Monitoring Hurricane Rita Inland Storm Surge

By Benton D. McGee, Roland W. Tollett, and Burl B. Goree

Pressure transducers (sensors) are accurate, reliable, and cost-effective tools to measure and record the magnitude, extent, and timing of hurricane storm surge. Sensors record storm-surge peaks more accurately and reliably than do high-water marks. Data collected by sensors may be used in storm-surge models to estimate when, where, and to what degree storm-surge flooding will occur during future storm-surge events and to calibrate and verify storm-surge models, resulting in a better understanding of the dynamics of storm surge.

Introduction

Storm surge associated with hurricanes occurs when winds push water up onto the shoreline. Storm surge can be intensified by sustained winds, low barometric pressure, excessive rainfall, and high tides (*http://geology.com/articles/storm-surge.shtml*, accessed September 11, 2006). Historically, the magnitude of hurricane storm surge has been measured by using water lines, called high-water marks, left behind by flood waters. Identifying and qualifying high-water marks and determining how well these marks represent the peak are often subjective. The quality of the high-water mark depends upon the type of mark, such as debris, seed, mud, or stain, and on whether the mark was created in a protected environment, such as the interior wall of a building, or in an unprotected environment, such as an exposed bridge piling or fence post. High-water marks do not record the date and time of their creation nor do they record the duration of the storm-surge event.

Methods

In the days prior to the landfall of Hurricane Rita (fig. 1), an experimental water-level and barometric pressure sensor network (fig. 2) was deployed to record the magnitude, extent, and timing of inland storm surge and coastal flooding in the monitored area along the Louisiana and Texas Gulf Coast. East of Rita's storm path, sensors recorded storm-surge water levels over 14 ft (4.3

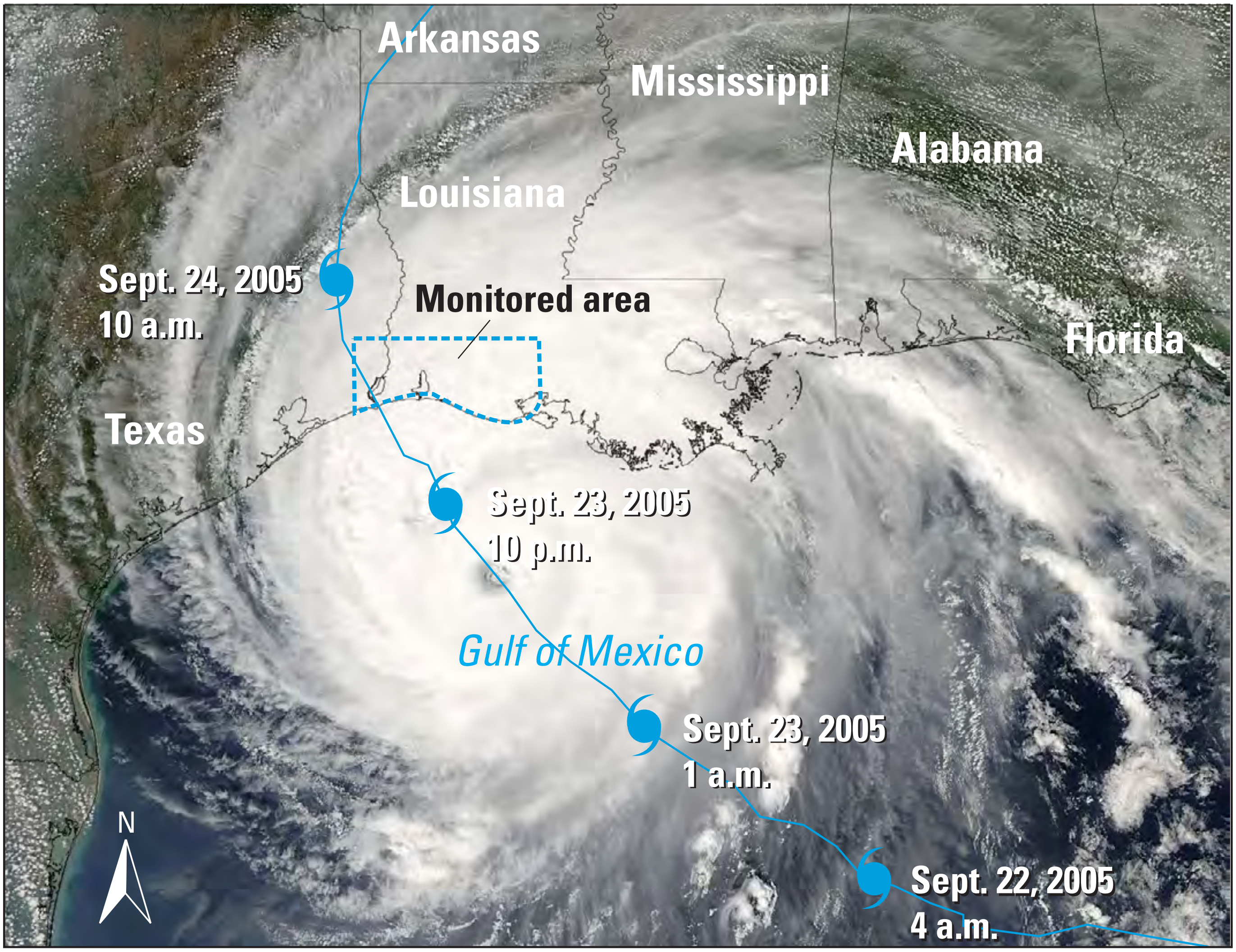

Figure 1. Map showing path of Hurricane Rita and study area (Hurricane Rita satellite imagery obtained from the National Aeronautics and Space Administration, 2006).

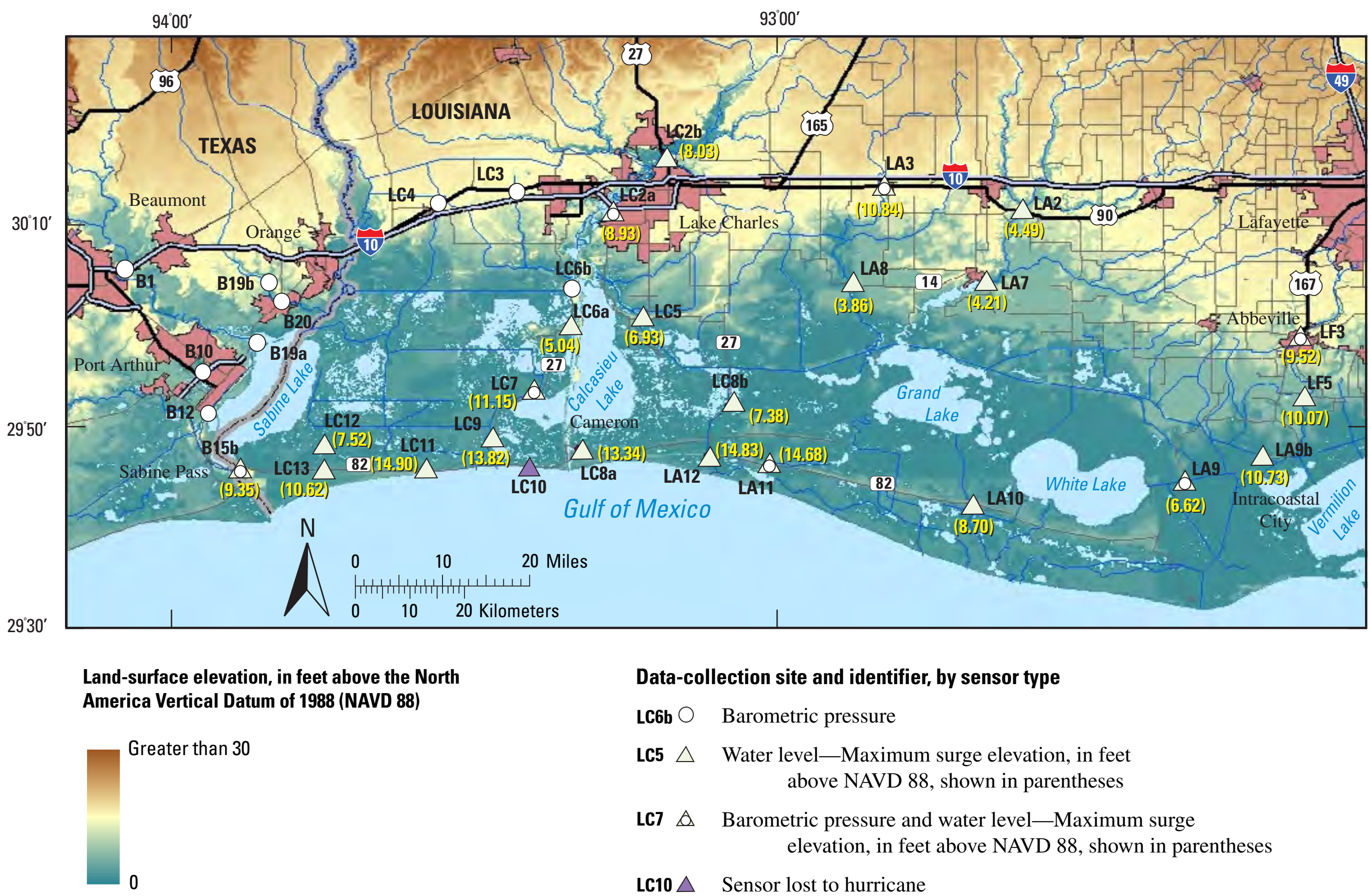

Figure 2. Map showing locations of storm-surge sensors in southwestern Louisiana and southeastern Texas. Maximum storm-surge elevation measurements are shown in yellow.

m) above the North American Vertical Datum of 1988 (NAVD 88) along the Louisiana Gulf Coast and rates of water-level rise in excess of 5 ft (1.5 m) per hour. Comparisons between high-water marks and water-level data from nearby inundated sensors indicated that the sensors recorded storm-surge peaks more accurately and reliably than did high-water marks. Data collected by the storm-surge sensors may be used in computer models (1) to estimate when, where, and to what degree storm-surge flooding will occur in future events and (2) to calibrate and verify storm-surge models, resulting in a better understanding of the dynamics of storm surge.

The study area was situated east of Rita's storm path (fig. 1), in the right front quadrant of the storm, where the maximum storm surge was expected to occur. The monitored area covered approximately 4,000 mi^2 (10,360 km^2) and was generally bounded to the north by Interstate 10 (I-10), to the south by the Louisiana and Texas coastlines, to the east by the Vermilion River, and to the west by the cities of Beaumont, Orange, and Port Arthur, Tex. A total of 47 sensors (34 water-level sensors and 13 barometric pressure sensors) were deployed at 33 sites during September 22–23, 2005, prior to the landfall of Rita (fig. 2). Sensors were deployed along and inland of the Louisiana and Texas coasts, usually along waterways, from Sabine Pass, Tex., through Abbeville, La.

The sensors were unvented pressure transducers capable of measuring and recording three parameters: absolute pressure, temperature, and internal battery voltage. Absolute pressure is the force exerted by air (barometric pressure) or water on the sensor. The force, or weight of water is converted to the height of water (water level) overlying the sensor. Inundated sensors were used to record storm-surge water levels, and noninundated sensors were used to record barometric pressure. Water-level data from inundated sensors were corrected for changes in barometric pressure by using data from a colocated barometric pressure sensor. If a barometric pressure sensor was not colocated with a storm-surge sensor, the data from the nearest barometric pressure sensor were used to correct the storm-surge data.

The sensors recorded temperature and pressure every 30 seconds during the storm and for several days afterwards. The dimensions of the sensors were approximately 6 inches (15.2 cm) in length and 1 inch (2.5 cm) in diameter (fig. 3) and were encased in 1.5 inch (3.8 cm) by 18 inch (45.7 cm) metal pipes and strapped to permanent objects, such as piers and power poles (fig. 4). Storm-surge sensors were deployed on permanent structures at elevations that would likely be inundated by storm surge, and barometric pressure sensors were deployed on permanent structures at elevations that would not likely be inundated by storm surge.

Water-level data from inundated sensors also were corrected for salinity because salinity content increases the density, and therefore the weight, of the water. Corrections for salinity were based upon the location of the sensor in proximity to the coast. In general, sensors located in the southern part of the study area were categorized as measuring

Figure 3. Photograph showing sensor used to record water level and barometric pressure.

Figure 4. Photograph showing metal pipe containing a water-level sensor or barometric pressure sensor strapped to a power pole.

salt water, sensors located in the northern part of the study area were categorized as measuring freshwater, and sensors located in the middle were categorized as measuring brackish water.

Elevation surveys were conducted to relate all storm-surge data, including water-level data from inundated sensors, high-water marks, and water-surface measurements, to sea level (sea level defined by the NAVD 88) (*http://www.ngs.noaa.gov/PUBS_LIB/NAVD88/navd88report.htm*, accessed September 11, 2006). Elevation surveys were conducted by using the Global Positioning System and differential levels.

Quality assurance measures included (1) placing multiple sensors at a site, (2) placing a sensor near an existing U.S. Geological Survey (USGS) stream gage, and (3) manually measuring water-surface levels from reference marks. Multiple storm-surge sensors were deployed at two sites (three sensors at site LF3 and two sensors at site LA7) to assess the variability between individual sensors. Sensors were deployed at two existing USGS stream gages (one each near sites LA2 and LA8) to assess the variability of water levels measured at sensors and USGS stream gages. Water-level data collected by multiple sensors agreed closely with each other (fig. 5), and sensors agreed closely with water-level data from USGS stream gages (fig. 6), as evidenced by the overlying plots of the sensor and USGS stream gage data during periods of sensor inundation.

Water-surface levels, commonly referred to as "tape downs," were determined by measuring the distance from a reference mark, such as a bridge railing or pier surface, to the water surface at a specific date and time. Tape downs were made at seven sites, namely LA2 (fig. 6), LA3, LA9, LC2a, LF3 (fig. 5), LC5, and LC8b, and all agreed closely with sensor data.

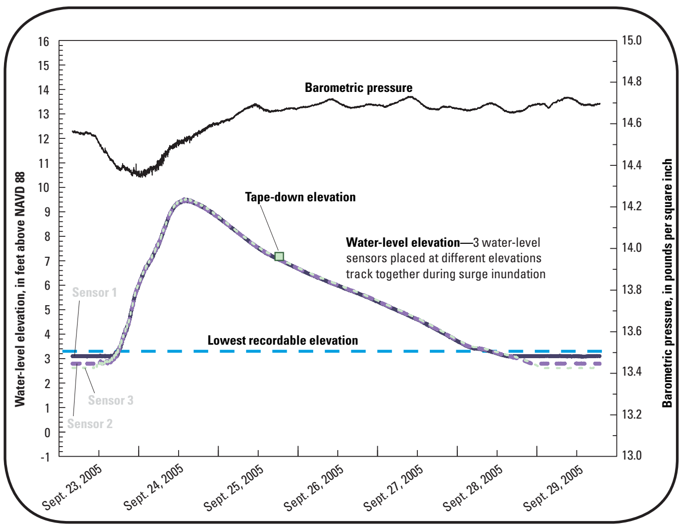

Figure 5. Hurricane Rita storm-surge data at site LF3a. The graph shows water-level elevations above North American Vertical Datum of 1988 (NAVD 88) from multiple storm-surge sensors and tape-down measurement.

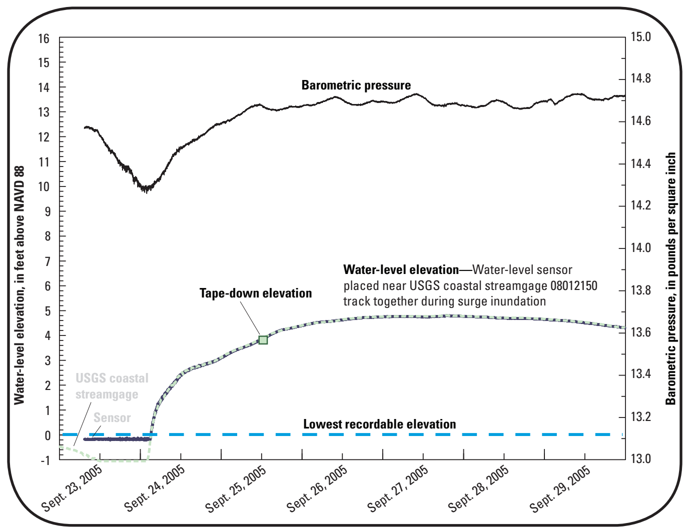

Figure 6. Hurricane Rita storm-surge data at site LA2. The graph shows water-level elevations above North American Vertical Datum of 1988 (NAVD 88) from storm-surge sensor and U.S. Geological Survey stream gage and tape-down measurement.

Results

High-water marks were identified and surveyed at seven sites, namely LA9b (fig. 7), LA12, LC2b, LC5, LC7, LC8a (fig. 8), and LF5, and were compared with nearby sensor data. Comparisons between high-water marks and storm-surge peaks from inundated sensors varied. In general, high-water marks of high quality agreed closely with the storm-surge peaks from the sensors, while high-water marks of lesser quality were consistently lower than the storm-surge peaks from the sensors. For example, the high-water mark near site LA9b (fig. 7) rated as "excellent" was approximately 0.2 ft (6.1 cm) lower than the storm-surge peak from the nearby storm-surge sensor, the high-water mark near site LC8a (fig. 8) rated as "good" was approximately 1 ft (30.5 cm) lower than the storm-surge peak from the nearby storm-surge sensor, and the high-water mark near site LF5 rated as "poor" was approximately 1.9 ft (57.9 cm) lower than the storm-surge peak from the nearby storm-surge sensor.

Conclusion

Sensors recorded storm-surge water levels over 14 ft above NAVD 88 at Constance Beach (LC11), Creole (LA12), and Grand Chenier (LA11), La., about 20 mi (32 km), 48 mi (77 km), and 54 mi (87 km), respectively, east of Sabine Pass, Tex., at approximately 2 a.m., September 24, 2005 (fig. 2). In general, storm-surge water levels increased eastward from the Sabine River into southwest Louisiana. The magnitude of the storm surge was greatest near the coast and decreased inland through the approximate latitude of I-10, about 35 mi (56 km) inland from the coast (fig. 2). Sensors reported rates of water-level rise during the storm-surge event in excess of 5 ft (1.5 m) per hour at sites LC8b, LC9, and LC13. By using data from the sensors and digital land-surface elevation data, a computer-generated map of storm-surge depth (fig. 9) in the monitored area was created and indicated over 13 ft (3.9 m) of water depth at 3 a.m. on September 24, 2005, along parts of the Gulf Coast of southwestern Louisiana (Dean Gesch, U.S. Geological Survey, written commun., 2006).

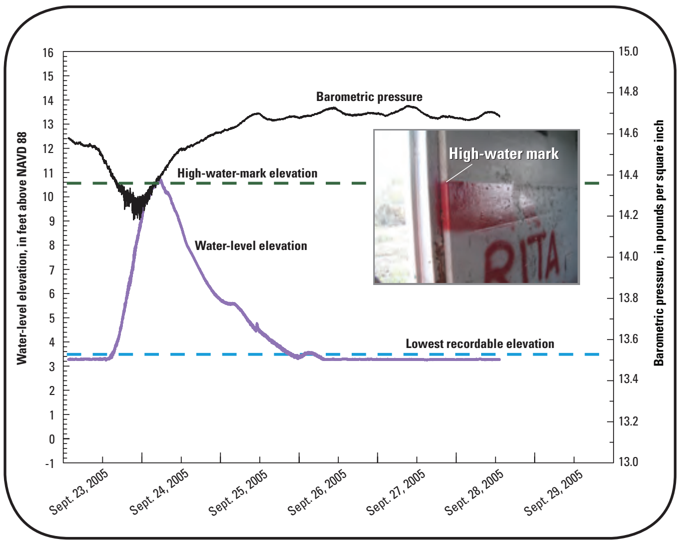

Figure 7. Hurricane Rita storm-surge data at site LA9b. The graph shows water-level elevations above North American Vertical Datum of 1988 (NAVD 88) from storm-surge sensor and high-water mark of excellent quality.

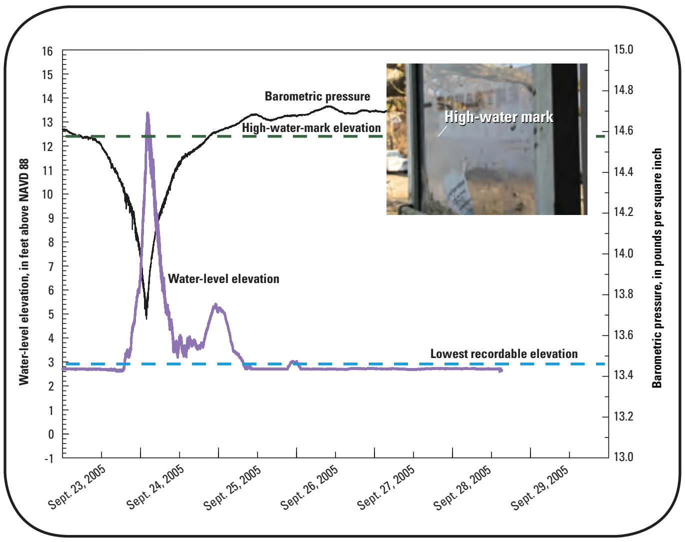

Figure 8. Hurricane Rita storm-surge data at site LC8a. The graph shows water-level elevations above North American Vertical Datum of 1988 (NAVD 88) from storm-surge sensor and high-water mark of good quality.

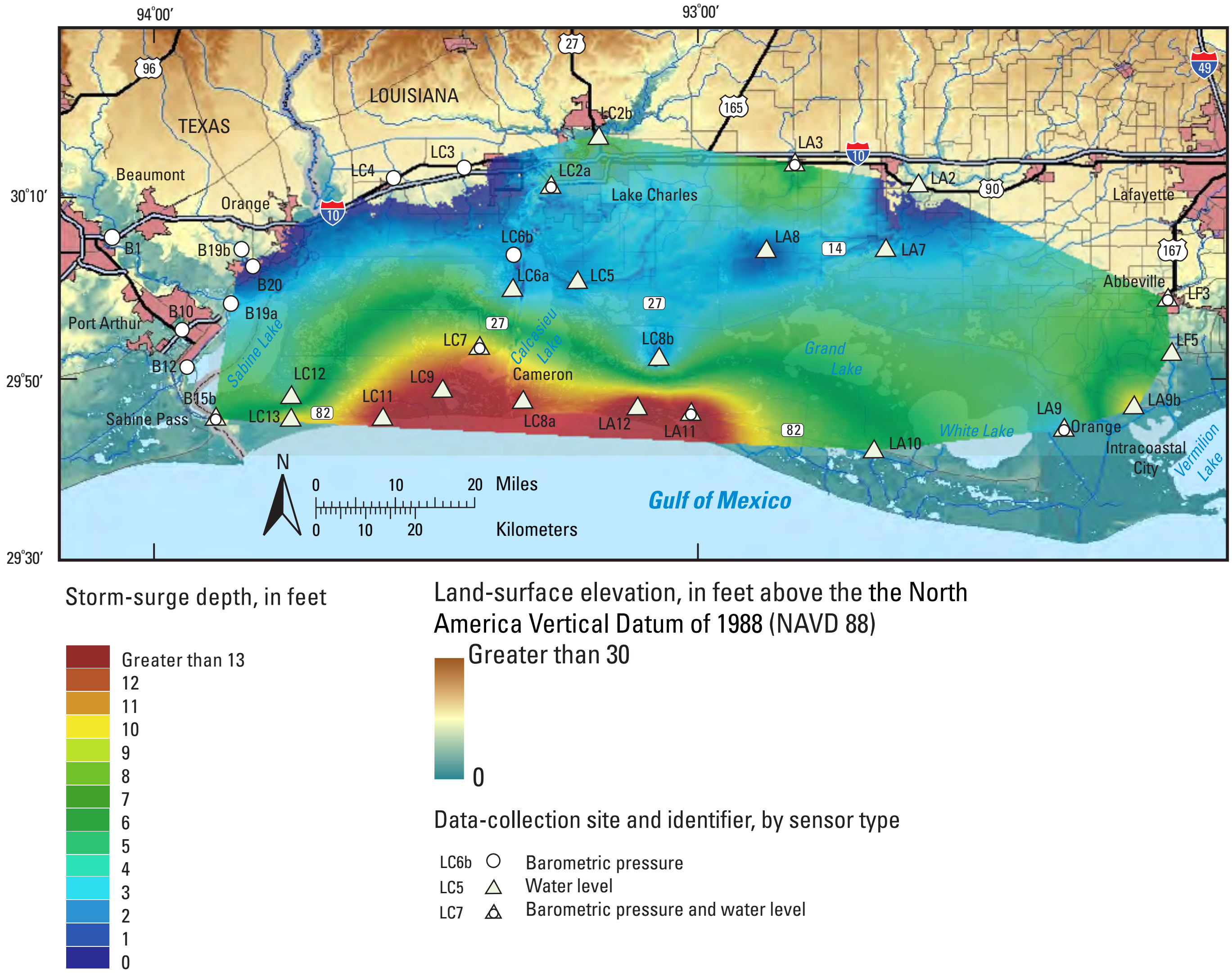

Figure 9. Map showing locations of storm-surge sensors and computer-generated storm-surge depth, in feet, on September 24, 2005, at 3 a.m. in southwestern Louisiana and southeastern Texas.

Contact Information

Benton D. McGee, Supervisory Hydrologist (*bdmcgee@usgs.gov*);
Roland W. Tollett, Hydrologist (*rtollett@usgs.gov*); and Burl B. Goree, Hydrologic Technician (*bbgoree@usgs.gov*)

U.S. Department of the Interior

U.S. Geological Survey

Louisiana Water Science Center

3535 S. Sherwood Forest Blvd., Suite 120

Baton Rouge, LA 70816