People of Manhattan at Risk

—by Monika Calef

Introduction

Problem

Global sea levels have been rising slowly for the past hundred years or so. This poses a significant danger to the more than one billion people worldwide living in the coastal zone (Nicholls et al. 2007). Coastal areas are already vulnerable to storms and other catastrophic events, as was powerfully demonstrated when Hurricane Katrina devastated New Orleans and other Gulf Coast cities in 2005 and when tsunamis razed several coastal communities located along the Indian Ocean coastline in December 2004 and in northeastern Japan in March 2011.

One densely populated and globally important city in the coastal zone is New York City. With rising sea levels and projected increases in the number and magnitude of storms and storm surges, it is reasonable to wonder:

- How many people in Manhattan are currently at risk from flooding by a major hurricane?
- How many people in Manhattan could rising sea level displace by 2100?

Location

Manhattan, New York, USA

Time to complete the lab

45 minutes

Prerequisites

Advanced geographic information system (GIS) experience and Spatial Analyst extension.

Keywords: environmental studies; climate change; sea level rise; risk analysis; disaster preparedness; vector data; raster data; add fields; calculate geometry; field calculator; feature to raster conversion; raster calculator; attribute tables; legends

Data used in this lab

Three Esri grids called *flood_bcs* (best-case scenario for sea level rise), *flood_storm* (sea level rise due to a hurricane), and *flood_wcs* (worst-case scenario for sea level rise) and a shapefile called *manh_pop*, which includes population numbers for 2000 and 2100 by census tract.

Census tract data for New York in projection Latitude/Longitude, 1927 datum at **http://www.census.gov/geo/www/cob/tr2000.html**

Census2000.xlsx (See **http://www.census.gov/** or **http://factfinder2.census.gov/**)

US Geological Survey national map server at **http://cumulus.cr.usgs.gov/webappcontent/neddownloadtool/NEDDownloadToolDMS.html**

The provided shapefile *manh_outline* (the boundary for the county of New York) was originally downloaded from the US Census Bureau at **http://www.census.gov/geo/www/cob/co2000.html**, then projected to universal transverse Mercator (UTM) NAD 1983 Zone 18N, and clipped to New York County (FIPS = '061'; FIPS stands for *Federal Information Processing Standard*).

Student activity

According to tide-gauge data and other reconstructions, global sea levels had been stable for several centuries before they began rising around 1820 (Church and White 2006). Since then, mean global sea level has increased by 200 millimeters (mm) (0.2 meters [m]), or at an average rate of 1.44 mm per year from 1870 to 2004. However, this rate of rise is not constant, and new data in fact shows that sea level rise has accelerated to a rate of 3.27 mm per year since 1993 (**http://climate.nasa.gov/keyIndicators/**). Rising sea level threatens coastal communities and structures. Besides inundation, sea level rise can cause infiltration of salt water into freshwater aquifers, wetland destruction, and coastal erosion. These rising tides will be accompanied by more frequent and more severe storms, exacerbating the destructive force of sea level rise.

Hurricanes, typhoons, and cyclones require three conditions: warm water (>26°C or 79°F), high humidity, and the absence of strong changes in wind speed or direction. As global atmospheric temperatures have been rising over the past century, oceans have absorbed 20 times more heat than the atmosphere, resulting in a gradual warming, especially within the first 600 m below the surface (UCS 2006); at the same time, atmospheric humidity has increased over oceans by 4 percent since 1970, because warmer air can hold more moisture, thus creating ideal conditions for storms. Scientific analyses of storm records in the past 30 years have found that the destructive power of storms in the Atlantic and Pacific Oceans has increased by 70 percent (Emanuel 2005) and that the percentage of hurricanes classified as Category 4 or 5 has increased (Webster et al. 2005). If these trends continue (which is very likely, since atmospheric and ocean warming will continue for several more centuries even if greenhouse gas emissions halt immediately), more frequent and more severe storms in the upcoming decades can be expected.

This is bad news for the more than one billion people currently living in the coastal zone worldwide, many of whom are in cities of global economic and strategic significance. Depending on assumptions of migration, this population in the coastal zone is expected to reach up to 5.2 billion within the next 70 years (Nicholls et al. 2007).

One of these economically significant cities is New York City, currently home to nearly 8.5 million people, 1.5 million of whom live on the island of Manhattan. The highest elevation on this island is only 80 m. The New York City area has been devastated by major hurricanes in the past—on average, once every 75 years (Naparstek 2005). The hurricane of 1893 was accompanied by a 10 m storm surge that destroyed virtually every man-made structure in its path through Brooklyn and Queens. Under the impacts of global climate change, so-called 100-year floods will become much more frequent (figure 1). If people continue to add greenhouse gases to the atmosphere at the current rate, they might be as frequent as once a decade in New York City by late in the century (NECIA 2007).

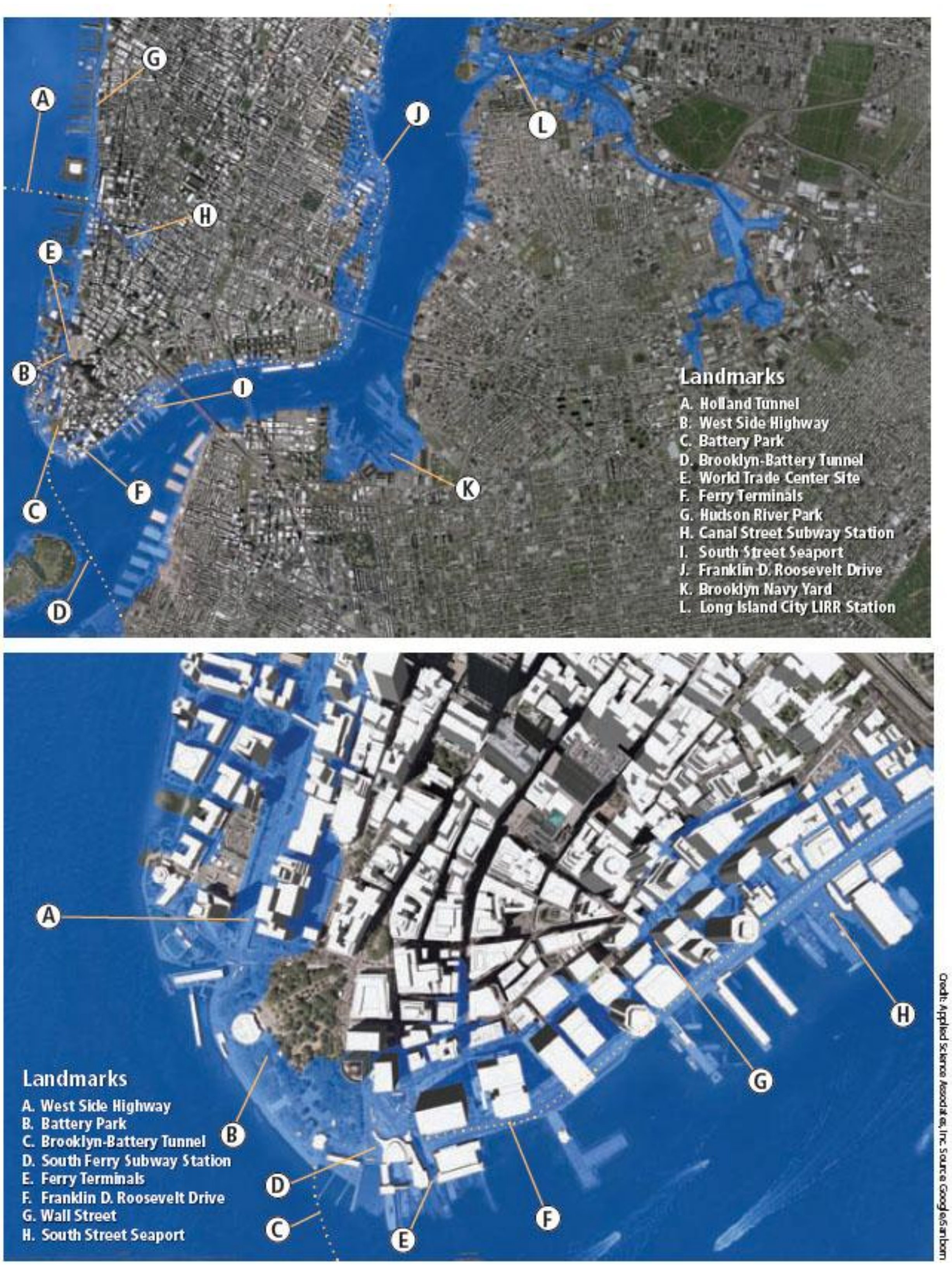

Figure 1: Today's 100-year flood could occur every 10 years under the higher emissions scenario. The light blue area depicts today's 100-year flood zone for New York City (i.e., the area of the city that is expected to be flooded once every 100 years).

With additional sea level rise by 2100 under the higher emissions scenario, this approximate area is projected to have a 10 percent chance of flooding in any given year; under the lower emissions scenario, a 5 percent chance of flooding in any year is expected. As the close-up shows, critical transportation infrastructure located in the Battery could be flooded far more frequently unless protected. The 100-year flood at the end of the century (not mapped here) is projected to inundate a far larger area of New York City, especially under the higher emissions scenario. (Source: Northeast Climate Impacts Assessment 2006 special report on New York State, available at **http://www.climatechoices.org/assets/documents/climatechoices/new-york_necia.pdf** Figure credit: Applied Science Associates.)

Projecting that by 2100, Manhattan, with a population of 3.9 millions (see SpatiaLAB exercise *Population Mapping and Modeling for Manhattan*), will have lost 5% of its current land area to inundation caused by sea level rise (see SpatiaLAB exercise *Impacts of Sea Level Rise on Manhattan)*, this exercise examines the following two questions:

Question 1: *How many people in Manhattan are currently at risk from flooding by a major hurricane?*

Question 2: *How many people in Manhattan could a rising sea level displace by 2100?*

To answer your research questions, you need to first determine the population density on the island for both time periods. Population density then needs to be converted to a measure that is comparable to the 30 m resolution elevation data. Once all datasets line up, you can overlay them and extract the answers to your questions.

COLLECT AND PROCESS DATA

In this exercise, you will analyze the impacts of a hurricane storm surge on the current population (year 2000) of Manhattan. Then, you will determine the impacts of sea level rise on the future population of Manhattan (year 2100) using two different scenarios. The two sea level rise scenarios are based on predictions by the Intergovernmental Panel on Climate Change (IPCC 2007) and consist of a best-case scenario (0.28 m sea level rise) and a worst-case scenario (1.12 m sea level rise; Meehl et al. 2007). Population information can be downloaded in vector format from the US Census Bureau. It was processed in a separate exercise, *Population Mapping and Modeling for Manhattan*, which resulted in a shapefile called *manh_pop* that contains population for 2000 (figure 2a) and 2100 (figure 2b) at the census tract level. Elevation information is in grid format and is available from the US Geological Survey. Data download and processing are performed in the stand-alone exercise *Impacts of Sea Level Rise on Manhattan*, which resulted in several grids: flood stages based on a best-case scenario for sea level rise (0.28 m, *flood_bcs*, figure 2c), worst-case scenario (1.12 m, *flood_wcs*), and 10 m storm surge (*flood_storm*). Thus, before you proceed with this exercise, it is helpful if you complete these other two exercises.

If *manh_pop* is missing population data for 2000, add the *Manh$* worksheet from *Census2000.xlsx* to your map and join it to the cartographic boundary shapefile (*manh_pop*) using *Tract*. Right-click *manh_pop* and select *Join and Relates » Join*. Select *Join attributes from a table*, base the join on the field *NAME*, and use *Manh$* as the table to join and *Tract* as the field on which to base the join. It is also advisable to then export this layer into a new shapefile to make the joined link more stable.

All data must be in the UTM projection Zone 18N using a 1983 datum. Make copies of the following data: *manh_pop*, *flood_storm*, *flood_bcs*, and *flood_wcs* before you begin (right-click the layer you wish to copy and select *Data*, and then *Export Data*) or copy the data in ArcCatalog™.

Never copy grids outside ArcGIS e.g. in Windows Explorer!

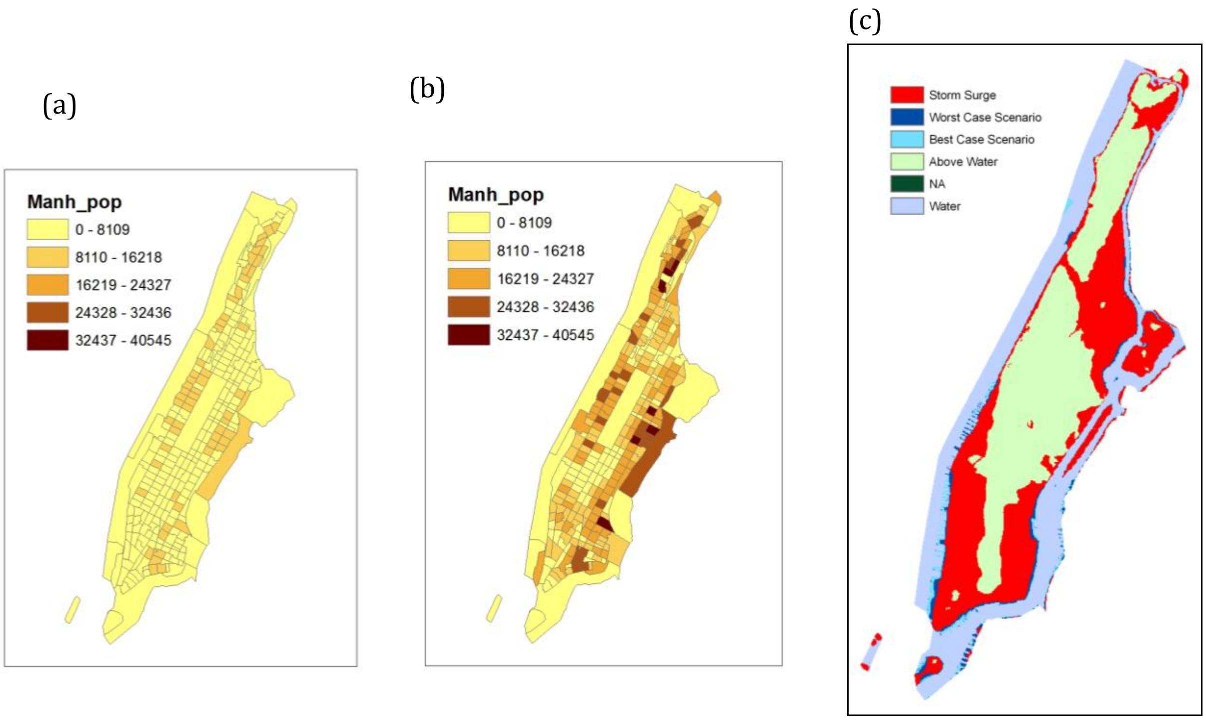

Figure 2: Population of Manhattan by census tract in (a) 2000 and (b) 2100 using five classes with equal intervals; (c) areas subject to flooding due to a hurricane storm surge or two climate change scenarios.

CURRENT POPULATION AT RISK FROM STORM SURGE

First, determine the area within each census tract. This is necessary to calculate population density. Since shapefiles do not have topology, the *AREA* and *PERIMETER* fields do not provide reliable information. You will add the correct area as a new field to the population shapefile *manh_pop*.

1 Before you get started, create a new subfolder in your c:/student folder and call it *AtRisk*. Use ArcCatalog to copy all files necessary for this exercise into *AtRisk;* you need the shapefile *manh_pop* and the following grids: *flood_storm*, *flood_bcs*, *and flood_wcs*.

2 Start ArcMap and add to your map the four files you copied during the previous step.

3 Go to *ArcToolbox » Data Management Tools » Fields » Add Field*.

4 The input table is *manh_pop*; name your new field *Area_m* and use *LONG* field type. Click *OK*.

5 Open the attribute table of the *manh_pop* layer, right-click the *Area_m* field , and select *Calculate Geometry*. Click *Yes* when you are warned that you will be performing a calculation outside of an edit session.

6 Select *AREA* for *Property* and *square meters* for *Units*.

Your *Area_m* values should range from 27,956 to 5,564,903. If your values are completely different, check your units and projection.

7 To calculate population density per cell (where each cell equals 30 by 30 m, or 900 m^2), add another new field called *PDens2000* with *SHORT* field type (*ArcToolbox » Data Management Tools » Fields » Add Field* or click on *Table Options » Add Field* in your open attribute table).

8 Open the attribute table, right-click *PDens2000,* and select *Field Calculator*. Calculate the new field as *([Pop2000] / [Area_m]) * 900* using the buttons on the calculator menu.

9 Change the symbology for *manh_pop* to show *PDens2000* in five classes using the default Jenks classification.

The result should resemble figure 3, with a data range from 0 to 82 persons per 900 m^2.

Next, you will convert the population shapefile to a grid called *PDens2000* using the newly calculated population density per cell as the field.

10 Go to *ArcToolbox » Conversion Tools » To Raster » Feature To Raster* and set *30* as the cell size (to match the elevation file).

Now determine how many people are at risk due to flooding in 2000.

11 Overlay population and flood information using *Raster Calculator* in *ArcToolbox » Spatial Analyst Tools » Map Algebra* (in version 9.x, this menu is accessible from the *Spatial Analyst* toolbar) and compute the following: *"flood_storm" * "PDens2000" / 5*. Save the output raster as *storm*.

You had to divide by 5 because all cells at risk from flooding during a hurricane storm surge were assigned a value of *5* during a previous analysis.

The result can be seen in figure 4. This map was created by using five classes before manually setting *1* as the break value for the first class, converting the labels to integers, and editing the first label manually.

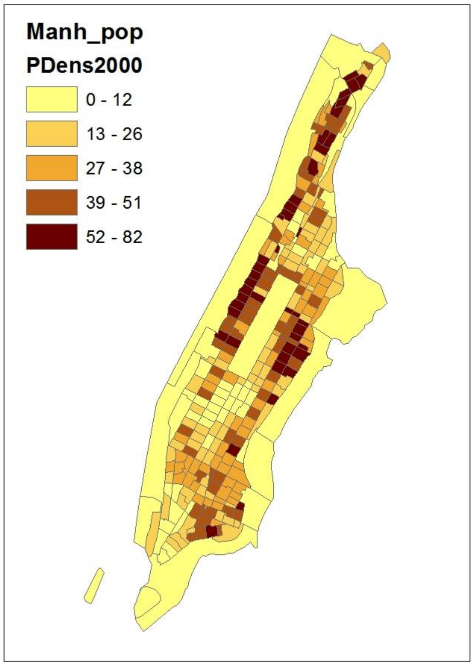

Figure 3: Population density per 900 m^2 for 2000 using five classes.

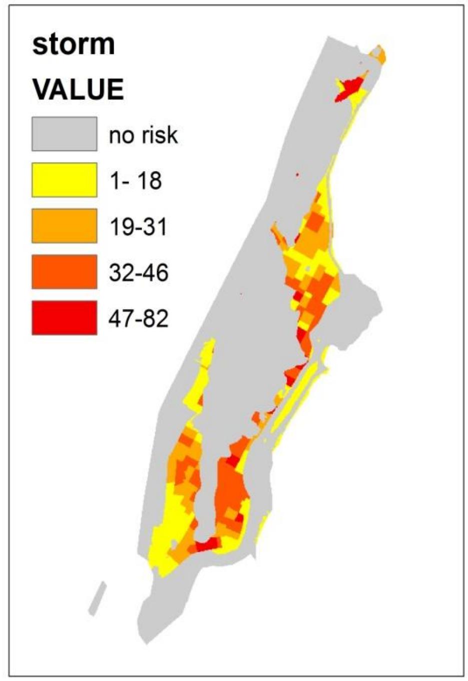

Figure 4: Number of people at risk from flooding after a 10 m storm surge in 2000. Value indicates the number of people per 900 m^2 grid cell.

You can now also calculate the total number of people inundated by a 10 m storm surge using the attribute table of the *storm* file.

12 Export the attribute table to Excel (in the attribute table, select *Table Options* then *Export*), where you can multiply the values in the *count* field with the values in the *value* field, and then calculate the sum of the products.

The value column in this file should range from 0 to 82, while the *count* values should go up to 66,812 (*for value = 0*). The final sum should amount to 644,191 persons currently at risk by a 10 m storm surge.

FUTURE DISPLACEMENT BY RISING SEA LEVELS

To determine population at risk in 2100, you must recalculate the population density field .

1 In ArcMap, add a new field *PDens2100* with *SHORT* field type to the shapefile *manh_pop* (*Data Management Tools » Fields » Add Field*).

2 Open the attribute table and calculate the values in this field with *Field Calculator* as *([Pop2100] / [Area_m]) * 900*. The resultant values in this field should range from 0 to 210 (see figure 5).

3 Convert *manh_pop* to a grid using *PopDens2100* as the field (*Conversion Tools » To Raster » Feature To Raster*) and *30* as the cell size. Call the new grid *PDens2100*.

Note: If your PDens2100 grid shows up blank but lists values ranging from way below zero to way above zero, close your ArcMap document and start a new one.

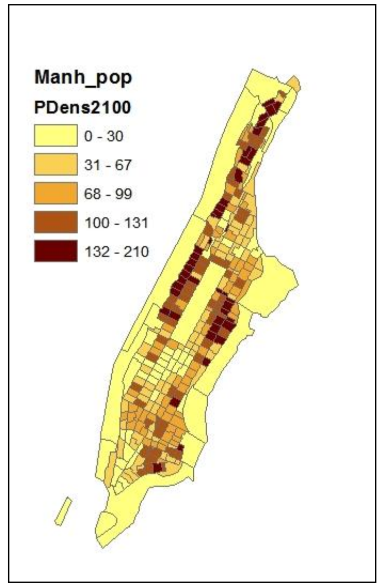

Figure 5: Population density per 900 m^2 in 2100.

4 Use the *Raster Calculator* (*ArcToolbox » Spatial Analyst Tools » Map Algebra*) to determine the population at risk under the best-case scenario (BCS) by typing *"flood_bcs" * "PDens2100".* Name the output raster *BCS*.

No division is necessary in this step, because all cells meeting the criteria for flooding during the BCS were assigned a value of 1 during a previous analysis.

The result shows cells ranging in value from 0 to 143 at risk of flooding. According to the attribute table, 92,670 cells have a value of 0 (no flooding risk).

5 Export the attribute table in dBASE format to Excel and calculate the total number of people at risk as done previously (the sum of the row products). The total number of people at risk should equal 32,996 persons.

6 Repeat the last two steps to calculate total number of people at risk under the worst-case scenario (WCS). The equation in *Raster Calculator* should read *"flood_wcs" * "PDens2100" / 3*, and the output raster is called *WCS* (see figure 7).

You need to divide by 3 because all cells subject to flooding under the WCS were assigned the value of *3* in a previous analysis.

7 Your values should range from 0 to 151, and the attribute table should show that 91,135 cells have a value of 0. Export the data to Excel as before and calculate the total number of people at risk, which should be 70,470 persons.

You are now able to answer your research questions:

Question 1: *How many people in Manhattan are currently at risk from flooding by a major hurricane?*

Answer: If a hurricane were to hit Manhattan with storm surges similar to what was experienced during the 1893 hurricane in Brooklyn and Queens, nearly 645,000 persons would be at risk of inundation. That is based on 2000 census population numbers.

Question 2: *How many people in Manhattan could a rising sea level displace by 2100?*

Answer: Based on a fairly optimistic best-case scenario, which would result in only a 0.28 m sea level rise, nearly 33,000 people will be at risk of inundation. Under a more pessimistic worst-case scenario of 1.12 m sea level rise, nearly 78,000 people will be at risk.

FURTHER ANALYSIS

If you would like to continue along this train of thought, determine how many people will be at risk in 2100 from a 10 m storm surge (which would be in addition to the sea level rise). Another option would be to calculate the people at risk from flooding in Brooklyn, Queens, or Long Island to get a better total for the entire New York City metropolitan area. Similarly, this analysis can be performed for any other coastal US city.

This exercise is based on several assumptions that might or might not be realistic: population is unlikely to continue growing for Manhattan at the rate suggested—some census tracts might simply run out of space for added population, while others might grow faster. Also, the exercise assumes no efforts on behalf of the city to protect low-lying areas from flooding with levees or other structures. Nonetheless, the exercise addresses a very interesting and relevant example of environmental and human interaction. New York City and many other major world cities are very vulnerable to disaster from rising sea levels and storms.

In August 2011, New York City did in fact get hit by a hurricane. Irene thankfully was not as devastating as feared, raising flood levels to only about 4 feet in New York harbor (Barron, 2011). But the city was well prepared: 370,000 people were evacuated from the city alone (more than a million people were evacuated in neighboring New Jersey) before bridges and the subway system closed. Hundreds of thousands of homes and businesses lost power (in many places it had been shut off as a precaution) but otherwise, very few lives were lost.

References

Barron, J. “New York Wakes to Hurricane Irene.” The New York Times August 27, 2011. Available from http://www.nytimes.com/2011/08/28/nyregion/new-yorkers-warned-of-possible-electrical-shutdown.html?_r=1&pagewanted=all.

Church, J. A., and N. J. White. "A 20th Century Acceleration in Global Sea-Level Rise." *Geophysical Research Letters* 33 (2006): doi:10.1029/2005GL024826.

Emanuel, K. "Increasing Destructiveness of Tropical Cyclones over the Past 30 Years." *Nature* 436 (2005): 686–688.

Meehl, G. A., et al. "Global Climate Projections," in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* edited by Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller. Cambridge, UK, and New York, NY: Cambridge University Press, 2007.

Naparstek, A. (2005) Storm Tracker. Available from `http://nymag.com/nymetro/news/people/columns/intelligencer/12908`.

Northeast Climate Impacts Assessment (NECIA). "Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions." Cambridge, MA: Union of Concerned Scientists, 2007.

Nicholls, R. J., P. P. Wong, V. R. Burkett, J. O. Codignotto, J. E. Hay, R. F. McLean, S. Ragoonaden, and C. D. Woodroffe. "Coastal Systems and Low Lying Areas," in *Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by Parry, M. L., O. F. Canziani, J. P. Palutikof, P. J. Linden, and C. E. Hanson. Cambridge, UK: Cambridge University Press, 2007.

Union of Concerned Scientists (UCS). "Hurricanes in a Warmer World." 2006. Summary at `http://www.ucsusa.org/hurricanepower`.

Webster, P. J., G. J. Holland, J. A. Curry, and H. R. Chang. "Changes in Tropical Cyclone Number, Duration and Intensity in a Warming Environment." *Science* 306 (2005): 1844–1846.

Credits

Images

Figure 1: Courtesy of Applied Science Associates, Inc. Wakefield, RI
Figures 2 – 5: Data courtesy of U.S. Census Bureau

Sources of supplied data

flood_bcs, created by the author using data derived from the U.S. Geological Survey, Department of the Interior/USGS

flood_storm, created by the author using data derived from the U.S. Geological Survey, Department of the Interior/USGS

flood_wcs, created by the author using data derived from the U.S. Geological Survey, Department of the Interior/USGS

manh_pop.shp, created by the author using data derived from the U.S. Census

Instructor notes

Updates for 2013

The exercises preceding this exercise which creates the flood files was changed significantly which results in three new flooding grids. This of course, changed the results. Figure 4 of this exercise was replaced but otherwise only minor editing was performed on the text to improve clarity.

Additional information

This exercise is one of three complementary exercises. *Population Mapping and Modeling for Manhattan* estimates the current population of Manhattan and the population for the year 2100. *Impacts of Sea Level Rise and Storms on Manhattan* estimates the land area threatened to flood from climate change-induced sea level rise as well as a hurricane-induced storm surge. *People of Manhattan at Risk* estimates the number of people at risk from hurricane-induced floods and sea level rise now and in 2100.

Data

Startup files are created in *Population Mapping and Modeling for Manhattan* and *Impacts of Sea Level Rise on Manhattan.* It is highly recommended that you work through these two exercises first to gain a better understanding of the thought processes underlying this exercise and the data.