Virgin Islands Water Resources Research Institute

Annual Technical Report

FY 2000

Introduction

The Virgin Islands Water Resources Research Institute (WRRI) is a unit of the University of the Virgin Islands. It serves the Territory of the United States Virgin Islands, which consists of four main islands, namely St. Thomas, St. John, St. Croix and Water Island. Since its establishment in 1973, the WRRI has conducted a program of research, training and information dissemination that addresses the particular needs of persons living on the small, tropical islands. These needs include having very limited sources of water, satisfy ever increasing water demands and social, environmental and other constraints that are results of a tourism based economy. Guided by its Advisory Committee, the WRRI in its 2000-2001 program focused on issues of concern, which not only affect the U.S. Virgin Islands, but also other islands of the Caribbean region.

Rain water is a principal source of water in the islands and projects this year dealt with issues related to this source. Increasing water for agricultural use through rainwater harvesting was investigated in the project "Utilizing Rainwater Catchments for Year-Around Agricultural Production." The project "Applicable Indicators of Risk for Coastal Water in Tropical Environments" continued the search for microbial indicators for assessment of water quality in tropical areas. The effects of rainfall runoff on coastal marine ecosystems was studied in "Delivery, Deposition and Effects of Land-Based Sediments on Corals in St. John, U.S. Virgin Islands." "Wellhead Protection Area Management Standards" was designed to identify contaminants of ground water and to develop a mechanism to protect the supply from contamination. Lastly, in addition to its continuous activity of serving as an information resource center to the Virgin Islands, the WRRI sponsored a two-day seminar on mitigation of coastal hazards due to extreme tropical events.

Using the format prescribed by the United States Geological Survey, the principal supporter of work conducted by the WRRI, this report summarizes the research, training and information dissemination activities of the Virgin Islands Water Resources Research Institute during the period March 1, 2000 to February 28, 2001.

Research Program

Basic Information

Title:	Applicable Indicators of Risk for Coastal Waters in Tropical Environments
Project Number:	D-01
Start Date:	8/1/1998
End Date:	2/28/2001
Research Category:	Biological Sciences
Focus Category:	Water Quality, Wetlands, Non Point Pollution
Descriptors:	Bacteria, Bays, Beaches, Biomonitoring, Coastal Zone, Lagoons, Marinas, Recreation, Risk Analysis, Viruses, Water Quality, Water Quality Monitoring, Water Quality Standards
Lead Institute:	Virgin Islands Water Resources Research Institute
Principal Investigators:	Mayra E. Suarez-Velez, Gary A. Toranzos

Publication

1. Progress completion report being prepared for distribution.

Problem and Research Objectives

Indicators of the biological contamination of waters that have been used for the last 100 years have been shown to lack certain characteristics to properly protect public health. This is especially true in tropical areas of the world, where the presence of these indicators may not necessarily be related to harmful contamination. Therefore, it is necessary to develop other indicators that can adequately provide the necessary information. One such alternative indicator is the use of fecal coliforms. However, strong evidence has recently been found against the use of fecal coliforms as indicator organisms of fecal contamination in tropical waters. Additionally, there are few sewage and water treatments plants adequately functioning and this indicates that there is a real need for the development of a rapid, easy, inexpensive and accurate method for assessing tropical water biological quality. Bacterial indicators of fecal contamination currently being used have been found to be inadequate in the tropics and this is a result of the presence of these indicators as part of the resident microbiota in these environments. One possible alternative of the indicators of biological quality of water is bacterial viruses which infect E. coli (coliphages).

Methodology

The following are the primary techniques that were used for this project:

- Bacteriological Analyses - Samples were analyzed by membrane filtration using mFC and mEnterococcus agar for thermotolerant coliforms and enterococci respectively. Media were incubated at the appropriate temperature for 24-48 hours, representative colonies counted and randomly chosen colonies were subjected to confirmation.
- Coliphage Analyses - Direct grab samples were used for the single-layer virus plaque assays (Grabow and Coubrough, 1986). A 100-ml volume was analyzed. The plaques were counted after 6 hours to eliminate the problem of background bacterial overgrowth which masks the viral plaques.
- Molecular Fingerprinting – The two methods used were the “Freeze-thaw” method and DNA Extraction from bacterial cultures.

Principal Findings and Significance

Several samplings were carried out at the Luquillo watershed area as well as in recreational beaches in Northern Puerto Rico. Soil and water samples were obtained throughout the year. From the several dozens of isolates, some were chosen at random for identification using the BIOLOG system. The results are shown below (Table 1). From these, several isolates identified as Escherichia coli were then subcultured to make sure we were working with pure cultures. The DNA was isolated using standard protocols and then the polymerase chain reaction (PCR) was used for the amplification of the 16S rRNA gene as shown in Figure 1. The amplicons were then subjected to restriction analyses (using the ARDRA, or Amplified Ribosomal DNA Restriction Analysis, fingerprinting method) and the results are shown in Figures 2 and 3.

It becomes clear that many of the isolates are in fact E. coli, and that the fingerprinting analyses using ARDRA confirm these conclusions. We are in the process of sequencing some of the fragments generated to further confirm the findings. We are in the process of obtaining more isolates and are also carrying out some coliphage assays. Data presented below indicate that soils are a possible source of E. coli in the environment (Table 4). In fact all soil samples obtained to a depth of 20 cm were positive for thermotolerant coliforms. Not all were shown to be E. coli, however, since they were B-glucuronidase negative, and most likely Klebsiella spp., as has been shown in our previous data from the same areas.

The data obtained at some recreational beaches in Northern Puerto Rico is shown below (Table 5). The indicators were detected in all samples and some appear to be in violation of the standards (35 enterococci/100ml geometric mean). We expect to get data from recreational areas of the U.S. Virgin Islands in the near future.

TABLE 1

	Coliforms	Bacteria
	Total	*Enterobacter cloacae*
	Total	*Citrobacter freundii*
	Total	*Burkholderia cepacia*
	total	*Klebsiella pneumoniae*
	total	*Burkholderia solanacearum*
	total	**Citrobacter freundii**
	total	*Erwinia amylovora*
	total	*Erwinia amylovora*
	total	*Citrobacter freundii*
	total	*Erwinia chrysanthemi*
	total	*Erwinia amylovora*
	total	*Citrobacter freundii*
	total	*Erwinia chrysanthemi*
	total	*E.coli*
	fecal	*E.coli*
	fecal	*Citrobacter freundii*
	fecal	*E.coli*
	fecal	*E.coli*
	fecal	*E.coli*
	fecal	*E.coli*
	fecal	*E.coli*
	fecal	*E.coli*
	fecal	*E.coli*
	fecal	*E.coli*
	fecal	*E.coli*
	Total	*Citrobacter freundii*

	Total	*Enterobacter cloacae*
	Total	*Escherichia vulneris*
	Total	*Pantoea agglomerans*
	Total	*Erwinia amylovora*
	Total	*No ID*
	Total	*Erwinia chrysanthemi*
	Total	*Erwinia amylovora*
	Fecal	*E.coli*
	Fecal	*Enterobacter agglomerans*
	Fecal	*Enterobacter cloacae*
	Fecal	*E.coli*

TABLE 2.

Total number of identified isolates from the Luquillo Watershed: 75

Thermotolerant Coliforms – 27 Total Coliforms- 48

Escherichia.coli – 27

Enterobacter – 17 (E.agglomerans 5, E.cloacae – 9, E.taylorae 1, E.gergoviae-1, E.hormaechei 1)

Citrobacter freundii – 6

Kluyvera cryocrescens – 4

Klebsiella – 4 (K.pneumoniae 3, K.oxytoca 1)

Erwinia –8 (E.amylovora – 4, E.chrysanthemi – 4)

Escherichia vulneris

Pantoea agglomerans

Burkholderia –2 (B.solanacearum, B. cepacia)

NO ID - 3

Table 3. Primer sequences for the 16S rRNA gene amplification		
Primer Designation	Position E. coli 16S rRNA	Sequence (5'-3')
PA	19-38	AGAGTTTGATCCTGGCTCAG
PH	1541-1561	AAGGAGGTGATCCAGCCGCA

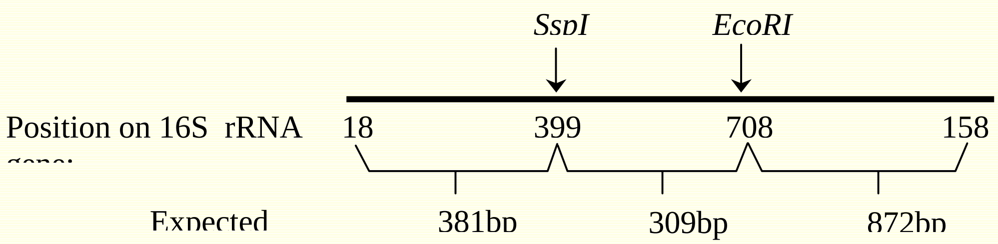
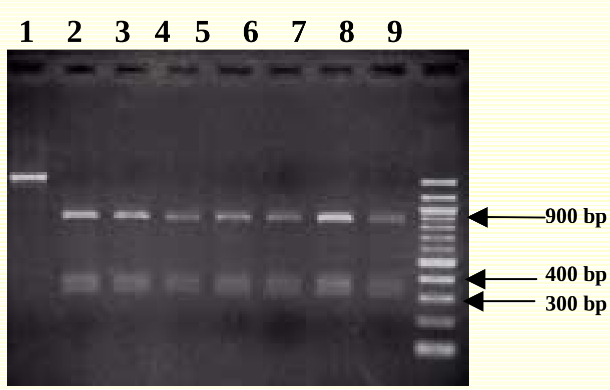


Figure 1. Restriction map for the enzymes *EcoRI* and *SspI*. Schematic representation of restriction digests of the 16S rRNA gene amplicon with the restriction enzymes *SspI* and *EcoRI*. Positions on 16S rRNA are based on the expected product of the PA/PH primers in a PCR.



<u>Figure 2. Restriction digest of amplicons:</u> Lanes: 1: PCR of Colony 3EL, 2: 3EL cut, 3: 5EL(5) cut, 4: 4EL cut, 5: 27LII cut, 6: 5EL cut, 7: 7EL cut, 8: 28LII cut, 9: NEB 100bp ladder. All cuts carried out with *SspI* and *EcoRI*. Expected sizes: 309 bp,

Table 4: Thermotolerant coliform and confirmed E. coli from soils at El Yunque rainforest and Mameyes area of Puerto Rico.

Site	Soil depth (cm)	Thermo-tolerant coliforms CFU/g	Percent of coliforms positive to Ec-MUG
Pristine	0-10	39.3	0
	10-20	14.2	8
Recreational	0-10	12.5	0
	10-20	1.2	0
Pasture/ recreational	0-10	1074.4	33
	10-20	241.5	78

TABLE 5

GEOMETRIC MEAN OF FECAL BACTERIA CONCENTRATION AT SELECTED SITES					
BEACH	**thermotolerant coliforms col/100 ml**	**Enterococci col/100 ml**	**SOURCE**	**Period**	**Samples**
Mar Chiquita	**3**	**5**	**PREQB**	**11/97-9/99**	**11**
			UPR	**na**	**1**
Puerto Nuevo	**31**	**42**	**PREQB**	**11/97-9/99**	**10**
	24	**14**	**UPR**	**11/00-2/01**	**3**
Cerro Gordo	**10**	**19**	**PREQB**	**11/97-9/99**	**10**
	4	**29**	**UPR**	**11/00-2/01**	**3**
Sardinera	**2**	**17**	**PREQB**	**11/97-8/99**	**8**
	11	**40**	**UPR**	**11/00-2/01**	**3**
Punta Salinas	**5**	**15**	**PREQB**	**11/97-8/99**	**11**
	4	**17**	**UPR**	**11/00-2/01**	**3**

Basic Information

Title:	Utilizing Rainwater Catchments for Year-Around Agricultural Production
Project Number:	VI00-02
Start Date:	3/1/2000
End Date:	2/28/2001
Research Category:	Ground-water Flow and Transport
Focus Category:	Water Supply, Agriculture, Surface Water
Descriptors:	Water Harvesting, Impoundments, Agriculture, Benefit-Cost Analysis, Drought, Water Quality
Lead Institute:	Virgin Islands Water Resources Research Institute
Principal Investigators:	John M. Martin

Publication

1. Project completion report being prepared for distribution.
2. Workshop is being planned.
3. Fact sheet entitled "Building a Rainwater Catchment and Storage Pond" has been compiled.

Problem and Research Objectives

The United States Virgin Islands are located in a tropical, semi-arid environment where an inadequate freshwater resource is the major factor limiting agricultural production. Several solutions to this problem have been proposed, but none have proven to be appropriate for the majority of small-scale, privately owned farms. This project addressed this problem through the construction of a low-cost rainwater catchment/storage pond that has a long, useful life. Although rainwater harvesting has been used for over 2000 years, recent advancements in materials, especially inexpensive, prefabricated high-density polyethylene, has made it a viable option for the territory.

Methodology

A 35' x 90' rainwater storage pond was excavated with an adjoining catchment of 35' x 55' giving a total surface area of 5,075 ft^2. The perimeter of the catchment/pond has a 1 ft dike to preclude the introduction of sediment-laden run-off. A 30-mil HDPE (high density polyethylene) liner was used to cover the entire surface area of the catchment/pond. This liner has outstanding chemical resistance, environmental stress crack resistance, dimensional stability, thermal aging characteristics and ultra-violet radiation resistance and has an expected life span of at least 15 years. It will retain rainwater, eliminate sediment and prevent furrows from forming during heavy rains that could distort the shape of the catchment. The edge of the liner, which covered the dike, was placed in a 1-ft deep furrow and buried. Outside the edge of the liner, a 4-ft tall goat-wire fence was installed to keep cattle and other animals from walking on the liner. The pond area was graded by a bulldozer and has a flat bottom with a width of 15 ft and a length of 70 ft. A 2:1 slope (26.6°) from the outside perimeter of the pond to the perimeter of the bottom will create a 5-ft depth. The pond bottom has a 3% slope allowing water to settle at one end. Because of this slope, the storage pond has an effective mean depth of 4 ft and will store up to 51,615 gallons of sediment free algae-free water. The floating pond cover, which will reduce evaporation, was fabricated from 40-mil low-density polyethylene (LDPE) with a white backing. This material shares the strength and stability characteristics of HDPE but because of its lower density will be able to float on the surface of the water collected thereby eliminating the interface between the water surface and the atmosphere. Bail holes of a ½ inch were cut in the cover on a 4 ft spacing to allow water trapped on the surface to drain through. The floating pond cover will reduce evaporation losses by about 80% thereby leaving approximately 80,000 gallons of water to be used for agricultural purposes.

Principal Findings and Significance

Rainfall and water storage was tracked for two months and rainfall at the site was 1.5 inches. This was insufficient data to determine the water collection efficiency of the catchment. However, anecdotal observations suggest that the catchment is collecting water efficiently and storing it as predicted. After completion of the project, it was realized that the size of the pond was too large for the surface area of the catchment, which can lead to excessive evaporation and increased pond costs. This was the result of a location change after the liner had been ordered. Also the pond should have been excavated on a flat surface to enable ease of calculation of the water storage capacity, and thus efficiency, of the pond. Finally, the floating pond cover did not float as well as anticipated. An easy way of addressing this is to place styrofoam sheeting underneath the cover, which is being done. Based on past experience, HDPE liners have proven to be quite durable and have a long service life. When the liner does deteriorate, replacement costs will be much lower than initial costs and the new liner can be installed over the old one.

Basic Information

Title:	Delivery, Deposition and Effects of Land-Based Sediments on Corals in St. John, U.S. Virgin Islands
Project Number:	VI99-02
Start Date:	3/1/1999
End Date:	2/28/2001
Research Category:	Climate and Hydrologic Processes
Focus Category:	Acid Deposition, Groundwater, Non Point Pollution
Descriptors:	Erosion, Runoff, Sedimentation, Urbanization, Roads
Lead Institute:	Virgin Islands Water Resources Research Institute
Principal Investigators:	Richard S. Nemeth, Lee H. McDonald

Publication

1. Project completion report being prepared for distribution.
2. Nemeth, Richard. 2000. The Effects of Sedimentation from Coastal Development on Coral Bleaching, in 6th Annual Non-Point Source Pollution Conference, St. Croix, VI, 19 pp.
3. Ramos-Scharron, C.E. & L. H. MacDonald (2001). Measuring and predicting runoff and sediment yield from an unpaved road segment, St. John, U.S. Virgin Islands. American Geophysical Union-Hydrology Days, Colorado State University, Fort Collins, CO.
4. Ramos-Scharron, C.E. (2001). Sediment budgeting on St. John, U.S. Virgin Islands. Presentation to the Water Resources Division of the National Park Service, Fort Collins, CO.
5. Ramos-Scharron, C.E.(2000). Erosion and sediment transport - Practical applications of the St. John erosion project. Water Resources Research Institute, St. John, U.S. Virgin Islands.
6. Ramos-Scharron, C. E. (2000). St. John Erosion Study-A Work in Progress. St. John Audubon Society. St. John, US. Virgin Islands.
7. Ramos-Scharron, C.E. (2000). Guidelines for the control of non-point source pollution from road and driveway erosion- With specific reference to Fish Bay, St. John, U.S. Virgin Islands. A brochure produced in conjunction with the Island Resources Foundation.

Problem and Research Objectives

Over the past several decades the U.S. Virgin Islands have witnessed rapid development of inland and coastal areas. Construction of unpaved roads and removal of the natural vegetation have greatly increased erosion rates relative to natural conditions. Recent studies in St. John, V.I. have identified the network of unpaved roads on the island as the most important source of sediment. Increased turbidity from clay and silt reduces light penetration essential for coral growth, while deposition of fine sediments increases coral energy costs, contributes to mortality due to suffocation, and reduces coral larvae settlement success. This load of sand, silt and clay poses a direct threat to the health of the corals and other reef organisms. The primary goal of this project was to link upslope sediment production from a developed basin (Fish Bay) and an undeveloped basin (Greater Lameshur Bay) to the downstream marine environment.

The objectives of the marine research component of the study were:

1) To quantify the amount of sediment deposited within Fish and Greater Lameshur Bays.
2) To measure water quality within Fish Bay and Greater Lameshur Bays.
3) To measure coral recruitment, percent algal cover, and composition of reef fishes at three sites within Fish Bay and Greater Lameshur Bays.
4) To assess coral reef condition in Fish Bay and Greater Lameshur Bays.

The objectives of the terrestrial component of the study were:

1) To determine if there is a relationship between the estimated delivery of road-related sediment and the condition of the channels in the Fish Bay basin
2) To conduct a semi-quantitative analysis of sediment delivery from unpaved roads to both fish Bay and Greater Lameshur Bay.
3) To quantify watershed-scale runoff rates and suspended sediment yields for the main guts draining into Fish Bay and Greater Lameshur Bay.

Methodology

Marine Component

The primary research sites are two watersheds and associated bays on the south side of St. John, United States Virgin Islands. The Fish Bay watershed is the largest watershed on the island (6.1 km^2), and it has experienced extensive road-building and development over the past 15-20 years. The Greater Lameshur Bay is slightly smaller (4.4 km^2) and relatively undisturbed as it is located almost entirely within the Virgin Islands National Park. The coral reefs in both bays are located along the eastern and western shorelines and extend from inside the bays to beyond their entrance. Both watersheds are similar in topography and the bays are only about 5 km apart, thus providing an ideal comparison with respect to their predicted sediment delivery rates and the condition of the marine organisms. Sedimentation was measured from July 21, 1999 to January 17, 2001 using tubular PVC sediment traps at three reef sites along both the eastern and western shorelines of both bays. Reef sites were located inside the bay, towards the mouth of the bay and just outside the bay in order to measure sedimentation rates along the linear fringing reef from inside to outside the bay. At each of the six sites two sediment traps were installed about 10 m apart. Each sediment trap was a 5.2 cm diameter and 20.8 cm long PVC tube that was capped on the bottom and open at the top. The tubes were attached to steel rebar stakes so that each opening was 50 cm above the bottom. The tops of the sediment traps were capped underwater and replaced, on average, every 60 days (range 31 to 84 d). The sediment obtained was oven dried and sieved to determine the sediment flux and sieved to determine the particle-size distribution.

Rainfall data was obtained from rain gauge stations established by Colorado State University for the period July 1999 to April 2000. Sea water samples were collected in 1 L plastic bottles from 1 m below the surface at each reef site and were analyzed for turbidity and total suspended solids. Turbidity was measured with a 2100P Hach Turbidimeter and TSS was measured by filtering the sample through pre-weighed glass-fiber filters.

Assessment of the coral reefs of both bays was based on the Atlantic and Gulf Reef Assessment methodology. Data included a measure of reef condition, percent cover of coral and macroalgae, density of *Diadema antillarium* sea urchins, coral recruitment levels, and composition of the reef fish community. Four reef sites were selected for both Fish Bay and Greater Lameshur Bay. Reef sites were located on the eastern and western shorelines inside the bay as well as outside the bay. Conditions of corals and coral cover were measured along 10 x 1 m line transects. Transects were added until a sample of 100 coral heads greater than 25 cm diameter was obtained. At each of the four sites algal abundance and coral recruitment were measured in fifty 25 x 25 cm quadrants and fish biomass and diversity were measured along ten 30 x 2 m belt transects.

Terrestrial Component

Channel morphology is controlled by the discharge, quantity and character of sediment inputs, and the composition of the materials making up the channel. A change in the rate of sediment inputs or runoff will affect the channel morphology. A well-documented response to an increase in fine sediment is a fining of the streambed. The streambed particle-size distribution at key locations in the Fish Bay basin was assessed to evaluate the balance between sediment inputs and the capacity of the channel to transport sediment. A hand-level, tape measure and hip chain were used to survey long profiles and cross-sections along the main Fish Bay Gut and Battery Gut. Streambed particle-size distribution at selected locations was quantified by pebble counts. The survey of the main Fish Bay Gut started about 30 m upstream of the sea berm that separates the gut from Fish Bay and extended for about 680 m to the confluence with Battery Gut. One cross-section and one pebble count was done about 170 m upstream. The Battery Gut survey extended from the confluence with the main Fish Bay Gut for approximately 2700 m to Adrian Estate. This survey included 10 cross-sections and 6 pebble counts.

Two stream gauging stations were installed in late 1998. The stations were located on Greater Lameshur Bay Gut and the main Fish Bay Gut. The main goals of these stations were to quantify runoff and sediment yields. Each stream gauging station consisted of a calibrated pressure transducer placed at the bottom of each channel. The pressure transducers were connected to a data logger that recorded stage measurements at 15-minute intervals. Automatic pump-samplers were located at each station to collect suspended sediment samples during flow events. Unfortunately, the pump samplers malfunctioned during the sampling period. As a result, suspended sediment sampling at the main Fish Bay Gut station was performed manually with a depth-integrated hand-held sampler (DH-48). A total of 27 samples were collected at this station between November 1999 and February 2000. The remoteness and inability to safely access the Greater Lameshur Bay Gut gauging station during flow events meant that no suspended sediment samples were collected during this study. Samples were kept refrigerated until they were analyzed.

Principal Findings and Significance

Marine Component

Monitoring stations were established on July 21, 1999. Subsequent sediment and water samples were collected on October 2 and November 22, 1999 and February 7, March 8, May 9, June 26, August 16 and October 25, 2000 and January 17, 2001. These sample periods represented 73, 51, 77, 31, 62 48, 44, 70 and 84 days, respectively. Although sampling was to be conducted on monthly intervals, the extended periods between sampling were due to mechanical failures of the research vessel and inclement weather.

Sedimentation onto the coral reef was significantly higher in Fish Bay than Greater Lameshur Bay ($F_{1,92}$=19.77,p<0.001), but there were no differences from inside the bay to outside the bay ($F_{1,92}$=2.29,p<0.13), or between the west side and the east side of the bays ($F_{1,92}$=0.66,p<0.52). Sedimentation rates tracked rainfall, with peak sedimentation rates being associated with peak rainfall during Hurricane Lenny in November 1999. During the underwater surveys, layers of fine sediment >1 cm hick could be observed covering dead coral heads. Water turbidity was significantly greater in Fish Bay than in Greater Lameshur Bay ($F_{1,104}$=10.02, p<0.002) and in both bays turbidity decreased with increased distance from the watershed outlet ($F_{1,104}$=7.02, p<0.001). No difference in turbidity occurred between the east and west shores ($F_{1,104}$=.177,p<0.675). The amount of total suspended solids was not different between bays or within bays ($F_{1,104}$=7.2, p<0.001) Total suspended solids were higher 1 m above the bottom than 1 m below the surface ($t_{1,47}$=2.97,p<0.005), whereas there was no difference in turbidity with depth ($t_{1,47}$=0.98,p<0.33). Historically, turbidity levels in Fish Bay have been substantially higher than in Greater Lameshur Bay.

Over 800 coral head were assessed using AGRA protocol. The number of benthic transects averaged 20 per site and the number of coral heads greater than 25 cm averaged 5.5 per transect. Assessment of the eight reef sited found coral cover to be substantially higher in Greater Lameshur Bay ($F_{1,155}$=122.3,p<0.001). The diameter of coral colonies averaged 55.0 cm, with exceptionally large colonies occurring on the east side of Greater Lameshur Bay. The composition of coral colonies greater than 25 cm diameter was dominated by *Montastrea annularis* in Greater Lameshur Bay and *Siderastrea siderea* in Fish Bay. The percent of old coral tissue mortality was significantly higher in Fish Bay

(38.8%) than in Greater Lameshur Bay (31.2%). This was largely because more than 35% of the coral heads in Fish Bay were more than 60% dead.

Nearly all of the reef sites had corals affected by bleaching, disease or damage by fish bites. Coral bleaching was recorded at all sites. The number of coral heads showing signs of disease was greater in Fish Bay (7.4%) than Greater Lameshur Bay (4.8%). The four general disease types were black band, yellow band, white band and dark blotch. Coral species most susceptible to disease included *Montastrea faviolata*, *M. franksi*, *M. cavernosa*, *M, annularis, Colpophyllia natans* and *Siderastrea siderea*. Damselfish and parrotfish were responsible for causing tissue damage to over 25% of the corals at several sites. Corals most frequently attacked were the same as previously mentioned with the addition of *Porites porites*. The percent cover of macroalgae and density of coral recruitment was similar between bays but varied considerably within bays. *Dictyota sp*. was the dominant macroalgae on Virgin Islands reefs. A very strong negative relationship was found between macroalgae cover and coral recruitment. The outer site on the east side of Fish Bay had the lowest percent macroalgae cover and the highest recruitment rate, while the inner site on in the west side of Fish Bay had the highest macroalgae coverage and the lowest coral recruitment rate. Coral recruitment rates were dominated by species that brood their larvae. The five most abundant species (*Siderastrea siderea*, *S. radians*, *Porites astreoides*, *P. porites* and *Agaricia spp*.) accounted for 70-80% of the coral recruitment at all sites. The density of *Diadema* urchins was greatest on reefs less than 5 m in depth. Fish assemblage structure was dominated by herbivores in both bays.

<u>Terrestrial Component</u>

Results show that approximately 60% of the 2.5 km of unpaved roads delivering sediment into Battery Gut, as well as a rock crushing operation, discharge their sediments into the channel just upstream of the location under study. It is believed that the fining of the streambed in this region is caused by the inability of this portion of the stream to transport all of the sediments coarser than 2 mm that are being delivered to it. The sediments finer than 2 mm are probably able to be transported by the stream during runoff events. In Fish Bay, 5.7 km of the road are in areas with high potential for sediment delivery, while only 1.2 km are in areas with low sediment delivery potential. In Greater Lameshur Bay, only 0.4 km of the roads have a high potential for sediment delivery, while 0.7 km of roads have a low delivery potential.

The road lengths are divided into 8 different classes of road gradients. The Fish Bay basin has more roads for nearly all gradient categories than the Greater Lameshur basin. Research shows that Fish Bay has more roads with gradients ranging from 6-20%, while the Greater Lameshur Bay has more very flat and slightly steeper roads. Since steeper roads have higher erosion rates this suggests that both basins have a similar amount of sediment from unpaved roads in areas with low sediment delivery potential. There is one road with high sediment delivery potential in the Lameshur Bay basin. This road, which is long and steep, drains directly into Little Lameshur Bay and is believed to be the most important source of sediment within this basin.

There are three general areas within the Fish Bay basin with a high potential for delivery of sediment. All of the roads in these areas are considered to have a high potential for sediment delivery because they are connected to the main Fish Bay Gut. However, the amount of sediment from one of the road networks should be minimal compared to the other two as this road network has been abandoned for at least fifteen years. Revegetation of the road surface, lack of traffic and absence of regrading operations should result in a much lower road erosion rate. The relative contributions of the other two areas should be similar, as the road lengths for roads with expected high erosion rates are generally comparable.   Analysis indicates that the amount of sediment being delivered from the road network should be much higher for Fish Bay than Lameshur Bay. Both basins have a similar distribution of roads in areas having a low sediment delivery potential, but the Fish Bay basin has many more road segments in areas with a high potential for sediment delivery. In general, the Fish Bay reefs were considerably more degraded than the reefs in Greater Lameshur Bay.

Basic Information

Title:	Wellhead Protection Area Management Standards
Project Number:	VI00-03
Start Date:	3/1/2000
End Date:	2/28/2001
Research Category:	Ground-water Flow and Transport
Focus Category:	Conservation, Education, Groundwater
Descriptors:	Aquifer Characteristics, Aquifer Parameters, Groundwater Hydrology, Groundwater Quality, Groundwater Management, Hydrogeology, Planning, Public Health
Lead Institute:	Virgin Islands Water Resources Research Institute
Principal Investigators:	Dayle Barry, Syed A. Syedali, Marjorie M. Hendricksen-Emanuel, Stevie Henry

Publication

1. Syedali, Syed. 2000. The Wellhead Protection Project in 6th Annual Non Point Source Pollution Conference, St. Croix, VI.
2. Project Completion report being prepared for distribution.
3. Barry, Dayle. 2001. The Wellhead Protection Project in Research and Public Service Advisory Council Meeting, St. Thomas, VI.

Problem and Research Objectives

Contamination of ground water in the U.S. Virgin Islands is a major concern and there is a need for the Territory to develop a mechanism to protect this supply source from contamination. One way of reducing this threat to human health is by the establishment of a state wellhead protection program (WHPP). The elements of this program would:

1) address the roles of various territorial, federal and other agencies within the context of the WHPP;
2) develop and evaluate the methodology for the delineation of wellhead protection areas (WHPAs);
3) establish a process for developing an inventory of potential contamination sources;
4) identify management mechanism adequate to protect groundwater supplies;
5) incorporate contingency plans for public water systems;
6) establish requirements for new well development; and
7) establish and expand the venue for public participation in the development and management of a WHPP.

The purpose of the project was to evaluate the methodology for the delineation of WHPAs on the island of St. Croix, inventory potential contamination sources within the delineated WHPAs and to prepare standards for the protection of wells that are utilized for public drinking water supply. The project also incorporates the planning to ensure proper management of those areas in order to project the groundwater resources that are utilized by the public. The project is intended to be developed and used as a model that can be applied for water quality protection of wells providing public drinking water within the U.S. Virgin Islands and in other small, tropical islands with similar hydrogeological and topographical conditions.

Methodology

There are seven wellfields owned/operated by the Virgin Islands Water and Power Authority (WAPA). Sample wells from within each of the seven wellfields were selected. An extensive literature survey was conducted to gather pertinent information regarding the well and hydrogeology of the WAPA wellfields selected. This information was then used to define the size of the wellhead protection areas (WHPAs) surrounding each selected wellfield, using either the Calculated Fixed Radii method or the Simplified Variable shapes method. The extent of the WHPAs for each selected wellfield was then developed into the ArcView® GIS and superimposed onto a digital orthophoto of St. Croix. Once the WHPAs had been established and delineated onto the aerial photograph, they were then inventoried for various contamination sources using the Trimble GeoExplorer II® Global Positioning System receiver and Pathfinder® software.

Principal Findings and Significance

Potential sources of contamination were grouped into five categories as established by a draft DPNR report, Wellhead Protection Program for the United States Virgin Islands (July 1999). The categories are as follows.

Category I	Sources designed to discharge substances
Category II	Sources designed to store, treat, and /or dispose of substances: discharges through unplanned release.
Category III	Sources designed to retain substances during transport or transmission
Category IV	Sources discharging substances as a consequence of other planned activities
Category V	Sources providing conduit of inducing discharge through altered flow patterns

Findings at each of the seven wellfields are as follows.

Adventure	A total of 35 potential sources of contamination were identified in this WHPA. The largest single category of potential sources of contamination was Category II sources (57%). These included illegally dumped materials, municipal trash containers, above ground storage of materials and underground storage. The other contamination sources were Category V (26%) and Category III (17%).
Barren Spot	There were 94 potential sources of contamination found in this WHPA. Potential sources of contaminations were found for all categories. The largest category was Category II (65%), then Category V (15%), then Category III (13%), then Category IV (6%) and Category I (1%).
Bethlehem	The field inventory revealed a total of 38 potential sources of contamination within this WHPA. The overwhelming majority were contaminants of Category II (89%). Three other Categories were also found - Category IV (5%), Categories III and V (3%).
Concordia	The majority of the 116 potential sources of contamination found in this WHPA, fell in Category II (74%). The next highest category was Category V (13%). The remainder was split between the other three categories – Category IV (9%), Category III (3%) and Category I (1%).
Golden Grove	At this WHPA, 24 potential sources of contamination were found. The largest category was Category II (50%). The remaining 50% was split between Category V (29%), Category III (13%) and Category IV (8%).
La Grange	During the inventory, 58 potential sources of contamination were found. Category II was the largest (85%). The remainder was split between Category V (10%) and Category IV (5%).
Negro Bay	A total of 71 potential sources of contamination were inventoried at this WHPA. Category II was again the leader (68%). Next was Category III (20%), followed by Category V (11%) and finally Category IV (1%).

Information Transfer Program

USGS Summer Intern Program

Student Support

Student Support					
Category	Section 104 Base Grant	Section 104 RCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	7	0	0	0	7
Masters	2	0	0	0	2
Ph.D.	3	0	0	0	3
Post-Doc.	1	0	0	0	1
Total	13	0	0	0	13

Notable Awards and Achievements

None

Publications from Prior Projects

1. MacDonald, Lee H., Robert W. Sampson, and Donald N. Anderson. 2001. Runoff and Road Erosion at the plot and road segment scales, St. John, US Virgin Islands. Earth Surface Processes and Landforms, 26, 251-272.