CEP Technical Report: 32 1994

GUIDELINES FOR SEDIMENT CONTROL PRACTICES IN THE INSULAR CARIBBEAN

UNEP

CARIBBEAN ENVIRONMENT PROGRAMME

GUIDELINES FOR SEDIMENT CONTROL PRACTICES IN THE INSULAR CARIBBEAN

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CHAPTER 1 INTRODUCTION

1.1 PURPOSE OF THIS HANDBOOK

The Caribbean region is blessed with an extraordinary diversity of natural and cultural resources. As the 21st century approaches, these resources are subject to unprecedented development pressures. Development activities encompass a broad range of modifications to the land ranging from agricultural practices to resort development to urbanization. However, all development activities have in common some impact on natural processes. Among the impacts of greatest concern in the insular Caribbean today are accelerated soil erosion and the delivery of eroded material to sites where it is not wanted -- e.g., to water reservoirs, navigable harbors, coral reefs, and zones crucial to the maintenance of tourism and fisheries.

The purpose of this document is to describe methods of anticipating, assessing and minimizing erosion and sediment impacts from site development. It is hoped that by outlining the processes of erosion and sedimentation, describing the principles behind erosion and sediment control, and providing examples of effective erosion and sediment control strategies, this handbook will support efforts to plan and implement construction activities in the insular Caribbean with a minimum of environmental damage.

These guidelines have been prepared as part of the task of the Caribbean Environment Program (CEP) of the United Nations Environment Program (UNEP) which focuses on the protection of the marine environment in the Wider Caribbean Region, specifically within the framework of activity 4.4.8 "Research on the Significance of Increased Turbidity and Eutrophication in the Wider Caribbean Region as a result of changing land-based activities", from the Regional Program "Assessment and Control of Marine Pollution (CEPPOL)".

1.2 WHO THE HANDBOOK IS FOR

The guidelines contained in this handbook are intended for professional planners, engineers, landscape architects, and other individuals involved in planning, designing, permitting, and monitoring site development. They are also intended for those directly involved in construction activities -- e.g., site owners, developers, contractors, and construction equipment operators. The handbook provides an overview of erosion and sediment control principles, and a description of specific best management practices (BMPs) applicable to construction activities in the insular Caribbean.

The focus of this document has been placed on the control of sediment from construction sites. BMPs to control sediment from agricultural, range, mining, and forest harvest activities are not emphasized in this handbook. This document also does not address sediment originating from dredging activities or coastline erosion.

1.3 INFORMATION CONTAINED IN THE HANDBOOK

Chapter 2 of this handbook contains basic information about processes of erosion and sedimentation, problems created by these processes, and considerations of particular relevance to the insular Caribbean.

Chapter 3 provides an overview of physical factors influencing erosion and sedimentation and discusses how these relate to principles of land use planning and practices for sediment control. The specific impacts of construction activities on erosion and sediment delivery are reviewed. Chapter 3 also discusses methods of prioritizing sediment control strategies by assessing sediment production from different land uses.

Chapter 4 discusses issues to consider when implementing a sediment reduction program in the insular Caribbean. It includes a discussion of watershed, stream corridor, and site-specific planning opportunities. It also addresses the institutional, educational, and informational support required to successfully implement a sediment reduction program.

Chapter 5 provides information on 14 specific BMPs for erosion and sediment control applicable to construction activities in the Caribbean. These include practices to minimize erosion at its source and practices to reduce opportunities for sediment to reach streams and coastal waters.

1.4 ACKNOWLEDGEMENTS

This publication was made possible under a Memorandum of Understanding entered into in November of 1993 between the Regional Co-ordinating Unit of the Caribbean Environment Programme of the United Nations Environment Programme (Kingston, Jamaica) and Island Resources Foundation (St. Thomas, U.S. Virgin Islands). Island Resources Foundation is a 23-year-old development assistance non-governmental organization (NGO) with a special interest in helping to protect and enhance the environments of small island developing states.

This technical review was, in part, an outgrowth of research already underway in the U.S. Virgin Islands, where investigators were conducting a study of sediment loading on the island of St. John. That study, known as the "Paired Watershed Study," was carried out within the Virgin Islands National Park and Biosphere Reserve, with funding from the U.S. National Park Service, Water Resource Division. Additionally, it involved cooperative agreements with Colorado State University and the U.S. Geological Survey in San Juan, Puerto Rico. The three-year project was initiated in 1992 and was designed to examine the influences of St. John land use and watershed processes on erosion and instream sediment transport rates by comparing the sediment yield of two different watersheds, one affected by upland construction activities and the other with undisturbed slopes. The project also identified areas of high, medium, and low erosion susceptibility on St. John, and recommended practices to reduce sediment delivery to the marine environment.

Because of the influence of this parallel study on the current handbook of best management practices, Island Resources Foundation wishes to acknowledge and thank the following: Dr. Caroline S. Rogers, Research Director for the Caribbean/Virgin Islands Project of the U.S. National

Biological Service; Dr. Lee MacDonald of Colorado State University; Dr. William Dietrich of the University of California at Berkeley; and Dr. Allen Gellis of the U.S. Geological Survey in San Juan, Puerto Rico. Mr. Donald Anderson, formerly of Colorado State University is the primary author of this document and was a part of Colorado State University's research team for the Paired Watershed Study on St. John.

This project would not have been possible without the support of Dr. Raul Mederos Baez, CEPPOL Co-ordinator at UNEP/CEP. The initial research design was defined by Island Resources Foundation president Dr. Edward Towle, and Mr. Richard Volk, former Senior Resource Planner at the Foundation, prepared the proposal submitted to UNEP. Dr. Towle served as project director.

Island Resources Foundation also acknowledges the support of the Eastern Caribbean Center of the University of the Virgin Islands, and its director Dr. LaVerne Ragster, under whose auspices the initial proposal was prepared and submitted. The Eastern Caribbean Center/University of the Virgin Islands is the UNEP/CEPPOL focal point for the Territory of the U.S. Virgin Islands.

Further institutional sponsors of this publication are the Virgin Islands Resource Management Cooperative (VIRMC) and the Caribbean Environment and Development Institute (CEDI). VIRMC is a coalition of public and private sector institutions cooperating on collaborative approaches for the management of natural resources in the wider Virgin Islands community. CEDI is an NGO member of VIRMC based in Puerto Rico. Its mission is to promote partnerships between business, government, academic and non-governmental environmental organizations for the sustainable use of natural resources.

External review of this publication in draft form was extremely helpful, and we acknowledge this contribution by: Dr. Caroline Rogers, Dr. LaVerne Ragster, Dr. Henry Smith, Dr. Bruce Horwith, Mr. David Grigg, Mr. Werner Wernicke, Mr. Adrian Schottroff, Ms. Julie Wright, and Ms. Jennifer Bjork.

CHAPTER 2 EROSION AND SEDIMENTATION IN THE INSULAR CARIBBEAN

2.1 TYPES OF EROSION

Erosion is the wearing away of soil by water, wind, and gravity. Where land has been disturbed by human activity, the rate of erosion usually increases. This accelerated erosion is typically many times the natural rate.

Splash erosion refers to the dispersal of soil particles resulting from direct raindrop impact on the soil surface. Sheet erosion occurs when water begins to flow over the soil surface, carrying particles detached by raindrops or runoff.

Surface runoff eventually concentrates to produce small eroding channels, a process described as rill erosion. As rills enlarge and join with other rills, gully erosion may result. Gullies are deeply incised and relatively difficult to erase from the landscape. In a gully, soil is rapidly removed by water cutting into the head (uphill end) of the gully, scouring the gully bottom, and removing material slumping from the gully sidewalls.

Erosion may also occur by mass wasting processes. Mass wasting is erosion induced by gravity alone, without a transporting medium such as water. Mass wasting includes slow processes such as soil creep (the shallow, imperceptible downslope movement of soil), and rapid processes such as debris slides and rockfall.

Figure 1. Four types of soil erosion on an exposed slope. (Source: Ref. 33)

2.2 SEDIMENTATION

Sedimentation refers to the deposition of eroded material (sediments). Sediments are deposited when the velocity or speed of flowing water is insufficient to transport the sediment or when barriers to sediment movement are encountered. Larger particles are the first to be deposited when flow velocities are reduced. Finer sediments, such as clays, do not readily settle out of water.

Not all eroded material reaches the outlet of a watershed. A portion of the eroded material will be redeposited on hillslopes, in landscape depressions, behind vegetation, and in and along stream channels. The fraction of eroded material reaching the watershed outlet (the sediment delivery ratio) generally decreases with increasing watershed area. However, factors affecting sediment delivery are complex and largely unpredictable. Thus, no simple and reliable methods exist for estimating the sediment delivery ratio. (See also Appendix A.)

2.3 PROBLEMS CAUSED BY EROSION AND SEDIMENTATION

Accelerated erosion and sedimentation have many adverse impacts. These include:

- Loss of agricultural productivity. Erosion removes valuable topsoil and thus reduces the productivity and water-holding capacity of agricultural land (Ref. 29).

- Degradation of water quality. The discharge of eroded material to streams, ponds and marine zones degrades the quality of receiving waters and damages freshwater and marine habitats. Water quality may be further degraded by pathogenic organisms, pesticides, and chemical fertilizers carried by eroded particles. Some of these pollutants can be trapped in marine sediments downstream.

- Lost reservoir capacity. Sedimentation reduces the water storage capacity of reservoirs and shortens their functional lifespan. In Puerto Rico, for example, some reservoirs have lost virtually all of their storage capacity, while others are filling with thousands of cubic meters of sediment annually (Ref. 21).

- Other downstream impacts. Sedimentation may fill culverts, ponds and storm drainage systems, resulting in costly maintenance. Sedimentation can also aggravate flood damages. Navigation may be impeded by increased sediment loading to receiving waters, necessitating expensive dredging.

2.4 SPECIAL CONSIDERATIONS IN THE INSULAR CARIBBEAN

Several aspects of erosion and sediment control merit special attention in the environments of the insular Caribbean. These include:

(1) Vulnerable coastal and marine resources. Most land in the insular Caribbean is relatively near the ocean, and coastal areas are generally subject to intense development pressures. As

a result, much of the sediment produced by human activity is generated where it is easily transported to the marine zone. Often, the receiving areas host biologically diverse, economically productive, and environmentally sensitive resources such as mangrove swamps, seagrass beds, coral reefs (box, page 7), and commercial fisheries. Receiving areas also may include pristine beaches or other popular recreational sites. Erosion and sediment control takes on a particular urgency when these unique resources are at risk.

(2) Storm intensity. Erosion increases with the kinetic energy of falling rain. In the Caribbean, rainstorms are often intense. High-intensity storms are more likely to deliver water faster than it can be absorbed by the soil, resulting in widespread runoff and erosion. Raindrop impact also can increase runoff and erosion by breaking break down the soil structure and sealing the soil surface. Erosion and sediment control measures should be designed and implemented with the potential of intense storms in mind.

(3) Unique physical, economic, and social conditions. Land is scarce in the Caribbean, particularly gently sloping land. Growth in the insular Caribbean is pushing development activities onto increasingly steeper terrain. This presents particular challenges because in such areas the implementation of effective erosion and sediment control practices is difficult, costly, and beset with more failures. In addition, regulations applied to marginal upland areas potentially affect the livelihoods of many rural poor. This can aggravate sensitive social issues and render the enforcement of sediment control regulations difficult or impossible.

Another limitation in many Caribbean nations is the availability of experienced and skilled technical personnel and an institutional structure conducive to implementing a comprehensive sediment control program. Often, the resident skills base in a particular technical area is only one or two layers/persons "deep" and is therefore vulnerable to being lost virtually overnight (Ref. 11).

FOCUS ON THE INSULAR CARIBBEAN:

SEDIMENTS AND REEF PROTECTION

Coral reefs are among the greatest natural assets of the Caribbean. They house diverse and productive marine ecosystems, supply the white sand that replenishes beaches, protect shorelines from erosion, and are a major attraction for the multi-million dollar tourist industry. However, the health and extent of coral reefs in the Caribbean is on the decline. One contributing factor to this decline is increased siltation of the nearshore environment.

Increased sedimentation can adversely impact coral reefs in a variety of ways. These include:

- Smothering coral;
- Screening out sunlight needed for photosynthesis;
- Scouring of the coral by sand and other transported bed sediment; and
- Poor survival of juvenile coral due to loss of suitable substrata.

Increased sediment loads in many small rivers have been reported to be fatal to coral reefs (Ref. 20). Even relatively small but chronic increases in suspended sediments (clays and silts) have the potential to severely degrade coral reefs. Reduced coral cover has been noted where levels of total suspended solids (TSS) were 3-5 mg/l over extended periods of time. The "normal" TSS range for most healthy reef systems is in the range of 1-2 mg/l (Ref. 19).

CHAPTER 3 IDENTIFYING EROSION AND SEDIMENTATION PROBLEMS

3.1 FACTORS INFLUENCING EROSION AND SEDIMENTATION

Four general factors influence the magnitude of erosion and sedimentation. These are climate, soils, topography, and land cover.

Climate

The frequency, intensity, quantity and duration of rainfall affect soil erosion and sediment transport. As already mentioned, intense rain tends to break down soil aggregates and seal the soil surface. This induces runoff and erosion. Runoff will also occur when the rate at which rain falls exceeds the infiltration capacity of the soil.

Even low-intensity rainfall will induce runoff in areas where soils are easily saturated. Typically these areas are located along streams, in swales, or in areas subject to abundant rainfall and low rates of evapotranspiration. A high clay content in soil increases the likelihood of saturation. Saturated areas producing runoff tend to expand as the duration and amount of precipitation grows.

Soil

Different types of soil have different susceptibilities to erosion. Soil erodibility varies with soil texture (particle size distribution), organic matter content, and structure (particle aggregation). Soils rich in silts and in very fine sands are relatively erodible, while those rich in clay are less erodible. A high organic matter content improves the structure and permeability of a soil, and thereby reduces its erodibility. A fine-textured soil with granular structure is the least erodible. However when soil structure is disrupted, such as with earth moving equipment, even clayey, granular soils will easily erode.

Topography

Slope length and slope steepness influence soil erosion. A greater slope length below the point where runoff begins tends to increase the depth and velocity of runoff, and thus will detach more soil particles. In areas where the soils are prone to saturation, long slopes and converging terrain increase opportunities for soil saturation, surface runoff, and slope failure.

Steeper slopes are susceptible to more erosion due to increased runoff velocity, greater downslope transport of rainsplashed soil, and greater susceptibility to landslides.

Land Cover

Vegetation and other materials covering the soil surface have an enormous influence on erosion. Cover vegetation absorbs the energy of falling raindrops, provides a physical barrier to particle movement, binds the soil in place with roots, and extracts water from the soil to increase its absorptive capacity. The first two of these functions also can be provided by artificial surface cover.

3.2 IMPACTS OF DEVELOPMENT

Of all land use changes, construction activities have the greatest potential to produce massive, short-term increases in erosion and sediment. This is because (1) the stabilizing effect of vegetation is lost, (2) soil surfaces are exposed to direct raindrop impact, and (3) additional precipitation is converted into runoff by impermeable surfaces (Figure 2).

Figure 2. An example of the effects of development on runoff. (Source: Ref. 15)

Erosion on a construction site varies with site conditions and soil types but is commonly 100 to 200 tons per acre and may be as high as 500 tons per acre (Ref. 33). Figure 3 illustrates the sediment production per square mile typical of various land uses ranging from woodland to heavy development. Actual increases in sediment will vary greatly depending upon soil, landscape, and climate conditions, but this illustration underscores the fact that sediment production from construction sites can be extreme.

Figure 3. Typical volumes of sediment eroded from different uses. (Source: Ref. 4)

The increase in total and peak runoff from construction sites increases the potential for gully erosion both on-site and farther downslope. Because site runoff is typically concentrated in one or several drainageways, the erosive potential of increased runoff can be enormous. Methods of safely conveying this runoff downslope during storm events is termed ***stormwater management***. Failure to address stormwater management needs can have severe erosion, sedimentation, and flood impacts.

A large proportion of erosion in the Caribbean is caused by poor road alignments and improper control of the drainage and runoff from roads. All of the eastern Caribbean islands investigated for the Caribbean Agricultural Research and Development Institute (CARDI) in 1983 suffered from serious road erosion problems (Ref. 5). Erosion along mountain roads is identified as a major, but largely neglected, watershed problem in Jamaica (Ref. 10) and a recurring problem in Puerto Rico (Ref. 9). Recent investigations in St. Thomas (Ref. 2) and St. John (box, page 11) reveal similar problems.

FOCUS ON THE INSULAR CARIBBEAN:

ST. JOHN EROSION AND SEDIMENT HAZARDS STUDY

In 1994, researchers from Colorado State University and the University of California investigated erosion and sedimentation on St. John, U.S. Virgin Islands, for the U.S. National Park Service (Ref. 36). Their experience underscores the importance of understanding the dominant erosion and sediment delivery processes within a watershed before undertaking sediment control efforts.

Over half of St. John island and much of its offshore area is owned by the Park Service and managed as Virgin Islands National Park. In recent years, concerns have been raised that accelerated development activity on the island is increasing erosion and sediment delivery to the marine environment. This in turn may be adversely affecting the health of the coral reefs that were a primary reason for the establishment of the Park.

Prior to visiting the island, the researchers suspected that construction sites probably were the primary sources of sediment. However, field analyses revealed that sediment delivery from construction sites was generally minimal due to (1) the limited areas disturbed by construction, (2) the natural regrowth of protective vegetation, and (3) implementation of site-specific sediment control measures. In contrast, the extensive road network on St. John, much of which is unpaved, was severely eroded and delivering sediment to stream channels and the ocean at unprecedented rates. Unpaved road surfaces typically eroded 1-2 cm/year or more, and island-wide production of sediment from road surfaces was estimated to be 2-10 times the natural rate.

As a result, study recommendations focused on the control of erosion from roads and parking areas rather than construction sites per se. For example, the investigators recommended that all road surfaces be paved, particularly those segments draining large areas and having steep slopes. Because the Park Service has little control over road construction on St. John, it was emphasized that Park protection efforts need to be integrated with the activities of other agencies including the Virgin Islands Department of Planning and Natural Resources, the Department of Public Works, and the U.S. Federal Highway Administration.

3.3 ASSESSING SEDIMENT SOURCES

A regional assessment of existing and potential sediment sources allows the most serious problems (or potential problems) to be identified and addressed as priority issues.

Visually assessing soil loss from sites subject to different land uses is a good place to start. Evidence of rill and gully erosion and slope failure should be assessed in different landscape and land use situations. It can be particularly revealing to observe the impacts caused by construction activity, road building, and storm runoff conveyance. Often, sites where "failures" have occurred are highly educational, as they clearly illustrate the problems associated with poor runoff and sediment control.

By investigating areas where sediment is deposited, rates of sediment production can be estimated. Sediment deposition in ponds, settling basins, and behind fabric fences provide opportunities to estimate sediment yield from disturbed areas (Figure 4). Survey pins or stakes planted in strategic locations can simplify the estimation of soil loss or sediment accumulation over time.

Figure 4. Eroded soil trapped behind fabric dams can be measured periodically to document erosion trends. (Source: Ref. 6)

The Universal Soil Loss Equation (USLE) can be used to predict the impacts of land use on soil erosion. The USLE was developed in the United States in the 1970's to predict erosion from agricultural land. The USLE estimates erosion based on six site-specific factors, including rainfall, soil, topography, and land cover/management characteristics (Ref. 22). (See also Appendix B.)

Application of the USLE to construction sites is discussed in various texts (e.g., Ref. 23). USLE estimates of soil loss do not always accurately reflect actual erosion rates, particularly in the tropics (Ref. 24) and under non-agricultural conditions. However, the equation is a useful tool for identifying and avoiding site conditions that are likely to produce the worst erosion. Moreover, if reliable data for each of the USLE factors are available in digitally mapped form, a geographic information system (GIS) may be used to identify potentially problematic areas within a watershed (Ref. 25, 36).

FOCUS ON TECHNOLOGY:
GEOGRAPHIC INFORMATION SYSTEMS
AS A WATERSHED MANAGEMENT TOOL

A geographic information system (GIS) is a computerized system for storing, analyzing, retrieving and displaying information in a spatial (mappable) format. Because GIS combines the power of a computerized database with the capability to view and analyze the data in a geographic context, it is a potentially powerful tool for watershed planning and management.

GIS is, however, only a tool. A GIS will not automatically "solve" complicated management problems, nor will it produce results that are any more reliable than the data fed into it. A well-conceived and thoughtfully-implemented GIS can serve as a useful platform for assembling and analyzing the information needed to make wise land management decisions. The following examples illustrate ways in which GIS can support watershed management:

Spatial database development

A GIS allows geographic data traditionally recorded in tabular databases to be displayed on maps. This assists in visualizing natural resource data and assessing spatial data relationships.

Resource queries and evaluations

A GIS can rapidly summarize information about soil types, vegetative cover, and existing or anticipated land uses within a watershed or subbasin, provided these data are mapped in digital format. This allows natural resources and potential demands on these resources to be assessed, compared across space, and compared over time. For example, a GIS might be used to identify areas undergoing accelerated land use changes, and assist in the selection of sites for water quality monitoring.

Hazards identification

A GIS can be used to identify areas particularly vulnerable to erosion or slope failure due to steep slopes, converging terrain, high rainfall, intensive land uses, and/or unstable soils. Typically, this involves "overlaying" and (if necessary) "weighing" GIS layers representing each erosion hazard factor. Hazardous areas identified in this manner might be classified as "off limits" to development, or otherwise earmarked for special protective measures.

Watershed modeling

At a more sophisticated level, GIS can be interfaced with rainfall/runoff or pollution models to predict, in a "mappable" format, storm runoff and pollutant loads. Such models may require years of data and highly detailed information to be useful. However, by interfacing these models with GIS, the user's ability to view and interpret various "what-if" scenarios is greatly enhanced.

Geographic information systems are not inexpensive. GIS data acquisition and personnel training expenses alone can be burdensome, often amounting to many times the cost of hardware and software combined.

The costs of a geographic information system may best be met by pooling the resources of various departments, agencies, and organizations interested in the system. Typically, cadastral agencies, utility departments, and emergency service providers (e.g., fire departments) are the first to realize benefits from a geographic information system, and therefore are more inclined to invest in the technology. By seizing opportunities to dovetail planning projects with other GIS database development efforts, geographic information systems can be a more affordable tool for planners.

Surface runoff is not the only generator of sediments. In humid, mountainous tropical areas, landslides are common (Ref. 7) and can be a major source of sediments under both natural and disturbed conditions. Evidence of slope failure in relatively undisturbed areas often indicates that landslides will be a problem if roads are constructed or other major land disturbances are introduced.

Aerial photographs of offshore areas following periods of intense rainfall often reveal sediment plumes at the outlet of severely eroding drainage basins. This can help identify problem areas. Also, regular offshore measurements of turbidity and suspended sediment provide a relatively inexpensive means of comparing and monitoring the condition of receiving areas. Bays or other offshore zones exhibiting elevated levels of turbidity are often indicators of problem watersheds.

CHAPTER 4 IMPLEMENTING A SEDIMENT REDUCTION PROGRAM

4.1 WATERSHED PLANNING AND MANAGEMENT

"Watershed-level planning" has recently attracted attention because of heightened interest in managing natural resources in a more regionally integrated, multi-disciplinary, and sustainable manner. A "watershed" is the area of land draining water (and sediment) to a common outlet point. Watersheds are natural units for sediment control because all sources within a watershed are potential contributors to the same receiving bays, lagoons, coastal areas, and intermediate points in the drainage basin.

Ultimately, sediment control practices for construction activities must be implemented on a site-by-site basis. However, a watershed-scale identification of existing and potential sediment sources can support a more coordinated approach to sediment control. Using this approach, the most serious threats can be identified and the most promising strategies can be prioritized. If data are available in a digital format, GIS may support watershed analysis (box, page 13).

A watershed management plan outlines a comprehensive approach to sediment control in a watershed. Suggested steps for the development of a watershed management plan are listed in Table 1 (Ref. 15).

Once a watershed management plan is developed that identifies sensitive areas, designates acceptable land uses, and specifies overall management goals, various regulatory strategies can be used to control sediment sources. These include :

- Limitations on impervious surfaces and protection of open-space (undeveloped) areas. By limiting impervious surfaces, more precipitation has the opportunity to infiltrate into the ground, resulting in less stormwater runoff. This reduces erosion caused by storm runoff and makes it easier to manage stormwater flows.

- Restrictions on steep-slope development. As discussed in Section 3.1, steep slope areas are particularly vulnerable to surface erosion and, in many cases, landslides. By prohibiting or restricting development in these areas, many potential sediment problems can be avoided.

- Road-building restrictions and design requirements. As discussed in Section 3.2, roads are a major source of sediment throughout the Caribbean. Where possible, watershed management plans for sediment control should seek to minimize the area disturbed by roads, and ensure that roads are sensibly designed and installed (see

Table 1. Watershed Management: A Step-by-Step Guide

1. Delineate and map watershed boundary and sub-basins within the watershed.

2. Inventory and map natural storm water conveyance and storage systems.

3. Inventory and map man-made storm water conveyance and storage systems.
This includes all ditches, swales, storm sewers, detention basins and reservoirs, and includes information such as size, storage capacity, and age.

4. Inventory and map land use by sub-basin.

5. Inventory and map soils by sub-basin.

6. Evaluate watershed water resource characteristics.
Analyze water quality, sediment, and biological data. Analyze subjective information on problems (such as citizen complaints). Evaluate impaired uses of water bodies (consider frequency, timing, seasonality of problem). Conduct water quality assessments (consider low flows, seasonality).

7. Inventory pollution sources in the watershed.
Assess both point and nonpoint sources, and record information on location, sediment loadings and runoff volumes. Land use impacts on storm water runoff rates should be considered.

8. Identify and map projected future land use by sub-basin.
Conduct sediment and storm water loading rate analyses to assess effects of various land use scenarios.

9. Identify planned infrastructure improvements -- 5-year, 20-year.
Measures to address stormwater and sediment management deficiencies should be coordinated and scheduled with other infrastructure or development projects.

10. Identify needs.
Determine infrastructure and natural resources management needs within each watershed.

11. Set resource management goals and objectives.
Before corrective actions can be taken, a resource management target must be set. The target can be defined in terms of water quality standards; attainment and preservation of beneficial uses; or other local resource management objectives.

12. Determine sediment reduction (for existing and future land uses) needed to achieve goals.

13. Select appropriate management practices (point source, nonpoint source) that can be used to achieve the goal.
Evaluate sediment control effectiveness, land owner acceptance, financial incentives and costs, feasibility, and availability of technical assistance.

14. Develop watershed management plan.
Since the problems in each watershed will be unique, each watershed management plan will be specific. However, all watershed plans will include elements such as:
- existing and future land use plan;
- erosion and sediment control plan;
- master storm water management plan that addresses existing and future needs; and
- infrastructure and capital improvements plan.

Source: Ref. 15.

BMP 1.2). Where appropriate, methods of assessing developers for a fair share of road design, building, and maintenance costs should be established.

- **Protection of buffer zones around streams and sensitive areas** (discussed in Section 4.2); and

- **Erosion and sediment control standards for site development activities** (discussed in Section 4.3).

FOCUS ON THE INSULAR CARIBBEAN:
MOUNTAINTOP DEVELOPMENT PRESSURES

Sediment sources near coastlines and along stream corridors tend to attract the most attention when regional sediment control strategies are developed. In many cases, this attention is justified because a large proportion of sediments produced in these areas is likely to reach a major water body. However, more distant sediment sources should not be ignored.

An example of particular relevance in the insular Caribbean is the increasing pressure to improve access to mountaintop areas. These sites are of special interest to the telecommunications industry, which prizes them for their panoramic exposure. In the Luquillo elfin cloud forest of Puerto Rico, for example, an estimated 13 percent of the forest has been replaced with communication facilities and their associated roads (Ref. 9).

Pressures to improve access to relatively isolated high-elevation zones are also coming from the growing ecotourism industry. Once road access to these areas is established or improved, the construction of rural homes or the establishment of new agricultural or forest harvest enterprises at formerly inaccessible sites is bound to follow.

The new roads, construction, farming and forestry in high-elevation zones will accelerate sediment production. The high rainfall and low rates of evapotranspiration typical of high-elevation zones in the Caribbean become important considerations because they increase the susceptibility of land to saturation-induced runoff and landslides. Landslides, some as large as 75,000 m3, were a recurring problem when roads were built in the Luquillo cloud forest, and slope failures remain a chronic and expensive reality (Ref. 9).

In summary, although mountaintop areas may be located far from the outlet of their watersheds, they have the potential to produce large quantities of sediment when disturbed by human activity, and they are under increasing development pressures throughout the insular Caribbean. To achieve the goals of a watershed-level sediment control plan, appropriate management of these areas is an important consideration.

On islands and in coastal areas, the value of mangrove swamps and coastal ponds should be considered in watershed-scale sediment control planning. Ponds and mangrove areas provide natural sediment sinks that help protect offshore areas, such as coral reefs, from sediment impacts (Ref. 16). In many regions of the Caribbean, these natural features have been largely eliminated by commercial and industrial development, or by coversion to landfill areas and solid waste disposal sites. Their disappearance increases the proportion of land-generated sediment reaching the marine environment.

4.2 STREAM CORRIDOR MANAGEMENT

While the identification and management of sediment sources at the watershed scale is an admirable goal, it is often difficult to achieve. Watershed problems are often so complex that it is hard to know where to begin. Moreover, it is often the case that the solution to problems which seem obvious at first in fact depend upon the solution of more fundamental problems revealed by further investigation (Ref. 34).

For these reasons, Dickinson and Tracy (Ref. 8) suggest that stream corridor management may be a more practical starting point for planners. By "stream corridor", they refer to the riparian (streamside) zone and adjacent buffer strips of undisturbed vegetation.

For erosion and sediment control, the most effective management of a stream corridor is to leave it alone, preserving as wide a buffer strip as possible. However, it is rarely practical to completely exclude human activity from the stream corridor. To maximize the effectiveness of the buffer strips that are established, factors listed in Table 2 should be considered. Because site conditions vary greatly, there is no universally recommended width for buffer strips. In temperate forests, nine meters is the width most commonly recommended (Ref. 17). Generally, the wider the buffer zone, the greater the erosion and sediment control benefits.

Streamside buffer strips are frequently established in the hope of preventing sediment generated upslope from reaching the stream. However, sediment transport to streams frequently occurs via channelized overland flow, which is not effectively filtered by buffer strips (e.g., Ref. 17). Thus, planners should avoid placing too much faith in buffer strips as barriers to sediment delivery to streams. The greatest value of buffer strips is probably in preventing erosion from the buffered area.

Streambank stabilization measures may be necessary where disturbances have caused streambank erosion. For example, streambank scouring may become a problem where protective vegetation is removed and/or cattle are allowed to graze. Streambank erosion can also result from increased storm runoff caused by upslope development.

Streambanks can be stabilized by installing riprap or establishing other protective measures. In areas where livestock create problems, protective fencing of stream corridors and the provision of alternative water sources may be an effective solution.

Table 2. Factors Affecting the Efficiency of Buffer Strips and Stream Channels in Removing Sediment and Nutrients from Surface Runoff	
FACTORS	**NATURE OF RELATIONSHIP**
Width of Vegetated Strip	As the distance surface runoff flowing through a buffer strip increases, the proportion of original sediment and nutrient concentration remaining in surface flow decreases.
Slope of Vegetated Strip	Below some critical threshold slope, filtering efficiency is a constant. As slope increases above the critical angle, filtering efficiency declines.
Slope Length Before Water Reaches Buffer Strip	Longer and steeper slopes tend to yield more suspended solids. Thus, filter efficiency declines as these increase.
Vegetation Type	Precise functional relationships are not clearly known. In general, the more flow velocity is reduced, the greater the filter efficiency.
Water Depth Relative to Vegetation Height	Filter efficiency declines as water depth approaches the maximum height of vegetation.
Detention Time	Filter efficiency increases as detention time increases.
Size Distribution of Incoming Sediments	Filter efficiency increases as the mean size of particulates increases.
Application Rate of Water	Filter efficiency declines as the volume of water moving across a buffer increases.
Land Use in Watershed	Filter efficiency declines as flows of contaminants increase due to expansion of agricultural, urban and other land uses.
Season	Buffer strips will be more efficient during the season with more active and healthy vegetation.
Grazing Intensity	As grazing intensity increases, buffer strip efficiency declines.
Source: Adapted from Karr, J.R. 1980. "Franjas de amortiguacion, recursos y desarrollo agricola en la region Guanare-Masparro, Venezuela." Serie Guanare-Masparro, CIDIAT. Merida, Venezuela.	

4.3 SITE-SPECIFIC EROSION AND SEDIMENT CONTROL PRACTICES

As discussed in Chapter 3, construction sites are often major sources of sediment. One of the most effective mechanisms for controlling sediment from construction is to require an erosion and sediment control plan for every proposed development project and to review the adequacy of this plan before construction begins.

An approved erosion and sediment control plan should serve as an agreement between the owner or developer of a construction site and the state or local sedimentation control authority. The plan should specify the minimum level of erosion and sediment control to be installed on the site during each phase of development. On sites where disturbances will exceed a specified area, work should not be allowed to begin without an approved erosion and sediment control plan. Recommended minimum contents of an erosion and sediment control plan are listed in Table 3 (Ref. 14).

Sufficient detail should be provided in an erosion and sediment control plan to implement the plan properly and control erosion and sedimentation during each phase of site development.

Erosion and sediment control plans are worthless if they are not put into practice on the ground. To help ensure that plans are effectively implemented, the following procedures are recommended:

- **Establish a single integrated process for building/site plan reviews and permitting.** If approval for site development involves a series of separate permits issued by separate individuals (for example, separate permits for building plans, for earth disturbance, and for erosion control), erosion and sediment control practices are less likely to be smoothly and sensibly integrated into the final site design.

- **Ensure that sediment control practices are designed into the construction job, not tacked on as an "afterthought" late in the process.** By incorporating sediment control practices into site design early on, it is more likely that the construction job will be budgeted and contracted to cover necessary costs.

- **"Close the connection" between plans put on paper and work performed on the ground.** For example, the developer should be asked to stake out the limits of clearing as shown on the erosion and sediment control plan before bulldozer operators begin work. Requiring a bond to cover the cost of correcting problems (if any) caused by failure to follow the plan may also help motivate developers to "close the connection".

While formal erosion and sedimentation control plans are important, they also need to be flexible and adaptable to changing conditions such as weather and construction schedules. Therefore, an approved plan should be viewed as an open-ended document subject to approved adjustments and modifications.

Table 3. Suggested Contents of An Erosion and Sediment Control Plan.
(Source: Ref. 14)

Devising an erosion control plan can best be accomplished by using a series of guidelines which establish a minimum standard of compliance. The following guidelines are a series of plans which provide a basis to follow when preparing an erosion control plan. It is recommended that local governments require the following items as a minimum on all erosion control plans submitted for their review. 4.1 Overall Plan The following should be included in all erosion control plans: 1. Map of the project area drawn to scale such as 1: = 100' or 1" = 2001. 2. North arrow. 3. Date 4. Name of individual or organization responsible for preparing the map. 5. Title block. 6. Intended use of the land. 7. Legal description 4.2 Drainage Plan 1. Contours based on 5 foot elevation contour data. 2. Natural drainageways where storm runoff would follow and the downstream areas affected by r unoff. 3. Existing drainage facilities and structures, i.e., storm sewers, street gutters, detention ponds, etc. 4. Property lines and adjacent property land use. 5. Flood plains delineated within the property. 6. Proposed outfall point for storm runoff from the area.	4.3 Area Plan The area plan should include specifics concerning land resources of the area. 1. Soils information including maps, descriptions, and interpretations. 2. Identify critical areas. 3. Identify potential water quality problems resulting from erosion and sedimentation. 4. Limiting characteristics of soil types 5. Inventory of the natural vegetation within the area. 6. Soil loss based on the Universal Soil Loss Equation for water. 4.4 Final Plan The final plan should take into account all the above information and present a detailed plan for implementing control measures: 1. Extent of area to be exposed at any one stage in the construction. 2. The timing and sequence of all proposed earth changes. 3. A description and location of all proposed temporary erosion and sediment control measures. 4. A description and location of all permanent control measures which will become a part of the final development 5. Alternatives considered. 6. Record of decisions.

Six basic common-sense principles should govern the development of an erosion and sediment control plan (Ref. 13):

(1) Plan the operation to fit the topography, soils, waterways and natural vegetation at the site;

(2) Avoid development in natural drainageways;

(3) Expose the smallest practical area of land for the shortest possible time;

(4) Apply soil erosion control practices as a first line of defense against off-site damage;

(5) Apply sediment control practices as a second line of defense against off-site damage; and

(6) Implement a thorough maintenance program during and after operations are completed.

The erosion and sediment control plan should be based on an analysis of natural site conditions. A checklist for the evaluation of specific erosion hazards and mitigation opportunities at construction sites is provided in Table 4 (source: Ref. 31).

4.4 PROGRAM IMPLEMENTATION

Achieving the objectives of an erosion and sediment control program involves more than adopting technically sound sediment control solutions. Several other factors having little to do with BMP design can undermine the success of the program.

In the U.S. Virgin Islands, Wernicke (Ref. 2) identified three categories of non-technical issues affecting the successful implementation of the Virgin Islands' Earth Change Law. These categories are: (1) institutional, (2) educational, and (3) informational needs. These three themes are addressed below:

4.4.1 Institutional Considerations

In many cases, sediment control responsibilities are shared among multiple agencies, including planning, public works, and extension organizations. In such cases, the most important challenges are to (1) identify a lead agency to implement regional or watershed-level sediment control efforts, (2) identify the specific responsibilities and limits of jurisdiction of each agency, and (3) ensure that key responsibilities are not overlooked and that assigned responsibilities are not duplicated.

Table 4. Checklist for Site Evaluation.

(Source: Ref. 3 1)

	DEVELOPMENT SITE CONDITIONS	YES	NO
POTENTIAL DETRIMENTAL EFFECTS	1.Are there areas where soil conditions indicate that erosion is a possibility?		
	2. Will erosion occur as a result of any or all proposed alternatives?		
	3. Will adjacent and nearby streams, ponds, and lakes be affected by project construction?		
	4. Is there the potential for flooding in natural and manmade waterways and channels from the increased runoff caused by changed soil and surface conditions?		
	5. Will the development disturb areas in or near stream channels?		
	6. Do the proposed roads have long stretches of excessive grade?		
	7. Will the drainage to streets and from streets to storm sewers or other runoff disposal systems cause water to erode the land or flood property further down gradient?		
MITIGATING OF DETRIMENTAL EFFECTS	1. Can areas of exposed soil be protected from erosion by the establishment of vegetative cover and by the diversion of runoff?		
	2. Can sediment from construction activities be contained on or near the project?		
	3. Will special erosion control and sediment collection measures be required to protect adjacent properties?		
	4. Will construction sequence, method of operations or season of work have an effect on control measures?		
	5. Does the adjoining property require special erosion control or sediment collection methods?		
	6. Can lots be graded without mass grading techniques?		
	7. Are underground utilities provided for?		
	8. Can trees and other vegetation be protected?		
	9. Are paved and other impervious areas held to the minimum?		
	10. Are onsite temporary storage of rainfall included?		
	11. Is fire protection included with sufficient and proper ingress and agrees?		
	12. Can the maintenance of all erosion control practices be adequately provided?		
	13. Is the design storm frequency adequate?		
	14. Can vegetation be allowed to remain in some areas?		

Requirements for erosion and sediment control are not always popular with developers. It is essential that the lead agency responsible for erosion and sediment control demonstrate a top-down commitment to the adopted sediment control program. Without full support for staff on the "front lines" of plan reviews and field inspections, the erosion and sediment control program is doomed to fail.

4.4.2 Educational and Training Considerations

Educational and training efforts are critical because they establish the foundation for all sediment control practices. Education should be targeted toward two general objectives: (1) to foster general public awareness of the need for erosion and sediment control and the costs involved in failing to address these issues, and (2) to provide technical information and training to those who engage in development activities.

By making clear to the public the costs of inaction, broader support for a sediment reduction program can be cultivated. This need not rely on appeals to abstract environmental concerns. Often, costs paid by the public to dredge waterways, clean debris from drainage systems, replace or abandon silted reservoirs and repair flood damages exacerbated by sedimentation provide ample motivation to address the source problems.

Educational opportunities for those engaged in development activities should be made broadly available. Training should be made available to private sector developers and contractors as well as government agencies involved in construction (e.g., public works, agriculture, and housing authorities). Special emphasis should be placed on providing adequate training to those who review site plans and inspect sediment control practices in the field.

Often, training and technical advice can be efficiently disseminated through local "extension service" organizations. The effectiveness of extension programs may be further enhanced by providing low-cost (e.g., bulk purchased) erosion control materials to interested parties.

4.4.3 Informational Needs

Wernicke suggests that informed sediment control decisions can be made only when decision-makers are provided with a comprehensive accounting of all damages from erosion and sediment. As indicated in Section 2.3 of this handbook, these damages may include drainage system maintenance, dredging of navigational channels, flood impacts, lost land productivity, degradation of water quality, lost reservoir capacity, degradation of freshwater and marine fisheries, and impacts on tourism (box, page 25). Quantifying these damages provides the basic information required for intelligent decision-making and wise resource allotment to address the source problems.

CASE STUDY: MEASURING ECONOMIC IMPACTS OF SEDIMENT POLLUTION

Until recently, few attempts have been made to determine the economic impacts of accelerated sedimentation in coastal areas. In 1988, Hodgson and Dixon (Ref. 30) addressed this issue by analyzing economic losses resulting from accelerated sediment production on Palawan Island in the Philippines. They concluded that revenues lost from the fishing and tourism industries were far greater than revenues generated by the logging industry. Timber harvesting was the greatest producer of sediment on Palawan Island.

Erosion rates measured from cut forest lands on Palawan Island were more than four times the rates from virgin forest, and erosion from road surfaces was 240 times greater. In a 78 km2 study basin, logging appeared to increase river sediment loads by a factor of about 100. This sediment was damaging fisheries, primarily by destroying the habitat and food supply provided by coral reefs.

Hodgson and Dixon analyzed the economic impact of two scenarios: (1) a ban on logging; and (2) continued logging as planned. Impacts on the fishing industry were estimated based on measured relationships between the cover and diversity of coral reefs and the biomass of fish populations. Impacts on the tourist industry were estimated based on the proportion of tourism revenue generated by dive resorts whose business depended upon pristine reefs and clear water. Hodgson and Dixon predicted that, over a ten-year time frame, Scenario 1 would generate $11 to $41 million more in total tourism, fisheries, and logging revenues than Scenario 2.

The researchers suggest that governments concerned with maintaining sustainable marine fisheries might consider improved sediment pollution monitoring, as well as additional support for basic ecological research into sediment impacts on economically important fish species. This may provide a base of economically useful information upon which to resolve resource conflicts in coastal zones.

4.5 PROGRAM MONITORING

As with any large-scale effort, a sediment reduction program should include a monitoring component that provides "feedback" on the success (or lack thereof) of program efforts. For a sediment control program, this should include components to monitor (1) success of program implementation, (2) efficacy of BMPs, and (3) resource impacts. These issues are addressed below:

4.5.1 Monitoring Program Implementation

Wernicke (Ref. 2) suggests that the effectiveness of sediment control programs should be assessed by (1) reviewing approved land development permits for technical adequacy; (2) determining the degree to which site inspections are performed and permit compliance is enforced;

and (3) reviewing the expeditiousness with which the program is being carried out. In the words of Wernicke:

The success of any such regulatory effort depends to a large degree on its perception and acceptance by the public -- the "clients" of the program. If application reviews, site inspections, [and] time to approve applications are carried out in a professional and expeditious manner, then a much more cooperative clientele is likely. In other words, determine if "red tape" exists and if so find ways to eliminate it.

4.5.2 Monitoring BMP Efficacy

The effectiveness of various erosion and sediment control measures can be evaluated by monitoring sediment production and the quality of streams or other water bodies adjacent to or near the construction site.

Site sediment production can be monitored, as discussed in Section 3.3, by measuring sediment accumulation in ponds, settling basins, and behind sediment fences. As already mentioned, the first line of defense in erosion and sediment control should be to prevent soil erosion. Therefore, the delivery of large volumes of sediment to sediment traps and barriers suggests that site erosion control measures may not be adequate.

Effective monitoring of off-site water quality ideally includes sampling before, during, and after construction. A monitoring plan should specify the water quality variables to be tested (e.g., turbidity) and how, when, and where the samples are to be collected. A map indicating sampling sites and sample schedules should be provided to those responsible for monitoring water quality. The timing of sampling depends on the conditions one wishes to assess; however, sample collection during and immediately following rainstorms will reflect water quality conditions during periods of peak sediment transport.

Effective water quality monitoring is not a trivial exercise. Horror stories abound of large and expensive data collection efforts that produced little or no useful information -- situations described as "data-rich and information-poor" (Ref. 32). An effective monitoring program consists of much more than the collection of samples. It specifies, prior to the collection of field data, the kind of information desired and the statistical methods by which this information will be extracted from "raw" water quality data. A water quality monitoring plan should specify who will review this information, and how this information will used to evaluate and modify the sediment control program.

4.5.3 Monitoring Offsite Impacts

Presumably, a sediment control program is designed to prevent or minimize specific erosion and sediment impacts, such as lost agricultural productivity, lost reservoir capacity, or lost commercial fishery revenues. Ultimately, the success of a sediment control program depends on the degree to which these impacts are minimized or reversed. Actual monitoring of the impacted resource (e.g., crop productivity, reservoir siltation rates, or fish populations) provides the ultimate yardstick against which the success of a program can be measured.

Unfortunately, accurate and meaningful measurements of impacted resources are often difficult and/or expensive to obtain. Moreover, they are vulnerable to natural fluctuations which produce ambiguous results. For example, a watershed may be subject to several consecutive years of unusually intense rains, or a particular fish population may undergo natural cycles of growth and decline. This makes "typical" conditions difficult to define.

CHAPTER 5 BEST MANAGEMENT PRACTICES FOR EROSION AND SEDIMENT CONTROL

This chapter describes erosion and sediment control best management practices (BMPs) applicable to construction activities in the Caribbean. "Best management practices" refer to a variety of site planning, design, and construction activities to minimize the production and transport of sediments.

Erosion and sedimentation can be reduced in three general ways:

(1) Stopping or minimizing erosion from disturbed areas;

(2) Controlling the erosive impacts of increased or concentrated runoff; and

(3) Minimizing opportunities for sediments to be transported to streams and coastal waters.

The BMPs discussed in this chapter address all three sediment control approaches. Site design should incorporate all three types of practices, but should emphasize prevention of erosion at the source to be effective.

The intent of this chapter is to familiarize the reader with the range of practices commonly used to minimize sediment production from construction sites. This list of BMPs is not intended to be exhaustive. Also, the BMPs discussed here often must be modified to fit unique site conditions.

Many of the BMPs discussed here require an understanding of structural design principles and the hydraulic characteristics of stormwater and sediment runoff. In many cases, this means that the BMP designs should be reviewed by a professional engineer or other qualified individual.

Finally, large permanent structural measures, such as settling basins located on major drainageways, are not discussed in this handbook. Undoubtedly, there are many sites in the Caribbean where such structures would be beneficial. However, the focus of this handbook is on site-specific practices applicable during planning and construction phases.

Fourteen erosion and sediment control BMPs are addressed individually in the order listed on page 29. Information on each BMP is presented under four subheadings: (1) Description and Purpose; (2) Design and Installation; (3) Applicability, Limitations, and Common Problems; and (4) Where to Get More Information.

1. Development Practices
    1.1 Clearing only essential areas
    1.2 Minimizing road disturbances

2. Surface Stabilization
    2.1 Seeding
    2.2 Mulching and matting

3. Runoff Diversion
    3.1 Perimeter dikes and swales

4. Runoff Conveyance
    4.1 Lined channels
    4.2 Temporary slope drains
    4.3 Check dams

5. Outlet Protection
    5.1 Outlet protection

6. Sediment Traps and Barriers
    6.1 Sediment fence
    6.2 Brush barriers
    6.3 Sediment basins
    6.4 Sediment traps

7. Stream Protection
    7.1 Buffer strips
    7.2 Riprap

Best Management Practices:
SITE DEVELOPMENT PRACTICES

BMP 1.1: CLEARING ONLY ESSENTIAL AREAS

Description and Purpose

Clearing practices have a major impact on the erodibility of the ground surface (see Section 3.1). To the extent that ground cover is left and the disturbance of soils (especially by bulldozers) is minimized, soil erosion can be drastically reduced.

Design and Implementation

Where possible, the site cleaning operation should be confined to vegetation alone, avoiding disturbances to the soil. On larger development projects, the phasing of construction activities is a viable and effective means of limiting the area disturbed at any given time. In addition, the periodic use of a rotary mower (such as a bush-hog) to clear land often reduces the need for clearing by more disruptive methods.

The clearing of steep sites (e.g., greater than 20% slopes) poses particular erosion risks and should be avoided where possible. Preservation of natural vegetation is also highly beneficial in floodplain and wetland areas, and along intermittent and perennial stream channels.

Applicability, Limitations, and Common Problems

Minimizing the removal of cover vegetation and the disturbance of soil is a low-cost and beneficial erosion control practice at all construction sites. The protection of disturbed areas can be facilitated by seeding and fertilizing bare surfaces (see BMP 2.1, Seeding and Planting).

For More Information

- Reference 28

BMP 1.2: MINIMIZING ROAD DISTURBANCES

Description and Purpose

Roads are a major and often underappreciated source of sediments, especially (in relative terms) in largely rural or forested watersheds. This is because roads (1) expose additional surfaces to erosion, including cut banks and fill slopes, (2) reduce infiltration capacity and increase runoff, (3) alter drainage patterns and concentrate runoff, and (4) accelerate de-livery of surface runoff and intercepted subsurface flows to the drainage network. By minimizing each of these disturbances, erosion from roads and road networks may be minimized.

Design and Installation

Many road design and installation features can help to minimize sediment production. These include:

- Paving road surfaces
- Revegetating cut banks and fill slopes
- Eliminating abandoned and unnecessary roads
- Properly sizing culverts for large (e.g., 25-year) storm events
- Locating roads and points of road discharge to avoid steep slopes and maintain a buffer distance from stream crossings, flood plains, and shorelines (see BMP 7.1, Buffer Strips).

Where roads are not paved, erosion can be minimized by:

- Avoiding steep road grades and long distances between culverts
- Minimizing vehicle use of roads

The most effective road erosion control strategy is to minimize the area disturbed by roads, especially in steep terrain, near stream channels, and adjacent to shorelines.

Applicability, Limitations, and Common Problems

Good road design and minimizing the area disturbed by roads is always good practice. Note that storm runoff will increase when road surfaces are paved, requiring that additional attention be paid to stormwater management. Good road design and construction techniques, especially handling drainage and properly sizing culverts, can be expensive. The burden of road costs is often borne by local governments with limited resources. Where possible, methods of assessing developers for their fair share of road design, building, and maintenance costs should be established.

For More Information

- Reference 10

Best Management Practices:
SURFACE STABILIZATION

BMP 2.1: SEEDING AND PLANTING

Description and Purpose

Seeding to establish vegetative cover on a disturbed site stabilizes the soil, reduces the amount and rate of runoff during storms, and filters out sediments. Fast-growing grasses may be established on a temporary basis where permanent plant growth is not necessary or appropriate. Where appropriate, vegetation may be established on a permanent basis using grasses, brush and trees.

Design and Installation

The appropriate vegetation, site preparation needs and timing of planting vary from site to site. Planting species native to the area will improve the odds for success and minimize long-term maintenance. Some grasses commonly used for revegetation in the Caribbean are listed in Table 5. Local extension agents and agricultural experts can assist in selecting the most appropriate plants.

Soil amendments, such as limestone or fertilizer, may need to be added to ensure planting success. Surface roughening may be appropriate on steep slopes to help retain seeds. Mulching approximately 75% of the ground surface is essential in most areas to ensure seed retention and plant survival (see BMP 2.2, Mulching and Matting).

Table 5 Common Grasses Used for Revegetation
(Source: Ref. 28)

TERRITORY	GENERA
Barbados	Axonopus, Cynodon, Elusine, Euphorbia, Portulaca
Belize	Axonopus, Cynodon, Paspalum
Jamaica	Bambusa, Vetiveria
Antigua	Andropogan, Axonopus, Dicanthium
Montserrat	Vetiveria, Sweet grass, Creeping grasses
St. Kitts	Axonopus (wet sites), Cynodon (dry sites)
Trinidad	Axonopus, Cynodon, Desmodium, Euphorbia, Mimosa, Sporobolus
Dominica	Vetiveria
Grenada	Andropogen, Axonopus, Cynodon, Cyperus, Panicum, Paspalum
St. Vincent	Vetiveria, Panicum

Applicability, Limitations, and Common Problems

Temporary seeding may be used on disturbed areas where permanent plant growth is not appropriate. Permanent seeding and planting should be used to stabilize all exposed areas where construction is complete. Permanent vegetation is especially important on steep slopes, in swales, bordering stream channels and adjacent to water bodies.

The most common problems with seeding and planting are poor germination and survival or patchy vegetative cover. This may result from inadequate seedbed preparation, unsuit-able plant materials, inadequate mulching, or dry weather conditions.

In much of the Caribbean, seeding will have a low success rate unless combined with mulching and/or watering. Because water is often unavailable or expensive, proper timing and luck often play a role in successful seeding/planting. In the Caribbean, this often means that clearing is best done in the late winter or early spring in order to take advan-tage of the April and May rains, so as to permit a cover to develop by the fall, when high-intensity rain often occurs.

For More Information

- Local extension services
- Reference 1
- Reference 28

BMP 2.2: MULCHING AND MATTING

Description and Purpose

Mulching and matting consists of materials such as cut grass, wood chips, wood fibers, straw or gravel temporarily placed on the soil surface to resist the erosive force of runoff and retain soil moisture until vegetation is established.

Design and Installation

Mulch is spread uniformly over the soil such that no more than 25% of the ground surface is visible. Mulch is anchored in place using matting stapled over the mulch, or a liquid tackifier. Matting is especially recommended for steep slopes and channels.

Applicability, Limitations, and Common Problems

Mulch mattings, netting, and filter fabrics are particularly useful in steep areas and drainage swales where loose seed is vulnerable to being washed away or failing to survive dry soil. Common problems with mulch include insufficient surface coverage, inadequate tacking or ineffective stapling, and insufficient protection against the amount of runoff.

For More Information

- Reference 1
- Reference 28
- Local extension services

Best Management Practices:
RUNOFF DIVERSION

BMP 3.1: PERIMETER DIKES/SWALES

Description and Purpose

A perimeter dike is a ridge of compacted soil used to keep upslope stormwater runoff from flowing across areas where there is a high risk of erosion, or to prevent sediment-laden water from leaving a disturbed site. A perimeter swale is an excavated depression that performs the same function. These structures may be temporary or permanent. (Figure 5).

Figure 5. Typical interceptor dikes and swales. (Source: Ref. 26)

Design and Installation

Dikes are constructed using soil dug from an adjoining swale along the perimeter of the disturbed site. Dikes and swales are placed upslope from a disturbed area to direct runoff away from areas vulnerable to erosion. They also may be placed along the margins of a disturbed area to prevent sediment-laden water from leaving the site.

Generally, perimeter dikes/swales should be established before any major soil-disturbing activity takes place. Dikes should be compacted with construction equipment to the design height plus 10% to allow for settlement. If they are to remain in place for longer than 10 days, they should be stabilized using either vegetation, filter fabric, or other material. Diverted water should be directed to a sediment trap (BMP 6.4) or other sediment treatment area.

Applicability, Limitations and Common Problems

Perimeter dikes/swales should be limited to a drainage area of no more than 0.8 hectares. These diversions usually work best on gently-sloping terrain. Perimeter dikes may not work well on moderate slopes, and they should never be established on slopes exceeding 20%.

Common problems associated with diversion structures include excessive erosion along unlined channels (usually because of excessive grade), erosion or sedimentation at the outlet point, or overtopping of the dike at low points.

For More Information

- Reference 26
- Reference 28

Best Management Practices:
RUNOFF CONVEYANCE

BMP 4.1: LINED CHANNELS

Description and Purpose

Lined channels are excavated channels or swales lined with grass, riprap, or other protec-tive material. They are intended to carry concentrated runoff to a stable outlet without causing erosion or flooding. In some cases they are designed to allow runoff to infiltrate into the surrounding soil (Figure 6).

Figure 6. Typical riprap-lined channel cross-sections. (Source: Ref. 1)

Design and Installation

Grass-lined channels may have V-shaped, parabolic, or trapezoidal cross-sections. Sideslopes should not exceed 3:1 to facilitate the establishment, maintenance, and mowing of vegetation. A dense cover of hardy, erosion-resistant grass should be established as soon as possible following grading. This may necessitate the use of straw mulch and the installation of protective netting until the grass becomes established (see BMP 2.2, Mulching and Matting).

If the intent is to create opportunities for runoff to infiltrate into the soil, the channel gra-dient should be kept near zero, the channel bottom must be well above the seasonal water table, and the underlying soils should be relatively permeable (generally, with an infiltra-tion rate greater than 2 cm per hour).

Riprap-lined channels may be installed on somewhat steeper slopes than grass-lined channels. They require a foundation of filter fabric or gravel under the riprap. Generally, side slopes should not exceed 2:1, and riprap thickness should be 1.5 times the maximum stone diameter. Riprap should form a dense, uniform, well-graded mass.

Applicability, Limitations, and Common Problems

A limitation of lined channels is that they tend to take up substantial land area on a site. Where land is expensive they may not be a cost-effective solution.

Grass-lined channels typically are used in residential developments, along highway medians, or as an alternative to curb and gutter systems. Grass-lined channels should be used to convey runoff only where slopes are 5% or less. They require periodic mowing, occasional spot-seeding, and weed control to ensure adequate grass cover.

Common problems in grass-lined channels include erosion of the channel before vegetation is fully established and gullying or head cutting in the channel if the grade is too steep. Trees and brush tend to invade grass-lined channels, causing maintenance problems.

Riprap lined channels can be designed to safely convey greater runoff volumes on some-what steeper slopes. However, they should generally be avoided on slopes exceeding 10%. Common problems include stone displacement or erosion of the foundation, or channel overflow and erosion because the channel is not large enough.

Channels established on slopes greater than 10% will usually require protection with rock gabions, concrete, or other highly stable and protective surface.

For More Information

- Reference 26

BMP 4.2: TEMPORARY SLOPE DRAINS

Description and Purpose

Temporary slope drains are pipes used to convey runoff water down the face of a cut or fill slope without causing erosion (Figure 7).

Figure 7. Cross-section of temporary slope drain and detail of inlet. (Source: Ref. 1)

Design and Installation

Slope drain pipe sizes are based on drainage area and the size of the design storm. Generally recommended pipe/tubing sizes for slope drains are listed in Table 6.

Pipes should be connected to a diversion ridge at the top of the slope by covering with compacted fill material where it passes through the ridge. Discharge from a slope drain should be to a sediment trap, sediment basin, or other stabilized outlet.

Table 6 Recommended Pipe/Tubing Sizes for Slope Drains
(Source: Ref. 28)

Maximum Drainage Area (hectares)	**Pipe/Tubing Diameter (inches)**
0.2	12
0.6	18
1.0	21

1.4	24
2.0	30

Applicability, Limitations, and Common Problems

Slope drains should be used as a temporary measure for as long as the drainage area re-mains disturbed. They will need to be moved once construction is complete and a perma-nent storm drainage system is established. Appropriate restoration measures will then need to be taken, such as adjusting grades and flushing sediment from the pipe before it is removed.

A common slope drain problem is overtopping of the inlet due to an undersized or blocked pipe, or erosion at the outlet point due to insufficient protection.

For More Information

- Reference 26
- Reference 28

BMP 4.3: CHECK DAMS

Description and Purpose

A check dam is a small temporary or permanent dam established across a drainage ditch, swale, or small channel to reduce the velocity of runoff. By reducing runoff velocity, erosion of the channel is reduced and larger sediments are allowed to settle out (Figure 8).

Figure 8. Typical check dams. (Source: Ref. 26)

Design and Installation

A check dam may be built from logs, stones, gravel-filled sand bags or rock-filled wire mesh (gabions). Expected rates of erosion and runoff should be assessed in order to properly size and design the dams. The center section of the dam should be lower than the edges, and generally no higher than 60 cm. Dam sides should have 2:1 slopes or less. Ideally, dams should be spaced so that the toe of the upstream dam is at the same elevation as the top of the downstream dam. Realistically, dams cannot be spaced this closely in steeper channels.

Dams should be inspected after each significant rainstorm for sediment and debris accumulation. If sediment has accumulated to one-half of the dam height it should be re-moved. Erosion around the edges of the dam must be repaired promptly.

Upon completion of site construction activities and establishment of other sediment control measures (such as seeding and planting, BMP 2.1), the check dams may be removed.

Applicability, Limitations, and Common Problems

Check dams are useful in steeply-sloped swales or small channels, or in swales where adequate vegetative protection cannot be established. Check dams should be used only in small open channels that will not be overtopped by flow once the dams are built. Check dams can be useful for erosion control in road ditches. Check dams should not be built in stream channels, either intermittent or perennial.

Common problems with check dams include channel bypass and severe erosion during storm runoff, and ineffectiveness due to accumulated sediment and debris. When designing check dams, it should be remembered that they will reduce the capacity of a channel to transmit storm runoff, and thus will need to be sized appropriately.

For More Information

- Reference 26

Best Management Practices:
OUTLET PROTECTION

BMP 5.1: OUTLET PROTECTION

Description and Purpose

Outlet protection usually consists of stone, riprap, concrete aprons, paved sections or settling basins installed at the outlet of a channel, culvert, or other concentrated drainage. Its purpose is to reduce the velocity and erosive potential of flow (Figure 9).

Figure 9. Typical details for rock outlet protection. (Source: Ref. 26)

Design and Installation

A licensed engineer, extension service professional, or other design professional should be contacted for information on materials and design features appropriate to the specific drainage conditions. Where riprap is used to dissipate energy, hard, angular, and highly weather-resistant stone is appropriate. Extra-strength filter fabric or six inches of well-graded gravel is normally the minimum foundation required for riprap. Larger flows may require rock gabions or concrete-lined protection. In order to dissipate the maximum runoff energy, grades for the outlet should be minimized and the protected length maximized.

Applicability, Limitations, and Common Problems

Outlet protection should be installed at all drainage outlets where flow velocity and quantity may cause erosion. They should be installed early during construction, although they are useful at any time.

Maintenance of protected outlets can be a problem because sediment accumulates where it is difficult to remove or because riprap is redistributed during high-runoff events. Other problems may include downstream erosion due to structure undersizing, excessive grade, or other characteristics that fail to dissipate a sufficient amount of runoff energy.

For More Information

- Reference 26

Best Management Practices:
SEDIMENT TRAPS AND BARRIERS

BMP 6.1: SEDIMENT FENCE (SILT FENCE, FILTER FABRIC FENCE)

Description and Purpose

Filter fabric stretched across posts, sometimes with wire support, with the lower edge of the fabric buried in the ground (Figure 10). Sediment fences retain sediment from small, sloping dis-turbed areas by reducing the velocity of runoff.

Figure 10. Sediment fence details. (Source: Ref. 26)

Design and Installation

Fences are located to be nearly level and at least 3 meters from the toe of slopes to pro-vide a broad, shallow sediment pool. Support posts generally should be spaced at no more than 2.4 meters if the fence is supported by wire, or 1.8 meters for extra-strength fabric without support-backing wire. The bottom 30 cm of fabric should be buried a minimum 20 cm deep. The fence height should not impound water to greater than 45 cm at any point along the fence. Support post should be steel or strong wooden stakes treated against insects. Recommended maximum slope lengths above a silt fence are listed in Table 7.

Table 7 Minimum Slope Distance For Which A Sediment Fence Is Applicable (Source: Ref. 1)	
Land Slope (%)	**Maximum Slope Distance Above Fence (ft)1**
<2	100
2 to 5	75
5 to 10	50
10 to 20	25
>20	15
1 Slope distance may be increased if design is supported by appropriate runoff calculations.	

Applicability, Limitations, and Common Problems

Sediment fences are appropriate only for small disturbed areas such as individual home-sites. The maximum drainage area to a silt fence should not exceed 0.2 hectare per 30 meter of fence. Also, a silt fence should not be used in channels, gullies, or other locations of concentrated runoff. Sediment fences are most effective when used in conjunction with other practices such as perimeter dikes or diversions.

The most common failure of sediment fences results from failure to bury the bottom edge of the fabric, or from locating the fence in an area of concentrated runoff. Failures may also occur if the pore size of the filter fabric is inappropriate. Sediment fences should be inspected frequently and maintained to ensure their effectiveness.

For More Information

- Reference 26
- Reference 1

BMP 6.2: BRUSH BARRIERS

Description and Purpose

A brush barrier is constructed of tree trimmings, limbs and brush obtained from the clearing operation. The barrier slows runoff and filters out sediment. To maximize effectiveness, a filter cloth is fastened over the brush.

Design and Installation

Brush barriers should be placed around the perimeter of a disturbed area. Ideally, trimmings, limbs, and brush are piled in long rows, a filter cloth is placed over the brush, and the front of the filter cloth is buried in a small trench on the uphill side of the barrier to prevent undermining. The filter cloth is attached to the brush by stapling or other means.

Brush barriers may be effective without a filter cloth if they are pushed into place with equipment that also establishes a berm of piled soil. Brush that is simply piled in rows without additional protection is unlikely to be effective.

Applicability, Limitations, and Common Problems

The brush barrier should be constructed in conjunction with the clearing operation and should be in place before any soil-disturbing construction activity. Once constructed, brush barriers typically require little maintenance. However, they may lose their effectiveness over time as sediment accumulates. Brush barriers need not be removed. Generally, the barrier will rot and natural vegetation will take over. However when the brush barrier is no longer needed, the fabric should be cut at ground height and any deposited sediment redistributed.

Brush barriers should not be used on slopes exceeding 40%. They should not be used in channels, swales, or other drainageways where concentrated flow is anticipated. Repairs should be performed immediately, and accumulated sediment should be periodically re-moved.

For More Information

- Reference 12

BMP 6.3: SEDIMENT BASINS

Description and Purpose

Sediment basins consist of a settling pond with a structure for controlled overflow release. They are built to retain sediment on the construction site by reducing runoff velocity and allowing the sediment to settle out (Figure 11).

Figure 11. Small sediment basin with outlet pipe discharging on energy dissipator to prevent erosion at discharge end. (Source: Ref. 23)

Design and Installation

A sediment basin may be designed as a temporary or permanent site feature. It is constructed by excavation and/or by placing an earthen embankment across a low area or drainage swale. It is designed to store a pre-determined quantity of runoff, allowing the runoff to slowly infiltrate through the basin floor or be gradually released after most sediment has settled out.

The basin should be large enough to retain runoff for a period sufficient to allow most sediment to settle out. Runoff should enter the basin as far from the outlet as possible to provide maximum retention time. Generally, trapping efficiency will improve with increased pond area.

The sediment basin should be built as close to the sediment source as conditions allow. The basin should have a principal spillway or a pipe-and-gravel outlet designed to safely release excess runoff.

The useful life of a sediment basin is dependent upon adequate maintenance. Basins should be inspected after each significant rainfall event and sediment should be removed when one-half of the basin volume is filled. Temporary basins should be removed after the drainage area is permanently stabilized.

Applicability, Limitations, and Common Problems

Sediment basins are expensive to build and have the disadvantage of requiring regular maintenance and cleaning. They will not remove the bulk of fine silts and clays unless used in conjunction with other erosion and sediment control practices. They are practical only on larger development sites and on gentler slopes.

Common sediment basins problems include:

- Slumping or settling of embankments due to poor-quality fill material and/or inadequate compaction;

- Erosion or caving along pipes and spillways due to inadequate design and protection;

- Poor access, resulting in difficult or costly maintenance; and

- Inadequate storage capacity because sediment is not removed when necessary.

Larger basins also introduce the risk of "blowing out" and creating flood damage down-stream during large storm events.

For More Information

- Reference 26
- Reference 28

BMP 6.4: SEDIMENT TRAPS

Description and Purpose

A sediment trap is an excavated pond or earthen embankment across a low area or drainage swale. It is similar to a sediment basin (BMP 6.3), but smaller in size and often temporary in nature. The trap is designed to retain runoff long enough to allow most sediment to settle out.

Design and Installation

A sediment trap should be large enough to allow most sediments to settle out of stormwater and should have the capacity to store accumulated sediment between cleanings. The volume of sediment storage provided by a trap should be determined based on expected rates of runoff and sediment loading. Typically, a minimum storage capacity of 250 m3 per acre disturbed is recommended.

Sediment traps should be installed prior to grading and filling. Embankments should not exceed 1.5 meters in height, and should have a minimum top width of 1.2 meters. Side slopes should be 2:1 or flatter. The embankments and all disturbed areas should be stabilized with vegetation immediately following installation.

A spillway or other protected outlet must be provided for stormwater release. Spillway protection is typically established with riprap (see BMP 5.1, Outlet Protection).

Applicability, Limitations, and Common Problems

Sediment traps are suitable for small drainage areas, typically 2 hectares or less. Because they are smaller than sediment basins, they allow more flexibility in placement and can be used in steeper-slope areas. Sediment traps should be located as near to the sediment source as topography allows. They should be used in conjunction with other sediment control measures. The effective life of a sediment trap depends upon adequate maintenance, therefore the trap should be placed in an accessible location and cleaned out when half of the storage capacity is filled.

Common problems with sediment traps include:

- Inadequate spillway size;
- Inadequate storage capacity; and
- Inadequate vegetative protection of embankments.

For More Information

Reference 26
Reference 28

Best Management Practices:
STREAM PROTECTION

BMP 7.1: BUFFER STRIPS

Description and Purpose

Buffer strips are vegetated strips of land adjacent to stream channels, coastal waters, or other receiving areas. They are intended to decrease the velocity and erosive potential of stormwater runoff and to filter out sediments. Buffer strips potentially provide additional environmental benefits including stream temperature maintenance and the protection of bi-ologically valuable streamside habitat.

Design and Installation

A buffer strip can be a vegetated area that is left alone during construction, or it may be planted. Because site conditions vary greatly, only the most general recommendations can be made. No specific width is universally appropriate. In temperate forests 9 meters is the most commonly recommended width (Ref. 17). Generally, the wider the buffer area, the greater the erosion and sediment control benefits. The optimal buffer width from an economic perspective is that point where the marginal benefits of widening the buffer equals the marginal cost of taking this additional land out of productive use (Ref. 17).

Applicability, Limitations, and Common Problems

Buffer strips can be used at any site that supports vegetation. Buffer strips are not popular with developers because they reduce the amount of land that remains available for con-struction. On the other hand, buffer strips can add aesthetic value to a site. Buffer strips may not be feasible on small lots or sites requiring waterfront access.

As already mentioned in this handbook (Section 4.2), sediment transport via channelized overland flow generally is not effectively trapped and filtered by buffer strips. Channel-ized flow is more common than sheet flow. Thus, one should avoid placing too much faith in the capacity of buffer strips to filter sediment before it reaches a stream. However, they may be very effective in preventing erosion from the buffered area.

For More Information

- Reference 26
- Reference 17
- Reference 8

APPENDICES

APPENDIX A EVALUATION OF EROSION AND SEDIMENTATION PROCESSES AND RATES

Field measurements provide the most reliable information on erosion and sediment transport rates. Ideally, the production and delivery of sediment is assessed by measuring precipitation, runoff, and the quantity of sediment carried by runoff during various storm events. In practice, such measurements are expensive, time-consuming, and impractical for all but the most serious researcher. Moreover, such measurements tend to be highly variable in time and space, typically requiring a minimum of 2-3 years of data collection to be useful (Ref. 24).

To some extent, surface erosion models such as the Universal Soil Loss Equation (Appendix B) help address these limitations. In areas where sheet and rill erosion are dominant erosional processes (as opposed to gullying or landsliding, for example), the USLE can provide estimates of the magnitude of erosion. In areas where landslides or other hillslope failures are widespread, the magnitude and frequency of these sediment sources must be assessed using tools other than the USLE.

When quantifying sediment production, it is important to recognize the difference between erosion rate and sediment yield. The quantity of sediment delivered to the outlet of a water-shed -- the sediment yield -- is less than, and often a small fraction of, the quantity of material eroded within the watershed (Ref. 35). This is because much of the eroded material is redeposited on hillslopes, in landscape depressions, behind vegetation, or in flooded areas and stream channels, perhaps to be remobilized during the next major storm. Hours or years may pass before an eroded particle reaches the outlet of a watershed.

For these reasons it is very difficult to accurately predict the movement of eroded material within a watershed. To assess erosion and sedimentation processes, detailed observations must be made, including evidence of sediment deposition and storage at various points on hillslopes, in stream channels, and elsewhere in the watershed. Unfortunately, only the most generalized "rules of thumb" exist for predicting the quantity of sediment leaving a watershed -- nothing substitutes for good field observations and measurements.

The sediment delivery ratio expresses the proportion of material eroded in a watershed that reaches the outlet of the basin (Ref. 35). All other factors being equal, sediment delivery ratios tend to decrease with the increasing size of sediment particles and increasing watershed area. Thus, a relatively large proportion of eroded silts and clays will rapidly be delivered to the outlet of a watershed encompassing only few square kilometers, while the proportion of sand- and gravel-sized sediments reaching the outlet of the same (or larger) watershed will be much smaller. This is an important consideration in the Caribbean region where both distance to the ocean and watershed size are smaller, on the average, than on larger continental land masses. Erosion in Caribbean watersheds therefore is more likely to have a measurable downstream sediment impact (Ref. 18, 19).

Published studies of erosion and sedimentation can provide valuable information for a particular region and reduce the need for additional field research. Unfortunately, quantitative erosion and sediment studies for the Caribbean are few. Worldwide, sediment yields between 20 and 5300 metric tonnes per year have been reported in relatively undisturbed, heavily forested tropical watersheds 0.18 to 650 km2 in size (Ref. 36). Although this range of values is broad, these rates are clearly very low in comparison to the 20,000 to 110,000 metric tonnes of erosion per square kilometer (100 to 500 tons per acre) reported for construction sites in the United States (Ref. 27, 33).

APPENDIX B THE UNIVERSAL SOIL LOSS EQUATION

The Universal Soil Loss Equation (USLE) is an empirically-derived relationship developed in the 1970's to predict average annual soil loss by sheet and rill erosion (Ref. 37). Statistical analysis of many years of runoff and soil loss data from numerous locations was used to develop the original empirical relationships for USLE. USLE became the most widely used erosion forecasting tool from the early 1970's through the 1980's (Ref. 24).

USLE was recently updated to become the Revised Universal Soil Loss Equation. The basic equations of the model have not changed, but RUSLE incorporates improved methods for estimating parameter values (Ref. 38).

Limitations of USLE

Every erosion model incorporates certain assumptions that limit its usefulness under certain conditions. Among the most important assumptions and limitations affecting USLE are:

(1) USLE is intended to estimate rainsplash, sheetwash, and rill erosion. It is not calibrated to estimate gully and stream channel erosion, nor does it identify areas susceptible to landslides;

(2) USLE does not identify areas of sediment deposition; and

(3) USLE was developed for use in the midwestern United States, and was not designed for use in tropical regions. Nevertheless, USLE has been widely applied throughout the tropics (Ref. 24).

In spite of these limitations, USLE remains a widely-accepted technique for evaluating erosion potential. Generally speaking, USLE is a useful tool for assessing relative erosion potential under different site conditions and land management practices. However, the specific quantities of eroded material predicted by USLE are often inaccurate, and should be interpreted with caution.

Model Parameters

Six factors reflecting the effects of precipitation, topography, vegetation, land management and soil characteristics comprise the USLE model. Specifically, USLE computes the expected surface erosion on a hillslope as:

$$\mathbf{A = R * K * L * S * C * P}$$

where ***A*** is the computed average soil loss per unit area (typical units of ***A*** are tons per acre per year). The predictive variables are:

R, the rainfall and runoff factor. If all other factors are held constant, soil loss is estimated to be proportional to the total storm energy times the maximum 30-minute intensity. ***R*** is highest in areas prone to large and intense storm events. For this reason ***R*** values are relatively high in many parts of the Caribbean.

K, the soil erodibility factor. This represents the inherent susceptibility of a soil to erosion. K values are influenced by soil texture (i.e., particle size distribution), organic matter content, and other soil characteristics. Soils with the highest ***K*** values tend to be those with a high proportion of silt, a low proportion of clay, and minimal organic matter.

S, the slope-steepness factor. This factor accounts for the increased potential for erosion with increasing slope steepness.

L, the slope-length factor. ***L*** accounts for the increased potential for erosion with the increased length of exposed slope. USLE's basic definition of slope length is the length of slope from the origin of overland flow to the area where sediment deposition occurs or flow enters a well-defined channel (Ref. 37).

In practice, the determination of a slope length consistent with USLE's definition can be problematic. However, the general concept is straightforward: all other factors being equal, longer slopes create more erosive conditions. At construction sites, ***L*** can be reduced by breaking a long slope into a series of shorter slopes using sediment fences (BMP 6.1), brush barriers (BMP 6.2), or other measures which impede site runoff.

C, the cover factor, is the ratio of soil loss from an area with specified cover and management to an identical area in clean-tilled continuous fallow. Thus C is close to 1.0 in disturbed areas where the soil surface is not protected, and a small fraction of 1.0 where soils are well protected by rooted vegetation, mulched and matted surfaces, or other dense cover (BMP 2.1 and 2.2).

P, the support practices factor, is the ratio of soil loss under a specific land management regime to soil loss with up-and-down-slope tillage. This factor is generally applied to agricultural land management practices, and can usually be ignored in the evaluation of construction sites.

Values for these six factors can be derived from detailed tables, maps and formulae provided in numerous erosion texts. These tables, maps and formulae are far too extensive for discussion here. The reader who wishes to calculate USLE values is encouraged to consult an appropriate reference (e.g., Ref. 37).

One simple example, however, may help illustrate the value of USLE. In Chapter 3 it was noted that unpaved road surfaces are a serious erosion problem in much of the Caribbean. A quick consideration of road impacts on USLE factors helps to explain why. The removal of cover vegetation (e.g., forest) and conversion to unprotected soil surfaces results in a massive increase in the ***C*** factor. Road cuts and fill slopes have the added effect of steepening slopes, increasing ***S***. In addition, road surfaces often create very long, uninterrupted slopes between culverts or other points of runoff diversion, thereby greatly increasing ***L***. Not surprisingly, the USLE predicts that erosion rates from unpaved roads will be many times that of the original, undisturbed surface.

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Lutz, E., S. Pagiola, and C. Reiche (eds.). 1994. Economic and Institutional Analyses of Soil Conservation Projects in Central America and the Caribbean. World Bank Environment Paper Number 8. The World Bank, Washington, D.C. 207 pp.

GLOSSARY of ACRONYMS and TECHNICAL TERMS USED IN THIS REPORT

Best Management Practice (BMP)

Planning, design, and construction practices that minimize the production and transport of sediments.

BMP

See "Best Management Practice".

CARDI

The Caribbean Agricultural and Research Development Institute, University of West Indies, St. Augustine, Trinidad and Tobago.

Design storm

The storm duration and intensity for which a BMP or other structure is designed.

Embankment

A man-made deposit of soil, rock, or other material, often used to form an impoundment.

Erosion

The wearing away of soil by water, wind, and gravity.

Erosion and sediment control plan

A plan specifying the minimum level of erosion and sediment control to be installed on a site during each phase of development activity.

Evapotranspiration

The combined loss of water from an area by evaporation from the soil surface and by transpiration of plants.

Gabion

A wire mesh cage, usually rectangular, filled with rock and used to protect channel banks and other sloping areas from erosion.

Geographic information system (GIS)

A computerized system for storing, analyzing, retrieving and displaying georeferenced (mapped) information

Gully erosion

Erosion resulting in a relatively deep incision of the soil surface, caused by concentrated overland runoff.

Mass wasting

Movement of earth materials caused by gravity alone, without a transporting medium such as wind or water. Mass wasting includes imperceptible processes such as soil creep and rapid processes such as debris slides and rock fall.

Rill erosion

Small eroding channels produced by surface runoff.

Runoff

That portion of precipitation that flows over the land surface, in open channels, or in stormwater conveyance systems.

Sedimentation

The deposition of eroded material (sediments).

Sediment delivery ratio

The fraction of the soil eroded from upland source that reaches a stream channel, water body or watershed outlet.

Splash erosion (or rainsplash erosion)

The dispersal of soil particles resulting from direct raindrop impact on the soil surface.

Stormwater

Runoff from a storm event or surface runoff and drainage.

Suspended sediment

Sediment suspended in runoff water, in a stream, or in any other water body.

Swale

An elongated depression in the land surface that is at least seasonally wet, usually heavily vegetated, and normally without flowing water.

25-year storm event

The greatest amount of precipitation expected within a given length of time (such as 1 hour) over any 25-year period.

Turbididy

A measure of the ability of a water sample to transmit light. High turbidity (poor light transmission) is normally caused by the presence of suspended matter such as clay, silt, fine organic matter, and microscopic organisms.

USLE

The Universal Soil Loss Equation. An equation developed in the United States in the 1970's to express estimated soil loss per unit area as a function of rainfall, soil type, slope length, slope steepness, land cover, and land management characteristics.

Watershed

The area of land draining to a common outlet.

Water table

The surface of water under the ground that is at atmospheric pressure. The water table is approximately that depth in the ground at which saturated soil is first encountered. The water table generally rises and falls seasonally.