Final Technical Report

HAZARD MITIGATION GRANT PROGRAM
GAR – PR-1552-PR08

Acquisition and Installation of Puerto Rico Tsunami Ready Tide Gauge Network

March 31, 2008
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Prof. Christa G. von Hillebrandr-Andrade, PI
Prof. Linda Vélez, Co-PI
Dr. Víctor Huérfano, Co-PI
Prof. Aurelio Mercado, Co-PI

March 31, 2008
ABSTRACT

Acquisition and Installation of Puerto Rico Tsunami Ready Tide Gauge Network

The Puerto Rico Seismic Network of the Department of Geology of the University of Puerto Rico at Mayagüez successfully installed and is operating a network of 6 tsunami ready tide gauges and meteorological stations. The stations are located in Arecibo, Fajardo, Peñuelas, Mayagüez, Yabucoa and Isabel II in Vieques. A GOES receiver and central recording system was installed at the Puerto Rico Seismic Network to record and analyze the data from these and other tsunamis ready tide gauges that are operated by NOAA in Puerto Rico (San Juan, Parguera, Mona, Aguadilla, Esperanza in Vieques and Culebra) and the Virgin Islands (St. Thomas, St. Johns and two in St. Croix), as well as present and future stations in the Caribbean and Atlantic. The data gathered are being analyzed along with earthquake information to decide whether or not tsunami information, warnings, watches or advisories should be issued and when to upgrade or cancel them if they have been issued. An AHAB (All Hazards Broadcast System) was installed in Mayagüez. As part of the project the tsunami protocols were reviewed, updated and presented. A full scale tsunami exercise was also held in Mayagüez as part of the project to test the AHAB and protocol.

All the tide gauges fulfill the requirements of the National Oceanographic and Atmospheric Administration (NOAA), National Ocean Service (NOS), Center for Operational Oceanographic Products and Services (CO-OPS) network and follow the guidelines of the National Tsunami Hazard Mitigation Program. The Geostationary Operational Environmental Satellite (GOES) system is being used to transmit all the data from the stations, not only to the PRSN, but the Pacific and West Coast and Alaska Tsunamis Warning Centers which are providing interim tsunami warning and guidance to the Caribbean and the US Caribbean (Puerto Rico and the Virgin Islands), respectively.

Given the heightened awareness on tsunamis, the PRSN was able to secure funding for the state thru the Puerto Rico State Emergency Management Agency for 24/7 operations. $500,000/year has been promised, with the first $250,000 having been assigned for the time period January-June, 2008. Also NOAA thru its National Tsunami Hazard Mitigation Program, Tsunami Ready and the Tsunami Law of 2006 is providing funding for the education and mitigation of tsunamis, as well as improved operations. At the Second (2007) and Third (2008) Sessions of the UNESCO/IOC Intergovernmental Coordination Group for Tsunamis and Other Coastal hazards for the Caribbean and Adjacent Regions member states have proposed the PRSN to be the Caribbean Tsunami Warning Center.

This project was carried out between October 2005 and December 2007. FEMA provided $565,000 for this project. The PRSN, thru University and LAW 106 funding ($155,276), the Puerto Rico State Emergency Management Agency ($30,000) and the Municipality of Mayagüez ($25,000) provided the matching funding required.
INTRODUCTION

The Puerto Rico Seismic Network installed a Tsunami Ready Tide Gauge Network which includes 6 tsunami ready tide gauge and meteorological stations and a central receiving station. The six tide gauge stations are located in Arecibo, Mayagüez, Peñuelas, Yabucoa, Fajardo and Isabel II in Vieques. At the facilities of the Puerto Rico Seismic Network in Mayagüez a GOES base station was set up to acquire the data from these and other sea level monitoring stations located in the Caribbean region and Atlantic basin, including NOAA’s Tsunami Ready Tide Gauges. The sea level information is analyzed along with the earthquake detection system. All the stations meet NOAA’s National Ocean Survey (NOS) and NGS (National Geodetic Survey) standards and the National Tsunami Hazard Mitigation Program guidelines. In addition to monitoring tsunamis, the data can be used for storm surge monitoring, navigation and sea level studies. The data and information gathered by this network will benefit all Puerto Rico coastal communities which are at risk from tsunamis and sea level changes in general. The meteorological data gathered will help the corresponding agencies and researchers improve weather and extreme weather forecast and their understanding of these phenomena.

The specific accomplishments of this project were:

- Tsunami ready tide gauges were installed in Arecibo, Mayagüez, Peñuelas, Yabucoa, Fajardo and northern Vieques.
- A central receiving site for the tide gauge data was installed at the PRSN
- The tide gauge stations were leveled and monumented according to NOAA standards so that the data of the tide stations can and be used for long term sea level monitoring and integrated into the systems of NOS and other agencies.
- The tsunami protocol for Puerto Rico was reviewed
- An All Hazard Broadcast (AHAB) system was installed in Mayagüez
- A full scale tsunami exercise was held in El Seco community in Mayagüez.

Each of these accomplishments will be discussed below.

A list of all the people that were involved in the purchase, installation, leveling, data acquisition and operation of the stations is listed in Appendix 1.
TIDE GAUGE STATIONS

The Puerto Rico Seismic Network installed 6 tsunami ready tide gauge stations. The six tide gauge stations are located in Arecibo, Mayagüez, Peñuelas, Yabucoa, Fajardo and Isabel II in Vieques (Figure 1, Table 1). In addition to the sea level stations, each site also has meteorological equipment. All the data are transmitted over the GOES satellite.

![Map of PRSN (this project) and NOAA tsunami ready tide gauges.](image)

**Figure 1.** Map of PRSN (this project) and NOAA tsunami ready tide gauges.

<table>
<thead>
<tr>
<th>Station</th>
<th>Satellite ID</th>
<th>Lat</th>
<th>NOAA Station ID</th>
<th>Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARECIBO</td>
<td>3366454E</td>
<td>18 28</td>
<td>975-78091</td>
<td>66 42 8.5 W</td>
</tr>
<tr>
<td>FAJARDO</td>
<td>3366C35A</td>
<td>18 20</td>
<td>975-32161</td>
<td>65 37 52 W</td>
</tr>
<tr>
<td>MAYAGÜEZ</td>
<td>336633DE</td>
<td>18 13</td>
<td>975-93941</td>
<td>67 9 31.9 W</td>
</tr>
<tr>
<td>VIEQUES</td>
<td>3366D02C</td>
<td>18 9</td>
<td>975-26191</td>
<td>65 26 37.7 W</td>
</tr>
<tr>
<td>PENUelas</td>
<td>3366A6BC</td>
<td>17 58</td>
<td>975-B0531</td>
<td>66 45 42.4 W</td>
</tr>
<tr>
<td>YABUCOA</td>
<td>3366B5CA</td>
<td>18 3</td>
<td>975-422B1</td>
<td>65 49 58.8 W</td>
</tr>
</tbody>
</table>

**Table 1. List of locations for tsunami ready tide gauge stations with coordinates and station ID.**
The stations, which are fully documented in Appendix 2, were installed at the following sites.

1) Arecibo Port, Vigía Sector of the Municipality of Arecibo. The facilities are owned and operated by the Puerto Rico Ports Authority.

2) Mayagüez Port, Mayagüez. The Mayaguez Port is owned by the Municipality of Mayagüez and is operated currently by the Holland America Group. It is located at the “Malecón” on Highway 341.

3) Eco Electric, Peñuelas. The tide station is located on the fueling pier. Eco Electric is located right off PR-127.

4) Shell Refinery Yabucoa Inc. at Yabucoa. It is on the pumping station dock.

5) Playa de Fajardo, Puerto Real, Fajardo. The tide gauge station is installed on one of the piers of the Maritime Transportation Authority which operates the ferries for Culebra and Vieques.

6) Isabel II, Vieques. The tide gauge was installed on the dock of the Maritime Transportation Authority which operates the ferries for Vieques.

At each of the six stations a current National Ocean Service (NOS) standard tidal monitoring station was installed (Figures 2 and 3). Each of the stations consists of:

Sea Level Sensors and Data Collection Platforms:

Primary gauge:

- Aquatrak acoustic water level sensor assembly. The Aquatrak assembly is mounted in a 4” PVC pipe. The head is located on the top, the sounding tube inside and at the bottom there is a baffler. Stainless steel brackets were custom designed to attach the pipe to the pier/dock.
- Tube (air) temperature sensors (two are required for proper Aquatrak operation)
- Water temperature sensor
- XPert with display, 4 additional com ports, voice modem, XPert analog and digital I/O modules and Enclosure

Redundant gauge:

- Bubbler gauge. A tube runs from the enclosure to a pipe fastened to pier/dock into the water.
- NOS G3 Redundant Gauge Expert without display, 4 additional com ports, voice modem, XPert analog and digital I/O modules and Enclosure

The following meteorology package was also installed at each station:

- Wind sensor
- Air temperature/relative humidity sensor
- Barometric pressure sensor
- Rain Gauge

Communications Infrastructure
- GOES Yagi antenna
- Satlink II GOES
- Satellite transmitter
- 6-minute interval transmissions are used (Appendix 2)

Power
- 2 Solar panels with regulators
- Power supply
- 2 Batteries

Timing
- Bullet GPS antenna for timing

Housing
- A 4 ft x 4 ft x 2.5 ft white aluminum (Arecibo, Mayagüez, Fajardo and Vieques) and Stainless Steel (Yabucoa and Peñuelas)
- The enclosure is mounted on an aluminum/stainless steel stand 4' x 2.5' and 2' high which is bolted docks.

For each of the stations a documentation package was prepared and also sent to NOAA/NOS. Once they review the documentation, along with information gathered during their sites visits, the data, including the meteorological data will be available at http://tidesandcurrents.noaa.gov/.
FIGURE 2. COMPONENTS OF TIDE GAUGE INSTALLATION (MAYAGUEZ, PUERTO RICO).
FIGURE 3. SCHEMATIC AND PICTURE OF INSTALLATION OF AQUATRAK AND BUBBLER (FAJARDO)

The installation of the equipment was part of the subcontract to Sutron Corporation. The installation crew for the different stations from Sutron included Tom Oliviera, Tom Keefer, Phil Libraro (subcontract) and Samant Garg. The civil works and installation team of the PRSN included Juan Lugo, Javier Santiago, Celestino Lucena and José Cancel. In Figure 4 the logistics of getting the equipment into the field can be appreciated.
FIGURE 4. UPRM VEHICLE LOADED WITH THE TIDE GAUGE EQUIPMENT FOR INSTALLATION.
CENTRAL RECEIVING SITE

The Central Receiving Site is operated at the Puerto Rico Seismic Network at the University of Puerto Rico at Mayagüez. The central receiving site consists of two main components, the satellite receiver equipment and the processing and analysis program. Figure 5 illustrates the schematics of the hardware configuration.

The satellite receiver communication infrastructure consists of the following equipment.

- 5 Meter Dish (Figure 6). A concrete pad was poured to support the dish.
- Feed/LNB filter
- 16 channel DSR receiver (Figure 7)

The DSR DRGS system consists of a DSR receiver and a standard desk top work station (Figure 7). All of the demodulation capability resides as software on the PCs. The PC provides 16 channels of demodulation. The DSR receiver communicates with the PC demodulator system via a “private LAN”. That is, the PC and the DSR have 10Mbit Ethernet connections to one-another. Data from the demodulators can be obtained in several ways.

The DSR DRGS is a fully automatic system. It has been designed for a minimum amount of maintenance and maximum trouble-free operation. Front panel indications are provided to give the user feedback and an overall system status with a quick glance. On power up it will automatically scan the received signals for the pilot tone and lock onto it. After lock is achieved, the system will monitor the channels assigned to capture and post any messages that are received. The DSR DRGS includes important quality measurements on each transmission to assist in managing a network of field stations. Messages posted to the sockets are in standard NESDIS format, and can be decoded using standard decoding methods.
FIGURE 5. SCHEMATIC OF CONFIGURATION OF CENTRAL RECEIVING SITE
The main hardware and software components at the PRSN for the processing, analysis and archival of the Puerto Rico Tide Gauge Network (Figure 7) are:

- Database Server
- Work station
- XConnect Software XConnect is Sutron Corporation's data collection, data processing, data handling, data viewing and data storage software.

The real-time message stream is received by the MUX module of the X-Connect software package using TCP Connection. The MUX application stores raw messages received by the DDRGS in a directory with *.raw extension. The messages received by MUX are then decoded and stored using XCDataView in a real-time database. XCDataView is the data viewer. The messages are actually read by XCDecode (a full description of XConnect and its modules can be found in Appendix 3).

In addition to the XConnect Modules, the PRSN Tide Gauge team developed some additional tools for viewing the real time data and developed Web Modules in addition to those provided by Sutron.

Backup and redundancy communication features
There are several ways to retrieve data from the DCP (Figure 8). Any single mechanism for retrieving data can fail. Some retrieval mechanisms depend on others. For example, if the entire DAPS system was to fail, all DOMSAT, NWSTG (internet), and NOAAPORT transmissions would also fail. (For this reason, internal redundancy is a critical design feature of DAPS-II). If University of Puerto Rico’s DSR DRGS ever failed, there are plenty of options for retrieving data. These backup mechanisms will be integrated in such a way as to have the least impact on the organization’s data processing system. For this purpose a program was written by the PRSN tide gauge team to continuously receive the data from the NOAA servers (Appendix 3).

**FIGURE 8. REDUNDANT COMMUNICATION SCHEMES.**

In the very rare event of University of Puerto Rico’s DSR DRGS failure, all messages will still be retrieved via DAPS DIALER Application. The DAPS DIALER application is a no-cost option to retrieve data from Wallops Island using an internet connection. The DAPS DIALER program runs on a user-defined scheduled time interval. It connects to the DAPS at Wallops Island in VA, automatically logs in using (customer supplied) user-name and password and downloads data for all the DCPs identified in the X-Connect software. DAPS usually stores last 72 hours of data for each DCP. This way the data collection process continues without any interruption.

In Appendix 3 there are also examples of the data recorded by the PRSN Tide Gauge Network.
TRAINING

For the acquisition and operation of the system, guidance and training were provided by Sutron in the following areas:

- Civil works for the construction of the concrete pad for the satellite dish and for each of the stations.
- Tide Station Installation
- Installation of Water Level Sensors and other Met Sensors
- Maintenance of tide stations
- Telemetry (GOES & Phone Communications)
- Configuration of Stations
- Lightning & Grounding Protection
- O & M Training
- Central station installation and maintenance
- Central station software and configuration
- DSR DRGS Theory of Operations
- Maintaining the DSR DRGS Hardware
- Monitoring DSR DRGS Status
- Configuring and Controlling DSR DRGS operations
- Selecting and Viewing DCP messages
- Trouble-shooting scenarios
- System Features and Overview
- System Applications
- Servers and Clients
- System Data Flow
- System Setup – Setup Desktop
- Advance Topics – Message Decoding
- Data Storage
- Troubleshooting

Formal training was held in Maryland and at the PRSN facilities in Mayagüez.

In addition to the training by the supplier, Sutron, the PRSN has benefited from guidance and orientations in Silver Springs and Puerto Rico from the NOAA/NOS. Personnel of the PRSN also participated in the installation and maintenance of NOS stations in Puerto Rico.

The data entering into the PRSN, is being analyzed along with the seismic data. The quality and stability of the sea level data has also been analyzed.

One of the quality control checks that was run was to compare the data from the NOAA stations in Puerto Rico as reported thru their systems with those collected and processed by the XC Connect. This exercise was very helpful and helped identify problems which were solved. As of now, the data from the 6 tide gauge stations was compared with data from other NOAA tide stations.
MONUMENTATION AND LEVELING OF THE TIDE GAUGE STATIONS

The PR tide gauge stations comply with all the most up to date standards of the NOS for the installation and operation of tide gauge stations. The monumentation phase consisted of the recuperation/installation and GPS observations of 5 bench marks at each of the stations and GPS Observations of the benchmarks. Once the sensors and equipment was installed second order, class I leveling was performed.

Monumentation

The installations of the monuments followed the directives of NOS and the NGS. Existing and new benchmarks were used for the project. All the bench marks consist of bronze disks set in man made structures located near the stations. Most of the structures consist of the docks. For the new monuments, 1/8-in. diameter hole, 3 1/4 in. deep, was drilled into the concrete to accommodate the shank of the disk. This was done with a powered rock drill or by hand using a star drill and hammer. Next, a counter-sunk solid level base is chiseled for the disk. Hydraulic cement was placed in the hole and on the underside of the disk to prevent air from becoming trapped in the concave portion. The prestamped disk was then tapped into the drill hole and leveled using a small line level (Figure 9). A plan view of the location of the benchmarks for each of the stations can be found in Appendix 2 as well as descriptions and digital photographs of one of the five benchmarks for each of the stations.
FIGURE 9. INSTALLATION OF BENCHMARKS (PEÑUELAS)

GPS Observations

Each of the monuments was observed for 5.5 hours for three days (Figure 10). The observation data were submitted to OPUS and Project report for each observation was prepared. The raw and Rinex GPS data is also available for each of the benchmarks. In Appendix 2 there is an example of the observation and visibility reports for one of the five benchmarks.
FIGURE 10. GPS OBSERVATION OF BENCHMARK (PEÑUELAS)

Leveling

Second-order, class I levels were used in connections at all the stations (Figures 11 and 12). The following tolerances were observed in leveling at all stations:

1. maximum length of sight, 60m (197 ft.)
2. max– difference in length of forward and backward sights was 5m (16 ft.) per setup (2
3. maximum closure between forward and backward runnings, 6 mm √K, (0.025 ft. √M) per section and line (2nd order, class I) – where K and M are the one-way distances in kilometers and miles, respectively.
4. minimum ground clearance of line of sight, 0.5 m (1.6 ft.) and determination of temperature gradient for vertical range of line of sight at each setup.

The NGS/NOAA Translev Program 4.1.2. was used to process the leveling data (http://geodesy.noaa.gov/PC_PROD/pc_prod.shtml#Translev). This program facilitates the process of editing, formatting and checking digital leveling observation data and creates abstracts, bok files, and VERTOBS datasets for submission to the National Geodetic Survey (NGS). The Leica DNA03 digital
level line created a custom ASCI file with a GSI subscript. The TRANSLEV software first required the creation of a description file of each of the benchmarks involved in the leveling using the WINDESC program (Examples in Appendix 2). Then the TRANSLEV program combines both the description and the raw data file into a leveling file and examines all of the data for blunders. As part of the examination process, the program checks to make sure that rod and instrument calibration data is provided, compares the time of each observation, the difference between the air temperature recorded at both the top and bottom sensor, the difference between the length of the backsight and foresights, as well as the relative elevation observations and creates an potential error list for the data. After any errors are addressed, the TRANSLEV program creates a field abstract of the leveling. In the transmittal, the raw data files as well as the abstract files are provided. In Appendix 2 an abstract for each of the stations has been included. This part of the project was done by Dr. George Cole, Visiting Professor of the Civil and Environmental Engineering and Surveying Dept. of the UPRM.

![Figure 11. Schematic of the Leveling Runs.](image)

**Figure 11. Schematic of the Leveling Runs.**

The following equipment and materials were purchased for the Leveling, GPS observations and monumentation of the Tide Gauge Stations:

- 25 domed bronze concrete markers
- 1 SDL 30 Invar Barcode Staff, 3m, set of 2
- 2 Struts for 3m Rod
- 2 Turning Plates
- 2 Dual Frequency GPS Receiver with Antenna
- 2 Computers for processing geodetic information (1 laptop and 1 desktop)
- 25 Domed Concrete Markers (Bronze)
- Meteorology package for leveling
- 1 Leica Invar barcode staff, 3 m, set of 2, calibrated
- 1 Leica DM03 Digital Level
FIGURE 12. LEVELING OF THE TIDE GAUGE STATIONS.
TSUNAMI PROTOCOL

Since 2000 Puerto Rico has a Tsunami Protocol. In 2003 the PTWC began providing interim tsunami warning guidance to Puerto Rico. In 2004 it underwent major revisions, as agencies outside of Puerto Rico were included (Figure 13). In Puerto Rico, the agency responsible for monitoring tsunamis is the Puerto Rico Seismic Network. As of March, 2008 the PRSN is staffed 24 hours. The State Emergency Management Agency is responsible for issuing evacuation orders, while the National Weather Service forecast disseminates the emergency message thru EAS. In June, 2007, the US agency responsible for issuing interim tsunami warnings for Puerto Rico was changed from the Pacific Tsunami Warning Center to the West Coast and Alaska Tsunami Warning Center. The Puerto Rico Tsunami Technical Review Committee which was established in 2004 provides advise on the tsunami warning system.


Current Protocol

The WCATWC and the PRSN have agreed on the protocol to respond to earthquakes and tsunamis that could affect Puerto Rico and the Virgin Islands. The PR/VI and the PRSN AOR is defined as the region from 17N to 20N, and from 63.5W to 69W and includes eastern Dominican Republic, Puerto Rico and the US and British Virgin Islands. The Caribbean region is shown in figure 14. It is divided into western and eastern halves for tsunami warning purposes at 75W. As of March 2008, the PRSN is staffed 24 hours and protocols and arrangements with other institutions and governments are under revision.
FIGURE 14. SUBDIVISION OF CARIBBEAN FOR TSUNAMI PROTOCOL.

Tsunami Product Definitions Used by the Puerto Rico Seismic Network and the West Coast/Alaska Tsunami Warning Center (WCATWC).

The products issued by the PRSN and WCATWC are warning, watch, advisory, and information statement.

Each has a distinct meaning relating to local emergency response. In summary:

<table>
<thead>
<tr>
<th>Product</th>
<th>Description</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warning</td>
<td>Inundating wave possible</td>
<td>Full evacuation suggested</td>
</tr>
<tr>
<td>Watch</td>
<td>Danger level not yet known</td>
<td>Stay alert for more info</td>
</tr>
<tr>
<td>Advisory</td>
<td>Strong currents likely</td>
<td>Stay away from the shore</td>
</tr>
<tr>
<td>Tsunami Information (WCATWC)</td>
<td>Minor waves at most</td>
<td>No action suggested</td>
</tr>
<tr>
<td>Earthquake Information (PRSN)</td>
<td>Minor waves at most</td>
<td>No action suggested</td>
</tr>
</tbody>
</table>

Based on seismic data analysis or forecasted amplitude (dependent on whether the center has obtained sea level data), the PRSN/WCATWC will issue the appropriate product. Warnings and Advisories suggest that action be taken. Watches are issued to provide an early alert for areas that are distant from the wave front, but may have danger. Once the danger level is determined, the watch is upgraded to a warning or advisory or canceled. The full definition of each message is given below.

Tsunami Warning - a tsunami warning is issued when a potential tsunami with significant widespread inundation is imminent or expected. Warnings alert the public that widespread, dangerous coastal flooding accompanied by powerful currents is possible and may continue for several hours after arrival of
the initial wave. Warnings also alert emergency management officials to take action for the entire tsunami hazard zone. Appropriate actions to be taken by local officials may include the evacuation of low-lying coastal areas, and the repositioning of ships to deep waters when there is time to safely do so. Warnings may be updated, adjusted geographically, downgraded, or canceled. To provide the earliest possible alert, initial warnings are normally based only on seismic information.

Tsunami Watch - a tsunami watch is issued to alert emergency management officials and the public of an event which may later impact the watch area. The watch area may be upgraded to a warning or advisory - or canceled - based on updated information and analysis. Therefore, emergency management officials and the public should prepare to take action. Watches are normally issued based on seismic information without confirmation that a destructive tsunami is underway.

Tsunami Advisory - a tsunami advisory is issued due to the threat of a potential tsunami which may produce strong currents or waves dangerous to those in or near the water. Coastal regions historically prone to damage due to strong currents induced by tsunamis are at the greatest risk. The threat may continue for several hours after the arrival of the initial wave, but significant widespread inundation is not expected for areas under an advisory. Appropriate actions to be taken by local officials may include closing beaches, evacuating harbors and marinas, and the repositioning of ships to deep waters when there is time to safely do so. Advisories are normally updated to continue the advisory, expand/contract affected areas, upgrade to a warning, or cancel the advisory.

Tsunami Information Statement (WCATWC)/Earthquake Information Statement (PRSN) - a tsunami/earthquake information statement is issued to inform emergency management officials and the public that an earthquake has occurred, or that a tsunami warning, watch or advisory has been issued for another section of the ocean. In most cases, information statements are issued to indicate there is no threat of a destructive tsunami and to prevent unnecessary evacuations as the earthquake may have been felt in coastal areas. An information statement may, in appropriate situations, caution about the possibility of destructive local tsunamis. Information statements may be re-issued with additional information, though normally these messages are not updated. However, a watch, advisory or warning may be issued for the area, if necessary, after analysis and/or updated information becomes available.

The criteria for issuing the different tsunami products for Puerto Rico are:

\[ M < 3.5; \text{PR/VI OR} \]

- PRSN will locate the earthquake and submit to its earthquake catalogue (http://redsismica.uprm.edu)

\[ 3.5 \leq M \leq 6.0; \text{PR/VI} \]

- PRSN will locate the earthquake and submit to its earthquake catalogue
- PRSN will issue message to Puerto Rico State Emergency Management Agency (PRSEMA) and update Broadcast system, a real time earthquake display at the PRSN and the Control Room of PRSEMA.
- PRSN will send message to press and general public lists
- If felt, PRSN will issue felt memo report, generate ShakeMap and also advise NWS San Juan Field Office
- If felt, PRSN will report event over emergency management radio frequency

\[ 6.0 \leq M \leq 6.4 \text{ OR } 6.5 \leq M \leq 7.8 \text{ and } h>100\text{km PR/VI} \]

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• PRSN will activate Tsunami Protocol, messages will be exchanged with Emergency Management over the RingDown phone, not over emergency management radio frequency.
• PRSN will issue earthquake information message, no tsunami expected
• Observe nearest tide gages/DART Buoys for tsunami.
• Normally only one message issued though a supplement can be issued if a tsunami is observed. If a significant tsunami is recorded, upgrade to warning or advisory.

**M >= 6.5 and less than 100km depth: PR/VI**

• PRSN will issue Initial Message: Tsunami Warning Message for all PR and VI
• Observe nearest tide gages/DART Buoys for tsunami.

**5.0 <= M <= 5.9; Caribbean**

• Issue Earthquake Information Message (procedures under development)
• Coordinate epicenter/magnitude with WCATWC/NEIC.

**6.0 <= M <= 7.5 OR (M >= 6.0 AND (deeper than 100km or inland)); Caribbean**

• Issue Earthquake Information Message (procedures under development)
• Coordinate epicenter/magnitude with WCATWC.
• Observe nearest tide gages/DART Buoys for tsunami.
• Normally only one message issued though a supplement can be issued if a tsunami is observed. If a significant tsunami is recorded and could be dangerous to PR/VI, upgrade to warning or advisory.

**7.6 <= M <= 7.8: Caribbean - Eastern**

• Issue Tsunami Advisory for all PR and the VI
• Coordinate epicenter/magnitude with PTWC.
• Observe nearest tide gages/DART Buoys for tsunami.

**7.6 <= M <= 7.8: Caribbean - Western**

• Issue Earthquake Information Message (procedures under development)
• Coordinate epicenter/magnitude with WCATWC/NEIC.
• Observe nearest tide gages/DART Buoys for tsunami.
• Normally only one message issued though a supplement can be issued if a tsunami is observed. If a significant tsunami is recorded and could be dangerous to PR/VI, upgrade to a warning or advisory.

**M >= 7.9; Caribbean**

• Issue Earthquake Information Message (procedures under development)
• Coordinate epicenter/magnitude with WCATWC/NEIC
• Initial Message:
  • If in Western Caribbean, issue Advisory for all PR and VI
  • If in Eastern Caribbean, issue Warning for all PR and VI
• Observe nearest tide gages/DART Buoys for tsunami.

**NOTE:** Given that the PRSN, NOAA TWC’s and the NEIC/USGS use different sations and products to monitor earthquakes there could be a variation on products issued for the same event. Coordination between the agencies is always pursued, but not always possible, especially during an extreme event.
In figure 15 is a bar graph of the different products to be issued by the US NWS Tsunami Warning Centers.

Throughout the project personnel of the PRSN and the CoPI’s gave talks, workshops and conferences within Puerto Rico on the Tsunami Warning System. These efforts also included interviews for the press (TV, radio and newspaper). 30,792 people attended PRSN outreach activities during the time period of this project.

**FIGURE 15.** BAR CHART WITH PRODUCTS TO BE ISSUED BY THE PACIFIC TSUNAMI WARNING CENTER AND THE WEST COAST AND ALASKA TSUNAMI WARNING CENTER FOR PR/VI, CARIBBEAN AND THE PACIFIC.
ALL HAZARDS BROADCAST SYSTEM

In 2006, the Municipality of Mayaguez was recognized as the first TsunamiReady community in Puerto Rico and the Caribbean. As part of this effort, the PRSN partnered with the NWS and prepared and distributed the first tsunami’s evacuation map in Puerto Rico for Mayagüez (Figure 16), reviewed/developed response procedures for the PRSN/NW-SJFO and the Municipal Office of Emergency Management, installed tsunami signage and carried out a drill. To complement this recognition, in 2007 the Municipality of Mayagüez assigned $25,000 to complement the FEMA funding of this project to install the first AHAB broadcast system in Puerto Rico. The pole on which it was mounted was donated and installed by the Puerto Rico Electrical Power Authority. This loudspeaker system can be heard within an average of one mile form the site and was installed in December 2007 (Figure 17). Messages below were pre-recorded on the AHAB system for rapid activation in case of an emergency, messages for drills were also prerecorded (Appendix 4).

On the 13th of December an end to end Tsunami Drill was conducted in the El Seco ward of the Municipality of Mayaguez. For the drill a General Document was prepared and a Table Exercise (Figure 18) was also conducted. Over 500 people participated in the exercise and drill (Figure 19). For the exercise the PRSN (this project) partnered with PRSEMA, OEM, NWS SJFO and other agencies. In Appendix 5 are all the documents and reports associated with the drill.
FIGURE 18. TABLE TOP EXERCISE FOR TSUNAMI DRILL, MAYAGUEZ, PR.
FIGURE 19. TSUNAMI DRILL IN MAYAGÜEZ (PARTICIPANTS FROM ESCUELA DE LA COMUNIDAD CONCORDIA)
CONCLUSIONS AND FUTURE WORK

All the tasks proposed in the project were accomplished. Together with the NOAA stations in Puerto Rico and the Virgin Islands, the region has a state of the art interoperable, robust and redundant Sea Level Monitoring Network which is very important for not only monitoring tsunamis, but also routine monitoring, extreme weather forecasts and longer term sea level variations. Given the heightened awareness on tsunamis, the PRSN was able to secure funding for the state thru the Puerto Rico State Emergency Management Agency for 24/7 operations. $500,000/year has been promised, with the first $250,000 having been assigned for the time period January-June, 2008. Also NOAA thru its National Tsunami Hazard Mitigation Program, Tsunami Ready and the Tsunami Law of 2006 is providing funding for the education and mitigation of tsunamis, as well as improved operations. At the Second (2007) and Third (2008) Sessions of the UNESCO/IOC Intergovernmental Coordination Group for Tsunamis and Other Coastal hazards for the Caribbean and Adjacent Regions member states have proposed the PRSN to the Caribbean Tsunami Warning Center. These discussions are ongoing. Important upgrades to the stations over the next years will be the installation of a two way communication system between the PRSN and the stations and the installation of high rate GPS. Every year the Aquatrak equipment needs to be calibrated by NOAA/NOS and the stations have to be leveled. PRSN has also been contracted by NOAA/NOS to install a Tsunami Ready tide gauge in Andres, Dominican Republic.
REFERENCES

CO-OPS Water Level and Meteorological Site Reconnaissance Procedures, National Ocean Service, June 2005


Tide and Current Glossary, National Ocean Service, January 2000
APPENDIX 1

UPRM PROJECT PERSONNEL

STAFF

Prof. Christa von Hillebrandt, PI. Geologist, Director of the Puerto Rico Seismic Network, Assistant Researcher Dept. of Geology, University of Puerto Rico at Mayaguez. Responsible for the oversight of the project.

Prof. Linda Vélez, Co-PI. Engineer and Surveyor. Professor of Civil Engineering and Surveying, UPRM. Responsible for the geodetic leveling, installation of geodetic monuments and the GPS observations. See attached Curriculum Vitae.

Dr. Victor Huerfano, Co-PI. Research Associate and Operations Manager, PRSN. Integration of the tide data to the seismic data. He oversees the operations of the PRSN and installed and maintains the Early Bird System for detection and distribution of potentially tsunamigenic events.

Prof. Aurelio Mercado, Co-PI. Oceanographer. Professor of Marine Science and Director of the Coastal Hazards Research Center, UPRM. Assisted with the verification of the quality of the data.

Mr. Juan Lugo. Scientific Instrumentation Specialist and Coordinator of the Instrumentation, PRSN. Participated in trainings and installation of equipment.

Mr. Javier Santiago. Scientific Instrumentation Specialist, Tide Gauge POC, PRSN. Participated in trainings and installation of equipment.

Mr. Celestino Lucena. Maintenance worker, PRSN. Civil works and installation of stations.

Ms. Gisela Baez, Chief Data Analyst, PRSN. Familiarization with sea level data. Participated in the Drill.

Mr. Harold Irizarry, Data Analyis, PRSN. Familiarization with sea level data. Participated in the Drill.

Mr. Angel Feliciano. Coordinator of Computer Systems, PRSN. Responsible for the installation and maintenance of computers and information technology.

Ms Jeanette Lopez. Administrative Assistant, PRSN. Responsible for the requisitions and bookkeeping.

Ms. Yamilette Vargas, Secretary, PRSN. Assisted with the requisitions and bookkeeping.

STUDENTS

Gerardo Rivera, PhD Graduate Student. Worked on the project from August – December, 2006.

David Cuevas, PhD Graduate Student. June-July, 2007. Familiarization with the XConnect tide data program and education and outreach.
Carolina Hincapie, PhD Graduate Student. August 2007-present. Acquisition, processing and distribution of the sea level and meteorological data and information.

Yadira Soto, MSc Graduate Student. 2007-present. Education and outreach, helped with the coordination of drills.

Natlee Hernandez, BSc Geology Student. 2007-present. Education and outreach, helped with the coordination of drills.

Denisse Ocasio, BSc Geology Student. 2004-present. Data analyst and Education and outreach, helped with the coordination of drills.

Carlos R. Vega, Surveyor and BSCE Student. Installation of Benchmarks and GPS Observations.

Juan A. Rodriguez Vargas, BSCE Student. Leveling.

Eduardo Torrens Bonano, BSCE Student. Leveling.

Anthony Gonzalez Casiano, BSST Student. Leveling.

Jose J. Ortiz Alemany, BSCE Student. Leveling.

Ralmary Vera, BSCE Student. Leveling.

Ivys Ocasio, BSST Student. Leveling.