Virgin Islands Water Resources Research Institute Annual Technical Report FY 2002

Introduction

The University of the Virgin Islands, a land grant university and Historically Black College or University, is committed to advancing the well-being of the people in the Virgin Islands community, and the broader world-wide community through its academic, research and public service programs. The Water Resources Research Institute (WRRI) is one of these programs. Receiving its primary support from the United States Geological Survey, the WRRI in FY 2002 with its three-fold mission of information dissemination, training and research the WRRI utilized guidance in setting its program priorities from an advisory group composed of community stakeholders. This insured that WRRI sponsored projects were responsive to community needs while fitting within overall program priorities established by the USGS and at the same time maintaining consistency with the University's mission. Project principal investigators were University of the Virgin Islands faculty and collaborators from other universities.

In its FY 2002 program, March 1, 2002 through February 28, 2003, the WRRI investigated climatic effects on the water resources of the Virgin islands, environmental influences on the quality of cistern water supplies and provided training on the restoration of wetland areas, critical to effective ecological balances in island systems. These focus area activities were in addition to its usual role of serving as an information resource to the community for water resources data, providing input and general guidance on water quality and quantity and other related issues. This report summarizes progress made on these activities.

Research Program

Seasonal to Century Scale Climate Effects on the Water Resources of the U.S. Virgin Islands

Basic Information

Title:	Seasonal to Century Scale Climate Effects on the Water Resources of the U.S. Virgin Islands
Project Number:	2002VI3B
Start Date:	4/1/2002
End Date:	4/1/2003
Funding Source:	104B
Congressional District:	Not Applicable
Research Category:	Climate and Hydrologic Processes
Focus Category:	Climatological Processes, Drought, Surface Water
Descriptors:	Rainfall modeling, Virgin Islands, precipitation patterns
Principal Investigators:	Amos Winter, Henry H. Smith

Publication

1. A working paper is being developed to be submitted to the Journal of Applied Meteorology.

Summary Report on

Seasonal to Century Scale Climate Effects on the Water Resources of the U.S. Virgin Islands

Problem and Research Objectives

The U.S. Virgin Islands is very sensitive to precipitation fluctuations and lies in a region that is susceptible to droughts and extreme precipitation events that can cause flooding and land slides. Understanding the cyclic nature of these events will lead to better preparedness for the population and emergency managers. Ultimately, research in this area may lead to the ability to predict future precipitation events with reasonable skill.

The main purpose of this project is to understand the behavior of rainfall process of U.S. Virgin Islands and its relations with climate general circulations. Five specific targets will be accomplished:

- Determine homogeneous climate zones using air temperature, and rainfall observations.
- Identify interactions between U.S. Virgin Islands rainfall changes with global climate changes.
- Identify significant correlations between rainfall behavior and meteorological indexes.
- Identify time series models to predict rainfall process at each coop station and compare with neural network prediction skills.
- Design and train a neural network to perform monthly rainfall predictions.

Methodology

The general methodology consists of seven major tasks: (1) Data collection (2) Estimation of missing values (3) Development of time series models (4) Identification of changes on the mean of the rainfall process (5) Identification of homogenous climatic regions (6) Designing a neural network, and (7) Comparing forecasting skills between neural network and time series models. This report describes the first four tasks. This project is expected to finish by September 2003.

Principal Findings and Significance

(1) Data Collection:
The identified data set of monthly rainfall of the Virgin Islands includes 14 coop stations and the records for most of them started in 1972. Our preliminary finding shows that the oldest stations started in 1961 and these stations are: Wintberg on St. Thomas and Annaly and Fountain on St. Croix. Table 1 shows the 14 coop stations.

Table 1. Coop Stations

	Name	I.D. Number	Records
1	Wintberg, St. Thomas	24470 679450	1961 - 2001
2	Annaly, St. Croix	24424 670240	1961 - 2001
3	Fountain Valley, St. Croix	673150	1961 - 2001
4	St. Croix FAA Hamilton	670198	1961 - 2001
5	Beth Upper New Works, St. Croix	24426 670480	1972 – 2001
6	Caneel Bay, St. John	24431 671316	1972 – 2001
7	Catheringburg, St. John	671348	1972 – 2001
8	Charlotte Amalie Harbor, St. Thomas	678905	1972 – 2001
9	Christiansted Fort, St. Croix	671740	1972 – 2001
10	Cruz Bay, St. John	671980	1972 – 2001
11	East End, St. John	672551	1972 – 2001
12	East Hill, St. Croix	24444 672560	1972 – 2001
13	Estate Fort Mylner, St. Thomas	672823	1972 – 2001
14	Granard, St. Croix	24456 673677	1972 – 2001

This work focuses on studying the monthly rainfall process of the longest four coop-stations and some well-known meteorological indexes. Figure 1 shows the rainfall observation for the most complete stations. Meteorological indexes were obtained throughout the web pages of federal agencies. These indexes exhibit monthly information during the period of 1961 to 2001. The studied meteorological variables are the following: SST in the North Atlantic (5-20°N, 60-30°W), SST in the South Atlantic (0-20°S, 30°W-10°E), SST in Tropical Equatorial (10°S-10°N, 0-360°). The SST in the equatorial Pacific: el Niño 1-2 (0-10°S, 90-80°W), el Niño 3 (5°N-5°S, 150-90°W), el Niño 4, (5°N-5°S, 160°E-150°W), and el Niño 3-4 (5°N-5°S, 170-120°W). The data set also includes the North Atlantic Oscillation index, the Artic Oscillation Index, the Sahel Rainfall Index (20-8N, 20W-10E), the North Brazil Rainfall Index, Cold tong Index, and Southern Oscillation Index.

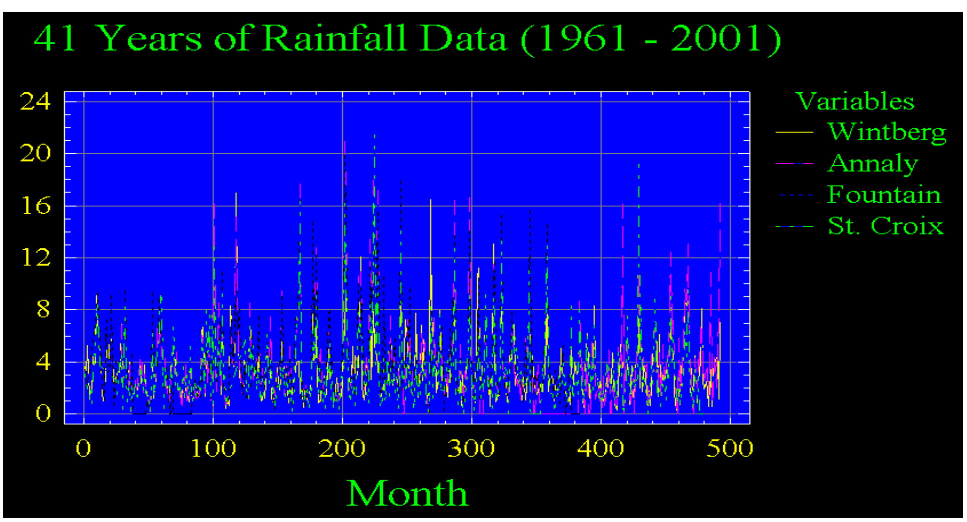

Figure 1. Monthly Rainfall Records

(2) Estimation of missing values:

The available time series exhibited some missing values. Therefore, missing observations were estimated to perform time series analysis and to develop the appropriate empirical functions. A method to perform time and spatial interpolation was implemented to estimate the missing values of the rainfall process (Ramirez et al., 2003). The interpolation algorithm is a convex combination of spatial and time interpolation methods. The convex combination can be written as follow:

$$y_{i,t} = a_i K_{i,t} + (1 - a_i) A_{i,t} \,, \qquad 0 \le a_i \le 1 \tag{1}$$

where a_i is the convex coefficient at the i^{th} station, $y_{i,t}$ is an estimate of the missing value in the i^{th} station at time t, $K_{i,t}$ is the spatial interpolation in the i^{th} station at time t obtained by using the Kriging algorithm and $A_{i,t}$ is the time interpolation in the i^{th} station at time t obtained by the seasonal autoregressive integrated and moving average (ARIMA) model (Storch and Zwiers,2001; Brockwell, and Davis, 1996; Matheron, 1979, Allard, 1998).

The convex coefficient was estimated using a cross-validation technique. A sufficient set of rainfall observations with no missing values was selected to estimate the a_i coefficients. The selected data include about 120 observations, i.e., 10 years of data. The selected time series were divided into two equal parts, the first one was used to fit the ARIMA models and the second one was used to perform time and spatial interpolation. The second part was also used to perform validation. Thus, 30% of the second part was randomly eliminated for each series and the eliminated values were declared as missing values. The Kriging algorithm and the ARIMA model were used to estimate the missing values for each station. Since the complete data set is known the a_i coefficients were estimated using linear regression techniques. Table 2 shows the estimated convex coefficient and the interpolation errors for each station. The interpolation errors are the difference between the observed rainfall value and the corresponding interpolation value.

Table 2. Convex Coefficients and Interpolation Errors

Station	Convex coefficient	Average absolute interpolation error
Wintberg	0.7523	2.7401
Annaly	0.7126	2.4516
Fountain	0.3316	2.0578
FAA, St. Croix	0.3361	2.0512

Table 2 shows that in Wintberg and Annaly stations the spatial-interpolation factor (K_{it}) is more relevant than the time-interpolation factor (A_{it}). However, the time interpolation was dominated in the remaining stations. The average absolute error of the interpolation method ranges from 2.05 to 2.74 inches. Wintberg, and St. Croix stations exhibit the maximum and the minimum interpolation errors, respectively. Since the interpolation algorithm provides a reasonable average absolute error it was used to perform the interpolation tasks to estimate all missing values in the working data series.

(3) Develop time series models:
A monthly rainfall process for a given station can be considered as a sequence of random variables. A sequence of random variables usually has deterministic and stochastic components. The deterministic components are known as seasonal and trend components. Figure 2 shows the periodogram for the rainfall of Wintberg stations. The periodogram shows that the highest spectrum is given at the frequency 0.0833 i.e., the period is 12. Periodogram also shows that at low frequency the spectrum is not significant and consequently the trend component is not significant.

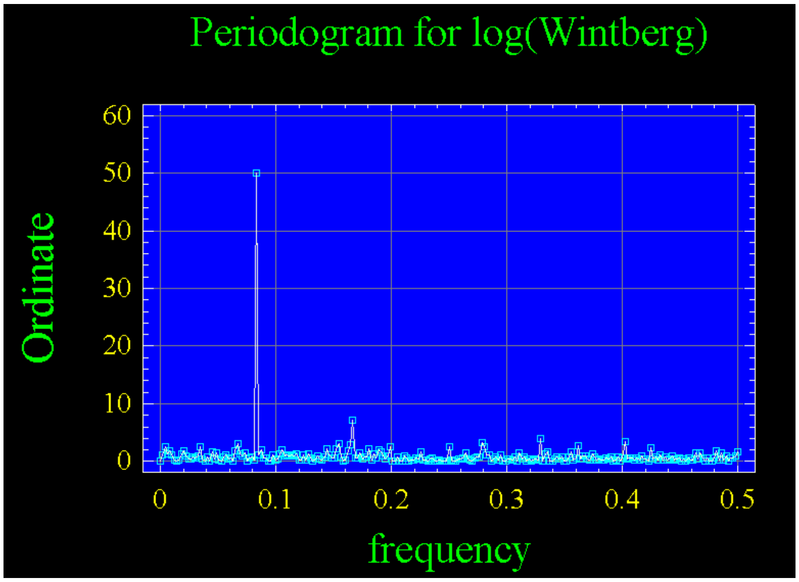

Figure 2. Periodogram for the Wintberg Station.

To model the rainfall process requires removing the seasonal component. Fitting a periodic function and then subtracting it from the original process can remove this component. A second alternative is to perform a twelve difference. Since the second alternative requires the minimum computational effort, this method was implemented. After removing the seasonal component the remaining process becomes a stationary process. However, a mathematical transformation was needed to stabilize the variance of the process. Finally the identified model includes a twelve and a first order autoregressive process. The developed model for the Wintberg station is as follows:

$$(1-B^{12})(1-\Phi B^{12})(1-fB)\,y_t = z_t$$

where y_t is the natural log of rainfall observations at month t, z_t is a white noise process with constant variance and cero mean, B is the back shift operator, $(1-B^{12})$ represents the twelve difference, Φ and f are the twelve and first autoregressive parameters which were estimated from rainfall observations. Table 3 exhibits the results of the parameter estimation and Figure 3 presents the observations versus model fitting estimation. Figure 4 shows a one-year forecast for the Wintberg station.

Table 3. Parameter Estimation (Wintberg Station)

Parameter	Estimate	Std. Error	p-value
Φ	-0.462539	0.040679	0.0000
f	0.121577	0.045714	0.0080

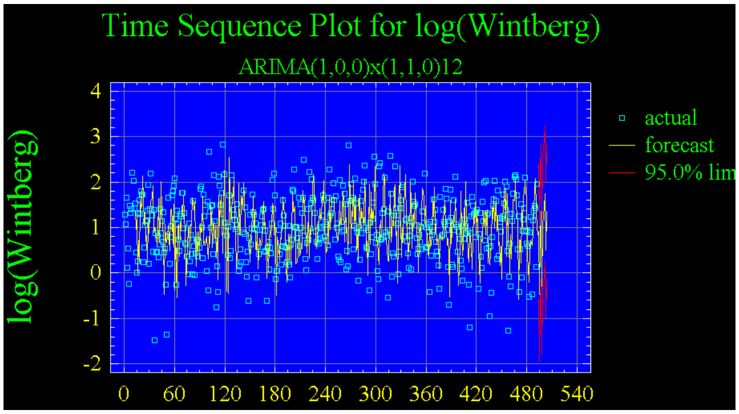

Figure 3. Rainfall Model Fitting at Wintberg Station

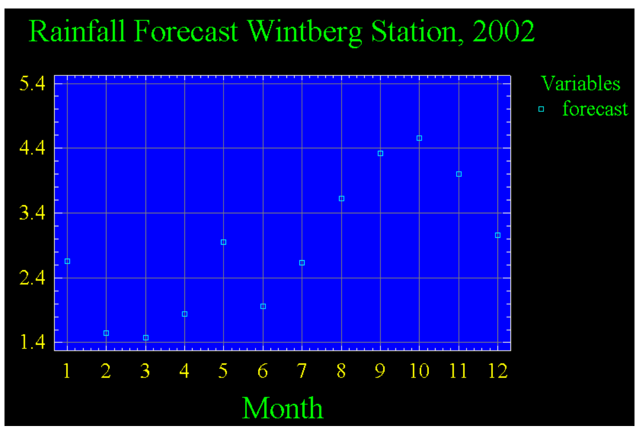

Figure 4. Rainfall Forecast for year 2002.

(4) Identify rainfall changes:

The main purpose of this task is to identify global climate changes throughout meteorological index changes and test the interaction with changes on the U.S. Virgin Islands rainfall. The available longest period of historical data is being collected for the following variables: sea surface temperature, sea level pressure, rainfall process, and air temperature. Most of the existing statistical tools to identify significant changes in the mean or in the variance of sequential information have been designed for independent time series (Cusum, Ewma, and Hotelling test). However, metereological time series are characterized by being auto- and cross-correlated processes. New statistical techniques are been tested and developed to identify significant changes on autocorrelated processes. A statistical test has been tested and compared with recent techniques (Ramirez and Sastri, 1997). Once the statistical test is selected, climate changes and Caribbean interactions will be identified. For example, it is expected to test how the North Atlantic

Oscillation index is affecting the rainfall process in the U.S. Virgin Islands; how the Sahel rainfall index interact with U.S. Virgin Island rainfall changes; how the Artic Oscillation Index interact with U.S. Virgin Islands rainfall changes. etc.

Outcomes

a. *Publications*: A working paper is being developed to be submitted to the *Journal of Applied Meteorology.*
b. *Proposal submitted/granted:* A proposal entitled: "Tropical Climate Research and Meteorological Data Management" was submitted. This proposal was submitted to the NASA program: Earth Science Research Education and Applications Solutions Network (REASON: CAN-02-OES-01). This proposal is pending. A second proposal entitled "Cloud Characterization and Time Series from Insolation Measurements Predicting" was submitted. This proposal was submitted to NASA IDEAS-ER Program and is pending. The Principal Investigator is Co-Investigator of a proposal entitled "Simulating the Hydrologic Water Balance of Puerto Rico Using a Coupled RAMS/LEAF-2/TOPMODEL/MODFLOW Modeling System." This proposal was submitted to NSF.
c. *Established partnership:* Research collaboration with NASA Goddard Space Flight Center was established. An official letter was received that research collaboration is underway. A visit to this NASA Center is planned for Summer 2003.
d. *Collaborations with internal groups:* Strong collaboration exists with remote sensing and numerical modeling groups. The statistical group is working very closely with Dr. Amos Winter, Dr. Ramon Vasquez, Dr. Jorge Gonzalez, Dr. Fernando Gilbes and Dr. Joe Eastman.
    e. *Student Participation:* Joan M. Castro is a student who is pursuing a Master of Science Degree in the Electrical Engineering Department. He is performing some statistical tests to detect climate change on meteorological indexes. Andrew S. Garcia is an undergraduate student in the Mechanical Engineering Department. He is organizing the meteorological indexes and rainfall data.

Drawbacks

The major drawback that has been identified is that the longest records started in 1961. The short records impose significant constraints to the proposed methodology.

General Future Projections

During the no-cost extension to this project, the remaining three major tasks will be completed. It is expected that a set of time series models will be developed to predict the expected rainfall one-year ahead at a specific station. The identification of significant rainfall changes and their interactions with global meteorological changes is expected. It is also expected that some correlations between meteorological indexes and rainfall processes will be identified. These correlations may suggest the physical mechanism that generates significant climate changes.

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Environmental Influences on Cistern Water Quality

Basic Information

Title:	Environmental Influences on Cistern Water Quality
Project Number:	2002VI5B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	NA
Research Category:	Water Quality
Focus Category:	Water Quality, Water Supply, Treatment
Descriptors:	Cisterns, Virgin Islands, Rainfall Harvesting
Principal Investigators:	Henry H. Smith

Publication

Summary Report on

Environmental Influences on Cistern Water Quality

Problem and Research Objectives

About two thirds of the residents of the U. S. Virgin Islands are not served by public water distribution systems. About eighty percent of Virgin Islands' homes rely on rainfall harvesting as their main water supply. This practice generally involves using a house's roof area for catchment of the rainfall, which is conveyed by gutters to a masonry cistern that forms a part of the house's foundation. The water is pumped to a pressurized tank for use upon demand.

Collection and storage of water by these means expose the harvested water to many sources of contamination. These may include atmospheric and other depositions on the catchment's surface, as well as contamination after entering the storage system which is generally not tightly sealed. While the United States Environmental Protection Agency has set water quality standards for all public water supplies, individual cistern systems are not considered public water supplies and are not subject to these regulations. Cistern water supplies then, may pose significant health risks to users in the Virgin Islands.

In this study, a broad survey of water quality in Virgin Islands cistern water supplies will be conducted to assess the influence of surrounding environment on water quality of cistern water supplies. Findings will provide information that will help to identify factors that contribute to the degradation of cistern water quality. Having this information will allow users of cistern systems to take steps to safeguard the water supply and reduce the health risks associated with using water from these systems.

Methodology

Homes located on St. Thomas and St. John were selected in a way that they represented areas influenced by as many different factors as possible. These included population density, varying degrees of annual rainfall, proximity to industry, shorelines and vegetal cover. These homes were surveyed and information recorded on the physical construction of the catchment, conveyance and containment structures, environmental factors, and maintenance and management practices affecting the systems.

The most common form of contamination of cistern water supplies is by coliform bacteria. Most of these bacteria are harmless and are free-living commensal organisms that live in soil and water as well as the gut of animals. These bacteria then may be used to indicate the general quality of water they are found in and are often used to estimate the likelihood that the water is fecally contaminated. In this study, tests were made for the presence or absence of total coliform and *E. Coli* bacteria. For sites where positive results of any of these tests were obtained, the following months' tests involved enumeration counts until negative results were obtained. The analysis procedure used was the IDEXX's Quanti-tray enumeration method using the Colilert-18 and Entralert media test kit for thermotolerant coliform and entercocci respectively. Media trays were incubated for at thirty-five degrees Celsius (35^oC) for eighteen (18) hours. The results were interpreted by a count of positive wells according to a most probable count table.

Physical characteristics of the samples recorded were temperature, pH and turbidity. These were measured consistent with procedures proscribed (prescribed) by the American Public Health Association and others in *Standard Methods for the Examination of Water and Wastewater.*

Principal Findings and Significance

Sampling was conducted during the period June to September 2002 on St. Thomas and St. John. While plans were initially to include St. Croix in the study, this was not due primarily to logistically and related cost consequences. Most samples in the study were taken three times, though this varied due to accessibility to the site, availability of suitable water from harvesting in the system and so on. Not surprisingly, the cisterns monitored tested generally positive for both Coliform and *E. Coli* during the study period. While at some site chlorination was practiced, it was not done in such a systematic manner that the stored water remained contaminant free during the monitoring period. This is fairly typical for most Virgin Islands' homes.

Obvious roof contaminants were found most commonly to be leaf litter, droppings from birds and other animals and dirt, soot and other sediments. Ponding due to blockages were not unusual in the guttering systems. Cisterns examined revealed insects, dust and debris floating on the water's surface and accumulation of sediments and other foreign items on the bottom.

Management practices to maintain water quality were for the most part lacking. Roofs were often easily accessible and overhung by vegetation. Cisterns too were easily accessible due to poor-fitting manhole covers and inflow and overflow ports that were inadequately screened. Devices to divert the first-flush of harvested water or in any other way provide for rinsing the catchment's surface were not present and there were no regular programs for adding disinfectants or cleaning conveyance or storage surfaces with which the water came in contact.

The data gathered, as intended, not only provided a snapshot assessment of cistern water quality and management practices associated with these supplies but also allowed establishment of a database on several water quality parameters and site characteristics that would be very helpful in future studies. Among these studies might be determination of variances in cistern water quality with time, examination for correlation between cistern water quality and overall public health in the Virgin Islands.

Information Transfer Program

Environmental Education and Hands-on Training on Mangrove Restoration Techniques

Basic Information

Title:	Environmental Education and Hands-on Training on Mangrove Restoration Techniques
Project Number:	2002VI1B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	Not Applicable
Research Category:	Not Applicable
Focus Category:	Education, Non Point Pollution, Wetlands
Descriptors:	Mangroves, vegetation restoration
Principal Investigators:	Richard Stephen Nemeth, Marcia Taylor

Publication

Summary Report on

Environmental Education and Hands-on Training on Mangrove Restoration Techniques

Problem and Objectives

Mangrove wetlands provide an important buffer between land and coastal marine communities. They slow the flow of stormwater, filter runoff, and help remove destructive pollutants before they enter fragile coastal environments. Unfortunately, the number of mangrove areas in the Virgin Islands has significantly declined in the last fifty (50) years because mangrove ecosystems have been routinely bulldozed to make space for marinas and other coastal developments. Additionally, hurricanes have also taken their toll on these wetlands.

Although mitigation has decreased the rate of mangrove habitat loss, limited awareness and a poor understanding of the role played by mangroves continue to hinder these efforts. There is a need to increase local awareness of the importance of mangroves in the Virgin Islands and to demonstrate the benefits of restoring lost or damaged wetlands.

The objectives of the project are to train a target group of ten (10) high school students on mangrove restoration techniques, and to increase awareness of the function of mangroves in reducing non-point source pollution.

Methodology and Accomplishments

In order to achieve the objectives the staff of the Center for Marine and Environmental Studies (CMES) first solicited for student interns to assist with the project (May 2002). Putting a notice in the newspaper to alert high school students of the opportunity did this. As a result, several students were given an orientation/training session on wetlands, mangroves and the project (June 2002). Students were then given an on-site training session at the University of the Virgin Islands (UVI) Wetlands and the area to be restored was identified (June 2002).

The students assisted with the first mangrove planting in July 2002 by planting fifty (50) red mangroves at the site. They also collected two hundred (200) black mangroves and planted them in tree cones using a media of mud from the site and potting soil. The germination rate was low, so additional seeds were planted in a media composed of a higher percentage of potting soil. These seeds grew well and were put in the UVI greenhouse for several weeks (July 2002-Sept. 2002). After the black mangrove seedlings were about six (6) inches tall, they were removed from the greenhouse and exposed to a greater amount of sunlight in an attempt to "harden" them to full exposure

(Oct. 2002). The black mangrove seedlings were planted at the site in Dec. 2002 and Jan. 2003.

Part of the program was to teach students how to conduct tours at the UVI wetlands. This reinforced what they learned and also allowed other students to see their peers doing outreach activities.

Students were given a training session on how to conduct wetland tours at the site and got an opportunity to watch and assist with the tours. The students then conducted tours while Center for Marine and Environmental Studies (CMES) staff watched. The students were enthusiastic and seemed to enjoy the experience of giving tours (July 2002).

As an additional outreach component to this project a website was developed where basic information on the project can be found (http://rps.uvi.edu/VIMAS/wriipage.html).

Principal Findings

Monitoring conducted at the site showed that only a few red and black mangrove seedlings had survived the transplant. A subsequent planting with differing conditions (different elevations, level of shade) showed similar results (Jan. 2002).

Based on these results, additional research was done in an attempt to find a way to increase mangrove survival at the site. The question was put out on the mangrove discussion list and several responses were received. In addition, contact was made with individuals who had been involved with mangrove restorations and discussed our results with them. All researchers suggested an alternative approach to black mangrove planting. They suggested that hand broadcasting of seeds be done repeatedly rather than starting the plants growing in the greenhouse. They indicated that a low survival rate should be expected, less than ten percent (<10%), which has still a higher survival rate than trying to transplant them. It was determined that transplanting easily shocks black mangroves and therefore survival is often low.

Because of the findings, a decision was made to request an extension of the grant in order to do additional plantings. Although the transplant results were a bit disappointing, the enthusiasm and initiative shown by the interns was inspiring. Thus the requested no-cost extension will also make allowance for the recruitment a new group of local high school students to this project and provide additional opportunities in conservation techniques for Virgin Islands youth.

Future Plans/During Extension Period (Feb. 2003-Aug 2003)

- Identify additional interns available (Feb. 2003 – March 2003)
- Collect and plant black and red mangrove seeds/propagules (March 2003)
- Monitor success of seedlings (March 2003)

- Collect additional seeds/propagules as needed
- Monitoring seedlings (March 2003-Aug.2003)

Train interns about UVI Wetlands (March 2003-April 2003)
Run Wetland tours with interns (March 2003-Aug. 2003, based on availability of tours)
Final report (Aug. 2003)

Students involved with the project to date and academic level

Name	Grade	School
Lamin Jackson	9	Good Hope School
Daniel Hodge	11	Educational Complex
Amaris Chew	10	Educational Complex
Candace Cornwall	10	Educational Complex
Michael Camacho	12	Central High School
Manuel Camacho	11	Central High School
Amalee Lockhart	12	Educational Complex

USGS Summer Intern Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	1	0	0	0	1
Masters	1	0	0	0	1
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	2	0	0	0	2

Notable Awards and Achievements

Publications from Prior Projects