# Coastal Flooding Analysis

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## OVERVIEW

In the aftermath of the deadly Indian Ocean tsunami induced by a magnitude 9.0 earthquake off the shore of Sumatra in late December of 2004, which killed close to 200,000 people, coastal communities have become understandably interested in the potential threat posed by rapid—as well as subtler—flooding events; such an event is certainly far from unique (cf. the article by Shaw *et al.*, *Nature Geoscience*, 2008, to learn about the effects of a similar event upon the Mediterranean in 365 AD, and reasons why this area is of special concern today). According to field measurements performed by U.S. Geological Survey (USGS) scientists in Sumatra less than a month after the tsunami struck, coastal waves up to 30 m in height fed extensive inland flooding roughly 15 m deep. Details about the earthquake and tsunami (and about tsunamis in general) are widely available online, but a few good places to learn more include:

http://walrus.wr.usgs.gov/tsunami/sumatra05/index.html
http://walrus.wr.usgs.gov/tsunami/indianocean.html
http://walrus.wr.usgs.gov/tsunami/index.html

Earthquake-induced tsunamis are certainly not the only way that coastal communities can be threatened by the water bodies to which they are adjacent. Flooding can result from other sources as well, including coastal storm surges, landslide- and impact-generated tsunamis, and/or the indirect effects of global warming, specifically the melting of continental ice sheets in Greenland and Antarctica and concomitant thermal expansion of ocean water as it elevates in temperature.

In this lab you will return to the **ArcGIS 9.2** environment. Using the Spatial Analyst and 3D Analyst capabilities in addition to methods learned in previous labs, you will examine several different flooding scenarios for the Long Beach area of California and assess the human impact of these events. Then, using the results from your analysis, you will calibrate an online flooding resource and use it to examine flooding in a second coastal area of your choice. The analysis is clearly a starting point, and doesn't take into account variations in coastal erosion or a wide array of other factors that would likely exacerbate the impact of the flooding scenarios examined in the lab. However, as has been learned recently from the events following hurricane Katrina's landfall in New Orleans, displacement of a densely populated coastal community from even one area can severely strain hazard management resources nationally, resulting in tragedies that extend well beyond the locally affected region. Assessing the potential for such displacement to even a first order is therefore a valuable exercise.

The data you have available for the Long Beach portion of the exercise includes a 5 m/pixel DEM ("surface") and three shapefiles that contain roads (for reference), city limits and census block data. You will also access high resolution imagery via a website later in the lab.

**Note: This assignment uses a 5 m DEM but can be completed as readily employing DEM data acquired directly from the National Elevation Dataset; other data are also publicly available. All data can also be obtained from the author at egrosfils@pomona.edu, as can the answer key and associated files generated as part of the solution process.**

## PART 1: Working in Spatial Analyst

Copy the data across from the server, load it into ArcMap (starting with the DEM to set the projection, in this case NAD_1927_Albers) and organize the display into a logical form, and then use ArcCatalog and the Attribute tables to get a sense for what information you will have at your disposal. A standard display for topographic data will be a rainbow spectrum, with red at the high end and blue at the lower elevations. Let me know if you can't figure out how to do this.

Once you have a feel for the data, verify that Spatial Analyst is loaded (Tools > Extensions and put a check next to Spatial Analyst) and be sure that the Spatial Analyst toolbar is displayed (View > Toolbars > Spatial Analyst). From the toolbar, select Options from the dropdown menu to configure the analysis for maximum efficiency. On the **General** tab, *Working Directory* should be set to the same location as your data (with no spaces in it anywhere!). On the **Extents** tab, set *analysis extent* to be the same as the layer "Surface" (a DEM). Finally, on the **Cell Size** tab, set the *cell size* to 5 m, i.e. the same as the DEM that will form the basis for much of the analysis.

For fun, you might want to try creating a hillshade image. If you do this, use the defaults and a cell size of 5 m, then set the product to 50% transparency and place it at the top of the raster stack in the Table of Contents. This yields a nice 3D look to the topography that makes it much more pleasing to the eye!

To calculate a flooding extent, select **Raster Calculator** from the Spatial Analyst dropdown menu. This tool is loosely equivalent to the "Select by Attribute" tools you have used before, but when used for our purposes the result will be a new binary raster layer in which the "false" outcome is assigned a value of 0 and the "true" result is assigned a value of 1. To create a new flood region for all elevations less than a specific value, enter a calculation such as "[surface] < x" (where x is the elevation desired, in meters) and the result will be a new raster layer. Note that the outcome from such a calculation is only stored in memory temporarily; if you want to preserve the results for later use, right-click on the Calculation raster that is produced and select **Make Permanent** to save it. Note that the Spatial Analyst dropdown menu also has a tool called *Convert* which will let you transform a raster into a shapefile or vice versa, handy if you want to use the output from a raster calculation to explore other shapefile-based datasets.

To define a shoreline against which future flooding can be assessed, verify that you understand the tools described above (starting with an equation "[surface] <= 0") to create a reference "Flood_0m" raster and then shapefile. How can you set things up so that the "false" outcome is clear, permitting you to see the land surface? Within the DEM study region, calculate the areas (in square kilometers) and relative percentages covered by land and water using both the raster and the derived shapefile, and report all these data in a clearly-labeled table (to which you will add new data later).

## PART 2: Working in 3D Analyst and ArcScene

Once you have created your shoreline, it would be nice to see the area in 3D, much the same way you did for the Mississippi river exercise you have completed recently. Go through the steps you used to turn on and display the Spatial Analyst extension and toolbar, but this time turn the 3D Analyst extension on as well.

Once 3D Analyst is on, there are two buttons at the right hand edge of the toolbar. One looks like a globe, and starts a tool called ArcGlobe that is a precursor to GoogleEarth; we won't use that today. The other, which we'll use for local display, starts a program called ArcScene.

Start ArcScene, then add your DEM raster, the Flood_0m raster, and the Flood_0m shapefile. Turn off everything but the DEM layer, and color code it so that reds are high and blues are low. Next, right click on the DEM raster and select Properties > Base Heights, then select "Obtain heights for layer from surface" and point this to the DEM raster. Click Apply and then Okay. Your DEM display should now be in 3D (grab and rotate, explore how to zoom in and out, etc.) with no vertical exaggeration. To enhance the vertical exaggeration, right click on Scene Layers, select Properties > General, and then select a vertical exaggeration (I recommend 5x). [Note: for the initial 3D rendering a low resolution is automatically used to make rotation and display quick and easy. You can change the resolution of the display by right clicking on the raster in the Table of Contents, selecting Properties > Base Heights > Raster Resolution, and then altering the cell size. The higher the resolution you pick, the better it will look but the more memory will be used and the more odds there are that the program will crash!].

Finally, experiment with the Flood_0m shapefile and Flood_0m raster, again using the DEM layer for the Base Heights, until you have generated a view that does a decent job of conveying the location of the coast in the 3D image. This may require some creativity as you blend fill colors, border colors, etc. in the 3D realm. To get a good product, you may need to generate what you want in 2D using the Raster Calculator before proceeding to the final 3D display.

## PART 3: Assignments – Do #1 and #4, plus ***either*** **#2 or #3**

1. Long Beach Flooding by an Earthquake. (*50 pts*)
    a. Read the article by McCaffrey *et al.* (from the journal *Science*, 2007) describing some of the earthquake-related concerns driving (in part) the current exercise. Assuming flood levels of 5, 10 and 15 m, continue filling out the chart begun earlier for the 0 m flood level (i.e. calculate the flooded and dry areas within the study region, in square kilometers, and the percentages of the total area these represent).
    b. Assess the total population for the study region and the net racial demographics, i.e. create a chart providing totals and percentages for white, black, Hispanic, etc. Be sure to include *only* those census blocks that fall completely within the limits of the area covered by the DEM. Then, for the 15 m flood level, prepare an analysis of the effects on the region's population, once again using total population and racial demographics. Include all demographic regions that **intersect** the flooded area. Would a flooding event of this magnitude have a disproportionate effect on any specific racial groups?
    c. Prepare a single 3D view (you can use the screen capture tool, PrintKey 2000, to snag the final image for inclusion in your lab report) depicting the extent of the 0, 5, 10 and 15 m flood levels in an effective manner. This single view should illustrate the relative flood lines (with Legend to enable telling them apart) and extents, superimposed on the land surface (perhaps transparently?) to the best of your ability.

d. Prepare a thorough 2D Layout map illustrating the 15 m flood and the results of your demographic analysis.

2. Long Beach Flooding by Global Warming. (*25 pts*)

    a. Estimates of global sea level rise by the end of the century peak at ~0.5 m (see http://www.ipcc.ch/ipccreports/assessments-reports.htm), and over the next 1000 years (with a lot of uncertainty!) estimated values approach the 10-15 m level. But, given that ice sheet breakup is already accelerating far more rapidly than models predict, just for "fun" let's examine a worst-case scenario in which all land-based ice has melted due to global temperature increase. In this scenario, some estimates of sea level rise approach 80 m! Add an 80 m flood level analysis case to your table of land/sea percentages.

    b. Assume that the relative population density remains the same as it is now within the study area (i.e., net population might go up and down, but the spatial distribution of the total population remains what it is today). Calculate the percentage of the net study region's population that would occupy the major new offshore island that is created. In addition, what cities will suddenly find themselves beachfront property on the island for the long haul (future real estate speculators take note!)?

3. Long Beach Flooding by Impact Cratering. (*25 pts*)

    a. Small solar system bodies strike the Earth with regularity, and those which hit the sea surface displace water to create—you guessed it—a tsunami. Calculations examining this effect, based on submarine nuclear explosion (and related) data, suggest that a small spherical iron impactor, 40 m in radius (the same size as the body thought to have induced the Tunguska airblast near the start of the 20$^{th}$ century, and moving at a velocity of 20 km/s to yield the same approximate kinetic energy), could do *considerable* damage. Assuming that the impact occurs 200 km off the west coast of the United States, the height of the deep-water wave that would be created is expected to be ~5-6 m, and estimates of the wave height when the coast is reached vary from 56-225 m depending on the details of the wave's interaction with the coastal bathymetry. Add an analysis of the 225 m flood level to your table of land/sea percentages. [Note: in reality the higher frequency wave generated by an impact event will react differently when striking the coast than a standard tsunami, spending more of its energy breaking at the coast and less inundating the interior.]

    b. Assume that the relative population density remains the same as it is now within the study area (i.e., net population might go up and down, but the spatial distribution of the total population remains what it is today). Calculate the percentage of the net study region's population that would occupy the major new offshore island that is created. In addition, what cities will be spared the direct effects of this short-lived flooding event (Survivor fans take note!)?

4. Global Flood Comparison. (*25 pts*)

    A limitation of the analysis provided above is that it is restricted to a single coastal area. Flooding effects however, especially those related to climate change, will be global in extent. Global topography and population datasets are readily available and can certainly be analyzed within ArcGIS (if anyone would like to fiddle with them in ArcGIS let me know, I'd be happy to provide them), but online tools are also becoming available that will let you do some components of the analysis. One example for the flooding process can be found at http://flood.firetree.net/?ll=43.3251,-101.6015&z=13&m=0 , but the question of course is, how accurate is the flooding product produced by this web site?

a. Zoom into the Long Beach area you have just been studying and compare the 10 m flood levels. Does the web site do a solid job? Your answer here should provide images of both, side by side within your Word document, and a documented assessment of the comparison based on these images (augmented with annotation in whatever way seems to make sense to you). Using the hybrid capability of the site and any other resources you wish, can you explore qualitatively the effect such a flood would have on the city's basic infrastructure (hospitals, housing, schools, etc etc.)?

b. Pick any other major coastal city in the world (be sure to tell me city/country!) and use the web site to flood the city to a depth of 10 m. [If you lack inspiration, try Naples, Italy (near Rome) and its population in excess of 1 million residents, which is located between two of the most hazardous volcanic regions on Earth – Vesuvius and the Campi Flegrei complex!] Add before/after images to your report, and use these to compare and then analyze the flooding extent relative to the Long Beach area. For the city you select, can you use the hybrid view to assess the general effect on infrastructure, and if so what can you learn?

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***Extra data, purely for your information (i.e., not needed for the lab):***

Using the Etopo2 & GTopo30 (global topography) and LandScan2002 (population) datasets, a pair of students working with me used ArcGIS to assess global effects of sea level rise on coastal populations to first order, with a specific focus on cities with more than 250,000 residents. They found that:

- For a 1 m sea level rise, ~1.4% of the Earth's current land surface will be flooded, including 87 cities with populations over 250,000 residents and, globally, somewhere in the 14 million persons range. Recently, more sophisticated analyses of similar datasets yielded estimates of closer to 110 million people (see article by Rowley *et al.*, *EOS*, 2007). This is probably the most immediately critical figure, and it helps underscore (albeit to first order) why global sea level rise will become so critical.

  *[To put this into context, the estimated displaced population due to Katrina is roughly 1 million people, though this includes far more folks than those who resided in the directly flooded areas so it's an apples-and-oranges sort of comparison. Think of the effect that this has had on the economy of one of the most strongly rooted countries in the world, and then imagine displacing 10-15x this number of people worldwide. Where would they live? How would the costs be borne? Etc. This, to me, is a very sobering scenario…]*

- For a 10 m sea level rise, the students calculated that ~2-3% of the Earth's current land surface will be flooded, including 144 cities with populations over 250,000 residents and, globally, somewhere in the 30 million persons range.

- For California specifically using these same data, a gentle 1 m rise in sea level would directly affect a few hundred thousand people (~0.6% of the state's population). A similar 10 m rise in sea level would directly affect 6% of California's (2002) population (i.e., a few million people), and in an 80 m rise scenario the Great Valley would flood to form a new inland sea, producing a direct effect on ~30% of the state's population.