Virgin Islands Water Resources Research Institute
Annual Technical Report
FY 2001

Introduction

The Water Resources Research Institute (WRRI) at the University of the Virgin Islands (UVI) is one of the 54 water resources research institutes established at land-grant universities throughout the United States and its territories. WRRI was established in 1973 and operates under the Water Resources Research Act of 1984 as amended by Public law 101-397. Like other water resources research institutes, it receives partial federal funding provided through the U.S. Geological Survey. Additional funding is provided by UVI and through contractual projects. WRRI is a part of the Research and Public Service component of the University. The Institute carries out its three-fold mission of research, training and information dissemination with the formal guidance of an Advisory Committee and with input from UVI’s many collaborators in the local and regional community.

This year’s research activity in the project "Applicable Indicators of Risk for Coastal Waters in Tropical Environments: Phase II" was a continuation of work started in FY 2000. This research is invaluable in the Virgin Islands and similarly simulated tropical communities where it is critical to have reliable means of assessing the quality of coastal waters.

The information transfer project "An Intensive Short Course on Water Resources, Coastal Hazards and Coral Reef Degradation" provided the opportunity for persons employed in the environmental field and others to gain knowledge on matters relating to coastlines and water resources of the Virgin Islands that they might not have been able to obtain elsewhere. This project in particular, grew out of a request from a local agency.

Training formed an integral part of both projects. This involved not only university students but also other staff and members of the public. The hands-on training and the experiences provided by the WRRI is important in the Virgin Islands and Puerto Rico where such opportunities for training in specialized areas seldom arise.

Research Program

Applicable Indicators of Risk for Coastal Waters in Tropical Environments: Phase II

Basic Information

Title:	Applicable Indicators of Risk for Coastal Waters in Tropical Environments: Phase II
Project Number:	2001VI4421B
Start Date:	4/1/2001
End Date:	3/1/2002
Funding Source:	104B
Congressional District:	Not Applicable
Research Category:	Biological Sciences
Focus Category:	Water Quality, Recreation, Waste Water
Descriptors:	Water Quality Standards,Water Quality Monitoring, Water Quality, Viruses, Risk Analysis, Recreation, Marinas,Lagoons, Coastal Zone, Biomonitoring, Beaches, Bays, Bacteria
Principal Investigators:	Gary A. Toranzos, Henry H. Smith

Publication

1. A project completion report is being prepared.
2. A paper is being prepared for presentation at a conference in South Africa.

Summary Report on

APPLICABLE INDICATORS OF RISK FOR COASTAL WATERS IN TROPICAL ENVIRONMENTS: PHASE II

Problem and Research Objectives

The control of water quality in terms of concentrations of microbial pathogens in recreational waters is of great concern for the protection of human health. Epidemiogical studies have shown an increase in the risk of morbidity in coastal water swimmers when compared to non-swimmers in waters polluted with total and thermotolerant coliform bacteria (1,2). Also, a significant relationship between bacterial indicators and gastrointestinal symptoms has been established (1). Other symptoms related to exposure to these bacteria are respiratory and skin infections. At risk populations are children playing in the tidal or swash zone, the elderly and people with poor immune system functions.

In the islands of Puerto Rico and St Thomas, in the Caribbean, many beaches are located near high population density areas. Studies have shown that populations near the coast may increase the chance of contamination of coastal waters with urban and industrial wastes and sewage effluents with high levels of pathogenic agents (2). Anthropogenic sources of microbial polluted waters can increase the probability of diseases. However, no formal studies have been conducted to quantify this in St. Thomas or in Puerto Rico. In addition, microbial concentrations in these beaches are not well understood or not well characterized in terms of temporal and spatial characteristics.

Climate conditions favor year-round coastal water activities for both native and tourist populations in these islands. This may increase the chances of contact with polluted waters and a consequent increase in morbidity. On the other hand, the practice of using thermotolerant coliforms, or even *Escherichia coli* to detect fecal pollution in tropical waters is in debate, since they tend to occur naturally in tropical waters (3,4). Also, their survival appears to be longer outside the gastrointestinal tract of blood-warmed animals in tropical environmental conditions (5).

The objectives of this study are to (i) establish temporal and spatial data of microbial indicators of tropical coastal waters, (ii) analyze different microbial indicators of water quality (like total and thermotolerant coliforms and enterococci), to observe their relation with physicochemical characteristics of the water (e.g. pH, temperature, total dissolved solids, salinity, sunlight) and other characteristics (number of people in the water at the time of sampling), and (iii) to investigate a probable pattern of fluctuations of microbial quality indicators in coastal waters year-round.

Methodology

From October to May, 2002, three public beaches (Coki Point, Lindberg Bay, and Magens Bay) from St. Thomas, Virgin Islands were sampled. An area of 200 feet long on the coastline was identified at each beach. Four samples were taken (two at chest depth and two at ankle depth) with a 200 ft of separation on the beach. Samples were taken in the morning (9:00 am), at noon (12:00pm), afternoon (3:00pm) and in the evening (6:00pm) for two consecutive days during the weekends. This was performed to observe the variation in time that bacterial measurements may have in the days of the week that are most frequented by bathers.

Physical parameters such as temperature, pH and dissolved solids were recorded from each sample before storing them in an ice cooler with cold packs. Samples were then stored at 4 °C in the laboratory for analysis within the next 24 hours. The quantity of swimmers at every hour in the beach was also recorded.

The same procedure was followed to sample five public beaches located mainly on the north coast of Puerto Rico island (Isla Verde, Luquillo, Cataño, Humacao, Manatí) from January to August, 2002. In addition to Colilert and Enterolert tests, we performed Membrane Filtration (MF) analysis (6) were performed in samples from Puerto Rico beaches.

Bacterial Analysis

Colilert and Enterolert tests were performed to analyze total and thermotolerant coliforms, as well as enterococci. The Colilert test is an enzyme-specific test that gives the most probable number (MPN) of total and thermotolerant coliforms in a 100 mL sample. This method consists of use of a reagent which in the presence of the enzyme B-galactosidase (present in all coliform bacteria) produces a change in color and in the presence of the enzyme *B*-glucoronidase (present in all thermotolerant bacteria) emits fluorescence under UV light (7). Enterococci can be detected using the Enterolert test, which under UV light shows the MPN of enterococcus bacteria in a 100 mL sample. Marine water samples must be diluted by a factor of 10 for better results as suggested by the manufacturer (Advance Systems Inc.). After mixing the reagent with marine water, samples were poured into a tray having 48 large wells and 48 small wells. The counting of the large and small positive wells for each test, gives us the MPN when compared to a standard MPN table.

Membrane filtration analysis (MF) was performed following the method described by the American Public Health Association (6). Samples analyzed by MF were expressed in colony forming units/ 100 mL of sample.

Statistics

The Minitab Statistical program was used to calculate basic statistics on this preliminary data. A simple linear regression analysis was performed to relate bacterial concentrations with physical parameters of the water. One-way analysis of variance (ANOVA) to observe the differences in bacterial concentrations within methods of analysis was also performed. In addition, another one-way ANOVA was performed to observe any difference in bacterial concentrations within water depth.

Principal Findings and Significance

Descriptive statistics of MPN/100mL of total coliforms, thermotolerant and enterococci in St. Thomas, VI are shown in Table 1. Mean total coliforms were found to be higher in Magens Bay than in Coki Point or Lindberg Bay. However, the highest mean value of the thermotolerant bacteria and enterococcus bacteria was found in Coki Point. Other ranges bacterial concentration ranges are shown in Table 1.

A one way analysis of variance (ANOVA) to verify the difference in bacterial concentrations within all three beaches in St Thomas showed a statistically significant difference for each bacterial measure as shown by a p value lower than 0.05 (Table 2).

A linear regression analysis showed a statistically significant relation between total coliforms and pH of water (p=0.000). This is also truth in the relation between thermotolerant coliforms and pH (p=0.000). Temperature and total coliforms showed a statistically significant relation (p=0.001). Thermotolerant coliforms were also significantly related to temperature of the water sampled. The rest of the *B* (regression coefficient) and p values of the regression analysis are shown in Table 3.

Mean results of the five beaches sampled in Puerto Rico island with MF are shown in Table 4. The highest mean total coliforms (in CFU/100 mL) value was found at Manatí. For thermotolerants, the highest mean was found in Cataño and for enterococci was in Humacao.

Mean MPN values (analyzed by Colilert and Enterolert) in beaches from Puerto Rico are shown in Table 5. The highest total coliforms value was found in Humacao beach. The highest in thermotolerant coliforms was Manatí beach, and for enterococci the highest value was found in Cataño.

The relation between environmental measurements of the water and the concentration of different bacteria analyzed by Colilert and Enterolert is shown in Table 6. A statistically significant relation was found between total coliforms concentration and the pH. Thermotolerant coliforms and enterococci were significantly related with temperature (p=0.001, p=0.000) as shown by a p value smaller than 0.05. Additional *B* values and p values of the simple linear regression analysis are shown in Table 6.

Discussion and Conclusions

Bacterial indicators of recreational waters have been questioned as to their efficiency to indicate risk to human health. Our results indicate that these indicators are present in high concentrations in recreational waters of St Thomas VI, and Puerto Rico. All bacterial measurements vary significantly from beach to beach in both islands but are still high in mean MPN values. The relationship of bacterial concentrations and environmental characteristics of water are not the same for both islands, but the number of swimmers at the time of the sampling was not related to the bacterial concentrations in any of the two islands.

It remains to be seen if the presence of these indicators represent a real public health problem. A prospective epidemiological study is being designed to investigate the morbidity of bathers and its relation to the presence of bacterial indicators of fecal contamination in these tropical waters.

Unfortunately it was not possible to use *Clostridium perfringens* as originally indicated in the proposal, as the difficulty of detecting them (possibly as a result of the low concentrations present) did not permit its use as a possible indicator to be measured.

Thus the original plans to fingerprint the isolates could not be carried out as a result as well. The fingerprinting of the *E. coli* isolates is currently being carried out.

The training aspect of the proposal was only partially met. Several people were trained at the University of Puerto Rico and the University of the Virgin Islands. In Puerto Rico the following students took part in the project:

Johanna Santamaria (M.S. defended her thesis in February, 2003)
Roberto Rodriguez (M.S. defended his thesis in February, 2003)
Elia Enid Sanchez (Ph.D. student)
Astid Huertas (M.S. candidate)
Clarivel Lasalde (M.S. candidate)
Francisco Calderon (Post-doctoral Associate)

All the above students got some support from the project. It should be mentioned that the lack of continuous funding makes it hard to train students at the University of the Virgin Islands. We were, however able to train two persons:

Rebelto Harrigan
Mayra Suarez

The results from the different portions of the project were presented at local, national and international meetings. The last portion of the proposal will be presented at the International Water Quality Conference to be held in Cape Town, South Africa in September 2003. One publication in a peer-reviewed journal is expected from the ongoing portion of the project. This paper will be presented at the South Africa meeting and will be submitted to a journal immediately thereafter.

References

1. Cabelli VJ. Dufour AP., Levin MA. McCabe LJ, Haberman PW. Swimming associated gastroenteritis and water quality. American Journal of Epidemiology.1982;115(4):606-616.

2. Cabelli VJ. Dufour AP., Levin MA. McCabe LJ, Haberman PW. Relationship of microbial indicators to health effects at marine bathing beaches. American Journal of Public Health. 1979;69:690-696.

3. Hazen, T. Fecal Coliforms as indicators in Tropical Waters. Toxicity Assessment 1988;3:461-477.

4. Rivera SC., Hazen TC., Toranzos GA. Isolation of fecal coliforms from pristine sites in a tropical rain forest. Applied and Environmental Microbiology. 1998;54(2):513-517.

5. Davies CM., Long JA., Donald M., Ashbolt N. Survival of fecal microorganisms in marine and freshwater sediments. Applied and Environmental Microbiology. 1995;61(5):1888-1896.

6. American Public Health Association. 1985. Standard methods for the examination of water and waste water. 16th ed. American Public Health Association, Washington D.C.

7. Tryland I., Fiksdal L. Enzyme characteristics of B-D-Galactoside and B-D-Glucoronidase-positive bacteria and their interference in rapid methods for detection of waterborne coliforms and *Escherichia coli*. Applied and Environmental Microbiology. 1998;64(3): 1018-1023.

Table 1. Mean total and thermotolerant coliforms and enterococci MPN (with the range in parenthesis) from beaches in St Thomas VI with Colilert and Enterolert tests.

Beach	N	Total Coliforms*	Thermotolerant *	Enterococcus*
Coki Point	64	571.7 (0.0-1421.0)	357.2 (0.0-1011.1)	111.3 (0.0-1782.0)
Lindberg Bay	64	652.7 (41-1376.0)	291.5 (0.0-1011.1)	35.4 (0.0-1011.1)
Magens Bay	63	933 (52-1011.1)	356.8 (0-2014.0)	98.5 (0.0-1722.0)

* MPN / 100 mL

Table 2. Analysis of Variance (ANOVA) results of bacterial concentrations (MPN / 100 mL) within beaches from St Thomas, V. I. (N=32)

Variable	SS	F value	p value
Total coliforms	5,508	2.92	0.023
Thermotolerant	15,702	3.14	0.016
Enterococcus	329,855	12.68	0.000

Table 3. Simple linear regression analysis for bacterial samples vs. environmental characteristics of water in beaches from St. Thomas VI. *B* (p value)

Bacteria samples	# of bathers	pH	Temperature	TDS
Total coliforms	0.44 (0.85)	495.9 **(0.000)**	121.30 **(0.001)**	-10.30 (0.646)
Thermotolerant	0.05 (0.96)	280.92 **(0.000)**	82.18 **(0.000)**	-4.21 (0.327)
Enterococcus	0.05 (0.94)	-0.97 (0.983)	13.60 (0.263)	-1.902 (0.345)

p values < 0.05 are in bold

Table 4. Descriptive statistics of mean total coliforms, thermotolerant and enterococci from 5 beaches in Puerto Rico with Membrane Filtration method of analysis

Beach	**N**	**Total Coliforms***	**Thermotolerant***	**Enterococcus***
Isla Verde	32	8.8	26.66	112.80
Luquillo	32	16.6	15.34	36.59
Cataño	32	17.1	29.40	19.09
Humacao	32	8.0	3.00	128.60
Manatí	32	23.8	10.50	32.34

*CFU / 100mL

Table 5. Mean values of the MPN / 100 ml of samples from PR beaches analyzed by Colilert and Enterolert

Beach	**N**	**Total Coliforms**	**Thermotolerant**	**Enterococcus**
Cataño	32	1964	461	410.7
Humacao	32	4961	25.9	60.7
Manatí	32	900	140.7	77.8

Table 6. Simple linear regression analysis for bacterial samples (in MPN) vs. environmental characteristics of water in beaches from Puerto Rico *B* (p value)

Bacteria samples	**# of bathers**	**pH**	**Temperature**	**TDS**
Total coliforms	2.08 (0.954)	2987 **(0.012)**	-405.5 (0.199)	144.8 (0.683)
Thermotolerant	0.038 (0.997)	199.5 (0.514)	-259.39 **(0.001)**	114.75 (0.198)
Enterococcus	-4.794 (0.223)	214.3 (0.104)	159.26 **(0.000)**	82.34 **(0.032)**

Information Transfer Program

Teaching an Intensive Short Course on Water Resources, Coastal Hazards, and Coral Reef Degradation

Basic Information

Title:	Teaching an Intensive Short Course on Water Resources, Coastal Hazards, and Coral Reef Degradation
Project Number:	2001VI4201B
Start Date:	4/1/2001
End Date:	3/31/2002
Funding Source:	104B
Congressional District:	Not Applicable
Research Category:	Not Applicable
Focus Category:	Groundwater, Acid Deposition, Education
Descriptors:	Fractured Aquifers, Geoindicators, Coastal Hazards, Beach Profiles, Hurricane Impacts, Coastal Management
Principal Investigators:	David M. Bush

Publication

1. The following web page was created and is available for use by the public: http://www.westga.edu/~dbush/USVI2001/webfiles/index.htm

Summary Report on

AN INTENSIVE SHORT COURSE ON WATER RESOURCES, COASTAL HAZARDS AND CORAL REEF DEGRADATION

Overview

In the Caribbean, issues of water supply, coastal erosion, and coral reef degradation are at the top of the environmental agenda. The islands in the region are relatively small and land use practices have an immediate and profound effect on the coastal environment that is important as a food supply, recreational area for residents and as the principal attractant for visitors in the tourism-based economy. It is critical then for all residents of the islands to have an understanding of the inter-relationship of all natural systems in the islands and to appreciate how each person has an important role in protecting these system.

This course was offered over a one-week period, July 16 to July 20, 2001, and was open to everyone. Workers in public and private agencies and non-governmental organizations were especially invited to attend. The topics addressed in the course fell under the following three general headings:

1. Coastal geology, coastal hazards, coastal management;
2. Coral reef ecology and stressors; and
3. Groundwater exploration and development.

The course consisted of 2.5 days seminar style lectures with discussions, 1.5 days field excursion, and 0.5 day wrap-up and final discussion. The complete course schedule appears later in this report.

Classroom sessions were held on the St. Thomas campus of the University of the Virgin Islands. In these sessions, presenters' lectures were supplemented with examples from their experiences in Puerto Rico and other locations in the Caribbean. Handouts, slides, videos and computer projections were used as tools in the lectures.

Field trips to sites of relevance around the island were used to reinforce the lectures. The trips consisted of lectures on site and demonstrations but also were structured so that application of methods described in class could be practiced.

Course participants were provided with packets of material to support the information presented in the lectures and the field trips. In addition, a website was created as further support for the course while it was being offered and for future reference by course participants and others. The site contains copies of reprints and Power Point slide shows used in the course and additional information that might not have been presented during the course. The site may be accessed at: http://www.westga.edu/~dbush/USVI2001/webfiles/index.htm.

Short Course Instructors

David M. Bush, Ph. D., P.G., State University of West Georgia

Dr. David Bush is Associate Professor of Geology at the State University of West Georgia in Carrollton, GA. He received his B.S. in Geology from the State University of New York, College at Oneonta, and both his M.S. and Ph.D. in Geology from Duke University. His graduate research focused on the sediments and storm processes along the northern Puerto Rico shelf and shoreline. He was a post-doctoral Research Associate with the Program for the Study of Developed Shorelines at Duke University for four years. It was then his research focused on coastal hazards, risk assessment mapping, and property damage mitigation. He has experience with the U.S. Atlantic and Gulf of Mexico coasts, the Bahamas, and the Caribbean, including Puerto Rico, Dominican Republic, St. Lucia, Antigua and Barbuda, Honduras, Yucatán Peninsula of Mexico, Colombian Caribbean coast, and the U.S. Virgin Islands. He was part of the National Academy of Sciences post-disaster field study teams after Hurricanes Gilbert and Hugo. He was involved with planning the U.S. Decade for Natural Hazard Reduction, and is the senior author of *Living with the Puerto Rico Shore*, *Living by the Rules of the Sea*, and *Living on the Edge of the Gulf: The West Florida and Alabama Coasts*, plus several peer-reviewed journal articles dealing with coastal hazards, risk assessment, and property damage mitigation. Dr. Bush serves on the editorial board of *Environmental Geosciences*. At West Georgia Dr. Bush teaches courses in risk assessment, geomorphology, and oceanography, and has published numerous papers on hurricane impacts and coastal hazards of developed shorelines.

Robert S. Young, Ph. D., Western Carolina University

Dr. Robert Young is an Assistant Professor of Geology at Western Carolina University in Cullowhee, North Carolina. He received a BS in Geology from the College of William and Mary, an MS in Quaternary Studies from the University of Maine and he was a James B. Duke Doctoral Fellow at Duke University where he received a PhD in Geology. Dr. Young serves on the editorial boards of the *Journal of Coastal Research* and *Environmental Geosciences*. He is currently the Technical Program Director for the Geological Society of America's Annual Meeting. Dr. Young's research interests lie in a wide variety of coastal and wetland areas. He has been working in the area of coastal hazards, coastal storm processes, and coastal planning for the last ten years. This work has been focused on the U.S. East Coast, the Caribbean, and in Central America with funding from FEMA, The Natural Hazards Center, New Hampshire Office of Emergency Management, and the National Science Foundation. During this time, he has conducted post-storm reconnaissance after the impact of nearly every major hurricane to strike the U.S. mainland and several in the Caribbean. He has written numerous professional papers dealing with coastal processes, numerical modeling, risk mapping, and property damage mitigation.

Randall L. Kath, Ph. D., P.G., State University of West Georgia

Randy Kath is Associate Professor of Geology, Center for Water Resources, State University of West Georgia, 6 years teaching and research; 11 years geological and geological engineering consulting; 3.5 years gold exploration; Registered Professional Geologist: PR, GA, TN; 13 years of attempting to understand the hydrogeology of igneous and metamorphic rocks; Doctor of Philosophy in Geology, Institute for the Study of Mineral Deposits, South Dakota School of Mines and Technology.

Short Course Topics

Offshore Coastal Zone Evaluation and Monitoring (Rob Young)

Monitoring the physical aspects of the coastal system is a critical part of any proposal to monitor potential reef/nearshore ecosystem degradation. Changes in the nearshore physical parameters are the link between terrestrial land use and the offshore impacts to coral reef health. Without direct measurement of coastal sediment dynamics, water quality, and coastal erosion, one cannot directly relate reef degradation to the onshore land use changes that may be harming the reef. Most monitoring efforts in reef ecosystems have focused on biological monitoring of reef change, possibly combined with some water quality measurements. These studies neglect the extremely important role that erosion and sediment loading of the coastal zone can play in raising turbidity levels and burying coral. Without vigorous coastal sediment transport monitoring along with the water quality analysis, reef harm from land clearing and vegetation removal cannot be separated from reef harm due to nutrient loading; and thus, proper management strategies to protect the reef ecosystem cannot be developed.

In order to preserve the valuable coral reef ecosystem during ecotourism development, we need to be able to link watershed level studies of land use directly to reef impact. This way we can determine whether reef degradation is due to increased sediment input or something like septic leaching, and by establishing this link, we may be able to institute management measures that will reduce the harm being done in time to preserve to resource we are all interested in preserving, the coral reef ecosystem.

Three important aspects of the offshore coastal zone must be evaluated:

1) The nearshore sediment cover and the amount of sediment in the water column. Numerous offshore study sites are established where three factors will be quantified: the average local thickness of sediment, the areal coverage of coral reef by sediment, and the turbidity of the water column.

2) At each of the above-mentioned sites, samples are taken for water quality analysis.

3) In addition, a detailed survey of the islands entire shoreline is made on foot and from the air. This survey catalogs shoreline type, degree of erosion (if any), beach width, vegetation cover, etc., using a geoindicator methodology developed for use in the Caribbean (Young et al., 1996; Bush et al., 1999–see below). This aspect is important to quantify any potential changes in coastal erosion or vegetation that may eventually impact reef viability.

All sites and surveys are located and recorded using GPS and entered into a GIS database for future reference and in order to relate these factors directly to a GIS database of land use and watersheds allowing determination of the focal point of any problems. This work can be carried out without the need for expensive or sophisticated field equipment. Initial monitoring stations and data collection are done with student assistance and local participants so that the methodologies are established and the bugs are worked out. After three years the program could be turned over to a local group for continued monitoring. All work can be carried out by divers/snorkelers working from a small boat.

Coastal Hazards and Risk Mapping (David Bush)

A Geographic Information System (GIS) is used to produce maps showing zones of relative risk of coastal storm damage for each study area. Applying GIS technology to hazard assessment and risk mapping along coastal areas, particularly barrier islands, benefits the communities by providing a basis for zoning, land use planning, and allocation of resources for post-storm property reconstruction and pre-storm damage mitigation plans. GIS may also be used to map and assess property damage or usefulness of attempts to protect and preserve coastal resources so that successful attempts may be continued and unsuccessful attempts abandoned. Such applications of GIS may ultimately lead to quantified assessments of ideal construction sites with areas of high risk left in a natural state--thus saving money and, possibly, lives.

Coastal risk mapping considers geography, geologic processes, and storm characteristics, all of which control the property damage potential of an island. Risk involves two components: hazards and vulnerability. Hazards are the physical processes of storms (wind, waves, surge) and vulnerability is the built environment which is subject to the storm physical processes (houses, other buildings, infrastructure, utilities). Observations made after several recent hurricanes and winter storms indicate that elevation and exposure to wind are the two primary factors controlling property damage. Secondary factors include dunes, vegetation, erosion rates, engineering, development, and historic storm response.

The goal of this project aspect of the workshop was to apply GIS technology to coastal risk mapping in terms of designating zones of relative risk for property damage during a moderate category 3 hurricane or equivalent strength winter storm. Coastal risk mapping is ideally suited to the application of Geographic Information System (GIS) computer technology. Island physical and geomorphic (landform) descriptive criteria are entered into a computer database, then, using GIS, any set of criteria can be combined to make risk assessments. The preliminary analysis can be made by GIS summing of elevation and forest cover digitally entered as separate layers. The secondary factors for revising the preliminary map can be added each as a separate digital layer, or summed separately depending on the users needs. When assessing potential coastal risk areas, zones are determined based on the above criteria, and an island divided into four categories designated as "Extreme Risk," "High Risk," "Moderate Risk," or "Low Risk" of property damage from hurricanes or other coastal storms.

Geoindicators (David Bush, Rob Young)

Coastal areas are at risk from such natural hazards as coastal erosion, storm-surge flooding, overwash, wind, dune loss, and human-induced problems (sand supply loss, increased erosion, loss of critical systems and water resources). The frequency, intensity, and location of active physical processes (or hazards) are controlled by *regional factors* (such as seismic setting and latitude), *local factors* (such as protective offshore barriers and coastal configuration), and *site-specific factors* (such as site elevation and vegetation). These factors, or *geoindicators*, provide clues to a coastal site's natural history and associated potential natural hazard risk.

When geoindicators are evaluated in a logically ordered checklist, shoreline erosion, potential coastal hazards and risks can be easily evaluated. This technique has wide application, spanning the range from an instructional tool to sophisticated coastal assessments on which to base coastal management policy. Further, the method fills a need for a scientifically valid method of qualitative shoreline assessment, given the reality of money and data shortages.

A geoindicators methodology will be applied to each study site, to evaluate shoreline change and coastal risk. The geoindicator approach is an outgrowth of recent experience in coastal hazard mapping, risk assessment, and property-damage mitigation studies summarized in Young *et al*. (1996) and Bush *et al*. (1999). National initiatives to develop coastal tourism potential carry the prospects for rapid, unsafe development, and need quick, reliable assessments of coastal-zone processes and associated hazards.

Geoindicators are defined by the International Union of Geological Sciences as "measures of surface or near-surface geological processes and phenomena that vary significantly over periods of less than 100 years and that provide information that is meaningful for environmental assessment" (Berger, 1996, p. 5). Geoindicators have a variety of management applications including environmental auditing and monitoring. In the coastal zone, shoreline change (usually erosion), risk/hazard assessment, and property damage mitigation are of primary concern. Although highly-sophisticated, high-technology environmental monitoring and historical analysis techniques are available as a means of collecting baseline data for coastal-zone management and policy determinations, these techniques are frequently expensive, time consuming, and require a high level of expertise. The geoindicator approach provides a viable, low-cost alternative.

The geoindicators approach identifies a minimum set of parameters that describe short-term environmental dynamics, and are proxies representing all the parameters on which processes depend (Berger, 1997). As a result, geoindicators can provide managers with simple, qualitative tools for rapid identification of coastal property damage risk potential that is scientifically valid. High precision isn't necessarily a requisite for coastal management decisionmaking. Applying a checklist of local-scale geoindicators provides a quick, inexpensive, practical evaluation of shoreline change along any particular stretch of shoreline. A simple photographic record taken at each site is an easy way to begin documenting changes as well as to allow re-evaluation of the surveyor's characterizations.

The risk setting changes frequently in the setting of coastal communities, subject to both natural and human processes that alter environmental stability. Use of geoindicators can provide rapid updates of management and mitigation plans. In many cases, especially in developing countries where funds are limited and adequate historical shoreline position data is frequently lacking, the coastal manager, planner, or scientist can attain an immediate assessment of coastal risk/hazards from geoindicators. In such cases, long-term state-of-environment and monitoring projects should be initiated, but such studies often take years to provide useful information.

Groundwater Exploration and Development in Volcanic Island Arcs (Randy Kath)

Exploration for, and development of, groundwater in deformed volcanic island arc rocks in regions with a sub-tropical weathering environment have been little studied, and are poorly understood. Much of the funded research and many of the recent and current studies in this regard seem to focus on the physics of groundwater movement in *fractured* rock. During the last several decades these studies have been driven by environmental containment and remediation problems and concerns. For this, the objectives and goals are quite different from that required for exploration and development of groundwater as a resource, where the quantity, quality, and sustainability of the resource is of utmost importance.

Thirty years of exploration and development of groundwater resources in igneous and metamorphic rocks of the southeastern United States, where older deformed and metamorphosed volcanic island arcs are exposed, has convinced us that, among the many factors that influence groundwater in these rocks, the *single most important factor is rock type*. Rock type directly influences all other parameters, i.e., type of weathering, depth of weathering, and topography. Without knowing the *detailed* geology of an area/site, all other factors influencing groundwater lack a full and meaningful context.

For success in groundwater exploration and development in areas of exposed volcanic rocks, more than an understanding of the physical parameters controlling groundwater movement is necessary. The interrelationships, both inherent and spatial, of rock type, structure, type and depth of weathering, and topography must be known and understood. Because the occurrence of groundwater does not rely on any single factor and because each of these factors will vary, groundwater exploration and development data in volcanic rocks must be site specific.

Current models that have been applied to volcanic arc rocks along the southern margin of Puerto Rico have assumed that groundwater occurs in the alluvium and fractured and weathered volcanic rocks, Graves (1992). Because the smaller, modern volcanic islands generally do not contain extensive areas of alluvial aquifers, groundwater exploration and development must focus on the weathered and fresh bedrock aquifer systems. The bedrock aquifer system can be divided into a fresh-rock, transition zone, and regolith aquifer system. The regolith- and transition-zone systems contain the same parent rock as the fresh bedrock aquifer, but differ in that it is highly fractured, shattered, and variably weathered. These aquifer systems are generally shallow and susceptible to droughts.

The deeper fresh-rock aquifer system is drought resistant. Because these rocks have no primary porosity or permeability, locating groundwater requires that zones of secondary porosity and permeability in the subsurface be located as precisely as possible. To accomplish this, a good understanding of the site-specific geology is of utmost importance.

The exploration and development approach outlined by Crawford and Kath (2000) has been very successful in exploration and development of groundwater resources in igneous (deformed volcanic arcs) and metamorphic rocks. Well yields using this exploration and development approach typically range from about 50 gpm to over 600 gpm in unique geologic settings. This approach begins with detailed site-specific geologic mapping to identify: rock type(s); discontinuities, due to compositional differences (layering) and fractures (joints and/or faults); topography; type and depth of weathering; nature and extent of the recharge area; and the spatial relationships of rock types and discontinuities to topography, type and depth of weathering, and recharge area.

The focus of this aspect of the course was on the team's experience with exploring for, and developing, groundwater resources. The exploration methods that were presented were directly applicable to many volcanic island arc systems.

Literature Cited

Aquirre, Benigno. E. and Bush, David M., 1992, Disaster Programs as Technology Transfers: The Case of Puerto Rico in the Aftermath of Hurricane Hugo: International Journal of Mass Emergencies and Disasters, v. 10, n. 1, p., 161-178.

Berger, A. R., 1996. The geoindicator concept and its application: an introduction. In *Geoindicators: assessing rapid environmental changes in earth systems*, ed. Antony R. Berger and William J. Iams, 1-14. Rotterdam: A. A. Balkema.

Bush, David M., 1991, Impact of Hurricane Hugo on the Rocky Coast of Puerto Rico, (in) Finkl, Charles W., and Pilkey, Orrin H., (eds.), Impacts of hurricane Hugo: September 10-22, 1989, Journal of Coastal Research, Special Issue #8, p. 49-67.

Bush, David M., Bruce R. Richmond, and William J. Neal, 2001. Coastal-zone Hazard Maps and Recommendations: Eastern Puerto Rico, *Environmental Geosciences,* 8(1), in press.

Bush, David M., Orrin H. Pilkey, and William J. Neal, 1996. *Living by the Rules of the Sea*, Durham, North Carolina: Duke University Press, 179 p.

Bush, David M., William J. Neal, Robert S. Young, and Orrin H. Pilkey, 1999. Utilization of Geoindicators for Rapid Assessment of Coastal-hazard Risk and Mitigation, *Ocean and Coastal Management*, vol. 42, no. 8, p. 647-670.

Bush, David M., Webb, Richard M. T., González Liboy, José, Hyman, Lisbeth, and Neal, William J., 1995. *Living With the Puerto Rico Shore*, Durham, North Carolina and London: Duke University Press, 193 p.

Crawford, T.J., and Kath R.L., 2000, Groundwater Exploration and Development in Igneous and Metamorphic Rocks: Part I Influencing Factors and Considerations: Drought 2000: Policy, Impacts, and Technology: V 1, N 1.

Graves, R.P., 1992, Geohydrology of the Aguirre and Pozo Honds Areas, Southern Puerto Rico: US Geological Survey Water Resources Investigations Report 91-4124.

Pilkey, Orrin H., William J. Neal, Stanley R. Riggs, Craig A. Webb, David M. Bush, Deborah F. Pilkey, Jane Bullock, and Brian A. Cowan, 1998. *The North Carolina Shore and Its Barrier Islands: Restless Ribbons of Sand*, Durham, North Carolina: Duke University Press, 318 p.

Pilkey, Orrin H., Jr., David M. Bush and Rafael W. Rodríguez, 1988, Carbonate-terrigenous sedimentation on the north shelf of Puerto Rico, (in) Doyle, L. J. and Roberts, H. H. (eds.) Carbonate-Clastic Transitions: Developments in Sedimentology, v. 42, Amsterdam: Elsevier, p. 231-250.

Rodríguez, Rafael, W., Webb, Richard M. T., and Bush, David M., 1994, Another Look at the

Impact of Hurricane Hugo on the Shelf and Coastal Resources of Puerto Rico, USA: Journal of Coastal Research, vol. 10, no. 2, p. 278-296.

Thieler, E. Robert, Bush, David M., and Pilkey, Orrin H., Jr., 1989, Shoreline Response to Hurricane Gilbert: Lessons for Coastal Management, (in) Magoon, O. T., el al., (eds.) *Coastal Zone '89*, Proceedings of the Sixth Symposium on Coastal and Ocean Management. New York: American Society of Civil Engineers, p. 765-775.

Thieler, Edward Robert and Bush, David Michael, 1991, Hurricanes Gilbert and Hugo Send Powerful Messages for Coastal Development: Journal of Geological Education, v. 39, p. 291-99.

Young, Robert S., Bush, David M., Pilkey, Orrin H., and Neal, William J., 1996, an Inexpensive Approach for the Qualitative Evaluation of the Shoreline Change Geo-indicator and Associated Risk from Coastal Hazards, (in) Berger, A.R. (ed.), Geological Indicators of Rapid Environmental Change. Rotterdam: A.A. Balkema, p. 193-206.

Reprints Provided–USVI 2001

Copies of several reprints on topics relevant to the course were provided to all participants.

Bush, David M., 1991, Impact of Hurricane Hugo on the Rocky Coast of Puerto Rico, (in) Finkl, Charles W., and Pilkey, Orrin H., (eds.), Impacts of hurricane Hugo: September 10-22, 1989, Journal of Coastal Research, Special Issue #8, p. 49-67.

Bush, David M., 1994, Coastal Processes, In: National Research Council, Hurricane Hugo: Puerto Rico, the Virgin Islands, and Charleston, South Carolina, September 17-22, 1989. Washington, DC: National Academy Press, National Academy of Sciences, Natural Disaster Studies Volume Six, p. 130-154.

Bush, David M., Neal, William J., Young, Robert S., and Pilkey, Orrin H., 1999. Utilization of Geoindicators for Rapid Assessment of Coastal-hazard Risk and Mitigation, *Ocean and Coastal Management*, vol. 42, no. 8, p. 647-670

Bush, David M. and Pilkey, Orrin H., 1994, Mitigation of Hurricane Property Damage on Barrier Islands: A Geological View, In: Finkl, C. W., Jr., (ed.), Coastal Hazards: Perception, Susceptibility and Mitigation, Journal of Coastal Research Special Issue No. 12, p. 311-326.

Bush, David M., Richmond, Bruce R., and Neal, William J., in press. Coastal-zone Hazard Maps and Recommendations: Eastern Puerto Rico, *Environmental Geosciences*.

Emery, K.O., 1961. A simple method of measuring beach profiles. *Limnology and Oceanography*, vol. 6, p. 90-93.

Hickey, R., D. Bush, and R. Boulay, 1999, GIS Applications in Coastal Risk Assessment. *Cartography*. v. 28, no. 2, pp. 11 - 19.

Pilkey, Orrin H., Jr., and E. Robert Thieler, 1992. *Coastal Erosion*. Text accompanying Society of Economic Paleontologists and Mineralogists (SEPM) Slide Set No. 6, 24 p.

Rodríguez, Rafael, W., Webb, Richard M. T., and Bush, David M., 1994, Another Look at the Impact of Hurricane Hugo on the Shelf and Coastal Resources of Puerto Rico, USA: Journal of Coastal Research, vol. 10, no. 2, p. 278-296.

Thieler, Edward Robert and Bush, David Michael, 1991, Hurricanes Gilbert and Hugo Send Powerful Messages for Coastal Development: Journal of Geological Education, v. 39, p. 291-99.

Young, Robert S., David M. Bush, Andrew S. Coburn, Orrin H. Pilkey, and William J. Cleary, 1999. Hurricanes Dennis and Floyd: Coastal Effects and Policy Implications, *GSA Today*, vol. 9, no. 12, p. 1-6.

Books/Videos/Reports–Display Copies Only

Sample copies of books, brochures, videos, and other publications were on display during the course.

Books:

Beatley, Timothy, David J. Brower, and Anna K. Schwab, 1994. *An Introduction to Coastal Zone Management*. Washington DC: Island Press, 210 p.

Bush, David M., and Pilkey, Orrin H., 1996, *Living by the Rules of the Sea*. Durham, North Carolina and London: Duke University Press, 179 p.

Bush, David M., Webb, Richard M. T., González Liboy, José, Hyman, Lisbeth, and Neal, William J., 1995. *Living With the Puerto Rico Shore*, Durham, North Carolina and London: Duke University Press, 193 p.

Kaufmann, Wallace and Orrin H. Pilkey, Jr., 1983. *The Beaches are Moving: The Drowning of America's Shoreline*. Durham, North Carolina: Duke University Press, 336 p.

Lennon, Gered, Neal, William J., Pilkey, Orrin H., Bush, David M., Stutz, Matthew, and Bullock, Jane, 1996. *Living With the South Carolina Coast*, Durham, North Carolina and London: Duke University Press, 241 p.

Pilkey, Orrin H., William J. Neal, Stanley R. Riggs, Craig A. Webb, David M. Bush, Deborah F. Pilkey, Jane Bullock, and Brian A. Cowan, 1998. *North Carolina and It's Barrier Islands: Restless Ribbons of Sand*. Durham, NC: Duke University Press, 318 p.

Videos:

The Beaches Are Moving
Living on the Edge
The Vanishing Lands

"Living With the Shore" books and all videos available from:

Environmental Media Corporation:
1102 11th Street
Port Royal, SC 29935 -2304
800.368.3382/843.986.9034 Voice
843.986.9093 Fax
email: bpendergraft@envmedia.com
http://www.envmedia.com/

Government Reports:

Williams, S. Jeffress, Kurt Dodd, and Kathleen Krafft Gohn, 1990. *Coasts in Crisis*. United

States Geological Survey Circular 1075, 32 p.

Federal Emergency Management Agency, 1999, Hurricane Georges in Puerto Rico: Observations, Recommendations, and Technical Guidance. FEMA Building Performance Assessment Report, FEMA publication FEMA-339, March 1999.

Coastal Management Solutions to Natural Hazards, 1990, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of Ocean and Coastal Resource Management, Coastal Programs Division Technical Assistance Bulletin #103, 50 p.

Federal Emergency Management Agency Publications Catalog.

Course Schedule

Monday July 16--*Course Begins, full day of lectures*

morning: Opening and Lectures

-Opening greetings and remarks ***(½hr)***

-Introduction of personnel

-Introduction of participants

-Lecture: Multiple Coastal Hazards Mapping: The Puerto Rico Experience (Dave Bush) ***(1.5 hr, including discussion)***

-Lecture: Abiotic Monitoring of the Coastal Zone in the Bay Islands, Honduras (Rob Young) ***(1.5 hr, including discussion)***

afternoon: Lectures and Video

-Lecture: Impact of Erosion and Sediment Loading on Coral Reef Vitality (Rob Young) ***(1 hr, including discussion)***

-Video and discussion: *Selected parts of coastal videos* ***(1 hr)***

-Video and discussion: *VI Non-Point Source Pollution* ***(1 hr)***

Tuesday, July 17: *lectures and field trip*

morning: Lectures

-Lecture: Coastal Hazards, Risk Assessment, and Property Damage Mitigation (Dave Bush) ***(1.5 hrs, including discussion)***

-Lecture: Monitoring Shoreline Change (Rob Young) ***(1.0 hrs, including discussion)***

-Video and discussion: *Beach Profiling Training Video* ***(15 minutes)***

-Introduction to field trip: Geoindicators Assessment of Shoreline Change, Coastal Risk Mapping, Beach profiling

afternoon: field trip

-coastal problems

Wednesday, July 18: *full day of lectures*

Groundwater Exploration and Development in Volcanic Island Arcs

Thursday, July 19: ***full day field trip***

-groundwater exploration and development

Friday, July 20: ***Course Conclusion***

<u>morning</u>: discussion

-closing discussion by all participants

-create list of site-specific problems

-end of course

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	4	0	0	0	4
Masters	1	0	0	0	1
Ph.D.	0	0	0	0	0
Post-Doc.	1	0	0	0	1
Total	6	0	0	0	6

Notable Awards and Achievements

Publications from Prior Projects

None