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**Government of Saint Lucia**  
**Ministry of Planning, Development and the Environment**

**WATERSHED AND ENVIRONMENTAL  
MANAGEMENT PROJECT - PHASE II**

**INCEPTION REPORT**

**October 1996**

**Hunting Technical Services,  
Hemel Hempstead,  
England.**

**IN ASSOCIATION WITH**

**Mott MacDonald  
Cambridge,  
England.**

**Under assignment by the Overseas Development Administration**

**HM Government, London, United Kingdom**



**SAINT LUCIA WATERSHED AND ENVIRONMENTAL  
MANAGEMENT PROJECT**

**c/o Forestry Department,  
Union, Castries,  
St Lucia.  
Tel 450 2231, Fax 450 2287**

The Permanent Secretary,  
Ministry of Planning, Development & the Environment,  
Government Buildings,  
Castries, St Lucia.

29 October 1996

Dear Sir,

**Watershed and Environmental Management Project.**

We have pleasure in submitting the Inception Report as required under the contract between Hunting Technical Services, in association with Mott MacDonald International and the Overseas Development Administration of the UK Government.

The report is submitted in ten copies and we understand that the onus for distribution to other parties falls upon your Ministry.

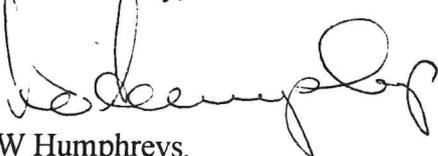
In the report, we show how the complex task of producing a National Watershed and Environmental Management Plan can be completed within the allotted time and our concerns at this stage relate to the availability of sufficient staff and financial resources to carry out the programme between February and August 1997.

Mention must be made of the serious flooding on the west and coastal parts of the Island during the weekend of 25/26th October and the impact that this has had on our review of the Phase I works. As originally conceived the review entailed an assessment of the level and completeness of works, their quality of construction and the place of bioengineering techniques in improving effectiveness.

The considerable damage observed both to the actual Phase I works and in some cases as a direct result of them, suggests that a much more detailed assessment is now essential and that plans must be drawn up for their rehabilitation and where necessary redesign. This activity is considered to be outside the team's terms of reference, but is seen by us as an essential and integral part of the review. We would appreciate your urgent consideration and some discussion regarding this issue.

We trust that the Report meets with your approval and should there be any other issues, which require further discussion our team is at your disposal.

Yours faithfully,



P W Humphreys,  
Team Leader

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## ACRONYMS AND ABBREVIATIONS

BDDC	British Development Division in the Caribbean
CIDA	Canadian International Development Agency
GIS	Geographic Information System
GoSL	Government of St Lucia
IoH	Institute of Hydrology (UK)
LCDC	Land Development and Drainage Committee
MALF&F	Ministry of Agriculture, Lands, Fisheries & Forests
MCW&T	Ministry of Communications, Works & Transport
NGO	Non-Governmental Organisation
OAS	Organisation of American States
ODA	Overseas Development Administration (UK)
OECS	Organisation of Eastern Caribbean States
SLBGA	St Lucia Banana Growers Association
TSD	Tropical Storm Debbie
UNDP	United Nations Development Programme
UWI	University of the West Indies
WASA	Water and Sewerage Authority
WINDECO	Successor to WINBAN

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## 1. INTRODUCTION

### 1.1. Background

Tropical Storm Debbie (TSD) hit St Lucia on the 9/10th September 1994, causing severe damage to the environment, property, agricultural land and the river/drainage system. Some loss of life was also recorded and many people were made homeless. Losses were estimated at EC\$ 112 million.

An urgent request for assistance from the Government of St Lucia (GoSL) to the World Bank brought a quick response and a team visited the island in late October and preparations were made to field a team of consultants. This team, with support from the British Development Division in the Caribbean (BDDC) worked in St Lucia from 29th November to 23rd December 1994.

The resulting report, "Watershed and Environmental Management Project" dated December 1994, proposed a two phase strategy:

- Phase I comprised a priority works programme to effect repairs to the rivers and drainage systems. This was costed and a loan of EC\$14.3 million was agreed with the World Bank. The British Overseas Development Administration (ODA) agreed to fund the technical assistance component and a Supervising Engineer arrived in February 1995. The Phase I works were largely completed by May 1996.
- Phase II was designed to take a longer term view of environmental management in order to achieve sustainable development of land and water resources through watershed management.

Phase II encompasses a wide range of issues and proposes to bring together and co-ordinate inputs from GoSL Ministries, NGOs and the Organisation of Eastern Caribbean States (OECS). The consultancy was planned to be completed in an elapsed time of twelve months with an initial series of inputs to:

- review all pertinent reports;
- review the results of Phase I;
- produce a management plan covering two representative watersheds;
- establish field trials in slope stabilisation and soil conservation.

In addition and in order to enhance the future success of implementation, community involvement in proposed institutional changes and development will be initiated. After a break to allow for construction and the establishment of field trials followed by part of a wet season to carry out meaningful observations, the team will return to evaluate the work done on pilot watersheds and extrapolate the results to cover the whole Island.

At this stage, a word of caution is required; the Phase I works were in response to the emergency rehabilitation of the river systems and associated structures damaged as a result of TSD and although Phase II is seen as a continuation of Phase I, its focus is significantly different. Phase I works will certainly be reviewed and recommendations made for improving the emergency response programme, but the main purpose of Phase II is the development of a sustainable Watershed and Environmental Management Plan. It must be appreciated that the resulting plan, will for reasons of history and project concept, be slanted towards drainage and soil conservation issues and other elements of a comprehensive Management Plan, such as the dry season management of water resources will inevitably receive less attention.

## 1.2. Mobilisation

Mobilisation started as soon as the consultants received a letter of intent from ODA, but without an agreed contract.

In order to facilitate a smooth handover from Phase I, Mr Jonathan Butterworth, the ODA funded Supervisory Engineer had a two week input from 1st to 15th October 1996. It was unfortunate that the GoSL had not been advised of the consultants' arrival which affected the early logistics.

The Consultants' team members arrived as follows

P W Humphreys	Team Leader	2/10/96
J I M Dempster	Project Adviser	8/10/96
C J Hatten	Environmentalist	9/10/96
P G Thompson	Institutions	10/10/96
D H Barker	Geotechnical Adviser	16/10/96
D N Moore	River Engineer	18/10/96

Mobilisation was not quite as originally planned, due to the later than expected start, but there was a satisfactory overlap between the Team Leader/Project Adviser and the Supervisory Engineer. New team members were briefed by those already in country and there was no loss of momentum. Mr J M Dempster left St Lucia on 25th October and Mr D H Barker on 27th October.

Mr R A Isaacs, Geotechnical Specialist joined the team on 17th October and Dr C Rogers Landslide and Hazard Mapping Specialist of UWI Trinidad, is expected to make an initial visit from 31st October as part of her 20 day input.

## 1.3. Familiarisation.

With a steady stream of consultants arriving during the first two weeks of the project, familiarisation was not unduly protracted. There were however some delays in establishing a local office and attendant services, due mainly to the lack of warning afforded to GoSL. Phone and fax connections were also a problem, but the team has been well supported through the goodwill of neighbouring Government offices. Officials at all levels have been most supportive, giving freely of their time, providing early access to transport/staff and most important, access to information and available data.

During this initial period, efforts focused on:

- **Meetings** - Subjects included introductions, background information, better definition of the terms of reference (ToR) and a most useful early contact with BDDC;
- **Field Trips** - Initially accompanied by the Phase I Supervisory Engineer and on some occasions by the Project Co-ordinator and other government personnel, the Team Members later made many trips to the field to increase understanding generally and to see specific works. In this regard, the heavy rain on 26th October, gave the team a good insight into the vulnerability of river works, roads, crops and homesteads;
- **Reports** - Relevant reports were listed and were readily made available to the team. Much time was spent in background and technical reading;
- **Data Gathering** - Starting from a list of suggested contacts, data gathering by interview and the provision of documents proceeded at an ever broadening pace and whilst there is still a need to contact a number of organisations, the Consultants are satisfied that good progress has been made.

## **2. PHASE 1 OF THE PROJECT**

### **2.1 Works**

#### **2.1.1 Initial Inspection and Data Collection**

The Phase I Supervising Engineer, returned to St Lucia for the first two weeks of this assignment. Brief inspections of the main works were carried out, initially with assistance and guidance from Mr Butterworth. Certain reaches of the Cul de Sac and Roseau rivers have been examined in greater detail. Broad categories of work have been:

- river bank protection through rip rap or gabions;
- river resectioning;
- river clearance and desilting; and
- river realignment.

Details of the Phase I works and costs are listed in Appendix A, Table A1, see Figure 2.1 for the general location.

Survey sheets, as-built drawings and design files have been collected and most examined. However, the data is incomplete and more information has to be collected. There is a need for a summary statement of the works undertaken together with location plans and extent of the works undertaken in each section of channel of each river. Such a document would have facilitated the review of the Phase 1 works which is to be carried out by the Consultants.

#### **2.1.2 Preliminary Observations**

The initial impression was that of extensive river works carried out to protect urban areas and infrastructure. Photo 1, presented at the end of the report, shows the major rip-rap river bank works to protect Dennery town. Photos 2 shows a gabion wall in the Cul-de-Sac river designed to protect a single house, but more importantly the main road between Bexon and Castries. Photo 3 shows an example of the severe damage which took place adjacent to the river in the town of Soufriere. Photo 4 depicts the same location but with the gabion training walls that were constructed on both banks of the channel to protect the houses from further damage and to provide the basis for rehabilitation. All of those works provided the designed protection in the 26th October event.

Desilting works were carried out on most of the main rivers to bring them back to, as near as practicable, the pre-TSD situation. There has been a certain amount of river training, and meander cutting. In some cases bank protection works have influenced river courses. The World Bank Mission and the Phase1 River Environmental Specialist have cautioned against such interventions, and it is clear that river regimes can and have been seriously affected (see Photo 2). This aspect will be examined carefully during Phase II.

An evaluation will be made of Phase 1 works to assess their technical, socio-economic and environmental impacts, particularly in relation to future programmes in these and other river basins. However, as stated in 2.1.1, the exact details of the works undertaken needs to be firstly documented.

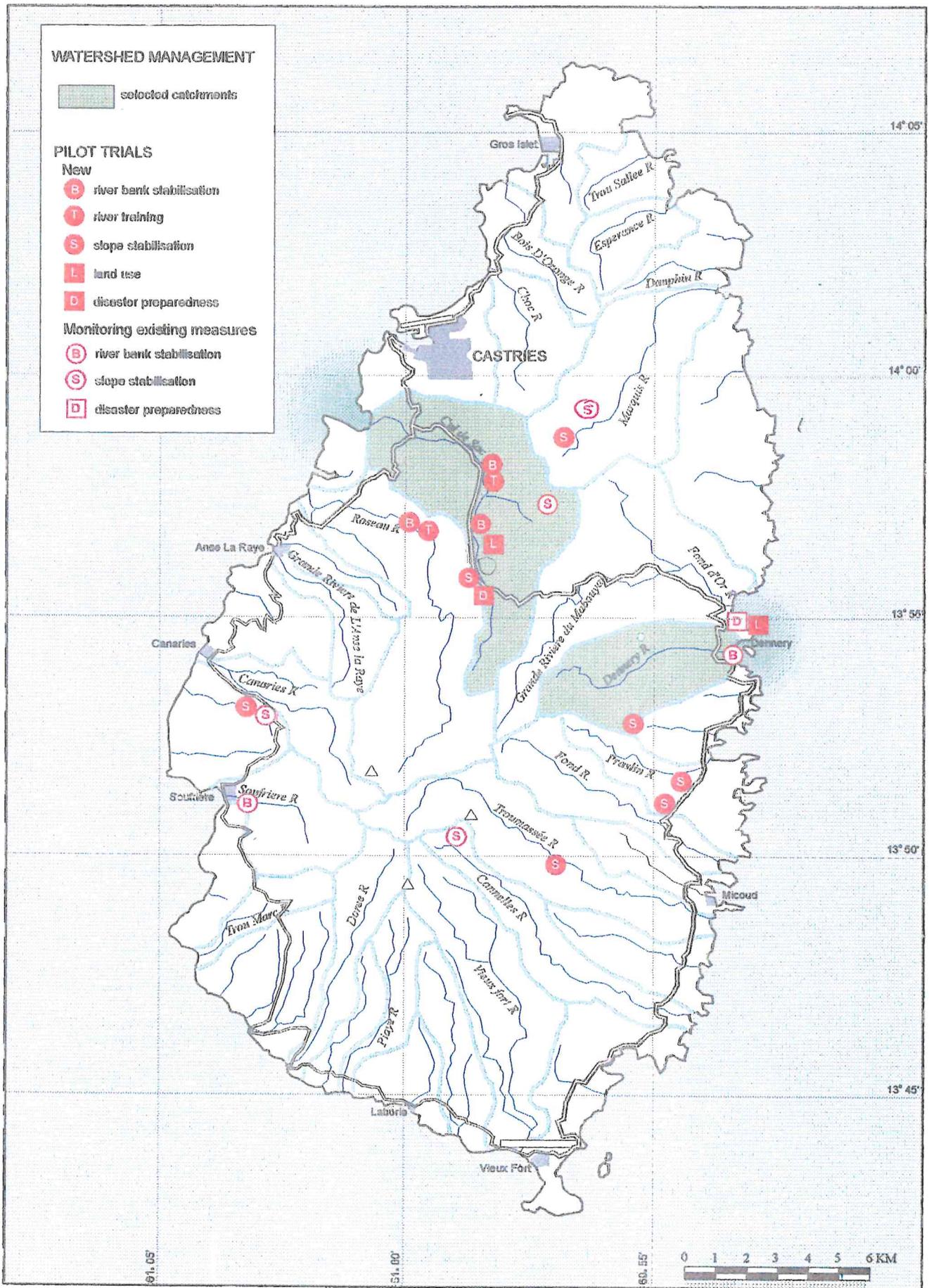


Figure 2.1 Preliminary location of Phase 2 activities

Preliminary indications of possible improvements include:

- the introduction of palisading using natural materials for bank protection;
- the combined use of selected vegetation with gabions and rip rap to create a more permanent and effective structure;
- the need to link loop cutting, where such is seen as the only solution, to channel profile control measures (small cross weirs or channel steps);
- the importance of establishing a system for the regular inspection of the river system particularly at key infrastructure locations (e.g. roads, service lines, main buildings);
- the importance of regular maintenance tied to regular inspection of the channel and contact with local landowners or farmers:
  - keeping the channel clear of obstacles;
  - reducing the danger of tall or overhanging trees from falling into or across the river channel by a defined system of top lopping.

The above will be elaborated in the course of the development of the Watershed Management Plan.

## 2.2 Hydrometeorological Networks

### 2.2.1 Existing Network

A useful summary is provided by the 1992 Report by the Institute of Hydrology (IoH):

*"The oldest records of rainfall on St Lucia date from 1890 at the Botanical Gardens in Castries, which is still in operation, with a few gaps. In 1933, 34 gauges were in operation of which six are still functioning, but by the 1950s the number had decreased to 15. Data at many stations are incomplete and instruments have been moved frequently. For example the rain gauge at Soucis has had four locations since its inception in 1908.*

*The current network of rainfall stations from which data are collected by the Department of Agriculture is 32 gauges."*

The details of the 32 gauges operational just before TSD are given in Appendix A, Table A 3.

*"The only rain gauge on the island for which short duration data are extracted on a routine basis is the autographic gauge at the Department of Agriculture's Union Research Station."*

The World Bank Report following TSD states that daily rainfall data is only available after 1955. This limits estimation of past floods bearing in mind the characteristics of flooding in the catchments. During TSD only 5 of the 15 rainfall recorders reportedly gave good results regarding the intensity of rainfall with 3 others giving data sufficient for estimates to be made.

There has thus been a significant variation in the numbers of rainfall gauges which have been functioning and reliable over the years. Care must be taken to ensure that a manageable number are operated and that there are adequate resources to operate, maintain and replace units. Hence, it would be advisable to keep a number of the units in store to act as replacements in case of damage. Failures of the tipping buckets with integral data loggers (as purchased) might be more common than manually read units. Their cost at perhaps EC\$4,000 each new unit might be a unwanted future expense.

The December 1992 Report by IoH also provides a useful summary of the River Gauging Stations. These are presented in Table 2.1.

**Table 2.1**  
**River Gauge Stations in 1992.**

River	Gauge	Operator	Installation Date
Marquis	Marquis Boquis	LWUU <sup>1</sup>	1986
Fond D'Or	Mabouya Bridge	LWUU	1984
Troumasse	Beauchamp Estate	LWUU	1984
Cul de Sac	Ferrand Bridge	LWUU	1985
Vieux Fort	La Retraite Bridge	LWUU <sup>2</sup>	1984
Doree	Coast Road Bridge	LWUU <sup>3</sup>	1984
Choc	Treatment Plant	LWUU <sup>4</sup>	1985
Cul de Sac	Ravine Poisson	WASA <sup>5</sup>	1983
Millet	Bridge	WASA <sup>5</sup>	1983
Roseau	Cable	WASA <sup>5</sup>	1983

Source : Table 3.4.1. IoH Report 'The impact of Urban Development on Flood Risk in the Cul de Sac Valley.

Notes

1. No reliable rating curve
2. Vandalised
3. Now heavily pumped
4. Poorly sited next to intake
5. WASA no longer maintain these gauges and is discussing (1992) possible transfer of operation to LWUU (Land and Water Use Unit of the Department of Agriculture).

The World Bank report post TSD stated that 'none of the installed recorders could register the flood wave that TSD caused, as all the sites were flooded.' Three of the recorders were put back into operation shortly after the event. Table 1 of the Report (Existing Hydrological Stations) indicated the operating units to be as per Table 2.2, all water level recorders.

**Table 2.2**  
**Hydrological Stations Post TSD**

Number	River Catchment	Station	Operational (post TSD)	Operational Currently
6	Fond D'Or	Mabouya	Yes	No
31	Roseau	Roseau Bridge	No	No
	Roseau	Ciacot Bridge	No	No
33	Cul de Sac	F Deoglos Bridge	Yes	No

### 2.2.2 Procurement and Installation

A list is presented in Appendix A, Table A 2, of the hydrometeorological equipment purchased to date under Phase 1. The major components being 33 raingauges, 26 of which

are tipping bucket type. Two evaporation pans have been procured as well as one sunshine recorder. The majority of the equipment has been supplied by Casella. Training is currently in progress.

Twelve staff gauges have been purchased with one automatic water level recorder and one pressure logger. In addition one Valeport current meter has been acquired.

Sites have been identified for most of the equipment and some items are already in position (see list in Table A.2). Checks will be made of the proposed sites as the continuation of records at a particular site is an important consideration in the assignment of new gauges.

### **2.2.3 Preliminary Observations**

Although many rainfall gauges have been procured and considerable rainfall information will be obtained in the future, streamflow records have historically been an area of information deficiency. This situation needs to be addressed in the future.

Only about two continuous water level recorders will be in operation based on the current equipment procured, although more equipment purchases in this area are planned. The flow characteristics of the river network is such that the time of concentration of a flood event is very short, perhaps of the order of 0.5 to 2 hours depending on the river basin and the storm movement characteristics. Hence, daily or even twice daily readings of staff gauges will not provide a very useful data set with respect to flood flows although base flow information will be relatively reliable and useful.

Information requirements for the stream flows during flood events are both the shape of the hydrograph for a particular storm profile and the peak water level attained. For such peaky, concentrated flows, autographic or continuous recording systems are essential. Peak flows can be gauged by the use of 'crest gauges'. The potential for the use of crest gauges will be explored, perhaps by modifying the procured gauges.

The need to obtain more information on stream flows is important for the following reasons:

- to enable better estimates to be made of the rainfall-runoff characteristics of the different watersheds;
- to enable flood events and flood frequency analyses to be carried out with more confidence to identify flood risks more accurately and confidently;
- to enable sediment transport assessments to be more accurately determined;
- to enable the assessment of river basin resources to be better determined since resource availabilities will inevitably become more critical as demands increase;
- to enable better assessments to be made of the impact on pollution discharges on the system and the level of dilution which might be expected at different times of the year.
- to provide the basis for quantifying the possible impact of sediment-laden flows on the coastal environment;
- to enable an accurate assessment to be made of the proportion of the streamflows which are being abstracted from the river system, particularly baseflows, and thereby the likely environmental impacts.

In order to facilitate assessments of rainfall versus runoff correlations, soil moisture determinations would also be a useful measure. This would provide information on antecedent moisture conditions in the catchment. Equipment for such measurements are

available and could be linked to an agricultural research station. However, antecedent soil moisture estimations could also be derived based on an analysis of rainfall.

Finally, it is important that sediment and bed load measurements are undertaken and correlated with discharges in the main river system. This need was identified in the World Bank Report, stated as an action for Phase II of the Project and equipment/procedures for doing this work should be considered.

It is assumed that water quality measurements will continue to be the responsibility of WASA. However, the whole institutional issue of water resources management will need to be addressed to ensure that an integrated, logical and mutually beneficial programme exists covering issues such as:

- data needs of the various organisations;
- monitoring capacity and budgets of the different organisations;
- identification of any overlapping activities and their impact evaluation;
- data and information dissemination procedures and effectiveness.

### **3. WATERSHED AND ENVIRONMENTAL MANAGEMENT PLANNING**

#### **3.1 Rationale**

The essential objective of Phase II of the project is to produce a watershed and environmental management plan for St Lucia. This will be an integrated plan for the watersheds, which will help to reduce the effects of natural disasters and human impacts on the environment and will form a basis for sustainable development. To prepare such a plan in a period of one year, it has been decided to select two catchments for detailed study. The resulting plans will be extrapolated to cover the rest of the Island and because no watershed is "typical", the choice is based on:

- a broad spectrum of technical, environmental and socio-economic problems;
- the availability of data; and
- the relative importance of the watershed

Following advice from GoSL the Cul de Sac (10,097 acres) and Dennery (5,234 acres) catchment areas were selected (see Figure 2.1).

The planning exercise will be supplemented by studies and pilot trials elsewhere in the Island as well as within the chosen catchments, so that extrapolation can be meaningful.

The following aspects will be covered to provide the building blocks for an integrated catchment management plan:

- land use (agriculture, forestry, urban, tourism, roads etc.);
- river systems, drainage, water supply and waste management, with an emphasis on drainage issues;
- hazards (landslides and flooding);
- coastal zones.

#### **3.2. Data Availability, Surveys and Mapping:**

##### **3.2.1. Existing Land Use, Land Suitability, and Land Use Planning**

###### **a) Existing Land Use**

Existing Land Use and Vegetation Mapping was produced by the OAS, CIDA and Ministry of Agriculture in 1984 as coloured maps at 1:50,000 scale. Further mapping based on air and satellite photography (1989) was produced as part of the Forestry Management Plan, 1992, at 1:25,000 scale. This mapping is adequate for island-wide coverage, but may need updating for the more detailed approach required for the two pilot watersheds. Land use changes up to 1992 are likely to have been fairly rapid over most areas, particularly in terms of increase in banana acreage and increase in land under construction, residential and tourism-related uses. However, after 1992 changes in land use would appear to have been much slower, due to falls in banana prices and a slow-down in the tourism and construction sectors.

For 1:25,000 or more detailed mapping, satellite photography is of relatively little use, particularly for a high relief area of intricate land use such as St Lucia. The Consultants elsewhere have undertaken Land Cover Mapping using combined LANDSAT TM and SPOT Panchromatic imagery hardcopy at 1:50,000 scale, and high resolution coloured SOYUZ photography at the same scale, but use of this imagery for areas of small land parcels and intensive, multiple cropping presents problems. High percentages of cloud cover for much of the time is a further problem in St Lucia, making use of satellite imagery difficult.

Air photos of 1992 at 1:10,000 scale are available to the team. They are therefore of much interest, both in giving further detail, and for showing land use changes over the period 1989-92, but they cover only the lower elevation parts of the island (approximately half of the two

pilot catchments). A comparison will therefore be made between information interpretable from these photos and the existing land use mapping. For the upper catchment areas, the Consultants are considering photography from a helicopter or light aircraft during the forthcoming dry season (late April-May).

#### **b) Soils and agro-ecological data**

The basic soil survey of the island was undertaken in the early 1960s, by Stark et Al, and was published as one of the 'Green Books' in 1966. Mapping at 1:25,000 scale was of complex mapping units comprising two or three Soil Series. Some 52 Soil Series were described, and analytical data was undertaken for most of these series.

Subsequent work on soil mineralogy and on soil correlation over all the islands of the Volcanic Windwards has been able to place most of the 52 Soil Series into mineralogy classes and USDA Soil Taxonomy Subgroups (Smith, G. 1981). This information is particularly useful in agro-ecological zoning, and in inter-island soil correlation.

Agro climatic data is available from the Agricultural Engineering Division of the Ministry of Agriculture, who produce useful Monthly and Annual Agromet Reports of current data. This includes rainfall, temperature, sunshine/radiation, relative humidity, windspeed, pan evaporation and computed values for reference evapotranspiration (Penman). This data, together with historic data going back 10-30 years, is now available in digital format and will be used by the Consultants for soil water balance and rainfall-runoff modelling, and for more refined agro-ecological zoning. However the quality implication of this data are currently under review

#### **c) Land Capability & Land Suitability Mapping**

Land Capability Mapping was undertaken by four studies over the last 30 years, all heavily influenced by USDA methodology:

- Stark et Al (1966) assigned Land Capability classes and subclasses to their Soil Series and slope combinations, using a 7-class system.
- OAS (1984) produced a coloured 8-class map of the island at 1:50 000 scale.
- Sheng and Ahmad (1988) adapted the above methodology in a 'Treatment Oriented Classification System for St Lucia', considering different classes of crops defined on ground cover they present, several classes of slope and soil depth and 3 classes of erodibility of soil.
- Polius (Dec 89) applied the above methodology to the Mabouya Valley, producing mapping at 1:2,500 scale of Capability Classes A1 to C3, representing Soil Groupings (stable, less stable and fragile) and Slope Classes (variable classes for each soil grouping).

Applicability of USDA methodology to the humid tropics, particularly for high value and perennial crops, can be questioned, as can the basis for the three Soil Groupings.

Work in most humid tropical areas on Land Capability and Suitability has adopted the FAO 'Framework for Land Evaluation' (1976) approach, and this is currently under study in Grenada. The Consultant intends to adopt this approach to work on the project, defining requirements for the major Land Utilization Types which apply to the island and similar environments.

#### **d) GIS and Derived Mapping**

A sophisticated GIS has been established within the Ministry of Planning using PC SPANS and CARTOGRAPHER/EXPLORER software, using funds from UNDP and CIDA Projects. All existing mapping and map themes have been digitised or scanned, and currently detailed parcel maps at 1:2,500 scale are being entered onto the GIS.

PC SPANS system is a raster based, quadtree system, and has advantages in being more conducive to analysis of data, overlaying, and being faster and more economical with hard disk space than competing vector-based systems such as Arc/Info. However, cartographic

output of data is relatively crude, and often not usable if only monochrome (black and white) versions of maps are to be produced for a report.

At present the GIS Unit is fully engaged in CIDA project activities and it may not be possible to use the unit in the next 4-5 weeks, although material may be available to meet a longer-term deadline. Of interest to the consultants would be the following mapping:

- current land use
- land slopes
- soil types
- contours
- natural drainage network (density and slopes)
- infrastructure: roads, tracks and settlements.

### **3.2.2. Hazard Mapping and Zoning**

This aspect can be basically separated into two categories, that associated with hazards from land slides and that linked to flood events.

Land slides are a significant problem within most of the catchments of the island, causing damage to infrastructure, generating potentially damaging soil erosion events, creating temporary unstable blockages in the river network, causing loss of agricultural production and endangering life.

In relation to flood events, the main dangers can be linked to either floods caused by extreme rainfall events generating large discharges in the drainage network or flood damage caused by the blockage or throttling of the drainage network either by man-made interventions or alternatively from natural causes such as fallen trees or small embankment slips.

Because of the topography of the various river basins, the upper reaches of the catchments will be more affected by channel blockages whilst flooding in the lower parts of the basins will be affected by channel morphology, blockages and land levels in and around the flood plain. Topographic maps are available for all of the river basins and will form the basis for flood plain mapping.

Previous reports have estimated flood flows in the different river basins, with the 1984 Report by Hunting Technical Services providing the main source of information. More detailed analysis has recently been carried out in relation to flood flows in the Cul-de Sac River which provides an alternative estimation. This and other reports will be reviewed. There is clearly a need to review this rainfall-runoff relationship since it is important in the estimation of sediment run-off estimates.

Limited water level information exists, as some river basins are without any form of river gauging. Under the circumstances it will be necessary to obtain indicative field reports as to the flood levels encountered during flood events and extrapolate such information to other parts of the river system. This will only be undertaken if confidence can be placed on the original data and upon the extrapolation being carried out. The need for additional water level and discharge information to provide the basis for flood plain mapping and flood hazard assessments will be identified during the course of the Project and recommendations made as to how such data deficiencies can be resolved without undue expenditure.

Flood plain mapping and zoning will be addressed in the context of TSD and of either a 1:50 year or 1:100 year event depending on local needs and data availability. Existing maps will be used to delineate flood extents (in the pilot catchments). Maps would be annotated where

hazards are foreseen in relation to the impact of structure constrictions or clearly identifiable natural hazards.

### **3.2.3. River Systems, Drainage and Water Supply.**

Adequate maps of the river network exist with the 1:50,000 map (Rainfall and Drainage System, Land and Water Use Unit, Ministry of Agriculture, 1984) providing an adequate base map of the main channel network.

Topographic maps at a scale of 1:25,000 and 1:10,000 provide a general contour and hence level information of the channel system from which channel slopes can be interpreted. River surveys carried out as part of the Phase 1 Programme provide additional detailed information in relation to the lower sections of the river network. This is supplemented by the 1:2,500 maps of the main towns in the lower parts of the basins. Aerial photographs at a scale of 1:10,000 have been obtained for April 1992. This is reasonably cloud free and provides useful pre-TSD channel alignments. A similar set of aerial photographs for the post-TSD situation would be of advantage but is not thought to be available..

Information on water supply systems in relation to abstraction points, abstraction volumes through the year and associated water qualities will be obtained from WASA. The ongoing Caribbean Environmental Health Institute Study (ODA funded) will also be approached for information. The information would provide the basis for control locations in relation to ensuring sediment loads are kept low and effluent discharges are avoided within the management planning process.

### **3.2.4 Coastal Zones**

The assessment of the quantity of suspended sediment passing out from the river system into the marine environment should be related to the areas declared as marine reserves in the Fisheries Act of 1986. Nineteen sensitive coastal areas were defined.

Impacts of sediment loads and pollution in the coastal environment can affect fisheries, coral, other marine life and tourism. The major causes of pollution are:

- agricultural chemicals and non point pollution;
- sewage effluent discharges
- industrial waste and petroleum discharges;
- solid waste.

Heavy sediment loading has been reported at a number of reefs along the west coast. Reefs near river mouths show higher impact levels, probably due to a combination of sediment and fertilizer loadings causing algal growth.

Information will be assembled on land use and effluent discharges and these will be assigned to coral reef and coastal zones. Secondary data related to the condition of the coastal zone area will be obtained from the Fisheries Department, whilst pollution discharge levels will be obtained from Water and Sewerage Authority (WASA). Agrochemical usage will be estimated from total chemical usage over the Island together with land use analyses for each catchment. Sediment loads will be estimated from hydrological, land use and catchment topography assessment data from SLBGA/WINDECO.

## **4. NATIONAL ENVIRONMENTAL LEGISLATION AND INSTITUTIONS**

### **4.1 Background**

The Consultants are forced to approach the project with a strong feeling of *deja vu*, inspired by experience early in 1984 and again from May 1985 to September 1987. At the time, Hunting Technical Services and the Engineering Services Division of the Ministry of Agriculture Lands Fisheries and Forests (MALF&F), worked in the Roseau, Fond D'Or and Cul-de-Sac Watersheds on a European Union funded project and spent some 37 expatriate staff months and EC\$ 3.7 million on various river engineering works.

It would be comforting to think that these civil works went some way towards mitigating the effects of TSD, but none of the institutional proposals were implemented, as will evident from Section 4.2.2. The lack of any progress towards an institutional framework for the conservation and development of the three watersheds can only have contributed to the damage caused by TSD and to the continuing problems caused by heavy rainfall since that time. In addition the Agricultural Services Division, which might be expected to carry the heaviest burden of any proposals emerging from this project, is without doubt weaker today than it was in 1987.

The above realities provide the background to a review of the country's environmental legislation and institutions and will inevitably determine the approach adopted in the Pilot Watersheds and eventually in the Watershed and Environmental Plan proposed for St Lucia.

### **4.2. Legislation**

During the period immediately prior to presentation of the Inception Report, a review of all legislation with a bearing on the environment was undertaken with the cooperation of the Attorney General's Office.

#### **4.2.1. General**

In response to the growing evidence of environmental decay, policy makers in St Lucia have undertaken various initiatives designed to arrest or reverse the situation, for example in the areas of pesticide control, forest conservation and coastal zone management. Thus a list of prohibited pesticides has been published, national parks and protected areas have been declared and an inventory of national forests has been produced. Work on the protection and/or sustainable development of mangrove and sea grass areas has been successful, as have efforts to monitor and manage coastal waters.

The following provides a brief summary of the existing environmental legislation, with comparatively little attention being paid to the laws and regulations dealing with the built environment. The division into various sectors such as agriculture and forestry is a matter of convenience and some overlap is inevitable.

#### **4.2.2. Agriculture**

Various legislation exists for the agricultural sector and the following have a definite environmental protection focus

Board of Agriculture Ordinance  
Plant Protection Act

Animals Trespass Ordinance  
Government Pasturage Lands Ordinance  
Animals (Diseases and Importation) Ordinance  
Importation of Bees Ordinance  
Agricultural Small Tenancies Act  
Pesticides Control

Subsequent work will consider the above legislation in more detail, but brief mention must be made of the Land Conservation and Improvement Act (Number 10 of 1992).

The Act provides for the conservation of land in St Lucia and for the establishment of a Land Conservation Board, which has wide ranging powers, including responsibility for making Protection Orders to:

- prohibit, regulate and control the clearing of land for cultivation, the grazing/watering of livestock and the lighting of fires.;
- prohibit or restrict the cultivation of specific crops;
- regulate the method of cultivation of land;
- destroy without payment of compensation, crops planted in contravention of the Act.

The Board may make such Regulations as appear necessary and there is provision for the appointment of Conservation Officers, for the acquisition of land by private treaty or compulsory purchase and for the imposition of penalties for offences.

To date no regulations have been formulated and the Board has no access to funds, other than those which might be provided by Government. This vital legislation has had a long gestation period and there appears to be a lack of political will to implement the Act. In this regard, it should be noted that the Consultants first recognised the need for the Act in 1984 and draft legislation became available by the end of 1987. The Act finally reached the statute books in April 1992, but nothing happened until after TSD, when a Board was finally appointed in 1995. It then met for the first time and only time to date, in November 1995.

#### **4.2.3. Forestry**

The controlling legislation is the pre-independence Forest, Soil and Water Conservation Ordinance which was up-dated in 1983. The Act provides for the appointment of a Chief Forestry Officer charged with the management of Crown Land and empowers the Governor-in-Council to declare any Crown Lands a forest reserve. There are also wide ranging powers for the prevention of soil erosion/landslips, the maintenance of water supplies and the protection of roads and bridges. In 1983, a number of forest reserves were declared including the Castries Water Works Reserve, and the Barre de L'Isle reserves.

#### **4.2.4 Fisheries**

Two principal enactments govern activities in the Fisheries sector, both of which also have a bearing on marine pollution. The Maritime Areas Act is primarily concerned with establishing the maritime jurisdiction of the state, whilst the Fisheries Act is concerned with the environmental management of maritime areas and of their resources.

#### **4.2.5. Water**

Policy makers in St Lucia are aware of the importance of adequate and effective measures to protect and preserve national water resources and mention is made in previous sections of the following legislation which has a bearing on water resources.

Forest Soil and Water Conservation Ordinance  
Land Conservation and Improvement Act  
Animals Trespass Ordinance etc.

The Water and Sewerage Authority Act is the principal legislation for the sector and imposes on government the obligation to promote a national water policy which appears to devolve on the WASA established by the Act.

Other relevant legislation, is the Public Health Act and the Public Health (Water Quality Control) Regulations established under the Act.

#### **4.2.6. Mining**

Apart from ilmenite in some beach sands, there are no known deposits of valuable minerals in St Lucia and the mining of industrial minerals, largely for the construction industry, is controlled by the Minerals (Vesting) Act, The Radio-active Minerals Ordinance and the Crown Lands Ordinance.

In addition, the Beach Protection Act governs sand mining on beaches, is administered by the Ministry of Communications Works and Transport and establishes the need for a licence to dig and remove sand/other materials from beaches. The illegal mining of sand continues apace in response to the demands of the construction industry and is a serious problem in spite of severe penalties introduced by amendments to the Act in 1984 and 1987.

#### **4.2.7. Tourism**

The quality of a country's tourist industry is, in the final analysis, dependent on the environmental health of several related sectors of the economy and inevitably involves a number of Ministries.

The principal legislation is the Tourist Industry Development Act which provides for the establishment of the Tourist Industry Development Board, with wide powers to promote and develop all aspects of tourism. In addition the Board is charged with the administration of tourist facilities and the promotion of amenities for the industry.

Other legislation which impacts on the tourist industry includes:

- Parks and Beach Commission Act
- St Lucia National Trust Act
- Forest, Soil and Water Conservation Amendment Act
- Wildlife Protection Act which establishes three categories of wild fauna (absolutely protected, partially protected and unprotected.)
- Fisheries Act.

#### **4.2.8. Marine Pollution**

The applicable enactments on the statute books relating to marine pollution are the Oil in Navigable Waters Act, the Maritime Areas Act and the Merchant Shipping Act

A section of the Merchant Shipping Act, in effect, incorporates the provisions of two wide ranging pieces of English legislation relating to pollution of the marine environment into the laws of St Lucia:

#### **4.2.9. Waste Management**

The Litter Act makes it an offence to litter public places, or private places without the consent of the owner and by amendments in 1985 and 1993 the effectiveness of the Act was considerably enhanced. Whilst the legislation addresses the problem adequately, it would appear that the legislation is not, or can not, be enforced.

The recent Solid Waste Management Act provides for the establishment of a Solid Waste Management (SWM) Authority charged with providing a co-ordinated and integrated system for the collection, treatment and recycling of waste including hazardous waste. The Authority acquires the assets, liabilities and functions of the Castries Corporation in relation to SW collection/disposal and is responsible for the management of sanitary landfills. Of interest to other environmental agencies, is the provision to raise funds from an environmental levy to be imposed on all visitors to St Lucia.

The Public Health Act focuses on promoting and protecting the health of the population and addresses the problem of waste disposal as an aspect of public health management rather than an environmental issue.

#### **4.2.10 The Built Environment**

At this stage of the project, relatively little attention has been paid to legislation concerning the built environment, but mention must be made of the Land Development (Interim Control) Act.

This is the controlling legislation for land use and development in St Lucia and provides for the establishment of a Development Control Authority. There is no requirement for environmental impact assessments to accompany applications for significant land use and development, or that environmental considerations should be taken into account when the Authority makes its decisions. Sooner or later this deficiency in the legislation must be corrected.

Other legislation of importance in the built environment includes, The Town and Country Planning Ordinance, The Housing Ordinance, The Parks and Beaches Commission Act, The National Development Corporation Act, The Rodney Bay Development Act, The Housing and Urban Development Corporation Act and The Aliens (Landholding Regulations) Act etc.

#### **4.2.11. Conclusion**

The existing resource legislation has been criticised for a lack of adequate environmental focus, but the Consultants believe that the laws generally meet most of the country's needs, although there are some areas of deficiency including:

- The Wildlife Protection Act does not afford protection for wild flora and the provisions of the Act may need enlarging to accommodate the international obligations assumed by Government;
- There is no requirement for environmental impact assessments to accompany applications for significant land use and development, or that environmental considerations should be taken into account when planning decisions are made;
- Licensing of water abstractions and effluent discharge consent legislation.

### **4.3. Institutions**

Using the legislation listed in Section 4.2 as a guide, the Consultants are carrying out a systematic review of the national institutions (both government and non-government organisations ) responsible for implementing environmental legislation.

#### **4.3.1. Institutions Serving the Natural Environment.**

To date, meetings have been held with nearly 50 percent of the organisations concerned with the natural environment and this review should be largely completed by the first week of November 1996. Until a complete picture is available, it is premature to discuss individual agencies and the ways in which their co-ordination, co-operation and areas of responsibility might be improved

A superficial impression and the subject for comment in other reports, is that there appears to be a dispersal of administrative authority over several government departments and a need for the co-ordination of government, NGO and private sector environmental activities to avoid duplication of effort and the poor use of scarce resources. In addition to a need for co-operation and collaboration amongst the various agencies involved in the protection and improvement of the environment there is an urgent need, at the national level, to recognise the cost of undesirable environmental practices. For a country, still heavily dependent on agriculture/fisheries/forests and whose natural beauty accounts for the crucially important tourist industry, there appears to be a surprising lack of interest in the environment at the political level.

#### **4.3.2 Institutions Serving the Built Environment**

The agencies serving the built environment such as the Development Control Authority and the Housing and Urban Development Corporation, are largely outside the Consultant's area of interest, although there are some concerns such as those set out in Section 4.2.10.

Finally, the terms of reference require the Consultants to comment on the roles, functions and responsibilities of central and local institutions regarding settlements in flood plain/coastal areas including the building regulations which apply or should apply in hazard zones. This matter will be dealt with in the Interim Report.

## **5 FIELD TRIALS**

### **5.1 Objective and Scope**

A series of field trials are being devised to examine various protection and conservation measures. The trials which will cover landslide/slope stabilisation, sustainable land use, river stabilisation etc. will provide guidelines and criteria for the watershed management plans. The field activities will not be restricted to the two selected pilot watersheds.

Watershed specific activities will involve the establishment of local Land Conservation and Drainage Committees (LCDCs) in the two watersheds and a programme of institutional development.

The field trials outlined below have yet to be discussed with Government officials in order to arrive at a realistic programme taking into account the available implementation and management capacity of various organisations. Some reduction in the number and scope of the trials may be necessary.

### **5.2 Structural**

#### **5.2.1 On-farm works**

With the increased area of banana plantations and with their development on the steeper slopes in many of the river catchments, it is reported that the rate of erosion of soil from the catchments has increased in recent times. The number of banana mats reported in 1996 was about 15 million, an increase of about 25% from 1986. Coconuts have declined in popularity (about 650,000 units), although plantain numbers are increasing. The increase in bananas cultivated in the 10 year period is considered to be indicative of the increase in cultivated area, being located on the more steeply sloping land with high erosivity indices. {Information source: 1996 St Lucia Census of Agriculture, Portrait of the Main Findings, June 1996}. However since 1992 there may have been a slowing of banana plantings as prices have fallen.

Topsoil, once removed from the land and passed into the drainage system, either has to be removed at considerable expense or alternatively the sediment passes to the estuaries and marine environment affecting marine life. Deposition is also likely to occur in the lower flood plains raising bed levels and increasing flood risk and destabilising the meandering river network on the plains. Loss of fertility due to topsoil removal is probably the major detrimental effect of this process.

It is therefore important to investigate means of :

- reducing the rate of erosion from the land surface, and
- making provision for the retention of at least part of the sediment load at farm level and thereby reducing the quantity of material entering the river system.

The implementation of pilot studies should ideally be located in one or two specific sites to facilitate planning, implementation and monitoring within the two watersheds.

### 5.2.1. On-farm Works

Three types of trial would be conducted:

- erosion and run-off control trials within typical high-slope banana fields;
- investigation of banana yield and profitability with respect to slope gradient;
- erosion and run-off measurements from natural forest, in comparison to data from banana cultivated areas.

#### a) Erosion and Run-off Control Trials

Sites would be under mature banana cultivation (2nd or 3rd year ratoon cropping) and would be under standard control conditions including:

- slopes within the range 15-30 degrees;
- application of fertiliser at the recommended rate (ie 0.5lb / mat / 3 months); application of lime at recommended dosage (ie to bring pH topsoil values to 5.7);
- some surface drainage
- management at typical levels.

These 'standard conditions' typically lead to the following problems:

- the soil surface is not adequately protected against raindrop impact;
- the unprotected surface quickly suffers soil structure breakdown and a reduction in infiltration rate;
- surface wash movements then occur over the surface, removing fertiliser and topsoil;
- existing drains remove excess surface water, but also much nutrient-rich topsoil;
- poor drain construction (unprotected sides, uneven and excessive slopes) lead to slumping, gulying, etc.

At each site the following parameters would be measured:

- composite topsoil analysis: exchangeable cations, CEC, total and available P, organic C and N;
- sprinkler infiltrometer measurements;
- fresh banana root density;
- soil run-off;
- banana fruit yield;
- banana fresh-trash weight;
- Leaf Area Index (LAI).

At each site the following treatments would be investigated:

- i). Control Conditions: involving some shallow surface drainage and banana trash left at random in piles;
- ii). Even coverage of banana trash: the trash would be placed over the entire surface, pseudostems being cut into strips, and this would be orientated along the contour; the trash would be obtained from production in situ.
- iii) Even coverage of banana trash, but at double the density; further trash would be brought in from production from flatter areas.
- iv) Banana trash placed in lines on contour, and held by short stakes. Trash obtained from production in situ.
- v). as (iv) above, but with installation of tied contour drains (silt traps);
- vi). as (v) above, but with banana trash also brought in from flatter areas to give double the standard application rate; half of the trash would be used to cover the ground surface, the other half placed in lines on the contour and held by short stakes.

The design of the tied contour drains (silt traps) as in (v) and (vi) above, needs careful consideration and would not be advocated for the landslide-risk areas, as water retained on the contour could further increase landslide risk. The assessment of benefits of soil conservation (ie control of surface wash erosion) against the slightly increased risk of mass movements (landslides, etc) will be considered by the project.

**b) Investigation of banana yield and profitability with respect to slope gradient;**

Banana yields and quality ratings would be measured from a number of sites covering the slope range 15-35 degrees. Labour inputs would also be measured for these same sites. Net profitability would then be related to the following parameters:

- slope gradient;
- age of holding, fertilizer use, and soil fertility status;
- distance from motorable road;
- distance of road access to boxing plant;
- distance of boxing plant to loading point.

It is considered that much of the very steep land (> 25degree) now cultivated to bananas would be very marginal, and with falling banana prices much of this land may come out of cultivation in the next few years. However, figures are require to support this premise, both in terms of yields per acre, and in use of labour and transportation resources per ton of bananas. For steep areas near motorable roads, it is likely that labour costs will be low irrespective of slope: these lands may need particular attention, as inappropriate land use practises may still be profitable.

**c) Erosion and run-off measurements from natural forest, as a comparison to data from banana cultivated areas.**

Both sprinkler infiltrometer measurements and soil run-off measurements would be undertaken as a further control on the experiments on the banana fields. It seems likely that surface wash erosion losses are very low, and that surface infiltration rates are very much higher than in the case of banana cultivation on similar land. Because of increased infiltration rates, landslide risk for these areas may actually be higher than in the case of banana cultivation, particularly if some of the larger trees, with the strongest anchoring roots, are removed. (This correlates with the observation that recently reafforested land often shows the greatest landslide risk: deep tap roots anchoring the trees into the bedrock are not yet established, but the higher infiltration afforded by the good vegetation and litter cover increases water content of the subsoil and hence risk of mass movements.)

### 5.2.2 Minor channel controls

**a)Sediment check structures in-stream:**

A second line of erosion control is that provided by the small flow volumes in minor channels. Porous structures such as check dams and filter fences can be used as sediment control measures, many using local materials.

Different cross structures have different trapping efficiencies and the pilot studies would enable these to be determined in relation to locally available material.

The problems of porous check structures is that although they can reduce sediment runoff down a channel, the downstream channel bed protection needs to be carefully designed depending on anticipated flow capacities and the channel slope. In addition, it is important that the check structures are regularly maintained by removing the retained material deposited upstream of the structure. This should be done as the structure 'porosity' is seen to decline with the majority of the flow passing over the structure as weir flow.

There is ample evidence during Phase I of capital intensive check structures and the focus during Phase II will be on low cost structures using indigenous materials, capable of being managed by small groups of labour.

**b) Sediment Detention Basins:**

The channel check structures require frequent monitoring and rehabilitation if they are to remain effective. More sediment storage can be provided by a detention basin, however the

topography of many parts of the catchments will probably mean that little scope exists for their development. The storage capacity of a basin should be approximately equal to or slightly less than the runoff volume of a design storm. Again, regular desilting of the detention basins will be necessary, with the sediment so removed being used on nearby cultivated land, particularly shallow soil areas on adjacent sloping land.

The design of detention basins should be such that they are not an excessively major undertaking and should not create a downstream hazard in case of failure of the structure during a major storm. Post storm release operation would need a degree of management.

The potential use of both check structures and detention ponds (downstream of the porous check structures) will be investigated. The pilot studies would not only investigate the effectiveness of such facilities but would also provide useful information on the rate of erosion from the watershed areas.

### **5.2.3 River Training and Bank Protection**

The pilot measures outlined above relate primarily to erosion control with the objective of reducing or stemming the rise in sediment being carried by the river system.

Most of the lower reaches of the river network pass through gentler sloping land where flood flows spread across the flood plain. Most of the flood plains are cultivated with buildings gradually encroaching onto the land as well. The lower reaches of rivers in the major catchments have a sinusoidal alignment with a degree of meandering evident. The meandering will be caused by the instabilities created by various factors including:

- raised river beds causing bank overtopping and breakthroughs during peak flows;
- gradual erosion of the outer bend of the channel again causing breakthrough;
- changes in flow direction caused by trees and embankment slips entering the main flow channel;
- changes in flow direction caused by human interventions etc.

Movement of the river channel at one location can cause the whole river alignment downstream to change. Care has to be taken over the level of human intervention that is imposed on the system and the regime of the river should be fully appreciated before making major changes.

The regime of a river is created by the dominant flows and alignments can change during extreme floods as the river channel system has to cope with abnormal flows. Although TSD caused the majority, if not all, rivers to fully utilise the flow area of the flood plain, not much evidence has so far been seen of the channel network being reconfigured by the event. The main channel alignment pre-TSD, is in the most part, still active with significant degrees of erosion at bends in the channel.

In order to increase the stability of the river, measures to counter natural river alignment change can be undertaken. However, it is important that river maintenance and the removal of debris is regularly undertaken before the intrusion destabilises the channel through increased bank erosion etc. Such maintenance will reduce the need for river training and channel alignment control.

Measures which can be undertaken include:

- gabion (boxes or mattresses) protection work to prevent lateral movement of the channel and erosion of the outer banks of a bend;
- revetments with the same objective;
- palisading with the same objective;
- gabion work to provide a hard nib to provide a degree of stability to the alignment;
- palisading or gabions to create a groyne to redirect flows;
- loop cutting with associated mini weir construction if a head loss is to be created to match that lost in the cut. Care has to be taken with such weir design.

In almost all of the above measures it is important to introduce different levels of bio-engineering.

Gabions need protection to prevent washouts of backfill material during overtopping during a flood. The introduction of reeds or grasses within the stone matrix of the gabions will help to reduce washout and also make the structure less pervious and reduce the visual impact of the structure. This will generally happen naturally; however, planting is deemed useful to reduce the risk of the vegetation not establishing itself soon enough to prevent structural damage. The best species to use and way of planting on gabion boxes, mattresses and rip rap needs to be investigated. In particular the problems associated with the 'structures' being overtopped and washed out from behind needs to be decided.

Palisading is work which is common in some countries in river training and bank protection works. Ease of use and low costs are important considerations and, for example, coconut palm trunks could be used for the horizontal members with the pile stakes being a readily available and waterlogging-tolerant wood. Different forms of palisading arrangement will be investigated both to form embankment protection as well as groynes. Brushwood options will also be identified.

Some of the pilot works will be undertaken to address shortcomings encountered in the Phase I works.

These could include:

- Cul de Sac River : Gabion protection work adjacent to house, modification to gabion length and alignment (vegetal cover to be established);
- Cul de Sac River : Protection of main road, water supply pipeline and electricity pole by gabion work or palisading;
- Roseau River : Introduction of weir formation at location of loop cut;
- Cul de Sac River : Introduction of hard nibs and/or palisading at location of severe erosion in banana plantation near Marc Marc junction;
- Cul de Sac River : Creation of timber frame as crib for river bed stones to be cemented with vegetation/creeper;
- Cul de Sac River : Several measures may be required in the vicinity of the new secondary school just north of Bexon where development has occurred on the flood plain and a undercapacity foot bridge has been constructed across the main river;
- Soufriere River : Establishment of vegetation on the river training infrastructure and the monitoring of the gabions after flood events for signs of weakness or undesirable impacts.

A pilot study will also be undertaken into an estimation of river maintenance requirements. This will be assessed in terms of estimates per km of channel length and relate to tree lopping, bank trimming, toe protection and debris removal. Estimates will also be made of channel training works required. This information would enable an estimate to be made of annual O&M costs which could be applicable to the different catchments. Sample sections would be taken from different reaches up the river network.

Whilst undertaking these surveys, enquiries would be made of human intervention activities, especially in relation to the removal of boulders or gravel from the river bed.

Other measures will be proposed for the Dennery River.

### **5.3 Bioengineering Preliminary Investigations**

#### **5.3.1 Initial Assessments**

Field visits were undertaken to provide a preliminary investigation into aspects associated with erosion and slope instability linked to:

- rivers
- forested upper catchments
- highways - west coast road and the new south access road currently under construction.
- agricultural areas - farms in the Cul-de-Sac, Praslin and Troumassée watersheds

Apart from visits undertaken to review the Phase 1 works, field visits were made to review highway slopes and off-road drainage provisions generally, upper catchment erosion and slope instability, use of vegetation as an engineering material along the West Coast Road and elsewhere, with some emphasis on farming and land conservation practices on steep upland areas of watersheds in the following river basins and locations:

Cul-De-Sac, Roseau, Troumassée, Praslin, Canaries, Soufrière, Marquis, Doree, Mt Gimie and the southern steep lands including Woodlands Estate.

Strong emphasis was placed on identifying suitable problem sites for investigating bioengineering techniques through field trials in the two pilot watersheds, Cul-de-Sac and Dennery.

A preliminary review of literature on West Coast Road bioengineering and St Lucia flora has been undertaken and publications on tropical bioengineering and local plants were reviewed at the Forest and Lands library and at the Central Library.

It is understood that under ODA Adaptive Research Project R5809 awarded to Dr J Clark a manual on vegetative techniques for soil erosion control with potential for use in the Caribbean steep lands was due to be published in 1995. This document, if published, would be a further useful resource and a copy has been requested from the UK.

Collation of data on unit costs has begun based on a listing of major plants and inert material and operations normally required for tropical bioengineering works. Further cost data has obtained from Clark 1994 in addition to information from MCW&T and Phase I.

Summaries have been made of local plant and vegetation types which could be used for different bioengineering applications. Initial enquiries have been made with regard to the sourcing and costs of such material. These investigations will be continued.

Much work remains to be completed on site surveys, detailed design and plant and other materials sourcing, and finally on the construction of the field trial installations. These must be completed by the middle of January at the latest, if trials are to be established successfully in the coming dry season. Thereafter irrigation of the installed plant material may be needed and significant labour and money resources allocated.

The heavy rainfall of the 26 October might have changed some of the sites substantially and proposals already in outline form may have to be adjusted accordingly.

### **5.3.2 Implementation and Monitoring Issues**

The process of design, material acquisition and installation is likely to take at least 2-3 months by which time:

- sites are surveyed topographically; geotechnically on site and in the laboratory as required (soil nutrients and pH)
- problems are identified and solutions/remediation concepts arrived at and agreed
- designs are prepared, costed, ranked and approved
- funds allocated
- site preliminary works - earthworks, drainage carried out
- live plants are grown, collected or harvested
- other inert materials sourced
- live plant and inert materials installed.

Some of these activities can be done in parallel, to shorten the implementation period and monitoring will have to be designed, costed and installed.

Monitoring of the bioengineering works will include the regular measurement of plant stem and leaf growth, root growth and soil moisture and will be kept very simple.

Erosion can be assessed measured by splash measurements, whilst both slip movement and soil loss can be detected through the use of erosion pegs and rows of exposed vertical (or possibly inclined) pegs along the contour.

It is unlikely that significant root growth will occur in the ensuing dry season and the early part of the 1997 wet season when Phase II is due to end. It is thus unlikely that any slope stability impact can be proven during the life of Phase II due to the fact that little root development will have been achieved to assist root based reinforcement and moisture reduction by plant evapotranspiration. The only effects which can be realistically hoped for are:

- enhanced soil protection against erosion arising from the shielding, armouring, flow retardation and surface soil binding effects of ground vegetation cover;
- instant mechanical and possibly hydrological effects of brush layers embedded into fills or the mechanical effects of driven stem cuttings at near-horizontal inclinations, or deeper-seated but shallow stabilisation of slopes by live poles up to say 1.5-2.0m depths.

River works should be undertaken last since the greater moisture levels to be expected along watercourses will help obviate drought problems likely to be experienced higher up the valley sides and along highways etc.

### 5.3.3 List of Proposed Field Trials

Field sites, will by agreement, include areas outside the chosen watersheds. The trials listed below, have yet to be costed, planned in detail and/or finally selected.

#### Site 1 Watercourses

Active instability, toe erosion of high hill slope by watercourse

Watershed: River Troumassée

Location: on River Troumassée N 13 50.18' E 60 57.00'

Details: - immediately below natural weir formed by line of large boulders across low flow channel, undercutting of the steep right-hand bank has caused multiple slippage of a shoulder of high ground with banana cultivation along and behind its crest. The highest back scarp visible from the watershed access road which runs on the opposite bank about 10m above the river bed is estimated at 40m above river level.

One possibility is the re-alignment of the river to provide room for toe rock armouring together with slope regrading to as flat as possible (say 40m with 1.5m wide berms at 5-6m vertical interval, together with mixed driven brush layers of *glyricidia*, elephant grass or *leucaena* butt end into the slope), brush layers to be 0.75-1.00 metre long and installed into 2/3 stem length holes opened up in the slope inclined downwards at 10 to 20 degrees along contour at 150-200 mm centres at 1.5m intervals measured on the slope.

Length:c. 50m.

Height:c. 10-15m.

#### Site 2 Low river bank instability 1

Watershed: River Roseau

Location: on River Roseau Phase 1 works channelised section east of Morne d'Or: N13 56.96 E 60 59.93

Details: basically, if land ownership considerations permit, the channelised section should be bermed for additional stability, with stone rip-rap along the toes of both slopes; surface treatments along the channel reach to be wired in 5m long panels with control sections between in some locations, with existing treatment retained elsewhere; slope failures to be reinstated using brush packing; weirs and river training buttresses to be provided as determined by the river engineer.

Length: as determined on site.

Height: 4-6m.

#### Site 3 Low river bank instability 2

Watershed: River Cul-de-Sac

Location: along River Cul-de-Sac along close to main Castries - east coast route N 13 58.52' E 60 56.61'

Details: bank collapse due to misaligned flow entering reach from the west and running parallel and close to the main road at the start of a right hand bend. This has undermined a large dead unrooted tree trunk, now lying in midstream and obstructing flow. Large black services pipe exposed, electricity and telephone communications are threatened.

Two possible remedial works could be carried out. The major component is an entry section of gabions of about 15-20 length obtained by dismantling a similar length of the downstream end of the gabion wall. Other remedial works downstream might include one or other of the following systems:

- Reinforced soil toe wall along the existing left hand bank along the highway with pillows of Maccaferri wire mesh wrapped with stone facing immediately behind the wire mesh, then a layer of filter geotextile enveloping fill excavated from the inside of the bend.
- Tubular gabions - 1-1.5m long 0.25-0.5m diameter rolls placed in crib fashion - each course of stone filled tubular gabions comprising one header with stretchers as transverse tie-backs for face. The upper 0.5m of 0.25m gabions can be filled with 50%:50% soil: crushed stone for better vegetation establishment. Stem cuttings of assorted *glyricidia*, *leacaena* and elephant grass are to be laid along the top of each course.

Length: 50m.

Height: 2-3m.

#### Site 4 Low river bank instability 3

Watershed: Cul-de-Sac

Location: on Cul-de-Sac river, Details: triangular buttress repair

Length: 3-5m.

Height: 3m.

#### Site 5 Active Landslides and Ridge Slides

Pelouze active slide below ridge

Potential trial site, potential cuttings.

Watershed Praslin River

Location N13 52.76' E 60 55.53'

Details; Large gully and translational slide below ridge between Praslin River and a smaller river/stream. Observed from across the valley

Length - c 75-100m

Height: >50m

#### Site 6 Non-Active Landslides

Landslide re-vegetation large rotational slip at Combat in Babonneau.

Watershed Marquis

Location on access track east of Forestiere N 13 52.76' E 60 55.53'

Details: potential trial site *Glyricidia sepium* brushlayer and live pole and *Bois mahoemang* stems plus bamboo and tree planting over slumped toe material

Length .c. 25m

Height: 15-25m

**Site 7** Infrastructural facility protection and stabilisation. Highway slope protection and stabilisation

West Coast Highway - Steep road slope bioengineering stabilisation by *Bois mahoemang* stems and panels say 3 no each 5 - 10m long with 5m gaps - details to be provided

Watershed Anse-la Raye

An additional trial site at Ravine Poisson was identified as a candidate for a disaster awareness study with strong geotechnical, social and land use connotations. This site is located along the upper part of the Cul-de-Sac River and lying at the toe of an area of historic instability (large slides occurred in 1938, 1940 and 1954 with considerable loss of life and property). Work has commenced on the task of undertaking a geotechnical appraisal of the area.

#### **5.4 Flood Hazard Warnings**

Flood hazard warning needs to be very prompt. Weather reports in relation to the movement of tropical storms are now regularly given over the television and radio. The information provided gives the first warning of possible problems: this could be improved by also indicating whether flood events might be severe due to the already saturated conditions in the catchments. However, the forecasts can only give indications as to the likely locations of storm centres and whether rainfall intensities are likely to be light, medium or heavy.

In order to improve flood warnings, better information is required on:

- soil moisture conditions in the catchments;
- more precise storm tracking;
- more accurate assessments of possible rainfall volumes and intensities.

The first item could be achieved by more ground level information whilst the latter two by the use of weather radar.

Catchment responses to storms are very quick and for this reason, warning windows are narrow. With the short response times, the movement of the storm is also critical in affecting storm runoff severity. A storm passing down a valley will create a larger flood impact per unit volume of rainfall than a storm passing up a valley. Such factors need to be taken into account in the warning process.

Rainfall stations with telemetric transmission of rainfall information are vital in improving flood hazard warning. With a time of concentration to flood peak of about 30 minutes, even a telemetric system linked to a good forecasting model is going to provide little lead time to a flood warning message. Interpreting the information and communicating the conclusions through the media to the populace in the specific problem areas would need to be highly efficient and automated.

The equipment and measures required to provide the basis for a flood hazard warning system would be studied in terms of its viability. The flood hazard warning would be linked to a response mechanism depending on the location and timing of the anticipated flood problem.

## 5.5 Land Conservation and Drainage Committees

There is provision in the Land Conservation and Improvement Act for the formation of local Land Conservation and Drainage Committees (LCDC) and it will be important to form such committees in the Pilot Watersheds early in November 1996. It would be helpful if the Land Conservation Board could meet to sanction the formation of LCDCs and be advised of the Consultant's proposals, but time is of the essence and the formation of committees will have to proceed without delay.

The proposed programme is as follows:

- A review of all the formal/informal organisations and government agencies which exist in the two Pilot Watersheds
- Organisation of a workshop to be attended by all interested parties to explain the objectives of the project
- The formation of one or more LCDCs in each of the watersheds with a defined programme for the next 12 months
- The establishment of linkages between the Consultant team and the LCDCs
- Carefully defined linkages between the Consultants and various government agencies. In this regard the locally recruited consultants (Sociologist and Geotechnical Engineer), will have an important and continuing role to play.

At this stage, it is difficult to predict the composition, scope of activities and responsibilities of the Committees, but there are obvious areas of common interest between, for example the LCDCs and the Local Emergency Committees of the Office of Disaster Preparedness.

## 6. PROGRAMME

### 6.1. Proposed Schedule of Activities and Inputs

Figure 6.1 illustrates the proposed work programme/staff inputs and is largely self explanatory. The following sections provide some additional information.

**General** - The later than anticipated start makes it necessary to break for Christmas and has the effect of extending the initial input from four to five months. The Team Leader and the River Engineer are the most affected by the change.

**Total Elapsed Time** - In reviewing the work programme, in relation to the seasons and pilot activities, a six month break is recommended between the first and second expatriate inputs. This effectively increases the total elapsed time from twelve to fourteen months, but with no increase in the staff inputs or costs. Trial and other initiatives, will be established during the dry season and the second input, coinciding with the end of the wet season, provides a good opportunity to evaluate progress.

**Socio-Economist** - This input is now scheduled to start in December 1996 and is later than originally planned

**Land Use Planner / Environmentalist** - Is scheduled to carry out an initial seven week input. Having designed the pilot trial programme, he will then make a second four week visit in April/May 1997, during the dry season, to carry out essential observations and check progress.

**The Geotechnical Specialist (locally recruited Consultant)** - Will have intermittent inputs and will play an essential supervisory role during the absence of the remainder of the team.

**The Sociologist (locally recruited Consultant)** - Will have intermittent inputs during November and December 1996 to assist the Institutions Specialist and Socio-Economist with the establishment of participatory groups in the Pilot Watersheds. He will then have an intermittent role during the absence of the remainder of the team.

**The Institutions Specialist** - Will limit his first input to eight weeks, leaving a balance of 19 days in October 1997 in order to review the programme in the Pilot Watersheds, and contribute to the legislative and institutional aspects of the final report.

### 6.2 Anticipated Procurement of Equipment

There is a need to purchase the following Hydrometeorological Equipment:

- Water level recorders with autographic or digital data storage;
- Sediment sampling equipment;

and if budget permits:

- Telemetry Equipment for linkage to raingauges at key hill locations.

Activities and Staffing Programmes

ACTIVITIES PROGRAMME	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J				
<b>REVIEW</b>																				
Collection, review and analysis of Phase 1 activities	█																			
<b>WATERSHED &amp; ENVIRONMENTAL MANAGEMENT PLAN</b>																				
Collect data, reports, maps etc	█																			
Consultations	█																			
Selection of 2 Pilot catchments	█																			
Surveys and mapping	█																			
Hydrological, surface water and erosion	█																			
Agro-econ/Soc-econ baselines	█																			
Environmental baseline	█																			
Draft WMEP for pilot catchments	█																			
WMEP for pilot catchments	█																			
Factor evaluation for St Lucia (as per pilots)	█																			
Draft WMEP for St Lucia	█																			
<b>FIELD TRIALS</b>																				
Confirm scope	█																			
Design and Procurement	█																			
Establish/install	█																			
Manage and monitor	█																			
Evaluate	█																			
<b>INSTITUTIONS AND LEGISLATION</b>																				
Review institutional structure	█																			
Review legislation	█																			
Consultations	█																			
Draft revisions to legislation	█																			
Draft institutional recommendations	█																			
Establish LCDCs	█																			
Final review and recommendations	█																			
<b>HYDROMETEOROLOGICAL NETWORKS</b>																				
Review / evaluate existing/past networks	█																			
Review upgrading proposals	█																			
Advise on installation/operation etc	█																			
Train staff incl processing & analysis	█																			
<b>REPORTING</b>																				
Inception Report	+																			
Progress Reports	█																			
Interim Report	█																			
Pilot Catchments WEMP	█																			
Field Trials Report	█																			
St Lucia WEMP	█																			
<b>STAFFING PROGRAMME</b>																				
<b>Consultants</b>																				
Team Leader/ Agriculturalist	█		█												█		-	7.0		
Project Adviser	█																█		0.5	
Socio-economist	█		█													█		4.0		
Sociologist	█		█													█		1.5		
River Engineer	█		█													█		4.0		
Environmentalist/Land Use	█		█													█		5.0		
Geotechnical Specialist	█		█													█		3.0		
Geotech/ Bioeng. Adviser	█		█													█		0.5		
Landslide Hazard Expert	█																█		0.5	
Institutions Specialist	█																█		2.5	
<b>Counterparts</b>																				
Manager																		█		28.5
Field Trials : Group A																		█		
Field Trials : Group B																		█		

## **Appendix A**

**Table A1      Phase I Works and Costs**

**Table A2      List of Hydrometeorological Equipment received to 11/10/96**

**Table A3      List of Rainfall Stations.**

## Appendix A 1.

### St Lucia Watershed and Environmental Management Project : Phase 1 Works

Contractor & Survey payments		Works Completed and ongoing in April 1996	Works Remaining in April 1996	Percentage Expenditure in April 1996	Works Completed and ongoing in April 1996	Percentage Expenditure in Oct 1996
Scheme/ Contract	Watershed	Updated Estimate ECD	ECD	ECD	ECD	ECD
A	Soufriere	2,800,000	2707495	92505	97%	
AA	Soufriere	750,000	0	750000	0%	
B	Cul-de-Sac	0	0	0		
C	Cul-de-Sac	10,879	10879	0	100%	
D	Cul-de-Sac	50,563	50563	0	100%	
E	Cul-de-Sac	30,506	30506	0	100%	
F	Cul-de-Sac	56,253	56253	0	100%	
G	Cul-de-Sac	2,134,695	2034695	100000	95%	
H	Roseau	2,100,000	1606843	493157	77%	
I	Roseau	8,261	8261	0	100%	
J	Canaries	1,365,421	1365421	0	100%	
K	Anse-la-Raye	533,663	533663	0	100%	
L	Fond	100,000	9740	90260	10%	
M	Dennery	1,462,561	1085971	376590	74%	
N	Canelles	100,000	16707	83293	17%	
P	Canelles	45,686	0	45686	0%	
R	Mabouya	740,733	630205	110528	85%	
S	Troummasse	500,000	437069	62931	87%	
T	Roseau	18,291	18291	0	100%	
U	Roseau	6,698	6698	0	100%	
V	Roseau	1,543	1543	0	100%	
W	Roseau	42,147	42147	0	100%	
X	Fond D'Or	134,765	134765	0	100%	
Y	Vieux Fort	58,400	58400	0	100%	
Z	Choiceul	149,871	149871	0	100%	
Sub-total		13,200,936	10,995,986	2,204,950	83%	
Gabion mattresses		981610	981610	0	100%	
Remaining as-built surveys		75000	0	75000	0%	
Total		14,257,546	11,977,596	2,279,950	84%	

#### Capital Works by river basin

River Basin	Contracts	Percentage	Expenditure rank
Soufriere	3,550,000	26.9%	1
Cul-de-Sac	2,282,896	17.3%	2
Roseau	2,176,940	16.5%	3
Canaries	1,365,421	10.3%	5
Anse-la-Raye	533,663	4.0%	7
Fond	100,000	0.8%	12
Dennery	1,462,561	11.1%	4
Canelles	145,686	1.1%	10
Mabouya	740,733	5.6%	6
Troummasse	500,000	3.8%	8
Fond D'Or	134,765	1.0%	11
Vieux Fort	58,400	0.4%	13
Choiceul	149,871	1.1%	9

Total 13,200,936

{excludes cost of gabions which were used primarily in the Soufriere area}

## List of Equipment received to date (11 October 1996)

ITEM	NUMBER	UNIT PRICE	TOTAL	PRICE ECS
<u>Casella Limited (UK)</u>				
Tipping bucket rainfall recorder with integral logger		UK Pounds		EC\$ (@4.26)
Snowdon Raingauges	26	698.00	18148.00	77310.48
Sunshine recorder with charts	7	87.00	609.00	2594.34
Stevenson Screen large	1	744.00	744.00	3169.44
Thermohygrograph with charts and bottle	3	554.00	1662.00	7080.12
Maximum thermometer	1	579.00	579.00	2466.54
Minimum thermometer	1	36.00	36.00	153.36
Kew Hygrometer	1	33.00	33.00	140.58
Cup counter anemometer (windrun)	1	117.00	117.00	498.42
Measuring jar	2	1702.00	3404.00	14501.04
Evaporation Pan Class A with stilling well and hook gauge	7	19.00	133.00	566.58
Staff Gauges	2	465.00	930.00	3961.80
Automatic Weather Station including data organiser	12	65.00	780.00	3322.80
Airfreight and insurance	1	5990.00	5990.00	25517.40
<b>TOTAL</b>			<b>1660.00</b>	<b>7071.60</b>
			<b>34825.00</b>	<b>148354.50</b>
<u>Valeport Ltd. (UK)</u>				
Revolution counter for repair				
Airfreight and insurance	1	116.50	116.50	496.29
<b>SUBTOTAL</b>		38.00	38.00	161.88
Control unit with PC interface lead			<b>154.50</b>	<b>658.17</b>
BFM0020/1 Impeller with nose cone	1	650.00	650.00	2769.00
BFM0020/2 Impeller shaft	1	85.00	85.00	362.10
BFM0020/4 Reedswitch assembly	1	34.00	34.00	144.84
SK14, 14 kg sinker weight	1	29.00	29.00	123.54
Airfreight and insurance	1	338.00	338.00	1439.88
<b>SUBTOTAL</b>		?	?	?
<b>TOTAL</b>			<b>1136.00</b>	<b>4839.36</b>
			<b>1290.50</b>	<b>5497.53</b>
<u>Stevens Water monitoring Systems (USA)</u>				
Type A/F Logger system for use with Type F water level recorder		US \$		EC\$ (@2.72)
(including: encoder, data card, communications cable, battery, weatherproof enclosure)	3	2070.00	6210.00	16891.20
Card reader				
Spare data card	1	675.00	675.00	1836.00
Airfreight and insurance	3	190.00	570.00	1550.40
<b>SUBTOTAL</b>			370.55	1007.90
5" copper float			<b>7825.55</b>	<b>21285.50</b>
5 oz. Counterweight	3	65.00	195.00	530.40
Stainless steel beaded cable (ft)	3	16.00	48.00	130.56
Set of end hooks	75	1.75	131.25	357.00
Pack of 12 cartridge pens	3	12.00	36.00	97.92
Airfreight and insurance	1	42.00	42.00	114.24
<b>SUBTOTAL</b>		150.93	150.93	410.53
<b>TOTAL</b>			<b>603.18</b>	<b>1640.65</b>
			<b>8428.73</b>	<b>22926.15</b>
<u>Hope Hydrology (The Netherlands)</u>				
Wirtharapan Pressure logger Type 5A, absolute 5 bar		Dfl		EC\$ (@1.72)
Airfreight and insurance	1	3850.00	3850.00	6622.00
<b>TOTAL</b>		350.00	350.00	602.00
			<b>4200.00</b>	<b>7224.00</b>
<u>MI (Barbados)</u>				
Thermometers, wicks, charts		BB\$		EC\$ (@1.35)
<b>TOTAL</b>		2834.50	2834.50	3826.58
			<b>2834.50</b>	<b>3826.58</b>
<b>Total paid on equipment to date is</b>				
(this excludes the airfreight for the second Valeport shipment which has not arrived as yet)			<b>ECS</b>	<b>187828.75</b>

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Appendix A 3.

	Name Station	Rainfall equip	New equipment	Posts	Fence	Gate	Date completed	Station History
1	Marquis Est.	RG	TB	yes	yes	nn	AUG96	Completed
2	Babonneau (Marquis)		TB, RG	yes		nn		Completed
3	La Caye	RG	TB	yes	yes	nn	AUG96	Completed
4	CARDI	RG, dRR	TB, Evap. Pan	nn	nn	nn	-	Completed
5	Errard Est.	RG, RR	TB					Completed
6	Mamiku Est.	RG	TB	yes		nn		Completed
7	Patience Est.	RG	TB			nn		Completed
8	Troumasse Est.	RG, RR	TB	yes	yes	nn	JUL96	Completed
9	Mahaut Est.	RG	TB	yes	yes	nn	SEP96	Completed
10	Edmund Forest	RG	TB	nn	nn	nn	-	Completed
11	Hewanorra	RG	Screen	nn	nn	nn	-	Completed
12	Beausejour	RG	TB					Completed
13	Saltibus	RG, RR	AWS	yes	yes	yes	JUL96	Completed
14	Delcer	RG, RR	TB	yes	yes	nn	APR96	Completed
15	Union Vale Est.	RG	TB	nn	nn	nn	-	Completed
16	Barthe	RG	TB, Anem., Sun	nn	nn	nn	-	Completed
17	Roseau (Winban)	RG	TB, Anem.					Completed
18	Soucis	RG	TB	yes	yes	yes	APR96	Completed
19	Bexon	RG, RR	TB	yes	yes	yes	JAN96	Completed
20	Barre de l'Isle	RG, RR	TB	yes	yes	nn	SEP96	Completed
21	Gov. House	RG	RR	nn	nn	nn	-	Completed
22	George V	RG	RR			nn		Completed
23	Vigie	RG	Screen	nn	nn	nn	-	Completed
24	Union Agr.	RG, daily RR	TB, Evap. Pan	nn	nn	nn	-	Completed
25	Trouya	RG	(TB)	nn	nn	nn	-	Completed
26	Cap Estate	RG, RR	TB	yes	yes	nn	SEP96	Completed
27	<i>Desraches</i>		TB, RG	yes	yes	nn	SEP96	
28	<i>Grace (School)</i>		TB, RG	yes		nn		
29	<i>Soufriere (The Still)</i>		TB, RG	yes		nn		
30	<i>Canaries (Belvedere)</i>		TB, RG	yes		nn		
31	<i>Millet (Roseau Dam)</i>		TB	nn	nn	nn	-	
32	<i>Anse la Raye (School)</i>		RG, RR	yes	yes	nn	SEP96	
33	<i>Blanchard (School)</i>		RG, RR	yes		nn		

nn = not necessary; RR = Rainfall Recorder; TB = Tipping Bucket rainfall recorder; RG = Rain Gauge; AWS = Automatic Weather Station; Nienke\_pc:\Nienke\werk\wbank\efence\_eq.wk4 Anem. = Anemometer.

## **PHOTOGRAPHS**

**Photograph 1      Rip-rap Work to protect Dennery Town**

**Photograph 2      Gabion Wall on the Cul-de-Sac River**

**Photograph 3      Damage to the Right Bank of the Soufriere River**

**Photograph 4      Damage to the Right Bank of the Soufriere River**

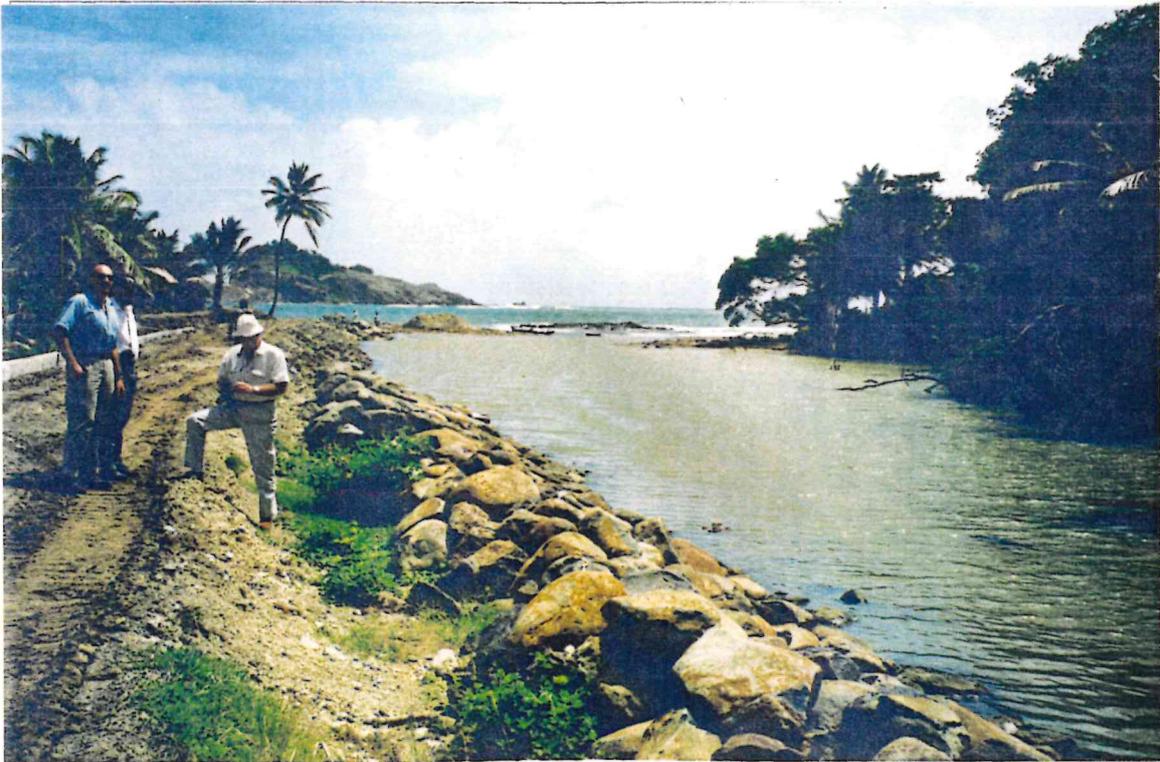


Photo 1 Massive rip-rap protection to Dennery town (view DS to outfall). Work still to be completed.



Photo 2 Gabion wall in Cul de Sac to protect infrastructure has inadvertently trained flow across the river to scour opposite bank (view DS)

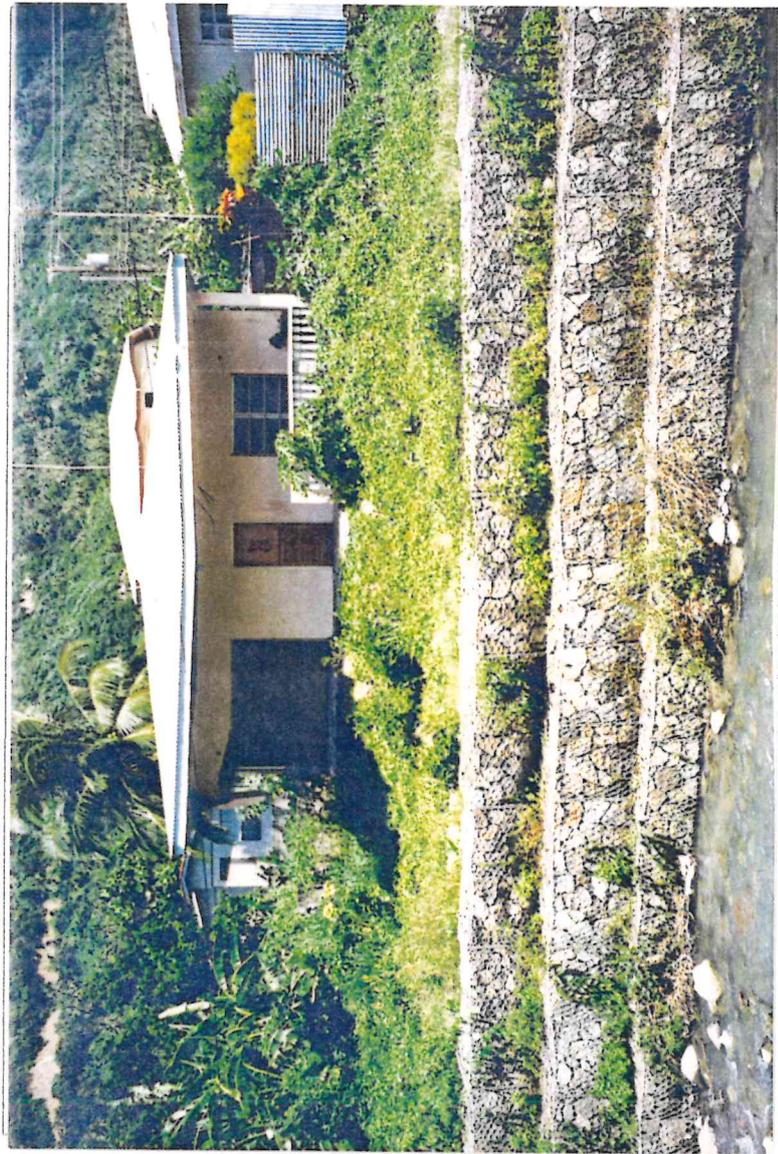


Photo 4 October 1996

Damage on Right Bank of Soufriere River as it enters the Town repaired under Phase 1



Photo 3 December 1994

