Disaster and Risk Management for Puerto Rico

Mr. Carlos J. RODRÍGUEZ ROSARIO and Mr. Carlos R. VEGA SANTOS, Puerto Rico

Key words: Height Modernization Program, Real Time GPS Networks and Disaster Management and Mitigation

SUMMARY

Puerto Rico is a little star in the Caribbean basin which has suffered in the last fifty years a dramatic urban development causing one of the world's highest population densities per square kilometer. Urban development for the eyes of the world means an economic productivity, but in this case it means a risky situation for the coastal communities in our island. In fact, with a population of 3.95 million, more than one million people live on or near the coastlines. Engineers and Land Surveyors have played an important role in planning, constructing and mitigating natural disasters or risks that involve our population or surrounding countries such as the Dominican Republic, United States and the Virgin Islands. Puerto Rico is working very hard to develop different methods to resolve and manage the effects of a disaster or an unpredicted natural situation such as tsunamis, flash floods, earthquakes, hurricanes and storm surge. Land Surveyors are currently working on a first order leveling network to provide high accuracy elevations to develop a "Height Modernization Program" promoted by the National Oceanic and Atmospheric Administration (NOAA) and managed by the National Geodetic Survey (NGS).

Parallel with this project, government and private companies are working on the first Caribbean Survey Grade Real Time GPS Network Solution for the whole island. This infrastructure supports any research or studies to develop different products that can support in any disaster management. Using the latest techniques such as Geographic Information Systems (GIS), Computer Aided Design (CAD) and the development of the Global Positioning System (GPS) make it possible to generate data to predict, manage and mitigate the damages caused by a natural disaster. The advantages in technology such as computers and different electronic devices can help our work in a significant, reliable and faster response under these situations. We are working on solutions feasible for our country and produce set new standards for disaster management and mitigation in the Caribbean.

RESUMEN

Puerto Rico es una estrella pequeña en el centro del Caribe que ha sufrido en los últimos cincuenta años un dramático desarrollo urbano causando una de las densidades poblacionales más altas en el mundo por kilómetro cuadrado. El desarrollo urbano para los ojos del mundo significa una productividad económica, pero en este caso significa una situación arriesgada para las comunidades costeras en nuestra Isla. De hecho, con una población de 3.95 millones, más de un millón de personas viven en áreas cercanas o en la costa. Los Agrimensores e Ingenieros han jugado un papel importante en la planificación, construcción y mitigación ante un desastre natural. Estos riesgos naturales por desgracia son reales para nuestra población y áreas circundantes tales como la República Dominicana, los Estados Unidos y las Islas Vírgenes. Puerto Rico trabaja para desarrollar diferentes métodos que nos ayuden a resolver y manejar el efecto causado por un desastre o fenómeno natural impredecible. En este momento los agrimensores trabajan en la primera red de nivelación de primer orden que proporciona el nivel de referencia oficial para desarrollar el "Height Modernization Program" promovido por el National Oceanic and Atmospheric Administration (NOAA por sus siglas en inlgés) y dirigido por el National Geodetic Survey (NGS por sus siglas en inlgés).

Paralelo con este proyecto, el gobierno y las empresas privadas trabajan para crear la primera Red de GPS a Tiempo Real con precisión centimétrica para toda la Isla. Esta infraestructura de posicionamiento apoya cualquier investigación o el estudio para desarrollar diferentes productos que pueden ayudar en cualquier manejo de desastres. Utilizando las últimas técnicas como los Sistemas de Información Geográfica (GIS por sus siglas en inglés), dibujo computadorizado (CAD por sus siglas en inglés) y el desarrollo del Sistema de Posicionamiento Global (GPS por sus siglas en inglés) se hace posible la generación de datos para predecir, manejar y mitigar los daños causados por un desastre natural. Las ventajas en la tecnología tales como las computadoras y diferentes dispositivos electrónicos pueden ayudar en nuestro trabajo de manera significativa, segura y eficaz ante una situación adversa. Estamos trabajamos para crear soluciones en nuestro país, Puerto Rico, que satisfagan las necesidades de nuestra población y que determinen el modelo a seguir para el manejo de desastres y mitigación en la cuenca del Caribe.

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1. INTRODUCTION

Nature is seldom accurately predicted and as a consequence lives may be lost. In the last decade, technology developments have crossed the barrier with unpredicted events in nature. Using a variety of equipment with new mathematical algorithms, procedures have been implemented to render models for predictions the weather and other geophysical events, such as flash floods, hurricanes and, in the near future, tsunamis.

A group of professionals such as Engineers, Land Surveyors, Geologists, Meteorologists and professionals from other related professions are aware of these events and have implemented this type of technology to benefit of the whole community. The use of tide gauges, meteorological sensors, seismometers sensors, buoys, and GPS stations; among others working with computer clusters and specialized computer software are only part of the new technologies being implemented in the little star of the Caribbean. Our goal is to set some standards for the Caribbean Disaster and Management Program.

2. PROBLEMS

2.1 Location – Lat. 18.22 N, Long. 66.49 W

Puerto Rico is an island between the Caribbean Sea and the North Atlantic Ocean, east of the Dominican Republic and west of the Virgin Islands (about 1,000 miles (1,600 km) southeast of Miami, Florida), see Figure 1. Based on the Caribbean Plate and bordered on its northeast side by the North American Plate. Surrounded by multiple gravitational anomalies caused by multiple ocean trenches and deep waters fringe Puerto Rico. The Mona Passage, which separates the island from Hispaniola to the west, is about 75 miles (120 km) wide and more that 3,300 feet (1,000 meters) deep. Off the northern coast is the 28,000 feet (8,500 meters) deep Puerto Rico Trench, and to the south the sea bottom descends to the 16,400 feet (5,000 meters) deep Venezuelan Basin of the Caribbean.

Figure 1: Caribbean basin

2.2 High Population Density

The 3.95 million people that inhabit the island of Puerto Rico have made it one of the most densely populated islands in the world. There are about 1,000 people per square mile, a ratio higher than the one in the state of New York in the United States. It is estimated that some two million Puerto Ricans have migrated to the United States. If these people would have remained in Puerto Rico, the island would be so densely populated that there would be no room for people to live. One-third of the population is concentrated in the San Juan-Carolina-Bayamón (metropolitan area).

2.3 Risks

2.3.1 Tsunamis

Throughout the history of Puerto Rico there have been several tsunamis that have impacted our coastlines. The most significant took place on October 11, 1918 see Figure 2, were 32 people drowned. This tsunami was caused by an earthquake of a magnitude of 7.3 on the Richter scale which generated an ocean landslide which occurred between the Dominican Republic and Puerto Rico.

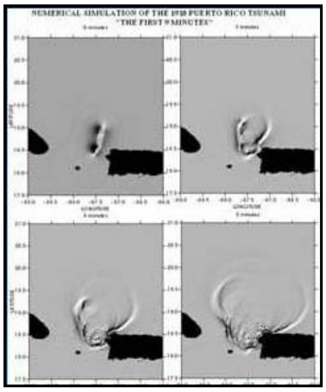

Figure 2: Tsumani Simulation

2.3.2 Flash Floods

The north coast gets twice as much rain as the south coast. Annual precipitation in the north is 155 cm (61 inches); in the south is 91 cm (36 inches), in coastal regions 101-381 cm (40-150 inches) and in the mountains 508 cm (200 inches). Having tropical weather all year round creates a high possibility of rain showers. Most of this precipitation produces high quantities of runoff. This phenomenon combined with irregular topographic conditions of our island creates the possibility of urban floods. Urban development projects are constructed nearby coasts and rivers which makes them vulnerable to these events. Puerto Rico Land Management Programs try to find real solutions to control flooded areas using different engineering techniques.

2.3.3 Earthquakes

As Puerto Rico sits on the Caribbean Plate, which slides under the North American Plate just a few kilometers from its north coast, large amounts of seismic activity are produced in this area. Since the beginning of this year until May 2006, a total of 980 seismic events had been registered, of which 11 were felt by the population, the Figure 3 show the seismic activity in May 2006. This leads to large possibilities of the occurrence of tsunamis in this area.

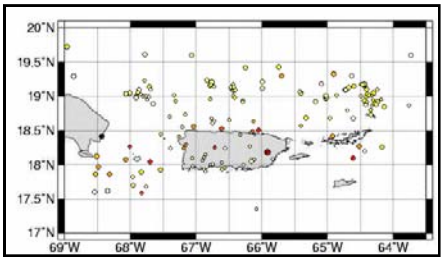

Figure 3: Earthquake Epicenters

2.3.4 Hurricanes

Puerto Rico is subject to frequent and severe impacts from hurricanes because of its location in the Caribbean. Since 1893 there have been 9 hurricanes that have passed directly through - out the island, see Figure 4. As these storms pass, they leave large amounts of destruction and rainfall. These are major problems for the island because the activity of hurricanes lasts from June through September (4 months). The process of Recovery and stabilization has a slow start as the Municipalities try to recover rapidly with their mitigation and management programs.

Figure 4: HurricaneTrayectories

2.3.5 Storm Surge

As tropical storms and hurricanes pass through the Caribbean Sea, conditions become difficult for navigation purposes. When these storms pass close by the island, the effect of storm surge can be present in our coastlines. Storm surges can increase tide levels up to 15 feet (4.572 meters) over normal conditions. This causes the need to evacuate densely populated coastlines; the danger produced by storm tides is tremendous and has to be taken as a serious threat for the citizens who live near coastlines. The island of Puerto Rico has approximately 311 miles (501 km) of coastlines of which most are highly populated.

3. PLAN FOR TSUNAMI WARNING

3.1 Prevention

3.1.1 Education

Knowledge is our most powerful weapon to defeat the loss of lives that can be caused by a tsunami. Education in elementary schools helps to understood of the occurrence and dangers involved when an event of this magnitude occurs. Time is a critical factor in these events and if communities had previous seminars and evacuation simulations; that would help in an emergency situation. Various seminars have been held throughout Puerto Rico to benefit students, communities and professionals for educational purposes. The University of Puerto Rico, Mayagüez Campus (UPRM) is the official institution to educate our population using the Puerto Rico Seismic Network (PRSN) as a qualified entity to observe, monitor and advise in the case of a possible emergency.

3.1.2 Maps

During the first quarter of 2006, the joint venture of PRSN and NOAA created the first tsunami evacuation map for the Caribbean Basin, see Figure 5. This map includes the tsunami hazard zone throughout the coastline of the municipality of Mayagüez, evacuation routes, bridges, assembly points, hospitals and schools as the most important characteristics to be located in a map. These were distributed free of charge to the communities of these areas and is available free of charge in the Puerto Rico Seismic network Homepage http://redsismica.uprm.edu/spanish/Noticias/TsunamiMap_Pub.pdf. The communities now have a clearer view of these hazard zones; and how and were to attend in case of an actual event.

Figure 5: Tsunami Map

3.1.3 Tide Gauge

One of the main components to register tidal changes in actual sea levels is a tide gauge. Different mechanisms have been developed during this century to measure these changes; among these are pressure, electronic and float sensors. Computers are integrated to these sensors to collect data, perform local data analysis and broadcast through Geostationary Operational Environmental Satellites (GOES) or by internet connection to the nearest Tsunami Warning Center (TWC) in case of abrupt changes. If this occurs, the alert will be automatically activated and the real time data stream is analyzed by TWC. These results will be broadcasted by emergency warning methods indicating a possible or eminent emergency.

Puerto Rico is taking advantage of the technology and is working on the implementation of the Caribbean Tsunami Warning Center (CTWC) in the PRSN headquarter. A total of nine new cutting edge tide gauges sponsored by Federal Emergency Management Agency (FEMA) and NOAA will be installed around the island. The Caribbean region will then have one of the most complete and dense tide gauge systems in the world. A total of 13 stations will be operating by the year 2007.

3.1.4 Buoys

To expand the U.S. tsunami warning system, NOAA has installed five deep-ocean assessment and reporting of tsunami (DART) buoy stations off the U.S. East and Gulf coasts and the Caribbean. The latest buoy station, off the coast of Louisiana, joins stations off South Carolina, Florida and two off Puerto Rico installed in March 2006. These buoys are a first line of defense in providing citizens of the Atlantic, Caribbean and Gulf regions with a comprehensive tsunami warning system. DART stations are an advanced technology that will help protect densely populated tourist destinations in the regions and protect their economic resources such as the case of Puerto Rico, see Figure 6. The DART system provides real-time tsunami detection as waves travel across the open ocean. The new installed stations, called DART II, are a more robust design than previously installed stations. These stations are equipped with advanced two-way satellite communications that let forecasters receive and retrieve critical data.

Figure 6: Buoys Location

3.2 Mitigation

3.2.1 Assembly Points

The Assembly Points are places with good characteristics to withhold large amounts of people for future assistance in case of an emergency. These points are stated in evacuation map routes confectioned for different types of emergencies. In the first tsunami evacuation map for the Caribbean Basin, it clearly locates these sites with a capital "A" within a red circle. Government officials treat these sites as priority points for early assistance of victims in case of disasters or emergency situations.

3.2.2 Routes to Hospitals

After a disaster strikes victims have to be transported to hospitals receive emergency care. This seems like an uncomplicated task, but in case of a disaster, not all routes are available. Alternates routes should be established to create an effective timeline from emergency site to emergency room. If these routes have been already predetermined all emergency personnel can perform more effective their jobs in coordination with unexpected disasters. Also, critical routes are given much more emphasis for clearing paths and any necessary repairs. Having these routes fully operational, as soon as possible, can make a huge difference when dealing with disasters.

3.2.3 Refugee Locations

Natural disasters affect man-made structures in all proportions. Some might loose their homes and others can experience minor losses of their belongings. The reality is that many people will become homeless and a reasonable relocation site must be available as a substitute home for them. Identifying in advance which structures are appropriate and least vulnerable to be affected by disasters helps in planning ahead of time where to transport these people who have arrived at the assembly points. It is also important have clear idea how many people can be affected in this emergency to consider if the municipality has enough refugee locations or if these citizens have to be relocated in other municipalities.

3.2.4 Extension of Disaster

The maps for tsunami flood zones were made using modeling programs which are not highly accurate because of the use of hypothetical data. Using existing information of historical events and predictions we can make predictions of the extents to which water could rise inland in case a tsunami occurs. It is of utmost importance to recognize which areas should be evacuated in case a possible threat is present to human lives. On the first tsunami evacuation map for the Caribbean Basin these areas were represented by a yellow background simulating those residences which were within this hazard zone and had to be evacuated to higher grounds. In the event of a tsunami, data would be collected in the field to recover actual water penetration inward, for future models and evacuation scheduling.

3.2.5 Redefining Existing Infrastructure

When a disaster has passed specialized survey crews must visit the areas impacted to collect actual data and redefine actual localization of existing infrastructure. With all the necessary data and equipment, field work can be done quite precisely. The survey data should be available before hand to be consistent with actual localizations. The need for available roads is essential in the process of recognition and reconstruction of impacted areas.

4. LEVELING NETWORK

4.1 Puerto Rico Vertical Datum 2002 (PRVD2002)

The importance of an accurate height system is needed to support numerous engineering, mapping, and scientific applications which require it to be very well established. A network of stable, easily accessible vertical survey control points, referred to as bench marks (BMs), is crucial to a wide range of activities including: flood mapping, tsunami evacuation routes, storm waters and sewer utility management, large scale engineering projects, hurricane evacuation and recovery planning, and topographic mapping. Networks of BMs are usually defined with respect to a regional, national, or international geodetic datum such as the North American Vertical Datum of 1988 (NAVD 88), and are a fundamental component of the National Spatial Reference System (NSRS) maintained by the National Geodetic Survey (NGS).

A proposed network of about 575 first-order, class II BMs, spaced approximately 1.6 km apart along public access roads over roughly 925 km (875 km on Puerto Rico, 40 km on Vieques, and 10 km on Culebra) to be referred to as the Puerto Rico Vertical Datum of 2002 (PRVD 2002). The origin will be defined as the NOS long-term tide gage (975-5371) located at the U.S. Coast Guard Station at La Puntilla, San Juan. The leveling routes will be planned to connect to as many as possible of the tide gauge sites established by the NOS Center for Operational Oceanographic Products and Services (CO-OPS). Initial leveling operations were performed by an NGS field unit and the remaining 765 km would be completed by surveyors of Puerto Rico in the near future. The final network adjustment for the island will be completed by NGS.

To obtain the improved geoid model, NGS, in cooperation with the Colegio de Ingenieros y Agrimensores de Puerto Rico, will develop a plan for GPS observations at selected BMs to be conducted in conjunction with the completion of specified portions of the leveling network. This activity is a component of the National Federal Base Network (FBN) modernization program.

4.2 Leveling with GPS Systems

Leveling procedures are a slow and complicated task especially in areas with high volumes of traffic. In an effort to complete a local network around the island faster, the use of GPS was implemented with positive outcomes. The first part of the leveling network run by personnel of NGS, ans was from San Juan to Aguadilla; the idea was to transfer an elevation datum from Aguadilla to Mayagüez. The transfer method was backsight and foresight observations of five minutes and no more than two kilometers apart from each other. A 30 km run which would have taken 2 weeks, took only 15 working hours using GPS methods. The run was made to a local survey control point registered at NGS to be horizontal order A and vertical FOURTH CLASS 1. Its elevation was known as 3.7 m; results from GPS observations came up with 3.72 m. With the use of more accurate geoids and modeling programs the precision of these results will be better.

5. GPS REAL-TIME KINEMATIC NETWORK (RTKN)

5.1 Rtkn

Figure 7: RTK Distribution Concept

Real - Time Global Navigational Satellite System (GNSS) is the most important growing technology in the world's positioning market. More cost -effective projects, reliable data, real time or post processing centimeter accuracy, data archive among others are only some of the benefits of RTKN. Governments and private organizations recently have implemented the use of RTKN to special tasks such as tectonic plate movements and structural monitoring, precise water vapor measurements, vehicle or aircraft tracking, and infrastructure positioning among others.

Using this cutting edge technology, Vernix Engineering Corp. is creating the first Caribbean Global Positioning System Real-Time Kinematic Network (GPS RTK Net) in joint venture with the National Geodetic Survey (NGS), United States Coast Guard (USCG), University of Puerto Rico-Mayagüez (UPRM), Marel Bayamón and Agrimensores 4N Inc. A strategically designed GPS reference system with computers running a real-time GPS network using modeling software which is the backbone of this project, gives way to an accurate three dimensional coordinate position. This system will create the necessary infrastructure to extend, among other things, the Global Navigation Satellite System (GNSS) capabilities available in Puerto Rico and surrounded islands such as the Virgin Islands (St. Croix, St. Thomas and Tortola). Figure 7 illustrates the network distribution concept of the Puerto Rico RTK Net. (Blue Cap-Master site, Green Cap-Available, Red Cap-In connection progress and Yellow Cap-In Installation Progress).

5.2 Continuous Operating Reference Stations (CORS)

The NGS, an office of NOAA, coordinates two networks of GPS continuously operating reference stations (CORS): the National CORS network and the Cooperative CORS network, see Figure 8. Each CORS site provides GPS carrier phase and code range measurements in support of three - dimensional positioning activities
throughout the United States and it territories. Geographic

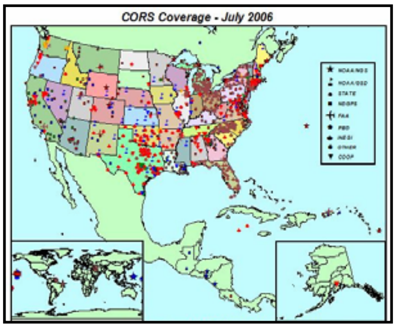

Figure 8: America's CORS Stations

Information Systems (GIS) / Land Information Systems (LIS) technicians, engineers, land surveyors, scientists, and other professionals can apply CORS data to position points at which GPS data has been collected. The CORS system enables positioning accuracies that approach a few centimeters relative to the NSRS, both horizontally and vertically.

The CORS system benefits from a multi-purpose cooperative endeavor involving many governments, academic, commercial and private organizations. New sites are evaluated for inclusion according to established criteria.

Figure 9: Puerto Rico & V.I. CORS Stations

All national CORS data are available from NGS at their original sampling rate for 30 days. After that time, the data are decimated to a 30 second sampling rate. Cooperative CORS data are available from the participating organizations that operate the respective sites. Figure 9 illustrates the Puerto Rico and Virgin Islands Available CORS Sites.

5.3 Positioning Products

The GPS network signal modeling software used by the Puerto Rico RTK Net is Leica Spider Net 2.1. The software has the capability to broadcast different RTK message in different ways. This feature allows all kinds of GPS Systems with network support which use real time message to apply the position corrections. The standard positioning product created by the software benefits the user making the service wide open to the positioning community. The real-time messages supported by the software are RTCM from 2.1 to 3.0, CMR and CMR+ and Leica proprietary message, see Figure 10. The system has available two real time positioning products; the first is the automatic cell selection with network real-time adjustment and the second is a single base solution from the nearest GPS Reference Station.

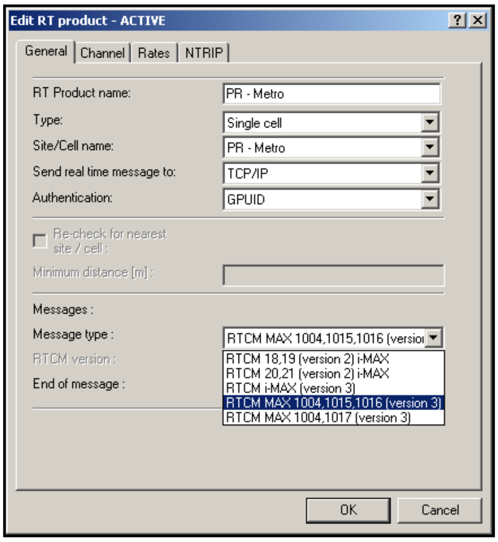

Figure 10: Positioning Product

5.4 Post Products

Data collected is supported by a Dell computer server located at the University of Puerto Rico with an Internet II connection. Remote GPS receivers send the data via internet using a static IP address. Data from different GPS Reference Stations have a dedicated archive folder to create a Receiver Independent Exchange Format (RINEX) files at a 30 second sample. The flexibility of the system supports the creation of different sampling rate products from the same GPS Reference Station; it also supports buffer rings with a minimum sampling rate of 0.03 seconds. The product saved in the server for the community can be used to make post processing files, saving time and money, and making work easier.

5.5 Determination of Availability

Puerto Rico GPS RTK Network has been designed to support the community 24 hours a day, seven days a week. The stability of the signal processing is very reliable 24 hours a day and the precision is in function of the distance of the cell or baseline solution which is used to process the data. With a fully operational network, the user could achieve one centimeter accuracy on three-dimensionally real-time or post processing data. The plans are to extend the service within the Caribbean basin making it available in Puerto Rico and surrounding countries.

6. CONCLUSION

The implementation of new technologies has supplemented traditional methods. To take advantage of this, we have implemented these updates to develop new strategies in disaster risk management. The consistent evolution of the technology provides alternatives for more effective solutions of real society problems.

Puerto Rico, as though a little star in the Caribbean, is promoting its initiatives to involve all surrounding countries to join in a master plan to protect the people that live in the Caribbean Basin. The collaboration of U.S. Federal and local governments, private organizations, and partnerships with other countries facilitates will make this project a reality. Hopefully, other countries farther away will follow these new strategies so one day it becomes an international organization for disaster management.

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BIOGRAPHICAL NOTES

Carlos R. Vega Santos
Academic experience: Bachelor's degree in Land Surveying (2001) and currently enrolled in the Civil Engineering bachelor's degree at the University of Puerto Rico at Mayagüez

Professional Standing: Land Surveyor in Training

Current position: Student, University of Puerto Rico at Mayagüez

Practical experience: Topography, geodetic leveling, bathymetric maps, route location, boundary definition, coastal surveys among others.

Participation in Activities: CEIA – Capítulo Estudiantil del Instituto de Agrimensores de Puerto Rico and the National Society of Professional Surveyors
March 2006: COINAR Congress San Juan, Puerto Rico
April 2006: ASCM Annual Conference, Florida, US

Carlos J. Rodríguez Rosario
Academic experience: Bachelor's degree in Land Surveying (2002) and Civil Engineering bachelor's degree (2003) at the University of Puerto Rico at Mayagüez

Professional Standing: Professional Land Surveyor and Civil Engineer in Training
Member of Puerto Rico College of Engineers and Land Surveyors

Current position: Associates of Vernix Engineering at Mayagüez, Puerto Rico since 2005.

Practical experience: Topography, geodetic leveling, route location, project stakeout, as-built plans, legal boundary survey, GPS static and RTK Surveys, GIS, CAD specialist, coastal surveys, hydrographic surveys, landuse mapping, land development, project management, tsunami evacuation map specialist among others.

Participation in Activities:

July 2000: Italy Study travel (3 credits in history and art of Italy)
March 2001: Regional and Southeast ASCE Civil Engineering Competition, Alabama, US
April 2002: Regional and Southeast ASCE Civil Engineering Competition, Florida, US
October 2002: FIG Conference Mayagüez, Puerto Rico
November 2004: NGS Convocation Washington, US
March 2005: COINAR Congress San Juan, Puerto Rico
October 2005: COPIMERA Congress La Habana, Cuba
March 2006: COINAR Congress San Juan, Puerto Rico
April 2006: ACSM Annual Conference, Florida, US

CONTACTS

Carlos R. Vega Santos
Land Surveyor in Training
University of Puerto Rico at Mayagüez
PO Box 5399
Mayagüez, Puerto Rico 00681-5399
Tel. + 1 787 543 6704
Fax + 1 787 833 8260
Email: carlosball3@gmail.com

Carlos J. Rodríguez Rosario
Professional Land Surveyor/Civil Engineer in Training
Vernix Engineering-Puerto Rico
Frank Souffront Street No. 617
Urb. Río Cristal Mayagüez,
Puerto Rico 00680
Tel. +1 787 833 9918
Fax + 1 787 833 9918
Email: carlos_rodriguez@vernixeng.com
Web site: www.vernixeng.com