Over the last few weeks, many of us have been following the flooding and the human impact resulting from Hurricane Katrina. The Gulf Coast was spared major damage as Hurricane Rita weakened shortly before making landfall. ‘Rita’ was the 17th named tropical cyclone in the Atlantic Ocean of the year, and hurricane season doesn’t officially end until November. The unusually warm waters of the Gulf are helping to fuel the hurricanes and what is happening this year is a preview of what we can expect as global warming intensifies and ocean temperatures continue to rise.

This series of posters is designed to help tell the story of Hurricane Katrina and the vulnerability of New Orleans to hurricanes. It is not intended to focus on the suffering resulting from Hurricane Katrina, although we are well aware of the human toll it is taking. Rather it focuses on the geological setting of New Orleans and illustrates why the flooding was so extensive. It also highlights some of the environmental consequences of the flooding. The last panel describes why we have built levees and channelized the Mississippi River and why this region is subsiding and sinking below sea level. It also explains why the Mississippi River is destined to ‘jump channels’ and take a shorter path to the sea, leaving New Orleans without the very river that has shaped its culture and driven its economy.

In the weeks and months ahead, as New Orleans begins to recover from the hurricane, the question of what to re-build and what not to re-build should be answered taking into account the geological and environmental realities of this situation. As anxious as we all may be to provide homes for the displaced refugees from Hurricane Katrina and re-settle New Orleans, geologists must speak out that now is the time for the development of a comprehensive plan that includes: the creation of reservoirs for water storage to minimize damage during future flooding; re-sedimentation of the coastal marshes and redistribution of sediment carried by the Mississippi River; and confront the reality that someday the Mississippi River will abandon its present channel and switch its path to the sea.

We welcome your questions and comments in response to this series of posters.

Bettina Martinez-Hackert (martinb@buffalostate.edu)
Jill Singer (singerjk@buffalostate.edu)
Hurricane Katrina: A Geological and Environmental Perspective

The Storm

Hurricane Katrina: A Record Breaker

The official hurricane season of the northern hemisphere runs from June to November. During this time, tropical cyclones (also known as tropical depressions, tropical storms, typhoons, or hurricanes, depending on strength and geographical context) form between 8° and 20° latitude (the ‘tropics’) where sea surface temperatures are warm—typically 26.5°C (80°F) or greater. The warmer the equatorial ocean waters and surrounding atmosphere are, the more favorable the conditions become for the development of tropical cyclones (see figure below). The rotation of a tropical cyclone comes from the effects of the Earth’s rotation (Coriolis effect), which has wind directions. A cyclone turns counterclockwise in the northern hemisphere and clockwise in the southern hemisphere.

Hurricane Katrina was the 11th tropical cyclone, 4th named hurricane and 1st category 5 hurricane of the 2005 Atlantic season. It first made landfall as a category 1 hurricane (see figure of hurricane track and table 1) just north of Miami, Florida on August 25, 2005, with 12 deaths attributed to the storm. After leaving Florida, Katrina intensified as it moved across the Gulf of Mexico (see figure of storm path), making its second landfall on August 29 along the Central Gulf Coast near New Orleans, Louisiana. Offshore, Katrina reached wind speeds over 155 miles per hour (category 5); just before making landfall it weakened slightly to category 4. The storm surge, rain, and consequent flooding of New Orleans and other Gulf Coast cities combined to make it the most expensive (estimates over $200 billion in damage), destructive (more than one million people displaced) and fatal (estimated death tolls are >1080 dead) natural disaster in US history.

Storm Surge: More Damaging than High Winds and Rain

As a hurricane moves closer to land, coastal communities begin to feel the effects of heavy rain, strong winds, and tornadoes. However, the greatest amount of damage due to hurricanes is the result of the storm surge. Strong onshore winds push the ocean surface ahead of the storm, piling up the water (see figure). The height of the storm surge in any particular area is determined by the slope of the continental shelf (the gently sloping region that begins at the edge of land). The continental shelf along the Gulf Coast region is gently sloping, a profile that favors the formation of especially large storm surges. Storm surges are generally responsible for the extensive damage and destruction to marinas, piers, boardwalks, houses, and other shoreline structures. Powerful storm surges also cause heavy erosion to protective marshes, beaches, and sand dunes and are capable of washing out coastal roads and railroads. Their nature is comparable to the inflow of water that occurs during tsunamis.

Louisiana State University (LSU) researchers developed a storm surge model (see figure above) that predicted water heights for a category 3 hurricane. The model was proven correct in its prediction because the areas in red were indeed the coastal areas most severely impacted by the rising storm surge (red on map to the right).

Table 1: The Saffir Simpson Scale for classifying hurricanes

<table>
<thead>
<tr>
<th>Category</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind speed (mph)</td>
<td>74-95</td>
<td>96-110</td>
<td>111-130</td>
<td>131-155</td>
<td>&gt;155</td>
</tr>
<tr>
<td>Storm surge (ft)</td>
<td>4-5</td>
<td>6-8</td>
<td>9-12</td>
<td>13-18</td>
<td>&gt;18</td>
</tr>
<tr>
<td>Damage</td>
<td>minimal</td>
<td>moderate</td>
<td>extensive</td>
<td>extreme</td>
<td>catastrophic</td>
</tr>
</tbody>
</table>

www.earthobservatory.nasa.gov

Image Credits:
- (top left) Illustration depicting development of a storm surge pushed to shore by high winds (www.nasa.gov)
- (bottom left) Illustration showing that the height of a storm surge increases as it approaches shore (www.noaa.org)
- (right) Storm surge model for a category 3 storm (www.noaa.org)

Image Credits:
- (top left) Satellite image of Hurricane Katrina over the Gulf of Mexico on August 27, 2005 (www.nasa.gov); (above) Infrared Image of Hurricane Katrina (University of Wisconsin (CIMSS)); (below) Illustration of Hurricane anatomy with orange arrow showing hot air rising and blue arrow showing rain rich cooling air (www.nasa.gov), and (below left) Track of Hurricane Katrina showing wind strengths (category levels) (www.noaa.gov.)

- (above) Sea surface temperature map for September 27, 2005 showing elevated temperatures for the entire equatorial region. (www.weather.unisys.com)

- Image credits: Illustration depicting development of a storm surge pushed to shore by high winds (www.nasa.gov)

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New Orleans: A Sinking City

New Orleans is sandwiched between levees and embankments that have been built along the Mississippi River and the southern shore of Lake Pontchartrain. As a result of being surrounded by these man-made structures, New Orleans sits in a bowl-shaped depression (figure above), with much of the city at or below sea level. Levee heights vary, but average around 16 feet—a height sufficient to withstand hurricanes of category 3 or less. Models predicted that these structures were insufficient to withstand a more powerful category 4 or 5 hurricane (or even a slow moving category 3 hurricane). Recently, some levees were raised and widened. A number of researchers, including some very vocal faculty at LSU, warned that the levees did not offer adequate protection for New Orleans. Unfortunately, the price tag for levee strengthening and improvement was/is very high and the resources necessary were not budgeted. So, as Katrina approached the Gulf Coast, many experts’ worst fears were realized.

A major cause of the subsidence (sinking) of New Orleans is the channelization of the Mississippi River and the compaction of the sediment in the Mississippi delta region. The sediments carried by the river are being transported offshore into deeper waters of the Gulf of Mexico and lost from the nearshore coastal zone. This is sediment that normally would be redistributed within the flood plain of the river and replenishing sediment to the coastal marshes. As a consequence, the entire region is sediment-starved and eroding. As the coastal marshes are being lost (see figure on panel 5), so goes nature’s buffer zone and first line of protection from storms. Consequently, powerful storms making landfall no longer dissipate their energy in the low-lying coastal plain, but instead release their energy on vulnerable cities such as New Orleans, Gulf Port and Biloxi.
Hurricane Katrina: A Geological and Environmental Perspective

The Extent of the Damage

One day after Katrina hit, 80% of the city was flooded. As seen in the satellite pictures below, what once was a golf course with ball fields turned into a lake and streets became canals. In some areas, only the rooftops of houses remained above water. The strong winds caused severe destruction to buildings. The Superdome, used as a temporary shelter, was damaged by the winds (see before and after satellite images below). Electricity was cut off by the winds and the flooding and repairs will take several months (or even longer). Major highways in/out of New Orleans were destroyed or severely damaged (see picture of Highway 10 to the right). Almost all of the eastern Gulf Coast region suffered significant damage from storm surges, displacing or razing many homes, hotels, casinos and roads (see picture of displaced casino to the right).

One month after Katrina made landfall, the city of New Orleans is still struggling to recover. The greatest damage resulted from the levee breaks and the mixing of floodwaters with every possible household and industrial chemical. The result in some New Orleans neighborhoods was 20 feet of standing contaminated water. Additionally, the already anxious residents and business owners of New Orleans that had returned in the days following Katrina were evacuated again when Hurricane Rita (a hurricane the size and strength comparable to Katrina) appeared to be heading toward New Orleans. Rain from Hurricane Rita caused a just-repaired levee to fail again, re-flooding parts of the city.
Hurricane Katrina: A Geological and Environmental Perspective

Draining the City
Because New Orleans sits in a depression, pumping stations and an elaborate system of canals are needed to continuously remove rainwater from city streets and neighborhoods. Following Katrina, the pumping stations were flooded and without electricity, so stagnant floodwaters remained for weeks. Even if the pumps had remained in working order, their pumping capacity could not have avoided some flooding damage to the city. Immediate efforts took place to repair the broken levees and to pump out water into Lake Pontchartrain. Initial estimates of taking months to pump the city dry have been revised downward to a couple of weeks. Pumping was interrupted after Hurricane Rita’s storm waters breached an already repaired levee. Two days later the pumps were running again.

The Stagnant Waters
During the time it took to bring the pumps back on-line, water mixed with all types of chemicals (e.g., cleaning agents, paint thinners, chlorine bleach, insecticides and herbicides), lead, spills from an oil refinery, and an oil production facility, gasoline and oil from vehicles and generators, and raw sewage. Adding to this toxic brew are organic material, plants, soils, perished animals, even the grocery store’s vegetables and fruits, meats and cans that deteriorated in the waters. These and other materials combined to contaminate the water with different types of bacteria, among them E. Coli. Chemical sampling was performed by the USEPA for over one hundred pollutants. Results from these analyses were compared to various Agency for Toxic Substances and Disease Registry (ATSDR) and EPA health levels and led to the issue of warnings that even touching the water was dangerous. One study by microbiologist Paul Pearce found the total sewage bacteria in a water sample from New Orleans’ Ninth Ward to be 45,000 times what would be considered safe for swimming in a pond or a lake. The Ninth Ward was one of the city’s hardest-hit neighborhoods. To more fully appreciate the impact of contamination on the city’s drinking water, the EPA to the left shows the location of damaged drinking water facilities.

Realities of Rebuilding New Orleans
As New Orleans attempts to rebuild, investigations will likely focus on the city’s reliance on levees and the wisdom of rebuilding in some areas of the city. Before rushing to rebuild the city must confront several lingering problems: 1. determination of why some levees failed as a result of their foundations being undermined, 2. ways to create flood protection through a reservoir system capable of temporarily storing flood waters, and 3. ways to stage intentional breaks in the Mississippi levee system to allow natural replenishment of sediments within the region.
Hurricane Katrina: A Geological and Environmental Perspective

Controlling Nature

Why Hold the Miss to its Present Channel?

It is not unusual for large river systems to migrate within a broad region known as a flood plain (figure to the right). Over time, a meandering river tends to shift its course always trying to find the steepest and shortest path to its mouth. Since the last time the Mississippi River changed paths, the city of New Orleans was established, as well as numerous petrochemical refineries and other water-dependent industries were built along its banks. New Orleans depends upon the river for its source of drinking water, industries for its processing water, and the shipping the economic survival of this area all require that the river ‘hold its course’.

The group charged with “controlling nature” was the Army Corps of Engineers and to achieve this, they have built a number of control structures along the Mississippi River. The largest and best known is the Old River Control Structure (see arrow in top left figure and close-up figures below and to the right) located ~150 miles upstream from New Orleans and near Baton Rouge, LA. This structure has been able thus far (albeit a few close calls during the early 1970s when massive flooding on the Mississippi almost took out the low structure—an event described by John McPhee in his essay on the Atchafalaya River in “The Control of Nature”) been able to keep the Mississippi from jumping channels to flow down the Atchafalaya—a much steeper gradient river that offers a much shorter path to the Gulf of Mexico.

With the destruction from Katrina, some questions have been raised about the eventual shifting of the Miss and how this should be considered when rebuilding New Orleans. Whether the shifting occurs now, or sometime in the future, most geologists agree that the control structures are buying time, but will probably not prevent the channel switching from eventually happening.

Why is New Orleans Sinking?

Over 1000s of years the Mississippi River’s channel has migrated (see lobes in the diagrams below) that show the former location of the mouth of the Mississippi, carrying and distributing sediment to the entire region. As the land would compact and sink under the weight of the sediment, the river mouth would migrate yet again bringing a new supply of sediment. Over long periods of time, the rate of sinking is balanced by the influx of new sediment, so land remains at the same level. But once we settled this region, we confined the Mississippi to its channel to prevent flooding and prevent it from switching paths to the sea. As the levees grew wider and higher (see diagrams), we increased the severity of flooding in places where the levees were breached. The channelization of the Mississippi River has caused the formation of its ‘bird foot’ delta (see figure) that now extends tens of miles into the Gulf of Mexico. There no longer is a way for sediment to be distributed in the entire area and sediment carried by the river (see blue areas in color-enhanced satellite images) is now entering the Gulf of Mexico at depths so great that much of it is lost from the coastal/near shore sediment system. The region, including the coastal marshes, is now ‘sediment-starved’ and the rate of subsidence (sinking) outpaces sedimentation. The loss of the protective coastal marshes makes the Gulf Coast vulnerable when powerful storms/hurricanes hit the coast and storm surges spread water into the low-lying coastal plain communities of New Orleans and Gulf Port, Mississippi.

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100+ Years of Land Change for Coastal Louisiana

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