A High-reliability System for Capturing Hurricane Wave Data

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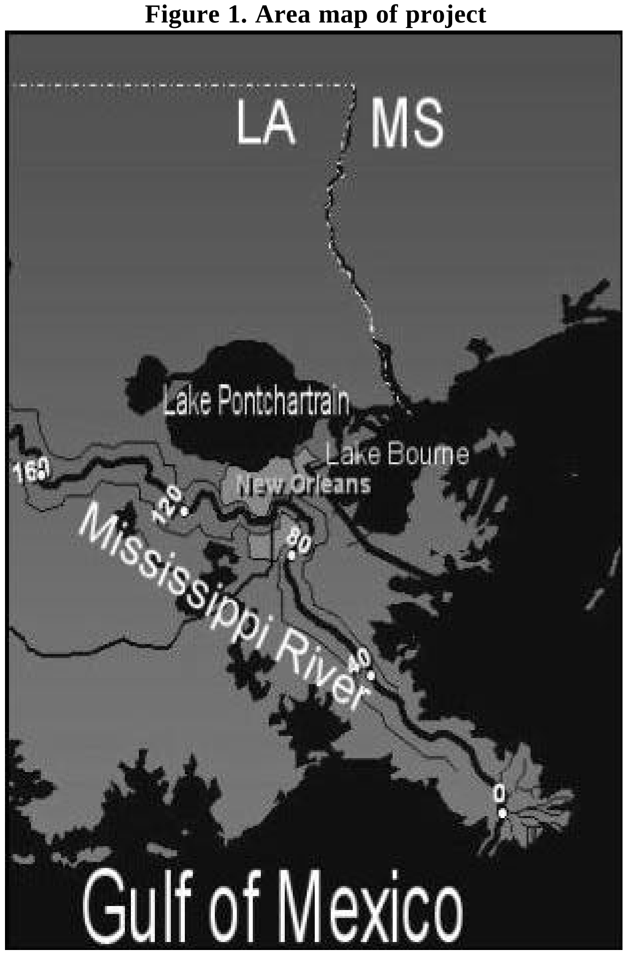
Abstract
The New Orleans District of the Corps of Engineers requires measurements of extreme wave conditions incident to the south shore of Lake Pontchartrain. The data is required to validate the method of selecting wave parameters that are used as input to wave runup models. Wave runup is a critical design parameter for the lakefront hurricane protection structures, principally levees and floodwalls, which protect the city of New Orleans from inundation. The challenge is developing a costeffective measurement system that maintains a constant state of readiness between hurricane strikes on the Lake (perhaps decades), becomes operational within hours, and performs flawlessly under violent environmental conditions. Functional requirements of the system, including hardware, operations plan, and data products are examined. Permanently mounted and eventdeployed gages are considered. The optimal system was selected and will be evaluated through a test deployment.

INTRODUCTION

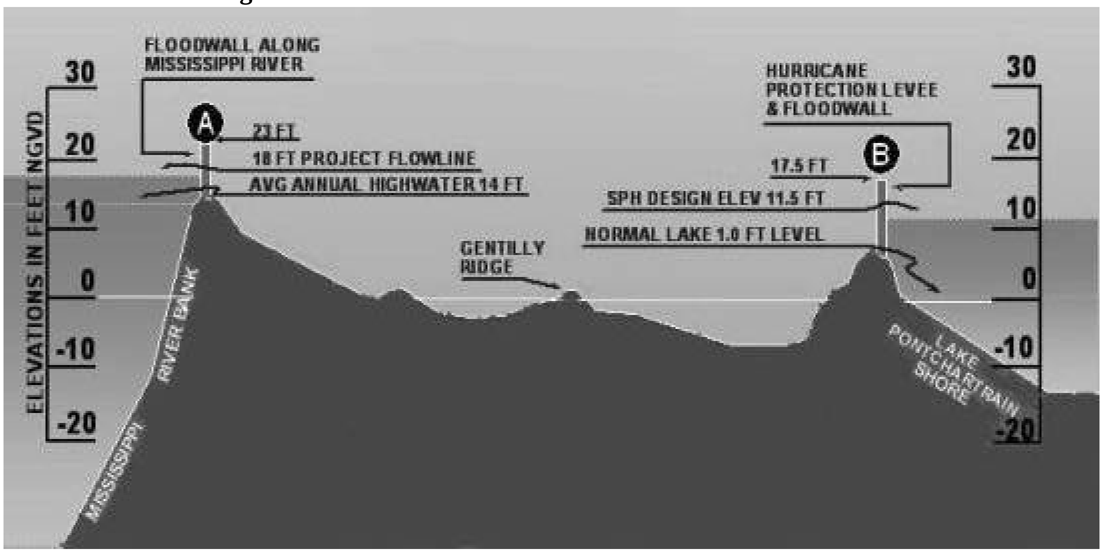
New Orleans is situated between the banks of the Mississippi River and Lake Pontchartrain about 161 km upriver from the Gulf of Mexico (Figure 1). The metropolitan New Orleans area is in a very tenuous position with regard to potential inundation from extreme hurricane storm surge. Perhaps the greatest vulnerability is along the Lake Pontchartrain lakefront levees. Lake Pontchartrain is a shallow lake with an average uniform depth of approximately five meters. It is slightly less than 40 kilometers across the lake in the critical north south direction. The worse case scenario is for strong easterly and northeasterly hurricane winds to persist pushing Gulf waters into Mississippi Sound and Lake Bourne. The head difference and duration would allow for significant volumes of water to flow through the passes connecting Lake Bourne and Lake Pontchartrain. The average water level in Lake Pontchartrain could rise several meters. The critical hurricane path is for the wind direction to quickly change so that intense hurricane winds are out of the north and then push the elevated waters of Lake Pontchartrain over the lakefront levees.

Figure 1. Area map of project



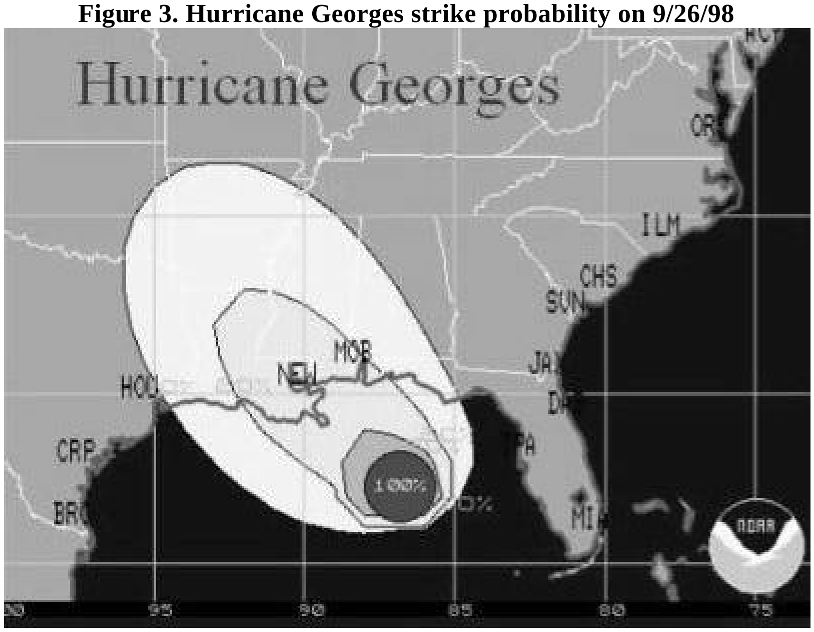
There is little doubt among hurricane observers that a category five storm on such a critical path would result in inundation and thus desolation for the metropolitan New Orleans area. Significant portions of the area are at or below sea level (see Figure 2). The area is protected by a series of ring levees. Interior drainage is provided by means of numerous large pumping stations. Many of the pump stations are at a low elevation. It is feared that if the area is inundated by storm surge, the pumps would fail when components are shorted by flood waters.

Figure 2. Cross-section of New Orleans with elevations in ft



Hurricane protection projects are designed for the Standard Project Hurricane (SPH) which in the case of the New Orleans area translates into a storm with roughly strong category two winds. Project construction is ongoing with numerous required levee lifts and considerable subsidence. Because of the enormous cost involved in the construction of the hurricane protection system, the District continually seeks refinements in the design methodology. The design height of the levees is determined by the maximum wave runup from the design wave. The design wave is that which would result from SPH conditions. In the past, empirical equations were used to predict wave parameters. These equations involved simplifying assumptions such as constant depth, constant sustained wind speed, etc. Presently, there are numerical models that will solve for greater complexity involving variable geometry and wind. These models can provide elevations for combined wind and wave set-up. However, the accuracy of the parameters obtained is uncertain. With storm wave measurements, the District would be in a better position to evaluate and calibrate the models that are used.

Figure 3. Hurricane Georges strike probability on 9/26/98



In late September 1998, Hurricane Georges was headed directly for New Orleans but veered east into Mobile Bay. Still, intense winds visited the area resulting in considerable damage. The near miss presented an opportunity for the District to examine both its emergency preparedness and the performance of the hurricane protection project. A deficiency in the post storm analysis was the lack of any wave information along Lake Pontchartrain. The only knowledge was anecdotal, i.e. the waves were big enough to destroy numerous camps east of the Lakefront Airport and big enough to put water onto the Lakefront Airport. The wind record from the airport could be used as input to numerical wave models. However, without real measurements, the results of numerical models are always questionable. The District began an examination of the alternatives and costs to obtain wave data should another hurricane event visit the New Orleans area. It could be decades before another hurricane threatens the area. On the other hand, a category five storm could come next hurricane season. Data collection is expensive and in the case of hurricane waves, it may be years before a payoff. Nonetheless, the District committed to a program for collection of storm wave data.

THE PLAN

A survey of data needs was performed. The need of the District is to have the wave parameters for intense storms. Data from small storms would be useful, but is not essential. The two basic methods for capturing extreme event wave data are continuous operation of a long-term gage or rapid deployment immediately prior to the event. The success of the first option is dependent upon the design of the system and the quality of the system maintenance. The success of the second is also a function of the system design, but is also highly dependent upon personnel readiness and commitment and the characteristics of the storm's approach - i.e., factors beyond the control of the system designer, especially far into the future.

The approach that was selected is based upon the principal that the single most difficult feature to ensure in a wave measurement system is reliability, and the most cost effective way of approaching it is redundancy. Redundancy can be in the number of gages, the type of gages, the location of gages, and the manner of transmitting and storing data. The plan that finally evolved will utilize each of these redundancies. Two types of instruments are utilized - the subsurface pressure sensor, and the surface-following accelerometer. A brief overview of each gage follows:

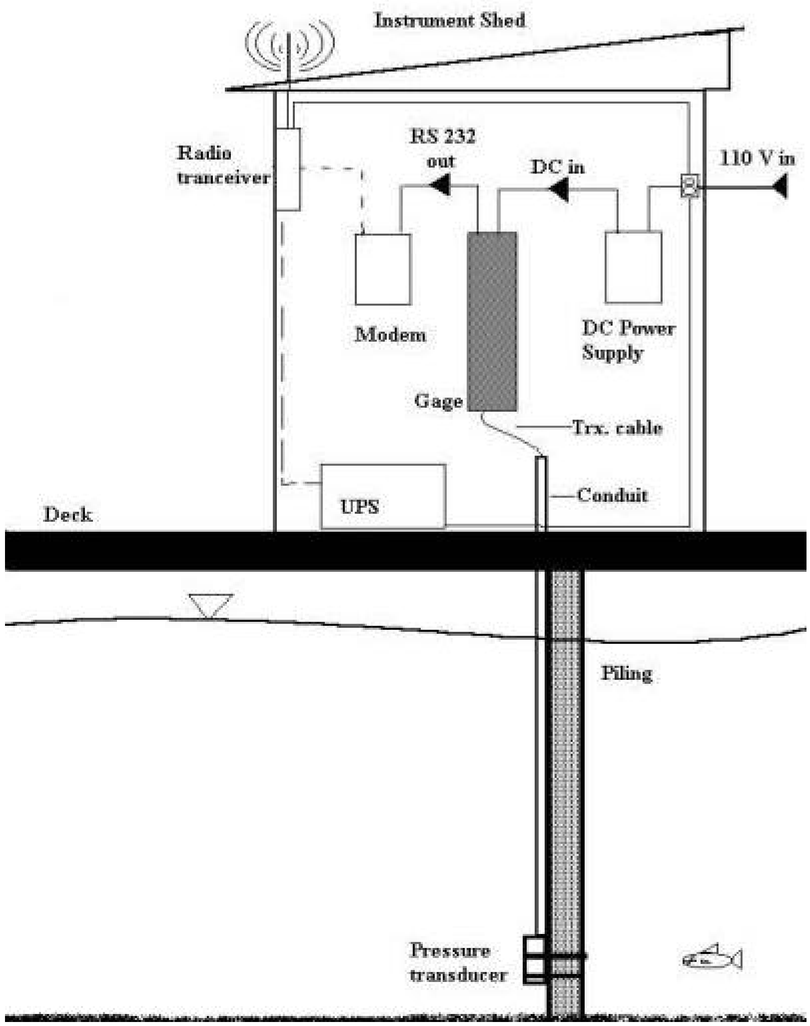
Subsurface Pressure Sensor Gage

A pressure sensor measures changes in pressure as waves pass overhead with an underwater pressure transducer. In the configuration utilized, a sturdy, pile-supported platform with a deck well above anticipated water levels is needed at the site where measurements are desired. Fortunately, a rugged pier was available adjacent to the Lakefront Airport on the south shore of the Lake.

Figure 4. Location of Airport Gage slave station and USCG master station

The subsurface pressure sensor is permanently mounted on a piling, near the lake bottom. It is connected by a submarine cable to the wave gage, housed in a waterproof case directly (more or less) above on the platform in an instrument shed. This shed contains the gage electronics, power supply, solid state memory and telemetry modules. The gage is powered by 110 AC with a custom-designed battery back up system to maintain power to the system for over a week in event power is lost.

Figure 5. Schematic of Airport slave station



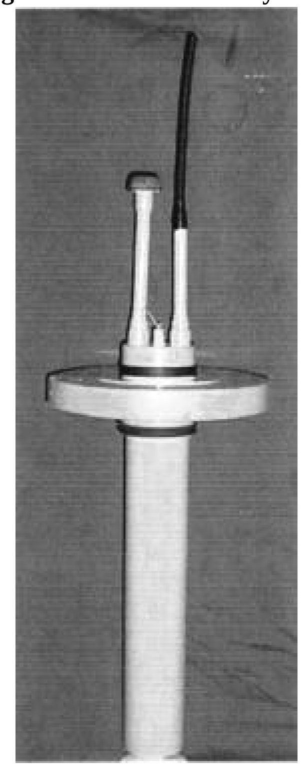
Measured wave data are both stored in the gage's internal memory and transmitted in near-real-time to a more secure, onshore location using packet UHF radio. The receiving, or master, station is located at the newly-constructed US Coast Guard (USCG) base located just to the west of the airport (Figure 4). The master station stores the data from the transmitting gage, or slave station, on a computer. This computer is equipped with a telephone modem, so all recovered data is available over the Internet from any remote location. Real-time telemetry offers two important advantages. 1) Status monitoring of the gage to assure operation and detect failure anytime prior to an event. 2) Secure capture of data up to failure in the event of catastrophic failure or loss of the gage itself during an event. In that case, all data received up to failure are retained.

Surface-following Accelerometer

This type of wave gage measures the displacement of a floating buoy with an accelerometer. It is the sensor of choice when a platform is unavailable, diving is inadvisable, or cable lengths become excessive, particularly when telemetry is desired. The buoy selected for this project is a commercially available wave gage from NSI and is based on a miniature buoy originally developed for the US Navy to be air dropped and expendable. The buoy holds a solid-state accelerometer, microprocessor, on-board memory, a VHF radio transmitter and batteries, memory, a GPS receiver, and telemetry components. All of the electronics fit on two circuit boards, each the size of a cigarette pack. Except for the antenna, the rest of the payload is batteries, so the size of the buoy, and the size of the required mooring and logistic effort to deploy them, is directly related to deployment length. The smallest buoy is about the size of a soft-drink can and weighs less than one kg, but only operates for one day. Fitted with sufficient batteries (standard D-size dry cells) to operate for a week, the buoy is about 9 cm in diameter by 50 cm long (excluding

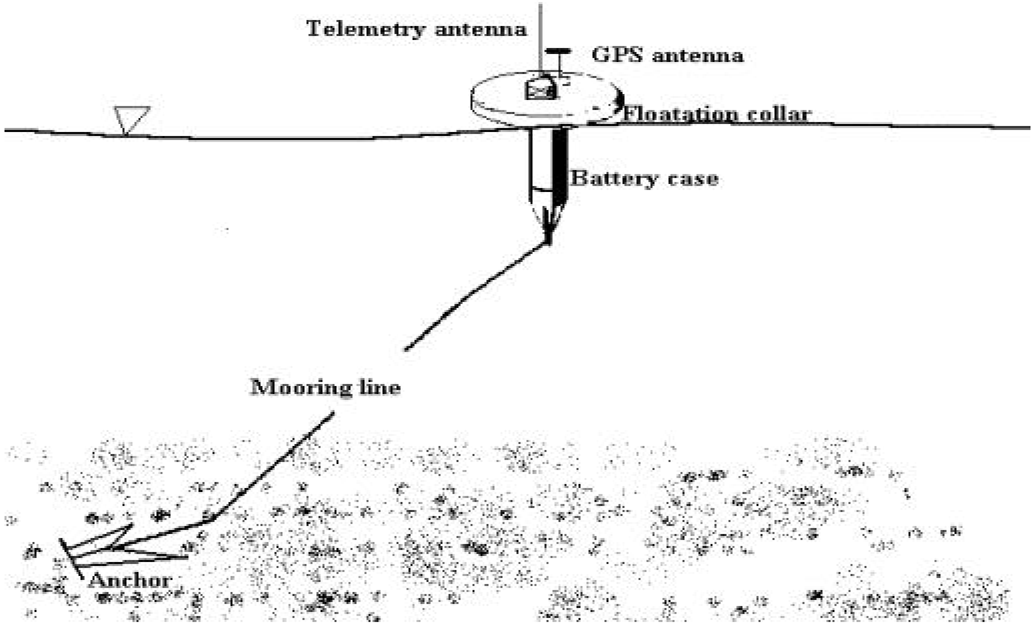
antennas) and weighs less than 4 kg (Figure 6).
Three of these buoys have been procured and will be used as event-deployed gages. Timing the deployment of event deployed gages is challenging because of the uncertainty of a storm's path. Because the Corps secures its boats relatively early in a hurricane's approach, distant storms could prompt numerous "false starts." However, many USCG vessels remain in the water to perform search and rescue during and immediately after the storm. The USCG base is ideally located near the deployment site and USCG personnel are trained in rapid response operations. By utilizing a USCG vessel to transport the Corps deployment team, deployment can be delayed until the storm's path is more certain to approach the city – say 36 to 48 hours before expected landfall. With a 7 day battery life, the buoys should be operational for the duration of the storm.

Figure 6. NSI Mini Sentry buoy



The buoys will be deployed at predetermined locations along the southern Lake shore. The locations will be about a kilometer offshore to avid the maximum surf zone, and within line of sight to the master station's antenna to ensure communication. Data are stored in the buoy on solid sate memory and transmitted every half hour to the master station. Like the data from the airport gage, data are stored at the master station but also available on-line. Each buoy will be equipped with a custom-designed mooring line and anchor in a compact, free-spooling package. The entire ensemble of buoy, line and anchor can easily be tossed overboard by a single person in a matter of seconds. The buoy automatically begins transmitting as soon as it contacts the water, and the self-embedding anchor secures the buoy on station (Figure 7)

Figure 7. Mini Sentry buoy in the deployed configuration



After the storm passes, the buoys can be recovered using a Corps vessel and crew by simply returning to the deployment site. Recovery will begin as soon as possible since tampering or theft is a potential risk. While the mooring is more than adequate to survive any hydrodynamic loads, it could become entangled in floating debris (e.g., trees, docks) and be drug off station. If the buoy is still above the surface, it will continue to transmit data, - and its position - for up to a week. A portable master station can even be brought onboard the recovery vessel to track and chase down a buoy anywhere in the lake. However, as long as the data were captured in the master station, recovery of the buoy is not essential.

CONCLUSION

The monitoring plan consisting of a permanently installed pressure transducer type gage that both internally stores data and transmits data by radio telemetry, coupled with an event based deployment of floating wave gage buoys that both store data internally and transmit data by radio telemetry, maximizes the chances of obtaining hurricane wave measurements. Either component could produce wave data on its own. Should the event deployment fail due to unforeseen complications, the permanently installed pressure transducer is a viable back-up. If the Lakefront Airport pier is demolished due to collision and battering from a loose vessel, the floating buoys provide alternative collection. If any of the gages are destroyed or lost, the data transmitted up to failure will be captured by the master station. If master station is destroyed, data will already have been transferred to a secure location via the Internet. Finally, each gage retains all of its data internally on solid state memory.

To minimize unforeseen circumstances, a test deployment will be staged once agreements are final and gages have been purchased. A winter storm front will be used for the test deployment. It is hoped that a test deployment will reveal any deficiencies in the plan. A deployment and operations manual will be produced to provide for changes in personnel in the decades to come. Finally, for the sake of the people residing in the city of New Orleans (including the principal author) it is hoped that a real deployment never has to be undertaken in earnest.

Acknowledgements

Assistance with the planning and design of this system from Neptune Sciences, Inc. is gratefully acknowledged.

Conversion Factors, non-SI to SI Units of Measurement

Multiply	By	To Obtain
feet	0.3048	meters
miles	1.852	kilometers
degrees (angular)	0.0174	radians

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