

# **Fish Bay Watershed Assessment: Recommendations for a Road Erosion Control Program**



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**In Collaboration with:**

Estate Fish Bay Homeowner's Association  
Catherineberg Homeowner's Association  
Skytop Property Owners Association, and the  
Virgin Islands National Park

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***TABLE of CONTENTS***

|                                                          |    |
|----------------------------------------------------------|----|
| TABLE of CONTENTS                                        | 3  |
| 1. Summary and Purpose of Report                         | 4  |
| 2. Problem Statement                                     | 5  |
| 3. Project Objectives                                    | 7  |
| 4. An Introduction to the Fish Bay Basin                 | 8  |
| 5. The St. John Erosion Model                            | 12 |
| 6. Overview of Fish Bay Sediment Loads                   | 15 |
| 7. Road Erosion Control Strategy for the Fish Bay Basin  | 19 |
| 8. Summary                                               | 21 |
| References Cited                                         | 22 |
| Appendix A: General Maps of the Fish Bay Basin           | 23 |
| Appendix B-1: Recommendations for Target Road Segments   | 32 |
| Appendix B-2: Additional Erosion Control Recommendations | 47 |
| Appendix C: Erosion Control Best Management Practices    | 60 |
| Appendix D: Sediment Production from Unpaved Roads       | 77 |

## 1. ***Summary and Purpose of Report***

This project report, “Fish Bay Watershed Assessment-Recommendations for a Road Erosion Control Program,” represents the first stage products for two funded grants, provided by the Gulf of Mexico Foundation (Grant Agreement #1003C) and the National Fish and Wildlife Foundation (Grant 11444), in addition to commitments of major contributions of materials, manpower, and construction projects by Island Resources Foundation, the Fish Bay Homeowners Association and the Skytop Property Owners Association. The Catherineberg Homeowners Association has also offered their assistance in this project. In addition, the US Fish and Wildlife Service Caribbean Office and the Virgin Islands National Park (which owns large properties adjacent to Fish Bay) have expressed interest in being involved in this project.

This report represents a compendium of available information regarding conditions pertinent to erosion control in Fish Bay, the range of Best Management Practices (Appendix A) that are in general use and availability in the Virgin Islands, plus a preliminary synthesis of that information (Appendix B) through the mechanism of the STJ-EROS GIS model, to tag major sediment sources potentially susceptible to remediation

The purpose of the report is to have all project partners on same page regarding both the overall erosion control strategy for Fish Bay, and also to develop agreement on specific tactical options on a site-by-site basis. The report will provide a framework to work with property owners to make final decisions on the details of BMP implementation. The final version of this report implies completion of the assessment and planning tasks of the two funded projects.



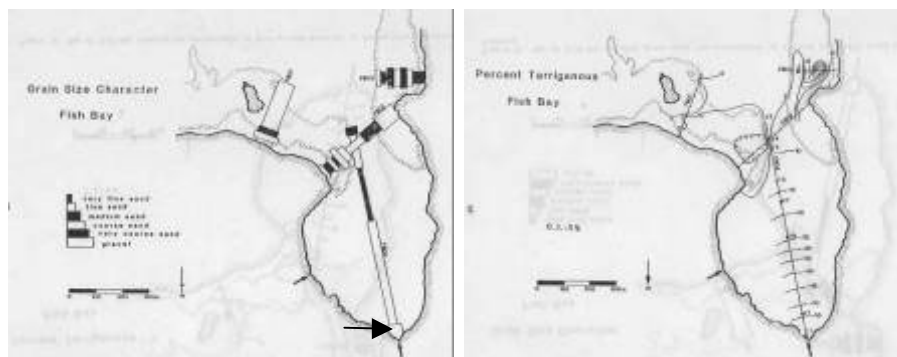
*High sediment loads have lead to deteriorated*

## 2. Problem Statement

The high rate of land development that has occurred throughout the U.S. Virgin Islands Territory in the past several decades has resulted in increased sediment yield rates into coastal waters and this has had detrimental effects on the quality of its marine resources (Jeffrey et al., 2005). Fish Bay (FB) on the island of St. John, U.S. Virgin Islands exemplifies the type of impact that high rates of unchecked land-based erosion may have on marine habitats. The poor quality of the marine environment in Fish Bay (>51% of macroalgae cover, <15% of coral cover, high sedimentation rates of up to  $11 \text{ mg cm}^{-2} \text{ day}^{-1}$ , high water turbidity, and sediment-laden salt ponds) is in sharp contrast to other nearby bays along the southern shores of St. John (Beets et al., 1986; Hubbard et al., 1987; Nemeth et al., 2001). Experts agree that increased erosion associated to the unpaved road network and land development occurring on the  $6 \text{ km}^2$  watershed draining into Fish Bay is responsible for its deteriorated condition.

The poor water quality conditions in Fish Bay are currently controlled by a number of factors.

First, we have to consider that the FB watershed has experienced a fast pace of development over the last three decades. The sediment



[Taken from Hubbard et al., 1987]

output originating from the Main Fish Bay Gut has created a depositional delta that extends seaward towards the deeper sections of Fish Bay. In the 1980's, the surface deposits close to the gut outlet contained up to 55% of terrigenous material, and this was in sharp contrast to bays such as Reef Bay and Hawksnest Bay where surface sediments generally contained less than 10-15% of terrigenous material (Hubbard et al., 1987). The settled sediment ranged in texture from coarse sands close to the Main Fish Bay Gut outlet to very fine sand on the deeper central portion of the bay. This sediment is commonly re-incorporated into the water column during high wave energy periods and is responsible for the poor water quality of Fish Bay during dry conditions.

Secondly, the Fish Bay basin contains different types of active sources that contribute sediment into the marine environment. Of special interest for the purposes of this project are those sources associated to anthropogenic activities. Among the types of land use practices that are considered to be

important sediment sources in the Fish Bay basin are land clearing and vegetation removal associated to home construction, a rock crushing and construction material storage site on the upper portions of the Fish Bay basin, and activities associated to road construction and maintenance. Even though our watershed analyses and erosion control strategy focus on the unpaved road network, we recognize the potential importance of the other two land use activities in delivering sediment into Fish Bay. While an individual homesite-development might not appear to contribute large quantities of sediment, its importance for basin-scale sediment yields should not be ignored given that this type of activity has been and is constantly occurring within the Fish Bay basin. As part of our dissemination efforts we are encouraging homeowners, developers, and the regulating agencies to follow the erosion control guidelines stated in the USVI Environmental Protection Handbook (UVI-CES, 2002) to mitigate current problems and to plan future development activities.



*Anthropogenic sediment sources currently active in the Fish Bay basin:  
home construction (left), a rock crushing-storage site (middle), and unpaved roads (right).*

The rock crushing and construction material storage site at the upper portions of the Fish Bay basin acts as a point source (*i.e.*, input of sediment is concentrated within well-defined boundaries) and it is perceived to contribute large quantities of sediment into the Battery Gut tributary of the Main Fish Bay Gut. A quantitative assessment of the streambed surface texture of the Main Fish Bay Gut showed an evident fining of the streambed texture immediately downstream of the runoff inputs from the material storage site (Nemeth *et al.*, 2001; Ramos-Scharrón, 2004), and it was interpreted as an indication of high sediment inputs. As part of our dissemination efforts we will make recommendations to the local regulating agencies to encourage the implementation of erosion control measures on this site. Simple and cost-effective measures such as properly installed and maintained sediment fences and detention basins could significantly slow the rate of sediment delivery into Battery Gut and Fish Bay.



*A fast-eroding unpaved*

Previous research on St. John has shown that unpaved roads can erode at rates that are up to 10,000 times higher than erosion rates on undisturbed hillslopes (Ramos-Scharrón and MacDonald, in press a), and that they are currently a dominant source of the terrestrial sediment entering Fish Bay (Anderson and MacDonald, 1998; Ramos-Scharrón, 2004). The application of a GIS-based erosion model (STJ-EROS) [Ramos-Scharrón and MacDonald, in press b] estimated that the average sediment load into Fish Bay, based on the condition of the unpaved road network in 1999, was about 275 tons per year, and this was seven times higher than background rates. Unpaved roads accounted for 85% of the total estimated sediment yield (234 tons per year). Approximately 65%, or 180 tons, of this annual sediment loading rate are estimated to be finer than 2 mm (i.e., sand-sized and finer) and are thus expected to be easily transported in suspension by the FB stream network. This size fraction is the same size fraction that accumulates on the bottom of Fish Bay and can also increase the turbidity of the water column.

STJ-EROS results showed that sediment pollution from unpaved roads in Fish Bay is truly a non-point source problem in that significant amounts of the sediment that reaches the marine environment originate from various road segments located throughout the entire watershed. Actions taken by the Estate Fish Bay Homeowner's Association in cooperation with the Government of the US Virgin Islands and Island Resources Foundation resulted in paving 1.6 km of roads. Even though these actions decreased the estimated annual yields by approximately 45 tons yr<sup>-1</sup>, newly constructed unpaved roads and driveways have increased current sediment yield rates to an estimated 280 tons per year.

### **3. Project Objectives**

The main goal of this project is to improve the condition of the marine environment in Fish Bay by reducing its sediment loading rates. Sediment loading rates will slow down following the implementation of cost-effective Best Management Practices (BMPs) designed to reduce sediment production rates from fast-eroding surfaces. The effectiveness of the BMPs in reducing erosion rates will be assessed by a monitoring program.

The overall project goal will be accomplished by completing the following objectives:

**Objective 1– Watershed analysis:** A sediment budget analysis was conducted using the GIS-based STJ-EROS model (Ramos-Scharrón and MacDonald, in press b) and field observations. STJ-EROS is a sediment budget model that allows the user to identify road segments within a given watershed that are contributing significant quantities of sediment to the marine environment. The outputs of the model are being used as tools to aid in the development of the erosion control strategy for the Fish Bay basin. A description of the STJ-EROS model and the results for the Fish Bay basin are presented later in this document.

**Objective 2– Development and implementation of an erosion control strategy:** The watershed analysis results presented here are being combined with field observations and consultations with the VI National Park and community members to choose target road segments where we will apply erosion control BMP's. In collaboration with our project partners we will choose appropriate, site-specific erosion control methods. This report should be considered a dynamic document, which will be edited and updated according to the decisions made by Island Resources Foundation's project management team in collaboration with its project partners.

The cost-effective erosion control methods to be applied will be selected from proven Best Management Practices described in local (Ramos-Scharrón, 2000; UVI-CES, 2002) and regional (Anderson, 1994) handbooks. Some of the erosion control practices to be considered include:

- a) Improving drainage by placing road drainage structures such as water bars, swales, deflectors, and culverts;
- b) Protecting the road surface with geotextiles and surface gravel using proven treatment guidelines;
- c) Promoting re-vegetation of unnecessary travelway surface area on low-usage roads by protecting the areas from traffic and by seeding with fast growing annual and perennial native grasses; and
- d) Applying tire-track paving on low-traffic, high slope roads (> 12 degrees).

**Objective 3– Evaluation of the effectiveness of sediment control Best Management Practices (BMP's):** Silt-fence sediment traps (Robichaud and Brown, 2002) will be used to measure sediment production rates from roads following BMP installation. Sediment production rates from roads with erosion control measures will be compared to those collected from untreated roads between 1998-2000 (Ramos-Scharrón, 2004; Ramos-Scharrón and MacDonald, 2005).

#### **4. An Introduction to the Fish Bay Basin**

The Fish Bay basin encompasses a 6.0 km<sup>2</sup> area that drains towards a well-enclosed bay on the southern shores of St. John (Appendix A). Slopes are generally very steep, as just over half of the basin

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has slopes exceeding 30% (16 degrees) [Appendix A]. The basin is composed of two main drainages known as the Main Fish Bay Gut and the Little Fish Bay Gut watersheds. The Main Fish Bay Gut and its Battery Gut tributary drain more than half of the basin as these guts extend towards the higher elevations (~280 m) on the northernmost portions of the basin.

The topography of St. John combined with the local relief and the prevailing wind direction creates a precipitation gradient within the Fish Bay basin. While the lower-southern portions of the basin have an average rainfall of 100 – 115 cm per year (40-45 inches), the average annual rainfall of the upper sections of the basin range from 125 – 140 cm per year (50-55 inches) [Bowden et al., 1970]. Rainfall intensities measured at Estate Fish Bay between 1998 and 2000 had a very high maximum 30-min intensity of 6.6 cm per hour (2.6 inches per hour), but the overall data showed that high intensities occurred infrequently as only about a third of the total recorded rainfall fell at 30-min intensities exceeding 1.0 cm per hour (0.4 inches per hour) [Ramos-Scharrón, 2004].

The average monthly temperatures recorded at lower elevations in the nearby Lameshur Bay area range from 76 to 81 degrees Fahrenheit (Bowden et al., 1970), while those at Catherineberg at the higher elevations of the Fish Bay basin range from 73 to 80 degrees Fahrenheit (NOAA, 2002). Due to the high temperatures the amount of water loss to evaporation and transpiration of plants is estimated to be very high. Annual potential evapotranspiration (PET) estimates are in the order of 150 cm, and with the exception of the months of May and November monthly PET estimates exceed monthly rainfall totals (Bowden et al., 1970). This general lack of excess precipitation explains the absence of perennial streams (i.e., constant flowing streams) on Fish Bay, with the only exception being a spring-fed section on the upper Main Fish Bay Gut. Runoff from the two main guts, and thus sediment delivery into Fish Bay, only lasts for time periods extending from hours to several weeks only as a result of moderate to high intensity rainfall events following wet periods (Ramos-Scharrón, 2004).

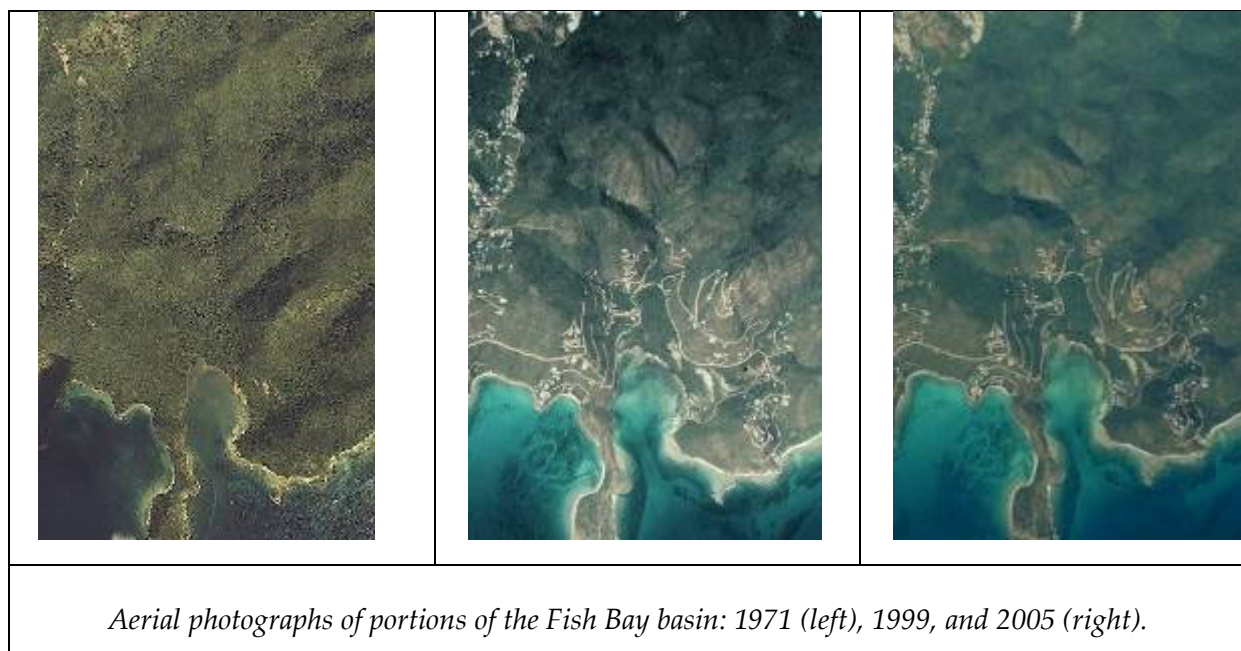
The precipitation and temperature gradient of the Fish Bay basin induces the generation of different vegetation types ranging from dry forest (392 ha or 65% of the basin) and shrubland vegetation (103 ha or 17%) at lower elevations to basin moist forest at the highest elevations (63 ha or 11%) (Woodbury and Weaver, 1987) (Appendix A). Mangrove forests and sand flat areas occupy 6.4 ha, or 1% of the total basin area.

The soils supporting the vegetation of the Fish Bay basin are dominated by the Annaberg-Maho and the Fredriskdal-Susannaberg soil complexes, and together they cover almost 80% of the entire basin area (NRCS, 1998) (Appendix A). These soil complexes have stony gravelly loam and gravelly clayey

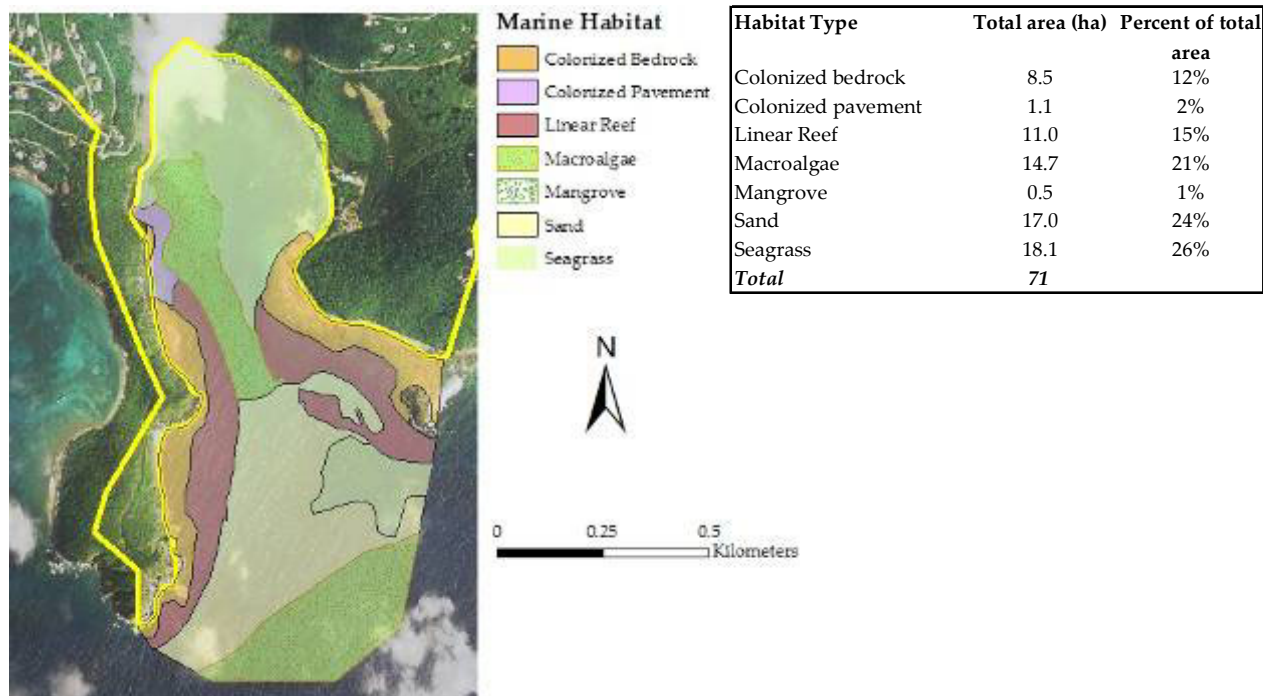
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loam textures, which means that they contain a balanced content of clays, silts, sands, and gravel in addition to a high content of coarse rocks. These textures produce soils with slow to moderate permeabilities, and even though they erode at a very slow rate under undisturbed conditions their soil erosion rating under a disturbed state is high due to their texture and predominant slopes.

Based on a generalized map, a total of 4.0 km<sup>2</sup>, or 67% of the basin, is managed by the Virgin Islands National Park (VINP), and with the exception of a few privately owned in-holdings, there is very little development on the areas within VINP [Appendix A]. All other areas have experienced a significant growth within the last 30 – 40 years, and this has been induced a growth of the road network within the basin. Between 1971 and 2000 the road network (including public access roads and private driveways) in the 6.0 km<sup>2</sup> Fish Bay basin nearly tripled in length from 8.3 km to 22 km, and this translates into a growth rate of about 0.5 km of new roads every year. Currently there are 27.8 km of roads within the Fish Bay basin, and 47% or 12.9 km of these roads are unpaved. The growth rate of the road network over the last six years translates to a doubling of the long-term trend to approximately 1.0 km of new roads every year, and it shows no sign of slowing down.



About 37% of all unpaved roads in the Fish Bay basin are actively used by traffic and they are graded at least once every two years ('graded'), while an equal amount is actively used but not frequently graded ('ungraded'). About 27% of all unpaved roads are only rarely used by traffic and experience no maintenance activity ('abandoned') [Appendix A]. Sediment production data collected from different areas of St. John between 1998 and 2000 showed that graded roads had the highest erosion rates, and that ungraded and abandoned roads had erosion rates that were on average only 40% and 6% relative to graded roads, respectively (Ramos-Scharrón and MacDonald, 2005). Graded roads within Fish Bay have a higher mean slope (10% or 6 degrees) than ungraded and abandoned roads (8% and 6%, respectively).



*Map taken from NOAA, 2001-*

The marine environment of Fish Bay covers an area of approximately 70 ha and it contains depths ranging down to 15 m below mean sea level. Fish Bay is dominated by seagrass, sand deposits, and macroalgae, and together these habitat types occupy just over 70% of the bottom of the bay (NOAA, 2001). It is presumed that the predominance of these habitats is due in part to the high loads of sediment and organic material that the bay receives from the Fish Bay basin, particularly from the Main Fish Bay Gut. The total area colonized by coral equals 20.5 ha, or only 29% of the bay, but this mostly occurs as scattered patches. Assuming that only approximately 10% of the 20.5 ha area of potential recruitment is currently occupied by live coral colonies (Nemeth et al, 2001), we can estimate that the actual surface covered by live coral is 2.0 ha, or only 3% of the bottom of Fish Bay. By decreasing the sediment loading rates entering Fish Bay we intend to improve habitat condition so that new coral colonies might get established on surfaces where recruitment is possible.

## **5. The St. John Erosion Model**

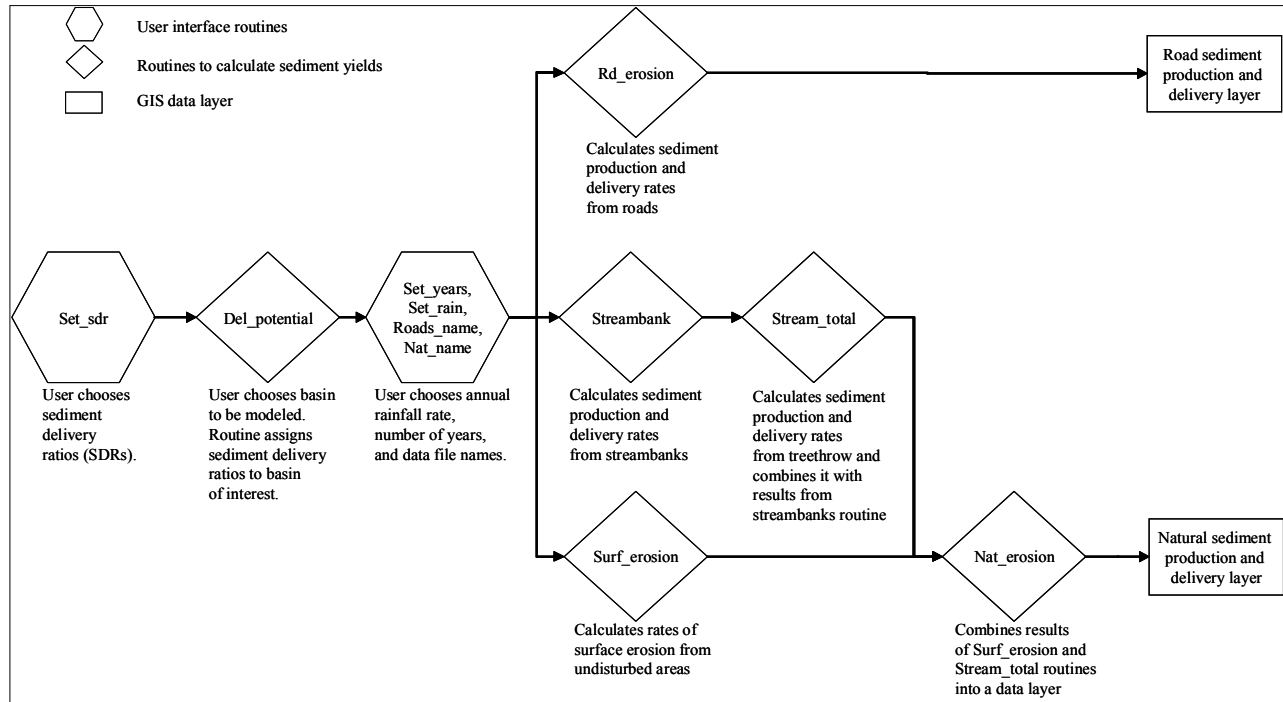
The St. John Erosion Model (STJ-EROS) is a Geographical Information System model that uses empirical erosion functions and delivery ratios to quantify watershed-scale sediment yields (Ramos-

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Scharrón and MacDonald, in press b). The approach used in STJ-EROS is conceptually simple, easy to implement, and appropriate given the model objectives and the intended use by planners and resource managers. The program consists of six input routines and five routines to calculate sediment production and delivery. The input routines have interfaces that allow the user to adjust the key variables that control sediment production and delivery (i.e., annual rainfall and sediment delivery ratios). The other five routines use pre-set erosion rate constants, user-defined variables, and values from nine data layers to calculate watershed-scale sediment yields from unpaved road travelways, road cutslopes, streambanks, treethrow, and undisturbed hillslopes.

STJ-EROS begins with the 'Set\_sdr' routine. This routine prompts the user to select the sediment delivery ratios (SDRs) for transferring sediment from their original sources to the marine environment. In STJ-EROS the SDR values account for both hillslope and channel storage, including the potential storage at the mouth of a gut (i.e., whether the gut discharges directly to the sea or into an intervening coastal wetland, salt pond, or mangrove swamp). In any watershed only a portion of the sediment produced is delivered to its outlet as hillslopes, streams, coastal wetlands, salt ponds, and mangrove swamps serve as short- or long-term sediment sinks. In STJ-EROS, the estimated rate at which terrestrial sediment is transferred to coastal waters is controlled by the user-defined sediment delivery ratios (SDRs), where SDR is the ratio of sediment delivery to the gross erosion in the basin. For the Fish Bay application we have used SDR values of 25% and 75% for areas with moderate and high sediment delivery potential, respectively.

High delivery potential areas drain directly to the sea without an intervening coastal wetland or salt pond. The watershed drained by the Main Fish Bay Gut and its Battery Gut tributary are good examples of this type of high delivery potential area. The delivery of sediment from catchments with an intervening wetland or salt pond is complicated because these wetlands vary with respect to their size, magnitude of fresh water inflows, potential for tidal inflows, and sensitivity to natural and human disturbance. These catchments are defined as having a moderate potential for sediment delivery. The Little Fish Bay Gut Watershed is a good example of an area with a moderate sediment delivery potential. Catchments that drain to a wetland or pond without any surface pathway to the marine environment are assumed to have a SDR value of zero. This type of delivery potential zone is not found within the Fish Bay basin. Approximately 68% of the Fish Bay basin lies within areas that have a high potential for sediment delivery into the marine environment, while the remaining 32% lies within moderate sediment delivery zones [Appendix A].



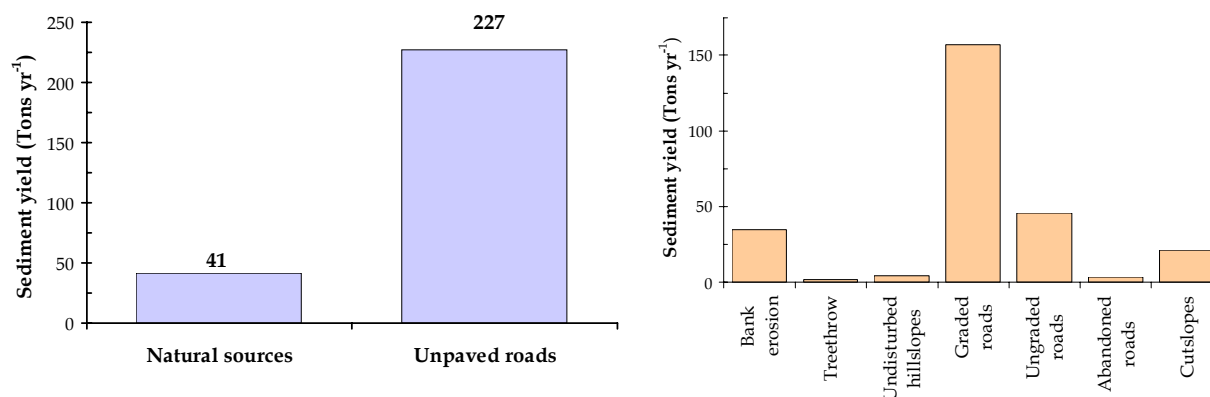
STJ-EROS estimates of sediment production rates from bank erosion, treethrow, surface erosion on undisturbed hillslopes, unpaved road surfaces, and road cutslopes are based on empirical equations that were developed from data collected in St. John between 1998 and 2000 (Ramos-Scharrón and MacDonald, in press a). Sediment production from unpaved roads was found to be related to rainfall, slope, and grading frequency and these are incorporated into STJ-EROS as factors into road erosion predictive equations. STJ-EROS currently assumes zero sediment production from paved roads as both field observations and limited measurements indicate that, in general, the cutbanks and fillslopes along paved roads in the Fish Bay basin currently produce relatively little sediment compared to unpaved road surfaces. STJ-EROS assigns a SDR value (i.e., 25% or 75%) to each road segment according to its location relative to the pre-defined sediment delivery potential zones, and multiplies this factor by the estimated gross erosion to calculate the contribution of each road segment to sediment loading rates into Fish Bay.

Limited runoff and suspended sediment yield data collected from the lower portions of the Main FB Gut between 1998 and 2000 was combined with a 15-year long runoff record collected from the nearby Guinea Gut watershed (USGS station 50295000) to provide another estimate of long term sediment yields into Fish Bay (Ramos-Scharrón, 2004). This calculation was performed to provide an observed value to informally test the validity of using STJ-EROS in predicting sediment yields into Fish Bay (Ramos-Scharrón and MacDonald, in press b). Sediment yields from the 3.5 km<sup>2</sup> area upstream of the Main Fish Bay Gut stream gauging station were 70 tons per year, or only 22% higher than the suspended sediment yield estimated by STJ-EROS for the same catchment area (i.e., 63 tons yr<sup>-1</sup>). The similarity of the results are encouraging and show that STJ-EROS does provide a reasonable methodology to estimate sediment yields into Fish Bay.

## 6. Overview of Fish Bay Sediment Loads

STJ-EROS estimated that current (2006) sediment yields into Fish Bay are 268 tons per year, and unpaved roads appear to contribute about 227 tons yr<sup>-1</sup> or almost 85% of the sediment yield. By assuming that each cubic meter of sediment has a mass of 1.5 tons (i.e., dry bulk density = 1.5 tons m<sup>-3</sup>) we can calculate that the annual volume of sediment delivered into Fish Bay from both natural sources and unpaved roads is about 180 m<sup>3</sup> (6,350 ft<sup>3</sup>). If all of this sediment would settle on the 70 ha of marine habitat within Fish Bay, this would translate into a sedimentation rate of 0.26 mm per year. This estimated sedimentation rate is only slightly higher than the 0.20 mm yr<sup>-1</sup> rate measured during a two-year study in Fish Bay (Nemeth et al., 2001).

The current sediment yield estimated by STJ-EROS is 6.5 times higher than the estimated



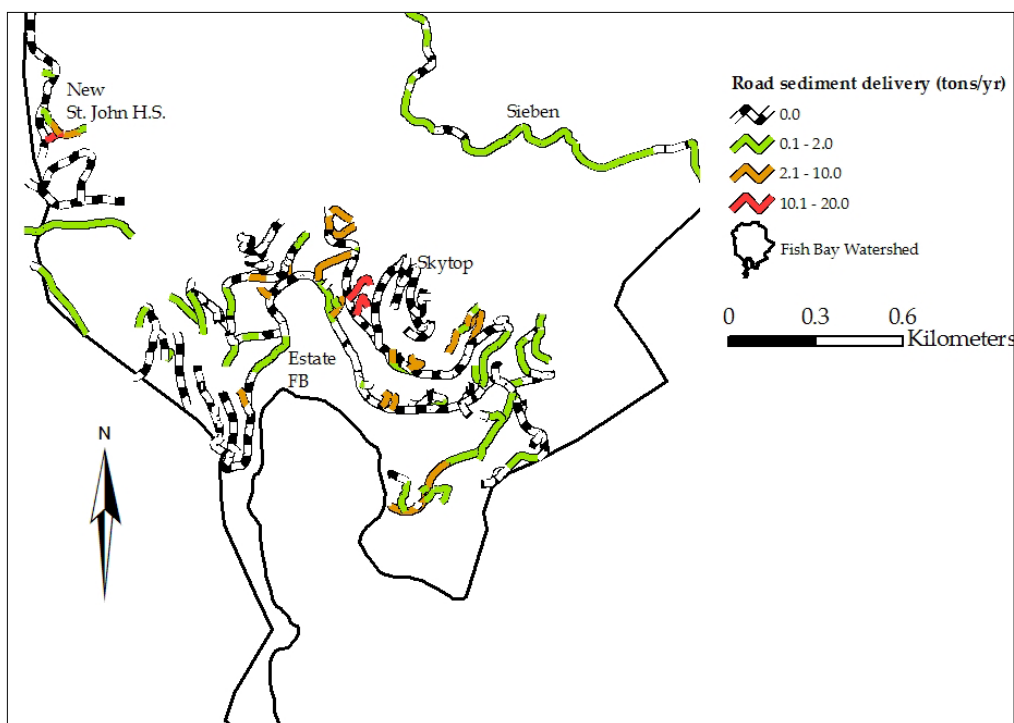
background sediment yield of 41 tons yr<sup>-1</sup>. Only

11% of the roads in the watershed account for 60% of the total sediment yield. Most of these roads are graded at least once every two years, and they drain directly into Main Fish Bay Gut in the lower portion

of the basin or into Battery Gut. Streambanks and cutslopes are each responsible for roughly 10% of the annual sediment yield, while surface erosion from undisturbed hillslopes, treethrow, and erosion from abandoned road surfaces each represent only 1% of the estimated sediment yield.

## 6.1 Sediment Contributions from the Lower Fish Bay Watershed

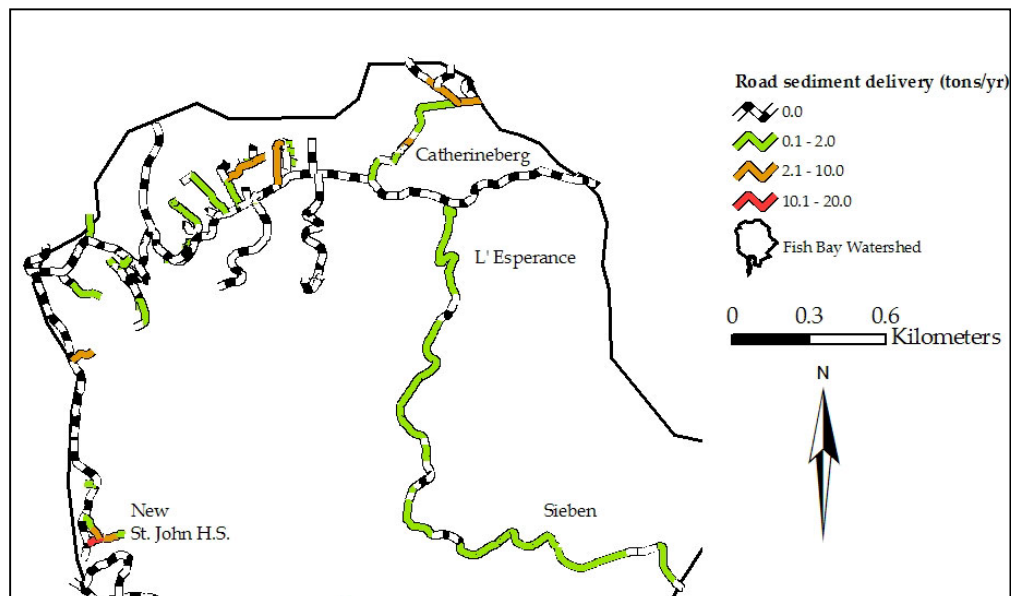
The 8.6 km of unpaved roads in the lower Fish Bay Watershed contribute about 170 tons of sediment per year, and this is about 63% of the total estimated sediment delivery into the bay. Road segments eroding at rates exceeding 10 tons yr<sup>-1</sup> total 0.3 km in length and contribute 43 tons yr<sup>-1</sup>, or 15% of the sediment reaching Fish Bay. These road segments are private driveways or lie within the active construction site for the new St. John High School. Although we are not planning to apply erosion control methods on some of these road segments, we will encourage property owners to implement erosion control methods on these roads. Road segments producing sediment at rates ranging between 2-10 tons yr<sup>-1</sup> total 1.8 km and contribute 97 tons of sediment per year, or 36% of the watershed sediment yield. Some of these road segments will be the target of our erosion control methods (Appendix B-1).



| <b>STJ-EROS model results</b>                                                                           | <b>Total for<br/>Lower FB</b>         | <b>Percent of entire FB<br/>Watershed</b> |
|---------------------------------------------------------------------------------------------------------|---------------------------------------|-------------------------------------------|
| <b>Length of roads</b>                                                                                  | 15.2 km                               | 55%                                       |
| <b>Length unpaved roads</b>                                                                             | 6.7 km                                | 54%                                       |
| <b>Unpaved road sediment contribution</b>                                                               | 170 tons yr <sup>-1</sup>             | 63%                                       |
| <b>Length &amp; total sediment contribution road<br/>segments yielding 2-10 tons yr<sup>-1</sup></b>    | 1.8 km<br>[97 tons yr <sup>-1</sup> ] | 6% of all road types<br>[36%]             |
| <b>Length &amp; total sediment contribution road<br/>segments yielding &gt; 10 tons yr<sup>-1</sup></b> | 0.3 km<br>[43 tons yr <sup>-1</sup> ] | 1% of all road types<br>[15%]             |

## 6.2 Sediment Contributions from the Upper Fish Bay Watershed

A total of 5.8 km of unpaved roads in the upper Fish Bay Watershed are responsible for about 39 tons of sediment that enter Fish Bay on an average year, and this is about 15% of the total sediment loading rate. The upper Fish Bay Watershed currently does not have any road segments producing sediment at rates exceeding 10 tons yr<sup>-1</sup>. Road segments producing sediment at rates ranging between 2-10 tons yr<sup>-1</sup> total 0.98 km and contribute about 21.5 tons of sediment every year, or 8% of the basin-wide sediment yield. Some of these road segments will be the target of our erosion control methods, and these include candidates for surface graveling and road drainage improvements (Appendix B-1).



| STJ-EROS model results                                                                              | Total for<br>Upper FB                    | Percent of entire FB<br>Watershed |
|-----------------------------------------------------------------------------------------------------|------------------------------------------|-----------------------------------|
| <b>Length of roads</b>                                                                              | 12.6 km                                  | 45%                               |
| <b>Length unpaved roads</b>                                                                         | 5.8 km                                   | 46%                               |
| <b>Unpaved road sediment contribution</b>                                                           | 39 tons yr <sup>-1</sup>                 | 15%                               |
| <b>Length &amp; total sediment contribution road segments yielding 2-10 tons yr<sup>-1</sup></b>    | 0.98 km<br>[21.5 tons yr <sup>-1</sup> ] | 4% of all road types<br>[8%]      |
| <b>Length &amp; total sediment contribution road segments yielding &gt; 10 tons yr<sup>-1</sup></b> | 0.0 km<br>[0 tons yr <sup>-1</sup> ]     | 0% of all road types<br>[0%]      |

## 7. *Road Erosion Control Strategy for the Fish Bay Basin*

A detailed description of the initial erosion control strategy being suggested by the Island Resources Foundation project management team is included as Appendix B-1. Once we have obtained a quote on the cost of the proposed work we might include additional road segments from Appendix B-2 into our target road segments (Appendix B-1). Sites shown in Appendices B-1 and B-2 represent most unpaved road segments identified by STJ-EROS as important contributors of the sediment that reaches Fish Bay (i.e., road segments producing an excess of 2.0 tons of sediment per year). Some road segments had high sediment contributions, but were left out of the target sites (Appendix B-1) because their location within sediment delivery potential zones was perceived to pose a lesser risk to Fish Bay than other roads. All of the roads selected in the current plan drain at close proximity to the bay or drain into high sediment delivery potential areas linked to the Main Fish Bay Gut watershed. The excluded roads may become integrated to future versions of the erosion control strategy pending on the availability of funds and resources.

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Appendices B-1 and B-2 contain recommendations for a total of ten target areas, and this includes seven sites in the lower portions of the basin and three in its upper sections and a total road length of 2.3 km. Road segments were assigned a Priority 1 or Priority 2 level according to their sediment contribution calculated by STJ-EROS and perceived connectivity with the Fish Bay marine environment. The priority category also considered the likelihood that we would be able to apply sediment control practices on the road segment. For example, Priority 2 was assigned to driveways along Cocoloba Trail and roads within the New St. John High School as all of these are located within private land. Almost all roads given a Priority 1 label are common use roads that are overseen by the collaborating homeowner associations or the VI National Park.

One important issue that should be noted with regards to vegetation removal and land clearing operations, such as the one for the new St. John High School, is the sedimentation risk posed by these activities during the construction phase. It is very likely that most of the disturbed land on this site will be eventually covered by pavement or vegetation and thus produce very little sediment, but the lack of any effective erosion control method during the construction phase allows for the delivery of significant quantities of sediment into the bay. The few sediment fences observed during our field visit were not effective as they allowed sediment-laden runoff to exit the site and enter Battery Gut. Land clearing for the high school appears to have begun in 2004, and large portions of the site still lacked any vegetation cover, pavement, or erosion control methods in October 2006. Our calculation for the sediment contributed by the 275 m of unpaved roads at the site yields a total of 28 tons per year, and this does not account for erosion occurring on disturbed surfaces other than the unpaved roads. Over the 3 years during which these unpaved roads have been active sediment sources, they may have contributed a total of 84 tons of sediment to Fish Bay. This type of analysis emphasizes the need to implement effective construction-phase erosion control methods on this and all other new developments.

Appendix B-1 contains detailed erosion control recommendations on the road segments that will be initially targeted by our erosion control methods. All of the road segments in Appendix B-1 have been categorized as Priority 1. The strategy currently described in Appendix B-1 involves applying BMPs to 0.84 km of unpaved roads, or 7% of all unpaved roads in the entire Fish Bay basin. The total sediment contribution from these road segments is estimated to equal 18 tons per year. This erosion control strategy will permit the establishment of approximately 13 monitoring sites (i.e., sediment traps), where we may evaluate the effectiveness of the BMPs in reducing erosion.

The BMPs being suggested as part of our strategy have been chosen from a literature review on cost-effective erosion control methods for forest roads. Appendix C contains a discussion on the

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application of these methods. The BMPs in Appendix C aid in slowing down erosion in one of two ways: 1) by reducing the force being applied by running water over unpaved road surfaces (e.g., runoff control structures); and 2) by improving the resistance of the road surface to the forces of erosion (e.g., strip-pavement and gravel- or vegetation-surfacing). A brief background on road surface erosion processes and how the BMPs in Appendix C are expected to reduce sediment production are presented in Appendix D.

## **8. Summary**

Fish Bay on the island of St. John, U.S. Virgin Islands exemplifies the type of impact that high rates of unchecked land-based erosion may have on marine habitats of the Caribbean Region. The poor quality of the marine environment in Fish Bay is in sharp contrast to other nearby bays along the southern shores of St. John. Experts agree that increased erosion associated to unpaved roads and land development occurring on the 6 km<sup>2</sup> watershed draining into the bay is responsible for its deteriorated condition. The application of a GIS-based erosion model (STJ-EROS) estimated that the current average sediment load into Fish Bay is about 280 tons per year, and unpaved roads appear to contribute about 239 tons yr<sup>-1</sup> or almost 85% of the sediment yield. The current yield rates are seven times higher than natural rates. The model results showed that sediment pollution in FB is truly a non-point source problem in which sediment originates from many road segments located throughout the entire watershed.

The erosion control strategy presented here targets unpaved road segments identified by STJ-EROS as important contributors of the sediment that reaches Fish Bay (i.e., road segments producing an excess of 2.0 tons of sediment per year). Our current strategy presents recommendations for a total of 0.84 km of unpaved roads, or 7% of all unpaved roads in the entire Fish Bay basin. Additional road segments will be added once we have a cost estimate of the recommended road work is obtained. The current erosion control strategy will permit the establishment of approximately 13 monitoring sites (i.e., sediment traps), where we may evaluate the effectiveness of the BMPs in reducing erosion rates.

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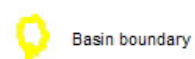
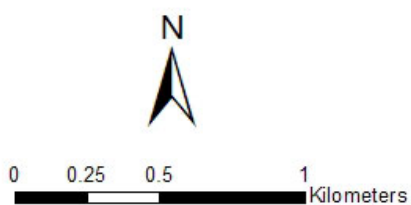
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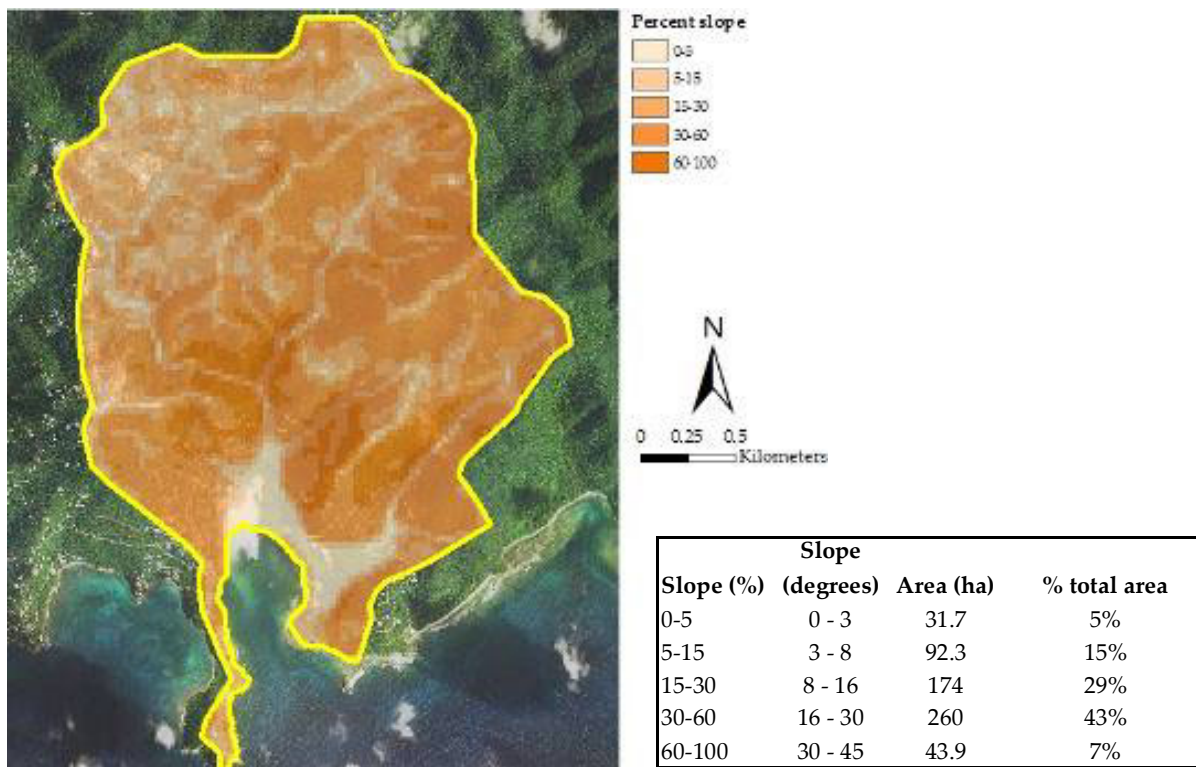
## ***Appendix A***

### ***General Maps of the Fish Bay Basin***

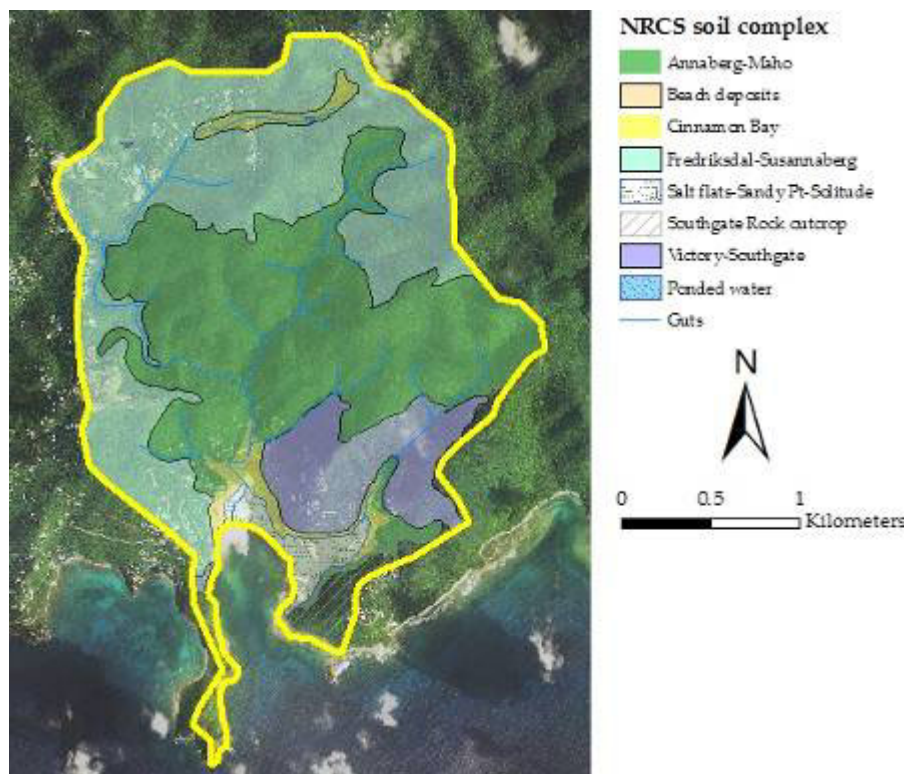
***2004 AERIAL PHOTOGRAPH OF THE FISH BAY BASIN.***



## ***FISH BAY SLOPES MAP***

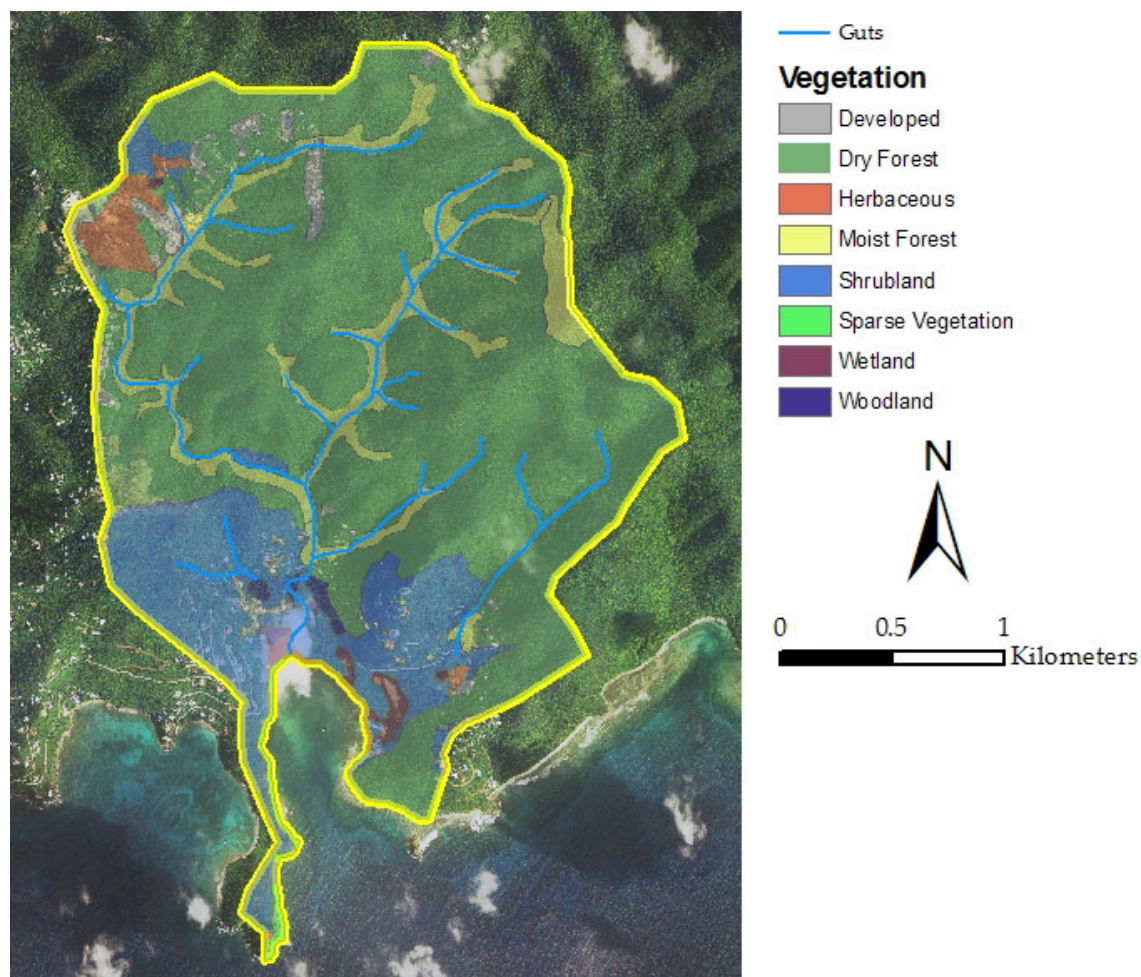


## ***FISH BAY SOILS MAP***



| Soil Complex                    | Area (ha) | % total |  | Texture              | Permeability | Soil depth (cm) | Erosion rating  |
|---------------------------------|-----------|---------|--|----------------------|--------------|-----------------|-----------------|
|                                 |           | area    |  |                      |              |                 |                 |
| Annaberg-Maho                   | 237       | 39%     |  | Stony gravelly loam  | Moderate     | 20-50           | Severe          |
| Beach deposits                  | 2.79      | 0.5%    |  | Sandy to stony       | High         | Deep            | n/a             |
| Cinnamon Bay                    | 22.3      | 4%      |  | Loam                 | Moderate     | >150            | Moderate-Severe |
| Fredriksdal-Susannaberg         | 236       | 39%     |  | Gravelly clayey loam | Slow         | 25-50           | Severe          |
| Salt flats-Sandy Point-Solitude | 15.6      | 3%      |  | Variable             | Slow         | Deep            | Slight          |
| Southgate rock outcrop          | 26.0      | 4%      |  | Stony gravelly loam  | Moderate     | 25-50           | Severe          |
| Victory-Southgate               | 61.1      | 10%     |  | Loam & gravelly loam | Moderate     | 50-100          | Severe          |

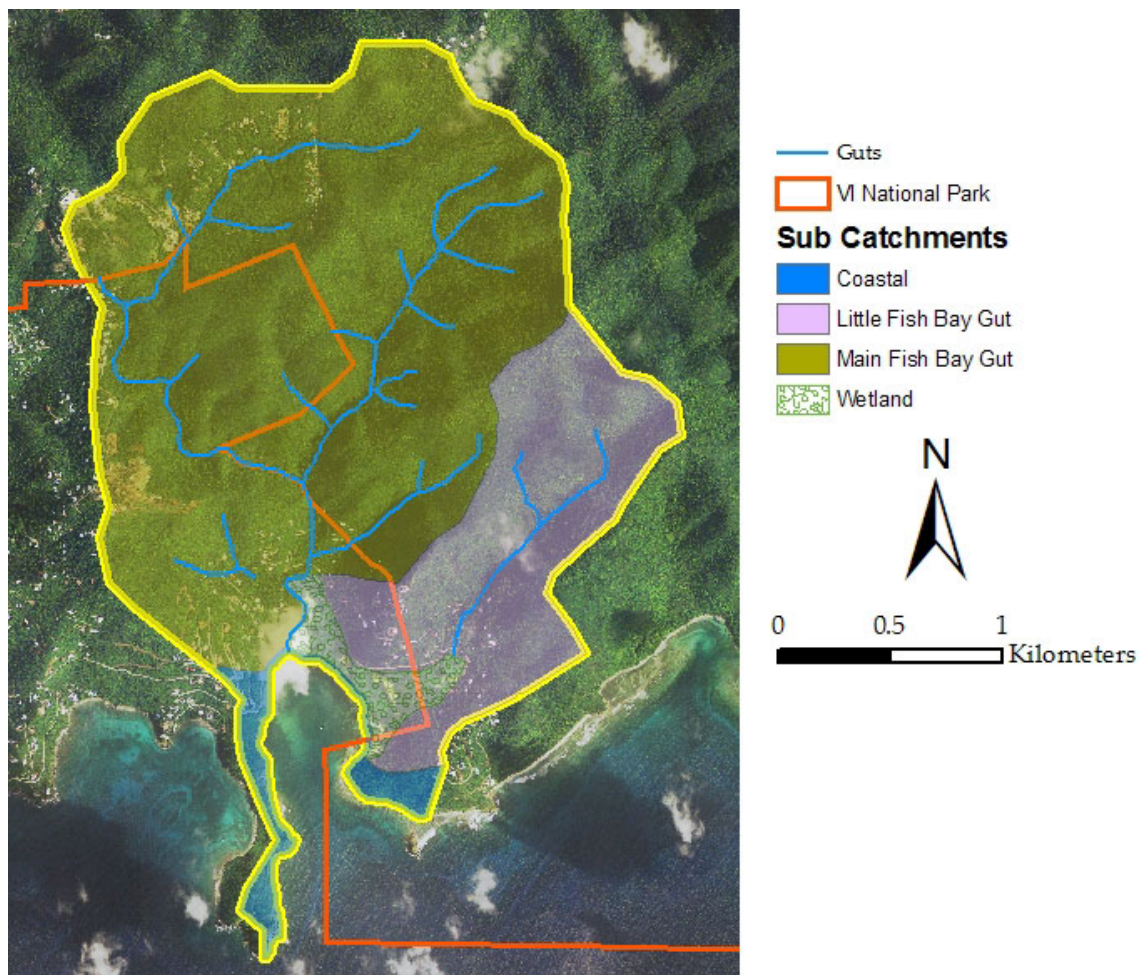
## ***FISH BAY VEGETATION MAP***



| <b>Vegetation structure</b> | <b>Area (ha)</b> | <b>Percent of total area</b> |
|-----------------------------|------------------|------------------------------|
| Developed                   | 18.9             | 3.1%                         |
| Dry Forest                  | 392.0            | 65.0%                        |
| Herbaceous                  | 11.3             | 1.9%                         |
| Moist Forest                | 63.3             | 11.0%                        |
| Shrubland                   | 103.0            | 17.0%                        |
| Sparse Vegetation           | 3.4              | 0.6%                         |
| Wetland                     | 6.4              | 1.1%                         |
| Woodland                    | 4.1              | 0.7%                         |

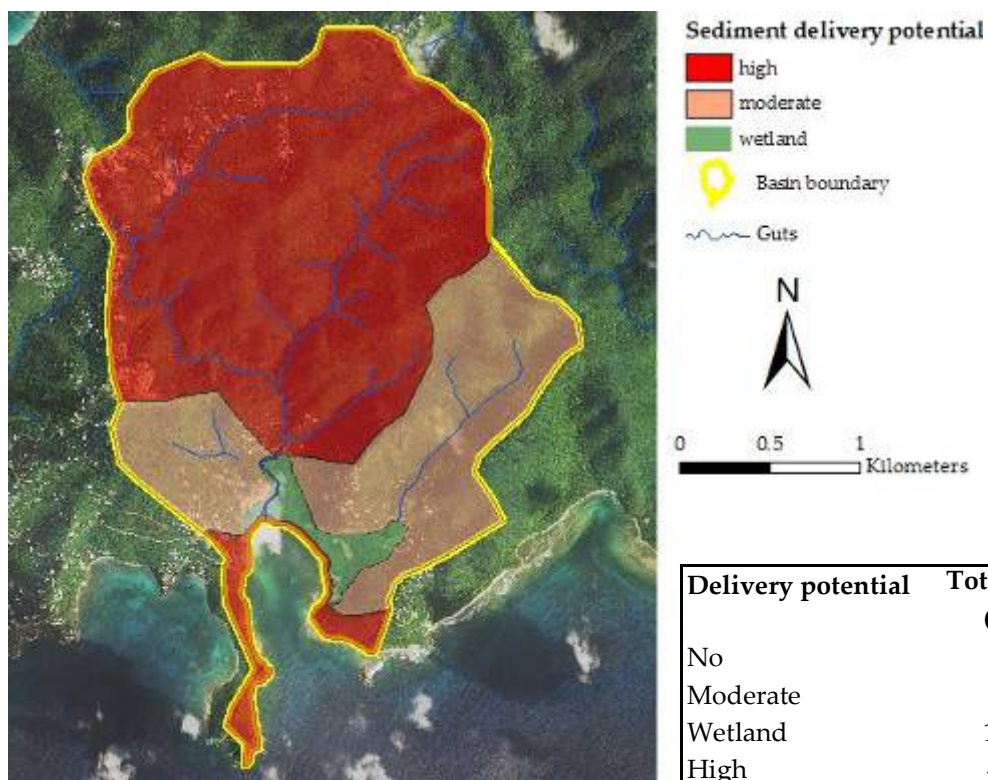


## VINP BOUNDARY AND FISH BAY SUBCATCHMENTS

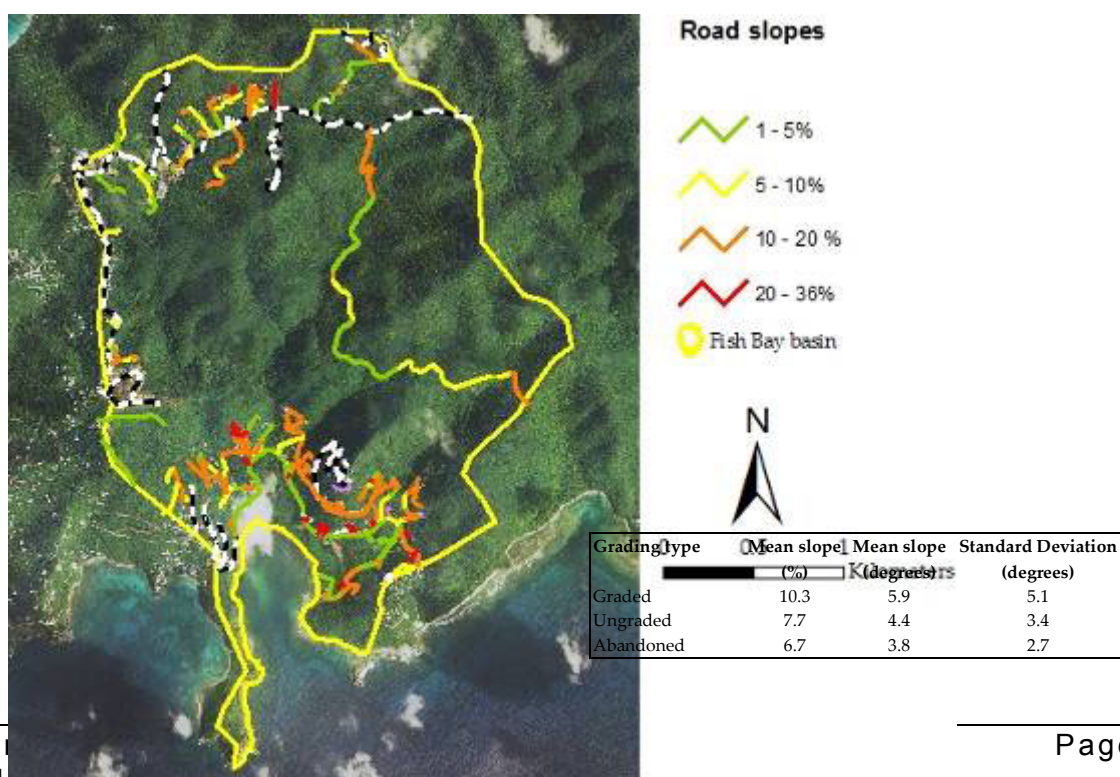
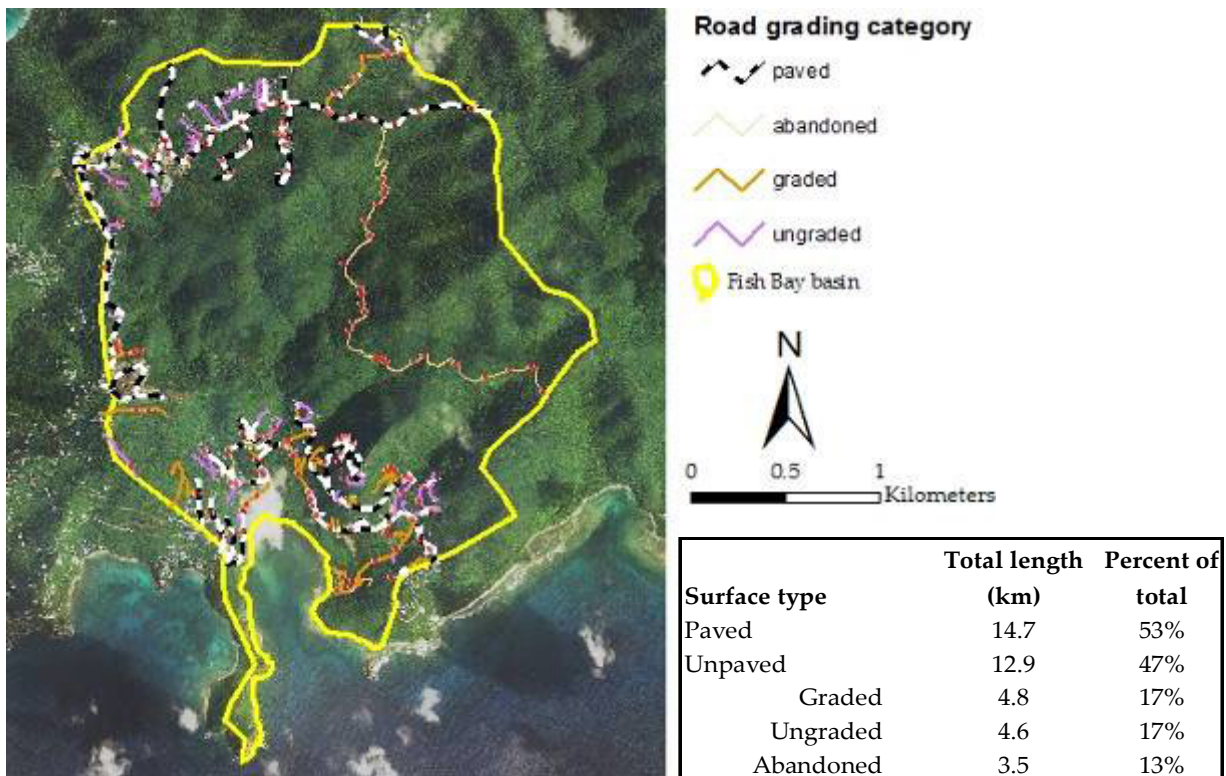


| Sub-Catchment       | Area (ha) | Percent of total area |
|---------------------|-----------|-----------------------|
| Coastal             | 22.9      | 4%                    |
| Little Fish Bay Gut | 128       | 21%                   |
| Main Fish Bay Gut   | 435       | 72%                   |
| Wetland             | 16.0      | 3%                    |

# ***FISH BAY SEDIMENT DELIVERY POTENTIAL MAP***



## FISH BAY ROAD MAPS



## ***Appendix B-1***

### ***Erosion Control Recommendations for Target Road Segments***

## COCOLOB TRAIL AT MARINA DRIVE

### Existing conditions

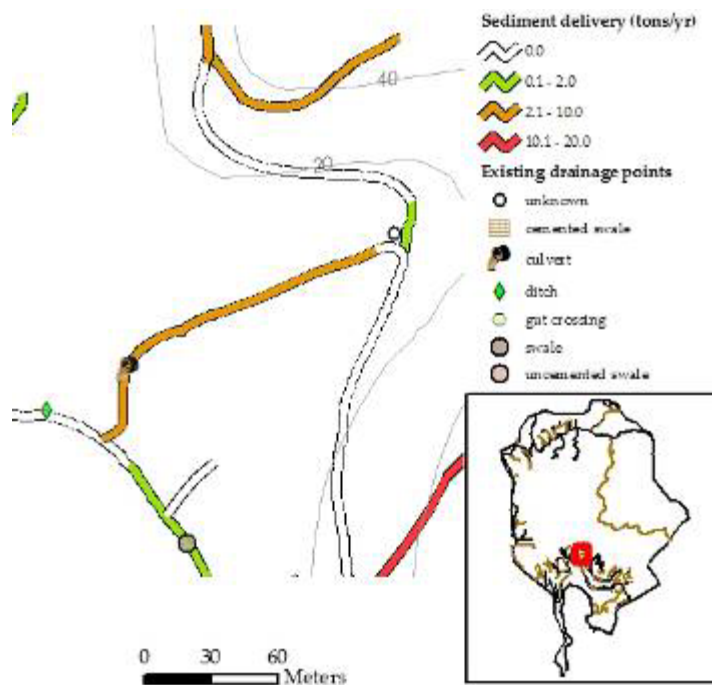
A. 165 m long x 4.1 m wide = 680 m<sup>2</sup>

Mean slope = 6%

Sed. contribution = 4.4 tons yr<sup>-1</sup>

Interested stakeholders: Estate FB HO &  
Skytop PO

Priority 1

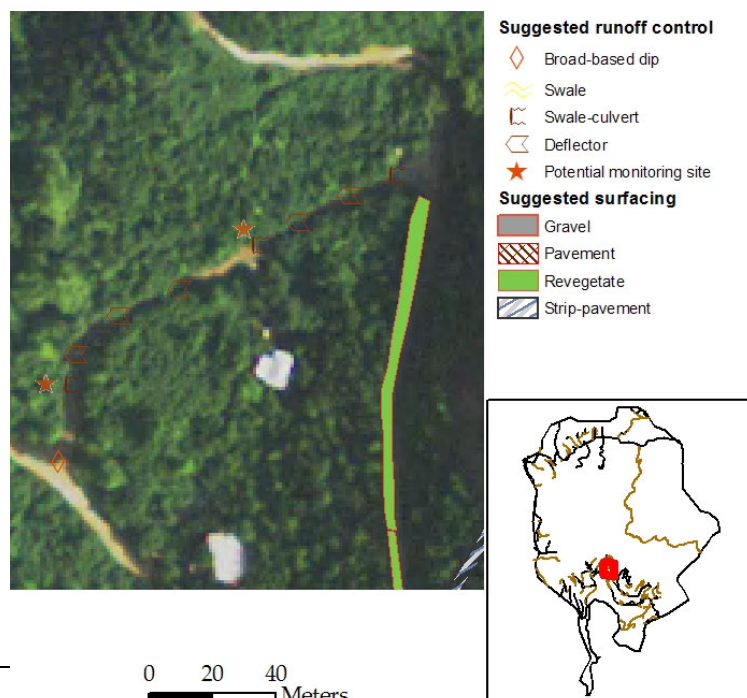


### Suggested BMP's

Method 1: 2 water bars  
  
1 pipe culvert  
  
5 deflectors  
  
1 existing dip

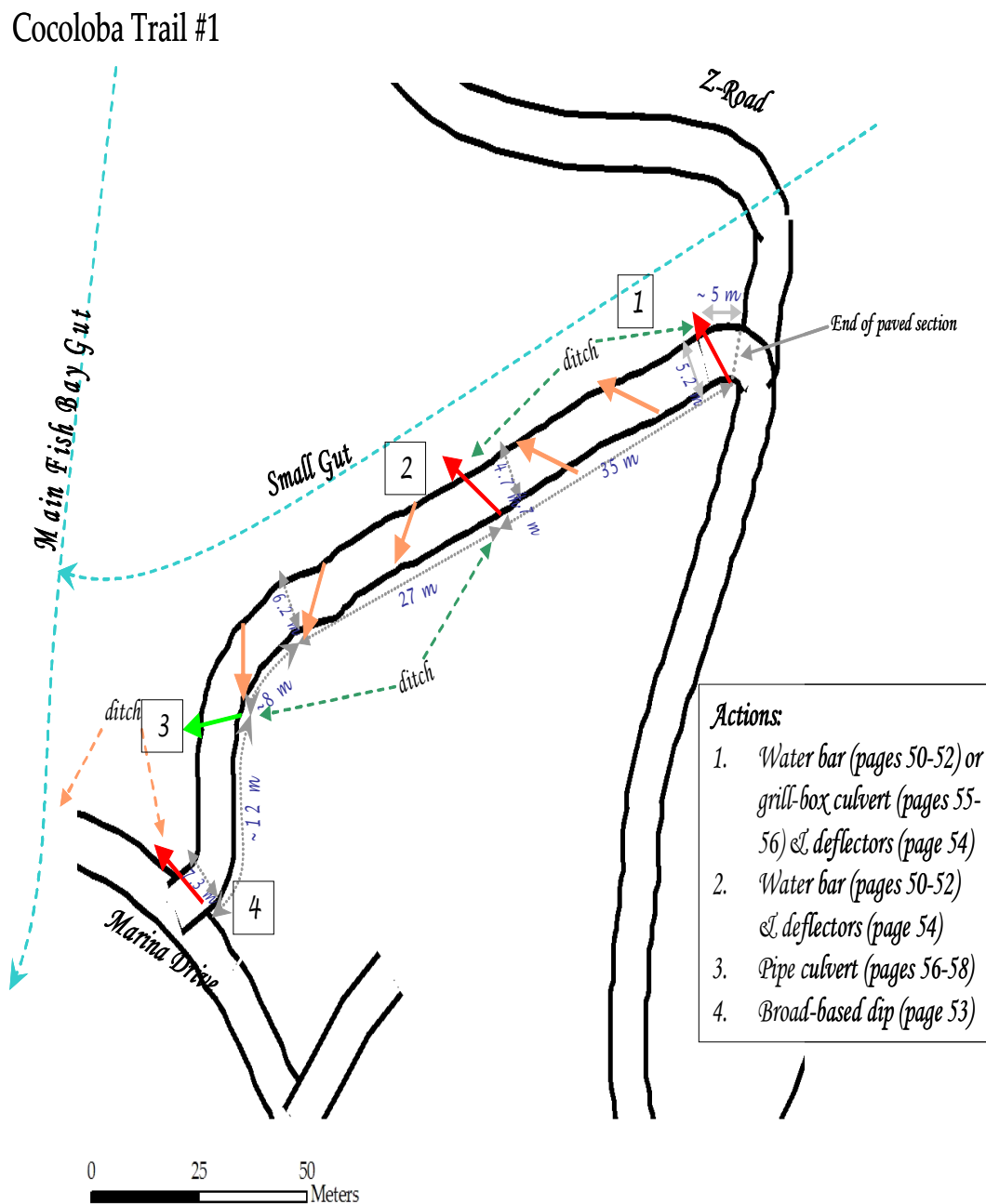
Cost 1: \$TBD

Expected effectiveness: TBD



---

*Monitoring sites: 2*



## COCOLOBA TRAIL AT JUNCTION WITH Z-ROAD

### Existing conditions

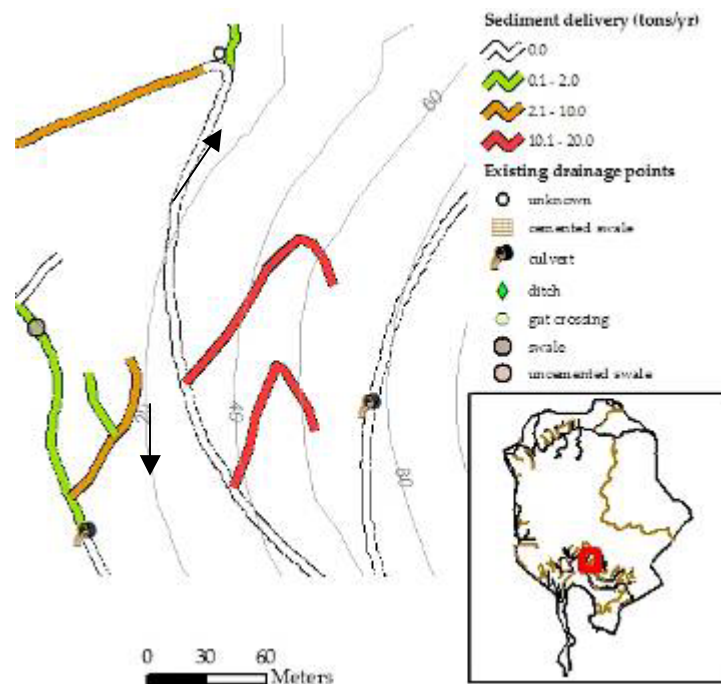
A. ~ 120 m long x 2.5 m wide = 300 m<sup>2</sup>

Mean slope = 11 %

Sed. contribution = ? tons yr<sup>-1</sup>

Interested stakeholders: Estate FB HO &  
Skytop PO

Priority 1



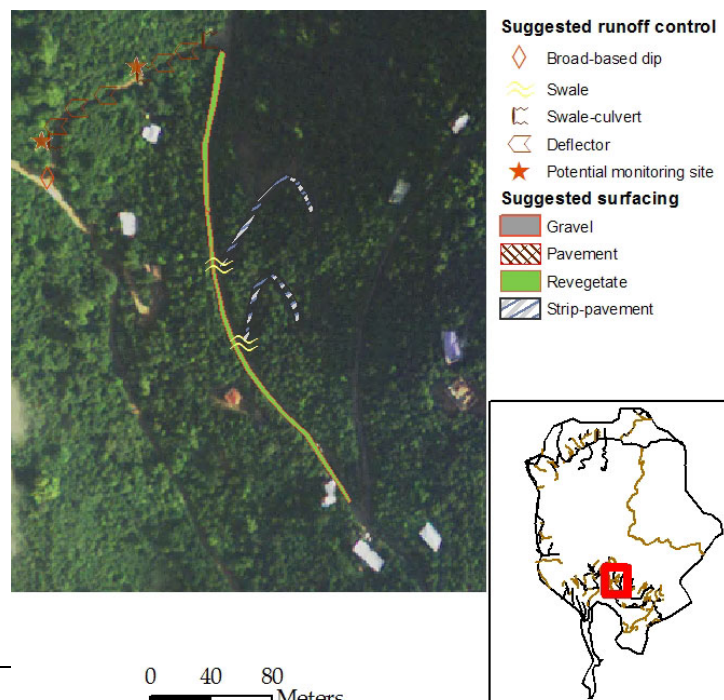
### Suggested BMP's

A. Method 1: 300 m<sup>2</sup> re-vegetation

Cost 1: \$TBD

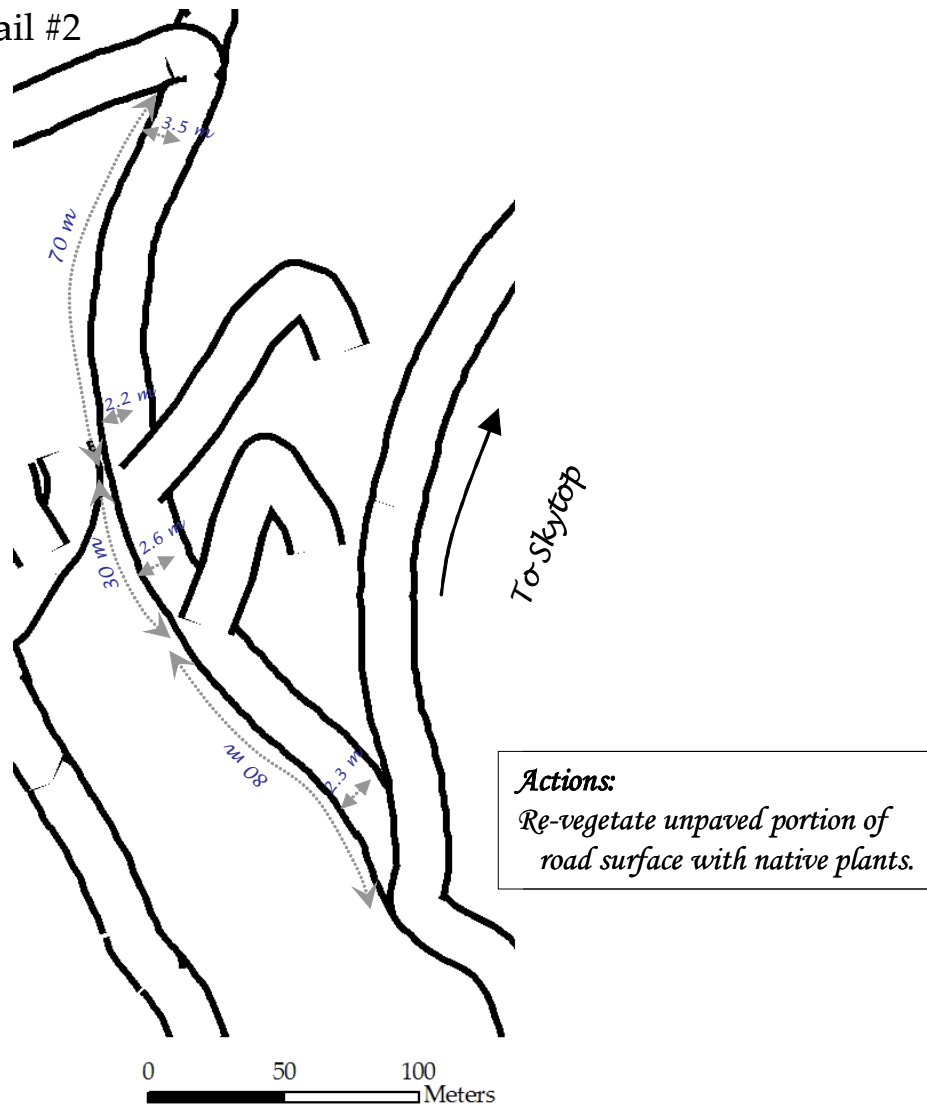
Expected effectiveness: TBD

Monitoring sites: 0





### Cocoloba Trail #2



## CARIBE ROAD AT MARINA DRIVE

### Existing conditions

A. 61 m long x 4.5 m wide = 275 m<sup>2</sup>

& 35 m x 2.5 m = 90 m<sup>2</sup>

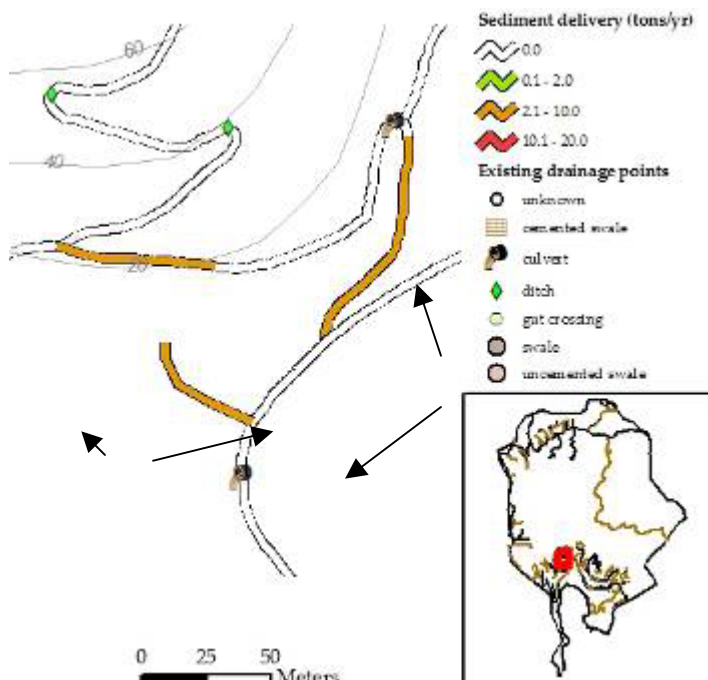
Mean slope = 11%

Sed. contribution = 4.5 tons yr<sup>-1</sup>

B. 91 m long x 4.0 m wide = 365 m<sup>2</sup>

Mean slope = 6%

Sed. contribution = 2.4 tons yr<sup>-1</sup>



Interested stakeholders: Estate FB HO

### Priority 1

#### Suggested BMP's

A. Method 1: 1 grill-box culvert

1 water bar

2 deflectors

Method 2: ~100 m<sup>2</sup> re-vegetation

Cost 1: \$TBD

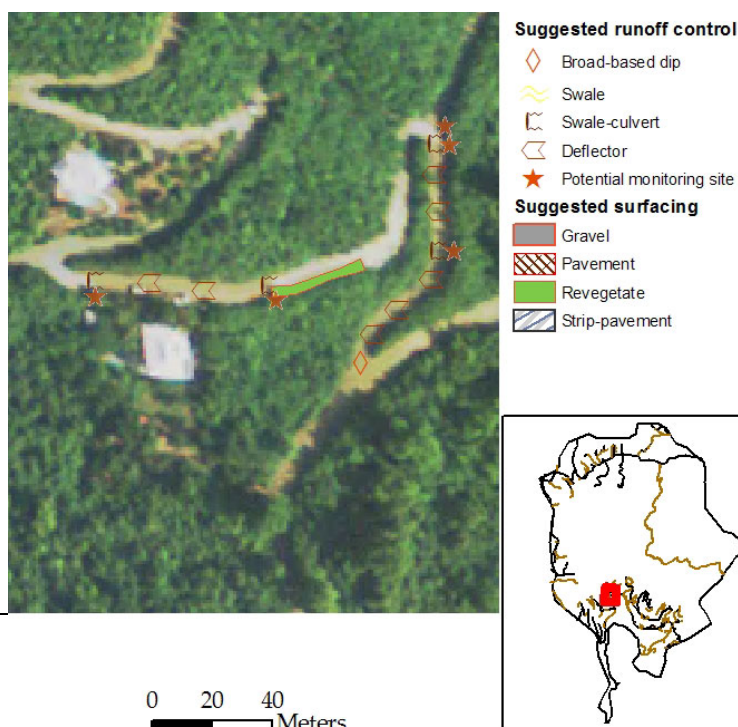
Cost 2: \$TBD

Expected effectiveness: TBD

Monitoring sites: 2

B. Method 1: 1 grill-box culvert

1 water bar or pipe  
culvert



4 deflectors

1 existing broad-based dip

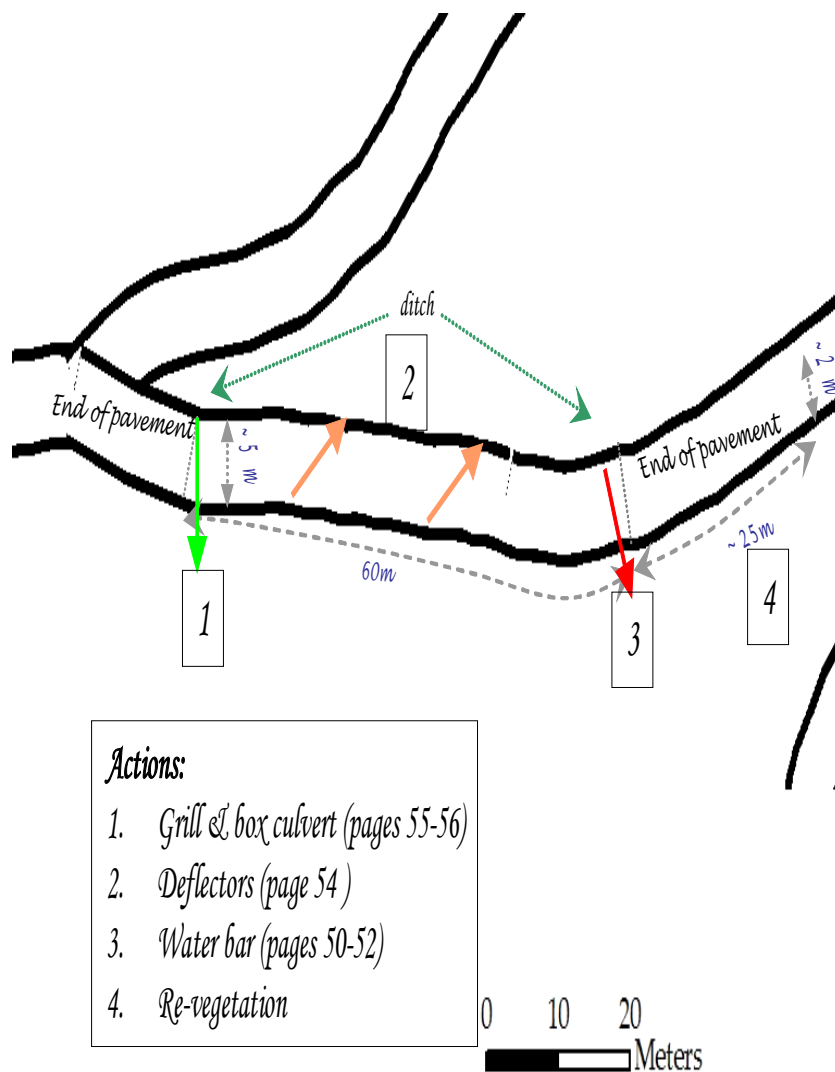
*Cost 1: \$TBD*

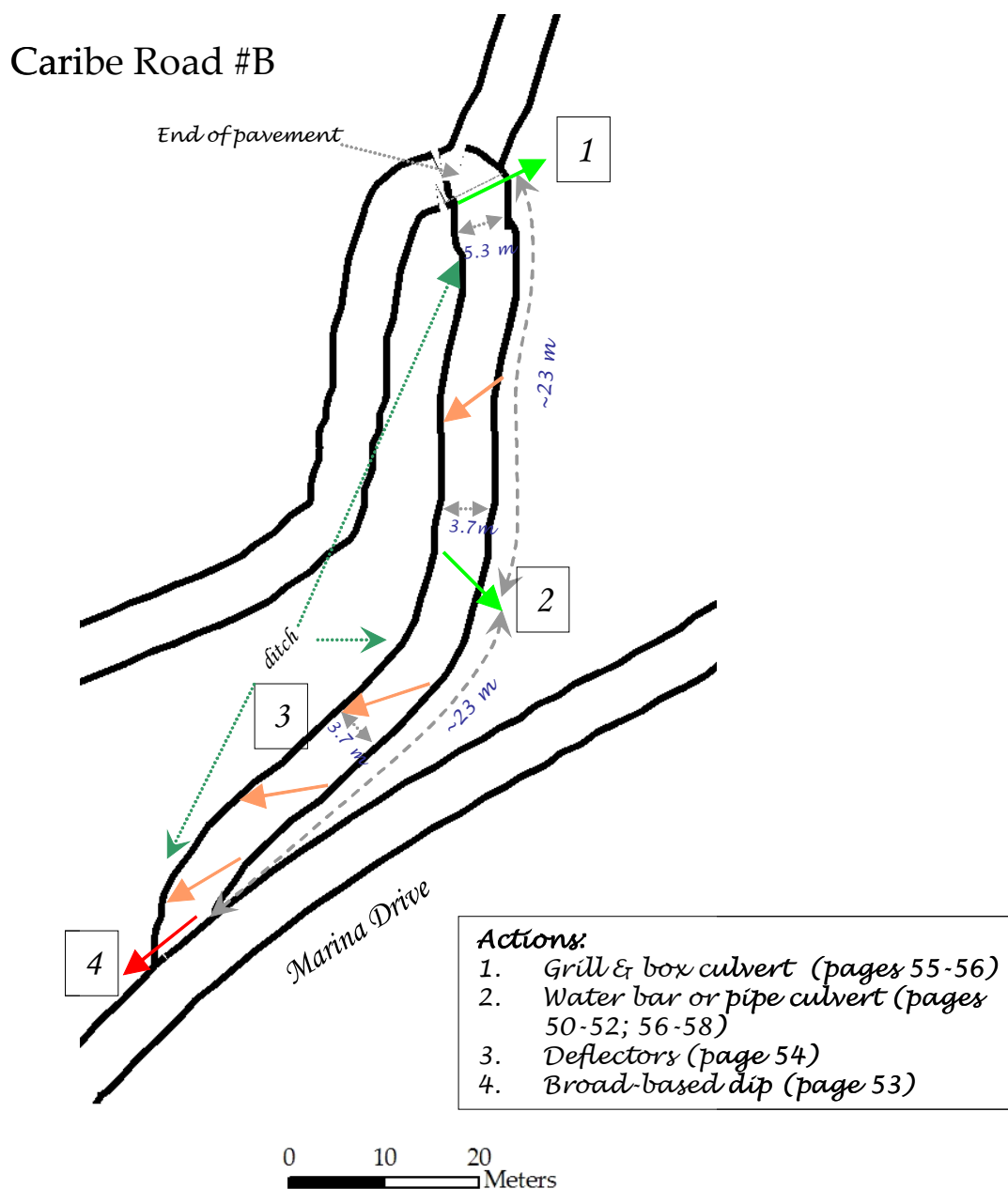
*Cost 2: \$TBD*

*Expected effectiveness: TBD*

*Monitoring sites: 3*

## Caribe Road #A





## JOHN HEAD ROAD AT VINP SUPERINTENDENT'S RESIDENCE

### Existing conditions

A. 155 m x 3.3 m wide = 510 m<sup>2</sup>

Mean slope = 13%

Sed. contribution = 4.0 tons yr<sup>-1</sup>

B. 145 m long x 4.0 m wide = 580 m<sup>2</sup>

Mean slope = 2%

Sed. contribution = 0.6 tons yr<sup>-1</sup>

C. 100 m long x 3.8 m wide = 380 m<sup>2</sup>

Mean slope = 6%

Sed. contribution = 2.4 tons yr<sup>-1</sup>

Interested stakeholders: VINP & Catherineberg  
HO

Priority 1

### Suggested BMP's

A. Method 1: 6 deflectors

Cost 1: \$TBD

Expected effectiveness: TBD

Monitoring sites: 3

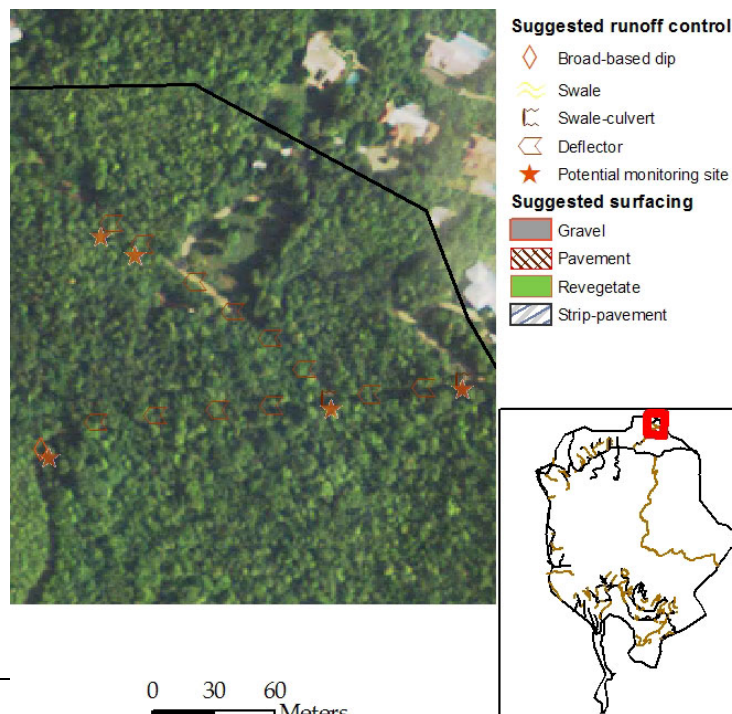
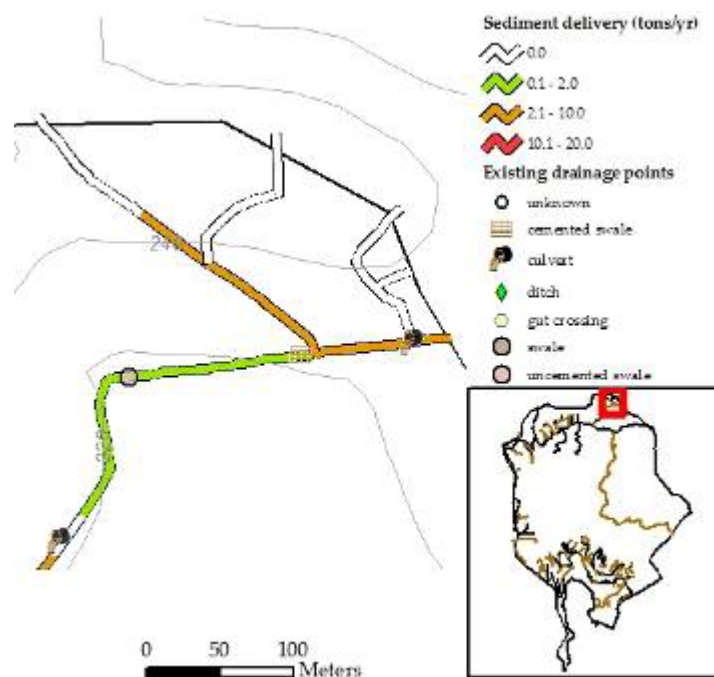
B. Method 1: 1 grill-box culvert

4 deflectors

1 existing dip

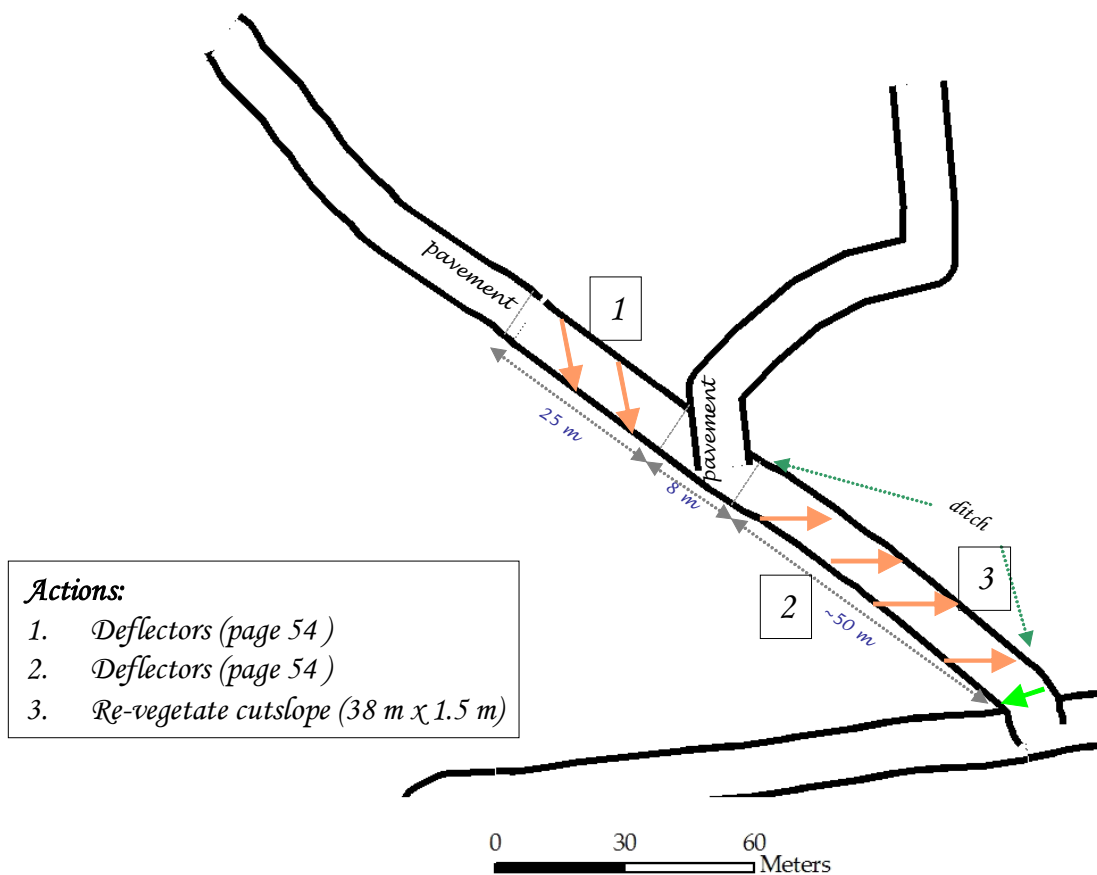
Cost 1: \$TBD

Expected effectiveness: TBD

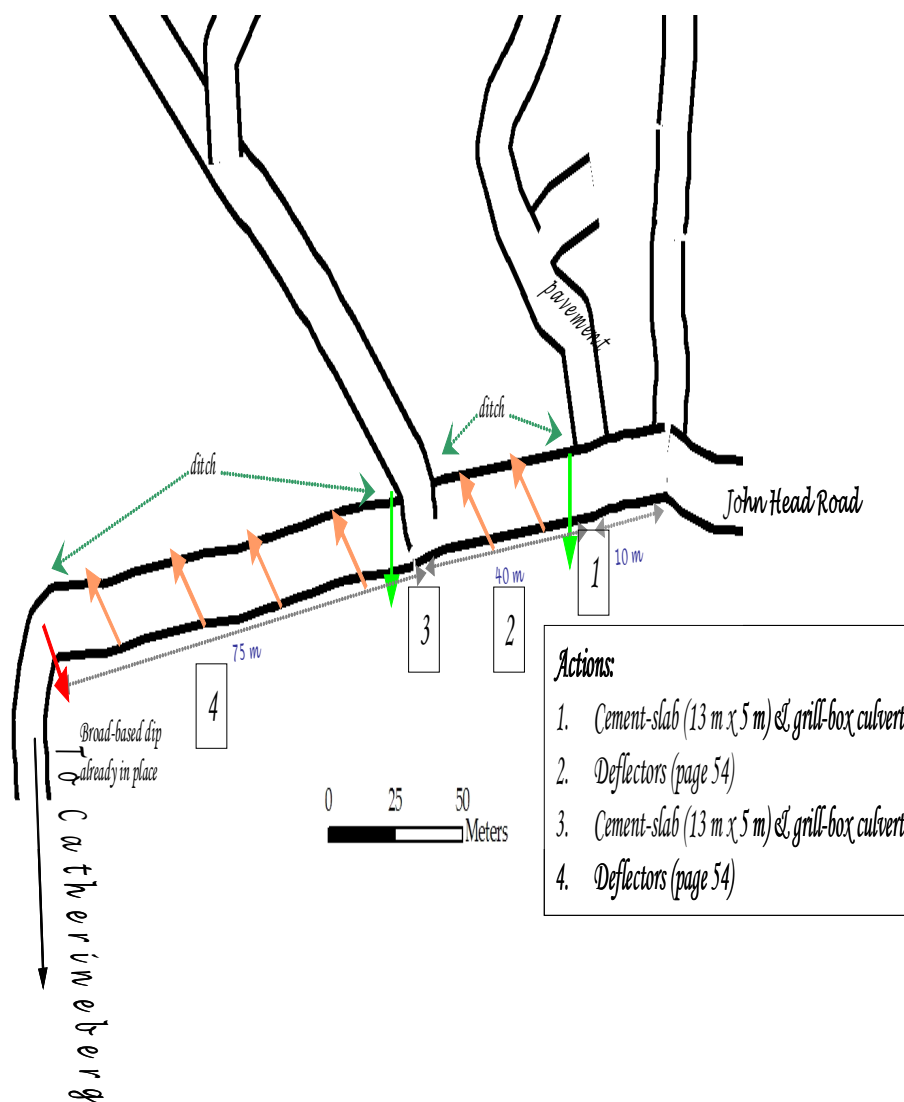




## John Head at Catherineberg # A



# John Head at Catherineberg #B & C



## ***Appendix B-2***

### ***Additional Erosion Control Recommendations***

## MARINA DRIVE AT SMALL DOCK

### Existing conditions

A. 92 m long x 4.0 m wide = 370 m<sup>2</sup>

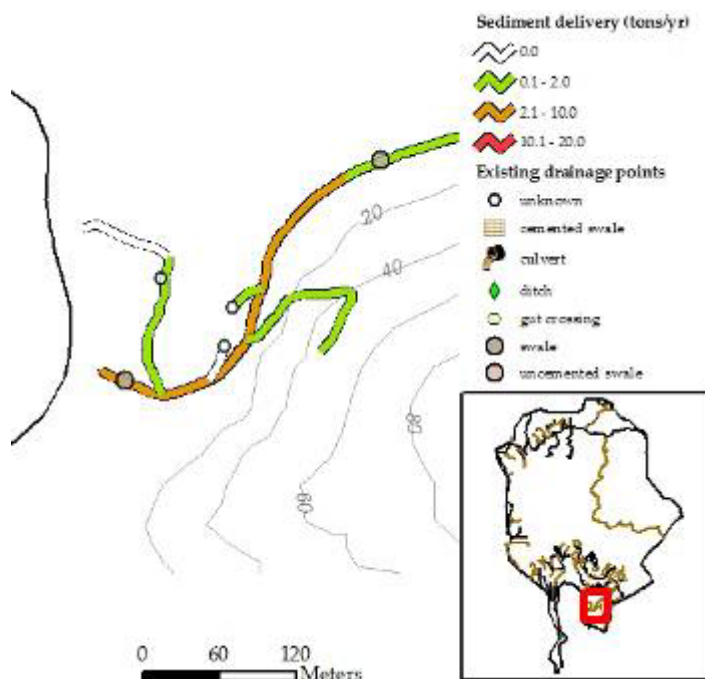
Mean slope = 17%

Sed. contribution = 5.8 tons yr<sup>-1</sup>

B. 160 m x 5.4 m wide = 865 m<sup>2</sup>

Mean slope = 13%

Sed. contribution = 5.9 tons yr<sup>-1</sup>



Interested stakeholders: Estate FB HO

Priority 1

### Suggested BMP's

A. Method 1: 92 m strip-pavement

Method 2: 1 swale

Cost 1: \$TBD

Cost 2: \$TBD

Expected effectiveness: TBD

Monitoring sites: 0

B. Method 1: 160 m strip-pavement

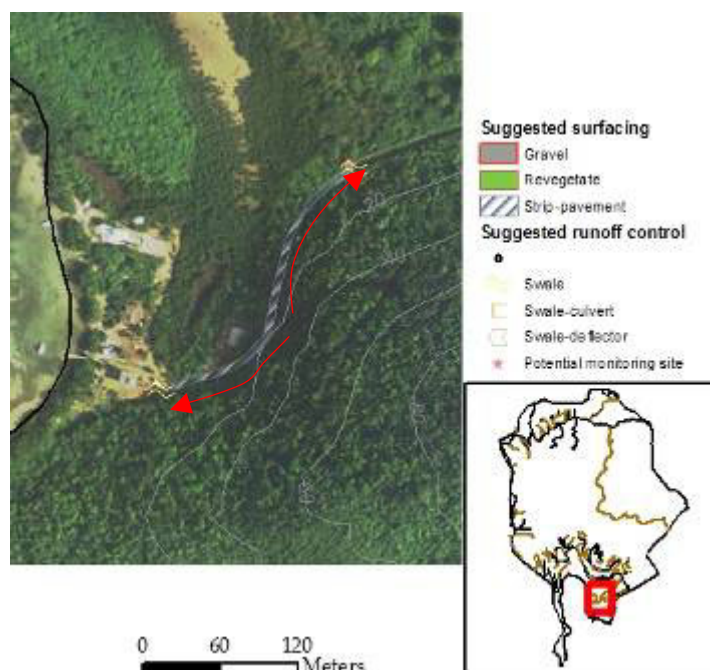
Method 2: 1 swales

Cost 1: \$TBD

Cost 2: \$TBD

Expected effectiveness: TBD

Monitoring sites: 1





## NEW PRIVATE DRIVEWAYS ALONG COCOLOBA TRAIL

### Existing conditions

A. 120 m long x 3.5 m wide = 420 m<sup>2</sup>

Mean slope = 20% (estimated)

Sed. contribution = 17.4 tons yr<sup>-1</sup>

B. 100 m long x 3.5 m wide = 350 m<sup>2</sup>

Mean slope = 20% (estimated)

Sed. contribution = 14.6 tons yr<sup>-1</sup>

Interested stakeholders: Estate FB HO &

Skytop PO, unidentified private owners

Priority 2

### Suggested BMP's

A. Method 1: 420 m<sup>2</sup> pavement or  
120 m strip-pavement

Method 2: 1 swale

Cost 1: \$TBD

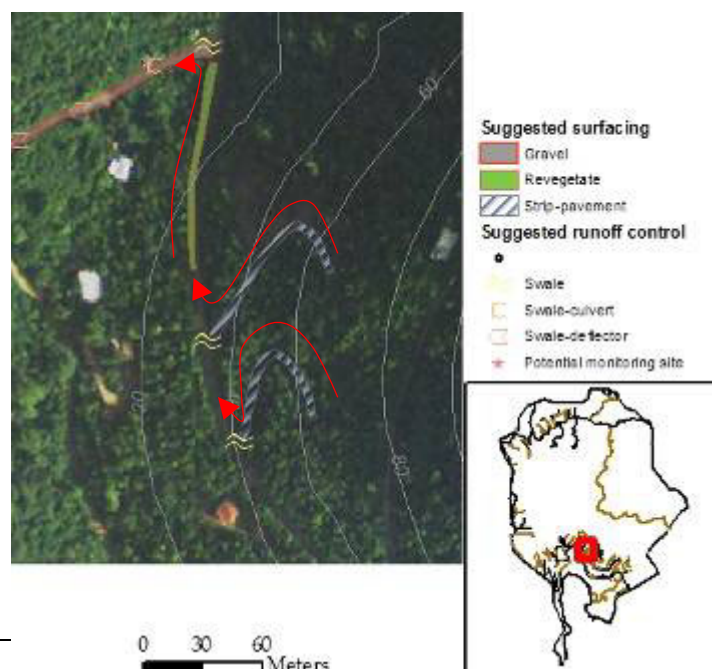
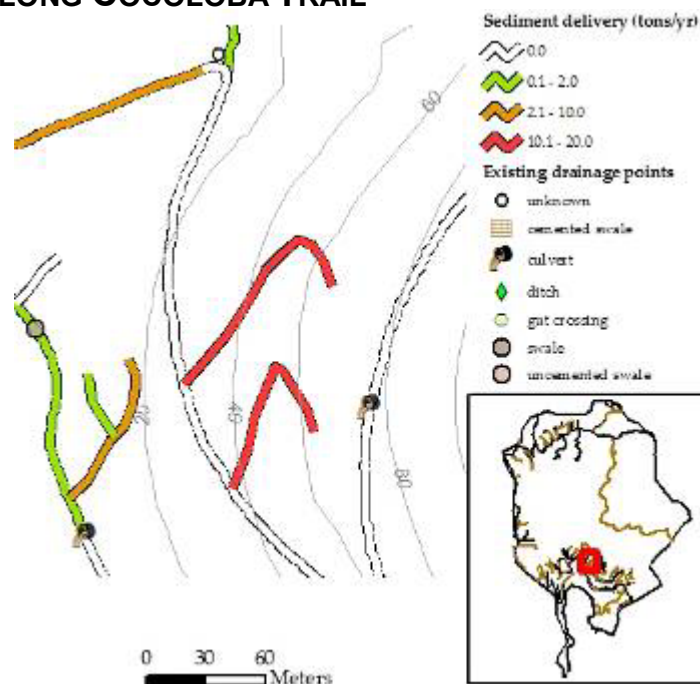
Cost 2: \$TBD

Expected effectiveness: TBD

Monitoring sites: 0

B. Method 1: 350 m<sup>2</sup> pavement or  
100 m strip-pavement

Method 2: 1 swale



*Cost 1:* \$TBD

*Cost 2:* \$TBD

*Expected effectiveness:* TBD

*Monitoring sites:* 0

## UPPER Z-ROAD

### Existing conditions

- A. 64 m long x 2.8 m wide = 180 m<sup>2</sup>

Mean slope = 15%

Sed. contribution = 4.7 tons yr<sup>-1</sup>

- B. 84 m long x 2.8 m wide = 235 m<sup>2</sup>

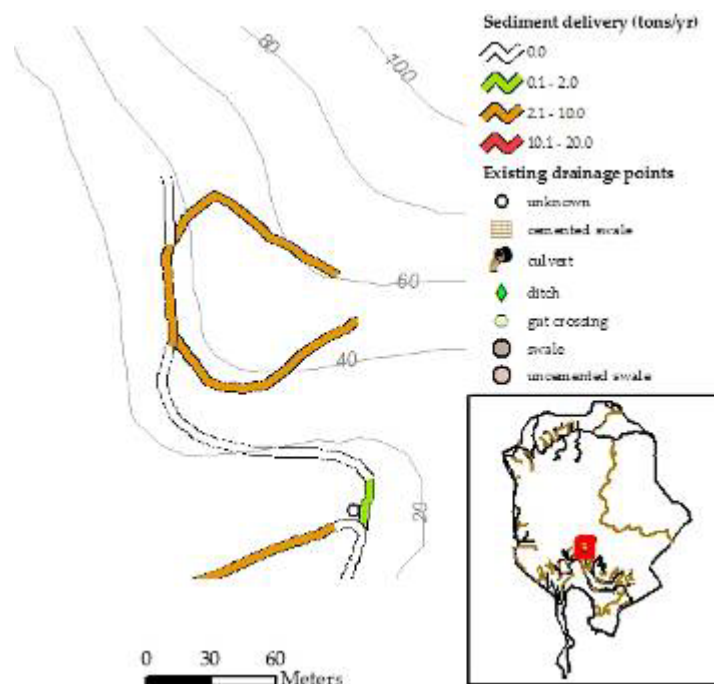
Mean slope = 14%

Sed. contribution = 2.1 tons yr<sup>-1</sup>

- C. 110 m long x 3.8 m wide = 420 m<sup>2</sup>

Mean slope = 14%

Sed. contribution = 3.6 tons yr<sup>-1</sup>



Interested stakeholders: Estate

FB HO, & unidentified private homeowners

Priority 1

### Suggested BMP's

- A. Method 1: 300 m<sup>2</sup> gravel

Method 2: 1 swale or deflector

Cost 1: \$TBD

Cost 2: \$TBD

Expected effectiveness: TBD

Monitoring sites: 1

- B. Method 1: 235 m<sup>2</sup> pavement or

84 m strip-pavement

Method 2: 1 swale or culvert

Cost 1: \$TBD

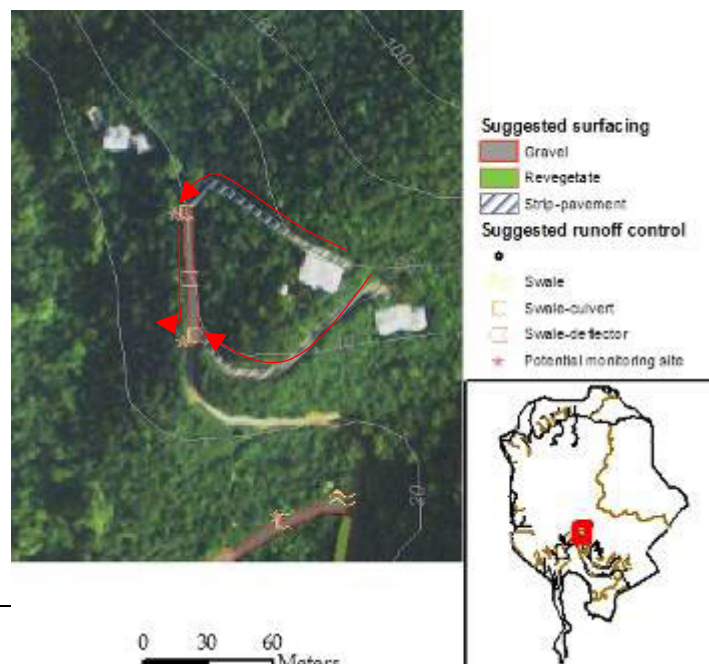
Cost 2: \$TBD

Expected effectiveness: TBD

Monitoring sites: 1

- C. Method 1: 420 m<sup>2</sup> pavement or

110 m strip-pavement



*Method 2:* 1 swale or culvert

*Cost 1:* \$TBD

*Cost 2:* \$TBD

*Expected effectiveness:* TBD

*Monitoring sites:* 0

## NEW ST. JOHN HIGH SCHOOL

### Existing conditions

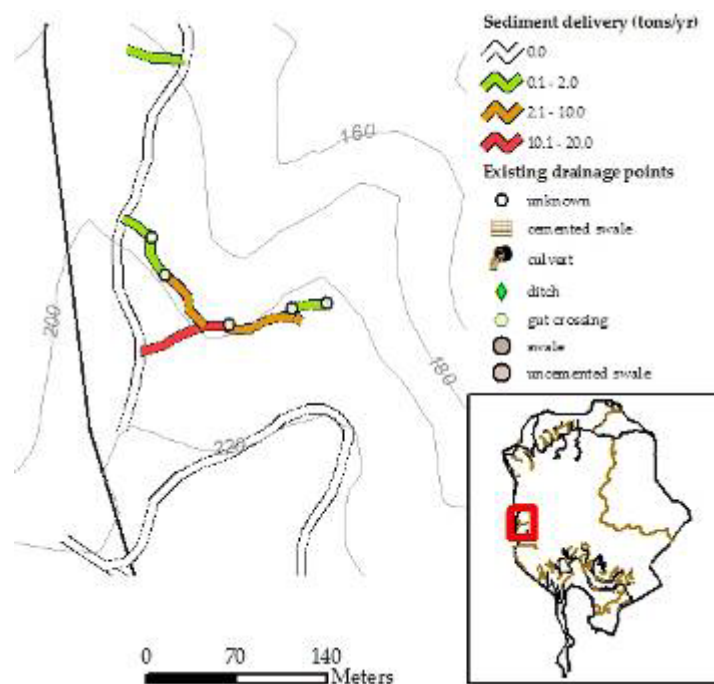
A. ~ 275 m x 6.3 m wide = 1,725 m<sup>2</sup>

Mean slope = 2 – 17%

Sed. contribution = 28 tons yr<sup>-1</sup>

Interested stakeholders: Unknown

Priority 2



### Suggested BMP's

A. Method 1: ~ 1,500 m<sup>2</sup> pavement

Method 2: 1 swale, 3 culverts

Method 3: Reduce road width and re-vegetate disturbed surfaces

Method 4: Porous pavement on areas to be used for parking

Cost 1: N/A

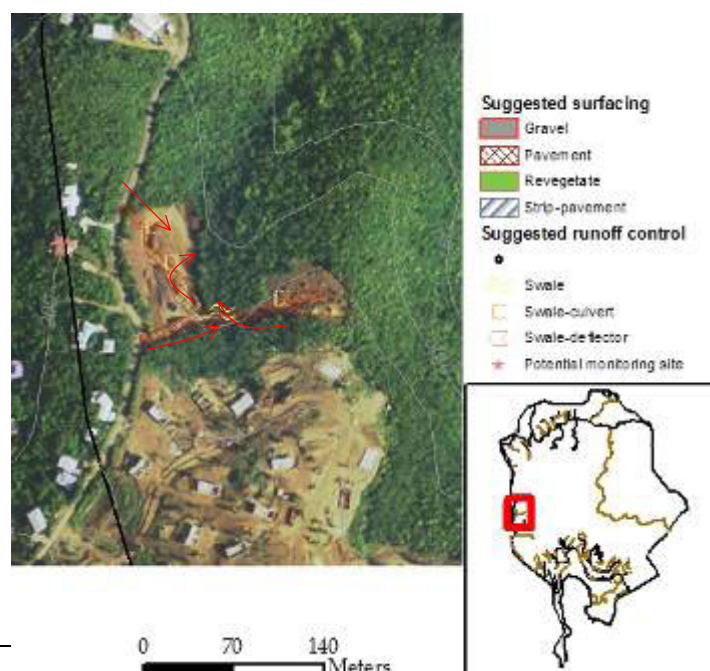
Cost 2: N/A

Cost 3: N/A

Cost 4: N/A

Expected effectiveness: TBD

Monitoring sites: 0





## UPPER FISH BAY AT CENTERLINE

### Existing conditions

A. 190 m x 3.4 m wide = 650 m<sup>2</sup>

Mean slope = 8%

Sed. contribution = 2.4 tons yr<sup>-1</sup>

B. 180 m long x 3.4 m wide = 615 m<sup>2</sup>

Mean slope = 12%

Sed. contribution = 4.3 tons yr<sup>-1</sup>

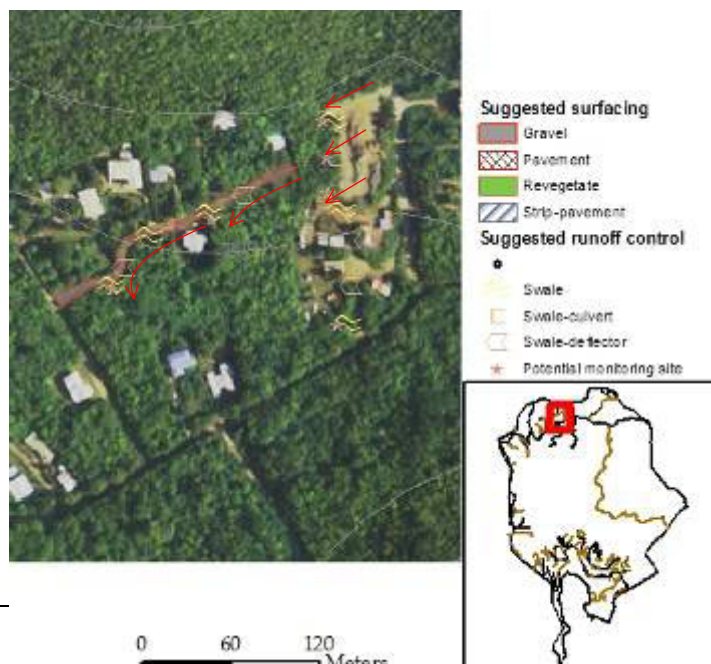
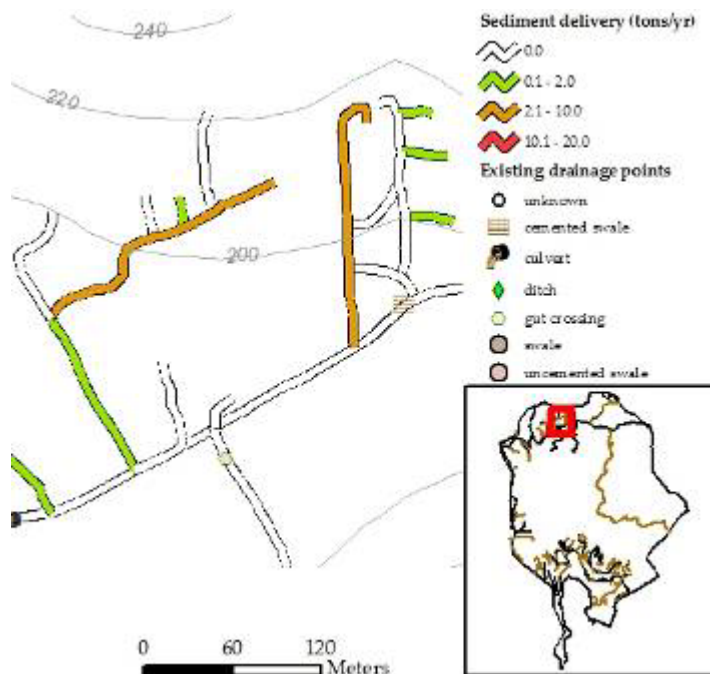
Interested stakeholders: Unknown

Priority 2

### Suggested BMP's

A. Method 1: 650 m<sup>2</sup> gravel  
Method 2: 3 swales, 2 swales or deflectors  
Cost 1: \$TBD  
Cost 2: \$TBD  
Expected effectiveness: TBD  
Monitoring sites: 2

B. Method 1: 3 swales, 4 swales or deflectors  
Cost 1: \$TBD  
Cost 2: \$TBD  
Expected effectiveness: TBD  
Monitoring sites: 4





## JOHN HEAD ROAD AT CATHERINEBERG RUINS

### *Existing conditions*

A. 40 m x 4.0 m wide = 160 m<sup>2</sup>

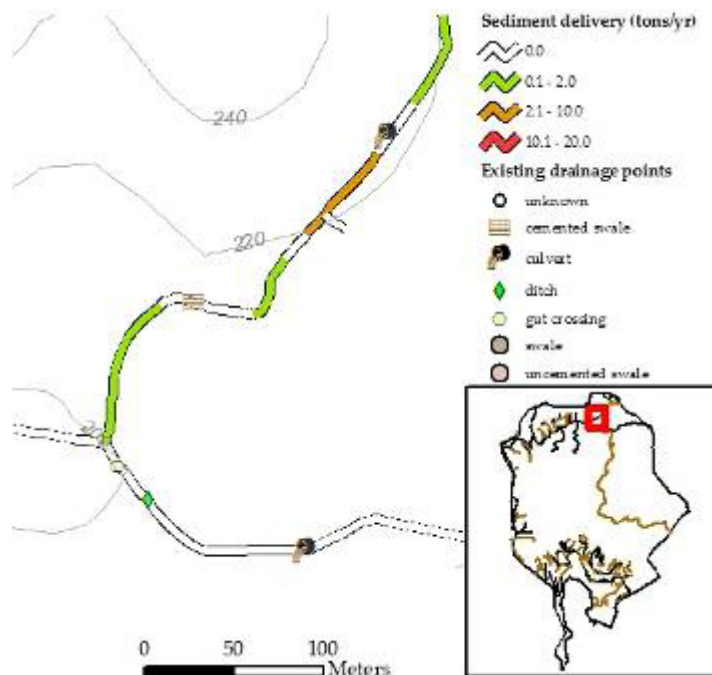
*Mean slope* = 5%

*Sed. contribution* = 0.7 tons yr<sup>-1</sup>

B. 60 m long x 4.3 m wide = 615 m<sup>2</sup>

*Mean slope* = 11%

*Sed. contribution* = 4.3 tons yr<sup>-1</sup>



*Interested stakeholders:* VINP & Catherineberg HO

*Priority* 1

### *Suggested BMP's*

A. *Method 1:* 1 swale

*Cost 1:* \$TBD

*Expected effectiveness:* TBD

*Monitoring sites:* 1

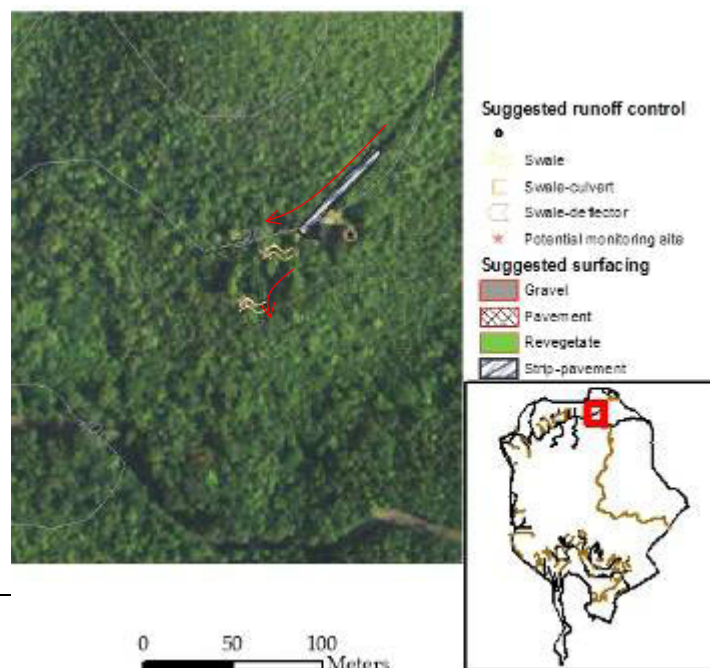
B. *Method 1:* 60 m strip-pavement

*Method 2:* 1 swale

*Cost 1:* \$TBD

*Cost 2:* \$TBD

*Expected effectiveness:* TBD



*Monitoring sites: 1*

## ***Appendix C***

### ***Description of Erosion Control Best Management Practices***

#### **Runoff Control Structures & Secondary Road Surfacing Options**

##### ***Runoff Control Structures***

###### **WATERBARS**

Road construction often requires the clearing of long strips of right-of-way over sloping terrain. The volume and velocity of storm water runoff tend to increase in these cleared strips and the potential for erosion is much greater since the vegetative cover is diminished or removed. To compensate for the loss of vegetation, it is usually a good practice to break up the flow length within the cleared strip so that runoff does not have an opportunity to concentrate and cause erosion. At proper spacing intervals, water bars can significantly reduce the amount of erosion which will occur until the area is permanently stabilized.

###### **Design Criteria**

1. *Drainage Area* - Less than 1.0 acre (0.40 hectare).
2. *Dimensions* - The minimum allowable height measured from the channel bottom to the ridge top is 18 in (457 mm). The minimum top width shall be 18 in (457 mm) and the base width minimum is 6 ft (1.8 m).
3. *Side Slopes* - 3:1 or flatter to allow the passage of traffic.
4. *Width* - The measure should be constructed completely across the disturbed portion of the right-of-way.
5. *Spacing* – See Table 1.

In most instances, waterbars are used to divert water from roads that are not heavily trafficked. A heavily trafficked road in this case may be considered as a secondary road and/or path such as the many types that lead to homes in St. John. However, this concept can also be modified for more heavily-used roads.

Water bars may be either a mound or a trench used to divert runoff from roads to more stable areas and these are built into the surface across the road. Water bars are also classified as deep or shallow.

The general standards for deep waterbars are:

- ❖ Mound 24 to 30 inches high
- ❖ Trench 6 to 10 feet wide

The general standards for shallow waterbars are:

- ❖ Mound 8 to 12 inches high
- ❖ Trench 6 to 12 feet wide

Water bars should be installed at about a 30° angle downslope.

Guidelines to determine the distance between waterbars on a long stretch of road is given in table 1.0 below. The erosion control strategies that suggest the use of waterbars in Fish Bay were defined following stricter guidelines (i.e., waterbars placed closer together) than the ones in table 1.0.

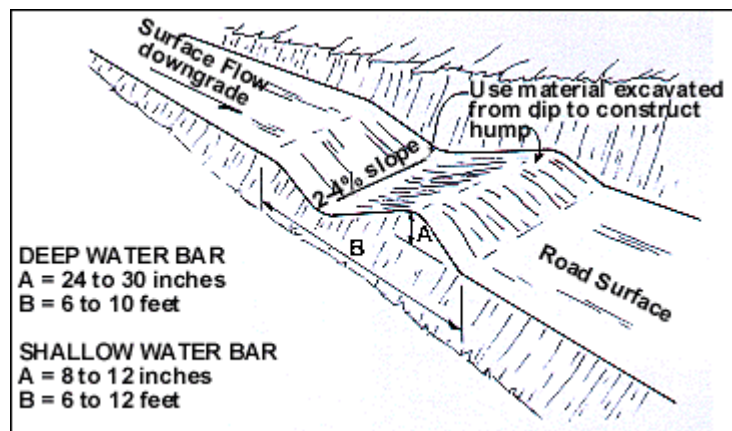


*Figure A: Water bars are narrow structures that may be shallow or deep. Deep water bars are usually used on roads that will be closed for extended periods.*

| Road Grade | Distance Between Waterbars | Distance Between Broad-based Dips and Cross-drain Culverts |
|------------|----------------------------|------------------------------------------------------------|
| 1%         | 400 Feet                   | 500 Feet                                                   |
| 2%         | 250 Feet                   | 300 Feet                                                   |
| 5%         | 130 Feet                   | 180 Feet                                                   |
| 10%        | 80 Feet                    | 150 Feet                                                   |
| 15%        | 50 Feet                    | 130 Feet                                                   |
| 25%+       | 40 Feet                    | 110 Feet                                                   |

*Table 1.0: Recommended distances between drainage structures on forest roads and skid trails<sup>1</sup>.*

For additional details on waterbar construction see the PDF link at [http://www.oregon.gov/ODF/PRIVATE\\_FORESTS/docs/fp/WaterbarsFPNote1.pdf](http://www.oregon.gov/ODF/PRIVATE_FORESTS/docs/fp/WaterbarsFPNote1.pdf)

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**Planning Considerations** (Taken from  
<http://grapevine.abe.msstate.edu/Tools/csd/NRCS-BMPs/pdf/water/erosion/waterbar.pdf>)

### BROAD-BASED DRAINAGE DIPS



These structures provide alternatives to waterbars on long stretches of roads with less than 10% slope. These allow for easier access, less wear and tear and do not slow significantly slow the speed of the vehicles. For construction specifications for broad-based drainage dips see diagrams below:

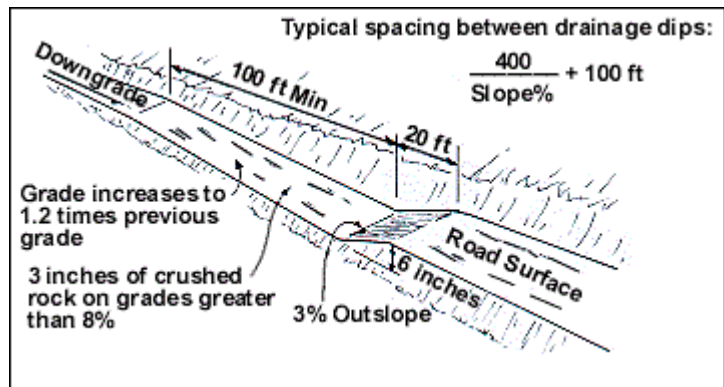


Fig. B: Broad-based drainage dip specifications.

**Photo A:** An example of broad-based drainage dip.  
Notice how the road gently dips to allow water to flow.

The recommended spacing distance between the dips are as follows:

| Table 7. Distance needed between water bars |                 |
|---------------------------------------------|-----------------|
| Road grade (percent)                        | Distance (feet) |
| 2 - 4                                       | 300 - 200       |
| 5 - 7                                       | 180 - 160       |

|        |           |
|--------|-----------|
| 8 - 10 | 150 - 140 |
|--------|-----------|

Table 2.0: Distances between waterbars.<sup>1</sup>

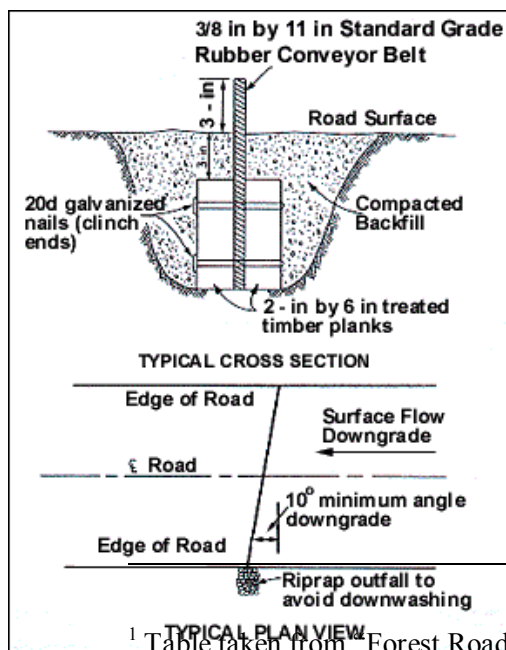
To calculate these distances, the following formula is employed:

$$\text{Spacing in feet} = \frac{400}{\text{Slope percent}} + 100$$

Existing roads can be reversed engineered for broad-based drainage dips, especially on areas where road construction and placement have reversed the drainage and flow patterns of runoff. They may also be used as a complementary measure to other forms of erosion and sediment control.

### DEFLECTORS

These are low-cost and low-maintenance alternatives to direct water from road surfaces. Though they may be inadequate for most steep roads on St. John they may be suitable for some of the more or less gently sloping road stretches.



Deflectors consist of piece of rubber belting 5/16 inch to 1/2 inch thick fastened between treated timbers. Different widths of belting can be used depending on the volume and rate of runoff and on availability of material.

It's designed in such as way that the only thing showing above the road is the strip of rubber. The design and implementation is somewhat similar to open culvert. They are angled downhill to help move the water off the road as fast as possible.

<sup>1</sup> Table taken from "Forest Road Construction and Maintenance."

Figure 1a below shows the design and specifications for a typical deflector. These specifications may be modified to suit local conditions.

Island Resources Foundation already has several 50-ft rolls of the rubber material in St. John and will be donating it for use in this project.

*Fig. C. Deflector design.*



*Photo B: Example of a deflector.*

### HUMPS

These are raised sections along the road that create lengths of reverse grades that force the water running along roads off to the side. They may coincide with waterbars and may also be classed as one form of these erosion control devices.

### CULVERTS

#### Open Top and Pole Culverts

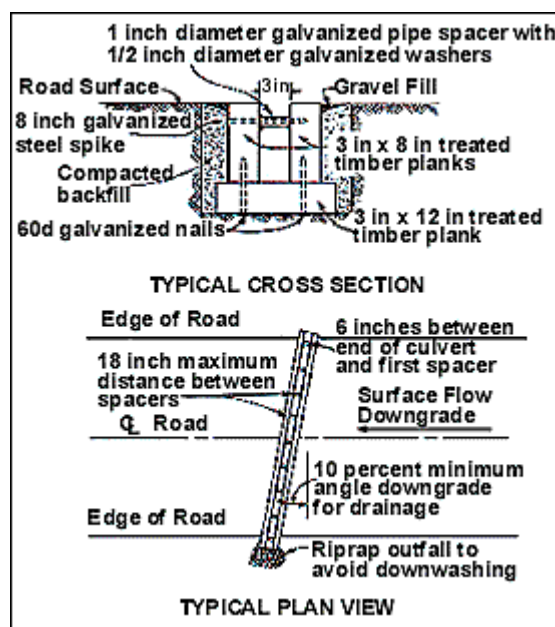
Though not generally recommended for Fish Bay due to the relatively higher rainfall levels than some areas in the U.S., open top culverts may prove useful for some landowners living in basin areas with gently sloping driveways and access roads.

Open top culverts and pole culverts are inexpensive and easy to construct alternatives to more costly and high-maintenance structures. Open top and pole culverts are not recommended for crossing live or intermittent streams, and should not be used in lieu of pipe culverts.

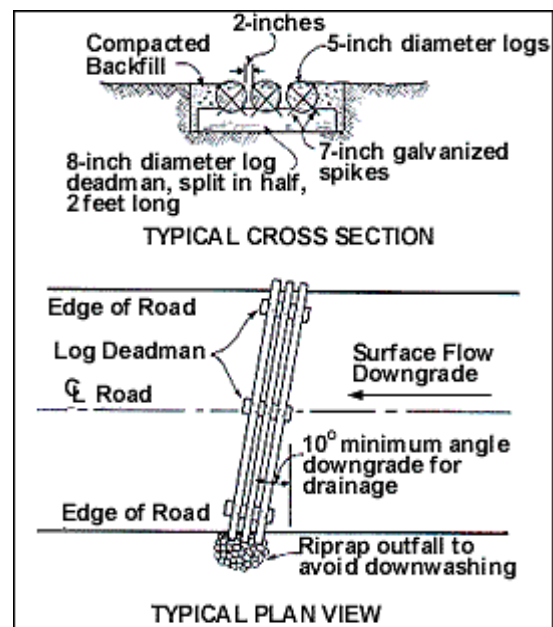
Specifications for installation and use of open top and pole culverts follow:

1. Install culverts flush or just below the road surface and angled 10° to 45° downgrade. More maintenance may be required as the angle approaches 10°, 30° to 45° is often times recommended, but this adds length to the culvert.
2. Upper end should be at the same grade as the side ditch and extend into toe of upslope bank.
3. The outlet will extend beyond the road surface with adequate riprap or other material to dissipate water velocity to prevent erosion of fill material.
4. Spacing is the same as for broad-based drainage dips.
5. Use is limited to low water flows and to roads located on flat ground with minimal fill.
6. They are recommended for ongoing operations only and should be removed upon completion of activities.

Diagrammatic representations of Open and Pole Culverts are below.



*Open-top culvert.*



*Pole culvert.*

### PIPE CULVERTS

A conduit placed under roads to divert water from streams, intermittent waterways and drains on one side to the downhill area.

The option to use culverts as opposed to other types of control measures is based in part on the expected traffic and the number of acres being drained.

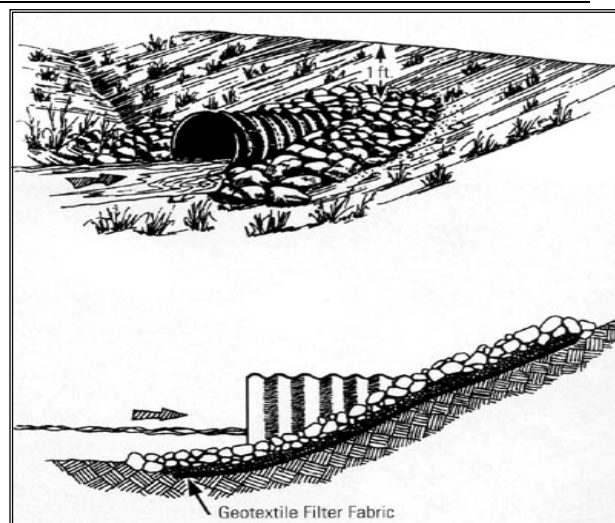
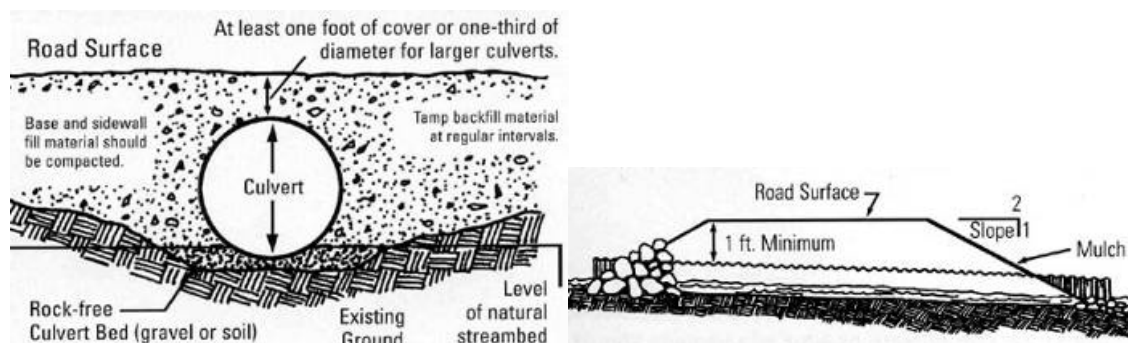


*Fig. F. Culvert construction and layout.*



*Figs. G. Recommended specifications for culvert construction and layout.*

| Area above pipe (acres) | Pipe Diameter (inches) |
|-------------------------|------------------------|
| 5                       | 18                     |
| 10                      | 24                     |
| 20                      | 27                     |
| 30                      | 30                     |

|     |    |
|-----|----|
| 40  | 36 |
| 50  | 36 |
| 75  | 42 |
| 100 | 48 |
| 150 | 54 |

*Table 3. Recommended diameters of culverts based on drainage area.*

Culvert diameter recommendations are based on medium soils. Light sandy soils would require smaller culverts and heavy clay soils would require larger culverts.

Culvert spacing can be determined by the following formula:

$$\text{Spacing} = 400' / \text{Slope \%} + 100 =$$

Slope in percent expressed as a whole number (i.e.: 15% = 15)

| Grade (Percent) | Spacing (Feet) |
|-----------------|----------------|
| 1               | 500            |
| 2               | 300            |
| 4               | 200            |
| 6               | 167            |
| 8               | 150            |
| 10              | 140            |
| 12              | 133            |
| 14              | 129            |

*Table 4. Guide for spacing between culverts.*

### GENERAL DRAINAGE GUIDELINES

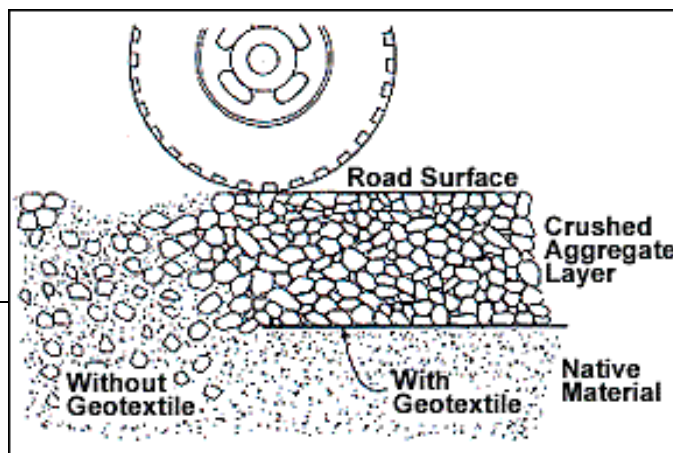
The following suggestions are made to promote suitably drained roads and haul tracks:

- ❖ Concave road surface should be maintained at all times.
- ❖ The installation of culvert pipes, and minimum earth fill over them, should be in accordance with manufacturer's guidelines (e.g., 600 mm for reinforced concrete pipe).
- ❖ Culvert pipes should be a minimum of 600 mm below the apex of the road surface at the time of construction (Figure 6-2).
- ❖ Side drainage for table drains. Side drain grade is 1-3%.
- ❖ Where high-water flow velocities are expected in high and very highly erodible soils, drains may require special treatment such as lining with stones, concrete, grass etc to reduce scouring.
- ❖ Where unacceptable erosion of a road cutting face is likely, catch-drains should be constructed along the top sides of the cuttings to collect surface run-off. Such drains should be gently graded and/or protected against scouring, particularly in the more erodible soils.
- ❖ Table drains should be dish-shaped and constructed to a minimum depth of 300 mm below the level of the top of the formation at the outer edge of the shoulder.
- ❖ Adequate provision will be made at culvert inlets and outlets to minimize erosion being caused by flow entering or discharging from the drain.
- ❖ Adequate provision of sumps or silt traps will be made to prevent salutation and blocking of culverts in highly erodible soils (Figure 6-3).
- ❖ Culvert pipes should be laid on a grade of between 1% and 3% to minimize silting up of the pipes and excessive scouring at the outflow.
- ❖ Outflow drains are not to directly enter watercourses but should be diverted into surrounding vegetation at least 50 m before a watercourse.

### **ROAD SURFACING OPTIONS**

#### GEOTEXTILES

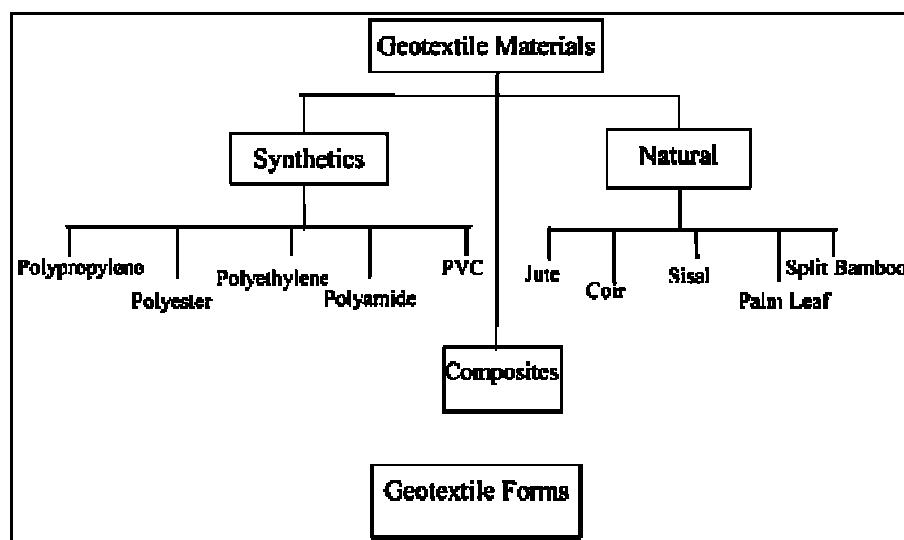
These are synthetic permeable textile materials used with rocks, gravel and other pavement materials for road construction, maintenance and drainage. Though often used on tertiary or heavily used roadways, they can also be used on secondary roads to reduce potholing and increase seepage of runoff



through the road surface thereby reducing the energy of the water and the likelihood of erosion and sedimentation.

*Figure H. above is an example of the use of a geotextile.*

The flow chart below shows several different types of geotextiles:



For our purposes, we would use synthetic textiles for road surfacing and naturals for mulching, although some sort of wood, grass or other vegetation fibers may be much more suitable for our purposes.

For resurfacing of secondary roads we would need geotextiles of moderate to strong textile strengths <sup>2</sup>. The following is recommended as a guide:

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<sup>2</sup> For further details on the use, types and requirements for geotextiles see *Geosynthetics Design Manual*:  
<http://www.wsdot.wa.gov/EESC/Design/DesignManual/desEnglish/530-E.pdf>

|                 | Required Characteristics |               |            |
|-----------------|--------------------------|---------------|------------|
|                 | Strength                 | Low Extension | Durability |
| Erosion Control | Ö                        |               | Ö to ÖÖ    |
| Agro-mulching   |                          |               | Ö          |
| Un-paved Roads  | ÖÖ                       | ÖÖ            | ÖÖÖ        |

KEY: Important: (ÖÖÖ); Less important (Ö); Not important ( ).

The estimated cost for geotextiles is listed below. Please note that the cost of these materials is very volatile, especially in the Virgin Islands.

| Application                      | Price              |
|----------------------------------|--------------------|
|                                  | US \$ per sq meter |
| <b>Erosion Control</b>           |                    |
| Synthetic                        | 1.00 - 3.00        |
| Wood-fiber/Straw                 | 0.55 - 1.10        |
| Jute                             | 0.30 - 1.00        |
| Coir                             | 0.90 - 2.20        |
| <b>Agro-mulching</b>             |                    |
| Plastic film (not geotextile)    | 0.10 - 0.25        |
| <b>Un-paved roads/separators</b> |                    |
| Synthetic                        | 3.00 - 5.00        |
| Jute                             | 0.60 - 1.00        |
| Coir                             | 0.90 - 2.20        |

### SEEDING AND MULCHING

Vegetative and post-harvest organic materials are also an option to help reduce sedimentation, increase water infiltration and reduce erosion. The US Department of Agriculture (USDA), through its Natural Resources Conservation Service (NRCS) arm and also the UVI Cooperative Extension maintain standards and procedures for seeding and mulching, including seed and mulching mixtures, types and species and applications.

For seeding, both live plants as well as seeds may be used. Live plants require the use of nursery seedlings rather than cuttings. This ensures a greater survival rate.

Seeding could either be done by hand or using a seeder/hydro seeder. The latter is far more expensive.

For both live plantings and seeding, prior planning would include the selection of appropriate species of plants (preferably native non-invasive species), drought resistant, fast growing and unpalatable species that are readily available and require little or no maintenance.

These should be established in the nursery months before they are to be planted.

For site preparation, this would require the selected/target area be cleared of obstructive materials and debris, tilled to allow planting and the establishment of stock, and moistened.

After planting, they should be mulched and watered. Watering should be done periodically or as needed until plants are established and independent. Some fertilizing may be needed for up to three years after planting.

For seeding, similar preparations are needed except that mulching would be done during or prior to planting.

Exact guidelines and specifications can be had from the NRCS and UVI Cooperative Extension Service, which provide assistance for local sources and types of mulch (these include wood fiber, coconut fiber, straw, excelsior, nylon or nylon with paper. UVI-CES recommends 1000 – 2000 pounds per acre.

Because these are specialty plants, no nurseries are likely to carry the species that we need so we may have to request that a local nursery prepare seedlings or import the species. Costing for this would have to be determined when we decide on the erosion control and treatment measures and select the sites.

We would also want to use local species such as *Wedelia trilobata* and *Talinum*.

#### **PERMEABLE PAVEMENT**

These are permeable structures that allow rainwater to infiltrate while allowing vehicles to drive on. These can vary from simple gravel and other types of aggregates being spread over the surface to both natural and synthetic composites such as concrete blocks and plastic networks being laid down.

For the purpose of Fish Bay, this option is the most expensive, especially when using composite cement blocks and plastics, not only due to the cost of the materials, but also because of the labor and time involved. These should only be considered only as a last resort or where other options are much less favorable.

#### **ROAD RESURFACING**

For our purposes we would only be concerned with gravel for resurfacing applications. For secondary roads the gravel types used are “crusher runs #1 and 3.” These are aggregates that range in sizes from one to ¾ inches. In St. John and St. Thomas, only crusher run #1 is used and is available. This cost \$19/ton, and is available from Rock Island Concrete Inc. at Cruz Bay, telephone 340-775-0605. This company is related to the VI Cement and Building Products of St.

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Thomas. The latter company deals with concrete and other heavy materials while the previous provides the aggregates.

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## Culvert Sizing Guidelines

### Culvert Sizing

#### Stream Size/Site Condition Method

##### Procedure:

- 1) Measure bottom channel width (W) and channel depth (D) from bottom to top of bank.
- 2) Determine whether slope upstream is flat, moderately or extremely hilly and refer to appropriate Table (A-C).  
For areas with no perceptible change in elevation upstream of the culvert area, choose (FLAT) slope.  
In moderately hilly areas, such as a rise of two (2) feet for every 100 feet of run, choose Moderate (MOD) slope.  
In extremely hilly areas, with an approximate rise of the (10) feet or more for every 100 feet of run, choose critical (CRIT) slope.
- 3) Read corresponding culvert size based on width and depth of stream channel.

##### Assumptions:

**Roughness factors:**  
n = 0.030 for channel  
n = 0.024 for CMP culvert

**Slope:**  
FLAT = 0.05%  
MOD = 2.00%  
CRIT = 10.00%

Calculations assume Corrugated Metal Pipes (CMP) which project slightly out of fill.

**Table A: Culvert Diameters (Inches) for Flat Conditions Slopes Upstream 0-0.05%**

| Stream Width (Ft.) | Stream Depth (Ft.) |     |     |     |     |     |      |      |
|--------------------|--------------------|-----|-----|-----|-----|-----|------|------|
|                    | 0.5                | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 3.5  | 4.0  |
| 1                  | 12                 | 12  |     |     |     |     |      |      |
| 2                  | 12                 | 12  | 18  | 24  |     |     |      |      |
| 3                  | 12                 | 15  | 18  | 24  | 30  | 36  |      |      |
| 4                  | 12                 | 18  | 21  | 27  | 33  | 36  | 42   |      |
| 5                  | 12                 | 18  | 21  | 30  | 36  | 42  | 48   | 54   |
| 6                  | 12                 | 21  | 24  | 33  | 42  | 42  | 54   | 60   |
| 7                  | 15                 | 21  | 24  | 36  | 42  | 48  | 60   | 60   |
| 8                  | 15                 | 24  | 30  | 36  | 42  | 54  | 60   | 2-48 |
| 9                  | 15                 | 24  | 33  | 42  | 48  | 54  | 60   | 2-54 |
| 10                 | 18                 | 27  | 36  | 42  | 48  | 60  | 2-42 | 2-54 |

**Table B: Culvert Diameters (Inches) for Moderate Hilly Conditions Slopes Upstream 2-10%**

| Stream Width (Ft.) | Stream Depth (Ft.) |     |           |           |           |           |     |     |
|--------------------|--------------------|-----|-----------|-----------|-----------|-----------|-----|-----|
|                    | 0.5                | 1.0 | 1.5       | 2.0       | 2.5       | 3.0       | 3.5 | 4.0 |
| 1                  | 12                 | 21  |           |           |           |           |     |     |
| 2                  | 15                 | 27  | 36        | 48        |           |           |     |     |
| 3                  | 18                 | 33  | 42        | 54/2-42   | 54        | 3-54/4-42 |     |     |
| 4                  | 21                 | 36  | 48        | 2-48/3-36 | 3-48/4-42 | 4-48      | *   |     |
| 5                  | 27                 | 42  | 54        | 2-48/3-42 | 3-48/4-42 | 4-54      | *   | *   |
| 6                  | 30                 | 42  | 60        | 2-54/3-42 | 4-48      | *         | *   | *   |
| 7                  | 30                 | 48  | 60        | 3-48/4-42 | 4-54      | *         | *   | *   |
| 8                  | 33                 | 54  | 2-54/3-48 | 3-54/4-48 | 4-54      | *         | *   | *   |
| 9                  | 36                 | 54  | 2-54/3-48 | 3-54/4-48 | *         | *         | *   | *   |
| 10                 | 42                 | 60  | 3-48/4-42 | 4-54      | *         | *         | *   | *   |

**Table C: Culvert Diameters (Inches) for Extreme Hilly Conditions Slopes Upstream > 10%**

| Stream Width (Ft.) | Stream Depth (Ft.) |           |           |           |      |     |     |     |
|--------------------|--------------------|-----------|-----------|-----------|------|-----|-----|-----|
|                    | 0.5                | 1.0       | 1.5       | 2.0       | 2.5  | 3.0 | 3.5 | 4.0 |
| 1                  | 15                 | 30        |           |           |      |     |     |     |
| 2                  | 21                 | 42        | 54        | 2-54/3-42 |      |     |     |     |
| 3                  | 27                 | 48        | 2-48/3-42 | 3-48      | 4-54 | *   |     |     |
| 4                  | 33                 | 54        | 2-54/3-42 | 3-54/4-48 | *    | *   | *   |     |
| 5                  | 36                 | 60        | 2-60/3-48 | 4-54/5-48 | *    | *   | *   | *   |
| 6                  | 42                 | 60        | 3-54/4-48 | *         | *    | *   | *   | *   |
| 7                  | 42                 | 2-48/4-36 | 3-54/4-48 | 4-60      | *    | *   | *   | *   |
| 8                  | 48                 | 2-54/3-48 | 4-54/5-54 | *         | *    | *   | *   | *   |
| 9                  | 54                 | 2-60/3-48 | 4-60/5-54 | *         | *    | *   | *   | *   |
| 10                 | 54                 | 3-54/4-48 | *         | *         | *    | *   | *   | *   |

\*Where flows were determined to cause the culvert size to exceed 4-60 inch pipes, no size is provided.

## ***Appendix D***

### ***Background on Sediment Production from Unpaved Roads***

## **Sediment Production from Unpaved Road Surfaces and Rationale Behind Erosion Control Best Management Practices**

An exposed soil surface, such as the travelway surface of an unpaved road, may be subject to the erosive effects of rainsplash and flowing water. While rainsplash energy principally depends on precipitation intensity (Wischmeier and Smith, 1958), the combination of precipitation intensity, infiltration capacity, road drainage design, and flow hydraulics determine the energy applied by flowing water. If we assume that the effects of flow hydraulics dominate the surface erosion process on unpaved roads, then the surface erosion rate ( $E_t$ ) is proportional to the difference between the shear stress applied by overland flow ( $\tau$ ) and the resistance of the material to erosion ( $\tau_c$ ) (eq. 1):

$$E_t \propto k_1 (\tau - \tau_c)^n \quad (\text{eq. 1})$$

where  $k_1$  is an index of the erodibility of the sediment and  $n$  is an exponent between 1 and 2 (Kirkby, 1980). The erosive energy applied by flowing water ( $\tau$ ) is dependent on the slope of the eroding surface and the depth of water flowing over this surface. The depth of flowing water depends in part on the amount of water being generated by excess precipitation. For an unpaved road excess precipitation is the amount of rainfall that does not infiltrate into its base material. Infiltration rates on unpaved roads are typically very low, therefore a large proportion of the rainfall (up to 70% for storms exceeding 2.5 cm of rainfall) is converted into surface runoff (Ramos-Scharrón and MacDonald, 2007).

The depth of flow for a road segment also depends on the road drainage pattern. In general terms, the higher the precipitation intensity and the larger the road surface area (i.e., the longer the length of road without road drainage structures) the deeper the flow on the road surface, and the higher the erosion rates. If we consider different road segments with similar infiltration capacities and we subject them to the same precipitation intensities, given this theoretical background we may expect sediment production to be a function of road surface area, slope, and precipitation:

$$E_t \propto k_2 (A * S * P) \quad (\text{eq. 2})$$

where  $k_2$  is an empirically defined index related to the resistance of the road material to erosion,  $A$  is road drainage area,  $S$  is road segment slope, and  $P$  is precipitation.

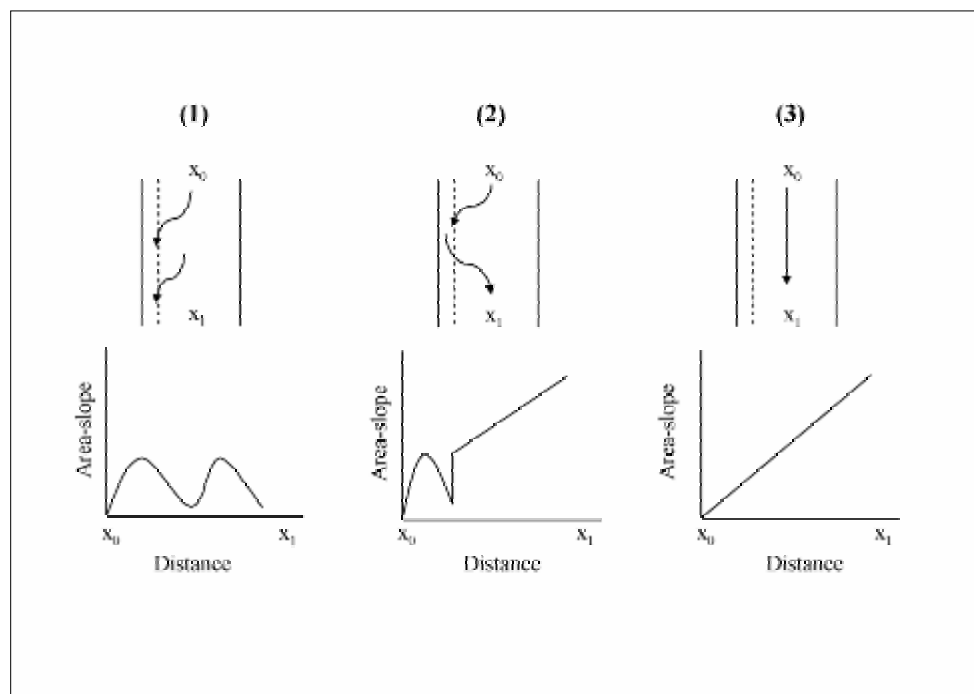
Ramos-Scharrón (2004) developed empirical road sediment production models based on  $A*S$  values for frequently graded roads (eq. 3a) and ungraded roads (eq. 3b):

$$E_{r_g} = -0.202 + 0.0039(A * S * P) \quad (\text{eq. 3a})$$

$$E_{r_u} = -0.202 + 0.0029(A * S * P) \quad (\text{eq. 3b})$$

where  $E_r$  is total erosion in  $\text{kg m}^{-2}$ ,  $A^*S$  is the areally-weighted average area-slope factor with area in  $\text{m}^2$  and slope in decimal ( $\text{m m}^{-1}$ ), and  $P$  is precipitation in centimeters.

Road drainage patterns affect the  $A^*S$  value of specific sub-segments along a road. Roads on St. John show three typical road drainage patterns: (1) insloped travelways directing the runoff into inside ditches; (2) insloped sections with blocked ditches that forced the runoff back onto the road surface; and (3) sub-segments with little or no cross-slope drainage due to deep ruts or the lack of an inside ditch (Ramos-Scharrón and MacDonald, 2005). Road segments with an effective insloped profile (type 1) generally have lower  $A^*S$  values and lower erosion rates than those with blocked ditches or those with no cross-slope drainage. Runoff control drainage structures such as waterbars, dips, deflectors, and culverts are used to reduce erosion rates by maintaining low  $A^*S$  factors for road surfaces. Application of a similar strategy in the Maho Bay area of St. John showed that improving road drainage by the construction of five swales on a 230 m long road segment reduced sediment production rates to about a third of pre-treatment levels (Ramos-Scharrón, 2006).



The resistance of an unpaved road surface to erosive energy ( $\tau$  in Equation 1) depends on the particle-size distribution, as this controls the exposure of particles to hydraulic forces, the cohesive forces between particles, and the tractive force needed to detach individual particles (Knighton, 1998). The general rule of thumb is that the resistance to erosion increases with the size of the particles on the road surface. The type of parent material is a major control on the size of the road surface material, but the road surface might also be affected by the amount and

type of traffic and the time or cumulative rainfall since construction or grading (i.e., blading). Newly-constructed and freshly-resurfaced roads typically have very high sediment production rates due to the abundance of easily-erodible fine particles (Megahan and Kidd, 1972; Megahan et al., 1986). The rapid erosion of fine sediment immediately after construction or regrading leads to a coarsening of the road surface, which increases its resistance to erosion. On St. John, vehicle-induced rutting and the absence of road ditches keeps much of the runoff on the road surface and this facilitates the detachment and transport of the loose, fine sediment applied during grading. Road surfacing materials and re-vegetation strategies are meant to increase the resistance of unpaved road surfaces to erosive energy. While the application of pavement and re-vegetation strategies are expected to reduce erosion to a level that approximates natural rates, surfacing with a 6- to 8-inch deep gravel layer has shown to reduce road erosion rates by 90% (Swift, 1984).

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