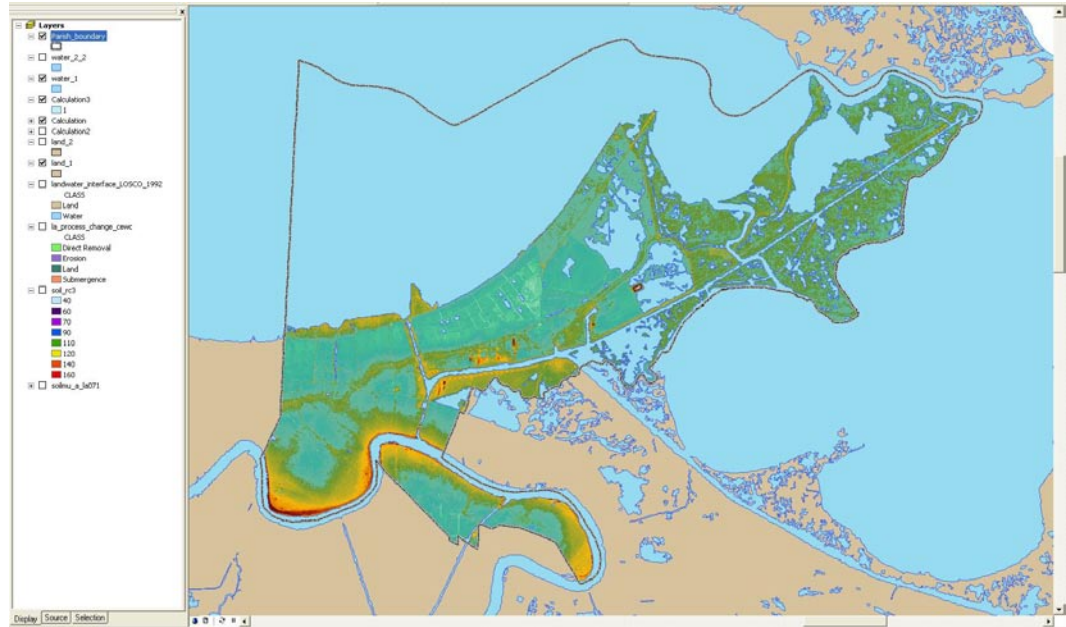
Figure 18

E) Creating a Binary Raster to Show Land Below Sea-Level, and Comparing This for the Year 2000 and the Year 2100

1. To show what parts of the land are below sea level, binary rasters were computed from the lidar Calculation (representing elevation for the year 2000) and from lidar Calculation2 (representing elevation for the year 2100).

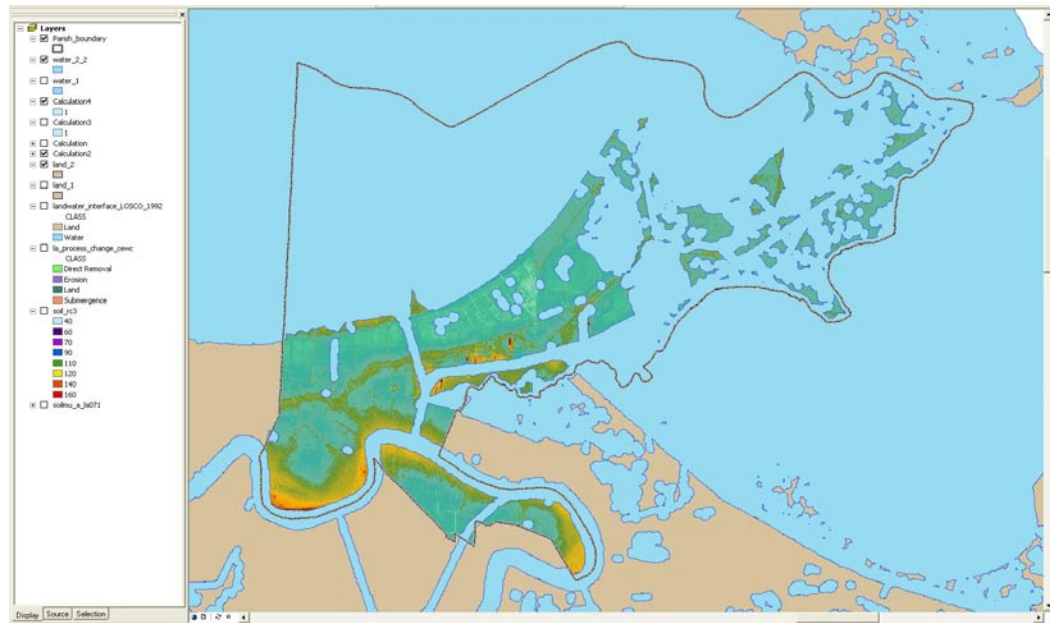
This was done by producing a Conditional Statement in the Raster Calculator. The statement used was  $\text{con}([\text{grid}] <= 0,1)$ , where [grid] is Calculation. The water areas for the new raster (named Calculation3) were then symbolized with a blue and the display was set as 50% transparent, in order to show the elevation information below. The result should look similar to figure 19.

This process was repeated for Calculation2. The result should look similar to figure 20.



Area below sea-level in 2000, represented by the transparent blue area (Calculation3) over the elevation raster (Calculation)

Figure 19



Area below sea-level in 2100, represented by the transparent blue area (Calculation4) over the elevation raster (Calculation2)

Figure 20



#### IV. Discussion

A) What percent of land in New Orleans is already below sea-level in 2000?

I clipped the land\_1 (the land in 2000) to the Orleans Parish boundary, named it land\_12, then found its area using 3D Analyst. This was done by setting the Layer for 3D Analyst to land\_12, then selecting Surface Analysis > Area and Volume... from the 3D Analyst drop-down menu. The Input surface was set to land\_12, and the “Calculate statistics” button was pressed to find area. The 2D area of land\_12 was found to be 416417900 m<sup>2</sup> [Fig. 21].

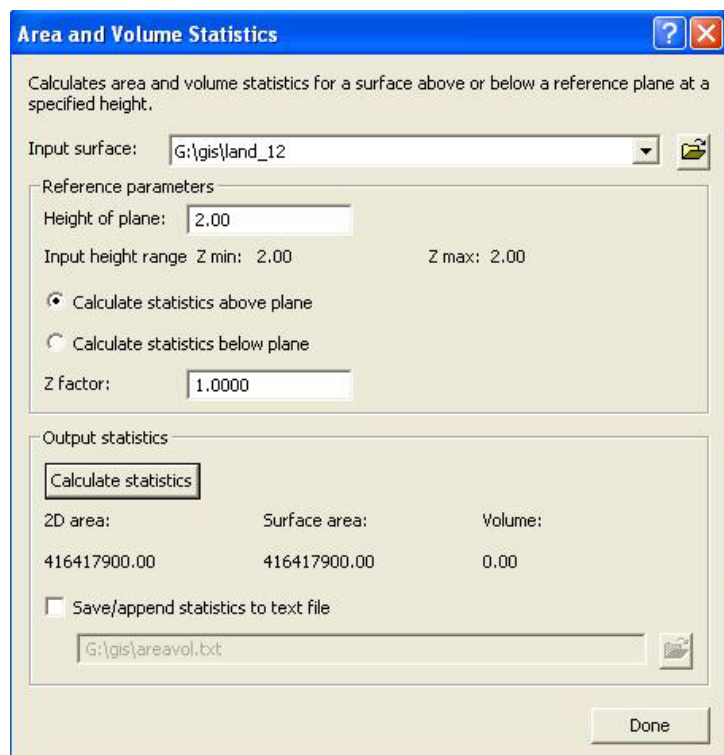
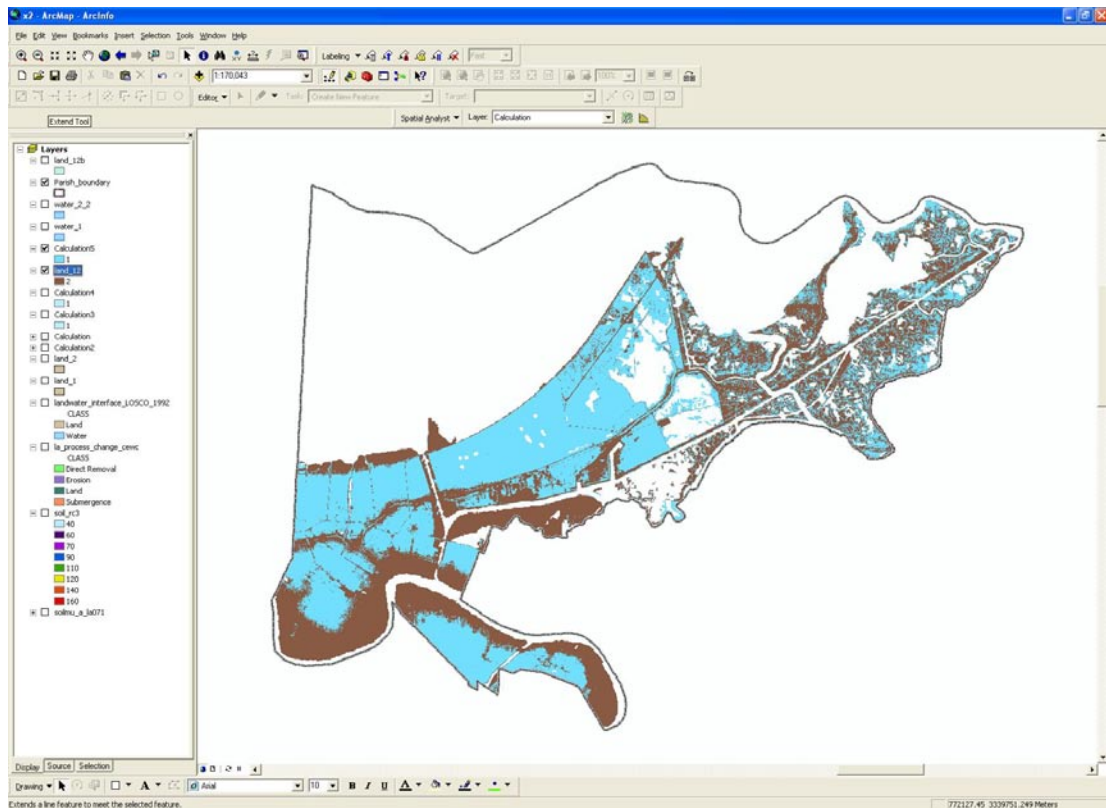


Figure 21

Then, I clipped Calculation3 (the land below sea-level in 2000) to a polygon version of land\_12 (which I named land\_12b). The result was Calculation5. The 2D area of Calculation5 was found to be 206469600 m<sup>2</sup>.



Calculation5, shown in light blue, resting on top of land\_12, shown in brown

Figure 22

To find the percent of land in New Orleans already below sea-level in 2000, I divided the area of Calculation5 by land\_12, and multiplied by 100.

The percent of land in New Orleans is already below sea-level in 2000 is 49.6%.

B) What percent of land in New Orleans may be below sea-level by 2100?

I attempted to follow the same process in determining areas for 2100. However, for unknown reasons, the land\_2 (the land in 2100) failed to clip to the Parish boundary, as it would not allow for conversion from features to raster.

While I was unable to determine an actual percentage, I visually compared areas to determine an increase in the area below sea-level in 2100 from 2000. Most of the area that went below sea-level between 2000 and 2100 was the wetlands are to the east and northeast of Orleans Parish. A reasonable value for the percent of land in New Orleans that may be below sea-level by 2100 might be about 70%

C) What is the overall change in elevation due to subsidence and sea-level rise from 2000 to 2100 in Orleans Parish?

In 2000, the maximum elevation was at 5900 cm (59 m) and the minimum elevation was at -2800 cm (-28 m). In 2100, the maximum elevation was at 5810 cm (58.10 m) and the minimum elevation was at -2870 cm (-28.7 m). The change in minimum elevation from 2000 to 2100 was -70 cm, and the change in maximum elevation was -90cm.

Within the Orleans Parish, sections changed elevation within a range of -40 cm to -160 cm from the year 2000 to 2100.

## V. Conclusion

New Orleans, although currently below sea-level by up to a value of -28 meters, is kept dry by protection from levees and removal of water by pumping. Despite this added protection, flooding is still a serious concern because the city is so low-lying and has such low-relief.

However, the man-made levees may actually harm New Orleans in the long-term because it disrupts a natural system in which flooding would drop out sediment to help replace that lost due to subsidence. In addition, the rate of subsidence is increased by of the weight of the overlying city compressing the sediments below. Subsidence rates are also increased by the extraction of water from the soil, effectively decreasing its volume, which would cause it to sink even more. The overall effect is that the ground beneath the City of New Orleans is slowly sinking. This may occur at up to a rate of -1.2 cm per year, which would cause an overall change of 120 cm (1.2m) from 2000 to 2100.

In addition, sea-level is on the rise, and low-lying coastal areas, such as New Orleans, are at a great risk. As water rises, the coastal land will begin to flood and be subjected to increasing erosion rates. Storms and wave-action are quickly eroding the shoreline of Louisiana, decreasing the land area. This can be clearly seen in comparison of figure 16 and figure 18. The area at greatest risk for flooding and erosion is the wetlands in the east and northeast of Orleans Parish.

If there was complete failure of the levee system, the current New Orleans would surely face some serious flooding problems. Up to 49.6% of the land in Orleans Parish is already below sea-level. With a storm surge from a major hurricane, such as Katrina, it is possible that up to about 80% of the city could become flooded. In some areas, flooding may even reach 28 meters. On average, flooding would be about 2 meters.

It is estimated that 70% of New Orleans may be below sea-level by 2100. If a similar situation created by Hurricane Katrina were to occur in 2100, it is likely that at least 90% of Orleans Parish would be underwater. In some areas, flooding could even reach 28.7 meters. On average, flooding would be about 2.5 to 4 meters.