Final Narrative Report **March 2, 2006**

Reefs at Risk: Improving the Information Available for Sound Management and Protection of Coral Reefs in Puerto Rico and the US Virgin Islands

A project supported by NOAA's General Coral Reef Conservation Program
NOAA Award No. NA03NMF4630325 to World Resources Institute

Report prepared by Lauretta Burke

Project Overview

The lengthy project title, *Reefs at Risk: Improving the Information Available for Sound Management and Protection of Coral Reefs in Puerto Rico and the US Virgin Islands*, reveals the overall project goal – to improve management of coastal resources by improving the base of information available for evaluating threats to coastal ecosystems. The project was a highly collaborative effort, involving a wide range of government agencies and NGOs in the US Virgin Islands and Puerto Rico, as well as the Special Projects Office of NOAA. The effort builds on present initiatives and supports local strategies for addressing threats to coral reefs. The project focused on land-based threats to coral reefs and developed a series of watershed-based indicators of threat to coastal ecosystems. Many spatial data sets were acquired, integrated and documented as part of this effort. All base GIS data as well as analysis results for Puerto Rico and the USVI have been released on the *Coastal Data CD for the US Caribbean*, jointly published by WRI and NOAA. In addition, WRI developed an atlas, *Land-based Sources of Threat to Coral Reefs in the US Virgin Islands*, which is available on the Data CD and over the internet via reefsatrisk.wri.org . Training in spatial analysis of land-based sources of threat was provided to over 40 workshop participants at the 9th Virgin Islands Non-point Source Pollution Conference held November 28-30, 2005.

Collaboration

WRI staff traveled to Puerto Rico and the USVI to meet with partners, discuss data holdings, establish data sharing agreements, and identify most pressing information needs. Trips included conferences on land-based threats (US Coral Reef Task Force Atlantic and Caribbean Area Land-based Sources of Pollution Workshop in San Juan, May 18-19, 2004 and 9th Virgin Islands Non-point Source Pollution Conference held on St. John, November 28-30, 2005), as well as individual meetings with government agencies and NGOs. Partners were key sources of data, provided guidance on the modeling approach and reviewed results. Groups which contributed data or provided guidance on the project include:

- University of the Virgin Islands \ Conservation Data Center (UVI \ CDC)
- USVI Department of Planning and Natural Resources (DPNR)
- PR Department of Natural and Environmental Resources (DNER)
- US Department of Agriculture

- US National Park Service
- US National Fish and Wildlife Service
- US Geological Service (USGS)
- The Nature Conservancy (TNC)
- Island Resources Foundation (IRF)
- The Ocean Conservancy
- International Coral Reef Action Network (ICRAN)
- UVI, VI Marine Advisory Service
- USDA / NRCS / Resource Conservation and Development Council

Data Products

An important result of the project collaboration is *the Coastal Data CD for the Caribbean.* The CD contains spatial data sets reflecting physical, environmental, and socioeconomic data for US Virgin Islands and Puerto Rico, as well as estimates of the vulnerability of land to erosion, and watershed-based indicators of threat from land-based sources. All spatial datasets have metadata and the CD contains full technical notes on the modeling approach. In addition, the CD contains technical reports on threats to and the status of the coral reefs in the USVI and Puerto Rico. The CD also contains a series of electronic maps reflecting threats to coral reefs from land-based sources of sediment and pollution, highlighting watersheds as a unit for evaluating and summarizing threats.

Over 35 GIS base data sets and over 70 data layers reflecting analysis results and indictors are provided on *Coastal Data CD for the Caribbean. (See spreadsheet summary attached* – Attachment 1.*)*

Analysis Approach

Alteration of the natural landscape for development, road construction, or agriculture can have adverse impacts on coral reefs through increased delivery of sediment and pollution to coastal waters. The threat associated with land clearing is higher in areas of steep relief, intense precipitation, and where soils are erosive in nature. This threat is often evaluated through application of the Revised Universal Soil Loss Equation (RUSLE) developed by the US Department of Agriculture (USDA, 1989). RUSLE is useful for examining erosion in many agricultural areas, but is not well suited to the very steep and rutted environments of the US Virgin Islands where road construction accounts for most erosion.

This study uses several spatial and statistical techniques to characterize watersheds across the US Virgin Islands and Puerto Rico with regard to relative erosion rates and the threat of land-based sources of sediment and pollutant delivery to coastal waters. A simplified version of RUSLE (using slope, land-cover, precipitation and soil characteristics) was applied, as well as an indicator of road density by watershed. Watersheds are an essential unit for analysis, since they link land areas with their point of discharge to the sea. The analysis ultimately focuses on watershed-based threat to coral reefs from land cover change and road development.

The spatial analysis of land-based sources of threat to coral reefs has four main components:

1. Delineation of watersheds (basins) based on a hydrologically-corrected digital elevation data set (DEM.) These basins reflect all land areas discharging to a single coastal location (river mouth / pour point).
2. Analysis of relative vulnerability of land to erosion based on slope, precipitation, and the soil characteristics (within each 30m resolution grid cell).
3. Analysis of the relative erosivity of land given current land cover within each 30m resolution grid cell. In addition, the relative sediment delivery for each river mouth is estimated.
4. The density of roads (paved roads, unpaved roads and tracks) is estimated for each watershed. For areas with roads, the vulnerability of the area (see #2 above) is considered, allowing the development of an indicator of the relative vulnerability of roads to erosion.

The attached Technical Notes provide details on the analysis method (Attachment 2).

Electronic Atlas

An electronic atlas of spatial indicators and analysis results for the US Virgin Islands is included on the data CD and is available over the internet from reefsatrisk.wri.org. *Land-based Sources of Threat to Coral Reefs in the US Virgin Islands* contains a series of maps are large, high resolution images, representing some of the indicators from the analysis:

1. Hydrology in the US Virgin Islands (JPEG)
2. Relative Vulnerability of Land to Erosion (JPEG)
3. Mean Vulnerability of Land to Erosion (by watershed) (JPEG)
4. Mean Vulnerability of Land to Erosion (by basin) (JPEG)
5. Vulnerability of Roads to Erosion (JPEG)
6. Estimated Erosion from Roads (mean for watershed) (JPEG)
7. Relative Erosion Potential (given current land cover) (JPEG)
8. Relative Erosion Potential (by watershed) (JPEG)
9. Relative Erosion Potential (by basin) (JPEG)
10. Relative Sediment Delivery (by basin) and Estimated Plume (JPEG)

A hardcopy version of the electronic atlas is provided as attachment 3.

Training / Capacity Building

The project analysis methods and results were presented at two technical meetings in Puerto Rico and the Virgin Islands - the US Coral Reef Task Force Atlantic and Caribbean Area Land-based Sources of Pollution Workshop in San Juan (May 18-19, 2004) and the 9th Virgin Islands Non-point Source (NPS) Pollution Conference (November 28-30, 2005.) Technical training in GIS and watershed analysis methods was provided to 45 participants at the VI NPS conference. (See attachment 4 for list of participants at "Application of GIS and Remote sensing to evaluate land-based treat to coastal ecosystems".) WRI staff also provided specialized training in GIS for USVI Department of Planning and Natural Resources Staff in December of 2004.

The analysis results were covered by a local USVI newspaper, *Tradewinds*. See attached news article (attachment 5.)

Conclusion

This project would not have been possible without the support provided by NOAA's General Coral Reef Conservation Program nor the collaboration provide by NOAA's Special Projects Office (Steve Rohmann and Aurelie Shapiro.) We believe that the project fostered spatial data sharing in the US Caribbean; improved the quality of easily accessible GIS data for the US Caribbean; has provided accessible indicators of land-based threats to coral reefs, as well as a tool for examining these pressures under changing land use scenarios. We hope this effort and these products promote better management of coral reefs in the US Virgin Islands and Puerto Rico.

Attachments:

1. Summary of GIS data sets on *Coastal Data CD for the Caribbean (.XLS)*
2. Technical Notes on an analysis of land-based sources of threat to coral reefs in the US Virgin Islands and Puerto Rico (HTML file)
3. *Land-based Sources of Threat to Coral Reefs in the US Virgin Islands* (Atlas sent as hardcopy)
4. *List of participants at* Application of GIS and Remote sensing to evaluate land-based treat to coastal ecosystems
5. *Tradewinds* article on analysis presented at conference (sent as hardcopy)
6. *Coastal Data CD for the Caribbean* (sent in mail.)

Virgin Islands - Base Data Layers

Category	Theme	Data Layer Name
Bathymetry	Bathymetry for St Thomas and St John, USVI	bath_st_sj
Bathymetry	Bathymetry for St Croix, USVI	bath_stx
Bathymetry	Bathymetry for Puerto Rico and USVI	bath_region
Elevation	Elevation of St Thomas and St John, USVI	stt_j_dem
Elevation	Elevation of St Croix, USVI	stx_dem
Landcover	St Thomas and St John Vegetation Communities (Landcover)	landcov_stt_j_usvi
Landcover	St Croix Communities (Landcover)	landcov_stx_usvi
Landcover	Landuse for St Thomas and St John, USVI	st_sj_landuse
Landcover	Landuse for St Croix, USVI	stc_landuse
Precipitation	Mean annual precipitation for St Thomas and St John, USVI	stt_j_matprec
Precipitation	Precipitation for the peak rainfall month for St Thomas and St John, USVI	stt_j_maxprec
Precipitation	Mean annual precipitation for St Croix, USVI	stx_matprecip
Precipitation	Precipitation for the peak rainfall month for St Croix, USVI	stx_maxprecip
Protected Areas	Marine Protected Areas for St Thomas and St John, USVI	sttj_mpa
Protected Areas	Marine Protected Areas for St Croix, USVI	stx_mpa
Reefs	Reefs of St Thomas and St John, USVI	st_sj_reefs
Reefs	Reefs of St Croix, USVI	stx_reefs
Rivers	Guts of St Thomas and St John, USVI	stsj_rivers_guts
Rivers	Guts of St Croix, USVI	stx_rivers_guts
Roads	Roads of St Thomas and St John, USVI	roads_st_sj
Roads	Roads of St Croix, USVI	roads_stx
Shoreline	Shoreline of St Thomas and St John, USVI	stsj_shoreline
Shoreline	Shoreline of St Croix, USVI	stx_shoreline
Slope	Slope, in degrees, for St Thomas and St John, USVI	stt_j_dslope
Slope	Slope, in percent, for St Thomas and St John, USVI	stt_j_pslope
Slope	Slope, in degrees, for St Croix, USVI	stx_dslope
Slope	Slope, in percent, for St Croix, USVI	stx_pslope
Soils	SSURGO Soil Data for St Thomas and St John, USVI	st_sj_soils
Soils	SSURGO Soil Data for St Croix, USVI	stx_soils
Water Quality	Water Quality data for St Thomas and St John, USVI	st_sj_water
Water Quality	Water Quality data for St Croix, USVI	stx_water
Watersheds	Basins for St Thomas and St John, USVI	sttj_basins
Watersheds	Basins for St Croix, USVI	stx_basins
Watersheds	Watersheds for St Thomas and St John, USVI	sttj_ws_uwi
Watersheds	Watersheds for St Croix, USVI	stx_ws_uwi

Analysis Layers

Category	Theme	Data Layer Name
Watershed Analysis	Digital Elevation Model, Burned, for St Thomas and St John, USVI	sttj_dem_b
Watershed Analysis	Digital Elevation Model, Burned, for St Croix, USVI	stx_dem_b
Watershed Analysis	Flow Direction Model for St Thomas and St John, USVI	flowdir_sttj
Watershed Analysis	Flow Direction Model for St Croix, USVI	flowdir_stx
Watershed Analysis	Flow Accumulation Model for St Thomas and St John, USVI	flowacc_sttj
Watershed Analysis	Flow Accumulation Model for St Croix, USVI	flowacc_stx
Watershed Analysis	Basins, in grid format, for St Thomas and St John, USVI	basin_sttj1
Watershed Analysis	Basins, in grid format, for St Croix, USVI	baxin_stx1
Watershed Analysis	Basins larger than 6 ha (70 cells), in grid format, for St Thomas and St John, USVI	bas_sttj_70
Watershed Analysis	Basins larger than 6 ha (70 cells), in grid format, for St Croix, USVI	bas_stx_70
Watershed Analysis	Pour Points, in grid format, for St Thomas and St John, USVI	ppt_sttj_70
Watershed Analysis	Pour Points, in grid format, for St Croix, USVI	ppt_stx_70
Watershed Analysis	Pour Points, in shapefile format, for St Thomas and St John, USVI	sttj_ppt
Watershed Analysis	Pour Points, in shapefile format, for St Croix, USVI	stx_ppt
Erosion Model Inputs	Soil Kffactor for St Thomas and St John, USVI	sttj_kffact
Erosion Model Inputs	Soil Kffactor for St Croix, USVI	stx_kffact
Erosion Model Inputs	Relative erosion rate based on land cover for St Thomas and St John, USVI	sttj_lnd_rer
Erosion Model Inputs	Relative erosion rate based on land cover for St Croix, USVI	stx_lnd_rer
Erosion Model Inputs	Grid file of roads for St Thomas and St John, USVI	sttj_road_30

Erosion Model Inputs	Grid file of roads for St Croix, USVI	stx_road_30
Erosion Model Outpu	Relative Erosion Potential (REP) for St Thomas and St John, USVI	sttj_rep_i
Erosion Model Outpu	Relative Erosion Potential (REP) for St Croix, USVI	stx_rep_i
Erosion Model Outpu	Erosion Vulnerability Analysis for St Thomas and St John, USVI	sttj_vuln_i
Erosion Model Outpu	Erosion Vulnerability Analysis for St Croix, USVI	stx_vuln_i
Erosion Model Outpu	Road Vulnerability Analysis for 30m cells which contain a road, St Thomas and St John, USVI	sttj_rd_vuln
Erosion Model Outpu	Road Vulnerability Analysis for 30m cells which contain a road, St Croix, USVI	stx_rd_vuln
Watershed Indicators	Watershed Indicators by basin for St Thomas and St John, USVI	sttj_bas_ind
Watershed Indicators	Watershed Indicators by basin for St Croix, USVI	stx_bas_ind
Watershed Indicators	Watershed Indicators by watershed for St Thomas and St John, USVI	sttj_ws_ind
Watershed Indicators	Watershed Indicators by watershed for St Croix, USVI	stx_ws_ind
Watershed Indicators	Pour point Indicators for St Thomas and St John, USVI	sttj_ppt_ind
Watershed Indicators	Pour point Indicators for St Croix, USVI	stx_ppt_ind
Watershed Indicators	Watershed Indicators by watershed for all of the US Virgin Islands	usvi_ws_ind
Watershed Indicators	Pour point Indicators for all of the US Virgin Islands	usvi_ppt_ind
Sediment Indicators	Relative Sediment Plume for St Thomas and St John, USVI	sttj_plume
Sediment Indicators	Relative Sediment Plume for St Croix, USVI	stx_plume
Watershed Indicator T	Watershed Indicator table by basin for St Thomas and St John, USVI	sttj_basin_table
Watershed Indicator T	Watershed Indicator table by basin for St Croix, USVI	stx_basin_table
Watershed Indicator T	Watershed Indicator table by watershed for St Thomas and St John, USVI	sttj_ws_table
Watershed Indicator T	Watershed Indicator table by watershed for St Croix, USVI	stx_ws_table

Data assembled or developed under the Reefs at Risk in the US Virgin Islands project,
World Resources Institute (WRI) and U.S. NOAA, 2005.

Puerto Rico - Base Data Layers

Category	Theme	Data Layer N
Bathymetry	Bathymetry for Puerto Rico	bath_pr
Bathymetry	Bathymetry for Puerto Rico and USVI	bath_region
Elevation	Puerto Rico Elevation	pr_dem
Landcover	Puerto Rico Landcover	pr_cover
Landcover	Puerto Rico Landcover - Modified Geocover,1990	pr_geo_90
Precipitation	Mean annual precipitation for Puerto Rico	pr_matprecip
Precipitation	Precipitation for the peak rainfall month for for Puerto Rico	pr_maxprecip
Protected Areas	Marine Protected Areas for Puerto Rico	pr_mpa
Reefs	Reefs of Puerto Rico	pr_reefs
Rivers	Rivers of Puerto Rico	pr_rivers
Roads	Roads of Puerto Rico	pr_roads
Shoreline	Shoreline of Puerto Rico	pr_shoreline_
Slope	Slope, in degrees, of Puerto Rico	pr_dslope
Slope	Slope, in percent, of Puerto Rico	pr_pslope
Soils	Soils of Puerto Rico	pr_soils
Water Quality	Water Quality data for Puerto Rico	pr_water
Watersheds	Basins for Puerto Rico	pr_basins
Watersheds	Watersheds for Puerto Rico	pr_watersheds

Analysis Layers

Category	Theme	Data Layer N
Watershed Analysis	Flow Direction Model for Puerto Rico	pr_flowdir
Watershed Analysis	Flow Accumulation Model for Puerto Rico	pr_flowacc
Watershed Analysis	Pour Points, in shapefile format, for Puerto Rico	pr_outflow
Erosion Model Inputs	Soil Kffactor for Puerto Rico	pr_kffact
Erosion Model Inputs	Relative erosion rate based on land cover for Puerto Rico	pr_lnd_rer
Erosion Model Outputs	Relative Erosion Potential (REP) for Puerto Rico	pr_rep_i
Erosion Model Outputs	Erosion Vulnerability Analysis for Puerto Rico	pr_vuln_i
Watershed Indicators	Watershed Indicators by basin for Puerto Rico	pr_bas_ind
Watershed Indicators	Watershed Indicators by watershed for Puerto Rico	pr_ws_ind
Watershed Indicators	Pour Point Indicators for Puerto Rico	pr_ppt_ind

GIS Training

Application of GIS and Remote sensing to evaluate land-based treat to coastal ecosystems

Lauretta Burke (WRI)& Aurelie Shapiro (NOAA)˝

NAME	ORG	EMAIL
Diane "Dee" Osinski	VIWMA	dosinkski@viwma.org
Craig Barshinger	Legislature, Senator	senator@barshinger.net
Sharon Coldren	CBLC	coralbaycommunitycouncil@hotmail.com
Leslie Leonard	DPNR	leonard.leslie@vidpnr-dep.org
Dalila Patton	DPNR	dalila.patton@viczmp.com
Kathryn Worrel	DPNR	kathryn_worrell@vidpnr-dep.org
Aurea C. Olive	DPNR	olive.aurea@vidpnr-dep.org
efrain hatchette	DPNR	hatchette.efrain@vidpnr-dep.org
dawn henry	DPNR	henry.dawn@vidpnr-dep.org
raul santini	DNER	prczmp@caribe.net
carlos ramos	island resources foundation	cramos@iff.org
yamil c toro	UPR	yw_toro@hotmail.com
juan martinez	NRCS	juan.martinez@pr.usda.gov
julie wright	usda-nrcs	julie.wright@pr.usda.gov
david rosa		david_rosa@juno.com
david baird	VI paving	db@islands.cc
elissa rock runyon		bushwacker@viaccess.net
william mccomb	civil engineer	wfmccomb.eng@attgloabl.net
lisamarie carrurbba	NOAA/NMFS	lisamarie.carrubba@noaa.gov
marcia taylor	UVI/CMES	mtaylor@uvi.edu
greg miller	BGM engineers	bgmiller@islands.vi
paige rothenberger	DPNR/CZM	paige.rothenberger@viczmp.com
nkohl james	DPNR/CZM	knkohljames@viczmp.com
cynthia rolli	TCPD/BVI government	cynthiarolli@yahoo.com
steve augustine	town & country planning	viso@hotmail.com
avelinda freeman	town & country planning	avfreeman@gov.vg
jeremiah blondeau	UVI/CMES	jblonde@uvi.edu
angela arnold	DPNR/DEP	arnold.angela@vidpnr-dep.org
amanda jackson	DPNR Permits	ajstx@viaccess.net
courtney Dickenson	DPNR/DEP	dickenson.courtney@vidpnr-dep.org
benjamin l. kewlarts	DPNR/DEP	kewlarts.benjamin@vidpnr-dep.org
carl bachelor	DPNR -Permits	carl_bachelor@hotmail.com
karima fredericks	DPNR/DEP	fredericks.karima@vidpnr-dep.org
emanuel liburd	DPNR/DEP	liburd.emanuel@vidpnr-dep.org
dave whitall	NOAA/NOS	dave.whitall@noaa.gov
violeta villanueva	DPNR/DEP	villanueva-mayor.violeta@vidpnr-dep.org
philippe a. mayor	the ocean conservancy	pamayor@oceanconservancy.org
shona paterson	the nature conservancy	spaterson@tnc.org
mark drew	the nature conservancy	mdrew@tnc.org
elvis a petersen	DPNR/DEP	pete2169@yahoo.com
barbara magras	DPNR/DEE	bmagras@yahoo.com
lenny hedrington	DPNR/DEE	
Algem Petersen	DPNR/CZM	algem.petersen@viczmp.com
jamil springer	DPNR/CZM	jamil.springer@viczmp.com
jean-pierre L. Oriol	DPNR/CZM	jp.oriol@viczmp.com
Louis E. Petersen	UVI-CES	lpeters@uvi.edu

CALL FOR PRESENTATIONS
(Training Seminars, Papers, Posters, Exhibits, Displays)

Training, Paper, Poster, Exhibit & Display submission deadline is August 1, 2005!

POSTER/EXHIBIT LIST

LIST OF PAPERS

CONFERENCE PROGRAM

CONFERENCE REGISTRATION
Registration deadline has been extended to November 14, 2005!

ALL presenters must submit a conference registration form!

HOTEL REGISTRATION INFO*
*For reduced conference rates, Register using this Westin site link!

CONTACTS:

Anita Nibbs, DPNR-DEP, (340) 773-1082, for presentation details.

Vanessa Peter or **Diane Capehart**, DPNR-DEP St. Croix, (340) 773-1082, for Conference details.

NPS Conference Home

Ninth Virgin Islands NONPOINT SOURCE POLLUTION CONFERENCE

Preventing Pollution in the Caribbean: Reshaping Our Communities for the Future

November 28 - 30, 2005
The Westin St. John Resort & Villas
St. John, U.S. Virgin Islands

photos courtesy of the Westin St. John Resort & Villas

Oral Presentations

Paper Title	Presenter	Affiliation
Our Past, Our Present and Our Future	*May Adams Cornwall*	*VI WMA*
"Just Do It": Using Marketing Tools for Effective Outreach	*Elizabeth Ban*	*UVI-VIMAS*
Watershed Hydrology: New Perspectives from the Southgate Valley, St. Croix, USVI	*Arthur G. Gaines, Jr. & Carol Cramer-Burke*	*WHOI & SEA*
Coral Bay Watershed: Management Measures and Activities to Address Non Point Source Pollution	*Barry Devine, Ph. D.*	*UVI-Eastern Caribbean Center*
Island Green Building Association	*Barry Devine, Ph. D.*	*UVI-Eastern Caribbean Center*
VI Wetlands & Riparian Areas Inventory	*Barry Devine, Ph. D.*	*UVI-Eastern Caribbean Center*
Using Gabion Baskets and Retaining Structures Early in Steep Slope Development	*Sharon Coldren*	*PERSONAL*
Starting a Landuse Planning and	*Sharon Coldren*	*Coral Bay Community Council*

V.I. RC&D Home

DPNR-CZM Home

DPNR-DEP home

Watershed Community Association		
Virgin Islands Sediment Monitoring Program	*Jeremiah Blondeau, et. al.*	*UVI*
Managing NPS Pollution in the Coastal Zone	*Susan Curtis*	*DPNR-CZM*
Innovative Telephone Constructed Wetlands System	*Elizabeth Goggins & Carlos Ferreyra*	*Innovative Telephone*
VI Clean Marina Project: A Education Outreach Program to Promote Best Management Practices for Marinas	*Kent Bernier*	*DPNR-DEP*
The Earth Change Program: A Report on the Transition & Current Status	*Syed Syedali*	*DPNR-DEP*
Guts in the Landscape	*Rudy G. O' Reilly, Jr.*	*USDA-NRCS*
Illegal Dumping of Solid Waste in the USVI	*Jason Henry*	*DPNR-DEP*
Current & Forthcoming Laws for NPS Pollution Management	*Aaron Hutchins*	*DPNR-DEP*
Update on the VI TMDL Program	*Amanda Sackey & Christopher Crawford, Ph. D.*	*DPNR-DEP*
Scale Issues in Groundwater Water Modeling for Spatial Decision Support	*Christopher Crawford, Ph. D.*	*PERSONAL*
Water Quality in the USVI: The Revised Water Quality Standards for the USVI	*Hector Squiabro*	*DPNR-DEP*
At Arm's Length: The Process of Negotiating, Executing & Fulfilling a Contract	*Dwayne Henry, B.S., J.D.*	*DPNR-DEP*
VI Beach Water Quality Monitoring Program	*Leah Motta*	*DPNR-DEP*
The EQIP Program	*Dr. Lawrence Lewis*	*Department of Agriculture*
Mon Bijou Flood Control Channel	*David E. Baird*	*Virgin Islands Paving, Inc.*
How Large Capacity Septic Systems Are Regulated by the EPA on the US Virgin Islands	*Robert Ferri*	*USEPA-Region 2*
Assessing Contaminants and Coral Health in Southwestern Puerto Rico: Towards an Understanding of Nonpoint Source Pollution Impacts on Coral Reefs	*Anthony S. Pait, et. al.*	*NOAA, et. al.*
Habitat Restoration: The NOAA Community Based Restoration Program, EPA Gulf of Mexico Program and Gulf of Mexico Foundation Partnership	*Quenton R. Dokken, Ph. D., et. al.*	*Gulf of Mexico Foundation, et. al.*
Sanitary Water Treatment Systems	*Justino R. Ferrer Hopgood*	*Specco Environmental*
Record of Sediment Input in Coastal Environments of St. Thomas and St. John, USVI	*Brooks, G. R, et. al.*	*Eckerd College*
Thinking Sustainably: Empowering Secondary School Students to Protect the Environment	*Mary Beth Sutton & Crispin D'Auvergne*	*Caribbean Student Environmental Alliance & St. Lucia Ministry of Physical Development, Environment and Housing*

Advanced Wastewater Treatment Using A Textile-Based Packed Bed Filter	*Terry R. Bounds, P.E. & Geoffrey S. Salthouse, MS, EIT*	*Orenco Systems*
An Alternative Animal Waste Management System for Small Scale Livestock Operation in Island Countries	*Dr. Allan Castro Sabaldica*	*NMC-CREES*
Reefs at Risk From Watershed-based Threats in the US Virgin Islands	*Lauretta Burke*	*WRI*
Clean Marinas & Boatyards – Keys to Successful Partnerships to Address Non-point Pollution	*Thomas J. Murray*	*Virginia Institute of Marine Science*
Phosphorus Removal in Soil-Based Wastewater Dispersal System	*Mark Gross*	*University of Arkansas*
STJ-EROS: A GIS-based Application to Assess the Impact of Unpaved Roads on Watershed-scale Sediment Yields	*Dr. Carlos E. Ramos-Scharron*	*Island Resources Foundation*
Development Impacts on the Environment	*Kolakaluri Mohan Krishna & Savalia Ramesh*	*Centre of Environment Education*
Mangrove Oysters as Indicators of Anthropogenic Effects in Areas of High Activity: La Parguera, Puerto Rico	*H. A. Minnigh, et. al.*	*RCAP, Inc.*
Watersheds in Urban Areas: Quebrada Mundaca, Caguas, PR	*H. A. Minnigh, et. al.*	*RCAP, Inc.*
The Environmental Profile of the USVI: Bench Marking with the USA and the Caribbean	*Carl-Axel P. Soderberg, P.E.*	*USEPA-CEPD*
Summit-to-Sea Mapping and Change Detection: Using Landsat Imagery Coastal Zone Management	*Aurelie Shiparo & Stephen O. Rohman*	*NOAA*
Cruise Ship Management in the USVI & the BVI – A Tale of Three Islands	*Nick Drayton*	*Ocean Conservancy*
The Comprehensive Land and Water Use Plan	*Marjorie Emmanuel*	*DPNR-CZZP*
Integrated Solid Waste Management Models	*Leslie Hamdorf*	*North Carolina State University*

TRAINING SEMINARS

Seminar Title	Presenter	Affiliation
Application of GIS and Remote sensing to evaluate land-based treat to coastal ecosystems	*Lauretta Burke & Aurelie Shapiro*	*WRI & NOAA*
Bringing your large capacity septic system into compliance with the Safe Drinking Water Act	*Robert Ferri & Luis Rodriquez*	*USEPA-Region 2*

Sponsored by:

- **Virgin Islands Department of Planning and Natural Resources:** ***Coastal Zone Management Program, Division of Environmental Protection & Division of Fish & Wildlife***
- **University of the Virgin Islands:** ***Cooperative Extension Service, Conservation Data Center & Marine Advisory Service***
- **Virgin Islands Resource Conservation & Development Council, Inc.**
- **Virgin Islands Nonpoint Source Pollution Control Committee**
- **U.S. Environmental Protection Agency**
- **U.S. Department of Agriculture - Natural Resources Conservation Service**

Check out information from our December 2003: ***Eighth Virgin Islands Nonpoint Source Pollution Conference***

Last Updated on November 22, 2005 by ***Julie Wright****, RC&D Coordinator, USDA-NRCS*

Land-based Sources of Threat to Coral Reefs in the US Virgin Islands

February 2006

A collaborative data product coordinated by

NOAA

WORLD RESOURCES INSTITUTE

Land-based Sources of Threat to Coral Reefs in the U.S. Virgin Islands

Project Goal

With support from the U.S. National Oceanic and Atmospheric Administration (NOAA), The "Reefs at Risk" project of the World Resources Institute (WRI) teamed with NOAA's "Summit to Sea" project to develop and implement analysis of land-based threats to coral reefs in the U.S. Virgin Islands (USVI) and Puerto Rico. The goal of the collaboration is to support improved management of coastal ecosystems by developing and making available extensive information on watershed-based threats to these ecosystems, including identification of watersheds which are highly erosive and those watersheds contributing elevated levels of sediment and pollution to coastal waters. Data assembled or developed under this collaboration, including analysis results, are published on the *Coastal Data CD for the U.S. Caribbean*[1]. The data CD also serves as a GIS data sampler for both the USVI and Puerto Rico, allowing users to do their own analysis of land-based sources of threat. This atlas provides a summary of some of the spatial indicators developed under the project.

Collaboration

The project was implemented by the World Resources Institute and the U.S. National Oceanic and Atmospheric Administration, in collaboration with many local institutions and other partners. Collaborating institutions were vital sources of information, provided guidance on the analytical approach, and offered critical review of analysis results. Groups which contributed data or provided guidance on the project include:

- University of the Virgin Islands / Caribbean Data Center (UVI / CDC)
- USVI Department of Planning and Natural Resources (DPNR)
- Puerto Rico Department of Natural and Environmental Resources (DNER)
- U.S. Department of Agriculture
- U.S. National Park Service
- U.S. National Fish and Wildlife Service
- U.S. Geological Survey
- The Nature Conservancy
- Island Resources Foundation
- The Ocean Conservancy
- International Coral Reef Action Network (ICRAN)

[1] World Resources Institute (WRI) and U.S. National Oceanic and Atmospheric Administration (NOAA), *Coastal Data CD for the U.S. Caribbean*, (Washington, DC: WRI / NOAA, 2005)

Analysis Approach

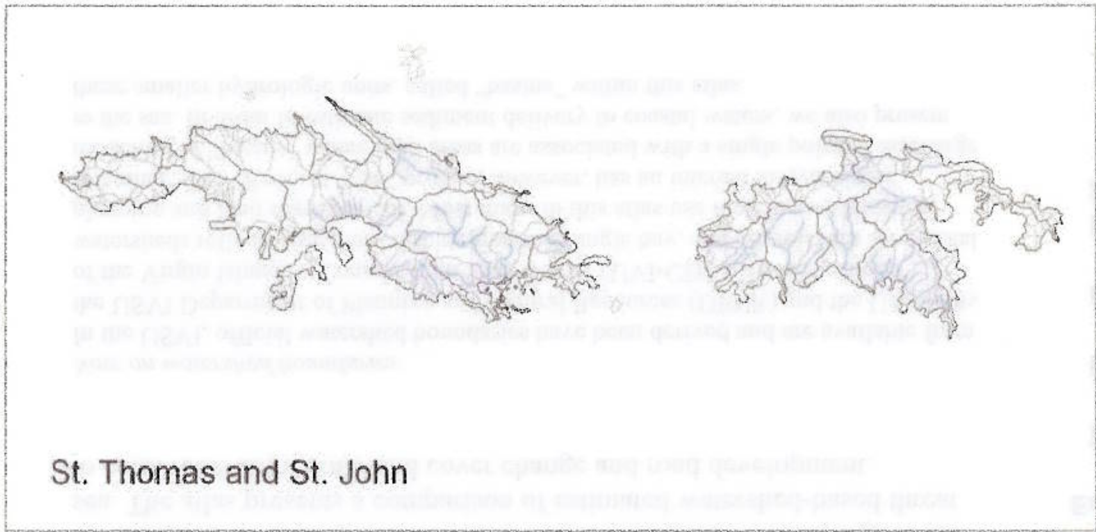
Alteration of the natural landscape for development, road construction, or agriculture can have adverse impacts on coral reefs through increased delivery of sediment and pollution to coastal waters. The threat associated with land clearing is higher in areas of steep relief, intense precipitation, and where soils are erosive in nature. This threat is often evaluated through application of the Revised Universal Soil Loss Equation (RUSLE) developed by the U.S. Department of Agriculture (USDA). RUSLE is useful for examining erosion in many agricultural areas, but is less well suited to the very steep and rutted environments of the U.S. Virgin Islands where road construction accounts for most erosion.

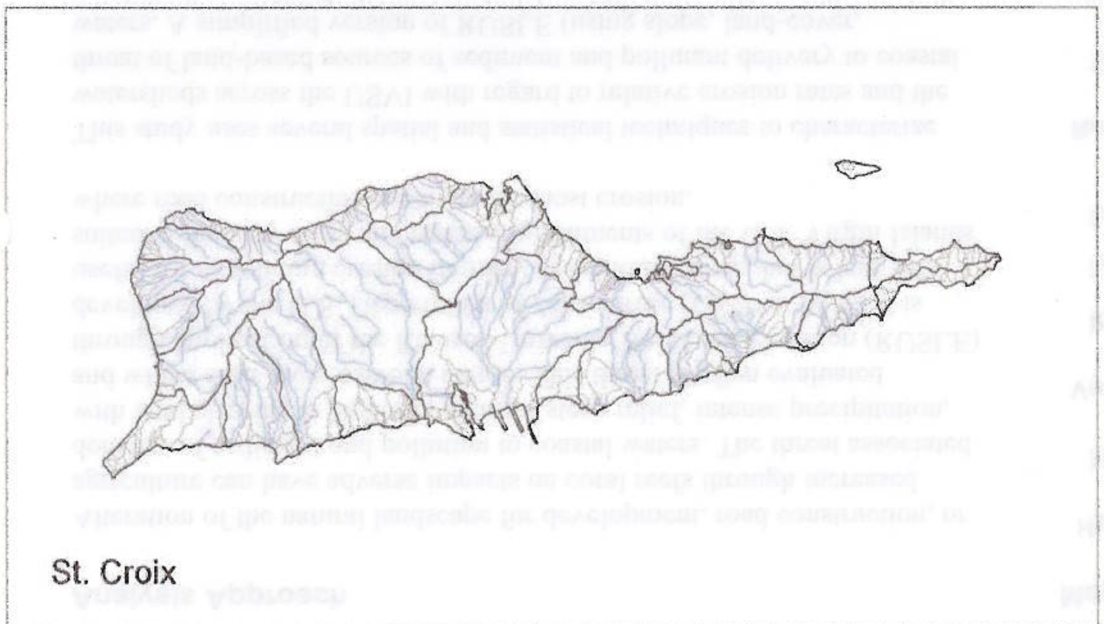
This study uses several spatial and statistical techniques to characterize watersheds across the USVI with regard to relative erosion rates and the threat of land-based sources of sediment and pollutant delivery to coastal waters. A simplified version of RUSLE (using slope, land-cover, precipitation, and soil characteristics) is applied, as well as indicators of road density and erosivity by watershed. Watersheds are an essential unit for analysis, since they link land areas with their point of discharge to the sea. The atlas presents a comparison of estimated watershed-based threat to coral reefs from both land cover change and road development.

Note on watershed boundaries:
In the USVI, official watershed boundaries have been derived and are available from the USVI Department of Planning and Natural Resources (DPNR) and the University of the Virgin Islands – Conservation Data Center (UVI-CDC). These "official" watersheds reflect large areas discharging to a single bay, and are relevant for coastal planning and land management. Most maps in this atlas use these watersheds for reference. The "Reefs at Risk" project, however, has an interest in hydrologic modeling of "basins" where land areas are associated with a single point of discharge to the sea. In order to estimate sediment delivery to coastal waters, we also present these smaller hydrologic units, called "basins" within this atlas.

Maps

Hydrology in the US Virgin Islands





This map presents two approaches to watershed mapping. The USVI has mapped "official" watersheds reflecting large areas discharging to a single bay. These 53 "watersheds" are relevant for coastal planning and land management.

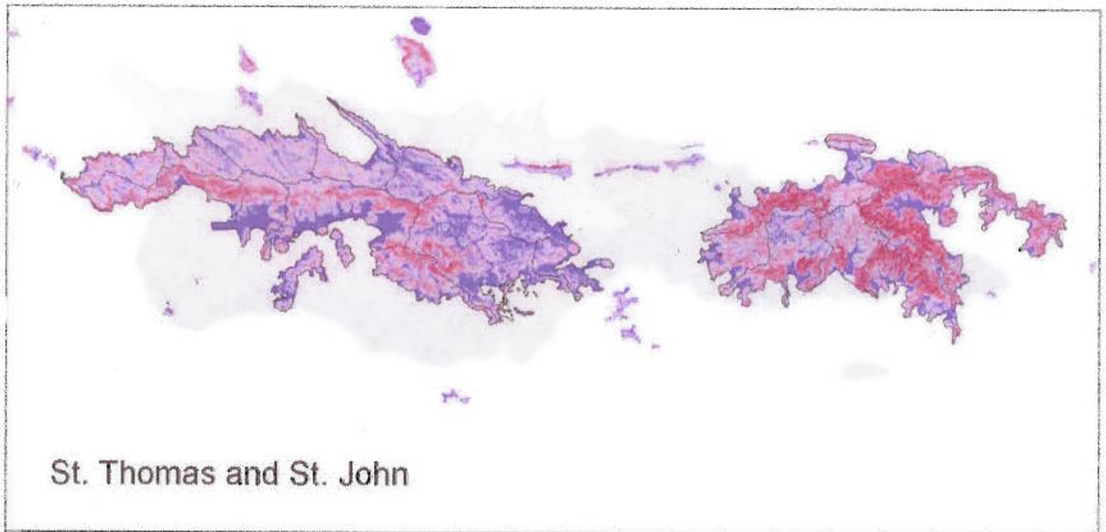
The "Reefs at Risk" project has an interest in hydrologic modeling of "basins" where land areas are associated with a single point of discharge to the sea. Over 400 basins with a minimum area of 6 ha. are presented.

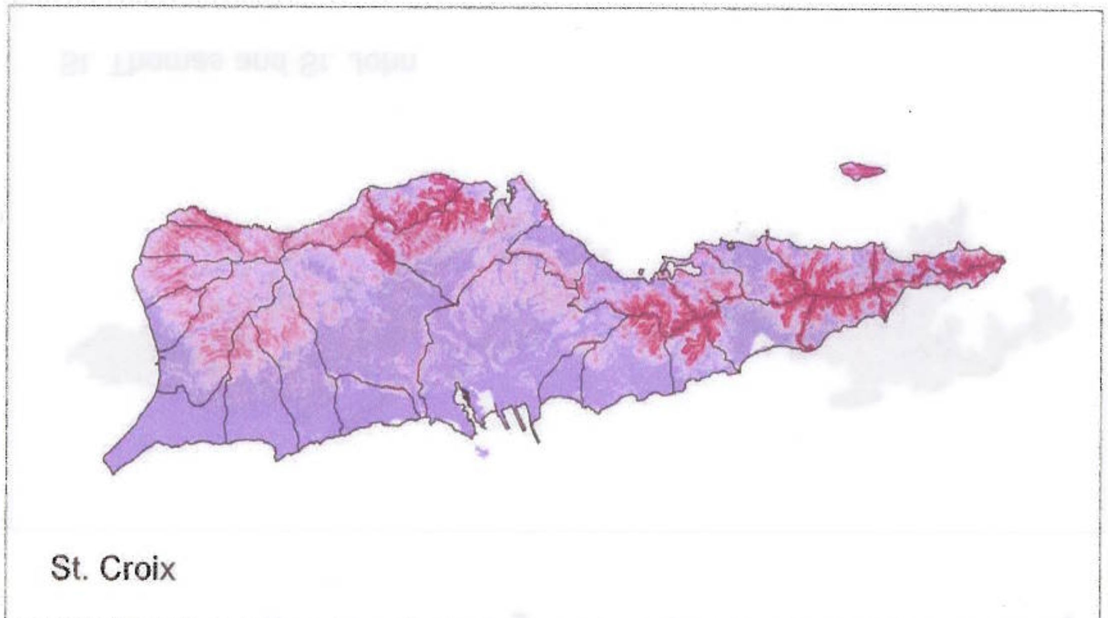
River Guts (Sttj_river_guts.shp)
Watersheds (Sttj_ws_uwi.shp)
Basins (derived) (Sttj_basins.shp)

Source:
Watershed boundaries provided by the USVI Department of Planning and Natural Resources (DPNR) and the University of the Virgin Islands (UVI/CDC).
Basins were derived by WRI and NOAA, 2005, under the Reefs at Risk Project.

5 0 5 Kilometers

Relative Vulnerability of Land to Erosion

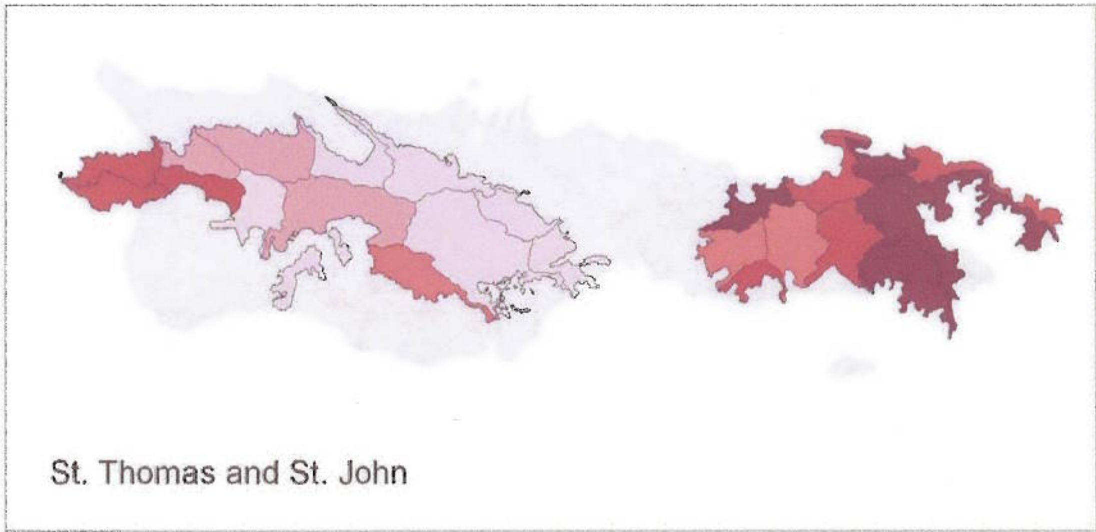


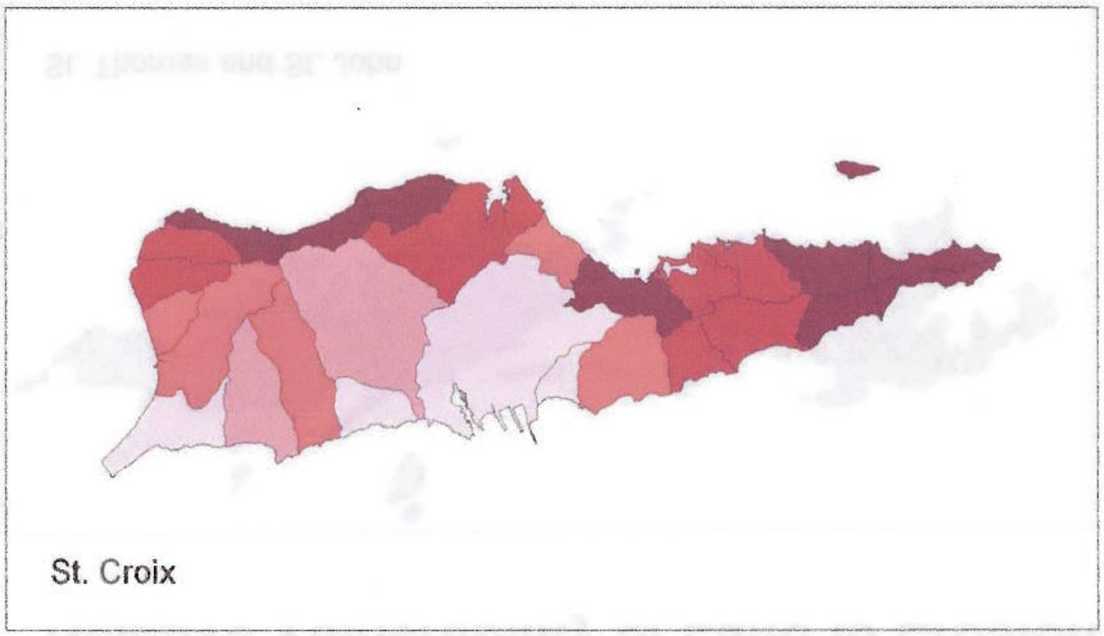


Physical factors, such as the slope of the land, the texture of the soil, and the precipitation regime influence erosion in an area. We have developed a simple indicator of the erosivity of the land based on slope, precipitation, and the K-ffactor of the soil (erodibility of the given soil type.) This indicator does not consider the current land cover or land use. Rather, it provides an overall indicator of erosion-prone areas, and hence, areas where development / land conversion / road construction should be avoided.

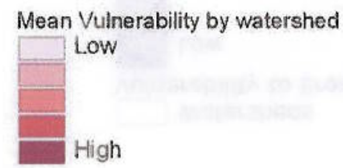
Source:
"Relative Vulnerability to Erosion" was developed by WRI and NOAA, 2005, under the Reefs at Risk Project. Watershed boundaries provided by the USVI Department of Planning and Natural Resources and the University of the Virgin Islands (UVI/CDC).

Mean Vulnerability of Land to Erosion (by watershed)



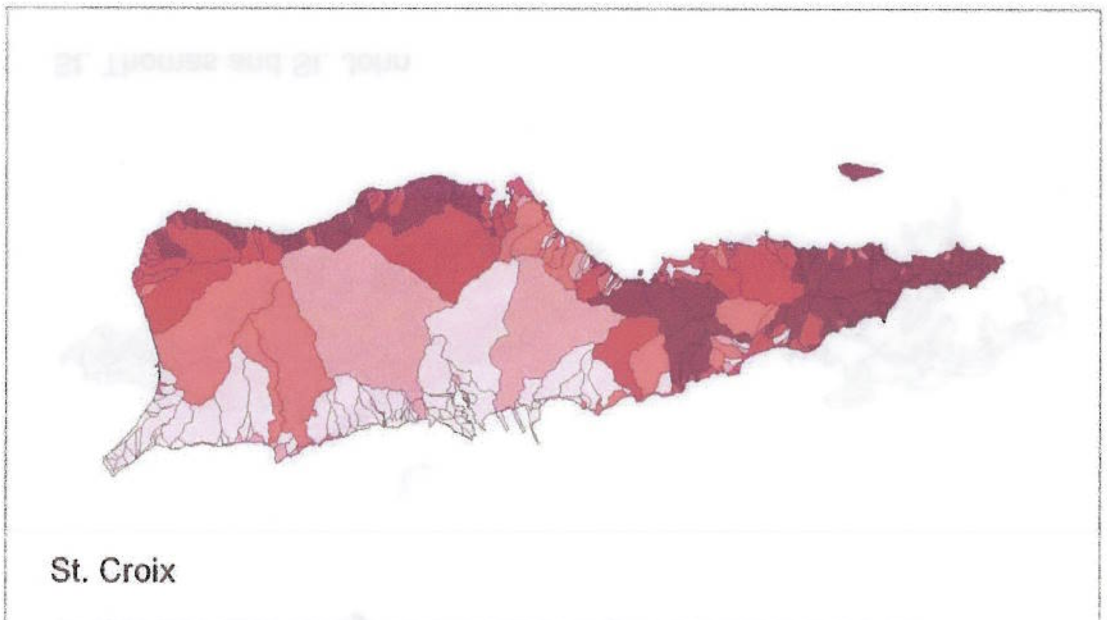


Physical factors, such as the slope of the land, the texture of the soil, and the precipitation regime influence erosion in an area. We have developed a simple indicator of the erosivity of the land based on slope, precipitation, and the K-ffactor of the soil (erodibility of the given soil type.) This indicator has been summarized for major watersheds in the USVI.

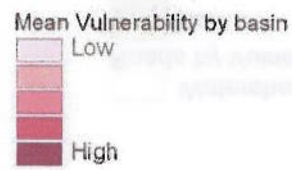


Source:
"Relative Vulnerability to Erosion" was developed by WRI and NOAA, 2005, under the Reefs at Risk Project. Watershed boundaries provided by the USVI Department of Planning and Natural Resources and the University of the Virgin Islands (UVI/CDC).

Mean Vulnerability of Land to Erosion (by basin)

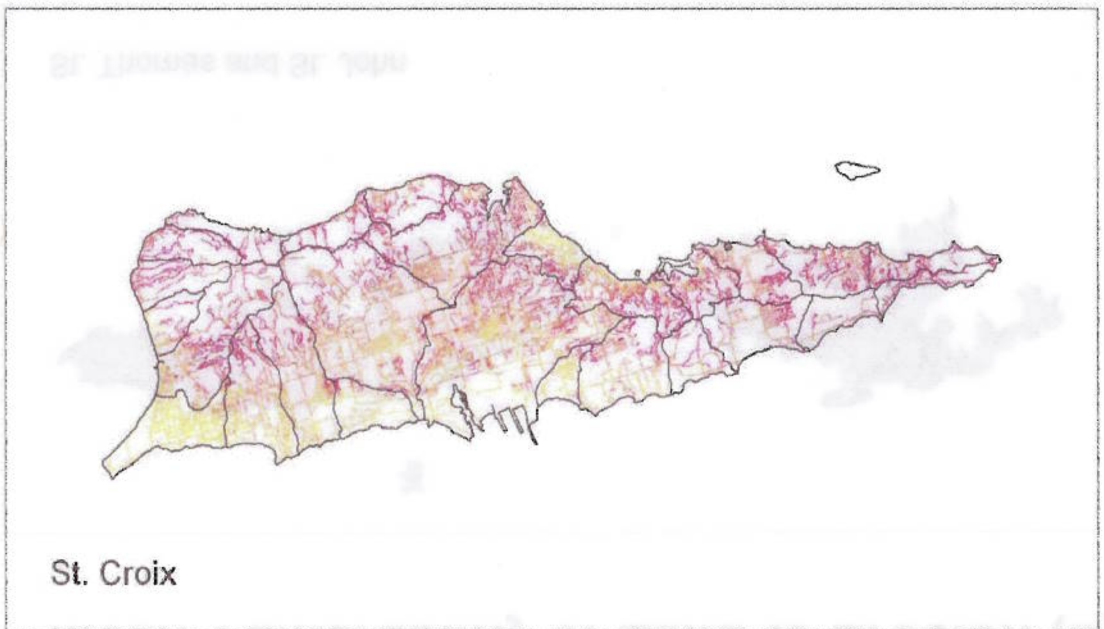


Physical factors, such as the slope of the land, the texture of the soil, and the precipitation regime influence erosion in an area. We have developed a simple indicator of the erosivity of the land based on slope, precipitation, and the K-ffactor of the soil (erodibility of the given soil type.) This indicator has been summarized for basins in the USVI.



Source:
"Relative Vulnerability to Erosion" was developed by WRI and NOAA, 2005, under the Reefs at Risk Project. Basin boundaries derived from a hydrologic model by WRI and NOAA, 2005.

Vulnerability of Roads to Erosion



Roads are a major source of erosion, particularly in steep areas on tropical islands. Roads are the largest source of erosion within the USVI. Erosion is generally most severe during road construction, but can also result in longer-term erosion due to exposed shoulders and abrupt changes in slope adjacent to the road.
We developed an indicator of the relative vulnerability of roads to erosion based upon slope, precipitation, and the K-ffactor of the soil (erodibility of the given soil type.)

Watersheds
Roads by Vulnerability
Low
High

Source:
"Vulnerability of Roads to Erosion" was developed by WRI and NOAA, 2005, under the Reefs at Risk Project. Watershed boundaries provided by the USVI Department of Planning and Natural Resources (DPNR) and the University of the Virgin Islands (UVI/CDC).

5 0 5 Kilometers

Estimated Erosion from Roads (mean for watershed)

Roads are a major source of erosion, particularly in steep areas on tropical islands. We have developed an indicator of the relative vulnerability of roads to erosion based upon slope, precipitation, and the K-ffactor of the soil (erodibility of the given soil type.) This indicator has been summarized by watershed. This is an area weighted indicator, so will be high in areas of high road density and steep terrain.

Mean Road-based Vulnerability by watershed

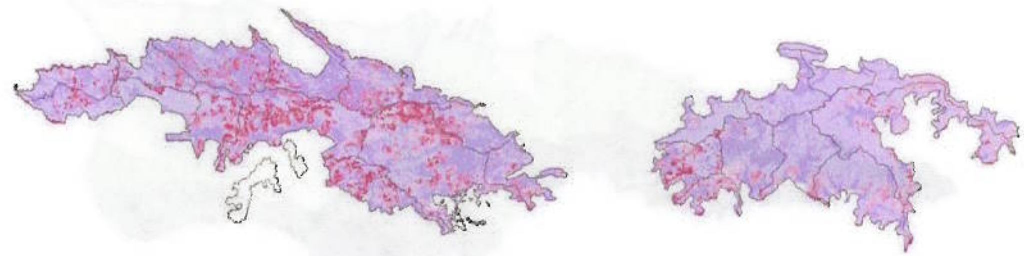
Low

High

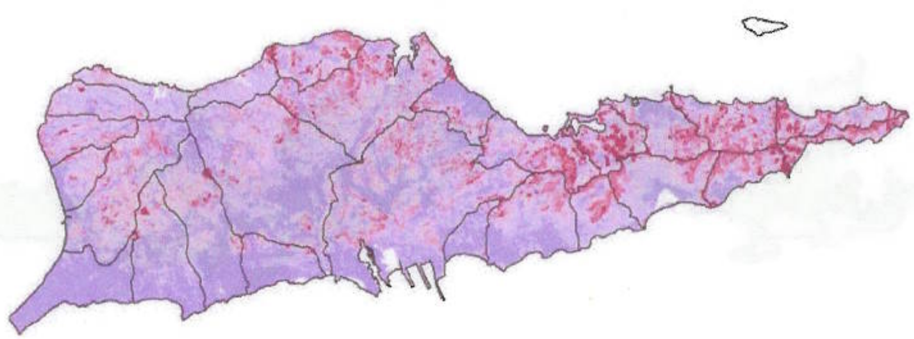
Source:
"Vulnerability of Roads to Erosion" was developed by WRI and NOAA, 2005, under the Reefs at Risk Project. Watershed boundaries provided by the USVI Department of Planning and Natural Resources (DPNR) and the University of the Virgin Islands (UVI/CDC).

5 0 5 Kilometers

Relative Erosion Potential (given current land cover)



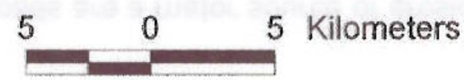
St. Thomas and St. John



St. Croix

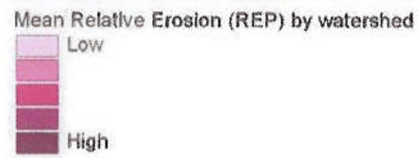
Agriculture and other land use activities far inland can have an adverse impact on coral reefs through the increased delivery of sediment and pollution to coastal waters. We have developed a simple indicator of relative erosion rates from the land, given current land cover. The analysis uses a simplified version of the Revised Universal Soil Loss Equation (RUSLE) (USDA, 1989). It incorporates land cover type, slope, the soil erodibility factor (k-factor), and precipitation for the peak rainfall month in order to estimate relative erosion rates for each 30m resolution grid cell.

Source:
"Relative Erosion Potential" (REP) was developed by WRI and NOAA, 2005, under the Reefs at Risk Project. Watershed boundaries provided by the USVI Department of Planning and Natural Resources (DPNR) and the University of the Virgin Islands (UVI/CDC).

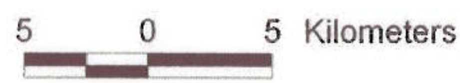


Relative Erosion Potential (by watershed)

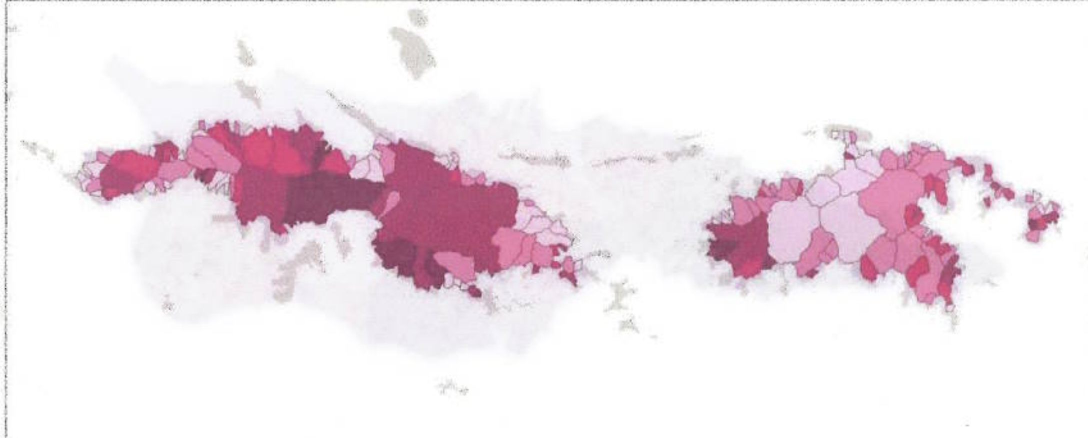
We have developed a simple indicator of relative erosion rates from the land, given current land cover. The analysis uses a simplified version of the Revised Universal Soil Loss Equation (USDA, 1989). This incorporates land cover type, slope, a soil erodibility factor (k-factor), and precipitation for the peak rainfall month in order to estimate relative erosion rates for all land areas within a watershed. The mean relative erosion potential (REP) for the watershed is presented.



Source:
"Relative Erosion Potential" (REP) was developed by WRI and NOAA, 2005, under the Reefs at Risk Project. Watershed boundaries provided by the USVI Department of Planning and Natural Resources (DPNR) and the University of the Virgin Islands (UVI/CDC).



Relative Erosion Potential (by basin)



St. Thomas and St. John

St. Croix

We have developed a simple indicator of relative erosion rates from the land, given current land cover. The analysis uses a simplified version of the Revised Universal Soil Loss Equation (USDA, 1989). This incorporates land cover type, slope, a soil erodibility factor (k-factor), and precipitation for the peak rainfall month in order to estimate relative erosion rates for all land areas within a watershed. The mean relative erosion potential (REP) for the basin is presented.

Mean Relative Erosion (REP) by watershed

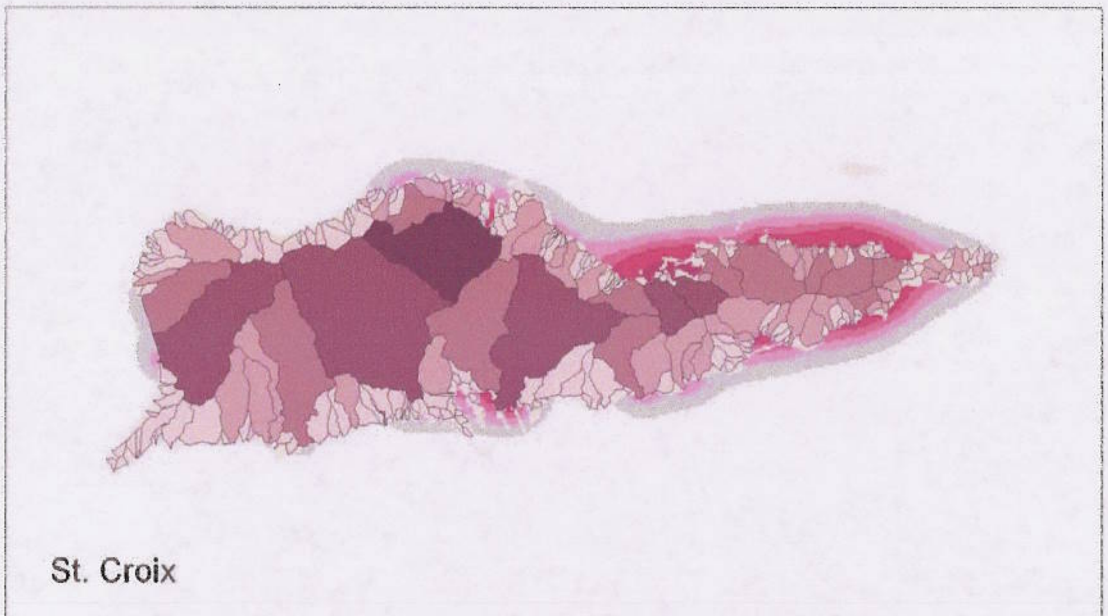
Low

High

Source:
"Relative Erosion Potential" (REP) was developed by WRI and NOAA, 2005, under the Reefs at Risk Project. Basins were derived from elevation data by WRI and NOAA, 2005.

5 0 5 Kilometers

Relative Sediment Delivery (by basin) and Estimated Plume



Relative sediment delivery by basin is estimated based on the total relative erosion potential (REP) within the basin, adjusted by watershed size. This approach uses a simplified version of the Revised Universal Soil Loss Equation (USDA, 1989). This incorporates land cover type, slope, a soil erodibility factor (k-factor), and precipitation in order to estimate relative erosion rates for all land areas within a watershed. (It does not specifically examine erosion due to roads.) Relative sediment plumes were evaluated based on relative sediment delivery at the gut outflow and distance from the outflow.

Relative Sediment Delivery by basin
Low
High

Estimated Relative Sediment Plume
Low
Medium
High

Source:
"Relative Sediment Delivery" was developed by WRI and NOAA, 2005, under the Reefs at Risk Project. Basins were derived from elevation data by WRI and NOAA, 2005.

5 0 5 Kilometers

Credits:

This analysis of land-based sources of threat to coral reefs in the U.S. Virgin Islands was funded by the U.S. National Oceanic and Atmospheric Administration, and was implemented by the World Resources Institute and NOAA, in collaboration with many partners. Project staff at WRI (Lauretta Burke, Robert Soden, Stephen Adam, and Zachary Sugg) and at NOAA (Aurelie Shapiro and Steve Rohmann) designed and implemented the analysis. The atlas was developed at WRI.

Reference: WRI and NOAA, 2005. *Land-based Sources of Threat to Coral Reefs in the U.S. Virgin Islands*. Washington, DC.

Photos: Coastal image by Aurelie Shapiro
Sedimentation in USVI by Lauretta Burke
Sponge and fish by Henry Woolcott

WORLD RESOURCES INSTITUTE

Land-based Sources of Threat to Coral Reefs in the US Virgin Islands

February 2006

A collaborative data product coordinated by

NOAA WORLD RESOURCES INSTITUTE

Land-based Sources of Threat to Coral Reefs in the U.S. Virgin Islands

Project Goal

With support from the U.S. National Oceanic and Atmospheric Administration (NOAA), The "Reefs at Risk" project of the World Resources Institute (WRI) teamed with NOAA's "Summit to Sea" project to develop and implement analysis of land-based threats to coral reefs in the U.S. Virgin Islands (USVI) and Puerto Rico. The goal of the collaboration is to support improved management of coastal ecosystems by developing and making available extensive information on watershed-based threats to these ecosystems, including identification of watersheds which are highly erosive and those watersheds contributing elevated levels of sediment and pollution to coastal waters. Data assembled or developed under this collaboration, including analysis results, are published on the *Coastal Data CD for the U.S. Caribbean*[1]. The data CD also serves as a GIS data sampler for both the USVI and Puerto Rico, allowing users to do their own analysis of land-based sources of threat. This atlas provides a summary of some of the spatial indicators developed under the project.

Collaboration

The project was implemented by the World Resources Institute and the U.S. National Oceanic and Atmospheric Administration, in collaboration with many local institutions and other partners. Collaborating institutions were vital sources of information, provided guidance on the analytical approach, and offered critical review of analysis results. Groups which contributed data or provided guidance on the project include:

- University of the Virgin Islands / Caribbean Data Center (UVI / CDC)
- USVI Department of Planning and Natural Resources (DPNR)
- Puerto Rico Department of Natural and Environmental Resources (DNER)
- U.S. Department of Agriculture
- U.S. National Park Service
- U.S. National Fish and Wildlife Service
- U.S. Geological Survey
- The Nature Conservancy
- Island Resources Foundation
- The Ocean Conservancy
- International Coral Reef Action Network (ICRAN)

---

[1] World Resources Institute (WRI) and U.S. National Oceanic and Atmospheric Administration (NOAA), *Coastal Data CD for the U.S. Caribbean*, (Washington, DC: WRI / NOAA, 2005)

Analysis Approach

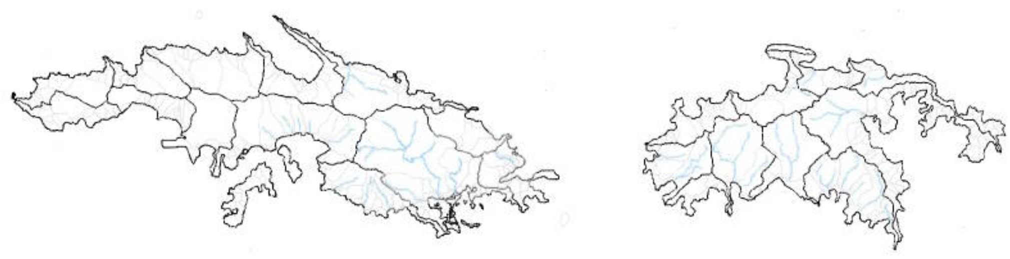
Alteration of the natural landscape for development, road construction, or agriculture can have adverse impacts on coral reefs through increased delivery of sediment and pollution to coastal waters. The threat associated with land clearing is higher in areas of steep relief, intense precipitation, and where soils are erosive in nature. This threat is often evaluated through application of the Revised Universal Soil Loss Equation (RUSLE) developed by the U.S. Department of Agriculture (USDA). RUSLE is useful for examining erosion in many agricultural areas, but is less well suited to the very steep and rutted environments of the U.S. Virgin Islands where road construction accounts for most erosion.

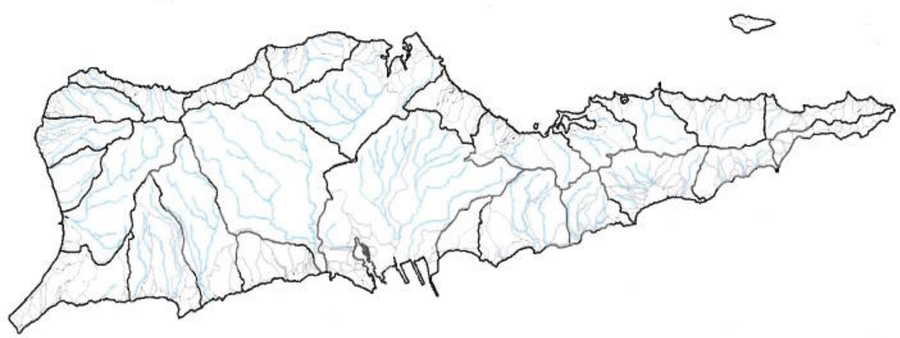
This study uses several spatial and statistical techniques to characterize watersheds across the USVI with regard to relative erosion rates and the threat of land-based sources of sediment and pollutant delivery to coastal waters. A simplified version of RUSLE (using slope, land-cover, precipitation, and soil characteristics) is applied, as well as indicators of road density and erosivity by watershed. Watersheds are an essential unit for analysis, since they link land areas with their point of discharge to the sea. The atlas presents a comparison of estimated watershed-based threat to coral reefs from both land cover change and road development.

Note on watershed boundaries:
In the USVI, official watershed boundaries have been derived and are available from the USVI Department of Planning and Natural Resources (DPNR) and the University of the Virgin Islands – Conservation Data Center (UVI-CDC). These "official" watersheds reflect large areas discharging to a single bay, and are relevant for coastal planning and land management. Most maps in this atlas use these watersheds for reference. The "Reefs at Risk" project, however, has an interest in hydrologic modeling of "basins" where land areas are associated with a single point of discharge to the sea. In order to estimate sediment delivery to coastal waters, we also present these smaller hydrologic units, called "basins" within this atlas.

Maps

Hydrology in the US Virgin Islands





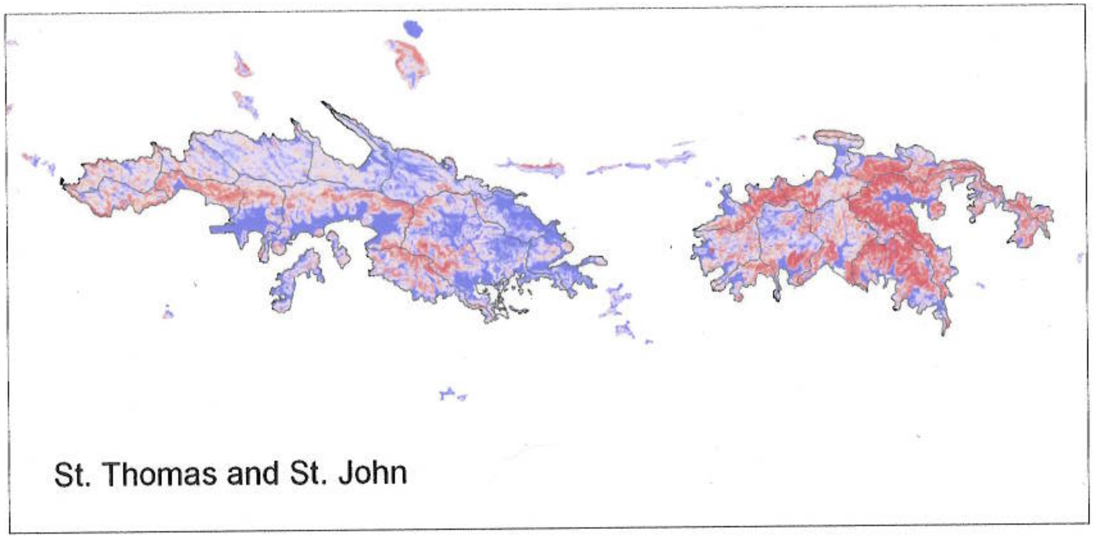
This map presents two approaches to watershed mapping. The USVI has mapped "official" watersheds reflecting large areas discharging to a single bay. These 53 "watersheds" are relevant for coastal planning and land management.
The "Reefs at Risk" project has an interest in hydrologic modeling of "basins" where land areas are associated with a single point of discharge to the sea. Over 400 basins with a minimum area of 6 ha. are presented.

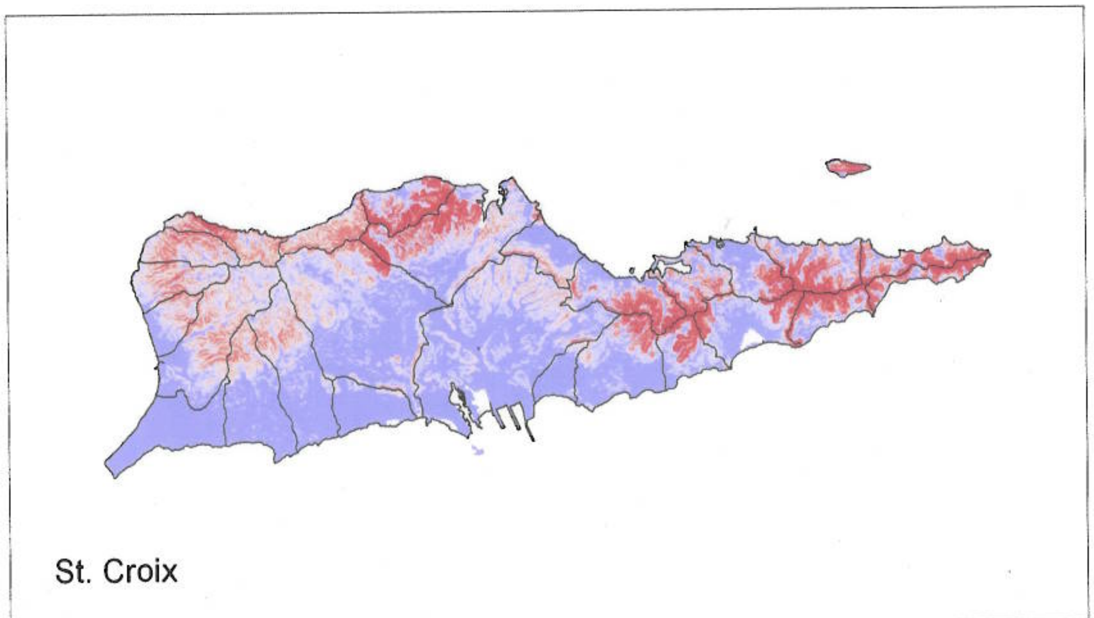
River Guts (Sttj_river_guts.shp)
Watersheds (Sttj_ws_uwi.shp)
Basins (derived) (Sttj_basins.shp)

Source:
Watershed boundaries provided by the USVI Department of Planning and Natural Resources (DPNR) and the University of the Virgin Islands (UVI/CDC).
Basins were derived by WRI and NOAA, 2005, under the Reefs at Risk Project.

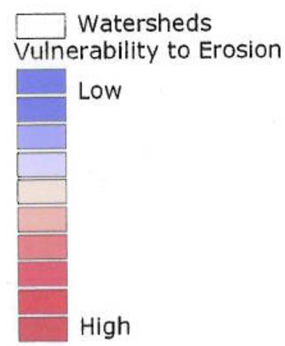
5 0 5 Kilometers

Relative Vulnerability of Land to Erosion

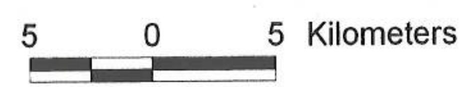




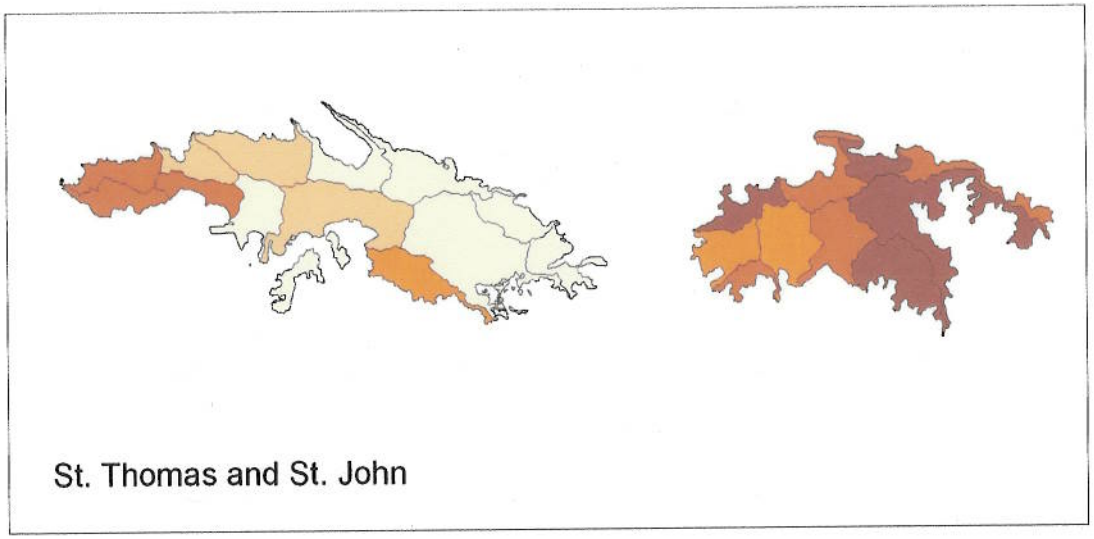
Physical factors, such as the slope of the land, the texture of the soil, and the precipitation regime influence erosion in an area. We have developed a simple indicator of the erosivity of the land based on slope, precipitation, and the K-ffactor of the soil (erodibility of the given soil type.) This indicator does not consider the current land cover or land use. Rather, it provides an overall indicator of erosion-prone areas, and hence, areas where development / land conversion / road construction should be avoided.

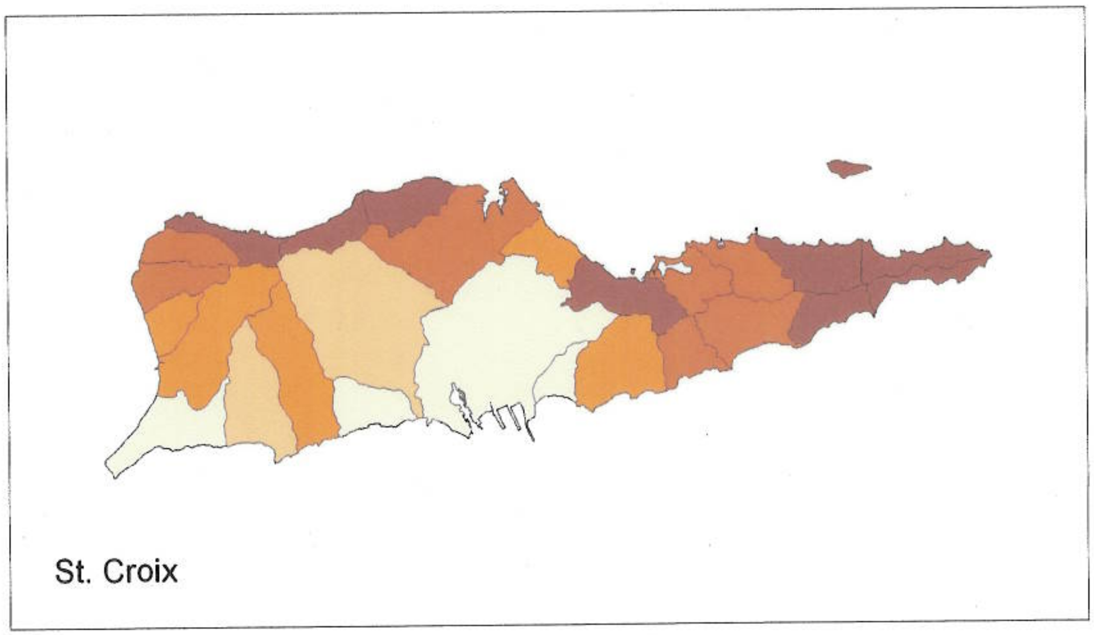


Source:
"Relative Vulnerability to Erosion" was developed by WRI and NOAA, 2005, under the Reefs at Risk Project. Watershed boundaries provided by the USVI Department of Planning and Natural Resources and the University of the Virgin Islands (UVI/CDC).

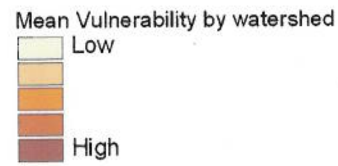


Mean Vulnerability of Land to Erosion (by watershed)

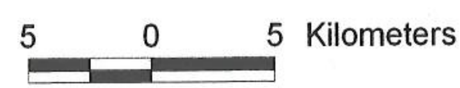




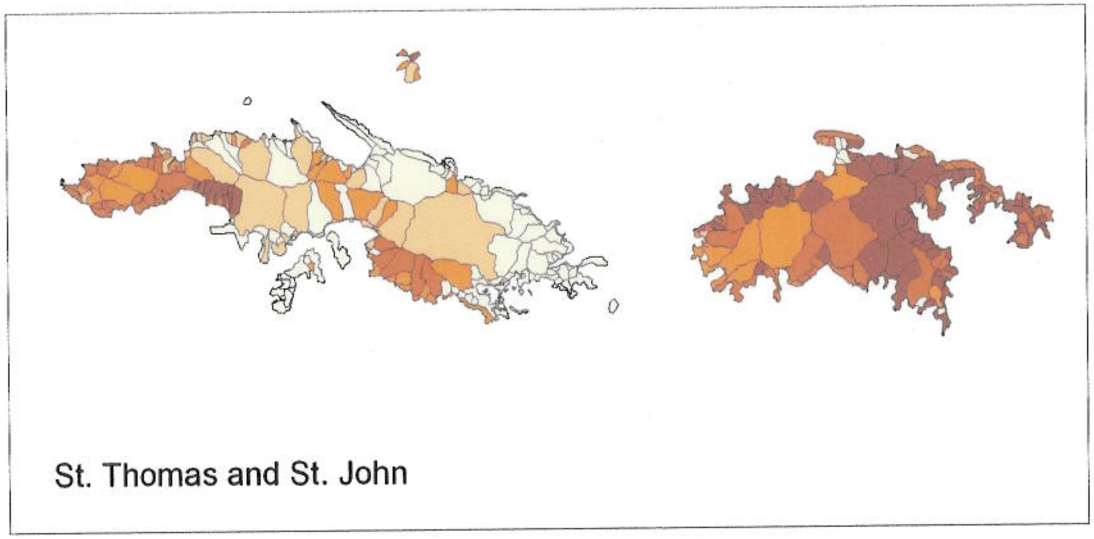
Physical factors, such as the slope of the land, the texture of the soil, and the precipitation regime influence erosion in an area. We have developed a simple indicator of the erosivity of the land based on slope, precipitation, and the K-ffactor of the soil (erodibility of the given soil type.) This indicator has been summarized for major watersheds in the USVI.



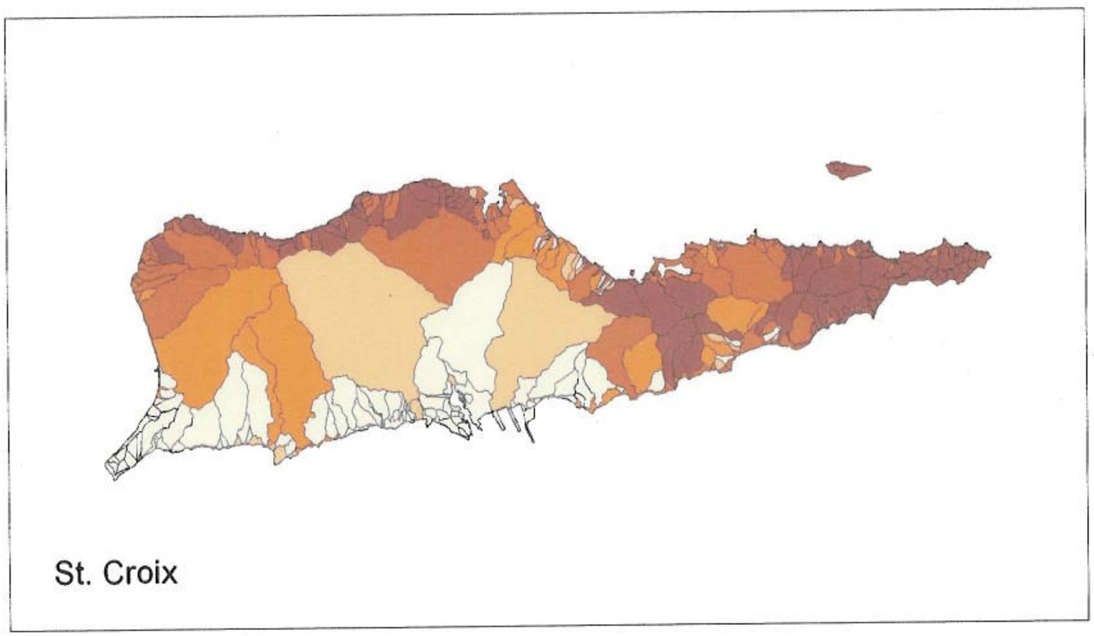
Source:
"Relative Vulnerability to Erosion" was developed by WRI and NOAA, 2005, under the Reefs at Risk Project. Watershed boundaries provided by the USVI Department of Planning and Natural Resources and the University of the Virgin Islands (UVI/CDC).



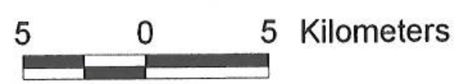
Mean Vulnerability of Land to Erosion (by basin)



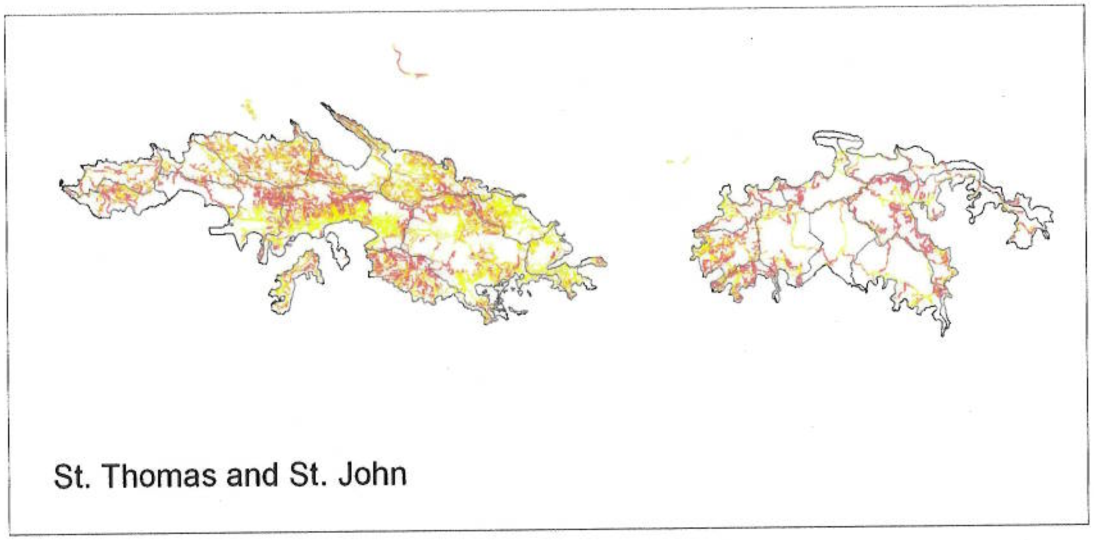
Physical factors, such as the slope of the land, the texture of the soil, and the precipitation regime influence erosion in an area. We have developed a simple indicator of the erosivity of the land based on slope, precipitation, and the K-ffactor of the soil (erodibility of the given soil type.) This indicator has been summarized for basins in the USVI.

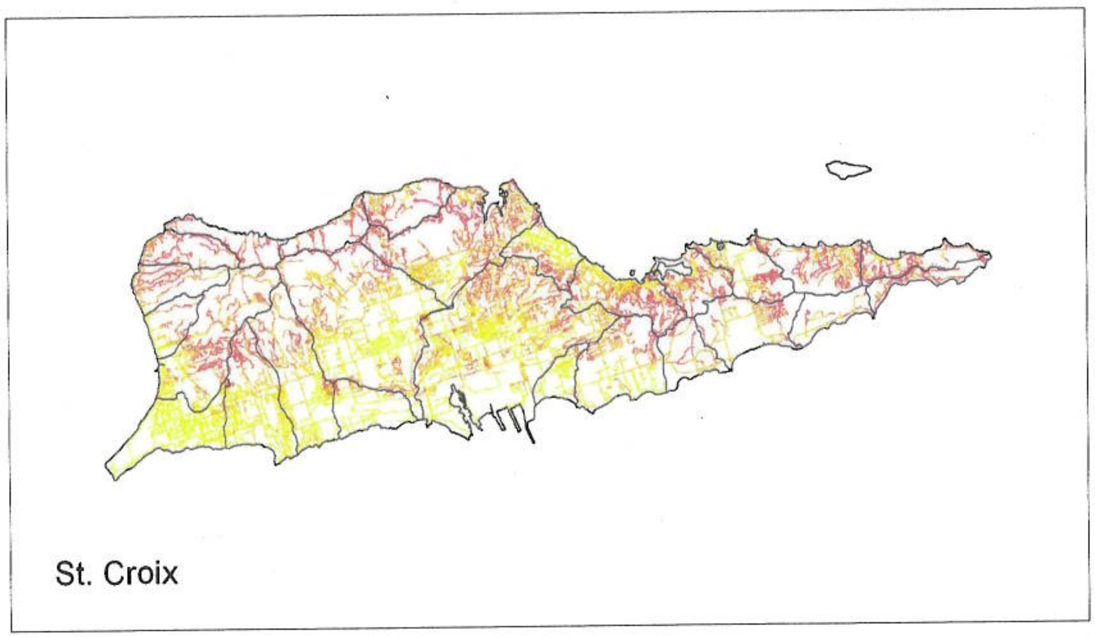


Source:
"Relative Vulnerability to Erosion" was developed by WRI and NOAA, 2005, under the Reefs at Risk Project. Basin boundaries derived from a hydrologic model by WRI and NOAA, 2005.



Vulnerability of Roads to Erosion





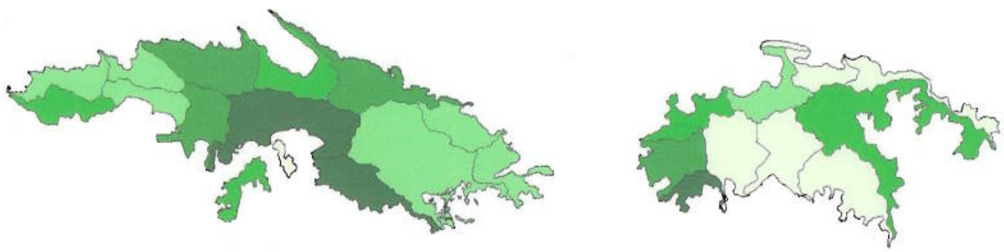
Roads are a major source of erosion, particularly in steep areas on tropical islands. Roads are the largest source of erosion within the USVI. Erosion is generally most severe during road construction, but can also result in longer-term erosion due to exposed shoulders and abrupt changes in slope adjacent to the road.
We developed an indicator of the relative vulnerability of roads to erosion based upon slope, precipitation, and the K-ffactor of the soil (erodibility of the given soil type.)

Watersheds
Roads by Vulnerability
Low
High

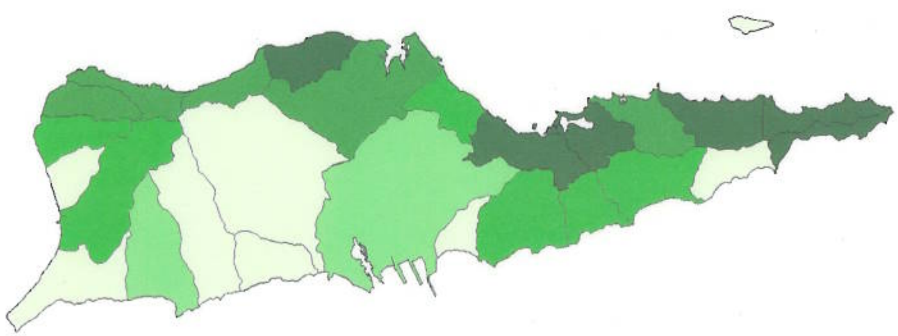
Source:
"Vulnerability of Roads to Erosion" was developed by WRI and NOAA, 2005, under the Reefs at Risk Project. Watershed boundaries provided by the USVI Department of Planning and Natural Resources (DPNR) and the University of the Virgin Islands (UVI/CDC).

5 0 5 Kilometers

Estimated Erosion from Roads (mean for watershed)



St. Thomas and St. John



St. Croix

Roads are a major source of erosion, particularly in steep areas on tropical islands. We have developed an indicator of the relative vulnerability of roads to erosion based upon slope, precipitation, and the K-ffactor of the soil (erodibility of the given soil type.) This indicator has been summarized by watershed. This is an area weighted indicator, so will be high in areas of high road density and steep terrain.

Mean Road-based Vulnerability by watershed

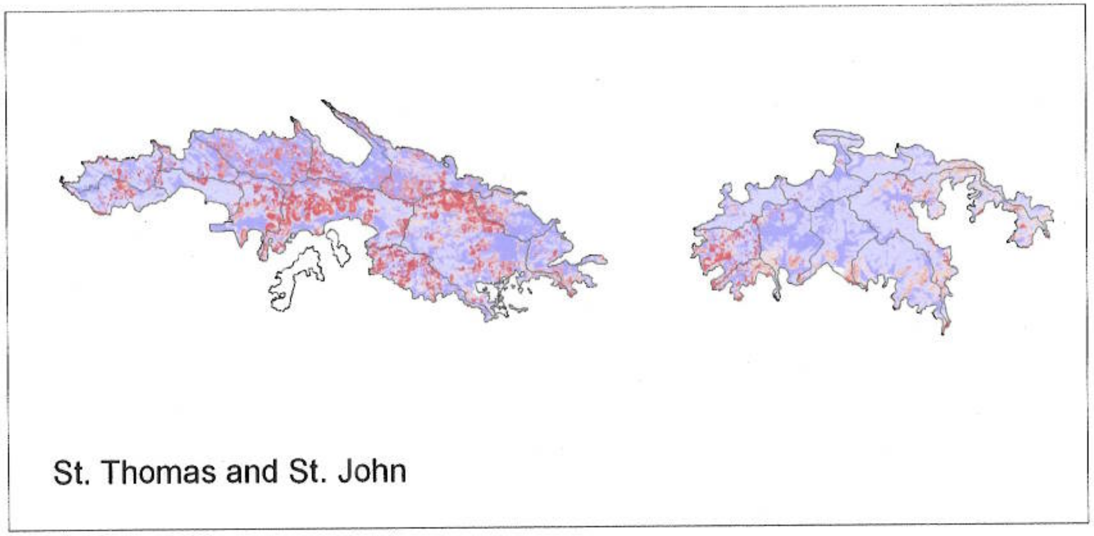
Low

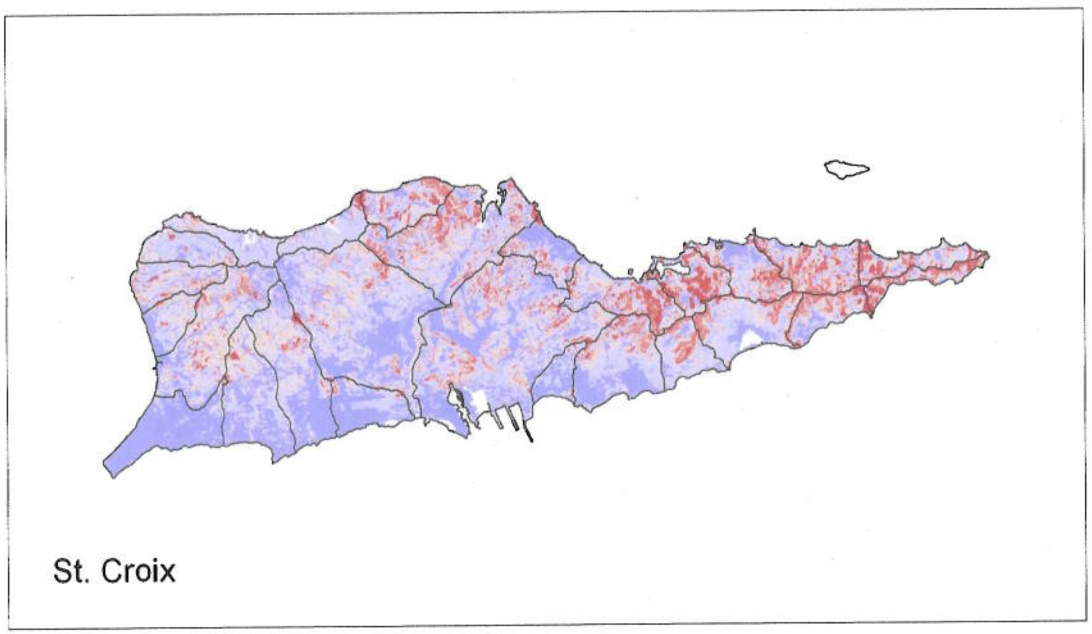
High

Source:
"Vulnerability of Roads to Erosion" was developed by WRI and NOAA, 2005, under the Reefs at Risk Project. Watershed boundaries provided by the USVI Department of Planning and Natural Resources (DPNR) and the University of the Virgin Islands (UVI/CDC).

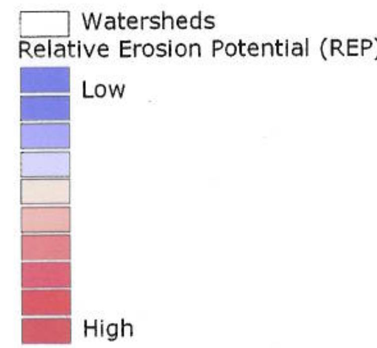
5 0 5 Kilometers

Relative Erosion Potential (given current land cover)

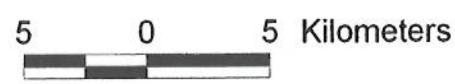




Agriculture and other land use activities far inland can have an adverse impact on coral reefs through the increased delivery of sediment and pollution to coastal waters. We have developed a simple indicator of relative erosion rates from the land, given current land cover. The analysis uses a simplified version of the Revised Universal Soil Loss Equation (RUSLE) (USDA, 1989). It incorporates land cover type, slope, the soil erodibility factor (k-factor), and precipitation for the peak rainfall month in order to estimate relative erosion rates for each 30m resolution grid cell.

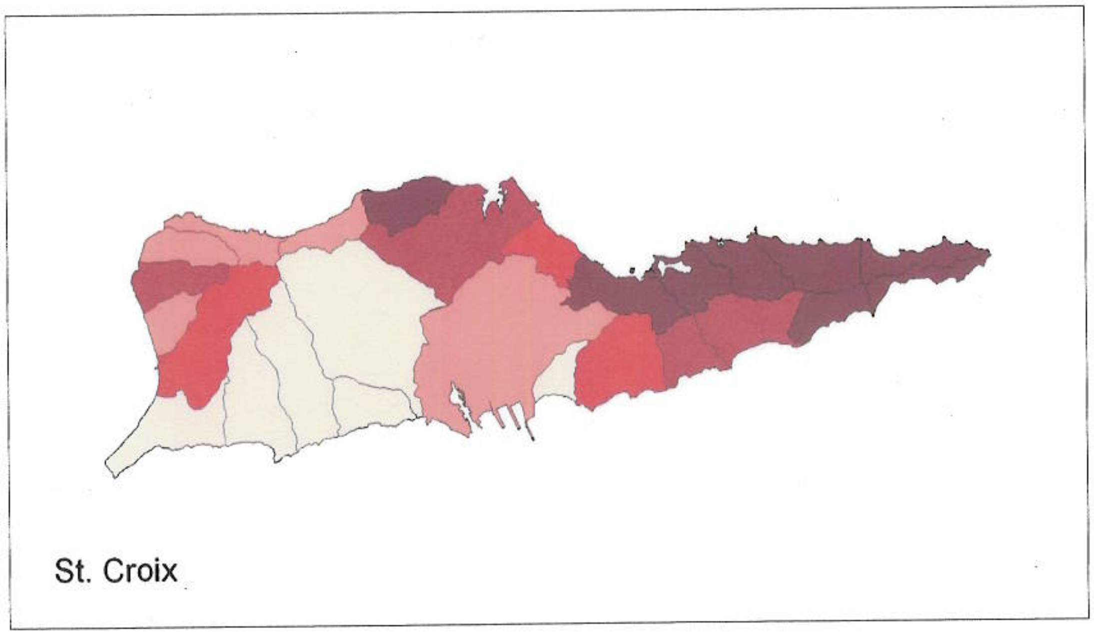


Source:
"Relative Erosion Potential" (REP) was developed by WRI and NOAA, 2005, under the Reefs at Risk Project. Watershed boundaries provided by the USVI Department of Planning and Natural Resources (DPNR) and the University of the Virgin Islands (UVI/CDC).



Relative Erosion Potential (by watershed)

We have developed a simple indicator of relative erosion rates from the land, given current land cover. The analysis uses a simplified version of the Revised Universal Soil Loss Equation (USDA, 1989). This incorporates land cover type, slope, a soil erodibility factor (k-factor), and precipitation for the peak rainfall month in order to estimate relative erosion rates for all land areas within a watershed. The mean relative erosion potential (REP) for the watershed is presented.

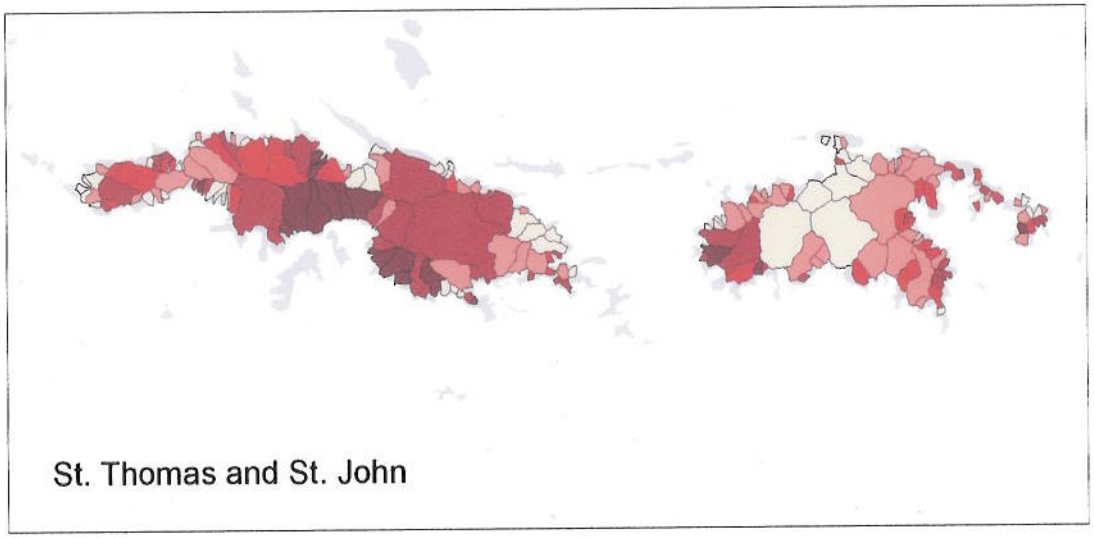


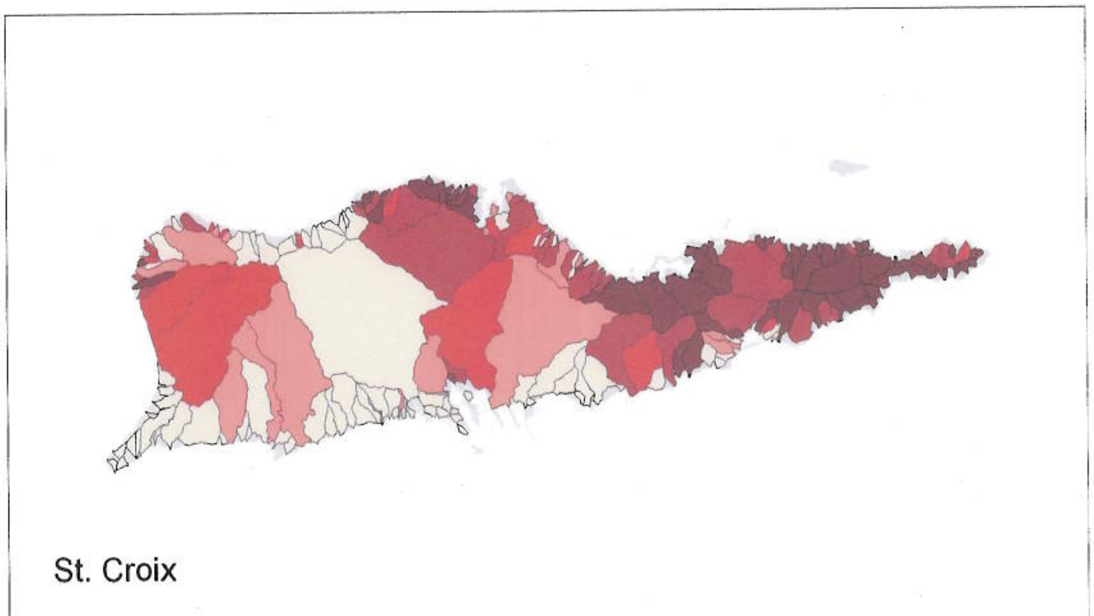
Mean Relative Erosion (REP) by watershed
Low
High

Source:
"Relative Erosion Potential" (REP) was developed by WRI and NOAA, 2005, under the Reefs at Risk Project. Watershed boundaries provided by the USVI Department of Planning and Natural Resources (DPNR) and the University of the Virgin Islands (UVI/CDC).

5 0 5 Kilometers

Relative Erosion Potential (by basin)





We have developed a simple indicator of relative erosion rates from the land, given current land cover. The analysis uses a simplified version of the Revised Universal Soil Loss Equation (USDA, 1989). This incorporates land cover type, slope, a soil erodibility factor (k-factor), and precipitation for the peak rainfall month in order to estimate relative erosion rates for all land areas within a watershed. The mean relative erosion potential (REP) for the basin is presented.

Mean Relative Erosion (REP) by watershed

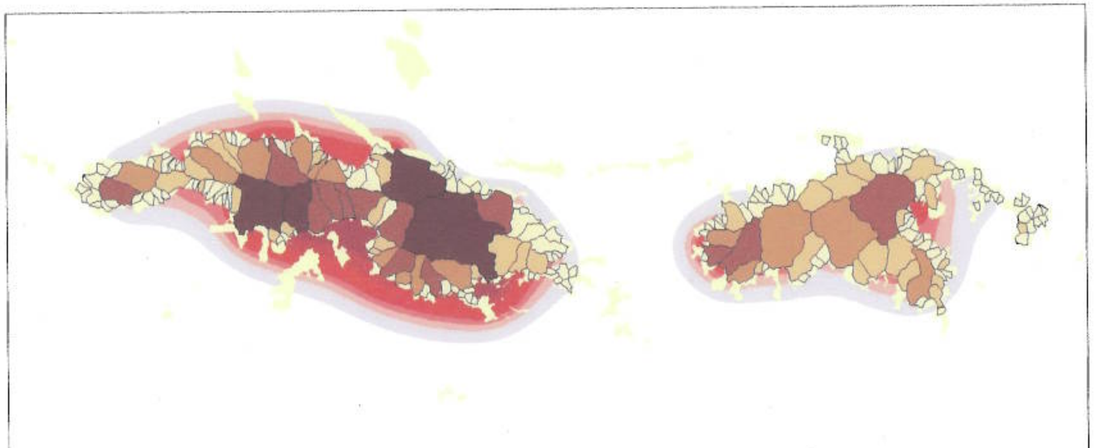
Low

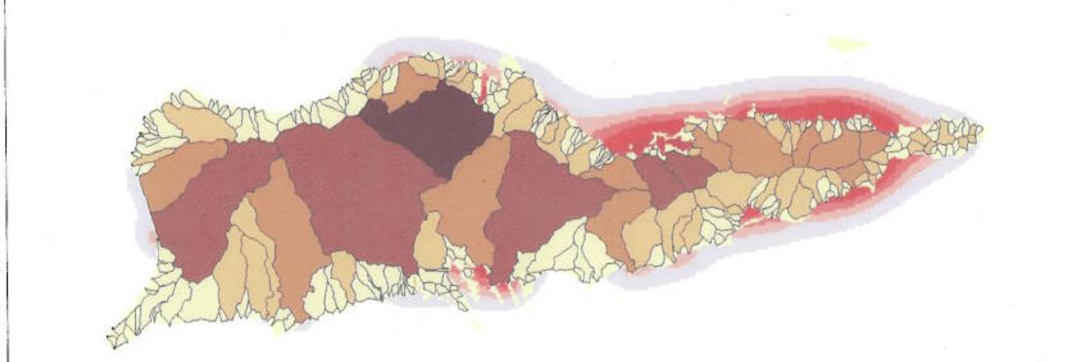
High

Source:
"Relative Erosion Potential" (REP) was developed by WRI and NOAA, 2005, under the Reefs at Risk Project. Basins were derived from elevation data by WRI and NOAA, 2005.

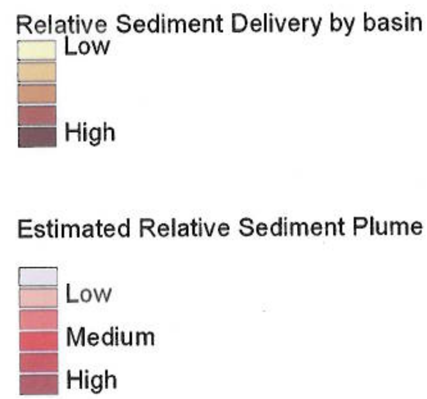
5 0 5 Kilometers

Relative Sediment Delivery (by basin) and Estimated Plume

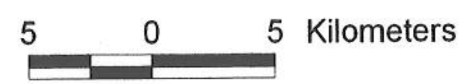




Relative sediment delivery by basin is estimated based on the total relative erosion potential (REP) within the basin, adjusted by watershed size. This approach uses a simplified version of the Revised Universal Soil Loss Equation (USDA, 1989). This incorporates land cover type, slope, a soil erodibility factor (k-factor), and precipitation in order to estimate relative erosion rates for all land areas within a watershed. (It does not specifically examine erosion due to roads.) Relative sediment plumes were evaluated based on relative sediment delivery at the gut outflow and distance from the outflow.



Source:
"Relative Sediment Delivery" was developed by WRI and NOAA, 2005, under the Reefs at Risk Project. Basins were derived from elevation data by WRI and NOAA, 2005.



Credits:

This analysis of land-based sources of threat to coral reefs in the U.S. Virgin Islands was funded by the U.S. National Oceanic and Atmospheric Administration, and was implemented by the World Resources Institute and NOAA, in collaboration with many partners. Project staff at WRI (Lauretta Burke, Robert Soden, Stephen Adam, and Zachary Sugg) and at NOAA (Aurelie Shapiro and Steve Rohmann) designed and implemented the analysis. The atlas was developed at WRI.

Reference: WRI and NOAA, 2005. *Land-based Sources of Threat to Coral Reefs in the U.S. Virgin Islands*. Washington, DC.

Photos:
Coastal image by Aurelie Shapiro
Sedimentation in USVI by Lauretta Burke
Sponge and fish by Henry Woolcott

WORLD RESOURCES INSTITUTE

Technical Notes on an analysis of land-based sources of threat to coral reefs in the US Virgin Islands and Puerto Rico

by Lauretta Burke (WRI), Aurelie Shapiro (NOAA), Robert Soden (WRI), and Stephen Adam (WRI)

World Resources Institute and NOAA, 2005.
November 17, 2005

Summary

Alteration of the natural landscape for development, road construction, or agriculture can have adverse impacts on coral reefs through increased delivery of sediment and pollution to coastal waters. The threat associated with land clearing is higher in areas of steep relief, intense precipitation, and where soils are erosive in nature. This threat is often evaluated through application of the Revised Universal Soil Loss Equation (RUSLE) developed by the US Department of Agriculture (USDA, 1989). RUSLE is useful for examining erosion in many agricultural areas, but is not well suited to the very steep and rutted environments of the US Virgin Islands where road construction accounts for most erosion.

This study uses several spatial and statistical techniques to characterize watersheds across the US Virgin Islands and Puerto Rico with regard to relative erosion rates and the threat of land-based sources of sediment and pollutant delivery to coastal waters. A simplified version of RUSLE (using slope, land-cover, precipitation and soil characteristics) is applied, as well as an indicator of road density by watershed. Watersheds are an essential unit for analysis, since they link land areas with their point of discharge to the sea. The analysis ultimately focuses on watershed-based threat to coral reefs from land cover change and road development.

The spatial analysis of land-based sources of threat to coral reefs has four main components:

1. Delineation of watersheds (basins) based on a hydrologically-corrected digital elevation data set (DEM.) These basins reflect all land areas discharging to a single coastal location (river mouth / pour point).
2. Analysis of relative vulnerability of land to erosion based on slope, precipitation, and the soil characteristics (within each 30m resolution grid cell).
3. Analysis of the relative erosivity of land given current land cover within each 30m resolution grid cell. In addition, the relative sediment delivery for each river mouth is estimated.
4. The density of roads (paved roads, unpaved roads and tracks) is estimated for each watershed. For areas with roads, the vulnerability of the area (see # 2 above) is considered, allowing the development of an indicator of the relative vulnerability of roads to erosion.

1. Delineation of Watersheds (basins)

Note: Data sets on watershed boundaries are available for both the USVI and Puerto Rico. In the case of the USVI, for example, official watershed boundaries have been derived and are available from the USVI Dept. of Planning and Natural Resources (DPNR) and the University of the Virgin Islands (UVI-CDC). These "official" watersheds reflect large areas discharging to a single bay, and are relevant for coastal planning and land management. The "Reefs at Risk" project has an interest in hydrologic modeling of "basins" where land areas associated with a single point of discharge to the sea are identified.

Hydrologic modeling allows one to develop a series of data sets from a single elevation data set (derived data sets include slope, flow direction, flow accumulation, basins, and pour points (river mouths).)

1. Hydrologic modeling for both the USVI and PR are based on the 30m resolution National Elevation Dataset (NED) from US Geological Survey (USGS.) Modeling was performed using ESRI's ArcMap software (though it is also possible in ESRI's ArcView, with the Spatial Analyst and Hydro extensions.)
2. For the USVI islands, the digital elevation data (also called DEM) was hydrologically corrected, meaning that the location of known rivers and streams ("guts" in the local parlance) are superimposed on the elevation data. The vector data set reflecting guts from DPNR was converted to a 30 m grid to match the DEM, and coded as -15. This value is used as an adjustment (subtract 15) to the original value in the DEM, forcing the hydrologic flow into these "depressed areas." This improves watershed delineation particularly in flat coastal areas and through wetlands. (For St. Croix, for example, the original NED data set is called STX_DEM, while the hydrologically corrected or "burned" DEM is STX_DEM_B. (For Puerto Rico, the raw (uncorrected NED) was the basis for the flow modeling.)
3. FLOWDIRECTION is run on the DEM. This results in a data set showing which of eight directions every given 30m cell flows. (coded as integer 1,2,4,8,16,32,64, and 128, with 1 being due East.) (For St. Croix, for example, the data set is named FLOWDIR_STX.)

4. FLOWACCUMULATION is run on the FlowDIR gird. This results in an integer grid reflecting the number of cells flowing into any given cell. (In St. Croix, for example, this data set is named FLOWACC_STX.) The Flowdirection grid can be used to identify rivers (gut) locations. Any cells above a given value (such as 200) represent a potential gut location.
5. The BASIN command is run on the FlowDirection grid. This produces a dataset of all grid cells discharging to a single outflow point. This includes many tiny basins. To eliminate these tiny basins, a minimum basin size (cell count) threshold was imposed. All basins with fewer than 70 cells (about 6 ha area) were excluded. (In St. Croix, for example, the dataset including all grid cells is called BASIN_STX1, while the grid dataset with basins 6 ha and above is called BAS_STX_70. The grid data set of basins of 6 ha or larger was converted to shapefile format (STX_BASINS.SHP). There is a unique identified (BASIN_ID) within each file to identify the basin.
6. A dataset reflecting pour points (gut discharge, or outflow) was developed. This is the point of maximum flow within each basin. These are identified by using the map calculator function in ArcView's Spatial Analyst or ArcMap, and identifying the cell count for the basin that matches the maximum FlowAccumulation grid value in each basin minus 1. This results in a binary grid, with a value of 1 being the pour points. The 0 are reclassed to NoData, and the 1's assigned the value of the BASIN_ID through multiplication of the grid of Pour point locations (1's) and the grid reflecting the basins (BASIN_ID or VALUE). This GRID data set, was then converted into a point data set (e.g. STX_PPT.SHP) using the data conversion tool in ArcMap (Raster to Point conversion).

The resulting set of basins and pour points is valuable for summarizing the spatial threat indicators developed in subsequent steps of this analysis.

Note: The basins developed for the USVI tend to be a subdivision (sub-watershed) of the official watersheds for the USVI. Both units were used for presentation of summary statistics for the islands.

2. Vulnerability to Erosion

Physical factors, such as the slope of the land, the texture of the soil, and the precipitation regime influence erosion in an area. Parts of Puerto Rico, and many parts of the USVI in particular, are very steep and erosion-prone. In addition, the nature of the soil and intense rainfall events promote severe erosion in these areas. Erosion can be extreme in exposed areas (cleared for a road or residential construction, or where soil is exposed due to cropping patterns or agricultural cycle.)

We have developed a simple indicator of the erosivity of the land based on physical factors of the location (slope, precipitation, and a soil characteristic called K-ffactor, which reflects the erodibility of the given soil type.) This indictor does not consider the current land cover or land use. Rather, it provides an overall indicator of erosion-prone areas, and hence, areas where development / land conversion / road construction should be avoided.

Inputs:

1. Slope (percentage) – for each 30m grid cell, derived from the (raw) DEM (without hydrologic correction.)
2. Precipitation during the peak rainfall month (in millimeters) – The long-term average monthly precipitation values for climate stations across the area were downloaded from NOAA's National Climate Data Center (NCDC). The mean monthly precipitation for the peak rainfall month was selected for each point location, and a 30m resolution grid was interpolated using the inverse distance weighting interpolation method. This variable was chosen because it is more indicative of the rainy season and more extreme events during the year.
3. Soil erodibility factor (K-ffactor) – the K-ffactor was obtained from the SSURGO database of the USDA.

Equation 1:

Vulnerability = Slope(%) x precip (mm for peak rainfall month) x soil k-ffactor

The analysis was implemented in ESRI ArcView 3.2 software, using the map calculator function in spatial Analyst, which is also available in ArcMap. The raster analysis was done at 30 m resolution in UTM projection (zone 20N, WGS84.)

The resulting grid reflects an estimate of <u>relative</u> vulnerability of land to erosion (called STX_VULN_I for St. Croix). It is a relative (unitless) value. Summary statistics have been derived from this 30 m resolution grid for both hydrologic basins and official watersheds.

3. Relative Erosion Potential (REP)

Agriculture and other land use activities far inland can have an adverse impact on coral reefs through the increased delivery of sediment and pollution to coastal waters. Particularly in steep areas of the USVI and Puerto Rico land cover change can increase erosion and ultimately sediment delivery to coastal waters. A watershed-based analysis of land-based sources of pollution (LBS) was implemented to develop a preliminary estimate of this threat.

Analysis Method
Watersheds are an essential unit for analysis, since they link land areas with their point of discharge to the sea. We have implemented a watershed-based analysis of sediment and pollution threat to coral reefs. This analysis incorporates land cover type, slope, soil erodibility factor (k-factor), and precipitation for all land areas, using a simplified version of the Revised Universal Soil Loss Equation (RUSLE) (USDA, 1989) in order to estimate relative erosion rates for each 30m resolution grid cell. These relative erosion estimates are summarized by watershed and by basin. Since not all erosion makes its way to the river mouth, sediment delivery ratios (based on watershed size) were applied in order to estimate relative sediment delivery at the river mouth. It should be noted that relative erosion rates and sediment delivery are being used as a proxy for both sediment and pollution delivery.

This information can be used to estimate sediment plumes and impacted reefs (ideally including circulation patterns for the area.) Model results need to be calibrated using available data on river discharge, sediment delivery, and observed impacts on coral reefs. We are working with NOAA's Summit to Sea project to use satellite imagery to maps areas of observed plume and identify habitat change, as well as to help calibrate model results.

Model Implementation

Step 1) The first step of the analysis involves estimating likely relative erosion rates for each 30 m resolution grid cell using a modified, simplified form of the Revised Universal Soil Loss Equation (RUSLE) (USDA, 1989). Information on slope, land cover type, precipitation, and soil porosity were integrated to develop an indicator of relative erosion potential (REP) for all land areas within the wider Caribbean.

Inputs:
(REP relies upon four input data sets, three of which were described under the analysis of vulnerability to erosion, above.)

1. Slope (percentage) – for each 30m grid cell, derived from the (raw) DEM (without hydrologic correction.)
2. Relative erosion rate by land cover type. Relative erosion rates for each land cover type were calculated using a look-up table (table 1 below.) For the USVI, data from UVI/CDC reflecting vegetation cover was used as the base. For Puerto Rico, a classification of landsat imagery for 2000 by Jennifer Gebelein of Florida International University was the base. Land cover categories was reclassified to relative erosion rates, ranging from 15 (for forest) to 220 for barren land. (See table 1 below) These relative erosion rates are based on published work involving conversion factors. (Grids were created at 30 m resolution.)
3. Precipitation during the peak rainfall month (in millimeters) – Long-term average monthly precipitation values for the peak rainfall month of the year is an interpolated grid based on data for climate stations from NOAA's National Climate Data Center (NCDC). This variable was chosen because it is more indicative of the rainy season and more extreme events during the year.
4. Soil erodibility factor (K-ffactor) – the K-ffactor was obtained from the SSURGO database of the USDA.

Table 1. Land Cover and Associated Relative Erosion Rates

Land Cover Type	Relative Erosion Rate for the land cover type
Water body	5
Forest	15
Woodland	15
Shrubland	45
Hedge	50
Mixed vegetation	50
Mangrove	80
Salt Flat	80
Salt Pond	80

Swamp	80
Pasture	120
Grassland	125
Cropland	200
Developed	210
Rock Pavement	210
Beach	220
Barren Land	220

Equation 2:

Relative Erosion Potential (REP) = Slope(%) x precip (mm for peak rainfall month) x soil k-ffactor x relative erosion rate for land cover type / 1000

The grid is divided by 1000 and converted to integer for a better data range and easier display.
The analysis was implemented in ESRI ArcView 3.2 software, using the map calculator function of Spatial Analyst, which is also available in ArcMap. The raster analysis was done at 30 m resolution in UTM projection (Zone 20N, WGS84.)

Two indicators indicative of erosion within the watershed were calculated for each basin:
mean REP for the basin (an indicator of average erosion rates for the basin) (REP_MEAN), and total relative erosion within the basin (REP_SUM).

Step 2) An indicator of relative sediment delivery at the river mouth was estimated by multiplying total relative erosion in the basin (REP_SUM) by the sediment delivery ratio (SDR) for the basin, which is a function of watershed size. SDR reflects the percentage of erosion within the basin (REP_SUM) which reaches the river mouth.

Equation 3:

Sediment Delivery Ratio (SDR) = 0.41 x basin area (in sq km)-0.3.

This factor comes from published research on watersheds in the Caribbean.

Equation 4:

Sediment delivery at the river mouth (SED_DELIV) = REP_SUM x SDR

4. Erosion from Roads

Roads are a major source of erosion, particularly in the steep areas of islands in the tropics. Road are the largest source of erosion within the USVI. Erosion is generally most severe during road construction, but can also result in longer-term erosion due to exposed shoulders and abrupt changes in slope adjacent to the road.

For the USVI, we developed indicators of road density by watershed (and basin) and, for areas with roads, developed an indicator of the relative vulnerability of those areas to erosion.

Analysis Method

- Road Density - a vector data set reflecting roads was converted to GRID at 30 m resolution using the LINEGRID command in ArcInfo, or vector to raster conversion in ArcMap. (Although 30 m is wider than the actual roads, this provides an indication of the number of 30m cells which contain any road, and might experience erosion due to the construction, expansion, or presence of a road. (Although information on type of road is available for the USVI, this information was not used. Our assumption being that small unpaved trails and unpaved roads are significant sources of erosion, as are larger paved roads with shoulders.) The percentage of 30m resolution cells containing roads is summarized for each basin.
- Relative Vulnerability of Roads to Erosion - for each location (grid cell) where a road is present, the vulnerability of the location (from equation 1 above) serves as the basis of the indicator.

Example
For St. Croix, a grid data set called STX_ROAD_30 was developed to reflect the presence or absence of roads within each 30m grid cell. (Grid is 0 for no road present, 1 for road present.)

STX_ROAD_30 is multiplied with the grid reflecting relative vulnerability to erosion (STX_VULN_I) to obtain an estimate of relative vulnerability for locations with a road (STX_ROAD_VULN). (Grid is 0 for no road present, and has the vulnerability value where a road is present.)

Both the road density grid and the road vulnerability grid were summarized for all basins and watersheds in the USVI.

5. Summary Indicators

Summary statistics at the basin or watershed level can be developed using the Summarize Zones function in ArcView's Spatial Analyst or the Zonal Statistics Tool in Spatial Analyst Toolbox in ArcMap. A basin (or watershed) grid is used as the data set reflecting zones, while the indicator (vulnerability or REP) is used as the data set in which the function is performed. Where possible, the following basin-level statistics are provided in the shape files in the WS_INDICATORS directory, such as STX_WS_IND.SHP shapefile reflecting watershed-level indicators for St. Croix.

Shapefile attributes:

1. WS_ID - Watershed or basin ID
2. AREA_M2 - basin area in m2
3. AREA_SQKM– basin area in km2
4. VULN_MEAN– mean vulnerability to erosion for the basin
5. REP_MEAN– mean relative erosion potential (REP) for the basin
6. REP_SUM – sum of REP for the basin
7. SDR – sediment delivery ratio (percentage of erosion (REP_SUM) reaching the river mouth)
8. SED_DELIV – relative sediment delivery to the pour point (river mouth)
9. PPRECIP_ME – mean precipitation in the basin during the peak rainfall month
10. PPRECIP_SU – sum of precipitation in basin during the peak rainfall month
11. ROAD_DENS – percent of cells in basin that contain a road
12. ROAD_VULN_MEA – mean vulnerability to erosion for all areas with roads, for the basin
13. ROAD_VUL_SUM – for cells with roads, the sum of the relative vulnerability

Table 2 – Summary Statistics by Island Group

Variable / Data set	**Mean and range**		
Input data sets	**St. Thomas and St. John**	**St. Croix**	**Puerto Rico**
Elevation (m.)	99 (0-472)	61 (0-354)	234 (0-1330)
Slope (pct.)	31 (0-187)	16 (0-127)	24 (0-750)
Precipitation for peak rainfall month (mm)	195 (66-272)	215 (87-276)	560 (131-1098)
Soil erodibility (K-ffactor)	0.24 (0.10-0.32)	0.18 (0.05-0.32)	0.17 (0.02-0.28)
Land Cover relative erosion rates	68 (5-220)	98 (5-220)	80 (0-210)
Erosion Indicators			
Vulnerability to erosion (relative)	1505 (0-9300)	645 (0-6600)	2360 (5-52000)
Relative Erosion Potential (REP) (relative)	76 (0-1960)	41 (0-845)	140 (0-7400)
Road Density (percent)	23%	23%	n.a.
Vulnerability to Erosion for Roads (relative)	1300 (0-9050)	534 (0-5500)	n.a.

Table 3 – Summary Statistics by Watershed

Watershed Name	**Area (acres)**	**Area (km2)**	**Mean Vulnerability to Erosion**	**Mean Relative Erosion Potential**	**Relative Sediment Delivery**	**Road Density (%)**	**Mean Erosivity due to Roads**
Mary Point	110	0.43	1,759	33	8,370	0.00	0
Leinster Bay	2.43	612	2,048	44	37,514	0.09	110
Mennebeck Bay	813	3.25	1,980	55	57,271	0.05	97
Coral Bay	3,005	11.92	2,226	74	190,942	0.18	369

Great Lameshur Bay	1,679	6.70	2,162	58	100,042	0.09	118
Hawksnest Bay	777	3.13	2,072	43	43,049	0.20	298
Maho Bay	984	3.95	1,830	35	41,772	0.12	215
Reef Bay	1,395	5.53	1,775	42	62,772	0.07	103
Fish Bay	1,487	5.99	1,512	42	66,777	0.13	169
Great Cruz Bay	1,037	4.17	1,499	114	141,528	0.31	448
Rendezvous Bay	420	1.66	1,651	117	76,122	0.37	626
Hassel Island	142	0.53	1,150			0.02	28
Water Island	490	1.87	943			0.33	351
Fortua Bay	801	3.21	1,738	79	81,450	0.23	346
Perseverance Bay	710	2.85	2,032	57	53,929	0.13	221
Cyril E. King Airport	1,126	4.54	1,109	94	124,176	0.28	374
St. Thomas Harbor	2,496	10.09	1,308	123	282,653	0.41	455
Frenchman Bay	1,180	4.74	1,594	128	172,973	0.36	602
Red Hook Bay	858	3.43	771	56	60,649	0.30	216
Smth Bay	862	3.48	709	66	71,721	0.37	280
Mandal Bay	1,592	6.40	1,090	85	142,189	0.39	426
Magens Bay	1,104	4.42	1,211	61	78,496	0.29	370
Dorothea Bay	1,682	6.78	1,256	72	125,476	0.33	412
Santa Maria Bay	789	3.18	1,381	60	61,668	0.19	227
Botany Bay	879	3.54	1,622	67	73,510	0.19	276
Jersey Bay	51	14.04	1,140	93	267,783	0.28	294
Buck Island	175	0.68	1,721			0.00	0
Teague Bay	1,021	4.12	1,444	83	101,888	0.25	316
Turner Hole	714	2.81	1,722	124	116,264	0.18	269
Madam Carty	1,043	4.17	1,370	73	89,818	0.08	55
Solitude	1,641	6.62	1,257	81	137,958	0.25	245
Southgate	1,398	5.63	792	58	88,112	0.22	186
Great Pond Bay	2,000	7.66	798	49	93,320	0.14	119
Altona Lagoon	1,241	4.85	959	112	153,811	0.25	219
Laprey Valley	1,134	4.55	959	47	61,694	0.12	107
Christiansted	1,799	7.27	1,082	75	137,649	0.35	311
Princess	1,102	4.45	421	37	48,376	0.34	112
Salt River Bay	4,157	16.61	899	53	170,998	0.25	191
North Side	1,278	5.17	1,540	64	92,620	0.19	241
Baron Bluff	929	3.75	1,127	32	35,783	0.17	162
Airport	1,291	5.05	102	13	18,318	0.17	24
Bethlehem	6,563	26.48	383	27	122,367	0.21	73
Sandy Point	2,017	8.09	37	5	9,461	0.31	15
Long Point Bay	2,482	10.01	322	24	54,009	0.28	78
Diamond	2,921	11.81	397	26	67,078	0.23	72
Hams Bluff	979	3.93	1,288	32	36,184	0.12	127

Creque Dam/Butler Bay	1,207	4.89	833	43	59,929	0.16	119
Prosperity	888	3.59	569	30	33,631	0.14	53
La Grange	3,257	13.17	627	39	107,274	0.21	106
Hams Bay	1,104	4.46	1,004	31	39,618	0.18	173
Bugby Hole	2,502	10.06	512	35	79,102	0.17	94
HOVENSA	8,135	32.02	262	31	161,085	0.26	75
Cane Garden Bay	677	2.74	142	14	13,279	0.23	33
average	**1,523**	**6.36**	**1,172**	**59**	**91,049**	**0.21**	**208**

The Reefs at Risk project for Puerto Rico and the US Virgin Islands is implemented by the World Resources Institute (WRI) in collaboration with National Oceanic and Atmospheric Administration (NOAA).

World Resources Institute · 10 G Street NE · Washington, DC 20002 USA | tel. +1(202)729-7600 · fax +1(202)729-7686