

AN INVESTIGATION OF SEDIMENT SOURCES AFFECTING MARINE RESOURCES AT VIRGIN ISLANDS NATIONAL PARK

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VIRGIN ISLANDS NATIONAL PARK encompasses more than half of the 50-square kilometer (19-square mile) island of Saint John in the West Indies of the Caribbean. The park also incorporates 23 square kilometers (8.9 square miles) of surrounding marine waters. Popular with tourists, the national park offers a tropical setting, white sand beaches, and diverse ecological communities, including coral reefs. In 1976, UNESCO designated the park an international biosphere reserve, thus focusing additional scientific attention on the natural resources of the island.

Unfortunately, valuable park natural resources are threatened; declining health of the coral reefs surrounding Saint John is of particular concern to park managers. Investigations suggest that coral growth rates have slowed substantially this century (Hubbard et al. 1987). Increased production and delivery of fine sediment to the marine zone is one suspected cause, as coral reefs are highly susceptible to chronic increases in suspended sediment and turbidity (Rogers 1990).

Accelerated development of private and public lands on the island is a likely source of sediments to the marine environment. In 1993, we initiated a study of sediment sources and transport on Saint John through a cooperative agreement with the NPS Water Resources Division and with the help of Trish Patterson of the Southeast Regional Office. The principal objectives were: 1) to identify and map areas of low, medium, and high erosion susceptibility; 2) predict delivery rates of sediment to the marine environment; and 3) recommend practices for minimizing erosion and sediment delivery to the offshore zone. We also wanted to develop a set of analytical procedures integrated with a geographic information system that could be used by

the park and the territorial government to assess erosion hazards and sediment sources.

EROSION AND SEDIMENTATION ON SAINT JOHN

Saint John is a rugged island characterized by small, steep watersheds, intermittent streams, and many small bays (fig. 1). Over 80% of the island has slopes in excess of 30%. The island supports predominantly dry evergreen and moist forest vegetation, the distribution of which is strongly influenced by elevation and the persistent easterly trade winds. Soils are generally very shallow (<50 cm or 20 in) and exceptionally stony.

The brief field component of our study in late 1993–early 1994 focused on assessing the relative importance of different erosion processes on Saint John and evaluating current sediment delivery rates in a historical context. The excavation of a 40-year-old sediment basin, the assessment of long-term sediment accumulation in conjunction with sea level rise, and the analysis of sediment data from other studies (e.g., Nichols and Brush 1988) led us to conclude that long-term sediment yield, under natural conditions, is about 20, and no more than 40, metric tons per square kilometer per year (57–114 short tons per square mile per year, respectively). This is quite low in comparison to rates reported for many tropical environments (Anderson 1994).

The low rate of erosion and sediment yield on Saint John is probably due to predominantly dry soil conditions (a result of generally brief showers and high evapotranspiration rates), associated low rates of bedrock weathering, and ubiquitous stony

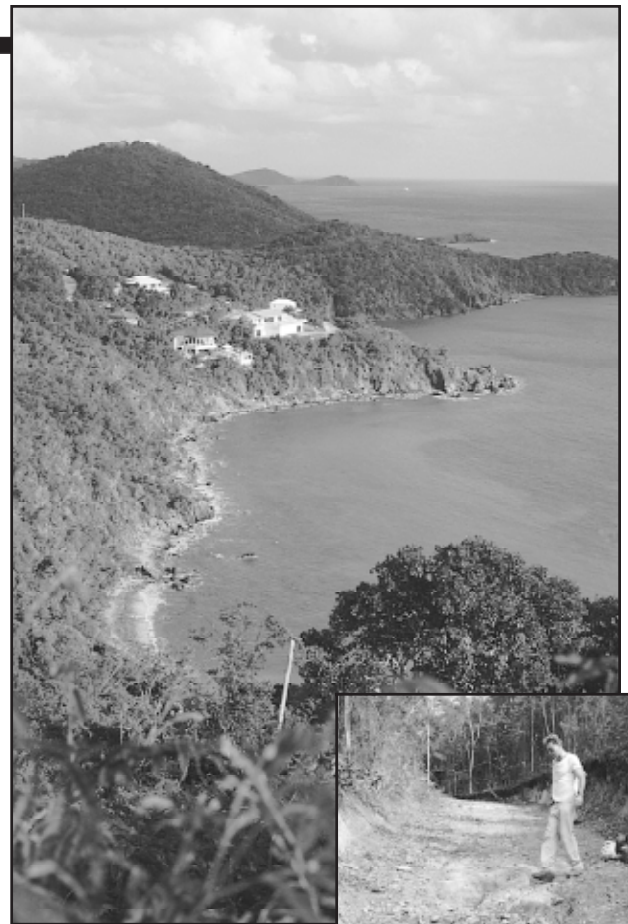


Figure 1 (above). The Rendezvous Bay area of Saint John is typical of island terrain: steep, forested, and replete with intermittent streams and many small bays.



Figure 3 (right). Dr. Lee MacDonald inspects what once was a smooth road surface. Unpaved roads like this require frequent regrading to remain passable, regularly replenishing the supply of erodible sediment.

soil surfaces that protect the soil against rainsplash and runoff erosion. Our field reconnaissance and inspection of air photos also revealed that landslides and debris flows are unusual on Saint John, despite the very steep slopes and occasionally heavy rainstorms.

In contrast, human activities have greatly accelerated erosion and sedimentation rates (fig. 2). Our observations indicate that although plantation agriculture was a significant sediment source in the 18th and 19th centuries, the rapidly-growing network of unpaved roads is by far the greatest source today. We estimate that more than 100 km (62 mi) of roads exist on Saint John, and



Figure 2. Approximately 50 km (31 mi) of unpaved roads, many of them crudely bulldozed on steep terrain, traverse Saint John Island; they provide a ready source of erodible soil to be carried bayward during longer-duration rainstorms.

that less than half of these are paved. These roads, many of which are crudely bulldozed access routes to homes, are commonly established at grades of 10-20%. The deeply incised road surfaces, obvious instability of sidecast material, and large quantities of accumulated sediment attest to the severity of road erosion (fig. 3). Unpaved roads on Saint John generally require frequent reggrading to remain passable to vehicles, and this regularly replenishes the supply of readily erodible sediment.

MODELING ROAD SEDIMENT PRODUCTION

Many studies in temperate and tropical environments show that roads often are the primary source of sediment from rural and forest lands (e.g., Hafley 1975; Ward 1985; Scatena 1993). Road-derived sediment can be generated in a variety of ways, including the erosion

of cut and fill surfaces, landslides caused by alterations in slope drainage and stability, and erosion from road surfaces. Our study focused on the latter mechanism, as this was the most obvious and probably largest source of road-derived sediment on Saint John.

We estimated road surface erosion rates at various sites by measuring the cross-sectional road erosion and determining the time since the road was last graded. These measurements indicated that at least 1-2 cm (0.4-0.8 in) of

material erodes from the surface of most unpaved roads each year. The erosion rate increases as the runoff-contributing road surface area increases and slope steepens. Figure 4 shows the erosion rate results from 23 study sites in one 6.1-square kilometer (2.4-square mile) catchment.

Linear regression indicates that road grade and drainage area together explain 51% of the variance in road surface erosion (expressed in cubic meters of removed material per linear meter of road per year). Other variables such as road use and road surface characteristics would probably account for some of the unexplained variability in the figure. Unfortunately, limited field time precluded a quantitative investigation of additional variables.

We formalized and largely automated our estimation procedures by writing a program in C, a popular computer programming language, that integrates the regression relationship illustrated in figure

4 with road data compiled using a commercial GIS package (Anderson 1994). This program, called ROADMOD, will allow the park to predict the quantity and location of sediment delivered from a specified road network. Required input data include the width, slope, surface, and drainage characteristics of each road segment.

We applied ROADMOD to road data gathered in the Fish Bay watershed of Saint John (fig. 5—page 28). This catchment has been subject to extensive home building and road construction. Careful mapping of all roads and culverts in this catchment allowed us to estimate the total road surface erosion and the portion of this sediment that is delivered into and through the stream network. The results suggest that road surfaces are responsible for approximately a fourfold increase in average annual sediment delivery to Fish Bay. This is a conservative estimate and does not include erosion from road cuts, fill slopes, or other development activities.

Taking these and other factors into account, we estimate that unpaved roads are increasing the islandwide amount of sediment delivered to the marine environment by a factor of two to ten. This finding has crucial ramifications for resource protection at the park.

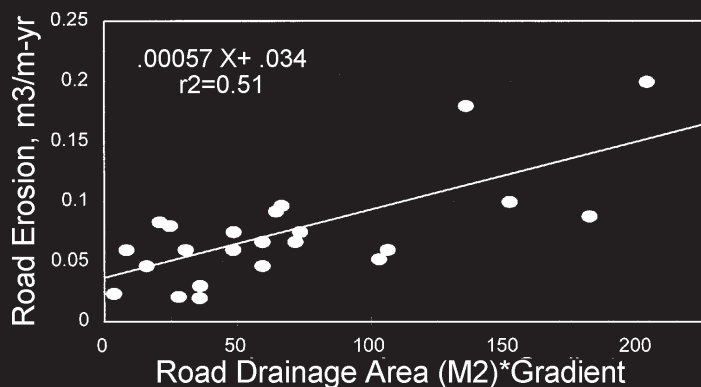
MODELING SURFACE EROSION SUSCEPTIBILITY

At NPS request, we also produced a map showing relative surface erosion susceptibility on Saint John. The purpose of this map is to help land managers identify areas that are particularly susceptible to erosion should vegetation be removed.

We determined erosion susceptibility from three variables: surface erodibility, hillslope gradient, and contributing drainage area. We determined surface erodibility from soil maps and descriptions provided by the Natural Resources Conservation Service (former Soil Conservation Service). Slope gradients and drainage areas for a 10 x 10 m grid of the entire island were estimated using digital elevation data and automated GIS terrain analysis techniques. We included no vegetative cover factor, because we were interested in the likely erosion rate following clearing for development or other purposes.

We used a modified version of the revised Universal Soil Loss Equation (Renard et al. 1991; Moore and Wilson 1992) to predict spatially distributed erosion susceptibilities. Although this equation is not designed or fully validated for steep, forested, tropical regions, it is a widely accepted tool for assessing relative erosion potential. The sensitivity of our predictions to topography and the resulting patterns of surface

Figure 4. Erosion rates on unpaved roads in the Fish Bay catchment show a correlation with road grade and contributing road drainage area. Erosion increases with slope (in decimal percent) and road surface area (in square meters).



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runoff give us some confidence that this map can help land managers guide development away from areas most prone to surface erosion.

SEDIMENT CONTROL PRACTICES

Because roads have a disproportionate impact on terrigenous sediment production (oceanic sediment derived from land sources) on Saint John, most of our recommendations address this source. For example, we recommend against the construction or widening of additional roads on the island, and we recommend that existing dirt roads be paved as soon as possible.

Other recommendations address the development review procedures currently in place for the territory of the Virgin Islands. For example, we are troubled that proposed subdivision developments on Saint John are not, as of this writing, subject to a formal public review, despite the great public interest in maintaining healthy marine ecosystems. Effective protection of the marine resources at Virgin Islands National Park will require coordinated efforts by both the National Park Service and the Virgin Islands territorial government.

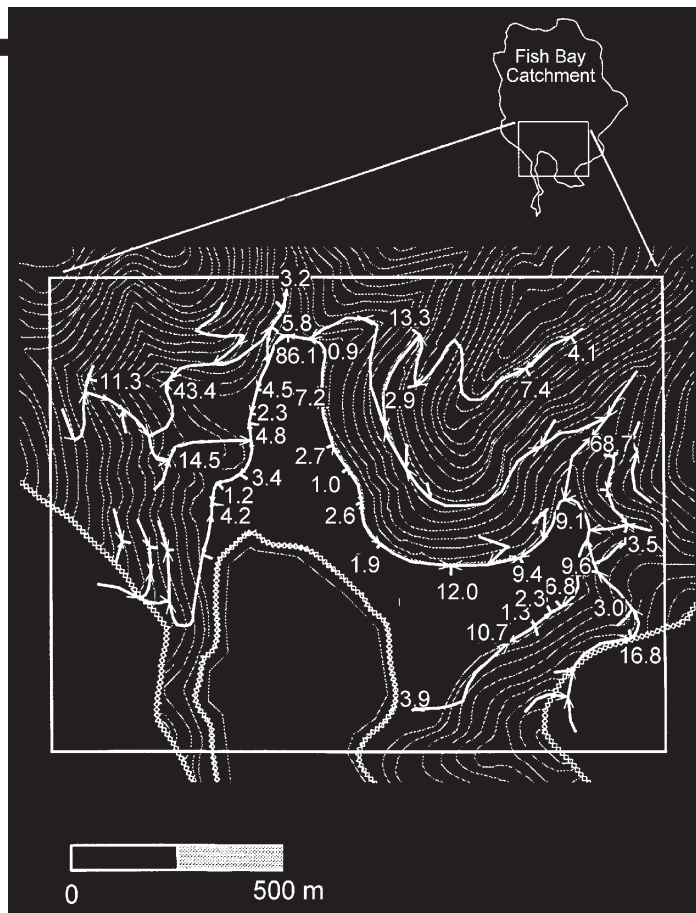
FOLLOW-UP WORK

This project is part of a larger NPS investigation into the effects of land use on marine resources at the park. Complementary work includes a paired watershed study of stream discharge and sediment delivery by the U.S. Geological Survey, and the collection of turbidity and other water quality data around Saint John by the National Park Service.

The progress we made in identifying and quantifying sediment sources on Saint John greatly enhances our understanding of park marine sediment delivery problems, but much remains to be done. For example, the delivery of sediment from hillslopes, stream channels, salt ponds and mangrove lowlands to the marine environment remains poorly understood. Sediment production from road cuts, fill slopes, and roadside ditches also merits further investigation.

The National Park Service, the National Biological Service, the nonprofit Island Resources Foundation, and the U.S. Environmental Protection Agency have expressed interest in supporting additional research

Figure 5. Road sediment delivery map of Fish Bay predicted by ROADMOD. Heavy lines represent the road network, dotted lines the elevation contours, and numeric values the road sediment delivery volume in cubic meters per year. Roads in the lower left part of the map are paved and have no sediment delivery values.



of these issues, and we hope that valuable follow-up work will be performed. However, the results to date already point to the primary source of accelerated sediment production on Saint John. Problems caused by roads can and should be immediately corrected if the marine resources of Virgin Islands National Park are to be adequately protected for future generations.

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