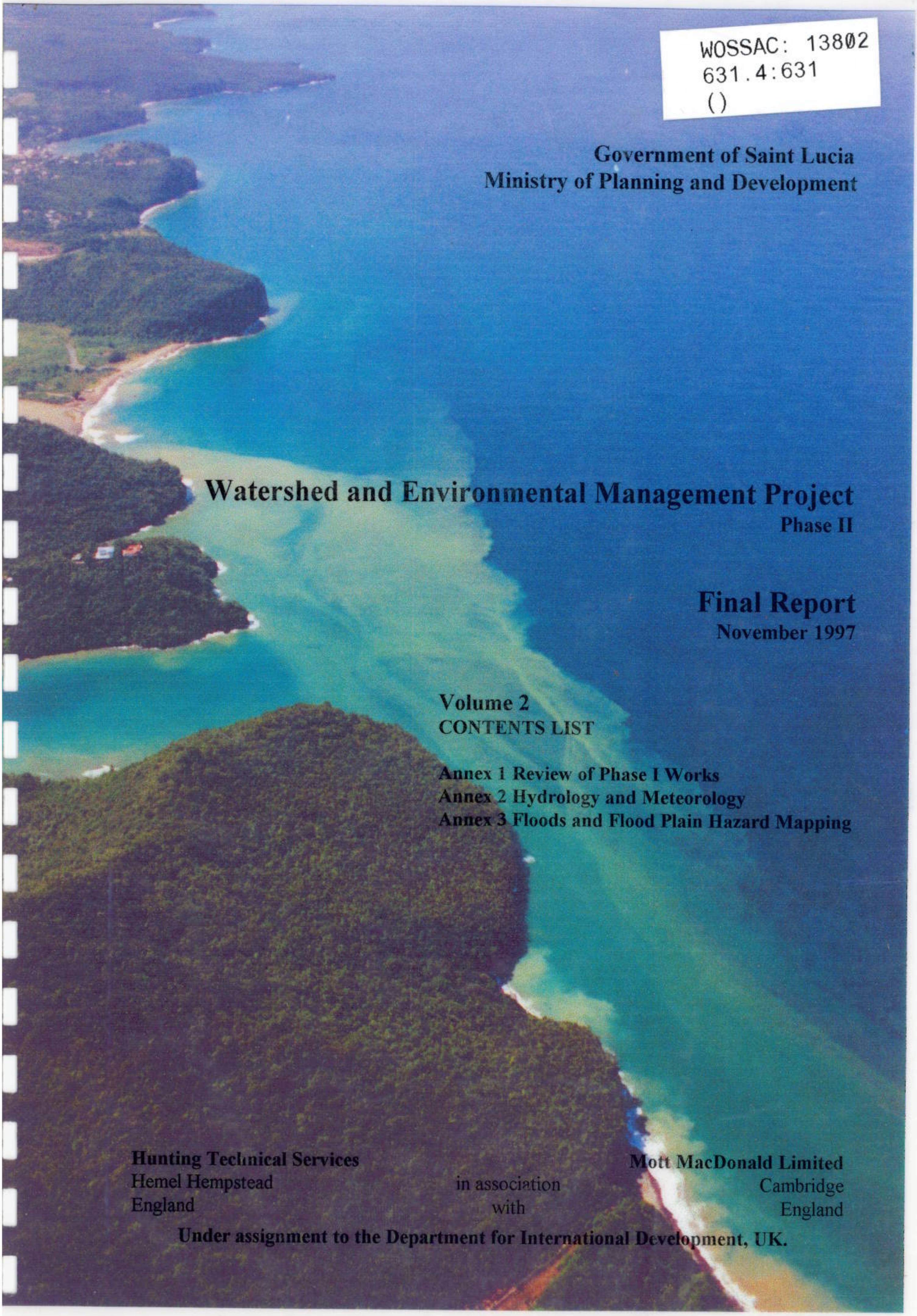

Government of Saint Lucia
Ministry of Planning and Development

Watershed and Environmental Management Project

Phase II

Final Report

November 1997

Volume 2
CONTENTS LIST

Annex 1 Review of Phase I Works
Annex 2 Hydrology and Meteorology
Annex 3 Floods and Flood Plain Hazard Mapping

Hunting Technical Services
Hemel Hempstead
England

in association
with

Mott MacDonald Limited
Cambridge
England

Under assignment to the Department for International Development, UK.

8808

WATERSHED AND ENVIRONMENTAL MANAGEMENT PROJECT
PHASE 2

VOLUME 2

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Annex 1. Review of Phase 1 Works

Annex 2. Hydrology and Meteorology

Annex 3. Floods and Flood Plain Hazard Mapping

ACRONYMS AND ABBREVIATIONS

ACP	African, Caribbean and Pacific
AESD	Agricultural Engineering Services Division (of MAFF&E)
ADCU	Agricultural Diversification Coordinating Unit
API	Aerial Photography Interpretation
BDDC	British Development Division in the Caribbean
CAMMA	Canaries and Anse La Raye Marine Management Area
CANARI	Caribbean Natural Resources Institute
CAP	Chapter of GoSL Legislation
CARDI	Caribbean Agricultural Research and Development Institute
CBO	Community Based Organization
CEHI	Caribbean Environmental Health Institute
CIDA	Canadian International Development Agency
CPP	Community Participation Programme
CRM	Coastal Resource Management
CZM	Coastal Zone Management
CZMU	Coastal Zone Management Unit
DCA	Development Control Authority (of MP&D)
DFID	Department for International Development (UK)
EC$	Eastern Caribbean Dollars
EEZ	Exclusive Economic Zone
EH	Environmental Health
EIA	Environmental Impact Assessment
ENCORE	Environmental and Coastal Resource Project
EU	European Union
FAO	Food and Agricultural Organization (of UN)
GATT	General Agreement on Tariffs and Trade
GIS	Geographical Information System
GoSL	Government of St. Lucia
GTZ	German Technical Mission for Co-operation
HTS	Hunting Technical Services
ICZM	Integrated Coastal Zone Management
IFAD	International Fund for Agricultural Development
IoH	Institute of Hydrology (UK)
ISM	Island System Management
LCB	Land Conservation Board
LCDC	Land Development and Drainage Committee
MAFF&E	Ministry of Agriculture, Forestry, Fisheries and Environment
MCWT&PU	Ministry of Communications, Works, Transport and Public Utilities
MF,P, IS&PS	Ministry of Finance, Planning, Information Services and Public Services
MH,HS,FA&W	Ministry of Health, Human Services, Family Affair and Women
MM	Mott MacDonald
NEAP	National Environmental Action Plan
NEC	National Environmental Commission
NEMO	National Emergency Management Organisation
NGO	Non-Governmental Organisation
NRMU	Natural Resource Management Unit (of OECS)
OAS	Organisation of American States

OCDP	Orchard Crop Diversification Project
OECS	Organisation of Eastern Caribbean States
PM	Prime Minister
PPU	Physical Planning Unit (of MP&D)
PS	Permanent Secretary of GoSL Ministry
SFAD	Small Farmer Development Project
SFAP	Small Format Aerial Photography
SI	Statutory Instrument of GoSL Legislation
SLAA	St. Lucia Agriculturalist Association
SLBGA	St. Lucia Banana Growers Association
SLNT	St. Lucia National Trust
SMMA	Soufriere Marine Management Area
SWM	Solid Waste Management
TDB	Tourist Industry Development Board
TOT	Technical Operations Team
ToR	Terms of Reference
TRoPRo	Tropical Produce Support Project
TSD	Tropical Storm Debbie
USAID	United States Agency for International Development
USDA	United States Development of Agricultural
UWI	University of the West Indies
WASA	Water and Sewerage Authority
WIBDECO	Successor to WINBAN
WINBAN	Winward Island Banana Growers Association
WMO	World Meteorological Organisation
WTO	World Trade Organisation
WWF	World Wildlife Fund

Annex 1

Review of Phase 1 Works

ANNEX 1

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St Lucia : Watershed and Environmental Management Project

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Review of Phase 1 Works

Chapter 1

Introduction

1.1 Preamble

One of the main elements of the first part of Phase 2 of the Watershed and Environmental Management Project was the review of the Phase 1 Works. The Works were undertaken in order to rehabilitate river reaches, road bridges and other areas of infrastructure damaged during Tropical Storm Debbie. The Phase 1 works were mainly undertaken over the period from early 1995 until mid 1996 although some works have only just been completed in the Autumn of 1997.

The review of the Phase 1 Works was hampered by the fact that damage to the new works took place during the October 26th 1996 storm event. The Phase 2 Consultants had just started their consultancy contract and had undertaken some of the field assessments related to the rehabilitation work when the severe flood flows took place particularly over the central part of the island causing further damage to the existing and new works. Significant further damage took place in the Cul-de-Sac, Roseau, Troumassee, Canaries, Canelles and Soufriere watersheds although other catchments were also affected.

The storms of October and November 1996 not only affected the rehabilitation works of Phase 1 but also limited the amount of time which staff of the Ministry of Communications, Works and Transport could devote to participating in the reconnaissance and review visits undertaken by the Consultants.

After the October 26th storm, it was also much more difficult to assess both the extent and the quality of the works undertaken during Phase 1 since the effect of the new floods were difficult to isolate.

The flooding which took place during the review did enable a good assessment to be made of the ability of the works to withstand a severe flood event. However, the severity of the flood event might be considered by some to be in excess of that which the Phase 1 rehabilitation works were to withstand. The other factor which has been pointed out is that the new works were subjected to a severe flood event prior to the establishment of any new vegetation on the river banks and other work areas and before the works had generally 'consolidated' themselves. Although these factors need to be taken into consideration, it is believed that some of the works should have better withstood the flood event of October 26th.

[*Since the undertaking of the Review of the Phase 1 Works by the Consultants, a further assessment of progress has been undertaken by a World Bank Mission in August 1997. The resulting Aide Memoire stated "Overall progress of the project continues to be good. About 90 per cent of the civil works were completed by the original closing date while the remaining works should be completed well in advance of the revised closing date of December 31, 1997.". The Aide Memoire also indicated that savings had been achieved from the original budget. The only works identified being problematic was the contractual problems associated with the Dennery Flood Protection Embankment and the delays in the completion of the new road bridge at Soufriere.*]

Chapter 2

Review of Phase 1 Works

2.1 World Bank Rapid Deployment Force

2.1.1 Background

Following Tropical Storm Debbie in September 1994, a two-phase programme was formulated for the rehabilitation and future management of the Island's watersheds. Phase 1 comprised a reconstruction programme involving priority works. It started in May 1995 and was substantially complete by mid 1996.

The works which were funded by the World Bank and GoSL were carried out by the Ministry of Communications, Works and Transport. A supervising engineer and supporting design group was funded by ODA.

2.1.2 Recommendations for Phase 1 Works

Most of the works proposed in the December 1994 Report were for desilting and river training.

In relation to river training, it was stated 'When intervening in the natural behaviour of a river, it should be realised that there is a relationship between the amount of water and sediment that is loaded on a river, and the longitudinal and cross section it adopts in the process; also that improper interventions could have unexpected negative effects.'......' Without much data regarding 'design' discharges, one should be prudent so as not to force too drastic changes upon a river otherwise, in the next wet season, the river could undo much of the work, choosing its own course.' (P13 ibid.).

It was also stated 'However, in St Lucia, relevant hydrological data are often inadequate, which makes it difficult to make a reliable assessment of the probability of higher-than-design discharges occurring and the extent of associated damage that could occur. In these circumstances, it might be better to allow rivers a certain degree of freedom of movement, using land use zoning regulations to keep an adjoining strip of land free from urban construction and used instead for parks etc.'

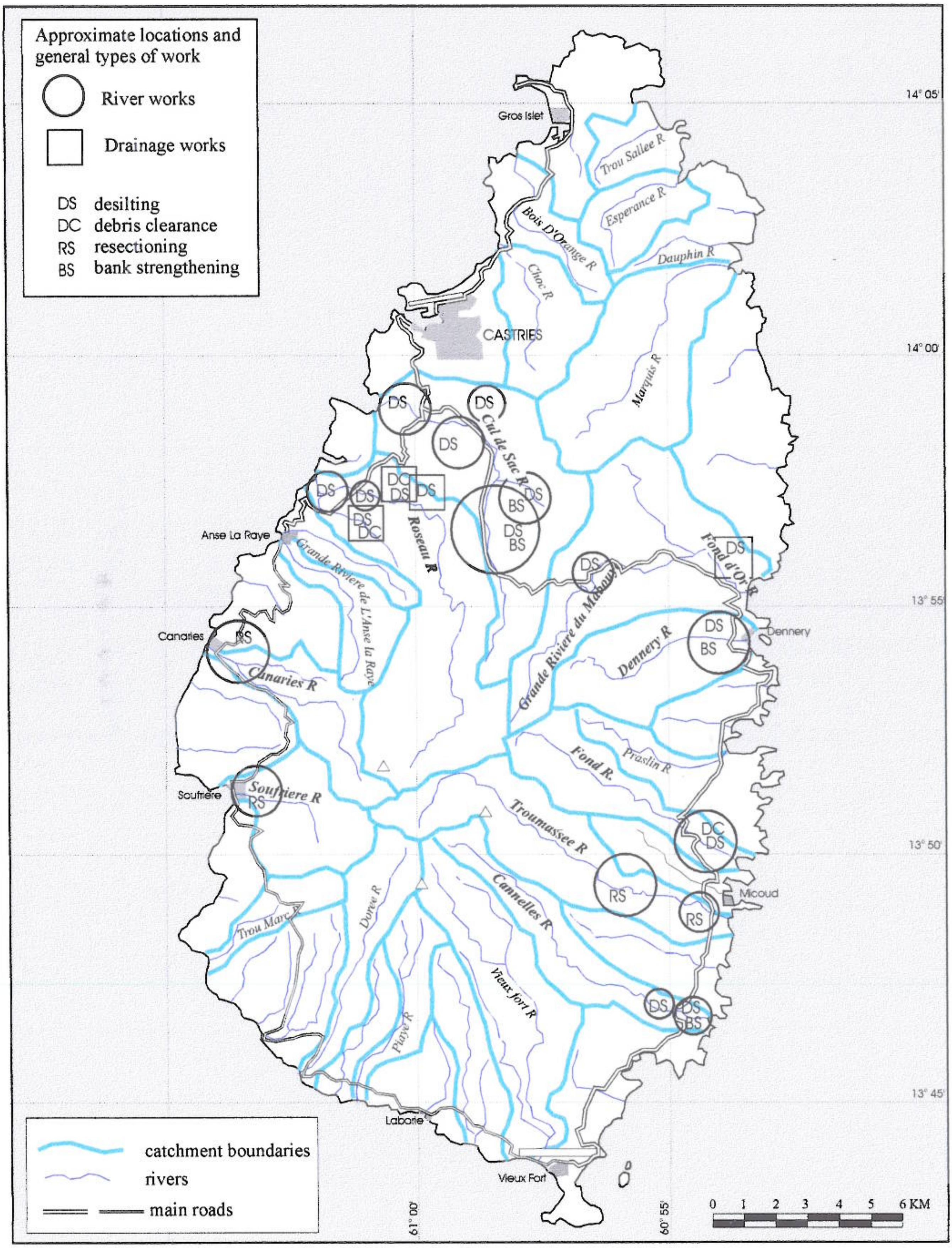
Desilting of the channel system was important since much debris and large boulders were carried down the main river system by the unusually high flows. The bed material of a river are such as to reflect the planform and slope and channel section characteristics of a river. During severe floods, the higher flow velocities enable larger quantities of silt to be taken into suspension and also introduce larger stones in to the active bed load movement. As these velocities reduce, either as the flow passes through the gentler sloping floodplain or through the backing up of water at a partially or blocked cross drainage structure so the bed load is partially dropped out and sediment is dropped as the sediment carrying capacity of the flow is reduced.

The location of the principal works as recommended by the initial World Bank Mission is presented in **Figure 2.1**, taken from the December 1994 Report.

SAINT LUCIA WATERSHED AND ENVIRONMENTAL PROJECT

PRIORITY WORKS IN PHASE 1

Figure 2.1



2.2 Phase 1 Design and Implementation of Emergency Works

2.2.1 Field Visits, Inspection and Data Collection

Broad categories of work have been:

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

Further details are given in **Table 2.1**, see **Figure 2.2** for general locations.

Survey sheets, as-built drawings and design files have been collected and examined. However, the data is deemed to be incomplete although more information has to be found. A broad summary statement of the works undertaken together with location plans and extent of the works undertaken in each section of channel of each river has been put together by the Phase 2 Consultants. There are some gaps in knowledge however, this is not thought to adversely affect the tasks as specified in the ToR for the Phase 2 Consultants.

A summary of the expenditure to date is presented in **Table 2.2**. This is as prepared in May 1996 by the Phase 1 Consultants, almost at the completion stage of the Phase 1 Works, and updated for the situation as of November 1996.

2.2.2 Design related to Phase 1 Works

In the emergency programme which was implemented, detailed design work might not have been possible.

The design work contained in the files made available to the Consultants can be considered to be outline designs, additional work would need to have been undertaken at field level during construction. Design criteria, data and information was and is relatively sparse.

The design information on file which has been made available to the Consultants has in the most part been design sketches for river training works and re-alignments or loop cutting.

The majority of the works have been related to the realignment and resectioning of the lower reaches of the various river channels. Both gabion protection works and rip rap provisions have been made for both scour protection and river training.

Design flood flows in the river system has been based on an estimated 1:5 year return period event, sometimes increased where deemed necessary. The values for the 1:5 year flow have been derived from the 1984 Report by Hunting Technical Services, The Roseau, Dennery and Cul-de-Sac Drainage and Conservation Project.

2.2.3 Implementation of Phase 1 Works

The extensive river works carried out to protect urban areas and infrastructure have in the most part been effective, however they were severely tested by the flood flows resulting from the storm rainfall of 26th October 1996.

Table 2.1

Saint Lucia Watershed and Environmental Management Project

Phase 1- Priority Works

Prior-ity	Watershed	River	Reach	Approximate Dimensions (m) L	W	D	Form of Works	Unit Rate EC$/km (from Dec '94 Report)	Total EC$M	General Remarks in Preparatory Report	General Remarks on Phase 1 completed works
RIVER WORKS											
1	Souffriere	a. Main channel	Mouth to 2km	2,000			Desilting, river training bank stabilisation	1,000,000	2.000	Some river training required to protect important social infrastructure	Major gabion training walls New bridge under construction
2	Cul de Sac	a. Main channel	Mouth to slope control weir #1	1,000	2 ?	0.3 to 0.8	Desilting	50,000	0.050		Desilting, debris clearance, channel re-alignment, loop cutting and channel resectioning
		b. Odsan Ravine	Confluence to Odsan Bridge	3,000	2	0.3 to 0.8	Desilting	18,000	0.054	Agricultural and industrial zone	
		c. Desglos Ravine	From confluence to 1km u/s	3,000	1.5 to 2	0.5 to 0.9	Desilting	18,000	0.054	Main drainage provison for agriculture	
		d. Ravine Souffre	Confluence to R Elibox lands	2,000	4	0.6 to 0.9	Desilting & bankstabilisation	52,100	0.104	Bank stabilisation over 150m	
			Taraprasad br. to Rav. Roches	1,000	4	0.3 to 0.4	Right bank stabilisation	50,000	0.050	Gabions, rip rap and vegetal cover	
		e. Main channel	Odsan bridge to L'Abbaye	8,000	3.4	0 to 1.4	Desilting, resectioning	70,000	0.560	Rip rap slope protection, more works Phase 2	Some gabion work
1	Roseau	a. Main channel	Mouth to 1.5km u/s	1,500	3 to 12	1 to 2	Desilting, mouth breaching	20,000	0.030	Regular mouth breaching indicated	Desilting, debris clearance, channel re-alignment, loop cutting and channel resectioning
		b. Main channel	Roseau bridge to 200m u/s	200			Debris clearance		0.004	Provisional sum	
2	Canaries	a. Main channel	Mouth to 4km upstream	4,000			Desilting	50,000	0.200		
				500			Bank stabilisation	300,000	0.150	Retaining wall to protect houses / gas station	Gabion works, masonry wall badly affected by later floods
2	Anse la Raye	a. Main channel	West coast Road to bridge	200			Bank stabilisation	400,000	0.080	Remove threat of abutment erosion	Some gabion protection measures
2	Fond	a. Main channel	Mouth to 2km u/s	2,000	3 to 4	0.2 to 1	Debris clearance, desilting	41,000	0.082		Debris clearance, desilting
3	Dennery	a. Main channel	Mouth to East Coast Bridge	1,000			Desilting, river training	500,000	0.500	Remove threat of overflow towards village	Embankment with rip-rap protection
3	Canelles	a. Main channel	Mouth to East Coast Bridge	1,400	6	0 to 1	Desilting, mouth breaching	25,000	0.035	Bank stabilisation with vegetative cover	Mainly desilting and debris clearance
		b. Main channel	EC Bridge to sugar mills	600	5	0.3 to ?	Desilting, bank stabilisation	41,000	0.025	Bank stabilisation with rip rap and v. cover	
3	Mabouya	a. Tributary	Grand Riviere bridges & u/s	1,200	4	1 to 2	Desilting	50,000	0.060		Desilting, debris clearance, channel re-alignment, loop cuts.
3	Troumassee	a. Main channel	Beauchamp to Moreau, 4km	2,000	8 to 20	0.4 to 1	Resectioning, lower & upper	80,000	0.160	Deposited material to be used plus vegetal	Debris clearance, river training d/s of bridge to form narrow section (badly affected by recent floods)
								Sub-total	4.198		
DRAINAGE WORKS											
1	Roseau	a. Morne d'Or	Outfall u/s for 1km	1,000	1 to 1.5	0.3 to 1.2	Debris clearance & desilting	46,500	0.047	1/3 of costs relate to transport of debris etc	
		b. Belair Mains	3km main drainage outlets	1,500		0.4 to 1.5	Desilting	46,500	0.070	Includes haulage costs of spoil	
				1,500		0.4 to 1.5	Desilting	31,000	0.047	Excavation only, spoil dumped along drain	
		c. Roseau Morne d'	Road drain for agriculture	1,100		0.4 to 1	Desilting	46,500	0.051	Costs include haulage	
		d. Hollywood-Jacme	Roseau Jacmel	6,000		0.4 to 1	Debris clearance & desilting	18,000	0.108		
1	Fond d'Or	a. Dennery-Farmco	Interceptor drainage channels	5,000	1.5 to 2	0.6 to 1	Desilting	18,000	0.090		
								Sub-total	0.412		
								Total	4.610 EC$M		

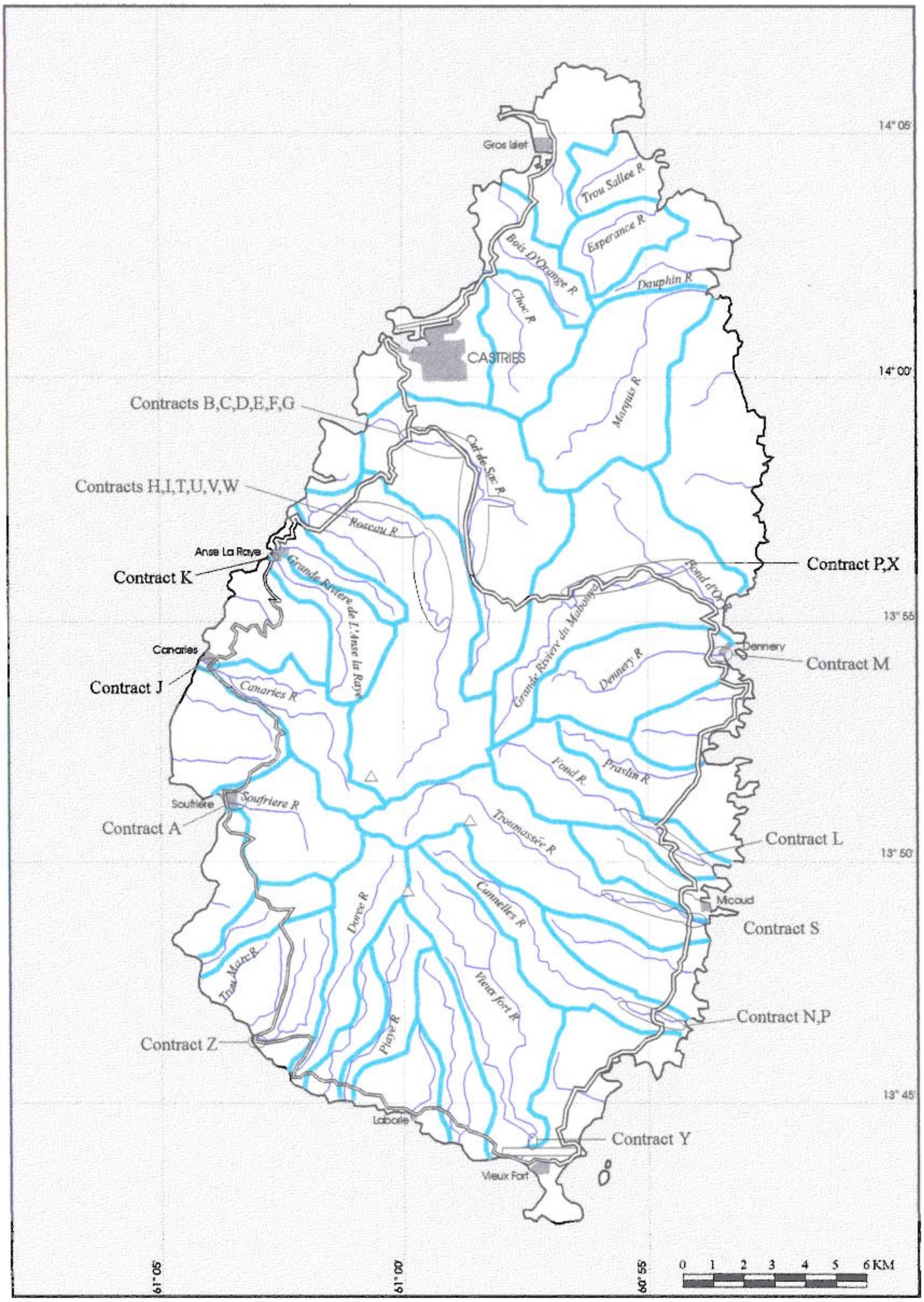
Summary of Phase 1 Summary Report of Works (May 31 1996) Includes works, gabion baskets, surveys etc Total 14.258 EC$M

Summary: World Bank Staff Appraisal Report (Ph 1 Works)	Local US$M	Foreign US$M	Total US$M			
River training, debris clearing	0.696	1.043	1.739			
Resectioning, bank stabilisation, drain clearing, desilting	0.765	1.362	2.127			
Unassigned 1996 works	0.209	0.312	0.521			
Physical contingencies (15%)	0.251	0.408	0.658			
Price contingencies (5%)	0.084	0.136	0.219			
Total:	2.004	3.260	5.264	This being equivalent to :	Total	13.161 EC$M

File: PH1-WK-S.WK4

Figure 2.2

Location of Phase 1 Contracts



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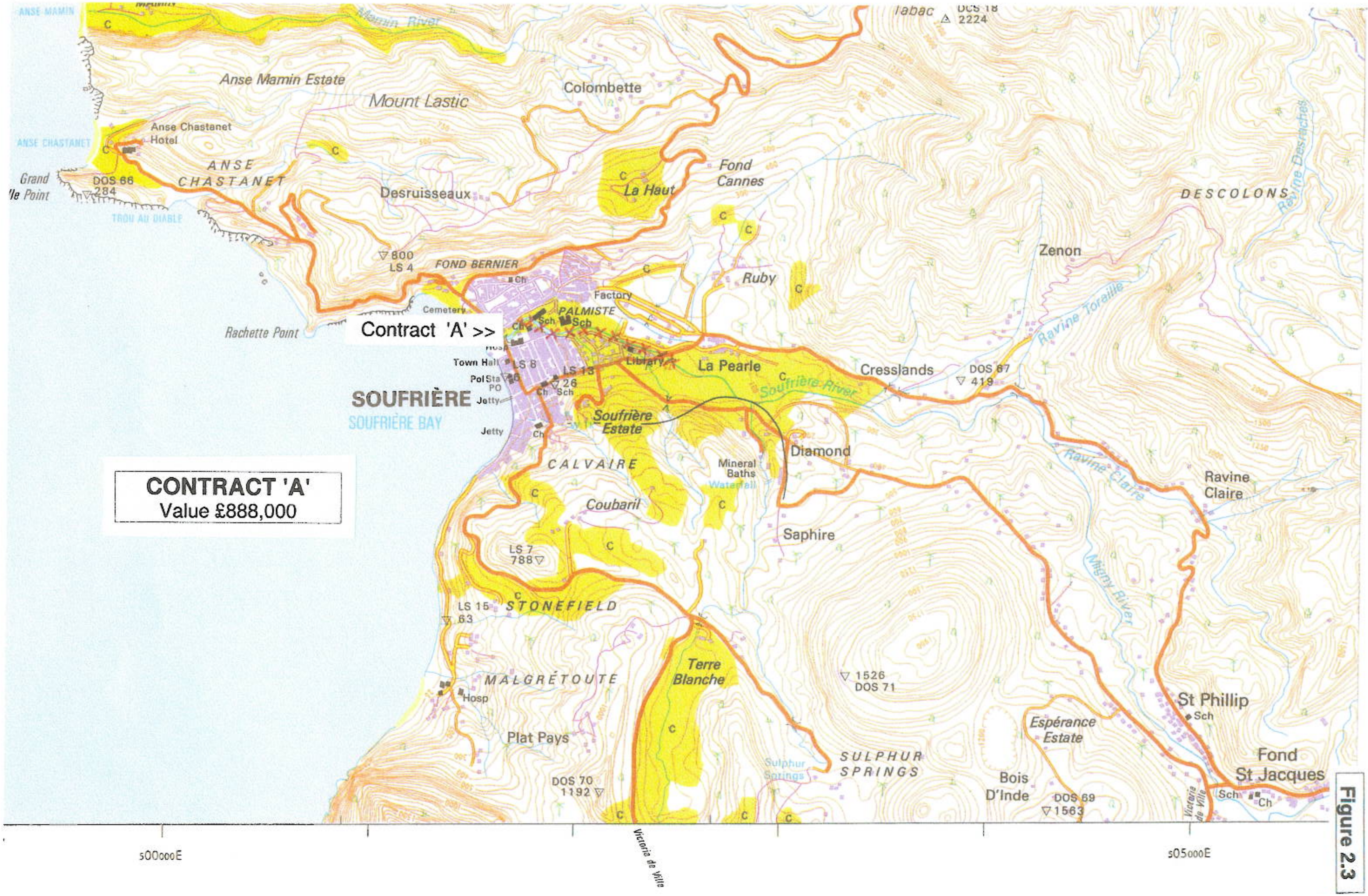

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SOUFRIÈRE BAY
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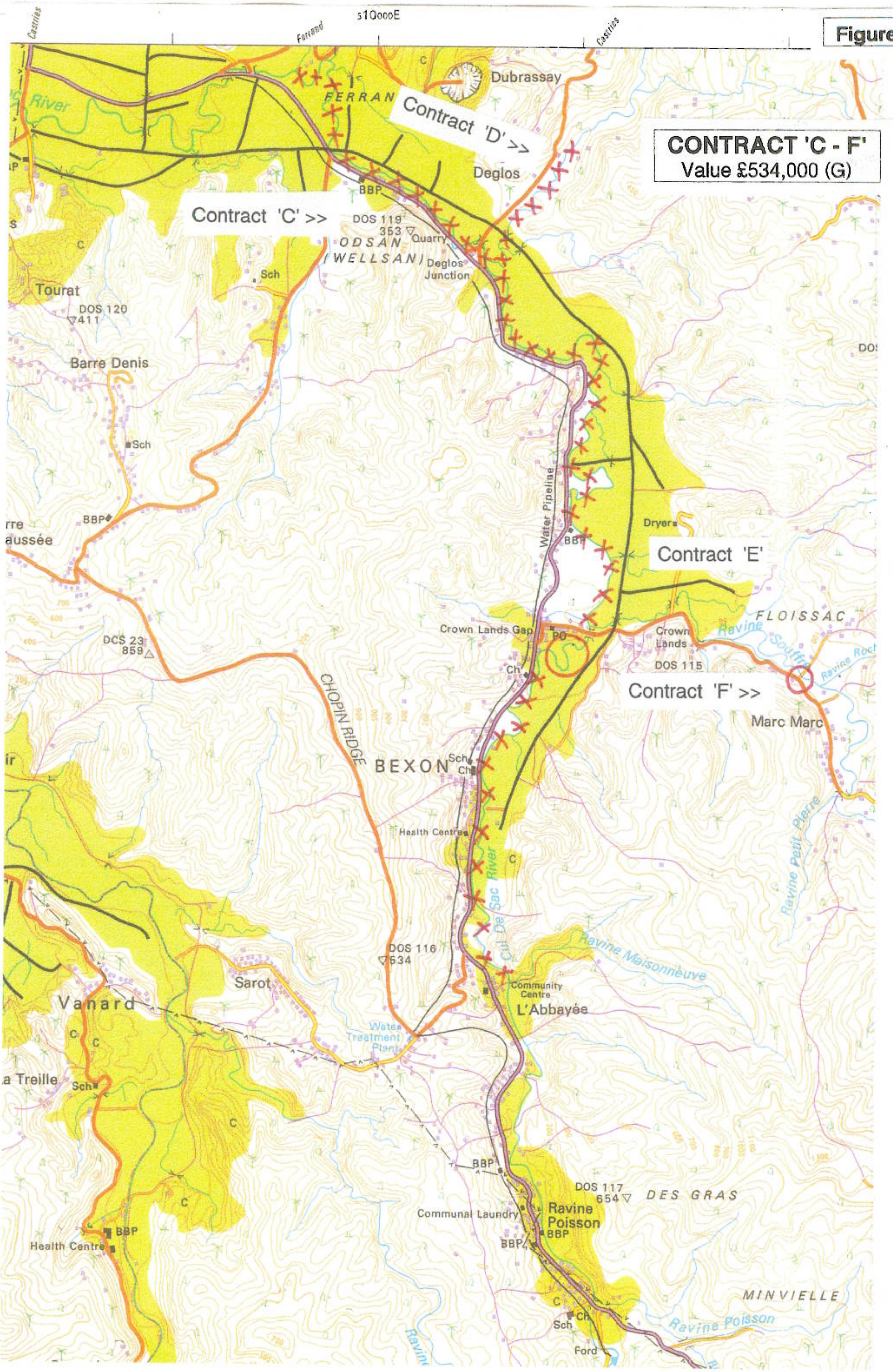
Mount Lastic
Colombette
Anse Chastanet Hotel
ANSE CHASTANET
Desruisseaux
La Haut
Fond Cannes
DESCOLONS
Zenon
Ruby
FOND BERNIER
PALMISTE
Factory
Cemetery
Rachette Point
Town Hall
Library
La Pearle
Cresslands
Soufrière River
Soufrière Estate
Diamond
Mineral Baths
CALVAIRE
Coubaril
Saphire
Ravine Claire
STONEFIELD
MALGRÉTOUTE
Terre Blanche
Plat Pays
SULPHUR SPRINGS
Bois D'Inde
Espérance Estate
St Phillip
Fond St Jacques
Mamin River
Ravine Toraille
Migny River
TROU AU DIABLE
ANSE MAMIN
ANSE CHASTANET
500000E
505000E
Victoria de Ville

Figure 2.3

Figure 2.4



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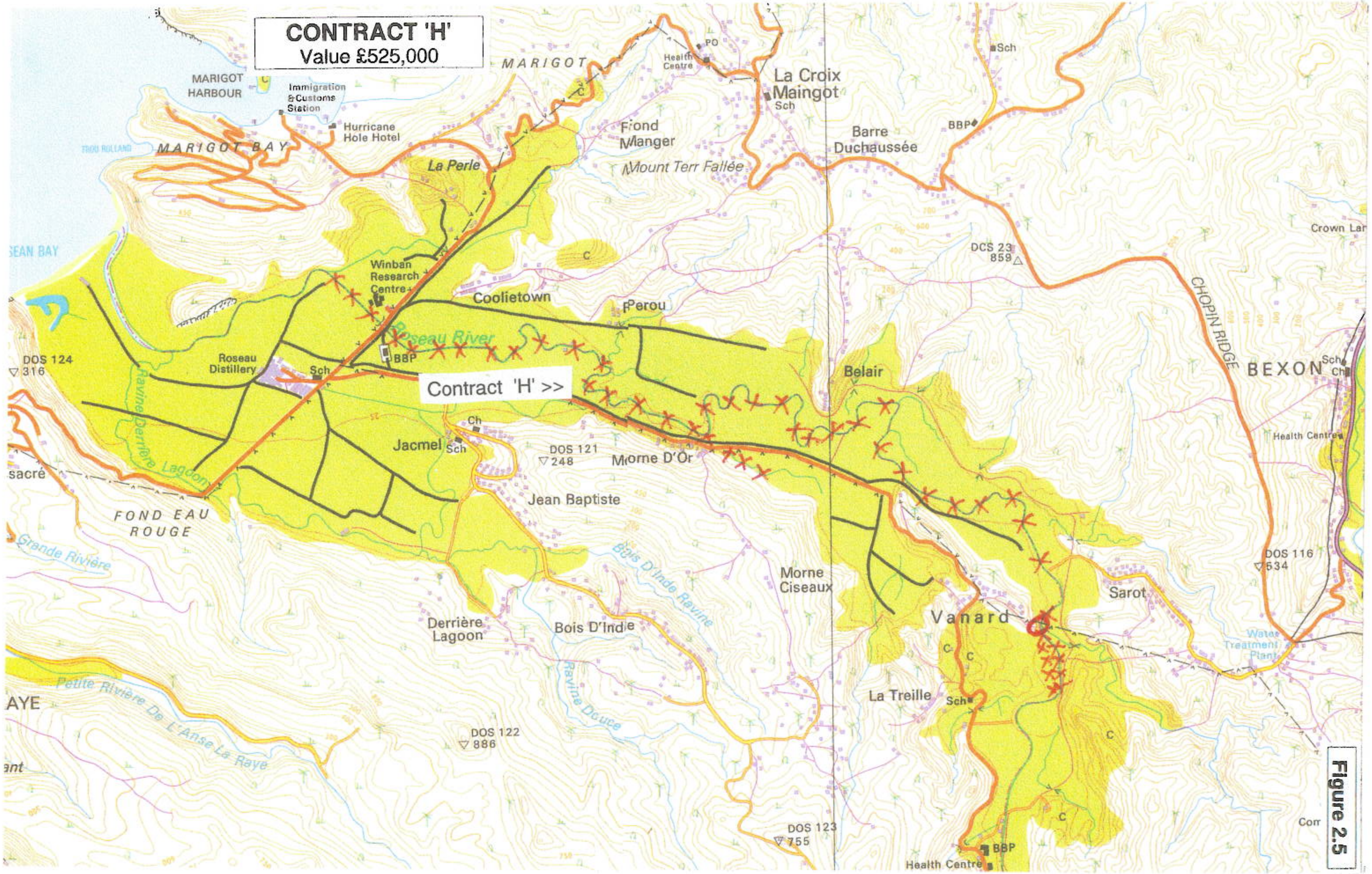
Contract 'D' >>
Contract 'E'
Contract 'F' >>
510000E
Castries
Ferrand
FERRAND
Dubrassay
Deglos
BBP
DOS 119
353
Quarry
ODSAN
(WELLSAN)
Deglos Junction
Sch
Tourat
DOS 120
411
Barre Denis
Sch
BBP
Water Pipeline
Dryer
FLOISSAC
Ravine
Crown Lands Gap
PO
Crown Lands
DOS 115
Marc Marc
Ravine Petit Pierre
DCS 23
859
CHOPIN RIDGE
BEXON
Sch
Ch
Health Centre
Cul De Sac River
Ravine Maisonneuve
DOS 116
634
Community Centre
L'Abbayée
Sarot
Vanard
Water Treatment Plant
a Treille
Sch
DOS 117
654
DES GRAS
Communal Laundry
Ravine Poisson
BBP
Health Centre
MINVIELLE
Ravine Poisson
Sch
Ford
River



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Contract 'H' >>
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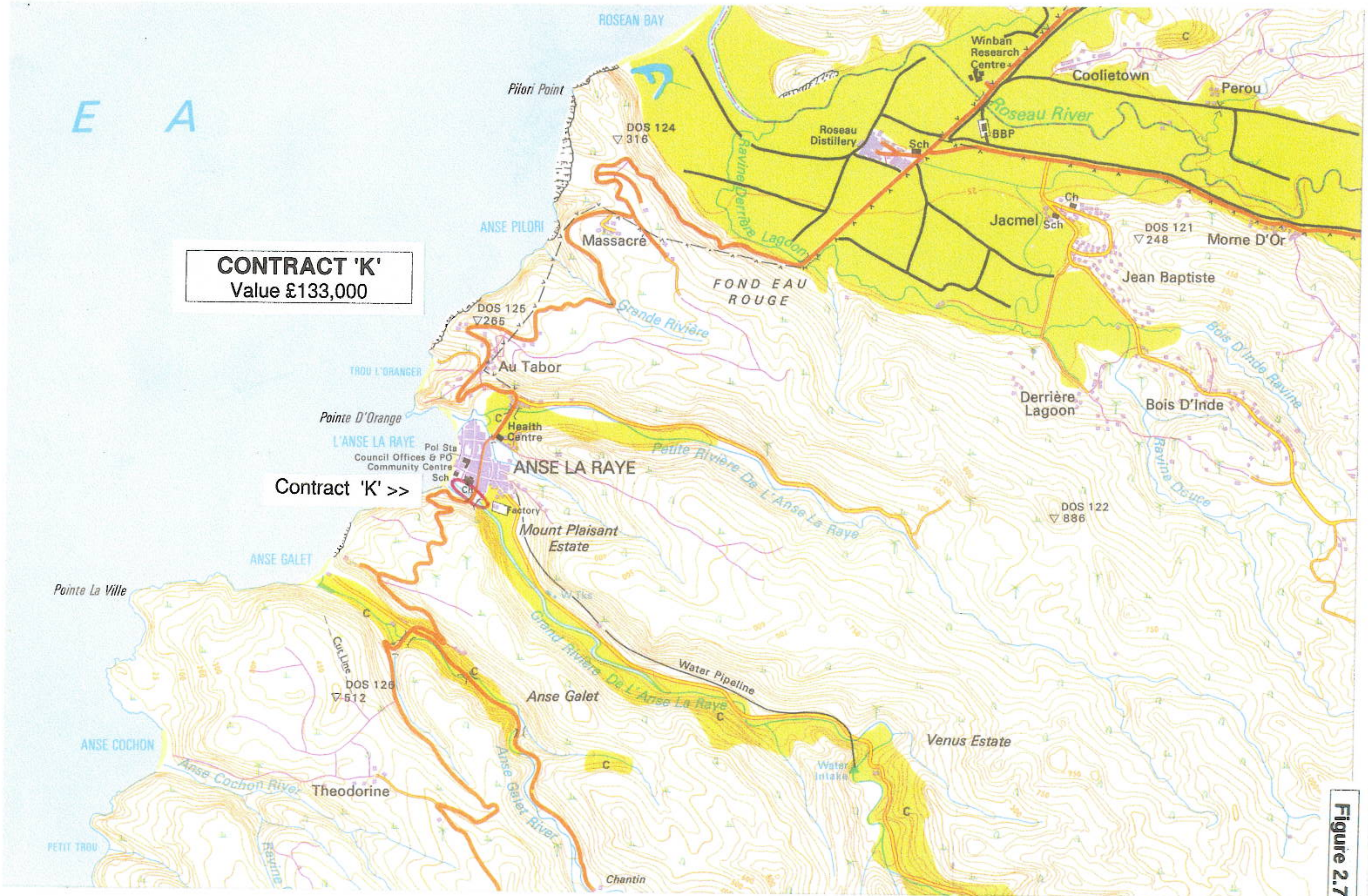
Immigration & Customs Station
Hurricane Hole Hotel
MARIGOT BAY
MARIGOT
La Perle
Winban Research Centre
Roseau River
Roseau Distillery
Sch
BBP
Coolietown
Perou
Health Centre
PO
La Croix Maingot
Fond Manger
Mount Terr Fallée
Barre Duchaussée
DCS 23 859
CHOPIN RIDGE
BEXON
Crown Lar
Belair
DOS 124 316
Ravine Derrière Lagoon
FOND EAU ROUGE
Grande Rivière
Jacmel
Ch
DOS 121 248
Morne D'Or
Jean Baptiste
Bois D'Inde Ravine
Morne Ciseaux
Vanard
Sarot
DOS 116 534
Water Treatment Plant
Derrière Lagoon
Bois D'Inde
Ravine Douce
La Treille
Petite Rivière De L'Anse La Raye
DOS 122 886
DOS 123 755
Health Centre

Figure 2.5

Figure 2.6

CONTRACT 'J'
Value £340,000
4km of channel, main works in reach 300m upstream of Canaries main road bridge
Contract 'J' >>
CANARIES
Council Offices & PO
Health Centre
Anse La Verdure
Anse La Verdure River
Anse La Verdure Estate
Ravine Joseph
SAUROT
Mount Parasol
DCS 21 1514
Ravine Combat
Ravine Tertullien
Ravine Parasol
Mount Regnier
Mount Marquis
GRAND BOIS FOREST
Canaries River
Espérance
Water Intake
Ravine Duval
RAVINE DUVAL
SIBIEUX
Mount Morton
Belvedere
DOS 84 752
Mount Siquot
Mahaut
Mahaut River
ANSE LA VERDURE
ANSE LA VOUTTE
Jambette Point
ANSE DES CANA
ANSE LA LIBERTÉ
ANSE MAHAUT



CONTRACT 'K'
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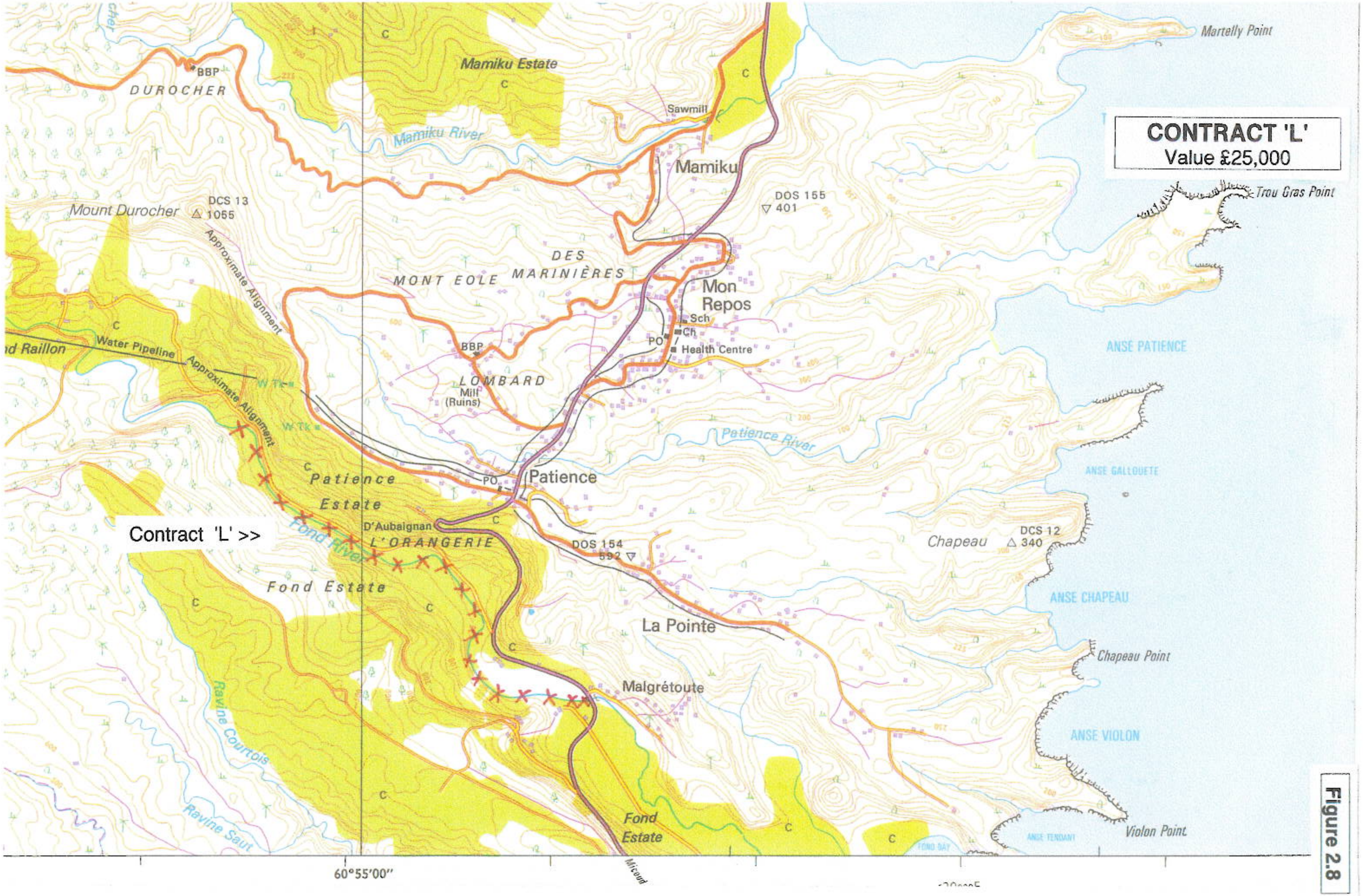
Contract 'K' >>
E A
ROSEAN BAY
Pilori Point
ANSE PILORI
TROU L'ORANGER
Pointe D'Orange
L'ANSE LA RAYE
ANSE GALET
Pointe La Ville
ANSE COCHON
PETIT TROU
ANSE LA RAYE
Health Centre
Pol Sta
Council Offices & PO
Community Centre
Sch
Ch
Factory
Mount Plaisant Estate
Au Tabor
Massacré
DOS 124 ▽316
DOS 125 ▽265
DOS 126 ▽512
DOS 121 ▽248
DOS 122 ▽886
FOND EAU ROUGE
Grande Rivière
Petite Rivière De L'Anse La Raye
Grand Rivière De L'Anse La Raye
Water Pipeline
Water Intake
W Tks
Cut Line
Anse Galet
Anse Galet River
Anse Cochon River
Theodorine
Chantin
Venus Estate
Winban Research Centre
Coolietown
Perou
Roseau River
Roseau Distillery
BBP
Ravine Derrière Lagoon
Jacmel
Jean Baptiste
Morne D'Or
Derrière Lagoon
Bois D'Inde
Bois D'Inde Ravine
Ravine Douce

Figure 2.7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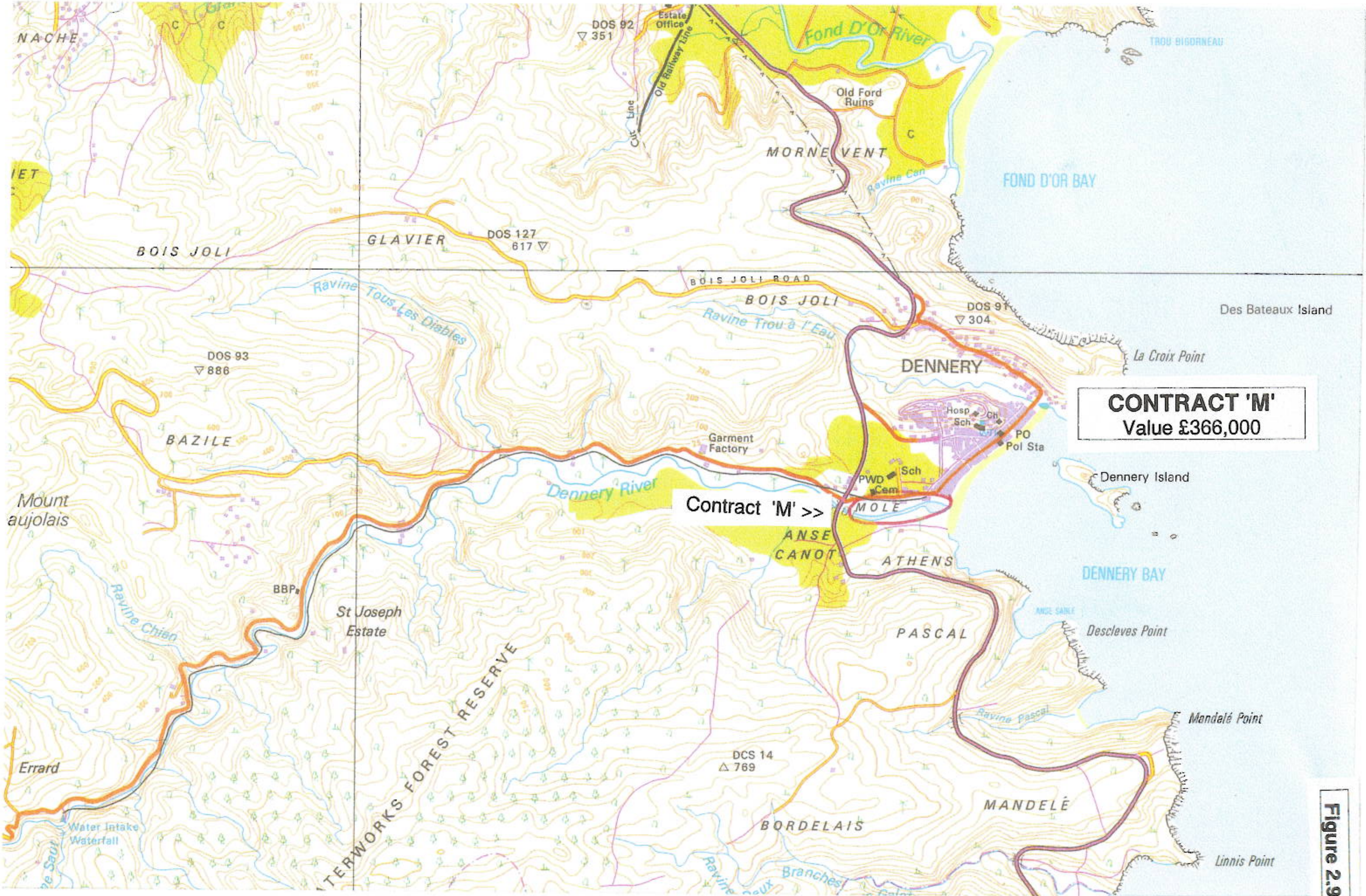
Value £25,000
Contract 'L' >>
Martelly Point
Trou Gras Point
ANSE PATIENCE
ANSE GALLOUETE
ANSE CHAPEAU
Chapeau Point
ANSE VIOLON
Violon Point
DUROCHER
BBP
Mamiku Estate
Mamiku River
Sawmill
Mamiku
DOS 155
401
Mount Durocher
DCS 13
1055
Approximate Alignment
DES
MONT EOLE
MARINIÈRES
Mon
Repos
Sch
Ch
PO
Health Centre
Water Pipeline
d Raillon
LOMBARD
Mill
(Ruins)
Patience River
Patience
Patience
Estate
D'Aubaignan
L'ORANGERIE
Fond River
Fond Estate
DOS 154
592
Chapeau
DCS 12
340
La Pointe
Malgrétoute
Ravine Courtois
Ravine Saut
Fond
Estate
Micoud
60°55'00"

Figure 2.8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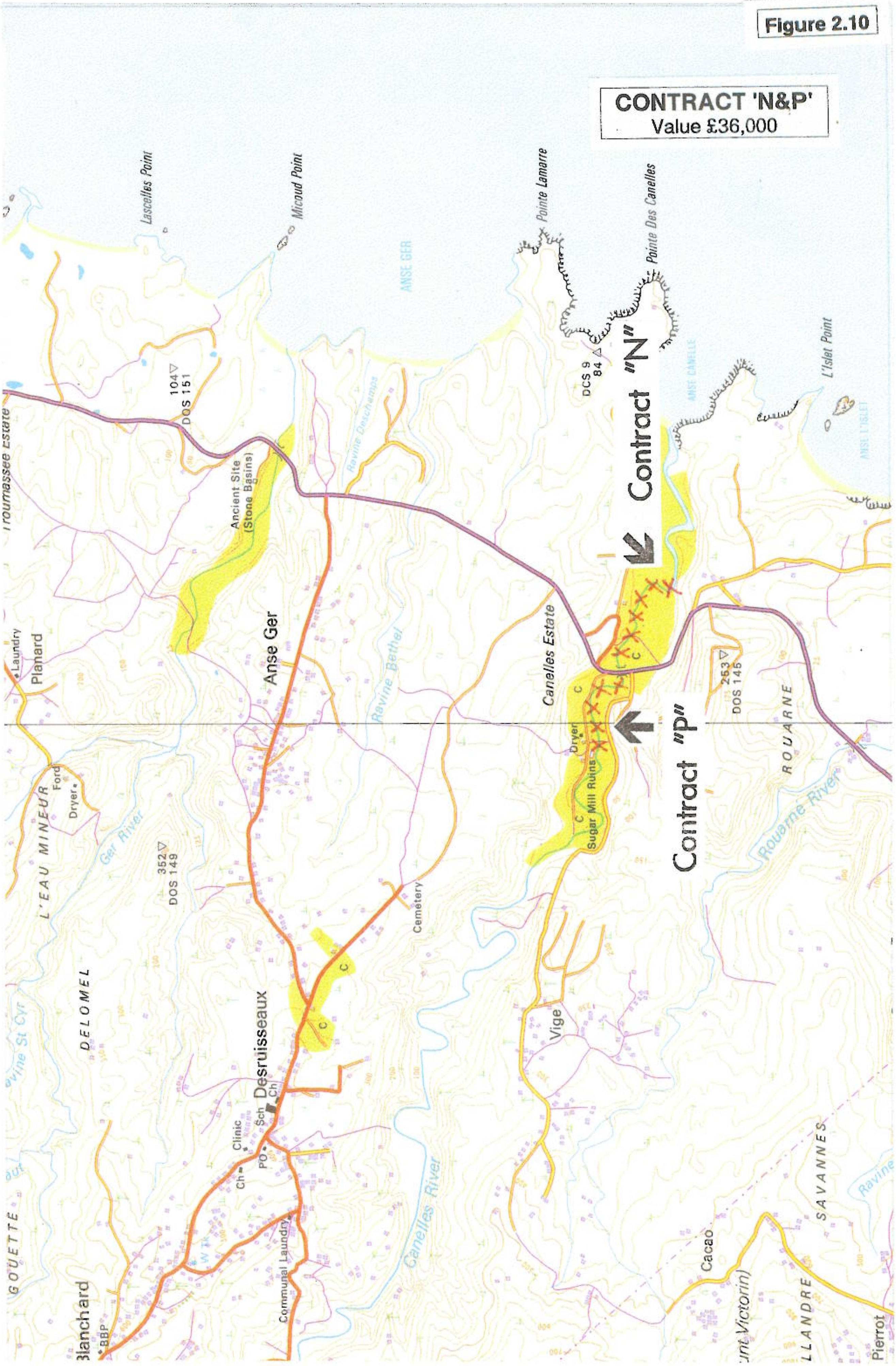
Value £366,000
Contract 'M' >>
DENNERY
FOND D'OR BAY
DENNERY BAY
Des Bateaux Island
La Croix Point
Dennery Island
Descleves Point
Mandelé Point
Linnis Point
TROU BIGORNEAU
ANSE SABLE
Fond D'Or River
Old Ford Ruins
MORNE VENT
Ravine Can
Estate Office
Old Railway Line
Cut Line
DOS 92
351
NACHE
BOIS JOLI
GLAVIER
DOS 127
617
BOIS JOLI ROAD
Ravine Trou à l' Eau
Ravine Tous Les Diables
DOS 9
304
Hosp
Sch
Ch
PO
Pol Sta
PWD
Cem
MOLE
ANSE CANOT
ATHENS
PASCAL
Ravine Pascal
DOS 93
886
BAZILE
Garment Factory
Dennery River
Mount
aujolais
BBP
St Joseph Estate
Ravine Chien
Errard
Water Intake Waterfall
TERWORKS FOREST RESERVE
DCS 14
769
BORDELAIS
MANDELÉ
Branches

Figure 2.9

Figure 2.10



CONTRACT 'N&P'
Value £36,000
Contract "N"
Contract "P"
Lascelles Point
Micoud Point
Pointe Lamarre
Pointe Des Canelles
L'Islet Point
ANSE GER
ANSE CANELLE
ANSE L'ISLET
Troumassee Estate
Ancient Site (Stone Basins)
Ravine Deschamps
Anse Ger
Planard
Laundry
Canelles Estate
Ravine Bethel
Sugar Mill Ruins
Dryer
L'EAU MINEUR
Ford
Ger River
DELOMEL
Cemetery
Desruisseaux
Ravine St Cyr
Clinic
Sch
PO
Ch
Communal Laundry
GOUETTE
Blanchard
BBP
Canelles River
Vige
ROUARNE
Rouarne River
SAVANNES
Cacao
LLANDRE
Pierrot
DOS 151
DOS 149
DOS 145
DCS 9

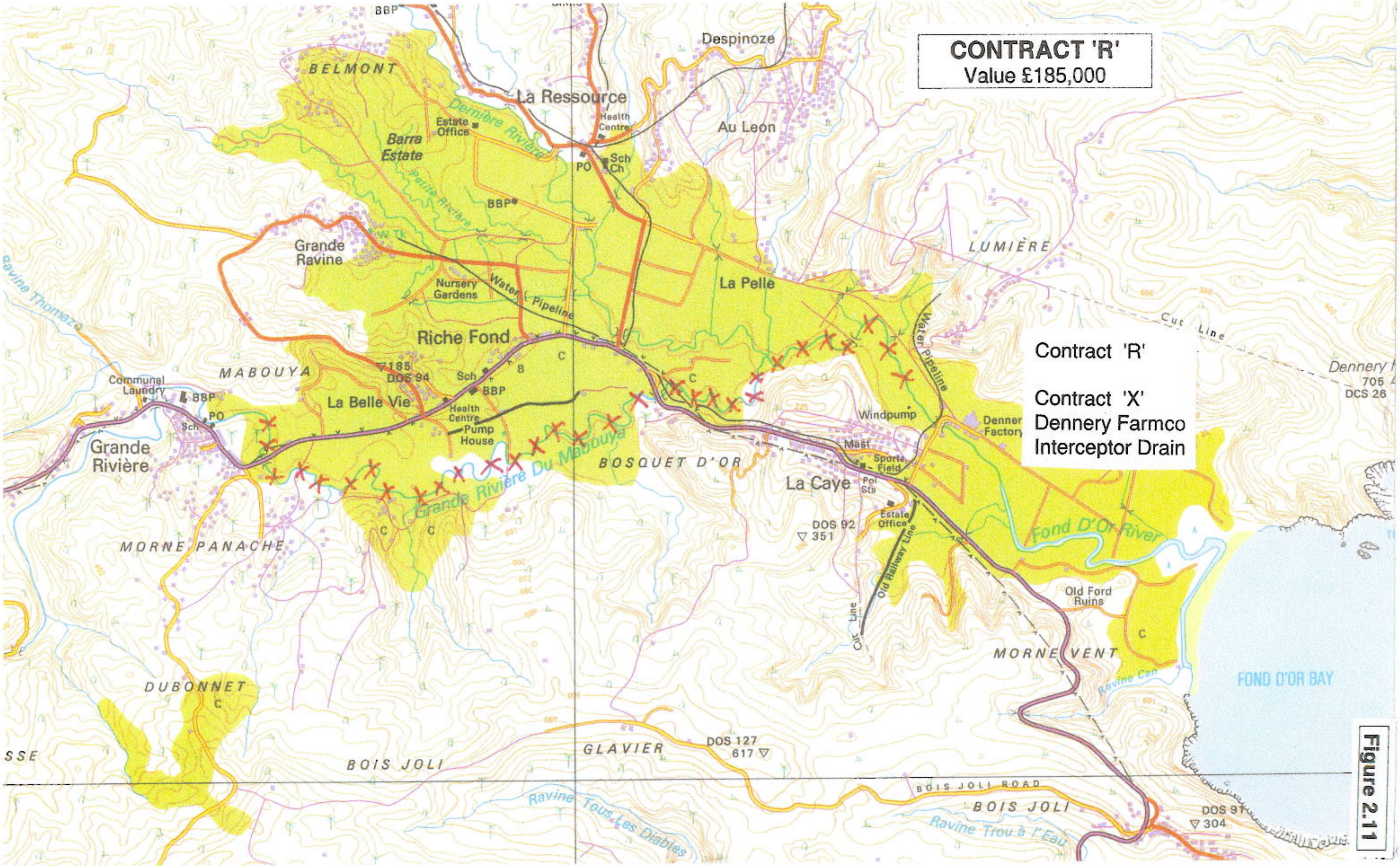

CONTRACT 'R'
Value £185,000
Contract 'R'
Contract 'X'
Dennery Farmco
Interceptor Drain
BBP
Despinoze
BELMONT
La Ressource
Health Centre
Estate Office
Barra Estate
Dernière Rivière
Au Leon
PO
Sch
Ch
Petite Rivière
BBP
Grande Ravine
LUMIÈRE
Nursery Gardens
Water Pipeline
La Pelle
Cut Line
Riche Fond
Dennery
705
DCS 26
MABOUYA
Communal Laundry
∇185
DOS 94
Sch
BBP
La Belle Vie
Health Centre
Pump House
Windpump
Denner Factory
Grande Rivière
Mast
BOSQUET D'OR
Sports Field
La Caye
Pol Sta
Grande Rivière Du Mabouya
Ravine Thomaze
DOS 92
∇ 351
Estate Office
Fond D'Or River
MORNE PANACHE
Old Railway Line
Old Ford Ruins
MORNE VENT
DUBONNET
FOND D'OR BAY
Ravine Can
SSE
GLAVIER
DOS 127
617 ∇
BOIS JOLI
BOIS JOLI ROAD
Ravine Tous Les Diables
Ravine Trou à l'Eau
DOS 91
∇ 304

Figure 2.11

Figure 2.12

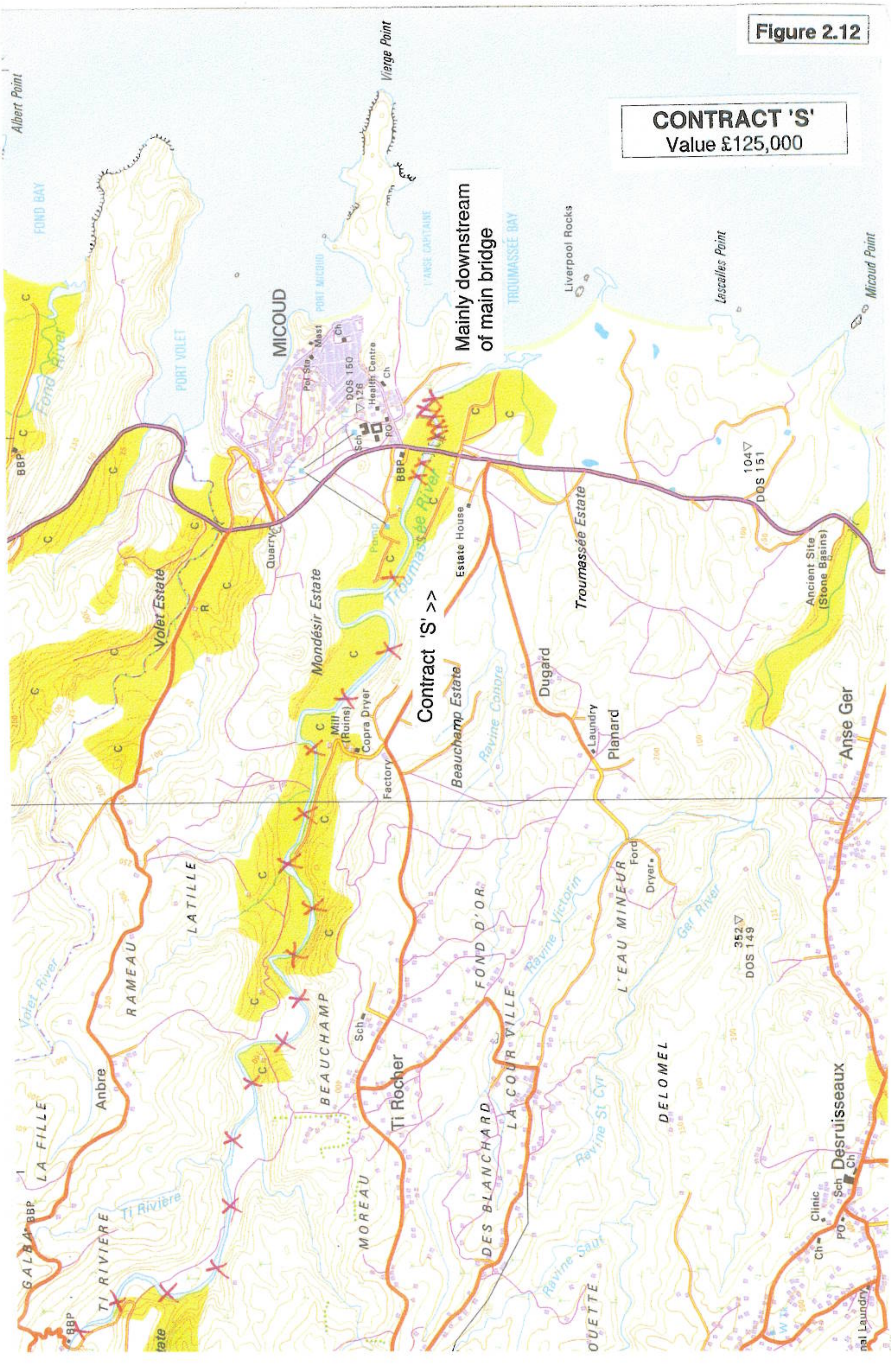

CONTRACT 'S'
Value £125,000
Mainly downstream of main bridge
Contract 'S' >>
MICOUD
Troumassée River
Troumassée Estate
Mondésir Estate
Beauchamp Estate
Volet Estate
Estate House
FOND BAY
PORT VOLET
PORT MICOUD
L'ANSE CAPITAINE
TROUMASSÉE BAY
Albert Point
Vierge Point
Liverpool Rocks
Lascelles Point
Micoud Point
Ancient Site (Stone Basins)
Health Centre
DOS 150
DOS 151
DOS 149
Quarry
Pump
Mill (Ruins)
Copra Dryer
Factory
Ti Rocher
Dugard
Planard
Laundry
Anse Ger
Desruisseaux
Anbre
Fond River
Volet River
Ti Rivière
Ravine Canoe
Ravine Victorin
Ravine St Cyr
Ravine Saut
Ger River
LA FILLE
RAMEAU
LATILLE
BEAUCHAMP
MOREAU
FOND D'OR
DES BLANCHARD
LA COUR VILLE
L'EAU MINEUR
DELOMEL
TI RIVIERE
GALBA

Figure 2.13
CONTRACT 'Z'
Value £37,000
Contract 'Z' >>
La Pointe Beach
Industry
Morne Sion
Martin
Newfield
La Riche
Cafeière
Debreuil
Gayabois
Mont Lezard Estate
PORTALESE
ANSE JOHN
CHOISEUL BAY
CHOISEUL
PO & Library
Pol Sta
Town Hall
Health Centre
Handicraft Centre
Community Centre
DCSIO
Reunion
Sauzay
La Fargue
Balca
La Perle Estate
Bongalo
Rectory
River Dorée
DOS 85
148
DOS 79
302
718
DOS 82
ANSE DE LA RIVIERE DOREE
Sapphire Estate
Balembouche
Piaye
Doree River
Grande Riviere Choiseul
Balembouche River

Photo 1 Phase 1 Works: Soufriere Bridge under construction. Looking upstream before 26th Oct.

Photo 2 Phase 1 Works: Location as Photo 5. Looking upstream after October 26th flood event.

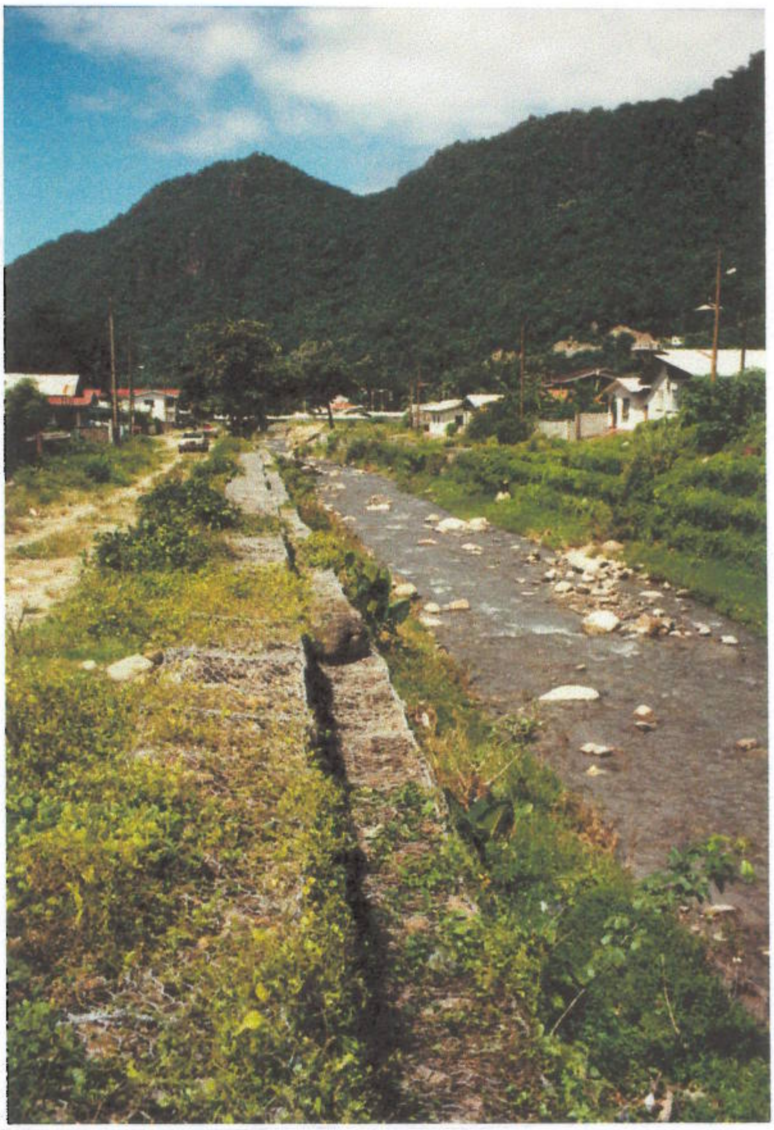


Photo 3 Phase 1 Works: Soufriere River Channel with gabion work before 26th October flood.

Photo 4 Phase 1 Works: Location as Photo 9 - Flood lowered bed through scour but gabions OK.

Photo 5 Soufriere Footbridge: Deep girder restricts waterway opening of bridge causing flooding.

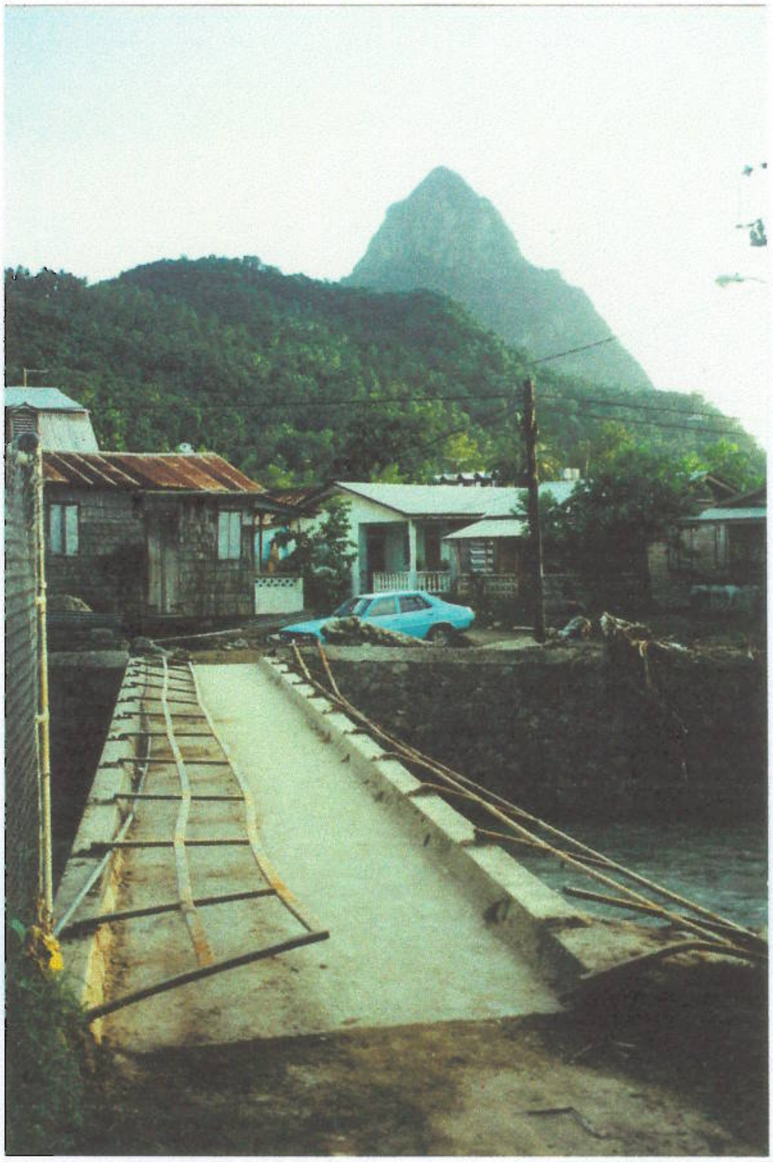


Photo 6 Soufriere Footbridge: Handrails broken due to the pressure of floodwater.

Table 2.2

COMPLETED WORK AND WORK OUTSTANDING AT 1st SEPT. 1996

CATEGORY 2 - CIVIL WORKS (EC$)

CONTRACTOR & SURVEY PAYMENTS					
SCHEME	WATERSHED	UPDATED ESTIMATE	WORKS COMPLETED AND UNDERWAY	REMAINING BALANCE	WORKS COMPLETED Y/N
A	SOUFRIERE	2,792,283	2,792,283	0	Y
* AA	SOUFRIERE	810,913	762,235	48,678	N
B	CUL-DE-SAC	0	0	0	
C	CUL-DE-SAC	10,879	10,879	0	Y
D	CUL-DE-SAC	50,563	50,563	0	Y
E	CUL-DE-SAC	30,506	30,506	0	Y
F	CUL-DE-SAC	56,253	56,253	0	Y
G	CUL-DE-SAC	2,132,595	2,080,582	52,013	Y
H	ROSEAU	2,125,900	2,100,833	67	Y
I	ROSEAU	8,261	8,261	0	Y
J	CANARIES	1,365,421	1,365,421	0	Y
K	ANSE-LA RAYE	533,663	533,663	0	Y
L	FOND	70,690	70,690	0	Y
M	DENNERY	1,430,561	1,328,003	102,558	N
N	CANELLES	95,000	94,657	343	Y
P	CANELLES	0	0	0	Y
R	MABOUYA	755,733	755,505	228	Y
S	TROMMASSE	494,000	493,569	431	Y
T	ROSEAU	18,291	18,291	0	Y
U	ROSEAU	6,698	6,698	0	Y
V	ROSEAU	1,543	1,543	0	Y
W	ROSEAU	42,147	42,147	0	Y
X	FOND d'OR	134,765	134,765	0	Y
* Y	VIEUX FORT	84,400	84,360	40	Y
* Z	CHOISEUL	149,871	149,871	0	Y
					Y
SUB TOTAL WORKS		13,200,936	12,971,578	229,359	
GABION BASKETS		981,610	981,610	0	Y
REMAINING "AS BUILT" SURVEY		75,000	62,500	12,500	Y
TOTAL		14,257,546	14,015,688	241,859	

NB: * New identified works

ST LUCIA WATERSHED & ENVIRONMENTAL MANAGEMENT PROJECT

PAYMENTS TO 15 APRIL 1996 & FORECAST FINAL COST

CATEGORY 1 - GOODS (EC$)

DESCRIPTION	ACTUAL COST
Vehicles	172,240
Hydromet Equipment	160,000
GRAND TOTAL	332,240

Detailed Daily Site Record sheets are available, however a detailed analysis of these has not been carried out. They are available for all contracts and basically cover equipment utilisation etc.

Several contracts were tendered and let in order to execute the Phase 1 works, these contracts are summarised in **Table 2.3**. The approximate location of the various contracts is shown on 1:25,000 maps **in Figures 2.3** to **2.13**, these have been taken from the 1:10,000 maps which have been used as base copies. The value of the contracts and progress indicators is given in **Table 2.4**.

Table 2.3

Contracts related to Phase 1 Works

Contract	Watershed	Reach of Channel or Works Description
A	Soufriere	Mouth of river to 2km upstream
B	Cul-de-Sac	Mouth of river to slope control weir No.1
C	‘’	Odsan Ravine confluence to Odsan Bridge
D	‘’	Deglos Ravine confluence for 1km upstream
E	‘’	Marc (Souffre) tributary confluence to Riley Elibox’s land
F	‘’	Tamprasads bridge to confluence with Ravine Roches
G	‘’	Odsan Ravine confluence at L’Abbayee (R. Maisonneuve)
H	Roseau	River mouth to 6 km upstream
I	‘’	Roseau bridge for 200m
J	Canaries	River mouth to 4 km upstream
K	Anse la Raye	Main channel: West coast road for 200m upstream
L	Fond	Main channel: East coast road for 2 km upstream
M	Dennery	Main channel: East coast road downstream to river mouth
N	Canelles	Main channel: East coast road downstream to river mouth
P	‘’	Main channel: East coast road upstream to sugar mill ruins
R	Mabouya	Tributary between Grand Riviere bridges and 150m u/s
S	Tromassee	Main channel: Beauchamp to Moreau - 4 km
T	Roseau	Morne d’Or outfall to 1 km upstream
U	‘’	Belair Mains (?) 3 km main drainage outlets
V	‘’	Morne d’Or agricultural main collector drain
W	‘’	Hollywood - Jacmel Roseau - Jacmel
X	Fond d’Or	Dennery Farmco Interceptor drainage channel network
Y	Choiseul	
Z	Vieux Fort	

Desilting works were carried out on most of the main rivers to bring them back to, as near as practicable, the pre-Debbie situation. There has been a certain amount of river training, mainly meander cutting and channel resectioning. In some cases bank protection works have been introduced which have influenced river courses. The World Bank Mission and the Phase 1 River Environmental Specialist have cautioned against such interventions, and it is clear that river regimes can and have been seriously affected.

A brief summary is provided below in relation to the designs and works which have been implemented in the main river basins. The majority of the works have been undertaken in the lower reaches of the channel network.

Table 2.4

St Lucia Watershed and Environmental Management Project : Phase 1 Works

Contractor & Survey payments							
Scheme/ Contract	Watershed	Updated Estimate ECD	Works Completed and ongoing in April 1996 ECD	Works Remaining in April 199 ECD	Percentage Expenditure in April 1996	Works Completed and ongoin in Oct 1996 ECD	Percentage Expenditur in April 199 in Oct 1996
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 survey		75000	0	75000	0%		
	Total	14,257,546	11,977,596	2,279,950	84%		

Capital Works by river basin

River Basin	Contracts Value ECD	Percentage of Overall	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)

File: PHASE1C.WK4

a. Soufriere

A major investment was put into the Phase 1 protection and river training works in and just upstream of the town of Soufriere. The majority of this work relates to gabion protection work with some large rip-rap in places. There is a bridge that is still under construction which will need a substantial effort to complete it. No design for the bridge has been found. Current progress (November 1996) on the new bridge is given in **Photos 1 and 2.**

The river training works were very effective in managing the floods of October 26th. The floods were at least as severe as those of TSD but possibly not as much debris was conveyed downstream. Some of the gabion protection work was dislodged but on the whole it served the purpose of containing the main flows in the river very well. See **Photos 3 and 4**. The vegetation which had grown in the gabions was destroyed by the flood event, however it is not believed that any planting of this vegetation had been undertaken. Consideration should be given to introducing bio-engineering measures to strengthen the gabion training walls.

The designs provided for a gabion walled channel 18 m wide with a single instep to a full width of 20m for a further height of 1 m. The full channel depth is just over 3 m whilst the channel slope in this main protected reach was 0.02 although variable between 1% and 4% (Dimensions to be confirmed). This would infer a bank full discharge of about 300 m^3/s with an average flow velocity of just under 5 m/s. This flow velocity is indicative of the bed material in the channel which is predominantly large stones and boulders.

It would be deemed prudent to provide an additional row of gabions, perhaps impregnated with bitumen or grout to provide an additional conveyance capacity. Other forms of additional containment through the Town of Soufriere could be considered but would need some set back from the existing channel bank top. However, when the channel reaches the footbridge adjacent to the main school (see below) more complex measures would be required to contain the higher design flow.

Considerable flooding and damage was caused in Soufriere during the most recent major storm event. The main cause of this has been assessed to be the small footbridge which is located near to the main school in the town and passes over the channel. The river is totally confined at this location, on a bend in the river, where the channel section if anything is narrower than elsewhere. The span of the bridge is about 15m although the active channel, because of the bend of the river is only about 10m. The footbridge is based on two large steel I beams of depth 560mm, supported centrally by a pier and supporting a 260mm reinforced concrete slab. On the 13th of November, with a low flow in the river, the clearance from water level to bridge soffit was measured as 1.54m. It is a substantial structure and would hold back trees or other debris which impinged against it. Both handrails were flattened by the October 16th event as debris must have collected against them as the bridge was overtopped, directing flows out of the channel into town. **See Photos 5 and 6**.

The footbridge predated TSD and the Phase 1 works. It was probably not tested during TSD since flows were lost out of channel upstream. However, there are indications that the flood discharge down the river on the 26th was larger than TSD however no flood discharge estimates are available to substantiate this The main evidence is the condition of the channel upstream from the new bridge, this has reportedly a far greater density and extent of deposited large boulders than post TSD..

b. Cul de Sac

Several cuts and channel re-alignments were undertaken. The design files indicate rip rap protection against flow velocities of 4m/s and 5m/s which are high channel flow velocities in silt - loam type bed material. The latter velocities requiring rip rap of D_{85} of 915mm and D_{15} of 508mm with a gravel filter base. Particle size assumptions for the streambank were D_{85} of 0.7mm and D_{15} of 0.06mm. The L'Abbaye diversion works required some gabion protection work to complete the realignment just to the south of the Marc Marc Road. The estimated new longitudinal section of the channel is presented in **Figure 2.14**. The gabion work is shown in **Photos 7 and 8**.

River bank samples have recently been taken from the river bank upstream of the Marc Marc bridge near the main road as part of a Island wide sampling programme. The sample, Appendix B sample 19, indicates that the above particle size values are representative of the river section. In addition, the design velocities assumed above are considered to be realistic, see **Figure 4.2**.

A substantial gabion structure was positioned adjacent to a couple of small houses next to the main Bexon to Castries road, just downstream of the road junction to the village of Marc Marc in the Cul de Sac Valley. The main benefit of the structure is seen to be that of protecting the main road and the adjacent services. The structure performed adequately during the flood event in October 1996 although the training works are probably a little too long and tend to direct flows directly against the opposite bank downstream. Whether this is intentional is unknown. No designs have been located for this work. The gabion work was overtopped due to the severity of the flood and highlighted the need for establishing a strong and resilient vegetation presence behind the gabion work to prevent washout of the backfill material. The degree of compaction of the backfill material and the material specification is not known.

Additional works were carried out at Marc Marc on a tributary of the River Souffre as it joined the main Souffre channel. {Note the Souffre River is often called the River Marc}. Detailed surveys were undertaken and gabion protection work was undertaken. Recent visits, post October 26th, have revealed that the channel was subjected to very high discharges, flooding many of the houses adjacent to the river and also washing out and destroying the bridge adjacent to which the new protection measures had been placed. The situation is problematic since the channel flows directly towards the main road at this location, the river turning at right angles to flow parallel to the road at the bridge point. The channel is relatively narrow, being no more than 6m between bank tops. The temporary crossing put in of steel pipes was made with no foundation, the bottom layer of 'reportedly' six pipes have now been buried leaving only the top layer of about 5 to pass the discharge.

c. Roseau

Considerable re-alignment work has been undertaken, the checking of the outline design work with the works actually constructed has been difficult and seriously aggravated by the flood flows of the 26th of October.

The design flows for the channel were based on the 1:5 year Qp. In the case of the River Roseau, the Qp value was 52.5 m^3/s whilst an increase of 50% was included to yield the design flow of 75 m^3/s. For the River Roseau, in the more alluvial reaches, a Manning 'n' of 0.035 was adopted. With a channel slope of 1:400 (0.0025) and a flood flow depth of 2.5m yielded a channel flow of 76 m^3/s with a channel bed width of 10.0m. {no mention was made of the potential impact of the new Roseau Dam on the approach to the hydrological assessment}.

The flows experienced on the 26th of October were estimated to be far greater than these discharges. See Annex 3.

One major meander loop cut was made just south of the village of Belair. This section has been the subject of considerable erosion during the floods of the 26th of October and subsequent rainstorms as

Figure 2.14

River Cul de Sac Longitudinal Section

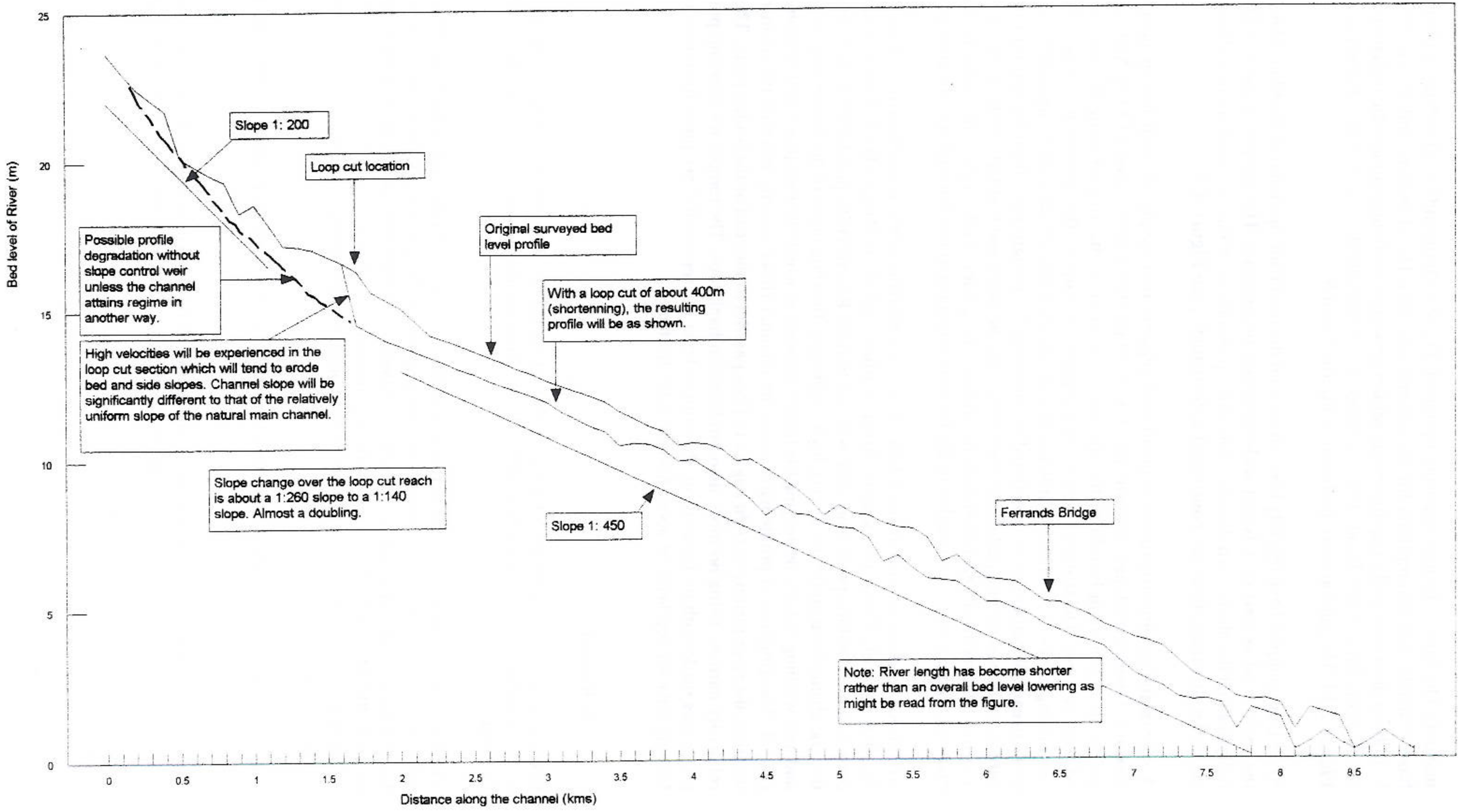


Photo 7 Phase 1 Works: Cul de Sac River near Marc road junction; gabions during event of 26th.

Photo 8 Phase 1 Works: Location as Photo 11- problem of countryside erosion by overtopping.

the river tries to accommodate the new channel bed slope which has been imposed by the new channel alignments See **Photos 9 and 10**.

Substantial works were undertaken in the reach of the river immediately upstream of the old WASA weir and abstraction plant and the road crossing between Bexon and Vanard. The works comprised loop cutting, a flood protection embankment, about 3 m above the protected agricultural land together with gabion protection walls at key locations. The embankment causes a degree of throttling of the flood plain at this location as is evidenced from the map (see **Figure 2.5**). During the floods of the 26th of October, the most upstream section of the embankment breached causing some flooding of the land under banana cultivation although the crop was not laid flat as occurred in other areas of the Roseau flood plain land.

The longitudinal bed profile details of the channel are presented in **Figure 2.15**.

The straightened channel will take some time to find regime stability during which time greater erosion and sediment loads are anticipated during storm events.

Table 2.5 Indicative Works with Outline Designs for the River Roseau

Section from (m)	to (m)	Design/works indicated
0	1300	Resectioning only
1300	1750	ditto
1750	2150	Major realignment
2150	2450	Major realignment at 2450, channel split at 2150 (WASA offtake)
2450	2900	Major realignment
2900	3250	Mostly resectioning
3250	3650	ditto
3650	4050	Slight resectioning
4050	4650	Details of weir for the new cut proposals
4650	5250	Two major loop cuts proposed
5250	5650	Some loops cut, mainly resectioning
5650	6050	Two major loop cuts
6050	6450	Some re-alignment but mostly resectioning
6450	6950	Major re-alignment throughout
6950	7450	Some re-alignment
7450	7950	Some loop cuts
7950	8350	Resectioning only

The works described in **Table 2.5** were part of Contract H.

d. Canaries

Remodelling was undertaken, as indicated in the design files, of the first 550 metres of the channel upstream of Canaries Town. The channel bed slope transitioning from a 1:100 value to 1:350 close to the town.(or approximately, three reaches of 500m at 1:250, 1:125 and 1:100 respectively)

The design bed width of 10m was adopted and a Manning 'n' of 0.050 yielding a discharge of about

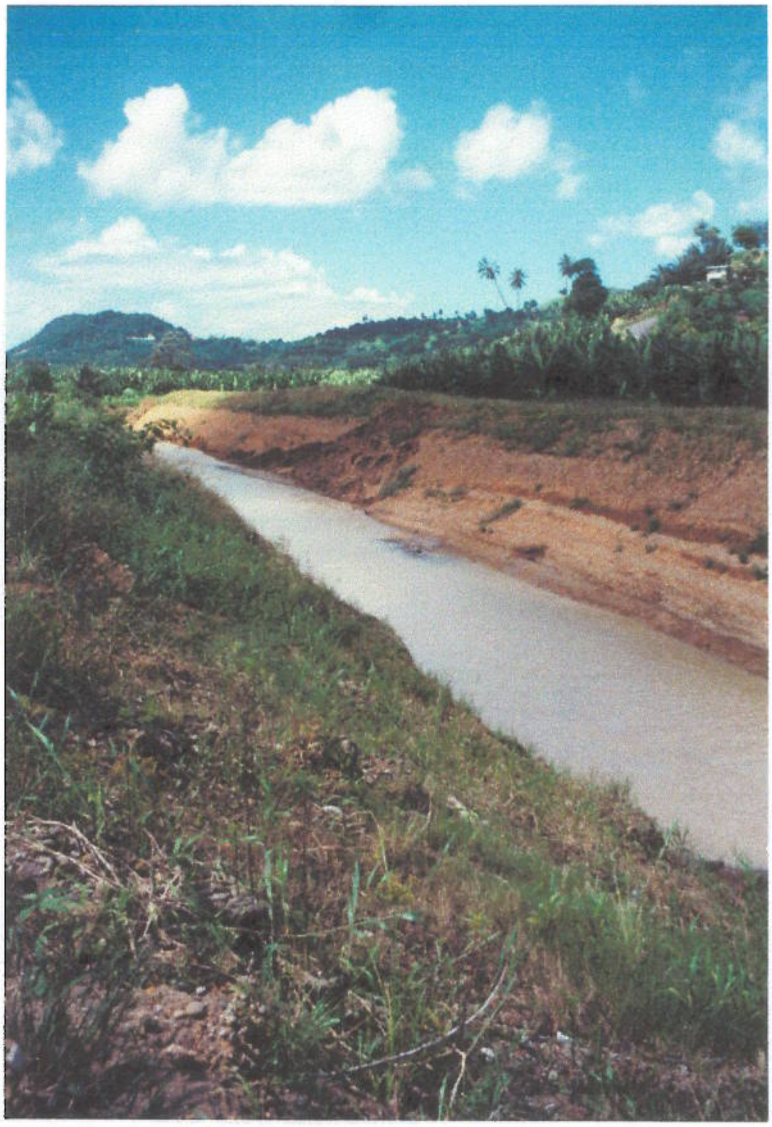
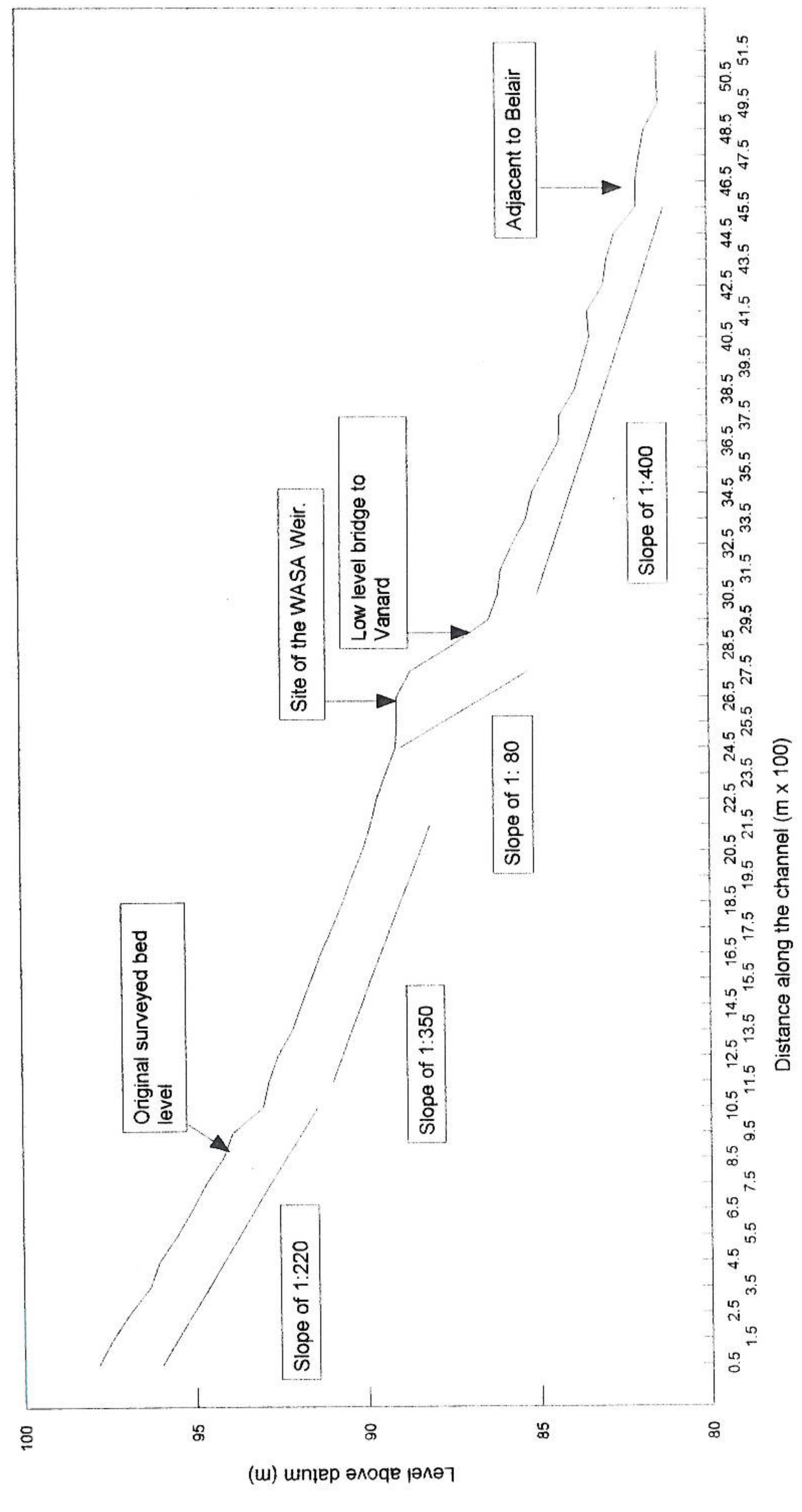


Photo 9 Phase 1 Works: Roseau River south of Belair. Meander loop cut, new straight channel.

Photo 10 Phase 1 Works: As Photo 9 but after 26th October. Embankment collapse.

Figure 2.15

River Roseau Longitudinal Section



73 m^3/s and a velocity of 4m/s at the average slope of 1:125. Rip rap protection of D_{50} of 500mm approx was deemed necessary.

In the upper section of the channel, about 7 rock weirs were to be constructed to provide a channel bed level difference of 0.5m at each structure. It is unsure as to whether these were constructed or not.

The main works in the channel were the gabion walls and the masonry retaining wall, the latter drawn to a height of 4.0m and 1.8m wide flat footing. The footing foundation was drawn as about 1.3m below 'proposed bed channel'.The detailed retaining wall design and scour depth calculations associated with the structure were not available and it is doutful that they were actually produced.

With the 3m high gabion wall, the cross sectional area of gabion work provided was about $7m^2/m$ run. Outline drawings or sketches are on file of most of the works.

The damage caused by the large discharges of October 26th was considerable. The collapse of the masonry wall and the dislodgement of some of the gabion protection measures is presented in **Photos 11 and 12.** Discussions with several local residents revealed that the general opinion was that the floods of 26th in the River Canaries were as bad if not worse than those of TSD. The Phase 1 works had not been designed for such an event. The damage to the main west coast road bridge at Canaries, some 100m downstream from the retaining wall failure is shown in **Photos 13 and 14.**

Additional photographs have been included to indicate the height of the flood wave passing down the channel. The flood marks were clearly visible on the louvred windows of the house just upstream of the main road bridge on the left bank of the river. This would indicate a flood level some 2m above the road or left bank top level or 6 m above bed level.

e. Anse la Raye

Most of the works at Anse la Raye, a shown on the town and river layout plans produced during Phase 1 was for gabion protection work as protection for the church. The works are shown in **Photo 15.**

Flooding in Anse la Raye continues to be a problem. However, this is thought to be caused by inadequate drainage capacity of two streams and associated road culverts on the northern part of the town.

f. Fond

Works carried out were reportedly mainly debris clearance and the removal of large stones. The channel currently looks in good order, hence it is presumed that the clearance post TSD was undertaken. Any remaining debris is likely to be due to the floods of October 26th. The lower reaches of the River were surveyed as part of Phase 1 and the resulting channel longitudinal section is given in **Figure 2.17.**

g. Dennery

The works at Dennery are principally those of a town flood protection scheme. This comprises the construction of a flood control embankment on the left bank of the Dennery River downstream of the main East Coast Road Bridge. The length of the works is approximately 400m.

The bank top of the embankment varies from 2.5m a.m.s.l. to 1.5 m a.m.s.l. at the downstream end (although the site plan indicates that the top of the embankment transitions into the normal ground level at a bank top level of 2.8m). The embankment was constructed of material from the opposite side of the channel with compaction undertaken. Rock rip-rap was provided to a specified top level of +1.0m a.m.s.l.over an embankment face of about 300m with an embankment side slope of 1:2 specified. The size of the rip-rap on site had a approximate average diameter of 1m and was deemed to be substantial. The level difference between top of rip-rap and top of embankment was not evidenced. {note BM on bridge of 5.33}. See **Photo 16**.

The bed level of the channel over this section was designed to be -1.9m transitioning to -3.0 near the river mouth although a higher bar normally exists at the entrance to the sea. The channel bed width as shown on the drawings was about 12m.

The Dennery Town drainage channel is redirected along the town side of the embankment to discharge into the sea at the end of the new embankment. No outlet structure was specified on the drawings, however one was being constructed in early November 1996 as part of the Phase 1 expenditure.

Immediately downstream of the main bridge on the left bank, two masonry retaining walls were specified, one 5.0m high parallel to the river and a second built to a wall top of +3.2m a.m.s.l.(a.o.d.?) At right angles to the river centre line and connected to the first wall. This structure being to protect a dwelling and a pump house.

h. Canelles

Little design information was available. A single channel cross section indicated a bed width of 8m and a need for 0.625m of desilting to give a full channel depth of 2m.

High flood flows were experienced in the channel as a result of the rains of the 26th October. Flood level indications were that it was not as severe as TSD, however, a large number of bananas were laid flat and uprooted during the storm.

Longitudinal bed profiles as surveyed during Phase 1 is given in **Figure 2.18**, however, this section, as with all the longitudinal sections will probably be different after the effects of the October 26th flood which was relatively severe in the Canelles channel.

i. Mabouya

Works proposed on the Grand Riviere de Mabouya are summarised from the sketch designs in **Table 2.6.** It is uncertain as to whether all these works were implemented, however local indications are that there was a considerable amount of channel re-alignment and straightening undertaken.

In the design, the 1:5 year Qp was obtained from the 1984 Hunting Technical Services (HTS) Report at 28 m^3/s. With a Manning 'n' of 0.035 and a surveyed slope of 0.004, the required bed width to contain the flow was estimated to be 4m (actual design discharge being 29.6 m^3/s).

Longitudinal bed profiles as surveyed during Phase 1 is given in **Figure 2.16** whilst for the Dernier Riviere, reference should be made to **Figure 2.18**.

Photo 15 Phase 1 Works: Anse la Raye gabion river training wall (Glyricidia poles planted).

Photo 16 Phase 1 Works: Dennery Town Protection under construction, October 1996.

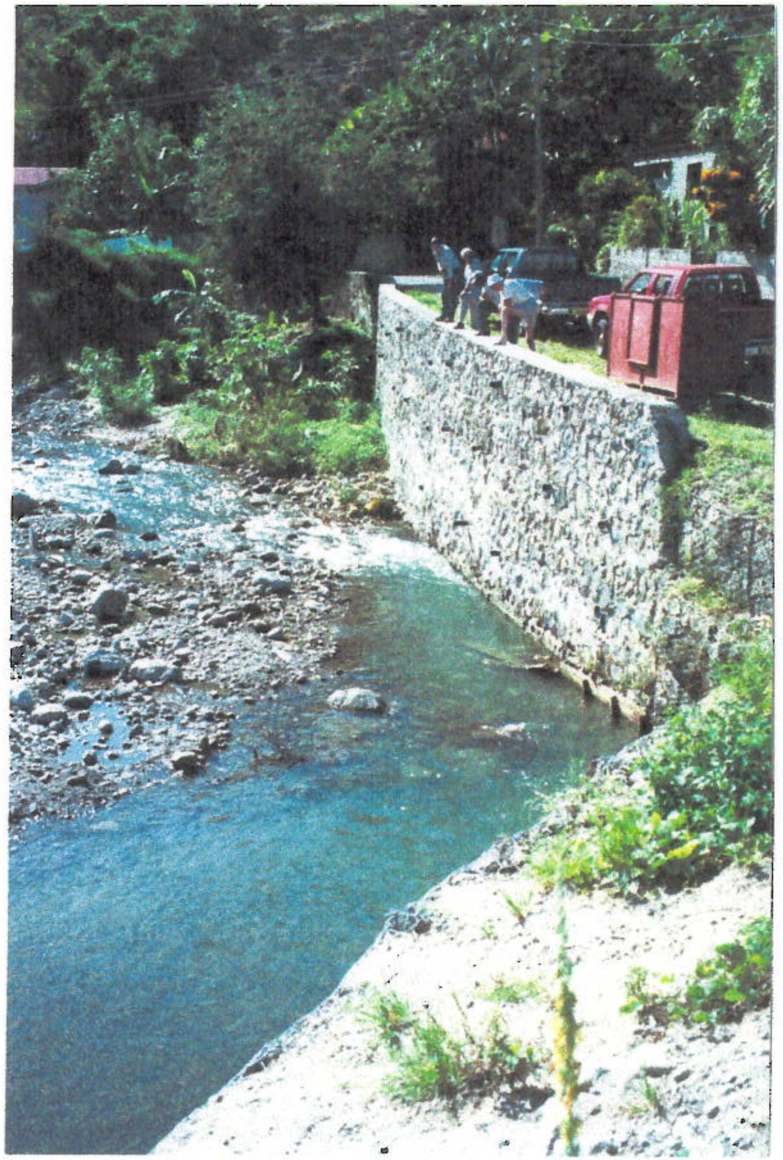


Photo 11 Phase 1 Works: Canaries just upstream of Photo 13. New retaining wall. Gabions fore.

Photo 12 Phase 1 Works: As Photo 11 but after 26th. Wall/road collapsed, gabions 'discarded'.

Photo 13 Canaries: Main West Coast Road bridge right abutment before 26th: Poor condition?

Photo 14 Canaries: Location as per Photo 13 showing abutment collapse after flood of 26th. Oct..

River Mabouya Longitudinal Section

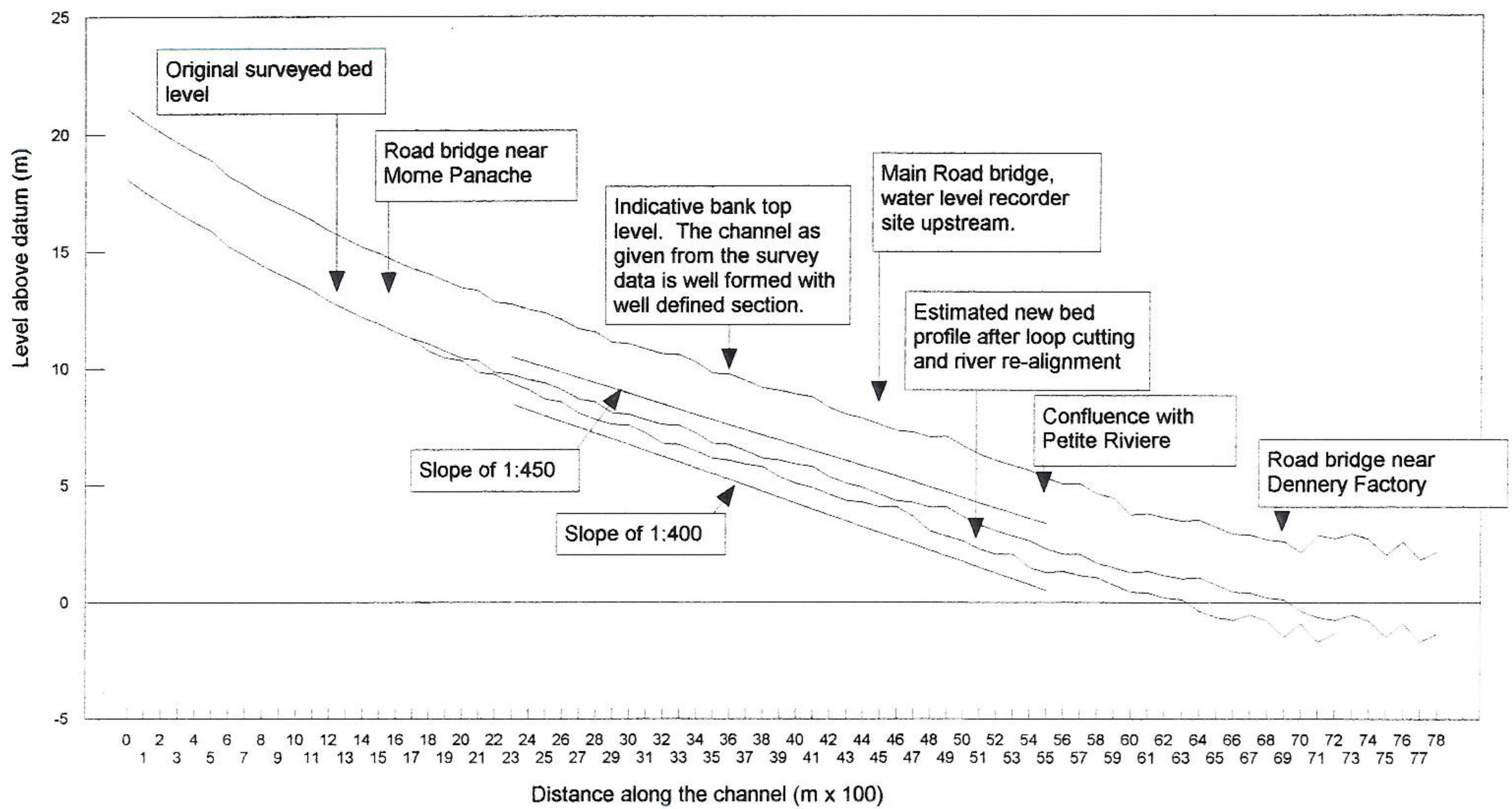
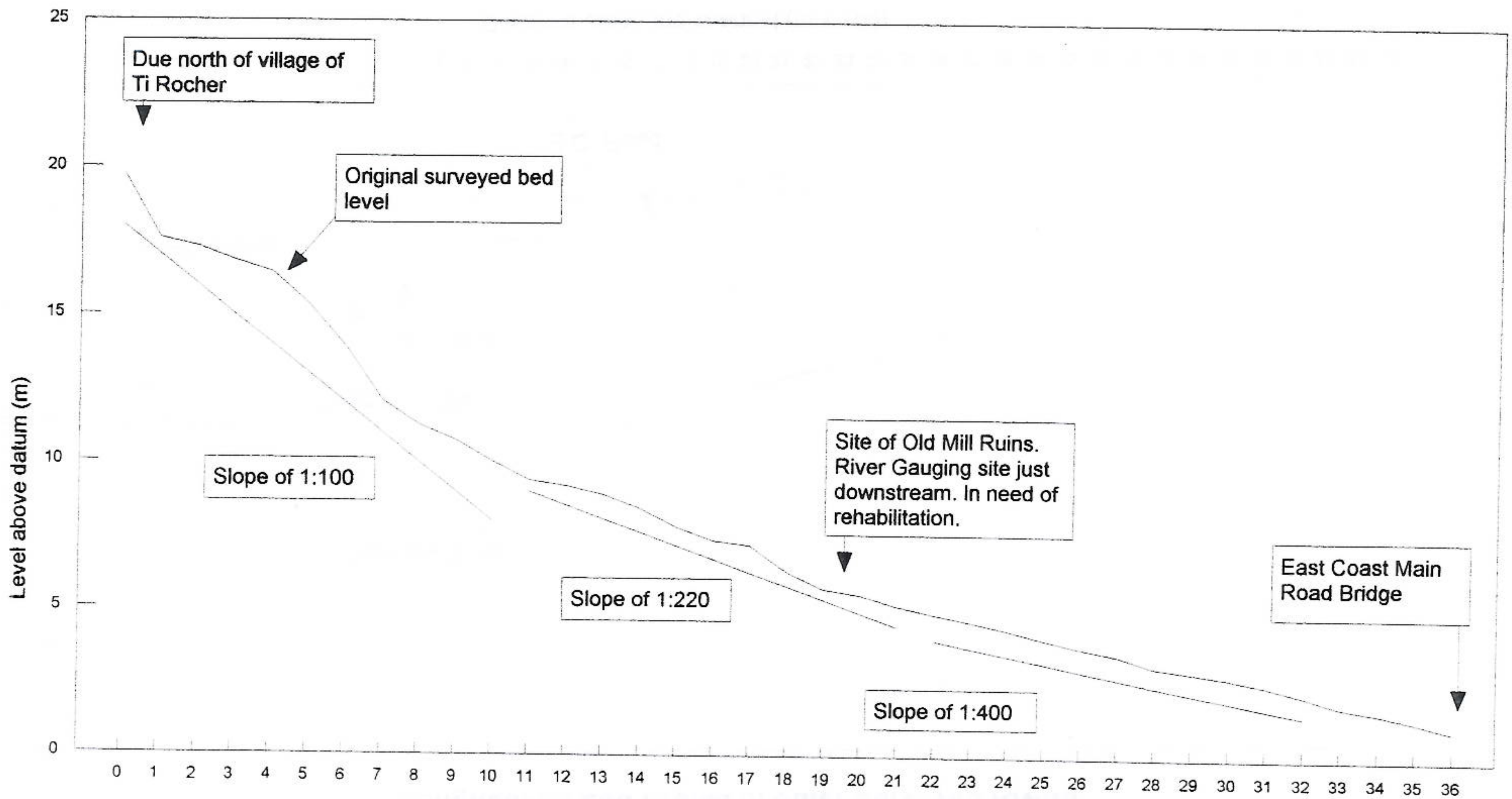


Figure 2.16

Figure 2.17

River Troumassee Longitudinal Section



File: MABOUYALS.WK4(C)

Figure 2.18

Longitudinal Bed Profile of other Surveyed Rivers

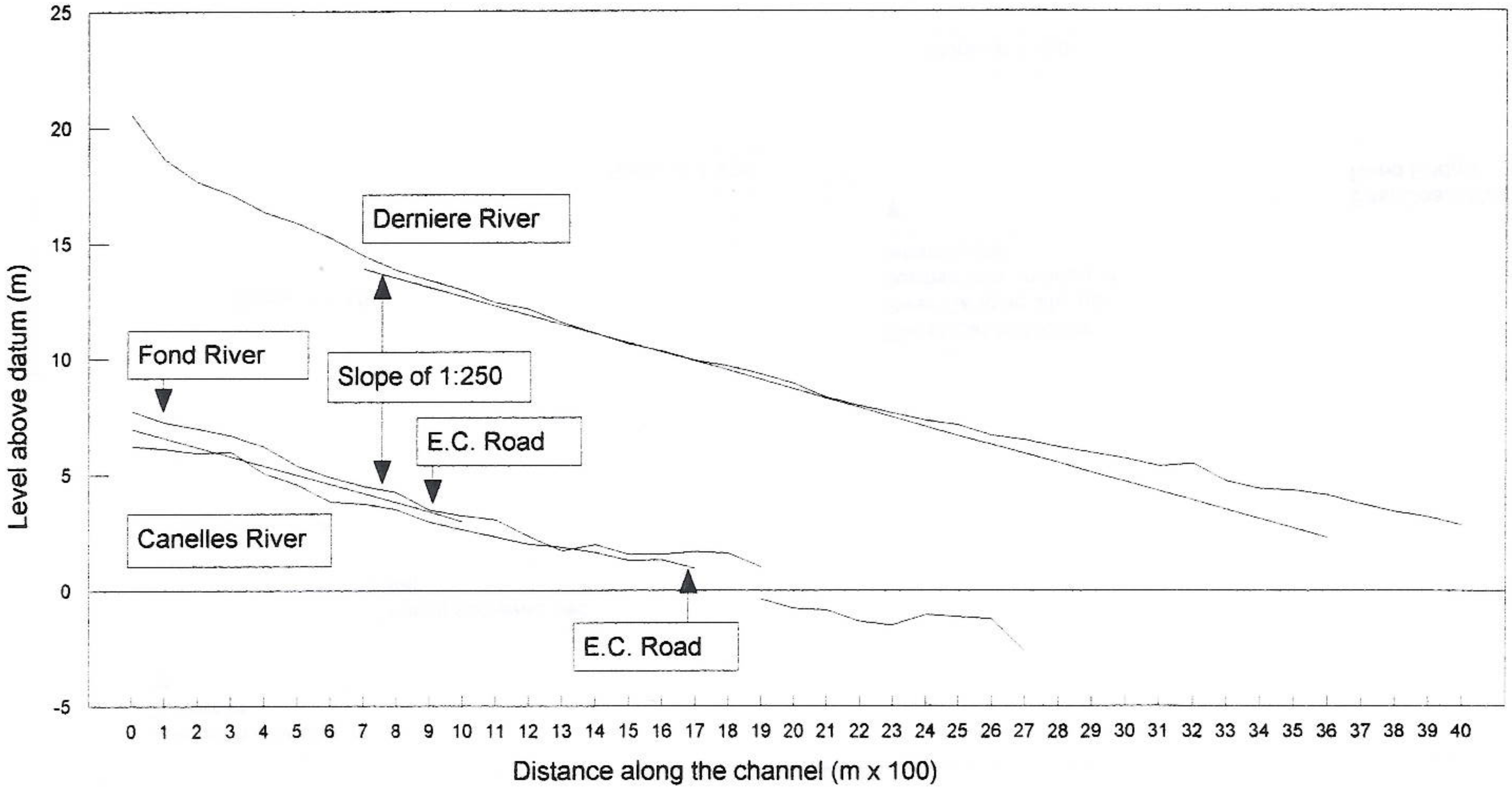


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Table 2.6 **Indicative Works with Outline Designs for the River Mabouya - Fond d'Or**

Section from (m)	to (m)	Design/works indicated
0	1070	Resectioning only
1070	1530	One loop cut
1530	1970	Some realignment with bed level lowering by 1m
1970	2600	Two loop cuts
2600	3100	About 50% of reach with major realignments
3100	5700	Major realignments throughout
5700	6200	Double loop cut and straightening
6200	7100	Resectioning
7100	7800	Gentle resectioning (with 6m bed width)

The works described in **Table 2.6** were part of Contract R.

The channel realignment works have impacted on the integrity of the river discharge gauging station at the main road crossing of the channel (furthest downstream crossing by the main road).

Flows in the Mabouya channel during October 26th were not very severe, flows of November during another storm on the 21st of November were probably as high.

j. Troumassee

Major works on the Troumassee river were undertaken downstream of the east coast Road and consisted of the introduction of a river training embankment, canalising the main flows of the river in what would have been the left hand portion of the natural channel.

The hydrology was based on the 1984 HTS Study which gives a 1:5 year peak flow of 52.5 m^3/s for a catchment area of 49.1 ha. An adjustment was made for catchment size on a directly proportional basis resulting in a design flow of 35 m^3/s accepting a 'design discharge' of 50 m^3/s. Assuming a flow depth of 2m, 1 in 1.5 side slopes and a Manning 'n' of 0.05 to 0.06 indicated a bed width of 15m.

The training embankment, sloped at 1:2, was designed with 1.1m thickness of rock protection (0.3m to 0.7m size) on a 500mm gravel filter bed on the river side. A 2m long toe protection was provided.

The material quantities for the works were given as:

Fill materials (on site)	780 m^3
Fill materials imported	1140 m^3
Rock for rip-rap	817 m^3
Fill material (river gravel)	161 m^3

The design implied that only half of the channel section upstream and downstream of the main road bridge was required to accommodate the design flows. The left half of the channel, closer to the main urban area was the chosen flow path. {This approach was reportedly questionned at the time}.

Upstream channel re-alignment from Ch 3350 to 3800, a bed width of 10m was considered adequate.

The events of the 26th of October indicated that the design discharge for a flood event should be larger than that used for the establishment of the layout for the Phase 1 works. However, assessments of the severity of the recent rainfall in the Troumassee catchment is that it must have been comparable to that of TSD. An event which was clearly not being designed for. Nonetheless, the decision to only select half the channel width as allowed for by a main road bridge is not considered justified. See **Photos 17 and 18** for the post October 26th situation.

The high flood flows which caused much damage upstream required the full bridge width to enable it to pass. The constriction to one half of the channel put the left abutment (north) in danger of being by-passed. Only minor damage was caused, but considerable accumulation of debris occurred in the upstream right bank area, with scour and some loss of land in the downstream left bank area.

The channel has since been re-cleared of debris with rip rap placed in the area of the upstream face of the left abutment. The central training wall is to be removed and replaced in the downstream left and right bank areas. {This has now been done using the rock rip-rap previously used as the central training bund (October 1997)}.

The longitudinal surveyed bed profile of the lower sections of the river are given in **Figure 2.17**.

Upstream in the Troumassee River, upstream of Mahaut, severe erosion took place with significant damage to the WASA access road on the left bank of the river. {This has also now been re-instated and vehicular access up the left bank to the WASA intake is now possible (October 1997)}.

k. Fond d'Or

See the report for the Mabouya River.

l. Vieux Fort

Works comprised the removal of debris resulting from TSD.

m. Choiseul

The works outlined by the design file in relation to Choiseul related to a masonry retaining wall of 2m height and a horizontal footing width of 1m. The structure being located downstream of the road bridge not very far from the mouth of the river.

2.3 River surveys and benchmark establishment

River surveys have been undertaken of several main channels, these relate to the post TSD, pre Phase 1 works although additional surveys have been undertaken of the river reaches where Phase 1 worked were undertaken. Both longitudinal and cross sectional surveys have been undertaken, **Figures 2.3** to **2.13** present the longitudinal sections of those channels surveyed. Cross sectional information is also available and primarily characterises the channel giving bed width, depth of main channel and side slopes of the river channel. The surveys were not carried across the flood plain and hence are of limited value in any flood flow modelling exercise.

Whilst the topographic surveys were undertaken, benchmarks were established. Unfortunately, these

Photo 17 Phase 1 Works: Troumassee Bridge from upstream after October 26th Flood.

Photo 18 Phase 1 Works: Troumassee Bridge from downstream after 26th- central training works.

benchmarks were located very close to the side of the channel and many are likely to have been washed away or dislodged during the storm event of October 26th.

The Surveyor responsible for the surveys and benchmark has been contacted to assist in identifying the existing benchmarks. These will be used for floodplain surveys to be undertaken during Phase 2.

It is also proposed that the River Cul de Sac and the River Roseau are resurveyed, at least for some of their main reaches where Phase 1 works were undertaken and immediately upstream and downstream of these reaches to check on the bed level changes which might have occurred as a result of the floods of October and November 1996.

These river surveys should assist in the assessment of drainage problems in the banana plantations in the lower river reaches. Large areas of banana cultivation occurs in these areas and it is important that drainage of the cultivated land is effective. The siltation of the drainage channels during flood events needs to be addressed in order to ensure that yields are not reduced owing to the development of waterlogged conditions. To be effective, the drainage system needs to be looked at as a whole, with the river network providing the final evacuation to the sea.

Chapter 3

Environmental Impact Assessment

Environmental Impact of Phase 1 Civil Engineering Works

3.1 Description of the Phase 1 Works and Initial Environmental Considerations

Phase 1 works are described in detail from an engineering and hydrological viewpoint in the River Engineering & Hydrometeorology section of the Interim Report. **Table 3.1** summarises the main features of these works, including their division into some 26 contracts (listed as A to Z, excluding O but including AA). For comparison, original estimates (Dec 94 report) and final sums allocated for the works are given in adjacent columns, and some further explanation on what was involved in the works is given in a remarks column.

The large difference in the original and final estimates can be explained by:

a) much more extensive gabion walls were finally constructed in three of the lower river systems, mainly for protection of urban areas, comprising Soufriere, involving an extra EC$1.6m; Canaries, an extra $1m, and Anse la Raye, an extra $0.45m;

b) major rip-rap protection for Dennery town (extra $0.96m);

c) more extensive re-sectioning and loop-cutting in four of the rivers (Cul de Sac, extra $1.5m; Roseau, extra $1.7m; Mabouya, extra $0.68m, Troumassee, extra $0.34m);

d) new identified works at Vieux Fort and Choiseul (extra $0.23m).

Comparisons of costs and cost benefits represented by the works will be undertaken in the Socio-Economics Sections. However, it should be appreciated that items a), b), and d) are essentially for protection of urban areas and vital infrastructure, while item c), involving an extra $4.2m, was undertaken mainly for the protection of agricultural land.

Environmental Issues relating to Ph1 activities were discussed by ERM in their March 1995 report ('St Lucia: River Engineering, Environmental Considerations'). A very comprehensive list of issues and accompanying notes was given, including:

* downstream drinking water, irrigation, industrial abstraction;
* downstream human water use (informal water supplies, bathing, laundry)
* livestock watering;
* land ownership, use, access, owner preferences;
* compensation - assessment, amounts, procedures;
* traffic - volume, timing, routing, safety;
* noise, dust, disruption;
* aesthetics, tourism/scenic values;
* spoil disposal
* enhancement possibilities;
* receiving marine environment;

Table 3.1

PHASE 1: PRIORITY WORKS

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Cont–ract	Watershed/River	Location	Reach	Approximate Dimensions (m) L	D	Form of Works	Unit Rate EC$/km (Dec'94	Total EC$M Rprt)	Actual EC$M (Apr96)	Remarks
RIVER WORKS										
A	Souffriere	a. Main channel	Mouth to 2km	2,000		Desilting, river training bank stabilisation	1,000,000	2.000	3.550	Major gabion walls protecting urban infrastructure
B	Cul de Sac	a. Main channel	Mouth to slope control weir #1	1,000	0.3 to 0.8	Desilting	50,000	0.050	0.000	}
C		b. Odsan Ravine	Confluence to Odsan Bridge	3,000	0.3 to 0.8	Desilting	18,000	0.054	0.011	}Included major loop–cutting
D		c. Desglos Ravine	From confluence to 1km u/s	3,000	0.5 to 0.9	Desilting	18,000	0.054	0.051	}channel re–alignment and
E		d. Ravine Souffre	Confluence to R Elibox lands	2,000	0.6 to 0.9	Desilting & bankstabilisation	52,100	0.104	0.031	}re–sectioning. Some gabion
F			Taraprasad Br. to Rav. Roches	1,000	0.3 to 0.4	Right bank stabilisation	50,000	0.050	0.056	}walls & rip–rap protn continuing
G		e. Main channel	Odsan Bridge to L'Abbaye	8,000	0 to 1.4	Desilting, resectioning	70,000	0.560	2.134	}
H	Roseau	a. Main channel	Mouth to 1.5km u/s??6KM??	1,500	1 to 2	Desilting, mouth breaching	20,000	0.030	2.100	}Included major loop–cutting
I		b. Main channel	Roseau bridge to 200m u/s	200		Debris clearance		0.004	0.008	}channel realignment/resectlong.
J	Canaries	a. Main channel	Mouth to 4km upstream	4,000		Desilting	50,000	0.200	1.365	}Incl.gabions & masonary walls
				500		Bank stabilisation	300,000	0.150		}protecting town infrastucture
K	Anse la Raye	a. Main channel	West coast Road to bridge	200		Bank stabilisation	400,000	0.080	0.534	Incl.gabions & masonary walls
L	Fond	a. Main channel	Mouth to 2km u/s	2,000	0.2 to 1	Debris clearance, desilting	41,000	0.082	0.100	Some gabion protection to town
M	Dennery	a. Main channel	Mouth to East Coast Bridge	1,000		Desilting, river training	500,000	0.500	1.462	Major rip–rap protectn to town
N	Canelles	a. Main channel	Mouth to East Coast Bridge	1,400	0 to 1	Desilting, mouth breaching	25,000	0.035	0.100	}De–silting & debris clearance
P		b. Main channel	EC Bridge to sugar mills	600	0.3 to ?	Desilting, bank stabilisation	41,000	0.025	0.046	}
R	Mabouya	a. Tributary	Grand Riviere bridges & u/s	1,200	1 to 2	Desilting	50,000	0.060	0.741	}Included major loop–cutting, }channel realignment/resectiong.
S	Troumassee	a. Main channel	Beauchamp to Moreau, 4km	2,000	0.4 to 1	Resectioning, lower & upper	80,000	0.160	0.500	}Included major loop–cutting, }channel realignment/resectiong.
DRAINAGE WORKS										
T	Roseau	a. Morne d'Or	Outfall u/s for 1km	1,000	0.3 to 1.2	Debris clearance & desilting	46,500	0.047	0.018	
U		b. Belair Mains	3km main drainage outlets	1,500	0.4 to 1.5	Desilting	46,500	0.070	0.007	
				1,500	0.4 to 1.5	Desilting	31,000	0.047		
V		c. Roseau Mrn.d'Or	Road drain for agriculture	1,100	0.4 to 1	Desilting	46,500	0.051	0.002	
W		d. Hollywd–Jacmel	Roseau Jacmel	6,000	0.4 to 1	Debris clearance & desilting	18,000	0.108	0.042	
X	1 Fond d'Or	a. Den'ry–Farmco	Interceptor drainage channels	5,000	0.6 to 1	Desilting	18,000	0.090		
OTHER										
Y	Vieux Fort	} New identified works							0.084	
Z	Choiseul	}							0.150	
TOTAL COSTS:								4.61	13.09	

* fisheries - freshwater, estuarine;
* wetlands;
* aquatic vegetation;
* bankside vegetation, especially trees;
* diversity/stability of existing channel and bank form;
* channel substrate;
* upstream sediment sources.

The ERM Report emphasised that all bankside vegetation, especially trees, should be retained (a recommendation largely carried out) but that new planting should also be undertaken (largely not yet undertaken). Excavation of only one side of river banks was emphasised (recommendation taken up in the detailed plans and then largely implemented). Stabilising landslide scars and other sources of sediment was also emphasised, as was disposal of silt and debris and land ownership and compensation issues.

However, area specific recommendations appeared not to have been made, and the controversial loop-cutting operations appear not to have been commented on. (Engineering inputs appear to have followed the environmental input, rather than running concurrently.)

3.2 Method of Assessment

The current assessment comprised the following stages:

i. Reconnaissance visit to the most important parts of all 26 schemes. This was undertaken during different periods in October and November 1996, and in June and July, 1997, accompanying both local Ministry engineers and the Consultant's engineering staff.

ii. Inspection of available detailed plans. A rapid inspection was made on all available plans, and more detailed assessment was made on three of the valleys where most disruptive work was undertaken (Cul de Sac, Roseau and Mabouya). In addition Troumassee valley was quickly inspected, with a closer inspection being given to the loop-cutting undertaken in the area below the main road bridge. **Table 3.2** (3 pages) gives major features of the plans for these three valleys.

iii. Listing of the major measures undertaken and identification of major issues applying to these measures (screening & scoping)

iv. Detailed field inspection of the major and most controversial areas: The most controversial areas included the Cul de Sac, Roseau and Mabouya Valleys, where major re-sectioning and loop-cutting operations have been undertaken. Field inspection included walking along riverbanks through most of the valleys, inspection of crops, groundcover, soil surfaces and materials and current sources of erosion. All local farmers encountered were consulted regarding extent of damage during TSD, extent of flooding during 26 October and 11 November 1996, effect of the works on their land, and their opinion on the effectiveness of the works. River mouth areas and adjacent beaches were also visited to see if actions upstream had adversely impacted on those areas.

CONTRACT G: CUL DE SAC: LIST OF DETAILED MAPS, SCALE 1:1000

Plan Name / no.	Date of Plan	Chainage	Old Bed Elevations	Prop.Bed Elevations	Resect–ioning	Loop–cutting	Infilling	Rock Protectn	Planting	Comment on Plans (wr to environment)	Comment on Field Situation (as of July,97)	Notes
Ferrands Quarry/ Texaco Garage	15–Jun–95	6330 – 7150			Y	160	370	Y	N	Some tree protn lost due to loop cutting Planting not specified Consultation w.land–owners specified	(Major cuts)	
Texaco Garage	14–Jun–95	6150 – 6330			Y			Y	N	Retention of trees Local spoil dumping	Repairshop & possibly road being threatened	15
	09–Jun–95	5900 – 6150			Y			Y	N	Retention of most trees–some to be cut Local spoil dumping		
Odsan	31–May–95	5700 – 5900			Y			Y	N	–ditto–		
Deglos Brdg(dwns	26–May–95	5420 – 5700			Y	70	70	Y	N	–ditto–		
Deglos Brdg(upst)	10–Apr–95	4950 – 5420			Y			Y	N	(fewer specifications)	[Deep drains now being cut in adjacent land]	16,17,18
Deglos Brdg(upst)	13–Apr–95	4850 – 5050			Y	40	10	Y	N			
Jules Spmkt Divrsr	26–Apr–95	4500 – 4850			Y	300	150	Y	Y	New trees for outside of bend.Partial filling of loops. Access for Mr George's land.Local spoil dumping.	Infilling to high elev. Land not used. Collapsing drain edge.	26
Jules Spmkt(upstr)	26–Apr–95	4000 – 4500			Y	110	110	Y	N	Divrn thru secondary channel.	Partly filled channel–v. uneven. Good cover.	27
DeglosRavn(upstr)	10–May–95	3775 – 4000			Y			Y	N			
Mr Wayne's Land	04–May–95	3400 – 3775			Y	150	170	Y	N	Consultation w.lndowners specified.	Big cut–off – some bank erosion now threatened.	19
Mr Brown's Land (prop.diversion)	16–May–95	1700 – 2320								2 Maps but in different format: Printed map, but no site instructns.	Major problems presented by loop cutting: loss of 2 acreas (not compensated); loss of access; new bank erosion.No tree planting on banks.	25
–ditto–	20–Mar–95				N	290	400	N	N	V.rough sketch		
Abbayee Divsn.& Rock Protcn. CDS/G/D/01	27–Mar–95	? ?			Y	130	?	Y	N			
TOTAL CUTTING/INFILL(m)						1250	1280					

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Table 3.2 (Sheet 1)

CONTRACT H: ROSEAU: LIST OF DETAILED MAPS, SCALE 1:1000

Plan no.	Date of Plar	Chainage	Old Bed Elevations	Prop.Bed Elevations	Resect- -ioning	Loop- -cutting	Infilling	Rock Protectn	Planting	Comment on Plans (wr to environment)	Comment on Field Situation (as of July,97)	Note
	22-Apr-96	8350 - ++				Y	Y			Crude sketch only: little detail & not to scale.	Farmer claiming additnl 0.5 acre lost, further land threatened. Land only 2m above river level. (Distillery effluent problems)	2
ROS/H/13	30-Jun-95	7950 - 8350			Y			Y	Y		V.little Perennial Tree Protection	
ROS/H/12	30-Jun-95	7450 - 7950			Y	200	200	Y	Y	Some tree protn lost due to loop cutting	Reasonable tree cover in places	
ROS/H/11	29-Jun-95	6950 - 7450			Y	150	150	Y	Y	Some tree protn lost due to loop cutting	Reasonable tree cover in places	
ROS/H/10**	29-Jun-95	6450 - 6950			Y	300	420	Y	Y	V.major loop cutting		
ROS/H/09	29-Jun-95	6050 - 6450			Y	150	150	Y	Y		Some bad localised bank erosion	
ROS/H/08	28-Jun-95	5650 - 6050			Y	250	250	Y	Y		Low areas not infilled/leveled to maximum effect-ie wasted land	3,4
ROS/H/07	28-Jun-95	5250 - 5650			Y	100	150	Y	Y		Some bad localised bank erosion -no perennial tree planting	
ROS/H/07	28-Jun-95	4650 - 5250			Y	150	150	Y	Y		Some bad localised bank erosion -no perennial tree planting	5
ROS/H/06	27-Jun-95	4050 - 4650			Y	230	200	Y	Y	Retention of Roseau Grass		6
ROS/H/05	27-Jun-95	3650 - 4050			Y			Y	Y	Spoil to form embankment problematic	Much bad bank erosion	7
ROS/H/04	06-Jun-95	3250 - 3650			Y			Y	Y	Spoil to form embankment problematic	Much bad bank erosion	8
ROS/H/03	04-Jun-95	2900 - 3250			Y			Y	Y	Spoil to form embankment problematic	Much bad bank erosion	9
ROS/H/02/4**	09-Jun-95	2450 - 2900	87.3 89.1	87.0 88.0	Y	300	250	Y	Y	Consultation w.lndowners specified.		
ROS/H/02/3/01/r1	22-Jun-95	2150 - 2450	89.1 90.4	88.0 89.0	Y	100	100	Y	Y	WASA intake		10
ROS/H/02/2	08-Jun-95	1750 - 2150	90.4 91.0	89.0 89.4	Y	200	200	Y	Y	Width of channel not specified	River consticted by embankment	11
ROS/H/02/1	07-Jun-95	1300 - 1750	91.0 92.5	89.4 90.5	Y		130	Y	Y	Retention of Roseau Grass Plant trees along embkmts Spoil embankments	OK None planted Coarse-textured, not stabilised	11
TOTAL CUTTING/INFILL(m)						2130	2350					

Note: any planting specified in Ph1 plans is for grasses only. No trees specified.

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Table 3.2
(Sheet 2)

Table 3.2
(Sheet 3)

CONTRACT R: MABOUYA: LIST OF DETAILED MAPS, SCALE 1:1000

Plan Name / no.	Date of Plan	Chainage	Old Bed Elevations	Prop.Bed Elevations	Resect--ioning	Loop--cutting	Infilling	Rock Protectn	Planting	Comment on Plans (wr to environment)	Comment on Field Situation (as of July,97)	Note
Downstrm.La Caye Bridge		7400 - 7800			Y			Y	N	Spoil to be used to raise tracks: further quarry waste also required Further desilting specified to river mouth (900m)	Raising track bunds/riverbanks means less silt deposited in floodplain and area of wetland forest.	1
Downstrm.La Caye Bridge	26-Jun-95	7100 - 7400		(-0.5m)	Y			N	Y	Planting of new trees specified		(2)
La Caye Rd Brdg	23-Jun-95	6700 - 7100		(-0.5m)	Y			N	Y	Spoil to raise tracks Retention & Replanting of trees specified		
Upstrm.La Caye	23-Jun-95	6200 - 6700		(-0.5m)	Y			N	Y	Retention & Replanting of trees specified	Much more tree planting requ. Infilling w.v.sandy material:Many b'na topples.Steep bank unvegtd	
Downstrm,confl.w. Derniere Riviere	23-Jun-95	5700 - 6200		(-0.5m)	Y	130	140	Y	N	Loop-cutting: partial infilling specified	Partial filling:stagnant ponds. Clouded land title, improper LU	4
Confluence with Derniere Riviere	22-Jun-95	5100 - 5700		(-0.5m)	Y	220	220	Y	N	Loss of several mature trees		
Downstream Riche Fond Bridge	22-Jun-95	4570 - 5100		(-0.5m)	Y	240	200	Y	N	Loss of several mature trees Only partial filling of channel.	Bad bank erosion.	16
Downstream Riche Fond	19-Jun-95	4000 - 4570		(-0.5m)	Y	120	100	Y	Y	Loss of several mature trees		
Downstrm. Grand Riviere	19-Jun-95	3500 - 4000		(-0.5m)	Y	40	30	Y	Y	Loss of many mature trees	Bank eroding. Some ipil-ipil plntd. (Loopcutting not undertaken)	14,15
Downstrm. Grand Riviere	19-Jun-95	3100 - 3500		(-0.5m)	Y			Y	N		(Loopcutting not undertaken)	13
Downstrm. Grand Riviere	19-Jun-95	2600 - 3100		(-0.5m)	Y	160	150	Y	N.		V.sandy infil material-much sand extracted by locals.Rough grazing.	12
Downstrm. Grand Riviere	18-Jun-95	1970 - 2600		(-0.75m)	Y	110	180	Y	N		Partly-filled area used only for grazing.Eroding banks(4m).Major (Major blockage in river at 2500.)	10,11
Downstrm. Grand Riviere	18-Jun-95	1530 - 1970		(-1.0m)	Y	100	130	Y	N		Infilling now only grazing land. Damage to banks by cattle.	8,9
Upstr.Bridge E.of Grand Riviere	10-May-95	1070 - 1530		(-1.0m)	Y	140	150	Y	N	S. diversion problematic	New land not fully used.	
Between Bridges at Grand Riviere	31-May-95	770 - 1070		(-1.0-1.5m)	Y			Y	N			
Downstr.of First Rd Brdg at Grand Riv.	?	550 - 770		(-1.5-2m)	Y			Y	Y			
DERNIERE RIVIERE To Grand Riviere Confluence	?	2930 - 4140		?	Y	190	200	Y	N	Considerable loop-cutting	More bankside tree planting req.	7
TOTAL CUTTING/INFILL(m)						1450	1500					

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3.3 Results of the Assessment

Comments on the detailed plans (covering the 3 major valleys) are given in **Table 3.2**. Any special comment on the plans with respect to environmental considerations is given in a separate column, while comment on the situation as observed in the field (July,1997) is given in the last column.

The Environmental Evaluation for the Phase 1 works programme is given in **Table 3.3** under the 12 main groupings of work measures undertaken.

In addition to this tabular data further important information, including external factors, should be noted:

Cul de Sac:

a. Beach area: Hess oil terminal (S area) and new road project (N area) dominates the bay, and both are major eye-sores. According to locals the beach has deteriorated greatly since the oil terminal was constructed. Dead trees along the seaward side of the beach indicate extent of recent beach erosion. Beach sand at the confluence of the river is currently being mined by locals for sales for building material (currently some 10-12 people employed here). Inland of the beach a substantial area of wetland forest exists together with a little degraded mangrove. Much rubbish (mainly plastic) lies on the surface in this area. However, many crabs and much birdlife was observed. Rocks in adjacent areas to the beach have substantial algal coverings. Water is slightly turbid in all areas, and very silty in areas where run-off is occurring from the road project. Some areas of destabilised embankments occur and potential mass movement materials are threatening the new road alignment.

b. Inland of wetland forest a major area is being used as a rubbish dump (c300x150m), and some of the forest area has clearly been bulldozed for this dump. Rubbish appears to be blown/washed into surrounding areas.

c. Lower floodplain is being drastically altered by the road project, with much spoil material currently being added to raise the level of the road. Alignment of the road, however, would appear too far to the south, with insufficient floodplain width between the industrial sites to the south of the river and the road project to the north (only 60-65m). Width of the main (straightened) river channel is very low (only 6m) with only 1m of freeboard existing to top of river bed. Width and height of main road bridge opening would appear also a major limiting factor during high flood periods: flood waters would spill over main road.

d. Unharvested coconuts are a major environmental hazard in the lower floodplain, harbouring water and breeding mosquitoes, and contributing to much of the solid rubbish being carried down by the river. Further upstream, later in the day, and following steady rain, the river rose to some 30% of channel capacity. Coconuts constituted some 90% of floating debris, other organic rubbish some 5%, and plastic rubbish another 5%.

e. Surface drainage in the bananas in the flood plane presents problems in that the sides of the drains are v.steep over a height difference of commonly 1.5-2m. Trash cover is

Table 3.3

ENVIRONMENTAL EVALUATION, PHASE 1 WORKS PROGRAMME

Measure Undertaken	Status of Operation	Observed Impact: Paramater	Size	Major effect	Comments & Lessons for Future Events
1)Clearance of loose debris (organic & rubbish)	Undertaken for 10 Rivers, usually combined with measures 2 & 3, below.	i)Removal of blockage, ii)Removal of org.mat.	+++ +++ +++ +/- +++	Less risk of collapsed infrastructr. Decreased floodplain flooding Decreased WTs in adj.land Increased channel flow rate Less eutrophication,health hazard	Non-controversial ,Debris to be removed to rubbish dump. Any decomposable rubbish can be used as compost / mulch on adjacent land, although separation from non-decomposables time-consuming
2)Removal of Sediment to original channel bed level within original channel (de-silting)	Undertaken for 9 rivers, often in association with other activities	i)Removal of blockage,	+++ +++ +++ +/-	Less risk of collapsed infrastructr. Decreased floodplain flooding Decreased WTs in adjacent land Increased channel flow rate	Non-controversial. Fine-textured sediment to be used for partial, but even, infilling of meander loops, and for increasing depth of shallow soil areas in nearby sloping land.
3)Resectioning:A:Widening of existing channel, smoothing channel sides, & some grading	Major work on 5 rivers:Cul de Sac, Roseau,Mabouya, Troumassee, Soufriere	i)Removal of riverbank material	+++ -- -- --	(all of above effects, plus:) Current loss of agric.land Future threats to agric land Loss of riverbank habitats	Overall beneficial, but some problems:a) needs to be combined with Measures 9 and esp.10 b)fine-textured sediment to be used as above c)level of detailed planning, consultation & compensation needs improvement, d)effect downstream needs consideration.
4)Resectioning:B:Deepening existing channel below original bed level	Significant work on 5 major rivers (as above)	i)Removal of riverbed material/deepening ii)Increased erosivity of existing channel iii)increased erosivity of tributary channels	++/- --- ---	(all of above effects, as in 3),plus: Aggravated bank erosion,under-cutting below rooting depths Aggravated erosion in tributaries	Overall problematic, & likely to create more problems than it solves. Deepening of channel should be undertaken only to orignal elevation of former channel.
5)Rock protection (Rip-rap) along base of eroding channel bank: Directly Protecting Infrastructure	Undertaken on all 10 rivers:major work at Dennery,	i)prevention of river bank erosion ii)possible movement during high flows	+++ --	Partial protection of eroding bank Movement causing channel obs-truction and bank scouring	Overall beneficial, but gabion baskets much more effective, although much more expensive.
6)Rock protection (above) Mainly protecting Agricultural Land	Undertaken on all 10 rivers	(as above)		(as above)	Expensive in relation to benefits
7)Gabion Baskets along eroding channel bank: Directly Protecting Infrastructure	Major works in most rivers: heavy invest-ment in Soufriere, Anse la Raye,Cul de Sac, Canaries,	i)prevention of river bank erosion ii)interstitial spaces within basket iii)appearance	+++ +++ ++ --	V.good protection of eroding bank Provision of shelter for riverine fauna. Permeable to tree roots Initially unsightly	Very expensive (c.EC$200/m2), but justified for protection of essential infrastructure. Should be combined with permeable/root penetrable filter blanket and planting of tree vegetation on adjacent land.
8)Gabion Baskets along eroding channel bank: Mainly protecting Agricultural Land	Undertaken in a few rivers only.	(as above)		(as above)	High cost not justified in most cases.
9)Planting cover crops/ grasses on river banks (vetiver, Rosseau grass)	Mentioned in many (but not all) plans, c.80% undertaken.	Est.of groundcover Est.of dense rooting Provision of fodder Lack of taproots	+++ +++ +/- ---	Prevention of raindrop impact Stabilisation of surface soil Cattle may trample bank Soil below 1m not stabilised	Effective in surface soil stabilisation, but not as effective for long-term river bank stabilisation as planting of trees. Should thus be combined with tree planting.
10)Planting trees along river banks	Not emphasised sufficiently in Ph1: only c10% planted.	Est.of deep root syst. Est.of litter layer Shading of undergrwth Shading of adj.crops	+++ +++ +/- --	Prevention of slumping Increased raindrop protctn increased infiltration Change of species Loss of crop income	Overall highly beneficial: double row of trees needs to be established on both banks, and maintained by land owners. Large number of species are possible, bringing med.& long-term income to farmers.
11)Meander (Loop)-Cutting	Major work on 3 rivs. (Roseau-2130m Mabouya-1450m Cul de Sac-1250m) Smaller work on Troumassee.	Imprvmt.in drainability ii)Increased erosivity Removal of trees/vegtn Large vol.of spoil Loss of agric.land Loss of access to cut-off land	+++ --- --- --- --- ---	Increased speed of drainage Aggravated bank erosion Loss of habitat, income. Further silting of river channels Need for compensatn to landowner Need for compensatn to landowner	Overall highly problematic: not recommended for any future programmes. Many land disputes /compensation claims outstanding. Increased flow rates of river may aggravate bank erosion during future floods, and increase claims from other landowners.
12)Infilling old meanders	Major work on 3 rivs. (Roseau-2130m Mabouya-1450m Cul de Sac-1250m) Smaller work on Troumassee.	Creation of new land	-- ---	Legal status of new land Texture,fertility of new land	Any benefits from new land creation have been fairly small due to clouded legal status, and quality of new land (texture of soil, fertility, even-ess of surface, flodd hazard).
-partial filling,upstream side only		Est. of some infilld area	++	Estab.of some new agric land.	
-partial but even filling		Est. of infilled areas Lower infilling elev	+++ ++ ---	Estab.of new agric land. Overspill flood channel Flood hazard for most crops	Partial, but even filling, has been more sucessful than filling of upstream part of loop only. Old loop then serves as reserve flood channel.

very good in the area between the double rows of bananas, but is non-existent over the steep sides of the drains, and very bad erosion is thus commonly observed in these locations. (Solution to the problem may be installation of trash lines, say at 30cm from the bottom of the drains.)

f. Current deepening of side channels (not a Ph1 activity) is being undertaken, drains excavated to 2.5-3m depth. Sides of drains are very steep (>>45deg) with no vegetative cover being provided. Spoil is dumped on the immediately adjoining land, raising adjacent track level by some 0.5m, and piled on the adjacent banana land by a further 0.5-1m. Some back-cutting of adjoining tributary drains was seen, level of the latter drains being some 1-1.5m higher.

g. Landowner badly affected by Ph1 loop-cutting activities:
i) approx 2 acres out of holding of 31.6 acres have been lost by the new channel;
ii) access to a further 2.5 acres of banana land has been lost: river is not fordable in wet weather, and banana production from that land is thus lost;
iii) river bend, at the start of the cut-off loop, is further eroding the right bank, threatening overspilling at the same place where TSD floodwaters cut through the land.
iv) bank erosion along new section of cut-off loop is affecting the right bank, with a 3m width already lost.
v) landowner has been prevented (!!?) from planting trees along the river bank, apparently because of access along the adjacent road being required for bank repair/desilting activities. Planting of trees - notably mango and Honduras mahogany has been undertaken in a line 9m from river (ie too far to be effective for bank stabilisation).

The landowner has not been compensated for lost land and is threatening to take legal proceedings against government. (This represents the clearest case investigated where Ph1 activities have led to problems.)

Roseau Valley:

a. Beach area: wide and high beach with little evidence of any coastal erosion or sand mining. River confluence appears slightly raised-ie tendency for beach sand to dam rivermouth. Riverwater is black in colour with very bad smell, due to influx of anaerobicly decomposing effluent from Bounty Rum Distillery. Adjoining sea area to the south of river mouth is discoloured for a distance of some 150-200m, over a width of 50m. Platform 30m offshore leads to 15inch pipe through which coastal tankers discharge molasses to supply rum distillery. Inland of beach is a large alluvial area with rough grazing, and some of this is clearly swampy. All is adversely affected by bad smell.

b. Landowner badly affected by Ph1 loop-cutting activities and distillery effluent in river. Land located 550m E of beach, 350m W of distillery. Owner had 5.91 acres, but 0.5 acres already lost to recent river erosion promoted by deflection of water from cut-off loop. Farmer claims 10 young coconut trees, 45 bananas, 20 plantains 1 breadfruit have been lost. Farmer has planted trees along river bank, but trees are too young to be effective for root stabilisation. Landowner clearly a very proficient farmer, having farmed here since 1992, with well-managed bananas, taro, citrus, hybrid coconuts (just bearing), and mahogany. Drainage and flooding in bananas is a major limiting factor, with lower banana areas only 2m above current river level. Land was fully flooded in TSD (5ft flooding) and 26 Oct 96 (2ft), but apart from 0.5 acre river bank, all trees and most bananas survived. Farmer currently deepening drainage from 0.5-0.7 to c.1m below mat level. Black distillery effluent prevents farmer from using tributary stream for irrigation. (Solution: buy another 80m of pipe, make small aqueduct over tributary, and take water from main channel 50m upstream?) Base of stream shows >1m of black anaerobic ooze. <<Landowner: William Gabriel>>

c. Wasted low cut-off loop, c 150m equilateral triangle, v.uneven landsurface, c2m above river bed level. Possible use as overspill channel, but land could be used for seasonal agriculture during non-flood periods (Dec-June), or planting to perennial trees. (Chainage 59).

d. Very bad riverbank erosion with banks 3-6m high. Some 6m high sections are subject to bad slumping. Almost no tree planting has been undertaken along these banks, although grass/weed vegetation is now good in most areas. Tree planting and care in early years is now urgently required. Bank materials mostly vfSL: ideal rooting medium for most crops. Silt disposal appears local, adding to the already high banks. (Chainage 48-32).

e. Left bank embankment recently constructed by large private landowner of mainly coarse textured materials (stoney/gravelly coarse sand). Banks steep 30-45degrees, but now fairly.well vegetated (wild species). Embankment however, constructed too near river, which is now being constricted. (Chainage 20-24).

f. Further downstream, left bank. Embankment continuing, c.2-3m height, v. coarse material being used. Some parts eroding. Urgently needs planting and stabilisation. River again is probably being constricted. Sand and gravel extraction is occurring in places. Right bank is well vegetated. Chainage 15-19.

Mabouya Valley:

a. Lowermost floodplain. Beach is protected by 150m-wide inland strip of wetland forest, relatively undisturbed. Inland is low floodplain, generally 0.1-0-6m above river level. Riverbank has artificially been heightened to c 1-1.5m above river level. Backswamp drains join main river within wetland forest area. Large floodplain area is used only for rough grazing, with much less disturbance than in other 2 large valleys. Raising of riverbank has clearly led to more silt deposition in the sea, and less in floodplain and wetland forest area.

b. Problems of loop-cutting and partial infilling of old meanders.
i) uneven filling at low elevation, leaving stagnant ponds;
ii) topsoil in infills is too sandy, causing banana topples. Old topsoil should be retained, and moved as surface material for new infill site.
iii) landsurface in infill is left in too uneven a condition.
iv) land title for infill appears uncertain: occupiers are essentially encroachers on government land, and government does not obtain money from beneficiaries.
v) sandy infill materials have subsequently been mined by locals for building material.

c. Silt removal from channels: much of silt has been added to existing bank, adding to uneveness of land. Texture is generally more sandy than surrounding soil material, which is not always beneficial for crops.

d. Cattle in riverbank areas: much evidence of cattle causing localised bank collapse in attempting to graze areas near the river and to move down to the river to drink. Cattle should be kept well away from river bank areas. Land use should exclude digestible grass in these areas. River banks should have double row of trees on each bank, then bananas inland. Lower cut-off meander loops should be under seasonal (flood-resistant) crops, eg taro, or perennial, hydrophyllic trees.

Chapter 4

Recommendations

4.1 Recommendations for Improvements of Existing and Potential Future Works

Some of the important aspects to take into account when dealing with flood flows and designing facilities to pass or protect against such flows are:

- ensure that major infrastructure is designed to accommodate a 1:50 or 1:100 year flood (not a 1:5 year event). The flood information is such, in relation to flood discharge estimates and flood levels, that in all probability it will be necessary to design against the worst recorded flood if this is considered to be an extreme event.

- minimise the degree of channel re-alignment particularly if it purely to protect of create new agricultural land in the flood plain.

Possible improvements include:

- the introduction of palisading using natural materials for bank protection;

- the greater use of gabion mattresses but incorporating permeable membranes to reduce washouts of backfill material;

- the use of a greater variety of man-made materials e.g. mac-mac which can provide the intial protection required to reduce new bank erosion whilst vegetation becomes established;

- 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 particular 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 which will affect the flow regime;
  - reducing the danger of tall or overhanging trees from falling into or across the river channel by a defined system of top lopping;

- the identification of drainage system re-habilitation needs in the floodplain areas with the assessment of the efficiency of the whole drainage system to the sea with considerations given to tidal level fluctuations in the lower areas. The re-excavation of field drainage ditches is an important factor in maintaining banana yields and qualities in the face of potential waterlogging.

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

The Review of Phase 1 works indicated that a series of design guidelines would be useful.

The Phase 1 works were by necessity carried out quickly and hence greater emphasis was placed in undertaking construction works. However, it is likely that more design work was undertaken than has been evidenced by the Phase 2 review process. Little design work is held by the Government offices and hence there are few guidelines to enable government staff to undertake similar works themselves in the future.

Design processes and good reporting is recommended for all river engineering work with feed back on intervention performance being included in the design files at a subsequent date. This feedback process should enable improvements to be made in the design and implementation process.

Any river engineering intervention needs a good appreciation of the natural condition of the river and of the potential impacts on the behaviour of the river of the measures being proposed. There is little point in solving one problem only to create another which might have more adverse impact.

Proper design approaches need to be established for:

- river training (when to do it and how, what to avoid)
- loop cutting if deemed essential;
- gabion wall protection to infrastructure;
- masonry retaining wall design in an aggressive river environment;
- cross drainage structure design;
- service duct attachment to bridges and culverts;

The key components of the design process which need to be established include:

General considerations covering:

- ▸ deciding when and where to implement the works;
- ▸ deciding what options exist, which will be the optimum solution in terms of ease of construction, cost, effectiveness and subsequent maintenance requirements;
- ▸ knowing the major pitfalls in the particular intervention proposed;
- ▸ awareness of environmental factors particularly that of the aquatic ecology;
- ▸ awareness of the impact on land loss and land appropriation and crop loss compensation factors and hence the socio-economic acceptability of the possible interventions;

- these should all be documented in the design file, at least in brief note form.

More detailed design considerations:

i. The discharges expected to be flowing in the channel in an extreme flood, a normal flood and dry season flows;

ii. The channel bed slope, channel bed roughness characteristics (normally in terms of Mannings 'n', and natural river section and hence the range of flow velocities and depths anticipated for each of the flows estimated in 'I';

iii. The need to incorporate flood plain flow assessments as well as main channel flows;

iv. The bed and river bank material, especially the D_{50} dimension; {Reference should be made to Appendix B wherein is presented a number of bed and river bank material particle size analyses which are considered representative of the main rivers on the Island. The programme of sampling and analysis was undertaken to facilitate future design and hence cost estimates for the trials programme};

v. The alignment of the river channel upstream and downstream of the proposed intervention and the existence of any 'hard points' and infrastructure (including electricity and telephone poles);

vi. The estimation of scour depths in normal straight channel and at bends if such exist or may exist in the with intervention situation;

vii. Identify embankment stability criteria, erosion protection and the benefits of a curvilinear alignment and the use of berms etc;

viii. The assessment of the changes in the dynamics of the river which will be brought about by the intervention and quantifying the impact;

ix. Design interventions allowing for anticipated scour depths, flow velocities, sediment loads and flow depths;

x. Evaluate the environmental impacts of the proposed intervention and modify the design if need be.

Typical stage discharge estimates for the River Cul de Sac is presented in **Figures 4.1 and 4.2** indicating the impact of different assumptions in the standard channel flow analysis process.

4.2 Comments following the Environmental Assessment

From and environmental standpoint the following needs to be noted:

a. By necessity Ph1 planning and implementation was undertaken in a hurry, and time did not permit environmental assessments of specific detailed plans. Although environmental lessons have now been learnt from both planning and implementation stages of the work, the Ph1 engineers should be complimented in doing much accurate work in a short period of time at the planning stage for a high proportion of the work undertaken. We should all now learn the environmental lessons coming out of the Ph1 works and change a number of items in any future work.

b. The Format of many of the Ph1 detailed plans (1:1000 scale) is good, with existing riverbanks, areas/features of flood damage, existing trees, and recommendations for remedial works required being clearly shown. Widening of river channels was correctly specified to occur only on inside of river bends, with the maximum of bankside vegetation retained on the eroding outside bend. A few of the plans very usefully showed location of landholdings, name, and even phone numbers of the owners. This format should be repeated in any future series of works, but with additions and modifications as shown in items below.

c. Planting of bankside trees should be specified as a top priority, a double row of trees on each bank being required. Tree seedlings should be provided by government, together with instructions on planting and maintenance (fertilising and spot weeding in the initial 2-3 years). A wide range of species should be made available, with final selection to be made by the landowner. Planting of grasses, which was specified in many of the plans, and also implemented in most cases, is not sufficient alone to stabilise banks below 1m depth. Maintenance of trees should be the responsibility of the landowner, who should obtain any produce from the trees.

d. Planting of grasses or leguminous cover crops should be undertaken on bare landsurfaces together with the above trees. For planting on exposed subsoil material, small NPK fertiliser applications should be made at the time of planting. Grasses and cover crops will be effective in the first few years in reducing soil erosion, but will eventually be largely shaded out by the more effective perennial trees. Vetiver (khus-khus) grass is a preferred species because it is not palatable and it has low maintenance requirements as well as being short (and therefore obstructing river flow to a lower extent than, for example, Roseau Grass). Cattle should be kept well away from river bank areas.

e. Making graded river embankments of unconsolidated transported material is likely to prove a failure, particularly where the river banks are more than 3m above bed level and not stabilised quickly by perennial, deep-rooting vegetation.

f. Deepening of river channels below original levels is likewise likely to lead to increased problems of riverbank erosion. Any future cleaning of river channels should only be undertaken to original bed levels.

g. Any future meander (loop)-cutting should not be undertaken, except in exceptional circumstances (eg where current meanders are threatening major infrastructure over a wide area). In these exceptional circumstances the following conditions should apply:
i) names and contact phone nos/addresses of landowners should be given on the plans, and inset boxes drawn showing details and dates of compensation, land exchanges, and conditions of land uses being accepted by the respective landowners. Access to cut-off land and possible compensation claims by owners losing land due to future erosion should be considered carefully.

ii) soil from new cuts should partly infill the old meanders to an even but lower elevation, in order both to make a secondary flood channel and to create new agricultural land, compensating for the loss of land represented by the loop cut. Topsoil (0-30cm) from the cut should be stored to one side, and finally positioned as topsoil for the infilled meander. Sandy materials should be avoided for the surface 30cm of these infill areas.

iii) Weir structures may have to be constructed in cut off sections to slow the flow of water and reduce risk of increased bank erosion.

h. Gabion baskets are highly effective at reducing bank erosion, but should only be used for protection of urban areas and essential infrastructure. (Gabion baskets, however, are too expensive to be considered for protecting agricultural land.) Gabions should further be stabilised by placement of permeable membranes, and adjacent bank areas should be planted to trees. Gabions are generally favourable environmentally, providing habitats for fish and small aquatic animals. They are somewhat unsightly, but are generally rapidly vegetated (vines, creepers, eventually shrubs and trees, although trees can rupture the baskets).

i. Heightening of banks in the lowermost parts of each valley reduce silt deposition in the floodplains, backswamps and wetland forest areas (including mangroves). Increased amounts of silt are then deposited in the sea. The lowermost part of floodplains should thus be kept under natural vegetation or rough grazing and allowed to flood. Further encroachment of these areas should not be allowed to occur, and likewise further raising of river banks/bunds in these areas should not be undertaken.

j. Although the above measures may be essential, contributory causes to peak flooding events should be appreciated. Major improvements can be made by better soil conservation measures, notably trash management in bananas, and by major planting programmes for perennial trees in place of both bananas and annual crops on sloping land, particularly that over 25 degrees.

Estimated Stage Discharge Characteritics of the Cul de Sac River

Assumptions as defined in the Table

Channel Depth m	Bed Width m	Flood plain Width (1s)	Side slopes 1in x	Flow Depth m	Mannings 'n' Main Channel	Mannings 'n' Flood Plain	River bed slope S	River bed slope (1: S)	Flood plain flow?	Main channel flow characteritics Flow Area m2	Wetted Perimeter m	Flow Area at full cap. m2	Wet Per	Velocity Main channel Part flow m/s	Velocity Main channel Full channel m/s	Above Main channel Area	Above Main channel Velocity	Flood Plain Flow Characteristic Flow Area	Wetted Perimeter	Velocity	Flow summation Main Channel m3/s	Above Main m3/s	Flood Plain m3/s	Total m3/s
2	8	0	1.5	0.5	0.035	0.065	0.00377	265	No	4.38	9.80	22	12.00	1.02	2.63 *	0	0	0	0	0.00	4.48	0.00	0.00	4.48
2	8	0	1.5	0.7	0.035	0.065	0.00377	265	No	6.34	10.52	22	12.00	1.25	2.63 *	0	0	0	0	0.00	7.93	0.00	0.00	7.93
2	8	0	1.5	0.9	0.035	0.065	0.00377	265	No	8.42	11.24	22	12.00	1.45	2.63 *	0	0	0	0	0.00	12.17	0.00	0.00	12.17
2	8	0	1.5	1.1	0.035	0.065	0.00377	265	No	10.62	11.97	22	12.00	1.62	2.63 *	0	0	0	0	0.00	17.20	0.00	0.00	17.20
2	8	0	1.5	1.3	0.035	0.065	0.00377	265	No	12.94	12.69	22	12.00	1.78	2.63 *	0	0	0	0	0.00	23.00	0.00	0.00	23.00
2	8	0	1.5	1.5	0.035	0.065	0.00377	265	No	15.38	13.41	22	12.00	1.92	2.63 *	0	0	0	0	0.00	29.56	0.00	0.00	29.56
2	8	0	1.5	1.7	0.035	0.065	0.00377	265	No	17.94	14.13	22	12.00	2.06	2.63 *	0	0	0	0	0.00	36.91	0.00	0.00	36.91
2	8	0	1.5	1.9	0.035	0.065	0.00377	265	No	20.62	14.85	22	12.00	2.18	2.63 *	0	0	0	0	0.00	45.03	0.00	0.00	45.03
2	8	36.75	1.5	2.1	0.035	0.065	0.00377	265	Yes	23.42	15.57	22	12.00	2.30	2.63 *	1.4	2.67	7.35	16	0.56	57.84	3.74	4.13	65.71
2	8	40.25	1.5	2.3	0.035	0.065	0.00377	265	Yes	26.34	16.29	22	12.00	2.42	2.63 *	4.2	2.74	24.2	16	1.24	57.84	11.52	30.04	99.39
2	8	43.75	1.5	2.5	0.035	0.065	0.00377	265	Yes	29.38	17.01	22	12.00	2.53	2.63 *	7	2.81	43.8	16	1.85	57.84	19.68	80.88	158.40
2	8	47.25	1.5	2.7	0.035	0.065	0.00377	265	Yes	32.54	17.73	22	12.00	2.63	2.63 *	9.8	2.88	66.2	16	2.44	57.84	28.19	161.12	247.15
2	8	50.75	1.5	2.9	0.035	0.065	0.00377	265	Yes	35.82	18.46	22	12.00	2.73	2.63 *	13	2.94	91.4	16	3.02	57.84	37.04	275.94	370.82
2	8	54.25	1.5	3.1	0.035	0.065	0.00377	265	Yes	39.22	19.18	22	12.00	2.83	2.63 *	15	3.00	119	16	3.61	57.84	46.18	430.90	534.93
2	8	57.75	1.5	3.3	0.035	0.065	0.00377	265	Yes	42.74	19.90	22	12.00	2.92	2.63 *	18	3.06	150	16	4.21	57.84	55.61	631.81	745.26

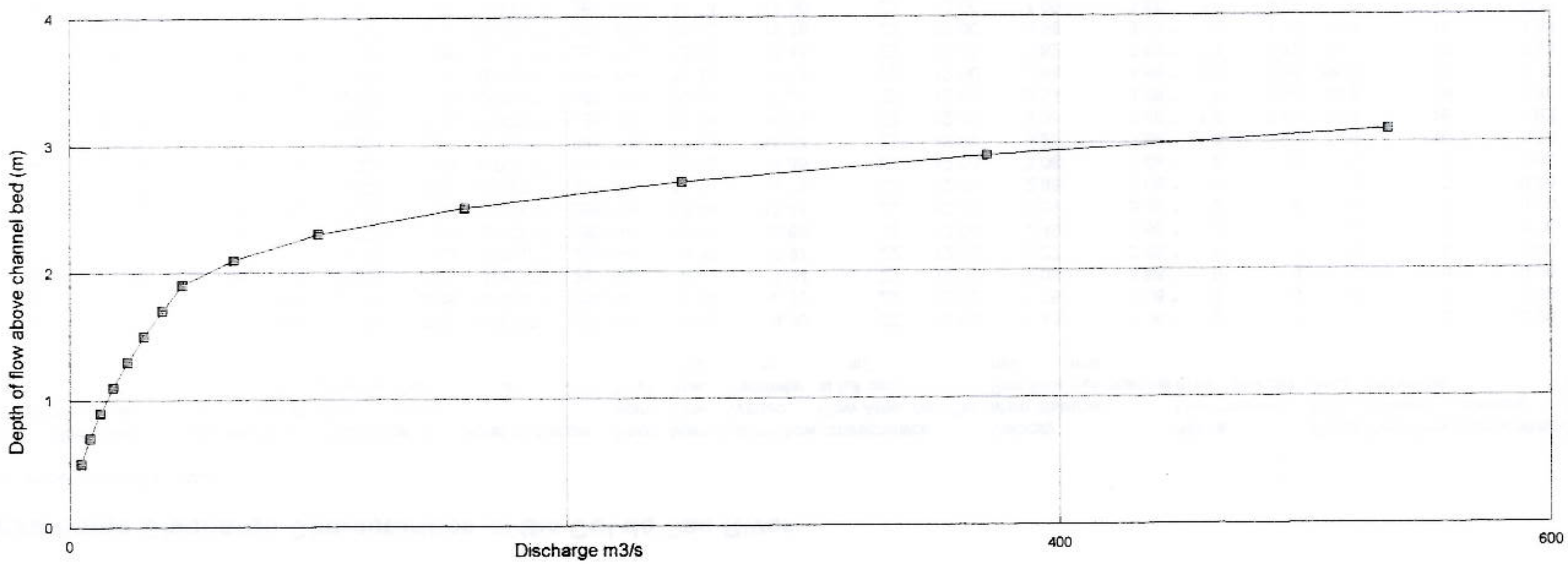

Figure 4.1

Estimated Stage Discharge Characteritics of the Cul de Sac River

Assumptions as defined in the Table

Channel Depth m	Bed Width m	Flood plain Width (1s)	Side slopes 1in x	Flow Depth m	Mannings 'n' Main Channel	Mannings 'n' Flood Plain	River bed slope S	River bed slope (1: S)	Flood plain flow?	Main channel flow characteritics Flow Area m2	Main channel flow characteritics Wetted Perimeter m	Main channel flow characteritics Flow Area at full cap. m2	Main channel flow characteritics Wet Per	Velocity Main channel Part flow m/s	Velocity Main channel Full channel m/s	Above Main channel Area	Above Main channel Velocity	Flood Plain Flow Characteristic Flow Area	Flood Plain Flow Characteristic Wetted Perimeter	Flood Plain Flow Characteristic Velocity	Flow summation Main Channel m3/s	Flow summation Above Main m3/s	Flow summation Flood Plain m3/s	Total m3/s
2	8	0	1.5	0.5	0.025	0.05	0.00377	265	No	4.38	9.80	22	12.00	1.43	3.68 *	0	0	0	0	0.00	6.28	0.00	0.00	6.28
2	8	0	1.5	0.7	0.025	0.05	0.00377	265	No	6.34	10.52	22	12.00	1.75	3.68 *	0	0	0	0	0.00	11.10	0.00	0.00	11.10
2	8	0	1.5	0.9	0.025	0.05	0.00377	265	No	8.42	11.24	22	12.00	2.03	3.68 *	0	0	0	0	0.00	17.04	0.00	0.00	17.04
2	8	0	1.5	1.1	0.025	0.05	0.00377	265	No	10.62	11.97	22	12.00	2.27	3.68 *	0	0	0	0	0.00	24.08	0.00	0.00	24.08
2	8	0	1.5	1.3	0.025	0.05	0.00377	265	No	12.94	12.69	22	12.00	2.49	3.68 *	0	0	0	0	0.00	32.20	0.00	0.00	32.20
2	8	0	1.5	1.5	0.025	0.05	0.00377	265	No	15.38	13.41	22	12.00	2.69	3.68 *	0	0	0	0	0.00	41.39	0.00	0.00	41.39
2	8	0	1.5	1.7	0.025	0.05	0.00377	265	No	17.94	14.13	22	12.00	2.88	3.68 *	0	0	0	0	0.00	51.67	0.00	0.00	51.67
2	8	0	1.5	1.9	0.025	0.05	0.00377	265	No	20.62	14.85	22	12.00	3.06	3.68 *	0	0	0	0	0.00	63.04	0.00	0.00	63.04
2	8	36.75	1.5	2.1	0.025	0.05	0.00377	265	Yes	23.42	15.57	22	12.00	3.23	3.68 *	1.4	3.74	7.35	16	0.73	80.99	5.23	5.37	91.59
2	8	40.25	1.5	2.3	0.025	0.05	0.00377	265	Yes	26.34	16.29	22	12.00	3.38	3.68 *	4.2	3.84	24.2	16	1.62	80.99	16.12	39.05	136.16
2	8	43.75	1.5	2.5	0.025	0.05	0.00377	265	Yes	29.38	17.01	22	12.00	3.54	3.68 *	7	3.94	43.8	16	2.40	80.99	27.55	105.14	213.68
2	8	47.25	1.5	2.7	0.025	0.05	0.00377	265	Yes	32.54	17.73	22	12.00	3.68	3.68 *	9.8	4.03	66.2	16	3.17	80.99	39.47	209.45	329.91
2	8	50.75	1.5	2.9	0.025	0.05	0.00377	265	Yes	35.82	18.46	22	12.00	3.82	3.68 *	13	4.12	91.4	16	3.93	80.99	51.85	358.72	491.56
2	8	54.25	1.5	3.1	0.025	0.05	0.00377	265	Yes	39.22	19.18	22	12.00	3.96	3.68 *	15	4.20	119	16	4.69	80.99	64.66	560.17	705.82
2	8	57.75	1.5	3.3	0.025	0.05	0.00377	265	Yes	42.74	19.90	22	12.00	4.09	3.68 *	18	4.28	150	16	5.47	80.99	77.86	821.35	980.19

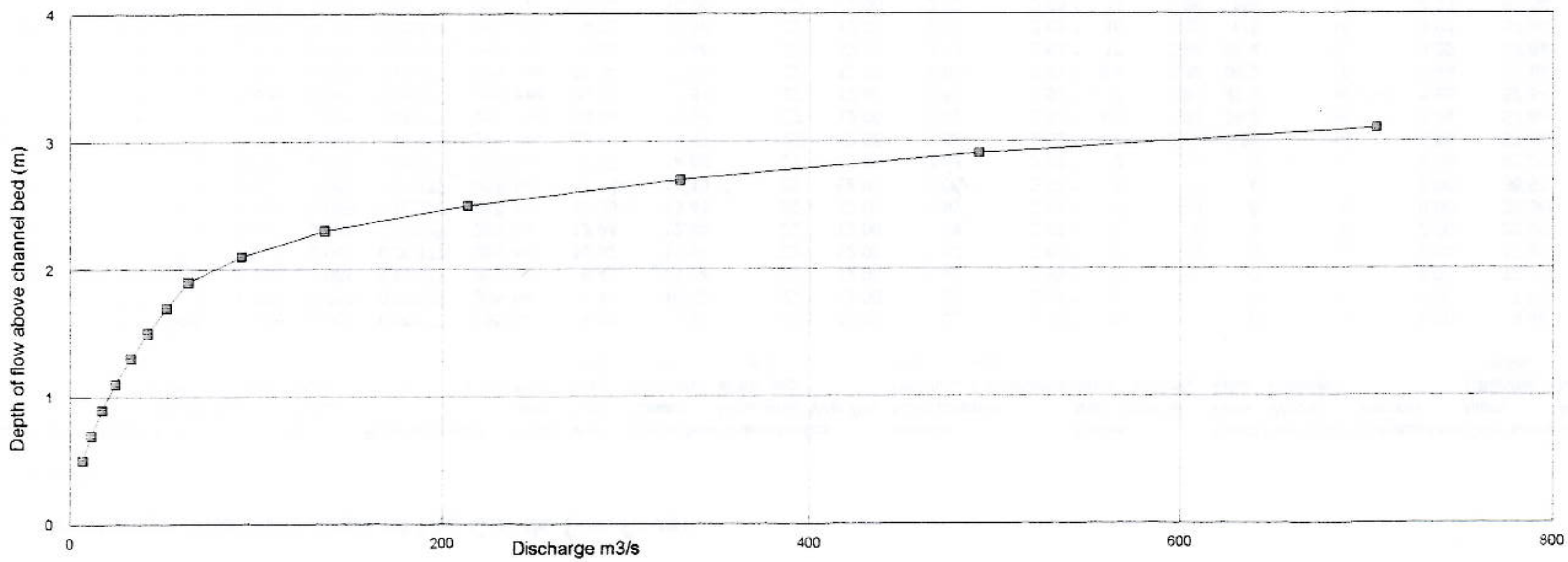

Figure 4.2

Annex 2

Hydrology and Meteorology

ANNEX 2

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A. Existing Networks and Data in Relation to Water Resources Issues

St Lucia Watershed and Environmental Management Project

Annex 2

Hydrology and Meteorology

Chapter1

Introduction

1.1 Preamble

The need for a review and improvement of the hydrological and hydrometric monitoring network became apparent during the World Bank Review in December 1994 of the damages and dislocation caused by Tropical Storm Debbie (TSD).

It was stated in the World Bank Review Mission Report that:

> *"There appears to be a dearth of hydrological data, including meteorological data and quantitative and qualitative data on the island water resources and coastal waters. In fact, no rigorous study of the nature and the severity of TSD is possible because of the paucity of the rainfall and river level data and the lack of streamflow data. The few instruments that were in place did not all function properly under the severe conditions of TSD, while others were washed away. The installation of instruments at high priority locations is thus essential before the onset of the next rainy season".*

Whilst undertaking the review and developing recommendations for the upgrading of the climatalogical network and the hydrometric stations, a more thorough assessment of the the status of the existing data base has been undertaken to identify shortcomings in relation to probable future environmentally based assessments.

Chapter 2

Review Approach

2.1 Introduction

The approach adopted for the review of the hydrometry has been multi-faceted, assessments have been made of:

- the historic development and changes experienced in the coverage of the various networks;
- the quality and accessibility of the existing data bases. It is important to not only look at the station year coverages but also at the integrity of that data;
- the use currently made of the data;
- the identified needs of data currently and in the foreseeable future;
- previous upgrading programmes and equipment supplies and their impact;
- the institutional involvement in data gathering, processing, storage, analysis and end use.

The gathering of data should not be seen as an exercise in itself. It should have a number of definable end uses as well as the general need for a hydrological perspective of the Island. Hence, the main focus of the review has been on 'current data base scope and quality' in the context of current and likely future issues.

Some of the current hydrologically based problems encountered on the Island were identified and the network and existing data bases investigated and analysed in order to identify the support that data gives to the problem quantification and solution

These problems have been:

- the evaluation of the hydrological significance of TSD and the storm of October 26th;
- the estimation of sediment transport from the river system into the various estuaries (in the context of increasing soil loss from catchments and the damage to coral);
- the estimation of dry season surface water resources associated with the positioning of the WASA water supply intake points and other strategic abstraction points which may be developed;
- the design of river training works and other hydraulic infrastructure (which requires hydrologic data);
- the potential development of a new reservoir in the south or south east of the Island;
- assistance to flood warning procedures.

Most of the above issues have a direct bearing in any 'Watershed Management' process.

Instead of purely listing the requirements for the above issues, the problems have been rapidly addressed based on the data currently available in order to highlight the shortcomings where they exist and also to provide examples of the shortcomings which are created in the problem solving process.

The data gathering process being addressed is primarily related to:

- rainfall;
- water level and discharge data within the river network.

However, other factors covered includes:

- sediment transport (within river waters);
- evaporation;
- relative humidities, temperatures, insolation, wind speed.

Issues related to water quality have only been tentitatively addressed since this introduces a far broader number of issues. However, the coverage given is believed to address the main components and identified the shortcomings that exist.

Chapter 3

Hydrometric and Climate Monitoring Networks

3.1 Historical Perspective

3.1.1 Rainfall:

A map of the hydrological river basins or watersheds of St Lucia is presented in **Figure 3.1.** The numbering of the river basins as shown is generally accepted as a standard.

A useful summary is provided by the 1992 Report by the Institute of Hydrology of the status of the rainfall data in St Lucia:

"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 it's 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 these 32 gauges operational in the past is given in **Table 3.1**.

"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 the TSD event states that daily rainfall data is only available after 1955. This provides a certain limit on the estimation of past flood events bearing in mind the characteristics of flood events in the catchments.

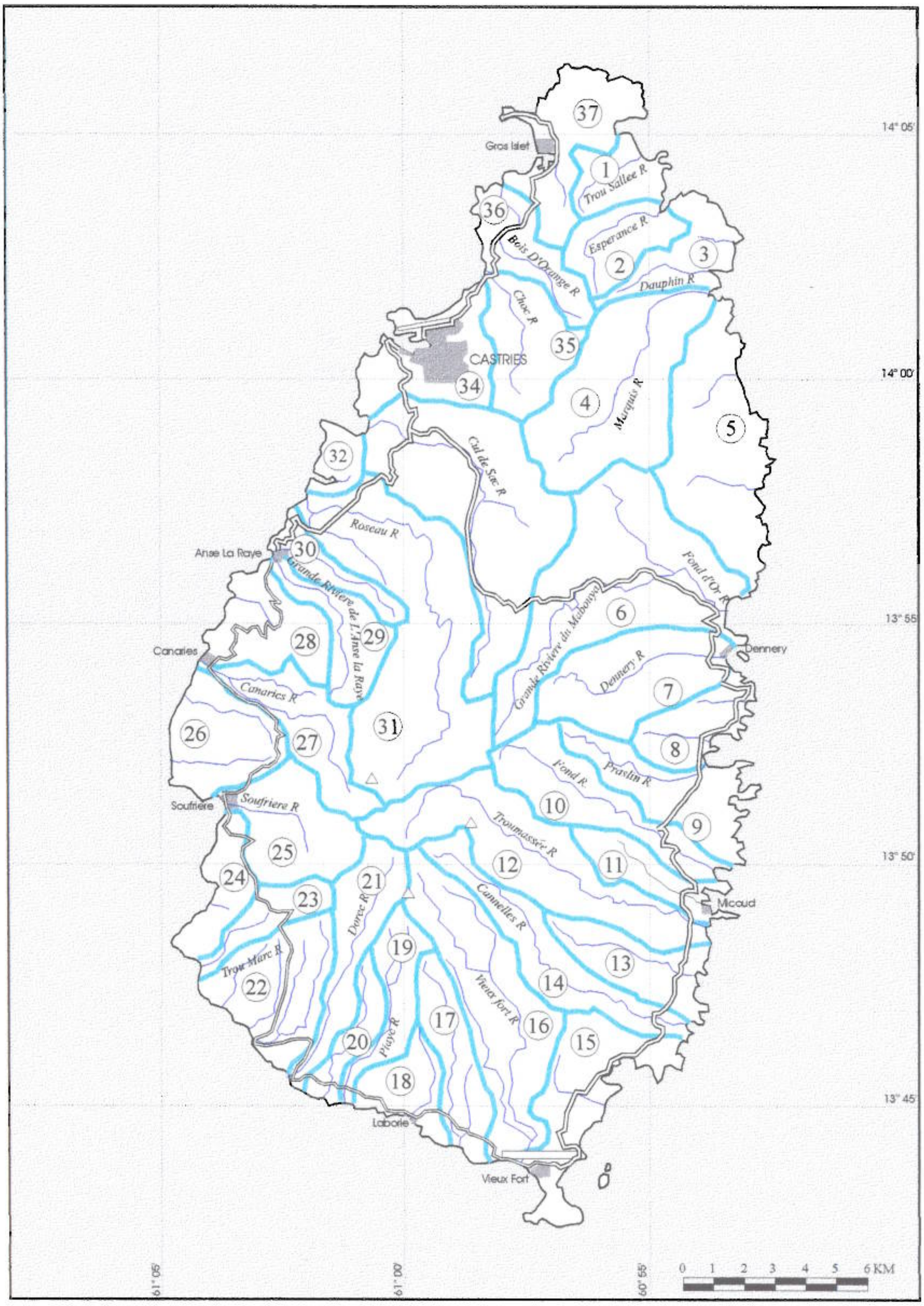
This latter report also states that in the 1980s, the number of operating gauges were down to 15.
During the TSD on the night of 9-10th September 1994, 5 rainfall recorders reportedly gave good results regarding the intensity of rainfall with 3 others giving data sufficient for estimates to be made.

There has thus been a significant variation in the numbers of rainfall gauges which have been functioning and reliable over the years. This variation in numbers should be avoided. Care should be taken to ensure a manageable number are operated and that there are adequate resources to operate, maintain and replace the units. Hence, it might be advisable to keep 15% to 20% 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.

After reviewing the rainfall records over the last 50 years at many of the stations, going through the ledgers of original records, it is apparent that there have been different levels of interest in the process. The current staff within AESD have established a good data retrieval, integrity checking and storage procedure. Good use is being made of the HYDATA software package as well as another software package called 'SURFER' to facilitate the isohyet plots and general station data/ information contouring.

Figure 3.1

Watersheds of St Lucia



File: HYMETDNM.CDR

Table 3.1

Rainfall Station Network (over the years)

Catchment Name	Nr.	Rainfall Station Ref.Nr.	Station Name	Date of Install-ation	Elev-ation m	Average Annual Rainfall (mm)	Years of Record	Latitude N o	'	"	Longitude W o	'	"	Type	Oper-ational Y/N '94
Marquis	4	4-R-1	Marquis Estate	1908	35	1906	70	14	1	26	60	54	36	RR	Y
		4-R-2	Marquis Babonne	1958	46	1873	28	14	0	11	60	55	17	RG	N
Fond D'or	6	6-M-1	CARDI La'Resource	1980	14			13	56	38	60	53	11	RR+EP	Y
		6-R-1	La Caye	1907	25	1884	71	13	55	46	60	54	8	RR	Y
Dennery	7	7-R-1	Errand Estate	1986	70	2100	0	13	53	2	60	55	29	RG	Y
Mamiku Patience	9	9-R-1	Mamiku Estate	1907	8	1802	71	13	51	57	60	54	10	RR	Y
Fond	10	10-R-1	Fond Estate	1907	50	1841	60	13	50	18	60	54	35		N
		10-R-2	Patience Estate	1951	92	1904	35	13	50	53	60	54	49	RR+R	Y
Troumasse	12	12-R-1	Troumasse Estate	1982	17	1762	63	13	48	47	60	54	16	RR+R	Y
		12-R-2	Mahaut Estate	1952	129	2593	9	13	50	26	60	57	2	RR+R	Y
		12-R-3	*Quilesse*	1935	320	3683	44	13	51	7	60	58	57		
		12-R-4	*Edmund Forest*	1979	490	3697	7	13	50	18	60	59	53	RR	Y
Roarne Rugeine	15	15-M-1	Hewanorra Airport	1974	10	1386	12	13	44	2	60	57	6	RR+R	Y
Vieux-Fort	16	16-R-1	Beausejour (Vieux F)	1975	16			13	44	37	60	57	30	RR	y
Doree	21	21-M-1	Saltibus	1985	274		1	13	48	13	61	0	43	RG	Y
Choiseul	22	22-R-1	Delcer School	1982	206	1807	4	13	48	0	61	3	18	RR+R	Y
L'Ivrogne	23	23-R-1	Union Vale	1923	242	1968	35	13	48	38	61	3	18	RR+R	Y
		23-R-2	Bathe Nursery	1948	367	2558	38	13	49	3	61	1	55	HMS	Y
Soufriere	25	25-R-1	*Belfond Soufriere*	1983	495			13	49	39	61	2	30		N
Canaries	27	27-R-1	Canaries	1985	54		0	13	54	19	61	3	53		N
		27-R-2	Desraches	1986	620		0	13	50	55	61	1	5		N
Roseau	31	31-M-1	Roseau Winban	1966	5	2158	20	13	57	20	61	1	9	RR+R	Y
		31-R-1	*Roseau Yard*	1970	5	2149	46	13	57	7	61	1	26		N
		31-R-3	Millet Tete Chemin	1983	260	2964	3	13	53	58	60	59	44		N
Cul De Sac	33	33-R-1	Soucis	1908	9	2432	71	13	58	43	60	59	47	RR	Y
		33-R-2	Bexon School	1985	23	N.A.	0	13	57	8	60	58	37	RR+R	Y
		33-R-3	Barre de L'Isle	1984	290	2980	1	13	55	30	60	57	28	RR+R	Y
Castries	34	34-M-1	Vigie Airport	1970	3	1815	16	14	1	9	60	59	35	RR+R	Y
		34-R-1	Government House	1945	137	1880	41	14	0	22	60	59	48	RR+R	Y
		34-R-2	George V Park	1890	6	2342	89	14	3	38	60	59	10	RR+R	Y
Choc	35	35-M-1	Union Agric. Stat.	1923	11	2040	63	14	1	21	60	57	32	RR	Y
Bois D'Orange	36	36-M-1	*Marisule*	1984	61		2	14	3	33	60	58	1		N
		36-R-1	Trouya	1977	15	1736	8	14	3	42	60	58	2	RR	Y
Cap	37	37-R-1	Cap Estate	1982	23	1307	34	14	5	41	60	56	10	RR	Y

{Note: those in italics not currently operational}

File: RF-STAT1.WK4

3.1.2 River Gauging.

The December 1992 Report by IoH also provides a useful summary of the River gauging stations. These are presented in **Table 3.2.**

Earlier, a larger number of stations had been operational, the details of these is given in **Table 3.3.**

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 3.4**, all were water level recorders.

Table 3.2 River Gauge Stations in 1992.

River	Gauge	Operator	Installation Date
Marquis	Marquis Boquis	LWUU[1]	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[2]	1984
Doree	Coast Road Bridge	LWUU[3]	1984
Choc	Treatment Plant	LWUU[4]	1985
Cul de Sac	Ravine Poisson	WASA[5]	1983
Millet	Bridge	WASA[5]	1983
Roseau	Cable	WASA[5]	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).

Discharge measurements have been made of the flows in several of the rivers listed in **Table 3.2** over the period 1984 to 1993. The main rivers covered have been the River Roseau, River Millet, River Cul de Sac, River Troumassee and the River Mabouya/ Fond D'Or (Station 6-A-2). For these stations, chart records are also available for many of the years and stage heights have been abstracted and are on file in the Offices of AESD. Many of the chart records are not considered to be very usable, comments on the charts indicating problems of stilling well siltation/ blockage, pulleys 'sticking' and gearing mechanism failures. Examples of the recorder charts, the abstracted water level information and the stage discharge relationships are given in **Figures 3.2 to 3.5.**

Flow gaugings have also been undertaken on other streams e.g. River Vieux Fort, River Choc, River Doree, but records are not very extensive. In determining/ re-evaluating the stage discharge relationship of the Mabouya River, about 20 discharge measurements were made in 1990.

The information on record would be adequate for deriving unit hydrographs for some of the catchments and also for facilitating the determination of stream base flows. However, in all cases the

Table 3.3

Previously Operating River Gauging Sites

Catchment River	Nr	Station Ref Nr	Name	Installation Year	Elevation m	Original Operator	Recorder Type	Catchment Area Total km2	Catchment Area Site km2	UTM Grid Reference (E)	UTM Grid Reference (N)
Marquis	4	4-A-1	Marquis Boquis	1986	18	LWUU	SEBA	30.67	22.63	5 16 844	15 48 550
		4-W-2	Marquis Babonneau	1984	16	LWUU			18.67	5 16 680	15 48 0
Fond D'or	6	6-A-2	Mabouya Bridge	1984	6	LWUU	STEVENS	40.64	8.38	5 17 400	15 40 350
		6-S-1	Factory Bridge	1983	4	LWUU			34.58	5 18 550	15 40 350
		6-S-2	Farmco pump	1986	5	LWUU			9.15	5 16 0	15 42 300
		6-W-3	La Pelle Bridge	1985	6	LWUU			8.38	5 17 300	15 40 550
		6-W-13	Deniere Bridge	1984	25	LWUU			4.54	5 16 0	15 42 300
Troumasse	12	12-A-1	Beauchamp Estate	1984	5	LWUU	OTT	31.4	27.49	5 17 500	15 27 650
		12-A-2	Mahaut Bridge	1984	110	USGS			14	5 12 900	15 30 100
		12-W-11	Coast road Bridge	1971	1	UMA			28.13	5 18 800	15 27 200
Canelles	14	14-W-1	Coast road Bridge	1984	5	LWUU		17.3	16.12	5 17 400	15 23 550
Vieux-Fort	16	16-A-1	La Retraite Bridge	1984	12	LWUU	MUNRO	28.48	18.32	5 12 300	15 20 600
		16-W-11	Tourney	1971	3	UMA			24.44	5 13 50	15 19 0
		16-W-12	Plut	1971	15	UMA			15.38	5 12 300	15 20 650
		16-W-13	Woodland	1971	210	UMA			4.65	5 10 400	15 25 850
Doree	21	21-A-1	Coast road Bridge	1984	22	LWUU	OTT	10.96	10.67	5 9 0	15 21 600
Ivorgne	23	23-W-1	Delcer Canal intake	1984	240	LWUU		6.46	1.41	5 3 100	15 26 900
Roseau	31	31-S-1	Coast road Bridge	1983	3	WASA		48.52	45.45	5 5 900	15 42 550
		31-S-2	Sarot	1983	8	WASA			33.03	5 9 100	15 41 900
		31-A-3	Millet at D. Traversay	1983	30	WASA	STEVENS		8.33	5 9 200	15 38 900
		31-A-4	Roseau at D. Traversay	1983	30	WASA	STEVENS		18.01	5 9 800	15 39 0
		31-S-5	Millet near Millet	1983	170	WASA			4.07	5 7 800	15 36 300
		31-S-6	Roseau at Dam	1983	110	WASA			14.14	5 9 400	15 36 100
Cul De Sac	33	33-A-1	Ferrands Bridge	1985	8	LWUU	STEVENS	40.45	26.61	5 9 775	15 45 325
		33-A-2	Ravine Poisson	1983	70	WASA	STEVENS			5 11 200	15 39 500
Choc	35	35-A-1	WASA treatment Plant	1985	11	LWUU	MUNRO	12.61	7.56	5 12 200	15 50 200

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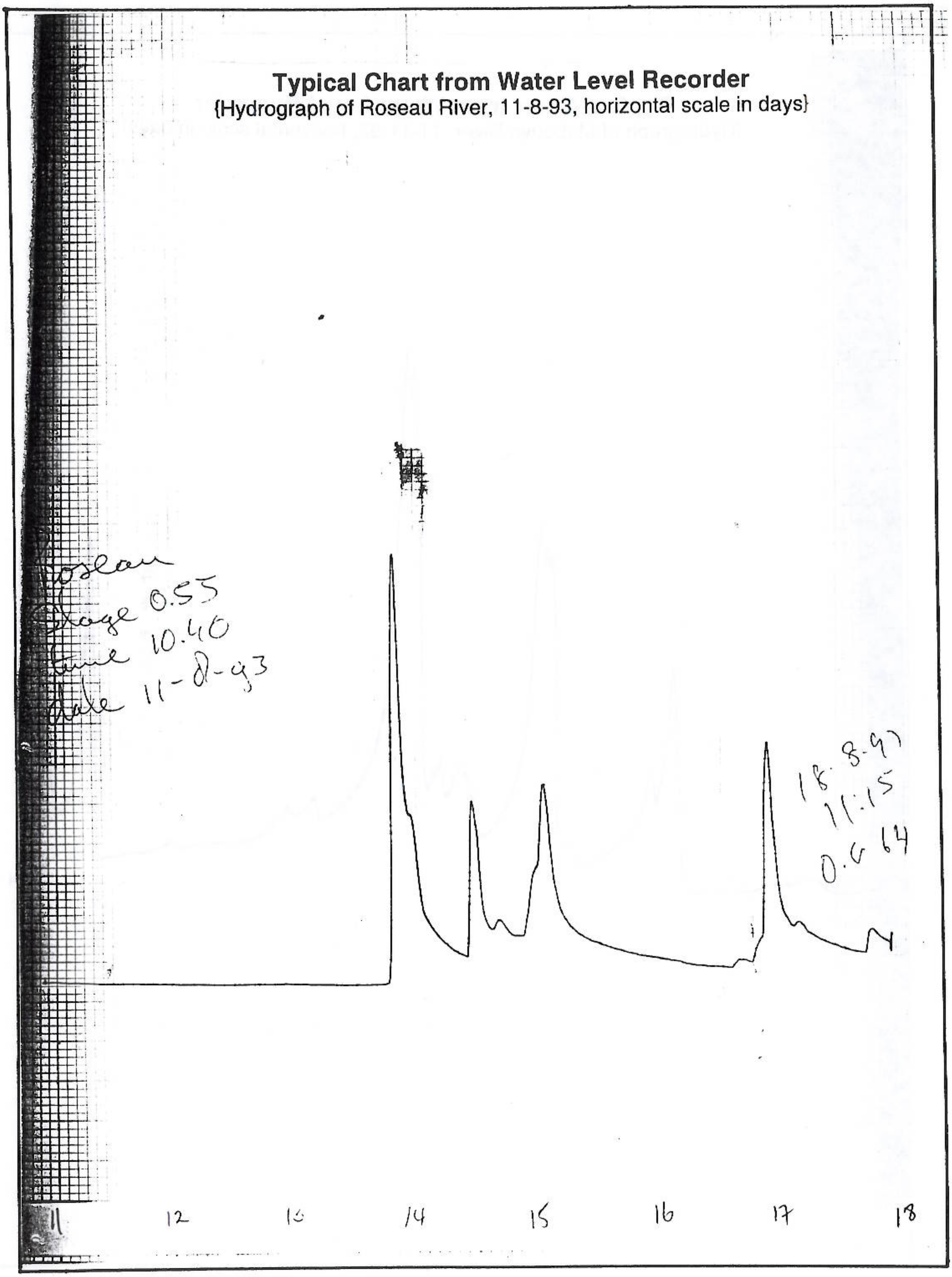
Figure 3.2

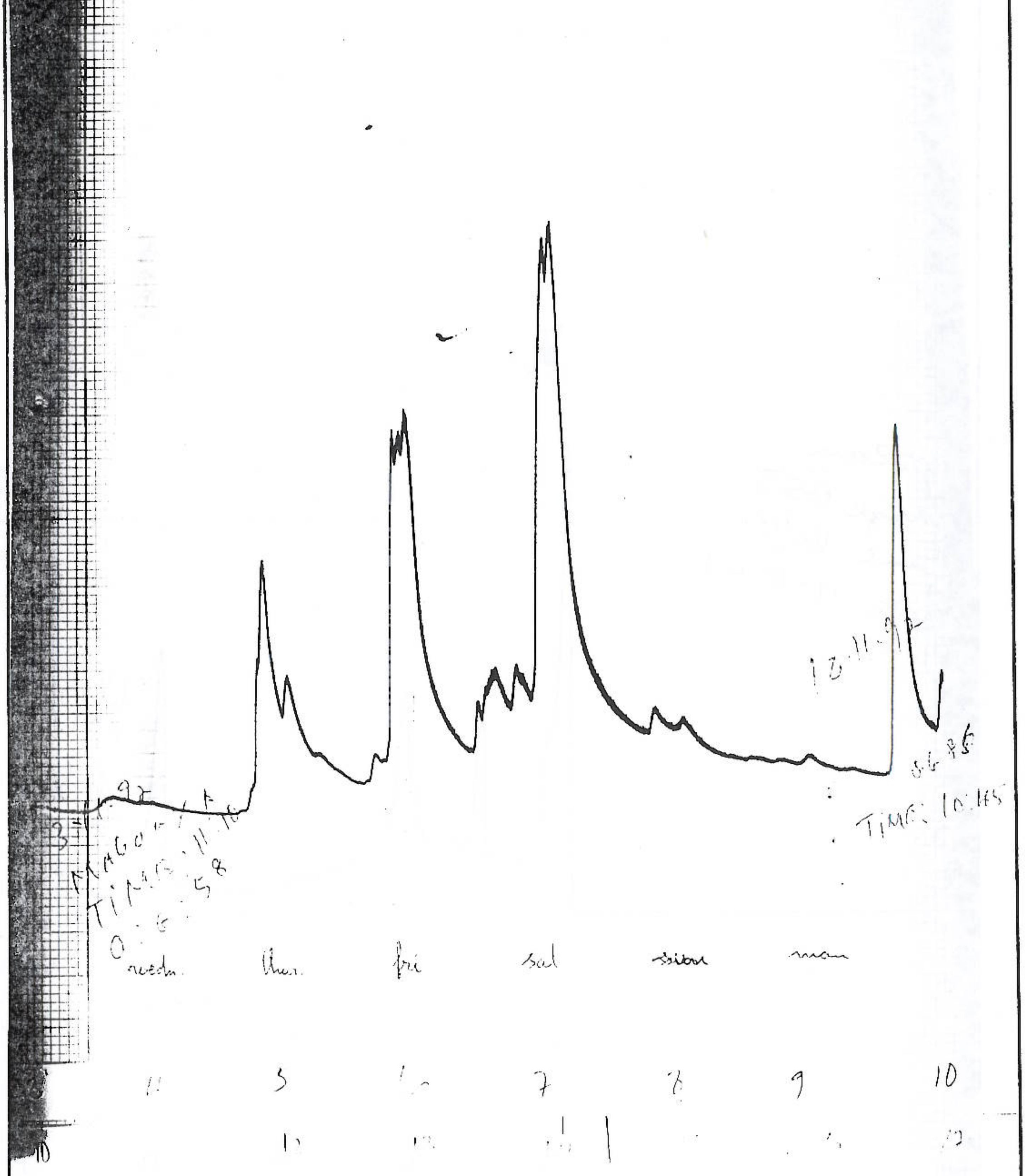


Typical Chart from Water Level Recorder
{Hydrograph of Roseau River, 11-8-93, horizontal scale in days}
Roseau
Stage 0.55
time 10.40
date 11-8-93
18-8-93
11:15
0.664
11
12
13
14
15
16
17
18

Figure 3.3

Typical Chart from Water Level Recorder

{Hydrograph of Mabouya River, 11-11-92, horizontal scale in days}



MONTH : *September* YEAR : *1991*

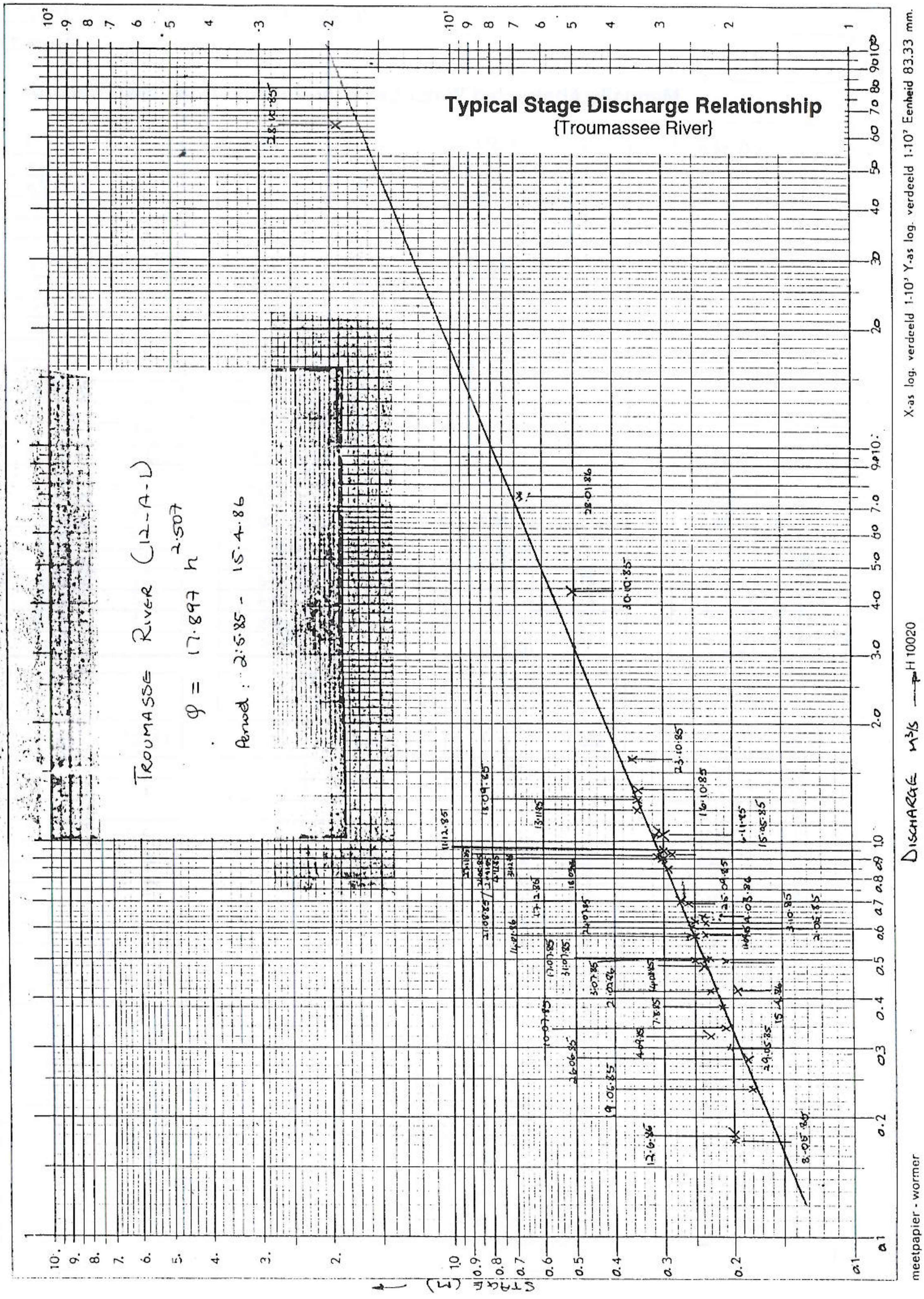
Figure 3.4

Manually Abstracted Water Level Information from Chart Records

(HRS)	25 (m)	(m)	(m)	(m)
0	0.360	0.350	0.350	0.375
1				0.375
2				0.380
3				
4				
5				
6		0.350	0.350	0.380
7		0.355	0.360	0.375
8		0.350	0.365	0.375
9			0.370	0.370
10			0.370	0.370
11			0.376	0.365
12			0.370	0.360
13			0.360	
14			0.360	
15	0.360	0.350	0.360	0.360
16	0.355	0.355	0.355	0.365
17	0.355	0.355	0.350	0.365
18	0.350	0.350	0.350	0.370
19		0.355	0.350	0.370
20		0.350	0.360	0.370
21			0.360	0.380
22			0.375	0.540
23			0.380	0.580
24	0.350	0.350	0.375	0.575

(HRS)	29 (m)	30 (m)	(m)	(m)
0	0.575	0.720		
1	1.260	0.675		
2	1.000	0.660		
3	0.800	0.740		
4	0.730	1.070		
5	0.660	0.920		
6	0.620	0.800		
7	0.580	0.720		
8	0.560	0.675		
9	0.580	0.630		
10	0.642	0.610		
11	0.675	0.590		
12	0.655	0.570		
13	0.630	0.560		
14	0.620	0.555		
15	0.620	0.600		
16	0.5905	0.735		
17	0.570	0.720		
18	0.555	0.665		
19	0.560	0.620		
20	0.700	0.600		
21	0.790	0.570		
22	0.720	0.560		
23	0.800	0.545		
24	0.720	0.535		

Figure 3.5


Typical Stage Discharge Relationship
{Troumassee River}
TROUMASSE RIVER (12-A-D)
Q = 17.897 h^2.507
Period : 2.5.85 - 15.4.86
DISCHARGE M3/S
STAGE (M)
X-as log. verdeeld 1.10³ Y-as log. verdeeld 1.10² Eenheid 83.33 mm.
meetpapier - wormer
H 10020

impact of abstractions from the river system needs to be allowed for.

In relation to flood flows, the problems of rapid water level rise, rapidly moving debris and sediment have all provided problems for the equipment in the past. Few if any large flows have been recorded whilst stage discharge relationships are below the flood flow ranges. The short flow duration of a flood event is evidenced in **Figures 3.2 and 3.3**.

Table 3.4 Hydrological Stations Post TSD

Number	River Catchment	Station	Operational
6	Fond D'Or	Mabouya	Yes (Nov'96 No)
31	Roseau	Roseau Bridge	No
	Roseau	Ciacot Bridge	No
33	Cul de Sac	Ferrands Bridge	No

The gauging station on the **River Cul de Sac** was damaged (see **Photo 19**) by Tropical Storm Iris which occurred on the 25th of August 1995 but this could have been affected by the river engineering works of Phase 1 which were then in progress. The water level recorder, a Stevens Type F has not as yet been replaced. Works are proposed to stabilise a channel section on the River Cul de Sac prior to the re-installation of the gauge.

The surveys undertaken during different discharges have indicated the varying river channel profile at each event with mobile bed conditions probably being introduced with the higher discharges.

A gauging station was operating until quite recently on the **Grand Riviere du Mabouya**, some 10m upstream of the main road bridge across the river. Since the installation was damaged flow estimates have been made 10m downstream from the bridge at a straighter section of channel. Staff gauge readings have continued to be taken. Stream bed profile changes are such that there is not a constant section, hence a stationary stage-discharge relationship cannot be obtained. More channel remodelling works as part of Phase 1 were carried out downstream of the site in March and April will probably further destabilise the natural section.

It is proposed to construct a concrete bed to the channel as an integral part of the current road bridge to provide the stable section deemed necessary for reliable and consistent low flow gauging. A similar design is proposed for the re-introduction of the gauge in the lower Cul de Sac channel.

Streamflow gaugings have been carried out in the **River Dennery** at a location about 100m downstream of the road junction to the Errard Estate. The right bank is solid conglomerate and the left bank is initially a relatively shallow sloped and gravelly floodplain leading to a steep embankment slope up to the road. The site is located downstream of a sharp bend in the river which will cause asymmetrical flow profiles with probably a strong thalweg. The site might be acceptable for low flow gaugings, but would be difficult for accurate high flow gauging both because of the difficulty in streamflow gauging at the site to establish a stage discharge relationship and because of the asymmetric flow characteristics.

In the **Troumassee** catchment, streamflow gauging has been carried out at Beauchamp, some 30m downstream of the water level recording installation which is positioned on the right bank against a strong conglomerate vertical rock face. The stilling well was reportedly silted up as a result of TSD and the recorder unit removed. As yet it has not been re-instated. The recent floods in the River Troumassee were very severe impacting significantly on the river section and washing away staff gauges which had been in place. Again, it will take some time for a new channel section to stabilise, however the site should be re-instated. When the stilling well has been repaired, the recorder re-installed and new surveys are undertaken, a regular current metering programme should be initiated. See **Photo 20.**

For the runoff from the **Roseau** catchment, flow measurement and water level gauging is undertaken near the bridge on the main road near the Winban Research Station. The bridge has a base support slab located between the abutments which provides a regular flow section . The stilling well and recorder house, located on the upstream side of the bridge was destroyed in the TSD. The channel section upstream is regular and straight whilst downstream there is also an acceptable channel condition, however, levels could be affected by downstream water level control either by the sand bar at the mouth of the channel or by tidal influences. {This needs to be checked}

In all the above, the prime focus of the gauging has been for low flow and baseflow estimation from a resource point of view. River flow gaugings have not been undertaken during flood events whilst water level data has not been found for flood flows. Streamflow gauging undertaken in 1995 on the Mabouya and Troumassee rivers covered only flows up to 0.6 m^3/s and 1.25 m^3/s respectively. This corresponds to the historic assessments of the stage discharge relationships of most of the river gauging sites on the island and indicates a greater concern over dry season resources than on flood events.

The road bridge at Winban was overtopped during the recent floods and flow bypassed the bridge area flowing across the road. Hence, even if the water level recorder had been operative, no direct assessment of discharge would be possible. Nevertheless the level information would still have been useful in analysing the flow hydrograph generated by the storm.

At all sites, water level information would be useful even if not within the gauged area of the stage discharge relationship.

All the above sites have been visited by the River Engineer. Visits have also been made to the Boguis bridge site on the River Maquis, the abandoned gauge on the River Doree and the La Retraite Bridge on the Vieux Fort River..

In the context of data use, few non-project uses appears to have been made of the data so far gathered. The AESD use the data for the establishment of the viability of irrigation projects that they design, discharge measurements normally being made near the abstraction site during the dry season prior to or during design. There should be allowances made for the rainfall characteristics which might have affected baseflow conditions in an effort to identify the probability that such gauged flows are unavailable in other years. Assessments should also be made of WASA abstractions, WASA plans and other water users downstream as well as ecological requirements.

Apart from AESD, there are no recent reports of any other organisation requiring knowledge of discharge information although MCW&T did recently request information on flow velocities in the Canaries River. The information is available in case WASA should request information, however, the data available does not currently specifically relate to the WASA intake sites and hence hydrological studies would be required to relate gauged flows with WASA needs.

Historically WASA used to measure discharges at their intakes, however this has been discontinued

Photo 19 Cul de Sac River. Broken water level recorder station at Ferrands Bridge.

Photo 20 Troumassee River. Broken water level recorder station at Beauchamp Estate.

due to budgetary problems and due to the absence of suitably trained personnel within the organisation. It is the intention of AESD to undertake this task on behalf of WASA. It is unsure as to whether the AESD planning in this respect will meet WASAs requirements. This needs to be addressed in the context of equipment proposals for Phase 2 of this Study and in relation to the capacity of AESD to undertake the tasks implied.

3.1.3 Sediment discharge measurements:

As stated in the WB Consultant's report of December 1994, no concerted effort has been made to collect data on sediment discharges.

The HTS Reports, 1980s, indicate that natural changes in the course of the Cul-de Sac River had taken place and that this was due to the change in land use and soil cover in the catchment which had given to generating more rapid run-off with higher sediment loads. The increased discharges being able to carry the additional sediment whilst the additional sediment or soil was made available by increased soil erosion. However, little sediment data was presented apart from a few numbers relating to a Study undertaken in 1973 for the Vieux Fort River. See Appendix A, Section A.4.

From the Roseau Dam studies, annual discharge of sediments were estimated to be 450 t/km^2 for the Roseau River catchment, 370 t/km^2 for the Cul de Sac River and 1,300 t/km2 for the Troumassee River and the Millet River. Sediment sampling was undertaken but only for generally low flow conditions in the Roseau, Cul de Sac and Troumassee rivers.

A survey was carried out in the 1980s of the erosion characteritics of the River Troumassee watershed as part of a Caribbean Study. {Details of this study have not been found}.

There would appear to be no specific demand for sediment discharge information, however, with the concern being expressed about soil erosion and coral damage, there should be need for information to assist in the quantification of the seriousness of these issues.

3.1.4 Climate

The main climatological stations currently in use are as reported in the 'AGROMET BULLETIN' produced by AESD, Ministry of Agriculture. The September 1996 issue presents information for :

Union
Winban (Roseau)
Hewanorra (Airport)
Cardi la Resource
and Barthe.

The Bulletin provides a summary of the following agro-climatological statistics for these stations:

Total rainfall and the number of raindays,
Open water (Pan) evaporation and Penman evaporation* estimates,
Mean average, maximum and minimum temperatures,
Mean vapour pressures, dewpoint, sunshine hours* and relative humidity,
Mean wind run*.
{*except Barthe Nursery Station)

An agrometeorological assessment was carried out in June of 1990 by a WMO (World

Meteorological Organisation) Consultant funded by UNDP this being to as a follow up to a visit made in 1988. The mission recommended the purchase of two Clicom software modules plus supporting hardware. A number of spare parts for existing equipment was also identified as needed to be acquired.

The Report listed a number of Evaporation (Piche) Stations delivered under the UNDP/WMO Project to SLBGA (St Lucia Banana Growers Association). These stations are listed in **Table 3.5**. The information is being used to help with the planning of weekly programmes of crop spraying.

Table 3.5 Evaporation (Piche) Stations.

Fond Assau	Canaries	Moreau	Bois l'Dne
Forestiere (Lower)	Grand Ravine	Forestiere (Upper)	Tonnes
Desrameau	Raillon	Plateau	Desbranches (Errard)
Union	Fond	Marquis	St Marie
Crown Lands	Blanchard	Cul de Sac	Ravine Noel (Mahaut)
Ravine Poisson	Retraite (Grace)	Marc	Belle Vue
Vanard	Morne Cayenne	Roseau	River Doree
		Six Miles	De Point

In addition, training programmes were identified and training undertaken, a course at Reading University on Statistical Procedures in agricultural climatology was highlighted as well as training at the Atmospheric Environmental Service in Canada.

3.1.5 Water Quality

Water quality measurements within catchments are undertaken by WASA in relation to water supply quality control. Samples are taken on a regular basis both of the raw water being diverted from the WASA Intake works and of the treated water being delivered to consumers.

A summary of the chemical and physical analyses which are regularly carried out is given in **Table 3.6.**

New laboratories exist as part of the new Ciceron Water Treatment Works near Castries. The equipment will enable the majority of the basic analyses to be undertaken. Compared to measurements related to water resources, these tests are considered acceptable in terms of scope.

More complex analyses can be undertaken at CEHI (Caribbean Environmental Health Institute) also based in Castries, however WASA do not currently avail themselves of this potential service centre. Options for more elaborate testing for herbicides and pesticides through CEHI might be logical.

The sampling is therefore based on the sites of WASA water intakes, these are important but are generally located in the upper part of the catchments. Additionally, WASA do not have intakes in every catchment. Hence, there is a need to expand the raw water sampling programme to other sites in the lower catchments where pollution levels will be higher.

An ongoing ODA project entitled 'The Development & Integration of Biotic and Chemical Monitoring with Land Use Assessment for Tropical River Resource Management' is undertaking a

Table 3.6

Physical and Chemical Characterisitcs of Raw Water Supplies in St Lucia

Parameters Monitored		Minimum		Maximum	Average	Number of samples	Treated Average
Physical							
Colour (colour units)			0	672	255	69	7.2
Temperature (degrees C)			20	22	21	70	21
Turbidity (NTU)			0.2	269	16.2	88	6.46
Conductivity			8.3	380	188	50	180
Chemical							
pH			5	8.4	7.3	72	7.12
Total alkalinity			16.8	110	43	58	38.9
Dissolved oxygen	mg/l		0	6.5	5.2	37	5.2
Total hardness			26	144	65	75	54
Calcium hardness			9	110	35.6	68	33.4
Magnesium hardness			9.5	79	30	67	18.5
Chloride	mg/l	Nil		53	22	66	25.2
Fluoride	mg/l	Nil		0.35	0.09	28	0.12
Total Iron	mg/l		0.01	3.1	0.26	67	0.16
Copper	mg/l	Nil		0.4	0.06	66	0.073
Manganese	mg/l	Nil		0.8	0.04	38	0.103
Silica	mg/l		6	71	36	44	24
Phosphates	mg/l		0.72	17	5	71	4.18
Nitrates	mg/l	Nil		2.4	0.9	49	1.1
Carbon dioxide			1	154	15	69	17.8
Aluminium	mg/l	Nil		0.14	0.05	30	0.027
Non-filterable residue		Nil		34	30		3.7

Source: Water Quality Monitoring and Assessment in St Lucia, 1979-92, R Eudovique (WASA)
Regional Workshop on Water Quality Monitoring, Port of Spain, 1993.

WASA-INT.WK4

comprehensive survey of the ecological condition of many of the rivers in the Island, the surveys and field sampling covering not only the WASA sites but also other reaches of the river network. More details are presented in Appendix A. The initial findings of the study are that there are water quality deteriorations as one progresses down the river system.

Any additional monitoring would need to be linked to existing or potential future water use activities or alternatively to aid general environmental monitoring as part of a Watershed Management Plan execution. It is recommended that such a programme could be operated by WASA in conjunction with CEHI.

3.1.6 Institutional Issues

At the moment two organisations are involved in hydromet data gathering and analysis. The Meteorological Services Department under the Ministry of Communications, Works and Transport (MoCWC) and the Agricultural Engineering Services Division of the Ministry of Lands, Forestry and Fisheries (MoALFF). The former is primarily responsible for the operation of the climatological stations at the two airports, Vigie and Hewanorra. The organisation is more concerned with synoptic forecasts and providing information for the two airport control units and the radio and television broadcasts. The Meteorological Services Department providing information for shipping etc.

To date no radar system has been introduced into the weather forecasting mechanism of NMS although there is a regional initiative to replace the old radar systems on some islands with new doppler radar equipment, however funds have yet to be secured. Currently the NMS are wishing to expand their activities and see the hydrometeorological and agrometereological areas as being potential areas. However, their staffing is primarily meteorologists and their assistants whilst the main area of overlap, rainfall measurements, NMS have one unit at each of the two main airports.

As mentioned above, SLBGA, are involved in the measurement of weekly evaporation measurements at several stations around the Island, whilst WASA undertake analyses of raw water and treated water qualities at their treatment and some water storage sites. The SLBGA information is believed to be stored centrally at the WINBAN office in the Roseau Valley. The WASA water quality testing is undertaken in their relatively new laboratories at Ciceron.

WASA are currently installing an advanced SCADA sytem to monitor the performance of and assist in the operation of their various water treatment plants and distribution systems. The telemetric system has spare capacity and WASA have indicated that some hydrometeorological information or hydrometric data could be managed by the system. This could include a data logger raingauge at the roseau Dam, waterlevel recorders at selected WASA intake sites and perhaps one or two of the data logger water level recorders which are to be installed next year.

In relation to water quality, excellent laboratories are available at the CEHI Offices on the Morne in Castries. The laboratories can undertake a variety of tests which cannot be undertaken at the WASA laboratories including, if required, chemical analyses related to pesticides and herbicides. {The laboratory kindly undertook TSS (Total Suspended Solids) analyses of river water samples taken by the Consultants in November 1996)}.

The AESD is currently responsible for the collection of data from the other raingauge and climate stations over most of the Island. The main interest of AESD is in agrometeorological data. Monthly 'Agromet Bulletins' are produced summarising the data of that month and comparing rainfall and water deficits (Effective Rainfall- Evapotranspiration Estimates) for the month and for the preceding months of the year. Mean values over the period 1982 to 1995 are also presented for information. Isohyet plots are also incorporated. The document is quite useful giving guidelines for farming activities. An Annual Agromet Bulletin is planned to be produced in February 1997.

Stream flow gauging was undertaken in the past by both AESD and WASA, however, an agreement was reached whereby AESD would take over full responsibility for this role, primarily focused at dry season base flows, due to both budgetary and staff capability levels within WASA. At the moment, due to recorder damage and malfunctions, no river gauging is being undertaken. However, use could be made of the SCADA system currently being installed at WASA to relay data back from various data loggers with possibly a terminal link to AESD.

There are plans to establish a National Hydrological Programme to link to the International Hydrological Programme. This would entail close collaboration between AESD, Meteorological Services, CEHI and OECS. It would be useful if representatives of WASA and MCW&T also be involved, perhaps in secondary roles.

From the above, the agrometeorological data gathering system would appear to be reasonably well actioned, especially with the introduction of the new rainfall data loggers and tipping bucket devices installed under Phase 1. However, the hydrometric system is in very poor status and needs to be re-activated and updated.

In terms of staffing levels, the following are the characteristics of the main organisations deemed to be involved in the hydrometeorological process:

AESD
- 1 Graduate Engineer as supervisor;
- 1 Senior Technician in charge of weather stations (3) and rainfall stations (26);
- 2 Technicians.

NMS
- 1 Senior Meteorologist (as Director of NMS);
- 2 Meteorological Officers (Data Collection and Analyses at Vigie and Hewanorra);
- 21 Meteorological Officers (?) Weather Forecasting at Hewanorra Airport;
- 5 Meteorological Weather Forecasting at Vigie Airport;

WASA
- 1 Water Quality Engineer / Laboratory Technician (?).

Department of Health - Environmental Officer(s)

3.2 Equipment Purchased and Installed under Phase 1

The proposals of the December 1994 World Bank Mission for new hydrometeorological equipment is given in **Figure 3.6.**

A list is presented in **Table 3.7** 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 (UK). Training has been undertaken by a representative from Casella who travelled out from the UK in September 1996.

The approximate locations of the new equipment is given in **Figure 3.7.** The majority of the tipping bucket rainfall data loggers have been installed at the sites of existing chart or manually read

SAINT LUCIA WATERSHED AND ENVIRONMENTAL PROJECT

HYDROMET NETWORKS AS REPORTED BY WORLD BANK MISSION - DECEMBER 1994

Figure 3.6

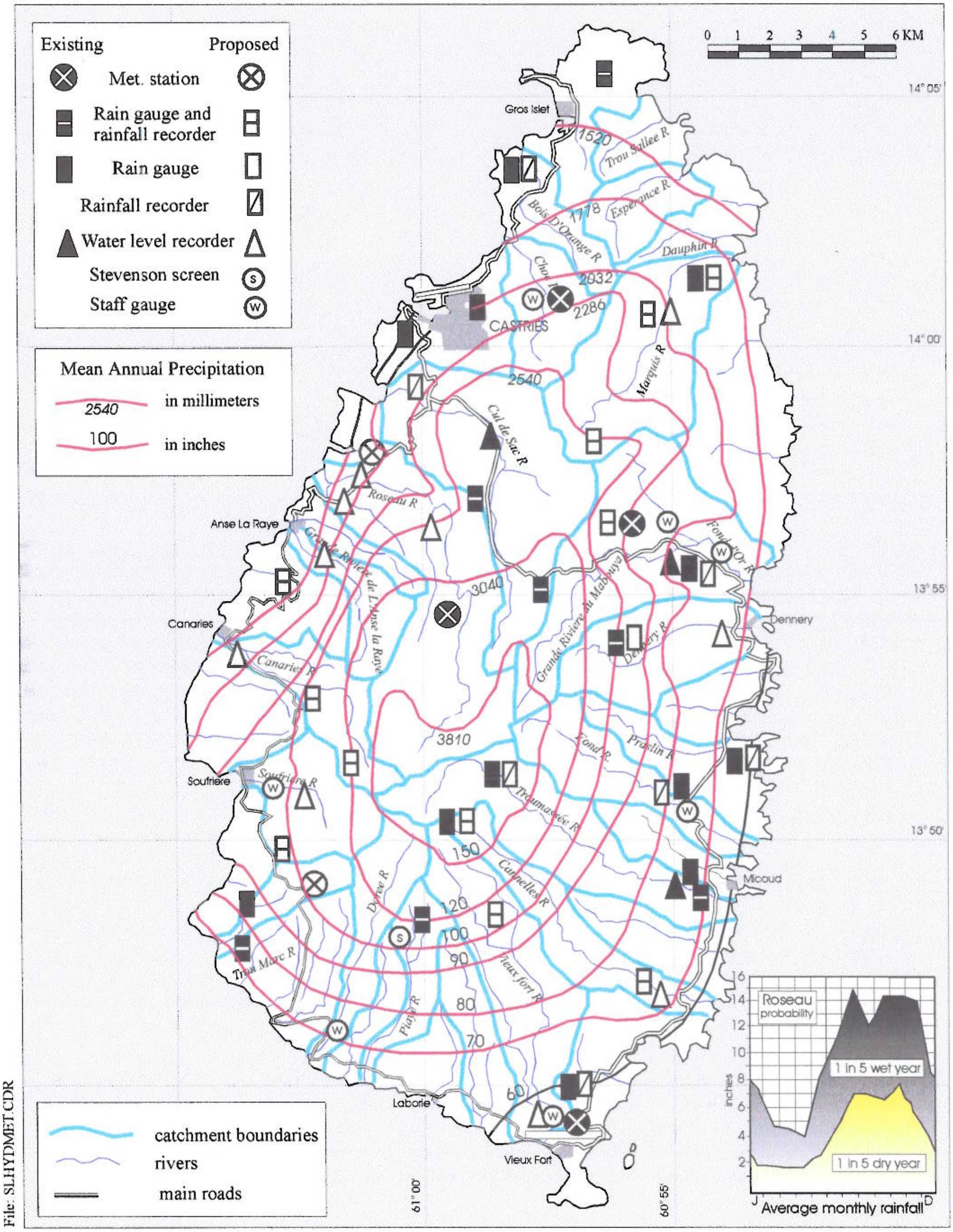


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Table 3.7

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

ITEM	NUMBER	UNIT PRICE	TOTAL	PRICE EC$
Casella Limited (UK)		UK Pounds		EC$ (@4.26)
Tipping bucket rainfall recorder with integral logger	26	698.00	18148.00	77310.48
Snowdon Raingauges	7	87.00	609.00	2594.34
Sunshine recorder with charts	1	744.00	744.00	3169.44
Stevenson Screen large	3	554.00	1662.00	7080.12
Thermohygrograph with charts and bottle	1	579.00	579.00	2466.54
Maximum thermometer	1	36.00	36.00	153.36
Minimum thermometer	1	33.00	33.00	140.58
Kew Hygrometer	1	117.00	117.00	498.42
Cup counter anemometer (windrun)	2	1702.00	3404.00	14501.04
Measuring jar	7	19.00	133.00	566.58
Evaporation Pan Class A with stilling well and hook gauge	2	465.00	930.00	3961.80
Staff Gauges	12	65.00	780.00	3322.80
Automatic Weather Station including data organiser	1	5990.00	5990.00	25517.40
Airfreight and insurance			1660.00	7071.60
TOTAL			**34825.00**	**148354.50**
Valeport Ltd. (UK)				
Revolution counter for repair	1	116.50	116.50	496.29
Airfreight and insurance		38.00	38.00	161.88
SUBTOTAL			**154.50**	**658.17**
Control unit with PC interface lead	1	650.00	650.00	2769.00
BFM0020/1 Impeller with nose cone	1	85.00	85.00	362.10
BFM0020/2 Impeller shaft	1	34.00	34.00	144.84
BFM0020/4 Reedswitch assembly	1	29.00	29.00	123.54
SK14, 14 kg sinker weight	1	338.00	338.00	1439.88
Airfreight and insurance		?	?	?
SUBTOTAL			**1136.00**	**4839.36**
TOTAL			**1290.50**	**5497.53**
Stevens Water monitoring Systems (USA)		US $		EC$ (@2.72
Type A/F Logger system for use with Type F water level re	3	2070.00	6210.00	16891.20
(including: encoder, data card, communications cable, battery, weatherproof enclosure)				
Card reader	1	675.00	675.00	1836.00
Spare data card	3	190.00	570.00	1550.40
Airfreight and insurance			370.55	1007.90
SUBTOTAL			**7825.55**	**21285.50**
5" copper float	3	65.00	195.00	530.40
6 oz. Counterweight	3	16.00	48.00	130.56
Stainless steel beaded cable (ft)	75	1.75	131.25	357.00
Set of end hooks	3	12.00	36.00	97.92
Pack of 12 cartridge pens	1	42.00	42.00	114.24
Airfreight and insurance		150.93	150.93	410.53
SUBTOTAL			**603.18**	**1640.65**
TOTAL			**8428.73**	**22926.15**
Hope Hydrology (The Netherlands)		Dfl		EC$ (@1.72
Tirtaharapan Pressure logger Type 5A, absolute 5 bar	1	3850.00	3850.00	6622.00
Airfreight and insurance		350.00	350.00	602.00
TOTAL			**4200.00**	**7224.00**
CMI (Barbados)		BB$		EC$ (@1.35
Thermometers, wicks, charts		2834.50	2834.50	3826.58
TOTAL			**2834.50**	**3826.58**
Total paid on equipment to date is			**EC$**	**187828.75**

(this excludes the airfreight for the second Valeport shipment which has not arrived as yet)

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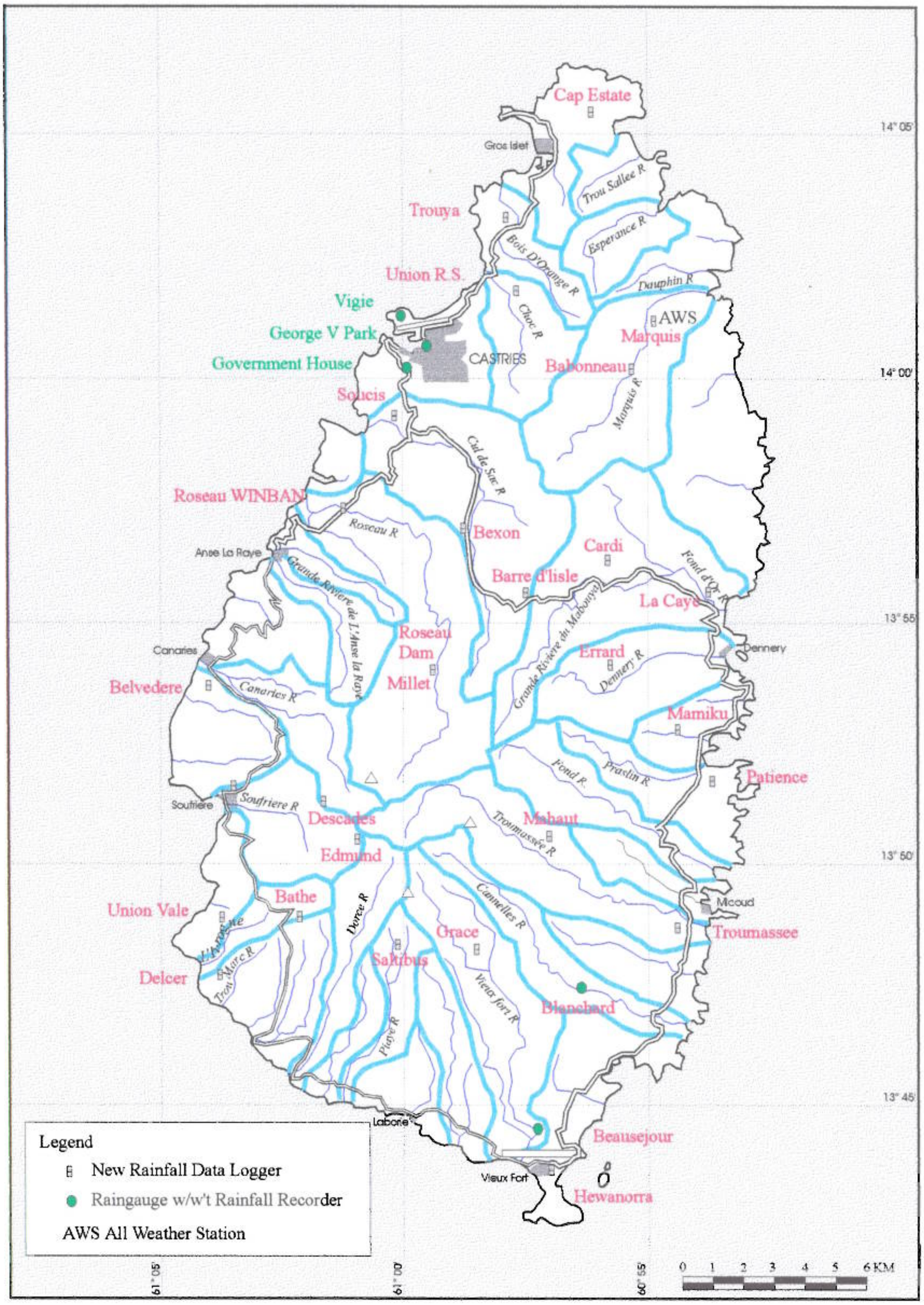
Figure 3.7

Location of Climatalogical Equipment Supplied under Phase 1



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raingauges.

The integrated automatic weather station has been established as a temporary measure outside the AESD office in Union. It is proposed that this is transferred to Cas en Bas.

12 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 have been put in position already, see list given in **Table 3.8**. It is proposed that some checks are made of the proposed sites although many items of equipment will be replacing stations lost or damaged during TSD. The continuation of records at a particular site is an important consideration in the assignment of positions for the new gauges. See **Photos 21,22 23** and **24**.

With regard to the rainfall data loggers, it has been decided to maintain the use of the old raingauges for at least one year, taking records from both in parallel. This should be undertaken to enable a correlation to be obtained of the relationship of the new rainfall measurements with recent records. One of the shortcomings of a tipping bucket type raingauge is the potential from inaccuracies in the hot, relatively dry season. This issue will thus be studied although no major problem is foreseen.

No water level recorders have yet been established since work is required to be undertaken during the dry season. Three old rehabilitated units are to be put in place as well as the single new Stevens Type Chart Recorder and the pressure transducer unit. Plans are in hand for the re-introduction of streamflow measurement equipment during the coming dry season. This includes not only the installation of the new equipment but also the re-installation of water level recorders which had been removed from damaged installations over the last couple of years. It is agreed that MCW&T undertake the civil works to enable the water level recorder equipment to be installed in the River Troumassee (Beauchamp), River Mabouya and the Cul de Sac River.

3.3 Prioritisation of Watersheds and Instrumentation Needs

3.3.1 General

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

Only two continuous water level recorders will be in operation based on the current equipment procured. 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, short time of concentration 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 is being explored, perhaps by modifying the existing gauges which have been procured.

Table 3.8

Siting of New Hydrometeorological Equipment as received under Phase 1

{by November 1996, about 85% of the installations were operational}

	Name Station	Rainfall equip	New equipment	Posts	Fence	Gate	Date completed	Date equip. installed	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	*Desraches*		TB, RG	yes	yes	nn	SEP96		
28	*Grace (School)*		TB, RG	yes		nn			
29	*Soufriere (The Still)*		TB, RG	yes		nn			
30	*Canaries (Belvedere)*		TB, RG	yes		nn			
31	*Millet (Roseau Dam)*		TB	nn	nn	nn	-		
32	*Anse la Raye (School)*		RG, RR	yes	yes	nn	SEP96		
33	*Blanchard (School)*		RG, RR	yes		nn			

nn = not necessary; RR = Rainfall Recorder; TB = Tipping Bucket rainfall recorder; RG = Rain Gauge; AWS = Automatic Weather Station; Anem. = Anemometer.

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ıoto 22 Soucis Data Logger, Cul de Sac Watershed (November 1st 1996)

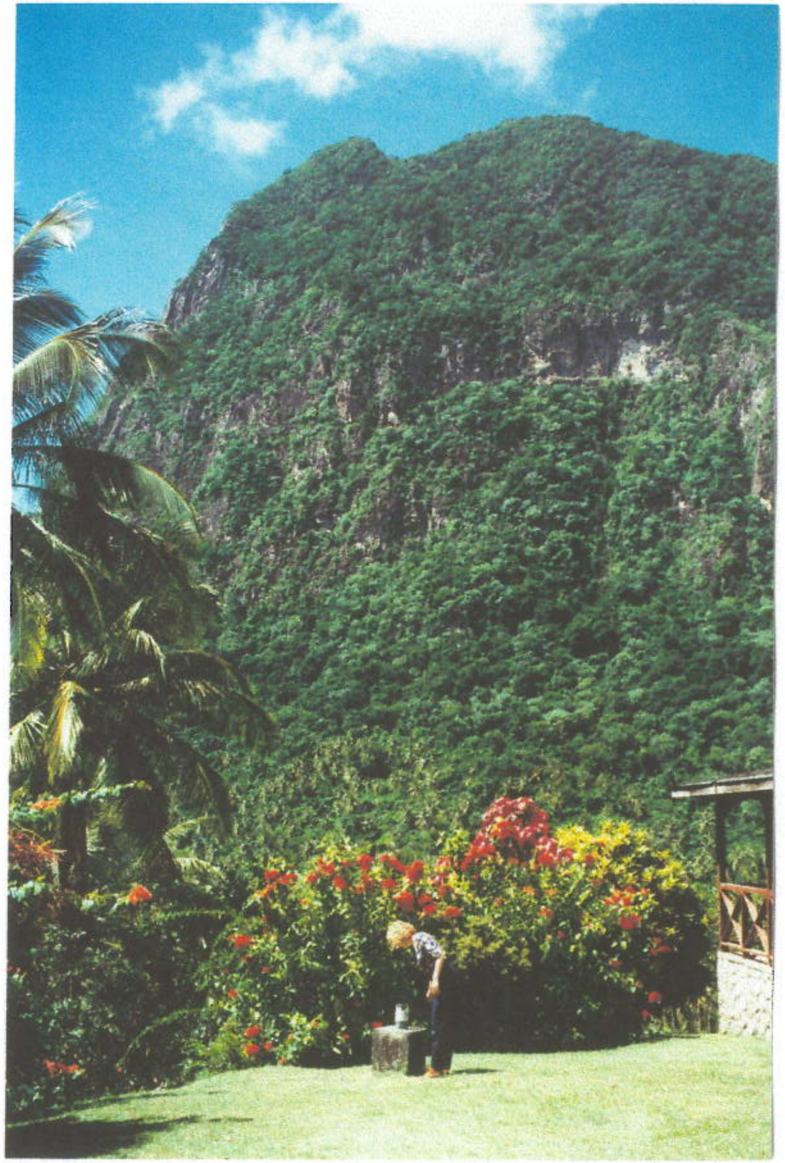


Photo 21 Existing Union Vale Raingauge: Now augmented by Rainfall Data Logger

Photo 24 Patience Rainfall Data Logger. Tipping Bucket arrangement.

Photo 23 Patience Rainfall Data Logger. Instructions being given to operator. (Novei

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 catchments on the island;
- 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 in the years to come as demands increase. {There is a growing interest in irrigation and with potential recommendations for crop diversification this could become a problem for the limited resources in the river system particularly when there would appear to be no abstraction controls, water rates or clearly defined water rights leglislation};
- 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 be derived based on an analysis of rainfall events over a period.

Finally, it is considered important that sediment and bed load measurements are undertaken and correlated with discharges in the main river system. Equipment and procedures for doing this should be considered for procurement. This need was identified in the World Bank Report and stated as an action for Phase 2 of the Project.

The river surveys which have been undertaken as part of Phase 1 indicates the expected natural profile giving relatively constant slopes over the meandering parts of the river to progressively steeper and concave slopes in the mountains where the channel is more confined in a ravine. Changing the channel slope appreciably in a meandering river, without bed level control can destabilise the channel and also cause degrading of the upstream channel until the alluvial channel is again close to a regime condition. Knowledge of the sediment loadings of the river system and of the bed material is required to enable these aspects to be studied.

Since erosion and the loss of soil from the land and the impact on the marine environment are key concerns, it is important that sediment discharge estimates are improved. Few measurements have been undertaken whilst those related to the building of the Roseau Dam are related more to estimating the sedimentation rate in the reservoir as against the loss from the river network. Depth integrated sampler equipment is recommended for use at the main bridges on:

- the Cul de Sac River;
- the Roseau River;
- the Mabouya - Fond d'Or River;
- the Vieux Fort River;
- the Soufriere River;
- the Canaries River.

The impact of the sediment deposition in the drainge systems in the flood plains impedes drainage and tends to create waterlogging problems and hence reduced crop yields. The design of systems to reduce this tendency needs consideration although this would increase the sediment loads in the main channel system. Regular drain re-excavation should be undertaken in the plantations with the excavated material being placed in positions where it will not subseqently pass back into the drainage channels or pass out into the river system. Sediment load concentrations would help in this analysis.

It is assumed that water quality measurements will continue to be the responsibility of WASA.

3.3.2 Main River Gauging.

Many of the rivers in St Lucia are difficult to gauge across the full range of discharges. Not only are peak flows very ''flashy' and often significantly out of bank, the base flows during the majority of the year are often very small.

Standard stilling wells with floats or other water level measuring devices can function well as long as a good, blockage free connection with the water in the river can be achieved. However, most of the rivers carry high sediment loads in the wet season, particularly during high flows. These high sediment concentrations can easily cause problems with blockage of the stilling wells as well as through changing the configuration of the channel bed.

Only the Troumassee river gauge is reported to have any lateral pipe connection with the river. The Mabouya River Gauge as well as those at Ferrands Bridge (Cul de Sac River) and at the main road bridge across the river Roseau all just have a 200mm to 300mm diameter heavy duty plastic pipe with the bottom open as the stilling well. These gauging stations have all had operational problems reported in the past and it is considered that many of these are related to the influx of sediment into the stilling well and causing blockage or damage to the float mechanism.

The other problem evidenced has been the location of the stilling wells. The ones at Ferrands bridge on the Cul de Sac River and the one in the River Roseau were both susceptible to damage through the impact of floating debris during flood events. It is appreciated that both gauges were damaged during TSD, when unusually large volumes of debris were in the flood flows. As indicated earlier, the damage to the Ferrands Bridge gauge was attributed to a combination of damage by TSD as well as river works upstream post TSD and heavy use of the bridge. A new site has been identified since the Ferrands bridge is now in a very bad condition.

Since all the hydrometric gauges are currently inoperable, mainly through damage to stilling wells and changed river configurations, there is the opportunity of re-establishing the gauging stations and addressing the problems which caused the previous failure. This in essence means ensuring the stilling wells are well protected and that intake ducts are installed which will provide for a better and more reliable connection between the stilling well and the river. Where possible, access to this ducting should be designed to facilitate maintenance.

Particular Issues:

Low flows.

As indicated in Table A.14, low flows in the rivers in St Lucia are generally less than 180 l/s excepting the River Troumassee. When such low flows occur in channels with bed widths in their lower reaches of between 5m and 20m, the depth of flow is very small, probably less than 100mm. Added to this is the variability of channel bed configuration from one storm event to the next makes any stage discharge relationship developed for the gauging site extremely uncertain. Changes in discharge between say 50 l/s and 150 l/s might be almost undetectable if bed configurations change. Hence, accurate measurement of base flows in the natural channel section through the use of continuous water level monitoring could be unreliable. This fact needs to be appreciated since there is the danger that a rating curve will be developed which, linked to the information from the data logger linked to the active stilling well would yield a 'definitive' discharge hydrograph. The potential inaccuracies of this hydrograph needs to be understood. Figure 3.5 presents the stage discharge relationship for the River Troumassee, the river with the highest dry season flows and probably the best for round the year gauging. Still, the relationship below 300 l/s is indicated as being uncertain.

Because of the uncertainty of the water level related gauging of low flows, a regular programme of current meter measurements should be undertaken. However, the low depths of flows and irregular channel bed will also make current metering difficult during low flows. The shallow flow will give rise to problems both of positioning of the current meter and of turbulence caused by the high relative roughness of the irregular channel bed in relation to the depth of flow. Careful selection of the gauging site will be required.

In order to facilitate the measurement of low flows, three potential options exist:

i. construction of a re-inforced concrete slab across the channel at the gauging site into which is incorporated a central weir or low flow channel section to concentrate low flows and hence provide a fixed bed width and greater flow depths;

ii. the use of sand filled gunny bags (or fertilizer bags) to form a low flow channel each time a current metering is undertaken. The bags would be used to create a channel of about 1.5m width and 10m length, with the upstream section 'funnelled' to improve the streamlining of flows approaching the gauged section. The gauging would be undertaken by current metering (note the impact of this on water levels being monitored by the stilling well and float system would need to be recorded to ensure that records were adjusted once the data logger information had been down loaded);

iii. basically as per the previous option but using a parshall flume or similar gauging apparatus to measure flows in the constricted section. This would need the construction of a parshall flume in plastic, fibreglass or steel plate which would be lifted into the river section each time a gauging was required;

Option 'ii' will be the preferred choice, however it is recommended that if time permits the development of some form of mobile flume gauge should be fabricated whilst the construction of a special low flow weir structure should be considered for the Cul de Sac River, just upstream of the proposed new gauging station by the old bridge.

Another factor which must be appreciated is the impact of water abstractions from the river system on low flows. The low flows recorded in the past have in places been defined as 'base flows'. These numbers being assumed to represent the unused resources within the river. However, the spatial and temporal factors related to the measurement must be considered. Abstractions for irrigation and other uses upstream during a low flow gauging should be noted to enable a 'naturalised' dry season flow to be calculated. Similarly, any use of water for irrigation or other purposes downstream of the gauge site could mean that the recorded low flow discharges are already 'assigned', at least in part, to existing use. Surveys need to be undertaken during the dry season to attempt to evaluate the true naturalised base flow of each of the rivers in relation to the gauged discharges. This needs to be evaluated for all the rivers on which discharge measurements are taken.

In order to investigate the issue of river water abstractions in the dry season, it is recommended that a more intensive current metering programme is undertaken on perhaps one of the rivers where water use is thought to be high. This would entail undertaking measurements at three or four sections of the river in the lower slopes of the stream on the same day.

The gauging of the low flows of streams other than the rivers Troumassee, Sul de Sac, Mabouya and Roseau is also planned.

Where staff gauges are to be installed on some rivers with daily water level measurements, the recording of base flows will be difficult even if a good site is identified.

High flows.

High flows are often very 'peaky' with rapid rise in water levels in the major rivers, the flood event being over it's major impact in a matter of about 3 to 4 hour.

The high water levels associated with the high flows are almost always out of bank. With the land use characteristics in the flood plains, flows in the out of channel area can be difficult to estimate and with the changes in the maintenance of the drainage network within the banana plantations, can be variable from flood to flood. Access into the banana plantations during a flood is possible, but needs a concerted effort to undertake a flood plain discharge measurement. Nevertheless, this needs to be undertaken at high flows to enable the stage discharge curve to be reasonable representative of the flood flow situation.

The stilling wells and data logger housing arrangements must be placed clear of any potential maximum flood event. With the knowledge of TSD, October 26th 1996 and previous experience at the proposed sites, this does not cause a significant problem. Peak water levels are known.

Where staff gauges are to be installed in some of the rivers, it will be necessary to organise more frequent measurement of water levels during flood flows. The staff gauges were bought previously and it is intended to install them on some of the smaller rivers to ascertain their effectiveness. A dedicated staff reader is essential in the context of the flow regime of the St Lucian rivers.

In order to improve flood hazard mapping, a number of crest level gauges are proposed. These will indicate peak water levels during a flood event and enable flood hazard mapping to be refined. This flood level measurement should be linked to a programme of Flood Event Reporting, checking on the extent and depth of flooding across the flood plain, especially in areas where infrastructure exists.

Main stations for development in the period February to July 1997.

3.4 Equipment Planned for Phase II of the Project

3.4.1 Site Location and Equipment Description

Table 3.9 summarises the Phase I supply and installation of equipment, the proposed equipment for Phase 2 as well as a summary of the original recommendations for equipment as given in the World Bank Mission Report of December 1994.

The main focus required is seen to be the measurement of river flows, both peak flows in the winter and dry flows in the March to June period, together with the estimation of sediment discharges. This latter factor will be important in monitoring the potential success of a watershed management programme.

Typical arrangements for the facilities to measure both low flows and high flows are given schematically in **Figures 3.8 and 3.9.** This layout would need to be modified for each of the sites.

Experience has shown that the development of such installations takes time. It is therefore proposed that temporary hydrometric stations are established at each of the sites to measure medium to high flows and that a current metering programme be established for the low flow gauging.

Cul de Sac River.

A new site has been identified for development as a gauging station. It is at the location of the old bridge across the River Cul de Sac some 400m downstream of Ferrands Bridge (and the Texaco Petrol Station).

It is proposed to offset the main stilling well assembly some 4 to 5 metres away from the upstream right bank pier of the old bridge. Two pipe ducts are proposed to feed from the river to the stilling well to ensure that low flows are monitored whilst in pipe filtered holes in the stilling well will help record high flows. A schematic layout is given in **Figure 3.10.**

Protection to the structure is provided by an old tree upstream with the bridge providing some protection downstream. Separate protecting bars are proposed upstream of the well itself if a vertical plastic pipe arrangement is selected.

Just upstream of the bridge, it is proposed to put in place a concrete apron such as to concentrate low flows in a relatively narrow preformed throat section.

During the construction of the stage discharge relationship, the impact of afflux caused by the bridge structure during high flows needs to be taken into account as well as the scale of over road/ bridge flows during flood events.

Roseau River

The existing damaged stilling well, of about 300mm dia rigid plastic, is located some 4m from the edge of the river bed, on the upstream right bank of the main road bridge near the WINBAN research station. The stilling well reaches up to just above road level however the lower section is embedded in the river bank. The well is out of vertical alignment owing probably to being hit by floating debris. The pipe is totally exposed with no supporting or protecting cage and would form a section around

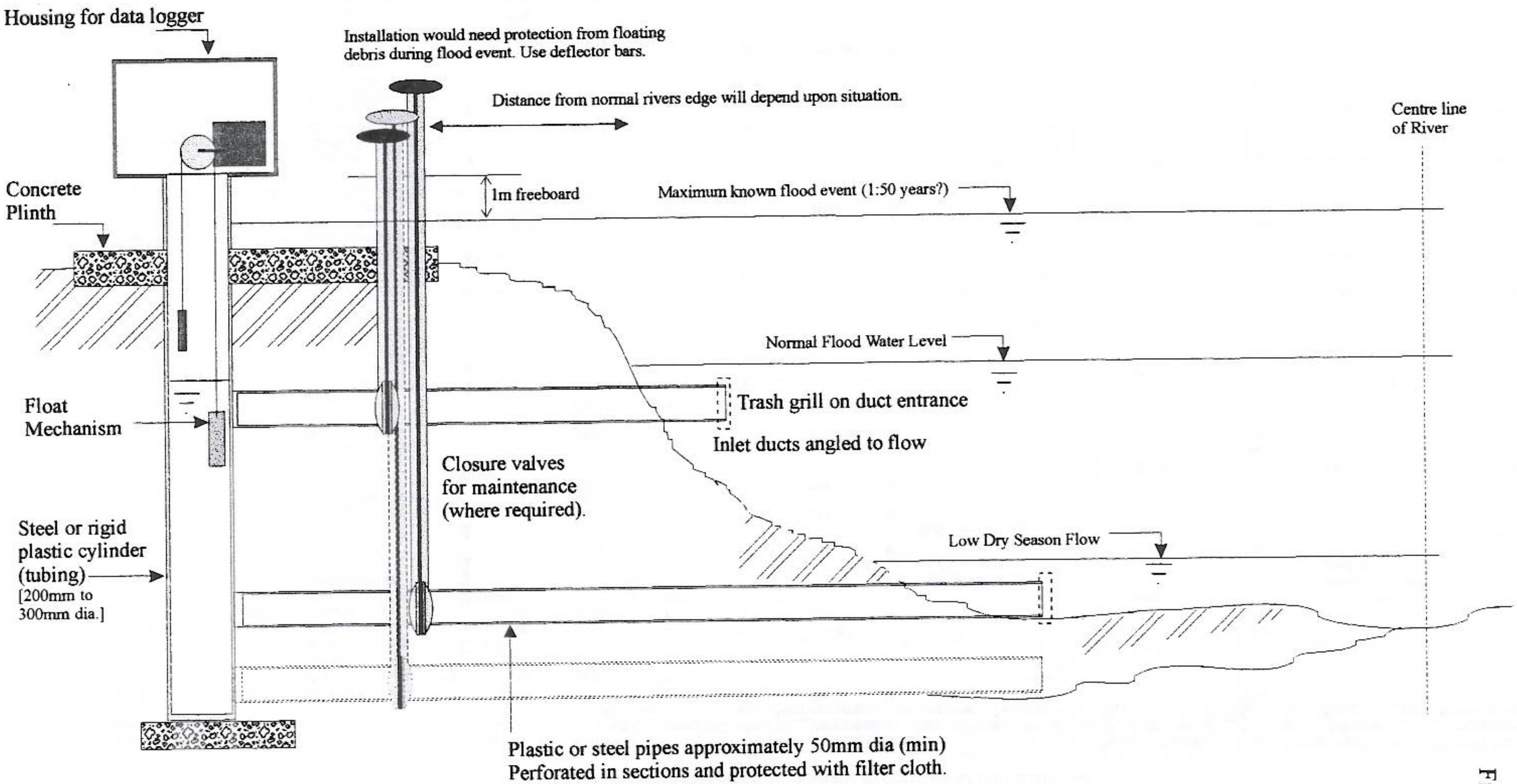
Table 3.9

Hydrometeorological Equipment Proposals and Installation

Catchment Name	Rainfall Station Nr.	Ref.Nr.	Name	Date of Installatio	Elevation m	New or Existing Met	New or Existing Hydr	Usable data during TSD	Operational after TSD Met	Operational after TSD Hydr	Phase 1 Meteorological Instrument	Phase 1 Meteorological Type	Phase 1 Hydrometrical Instrument	Phase 1 Hydrometrical Type	Phase 2 Procure Meteorological Instrument	Phase 2 Procure Meteorological Type	Phase 2 Procure Hydrometrical Instrument	Phase 2 Procure Hydrometrical Type	Phase 2 Installation & after Meteorol. Equip	Phase 2 Installation & after Meteorol. In?	Phase 2 Installation & after Hydromet Equip	Phase 2 Installation & after Hydromet Site/In	Phase 2 Proposed New Equipment Meteor.	Phase 2 Proposed New Equipment Hydromet
Marquis	4	4-R-1	Marquis Estate	1908	35	X		N	Y		RR	M			AWS				Cass	Y				
		4-R-2	Marquis Babonneau (to '91	1958	46	N		N							RR+RG				Cass	Y				
			Chassin												RR+RG									
			Marquis (Boquis)	{1986}			N										WLR							
Fond D'or	6	6-M-1	CARDI La'Resource	1980	14	X		N	Y		RR+EP	E							Cass	Y				
		6-R-1	La Caye	1907	25	X		Y	Y		RR	M							Cass	Y				
			Mabouya (Bridge)	{1984}			X	N??		Y							WLR				RI (Stevens	Y/N		
			Derniere Riviere				N						Staff Gauge	M							Staff G	N/N		
			Main Channel				N						Staff Gauge	M							Staff G	N/N		
Dennery	7	7-R-1	Errand Estate	1986	70	X		Y	Y		RG	M							Cass	Y				
			Dennery				N						Staff Gauge	M			WLR							WLR
Mamiku Patience	9	9-R-1	Mamiku Estate	1907	8	X		N	Y		RR	M							Cass	Y				
Fond	10	10-R-1	Fond Estate (closed in '86	1907	50																			
		10-R-2	Patience Estate	1951	92	N			Y		RR	M							Cass	Y				
			Fond River				N										Staff Gauge				Staff G	N/N		WLR
Troumasse	12	12-R-1	Troumasse Estate	1982	17	X			Y										Cass	Y				
		12-R-2	Mahaut Estate	1952	129	X		N	Y-RI		RR+RG	M							Cass	Y				
		12-R-3	Quilesse (until '78)	1935	320	-																		
		12-R-4	Edmund Forest	1979	490	X		N	Y		RR	M							Cass	Y				
			Beauchamp Estate	{1984}			X-RI	N	N								WLR				RI (Stevens	N		
Canelles	14		Main channel				N										WLR							
Roarne Rugeine	15	15-M-1	Hewanorra Airport	1974	10	X		N	Y-RI										Screen	N				
Vieux-Fort	16	16-R-1	Beausejour (Vieux F)	1975	16	X		Y	Y															
			Woodlands (not now proposed)			N									RR+RG									
		16-R-2	Grace School			N													Cass	Y				
			La Retraite Bridge	{1984}									Staff Gauge	M							Staff G	Y/N		WLR
Doree	21	21-M-1	Saltibus	1985	282	X		Y	Y		SS				HMS				Cass	Y				
			Coast Road Bridge	{1984}			N						Staff Gauge	M			WLR				Staff G	N/N		
Choiseul	22	22-R-1	Delcer School	982	206	X		Y	Y										Cass	Y				
L'Ivrogne	23	23-R-1	Union Vale	1923	242	X		Y	Y										Cass	Y				
		23-R-2	Bathe Nursery	1948	367	X		Y	Y		HMS	M							Cass*1	Y				
Soufriere	25	25-R-1	Belfond Soufriere (not use	1983	495	-									RR+RG									
		25-R-2	{Site to be determined}			N																		
			Soufriere				N						Staff Gauge	M			WLR		Cass	Y	Staff G			WLR
Canaries	27	27-R-2	Canaries - Belvedere	1985	54										RR+RG				Cass	Y				
		27-R-1	Desraches	1986	620	X		N	N						RR+RG				Cass	Y				
			Canaries				N										WLR				Staff G			WLR
Anse Galet	28		Anse Galet/Cochon			-					RR+RG	M												
Anse la Raye	29		Sugar Estate (?)			N													RR&R	?				WLR
Roseau	31	31-M-1	Roseau Winban	1966	5	X-RI		N	Y-RI		RR+EP	E							Cass	Y				
		31-R-1	Roseau Yard (not used)	1970	5	-																		
		31-R-2	Roseau Dam	1996		N																		
		31-R-3	Millet Tete Chemin (not us	1983	260	-																		
			Roseau Bridge				X	N		N			WLR	E							RI (Stevens	Y/N		
			Ciacot Bridge				X	N		N			WLR	E							Staff G			
Cul De Sac	33	33-R-1	Soucis	1908	9	X		Y	Y		RR	M							Cass	Y				
		33-R-2	Bexon School	1985	23	X		Y	Y										Cass	Y				
		33-R-3	Barre de L'Isle	1984	290	X		Y	Y		RR	E							Cass	Y				
		[WASA]	Ravine Poisson	{1983}																	?			
			F Deoglos Bridge	{1985}			X	Y		Y			WLR	E							RI/N Trans	Y/N		
Castries	34	34-M-1	Vigie Airport	1970	3																			
		34-R-1	Government House	1945	137																			
		34-R-2	George V Park	1890	6																			
Choc	35	35-M-1	Union Agric. Stat.	1923	11	X		Y	Y		RR+EP	E							Cass	Y				
Bois D'Orange	36	36-M-1	Marisule	1984	61																			
		36-R-1	Trouya	1977	15	X		Y	Y		RR	M							Cass	Y				
Cap	37	37-R-1	Cap Estate	1982	23														Cass	Y				

Water Level Recorder in Natural Streams : High and Low Flow Gauging

{Outline sketch only}

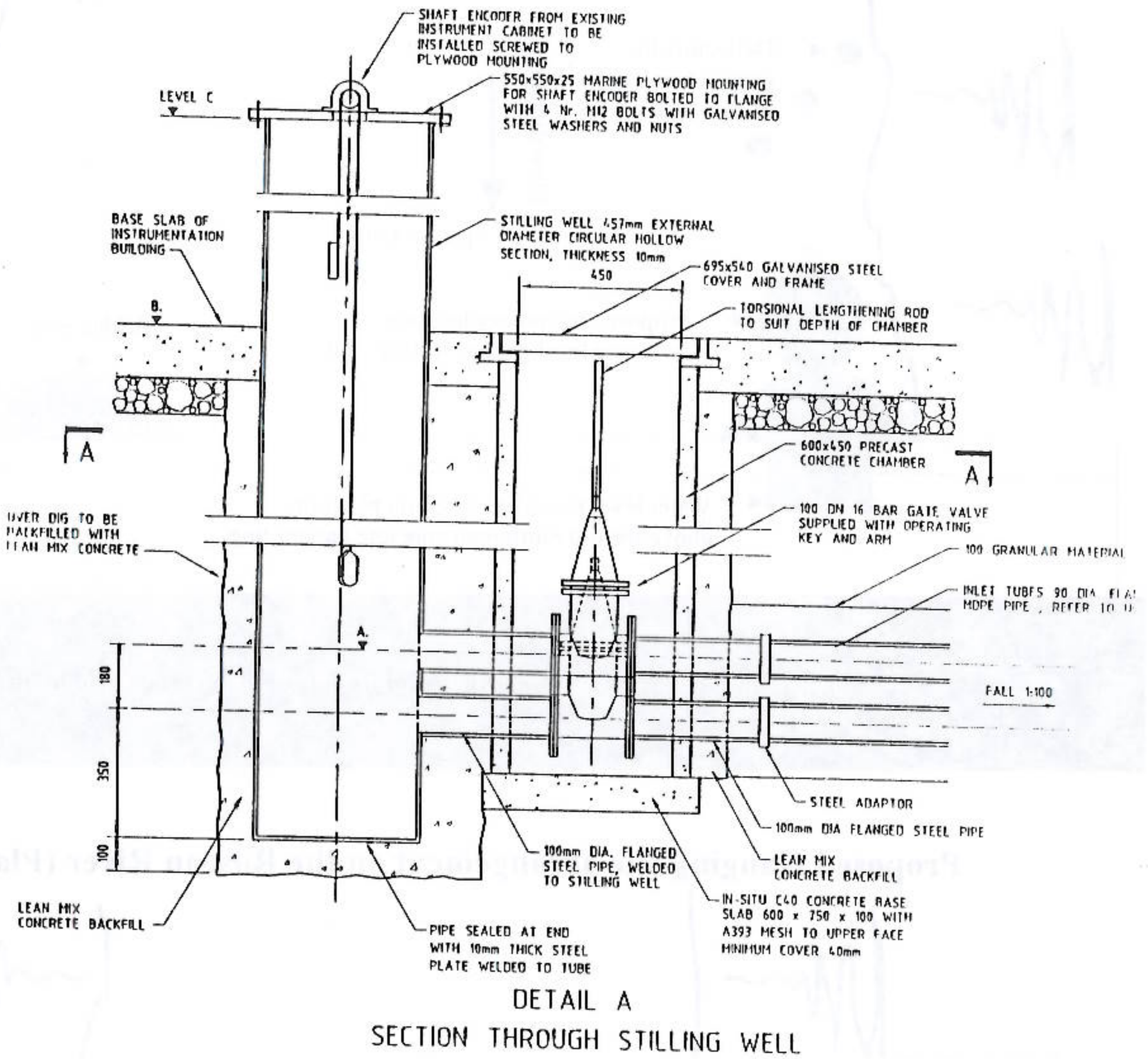


Note: Access/ facility for regular cleaning out of intake ducts is critical

Figure 3.8

Figure 3.9

Typical Layout of River Gauging Station Stilling Well for an Average U.K. Gauging Site.



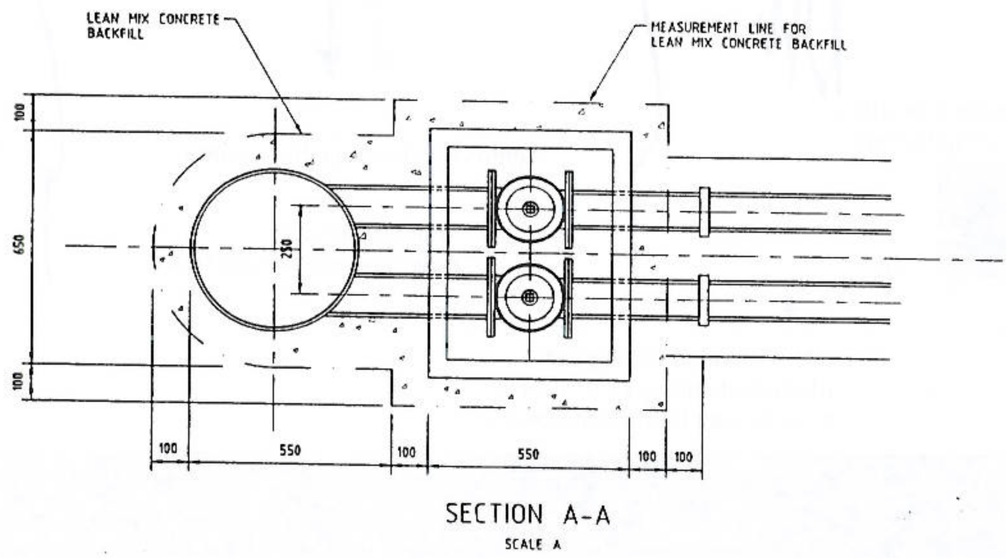
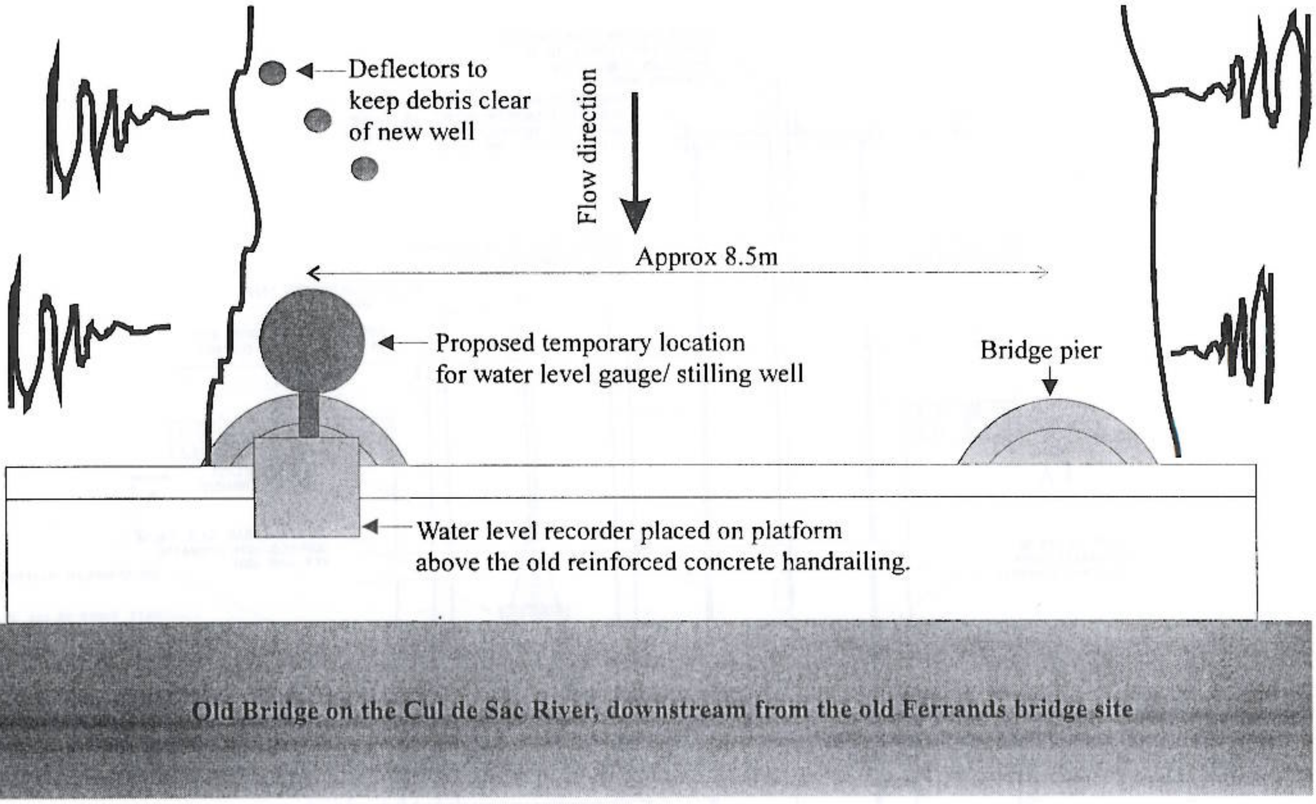


Figure 3.10

Proposed Gauging site arrangement on the Cul de Sac River (Plan)



Proposed Gauging site arrangement on the Roseau River (Plan)

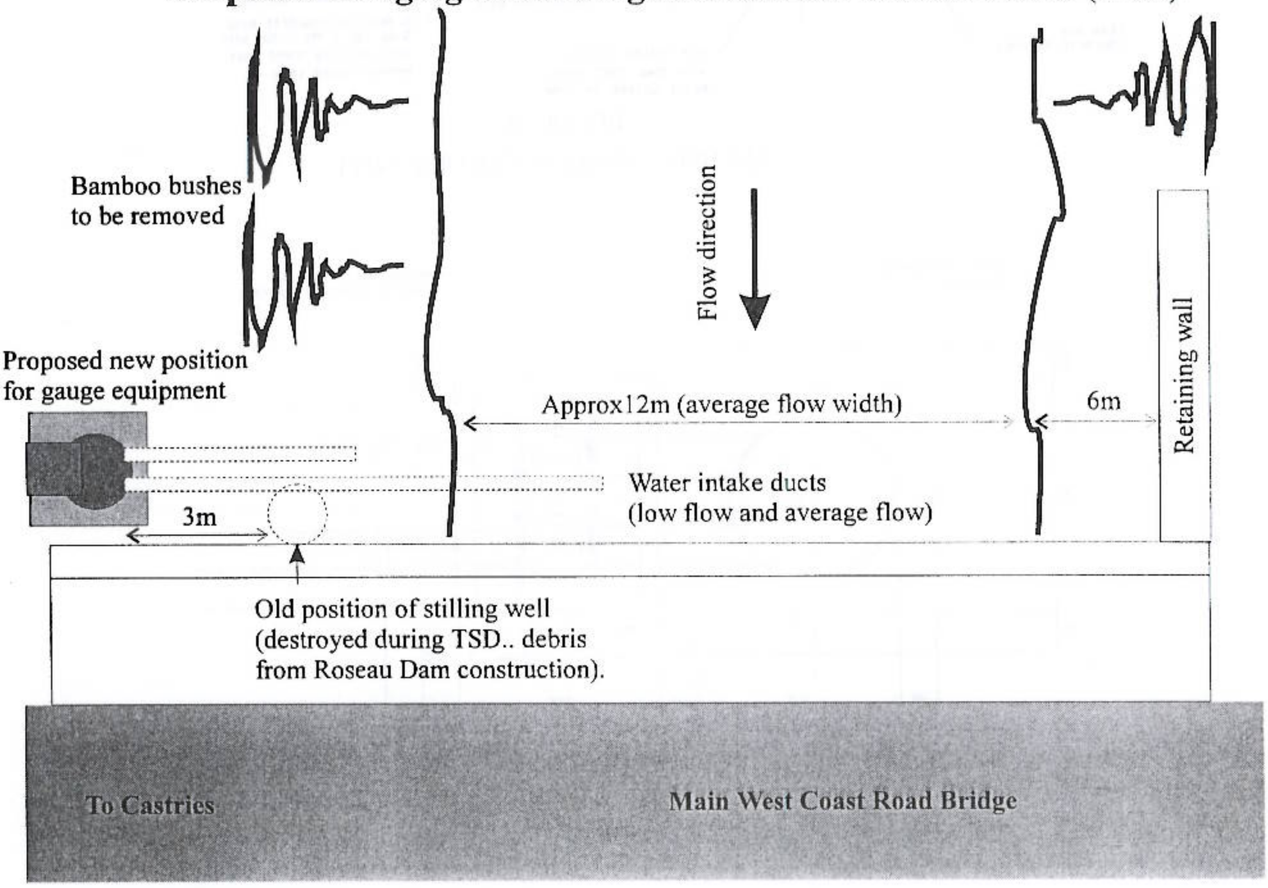
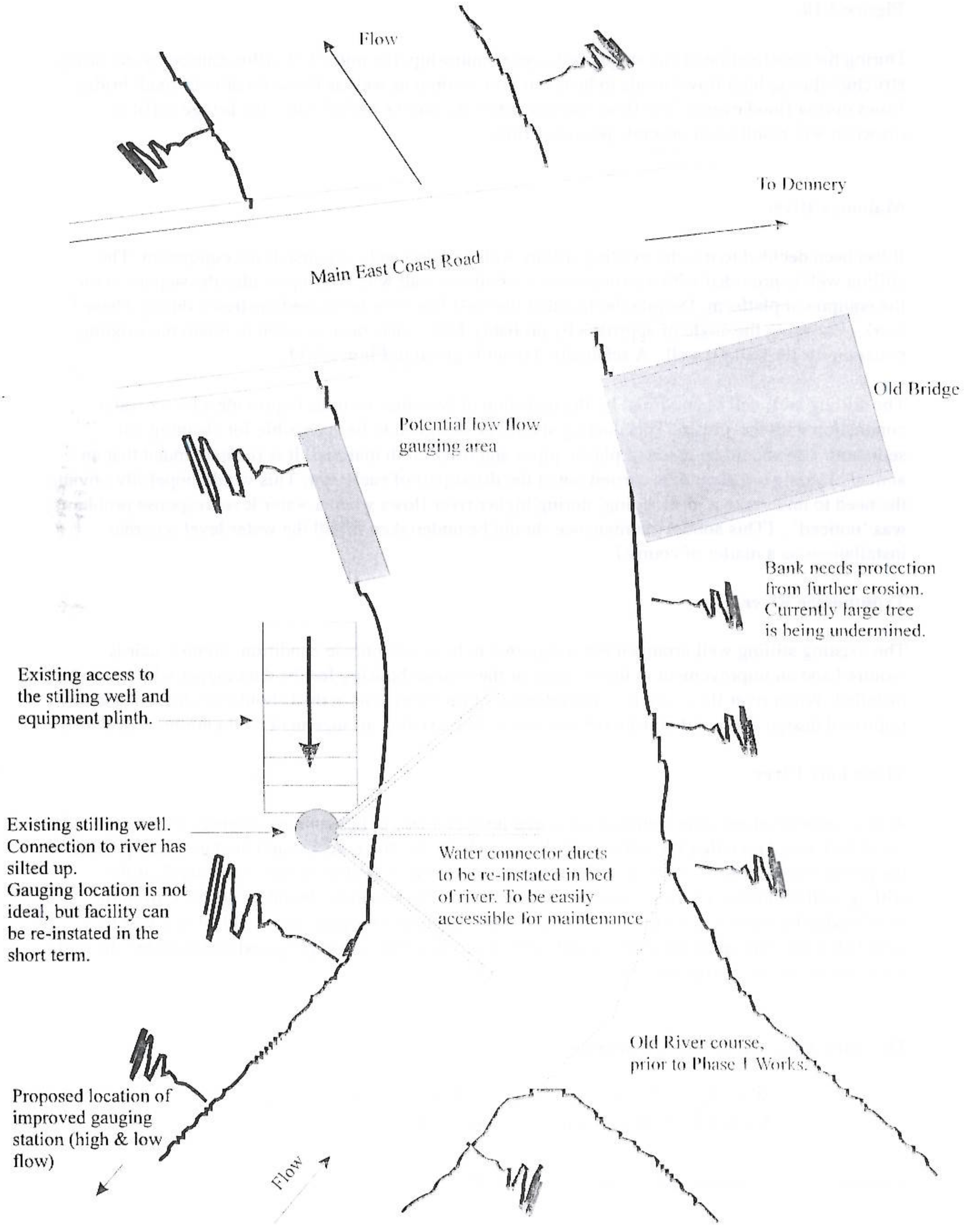


Figure 3.11

Location and Layout of River Gauging Station : Mabouya



which debris would collect during a flood, increasing the lateral friction force of the flowing water against the pipe.

A new arrangement is proposed, better protected and with specially designed connections to the river channel to enable the full range of water levels to be recorded. A schematic layout is given in **Figure 3.10.**

During the construction of the stage discharge relationship, the impact of afflux caused by the bridge structure during high flows needs to be taken into account as well as the scale of over road/ bridge flows during flood events. The flow characteristics during the period when the bridge soffit is drowned will result in an unstable period of flow.

Mabouya River

It has been decided to use the existing stilling well location and to re-install the equipment. The stilling well is provided with a strong masonry buttress wall which also provides the step access to the equipment platform. Despite the fact that the river has been re-aligned upstream during Phase I works, changing the angle of approach by probably 110°, it has been decided to retain the existing situation for the stilling well. A schematic layout is given in **Figure 3.11.**

The stilling well will be modified by the inclusion of two duct systems to provide a better water connection with the stream. This ducting should be designed to be accessible for cleaning out sediment. Use should be made of plastic pipes and filter cloth material. It is recommended that an annual cleaning out should be carried out at the driest part of each year. This would hopefully obviate the need to undertake a 'declogging' during higher river flows when a water level response problem was 'noticed' . {This annual maintenance should be undertaken for all the water level recorder installations as a matter of course}.

Troumassee River

The existing stilling well arrangement is reported to be in reasonable condition. Some repair is required and an improvement in the security of the cabinet housing for the data logger which is to be installed. When river flows are low, the integrity of the short lead in duct should be checked and an improved design applied if considered necessary. The existing arrangement could not be established.

Vieux Fort River

A new water level recorder station is proposed just upstream of the main road bridge at la Retraite. It could be located on either the left or right hand banks of the river, access and land ownership being the prime considerations. Access on the left bank is relatively simple, however the depth of the stilling well arrangement would need to be quite large. The structure should be set back from the river's edge by some 6 to 8 metres whilst horizontal ducting arrangements would be required to establish water linkage between river and well. A survey of the site is proposed to determine the best/ most cost effective configuration.

The major equipment needs are therefore:

Water level discharge recorders (with data loggers): 8 Number;
Sediment sampling equipment : 1 or 2 Sets;

Pressure transducer sediment discharge measurement : 1 Unit
Staff gauges.

The proposed siting of this equipment is presented in **Figure 3.12**. Ideally the whole network should be brought into operation at the earliest, however, it is appreciated that this may not be possible without technical assistance bearing in mind the limitations imposed by manpower availabilities within AESD, the organisation currently presumed to be the best organisation to initiate the establishment or re-establishment of the network. A description of the network is given in **Table 3.10**.

In addition, it is recommended that standby rainfall data loggers are provided to act a an immediate replacement for malfunctioning units.

Rainfall data loggers (stand-by units) (Casella) : 2 Number.

The estimated costs of the Phase 2 equipment is given in **Table 3.11**.

Consideration is being given to linking some of the proposed gauging systems through telemetry to the WASA facility which is currently being established to monitor the operation and control of their treatment works. This is being investigated.

The concept of introducing a radar facility for rainfall forecasting has been considered. Radar facilties currently do not exist in St Lucia although there are existing relatively old systems in use on other Caribbean Islands. The National Meteorological Services Department is part of a regional group seeking funds for such facilties, however the aim is for a sytem for medium range weather forecasting rather than on-land rainfall intensity predictions. No funds are thought to be available at the moment within the Project Budget, however, the option will be investigated further in early 1997.

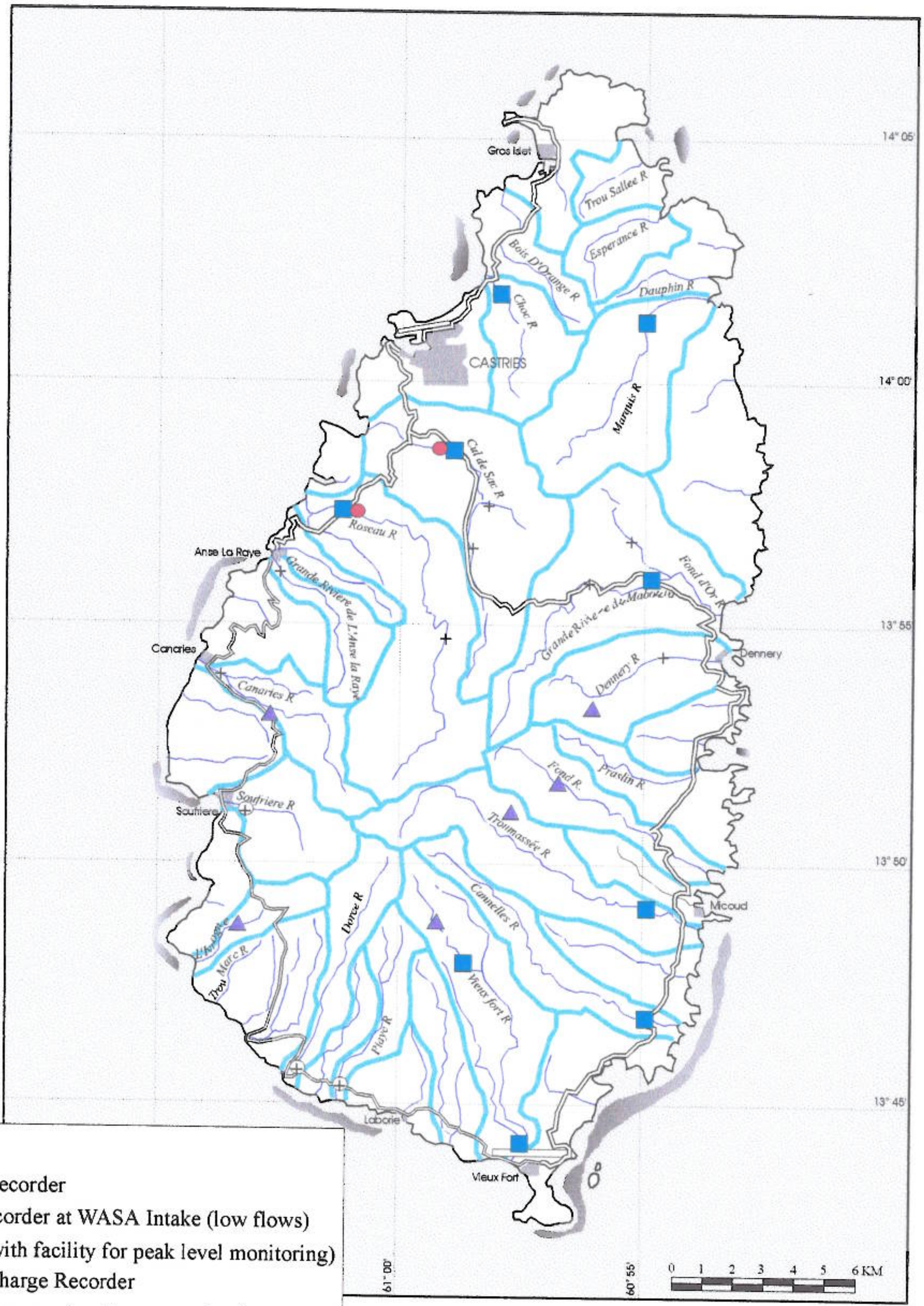
3.4.2 Equipment Procured during Phase 2

Based on discussions during earlier inputs by the consultants Oct./Nov. 1996 and January 1997, the following hydrometeorological equipment has been delivered during the period to October 1997:-

From OTT Hydrometry		
Crest Level Gauges (peak flood level estimation)	2 Nr	654 pds.
From Valeport		
Suspended Sediment Sample	1 Nr	1 635 pds.
From Stevens		
Stevens Type F Water Level Recorder (plus all accessories) (- enclosures etc. for 5 Nr) (- solar panels for 5 Nr)	10 Nr	US $
From Casella		
Tilting Bucket Rainfall Recorder and Logger	2 Nr	1 670 pds.

Figure 3.12

Proposed Hydrometric Network



Legend:
- Water Level Recorder
- Water level recorder at WASA Intake (low flows)
- Staff Gauge (with facility for peak level monitoring)
- Sediment Discharge Recorder
- Site for staff gauge and sediment monitoring
- Coral reef (from Environmental Action Plan (Draft))

Table 3.10

Hydrometric System Development

River	Location	Objectives	Low flow current meter gauging programme	Crest Gauge Installation (peak WLs)	Sediment Sampling Programme	Continuous Water Level Monitoring Float	Continuous Water Level Monitoring S Gauge	Gauging Section
Choc	Near main bridge?	Flooding		Yes				River
Marquis	Near Bridge	Flood/Resource	Yes	Yes			Yes	River
Cul-de Sac	D/S of Ferrands Bridge	Flood/Resource	Yes	Yes	Yes	Yes		Bridge/weir
Roseau	Existing Site : Rehab/move	Flood/Resource	Yes	Yes	Yes	Yes		U/S Bridge
Mabouya	Existing site : Rehab	Flood/Resource	Yes	Yes	Yes	Yes		D/S Bridge
Troumasse	Existing site : Rehab	Flood/Resource	Yes	Yes		Yes		River
	WASA Intake	Resources	Partly					
Dennery	Near main bridge	Flooding		Yes			Yes	River
	WASA Intake	Resources	Partly					
Canelles	Near main bridge?	Flooding		Yes			Yes	U/S Bridge
Vieux Forte	La Retraite Bridge: New sit	Flood/Resource	Yes	Yes	Yes		Yes	U/S Bridge
		Resources	Yes				Yes	River
	WASA Intake	Resources	Partly					
Soufriere		Flooding		Yes	Yes		Yes	River
Delcer		Resources	Yes					River

Hydromet Equipment Requirements

River	Location	Existing Situation	Equipment Needs: Steven System Complete	Water Level Gauge	Crest Gauge	Construction Needs: Stilling Well Site (Off set)	Low flow Weir or structure	Crest Gauge Base	WASA Weir Rehab/Mod
Choc	Near main bridge?	Nothing			*To make*			Yes	
Marquis	Near Bridge	Old recording site, nothing exists		In storage	*To order*			Yes	
Cul-de Sac	D/S of Ferrands Bridge	Ferrands Bridge broken, equip OK	Exists		*To order*	Yes	Yes	Yes	
Roseau	Existing Site : Rehab/move	Old station damaged, too prone	Exists		*To make*	Yes		Yes	
Mabouya	Existing site : Rehab	Site affected by u/s loop cut	To order		*To make*	Yes		Yes	
Troumasse	Existing site : Rehab	Equipment to be replaced	Exists		*To make*	Rehab		Yes	
	WASA Intake	Existing weir (needs rehab?)	To order?						Yes
Dennery	Near main bridge	Nothing		In storage	*To make*			Yes	
	WASA Intake	Existing weir (needs rehab?)	To order?						Yes
Canelles	Near main bridge?	Nothing		In storage	*To make*			Yes	
Vieux Forte	La Retraite Bridge: New sit	Previously gauged site?		In storage	*To make*			Yes	
	0	Nothing							
	WASA Intake		To order?						Yes
Soufriere	0	Nothing		In storage	*To make*			Yes	
Delcer	0	Nothing		In storage				Yes	

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Table 3.11

Hydrometeorological Equipment : Phase 2

Item	Number	Unit Rate £	Estimated Cost £	Freight & Insurance £	Total Cost £	Total Cost EC$ 4.2
Equipment Procurement						
Water Level Recorders Digitial type, pressure transducer	4 {1 in Phase 1}	1600	6400	600	7,000	29,400
Sediment Concentration Monitor Digitial type, pressure transducer	3	2000	6000	300	6,300	26,460
Water Level Recorder Stevens type, Chart	2	1500	3000	400	3,400	14,280
- floats, cables, pens etc	2	120	240	50	290	1,218
- spare parts	Set	Sum	1000	80	1,080	4,536
Water Level Recorder Repair	3	Sum	1000	100	1,100	4,620
Water Level Gauges (Crest Type) {modifications to existing}	8	30	240	5	245	1,029
Sediment (Suspended) Sampling Equipment	1	400	400	50	450	1,890
WASA Weir Equipment Small Loggers for dry season {Remote total flow meter}	7	300	2100	100	2,200	9,240
Rainfall Data Loggers Stand-by & Research	3	700	2100	50	2,150	9,030
			Sub total £		**24,215**	**101,703**
			Sub total US$		**40,197**	
Supporting Work by GoSL		EC$				
Rehabilitation of Existing Sites {Troumassee, Mabouya, Roseau}	3	8000		24000		
Modification of the above for pressure transducers	2	800		1600		
Civil Works for WLR (Pressure Tr.)	3	8000		24000		
Civil Works for WLR (Well & Chart type	2	10000		20000		
Civil Works for WLR & Sediment (Tr.)	1	8000		8000		
Civil Works for low flow weirs (WASA)	7	2000		14000		
					Sub-total:	91,600
					Totals	193,303

Installation of the Crest Level gauges will be made at the earliest whilst the rainfall recorder were procured as a 'contingency pool'. Problems are already being encountered with regard to the rainfall recorders installed in September/October/November 1996 as the Consultants are assisting in resolving the issue with the supplier.

Plan for the new water level recorders are being formulated for their installation in the coming dry season (1997/98).

3.5 Proposals for Institutional Responsibilities and Operation and Maintenance.

The whole institutional issue of water resources management needs to be addressed to ensure that an integrated, logical and mutually beneficial programme is executed. This covers 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.

The relationship between data gatherers and data users is summarised by data type in **Table 3.12**. The table lists the type of data in a hydrometeorological and hydrometric nature and identifies the use to which each type of data is or should be put. The uses of the data are based on the currently seen issues in St Lucia and are generally non-project related. Project related data would include the data requirements associated with the development of a new water storage reservoir in the south of the Island.

As indicated by the table, there would appear to be a deficiency of data to meet the requirements of many analyses. Use has to be made in many instances of a very limited data set which impacts on the integrity of detailed analyses and of conclusions thereby drawn. However, it should be pointed out that the 'uses' defined in the table are not necessarily being 'undertaken' as tasks by the relevant organisations.

In relation to the institutional arrangements related to the hydrometric and hydrometeorological networks, **Table 3.12** summarises the important elements in the process. It is important to differentiate between the data gatherers and the data users, or who should be the data users. Without the data being used, there is often a loss of interest on the side of the data gatherer. Attention must be paid to this aspect by the establishment of an active committee group. A National Hydrological Committee exists.

As mentioned earlier, the current staff within AESD have established an acceptable working procedure for the collection, checking and storage of agrometeorological data. The new rainfall data loggers and climate stations have been received with interest and effectively installed. Based on the history of erratic periods of rainfall records, it is advised that the current team within AESD should continue with the operation and management of the new equipment recently installed.

Although there is a common acceptance that issues such as flood estimation, water resources management, erosion and pollution monitoring are important, most of the government personnel interviewed indicate that they generally do not have the right background and more importantly the time to address the issues adequately.

The responsibility for the collection and analysis of hydrometeorological and hydrometric data should lie within the group of organisations WASA, AESD, MCW&T and NMS. Other

Table 3.12

Hydrometeorological and Hydrometric Data Interest Matrix

Hydrometeorological and Hydrometric Element		Data Gatherers and Storage: AESD	NMS	WASA	SLBGA	CEHI	Project Information - Limited	Data Users	Use to which the data put (or should be put)	Is data used?
Rainfall	Daily	✔	✔		✔			AESD/NMS/DP	Disaster Preparedness Activities	?
								NMS	Weather reports & forecasting	Yes
	Monthly	✔	✔					MCW&T	Prediction of Landslips near roads	Yes?
								WASA	Checking on intake resource security	No
	Annual	✔	✔					Forestry	Forestry condition assessments etc	?
								General	Inter-annual variations, trend analyses etc	Yes
River Water Level	Peak levels	✔⊗					✔	MCW&T	Positioning of Services	No data?
								MPD&E	Flood Zone, granting building permission	No data?
								AESD/NMS/DP	Disaster Preparedness Activities	No data?
River Discharge	Low flows	✔⊗		?			✔	WASA	Checking on intake resource security	Data?
								AESD	Checking irrigation potentials	Data?
								MPD&E??	Checking aquatic ecology	No
	High flows	✔⊗		?				MCW&T	Designing cross drainage structures	No data?
								WASA	Intake designs, O&M	No data?
								Others?	Designing cross drainage structures	No data?
Sediment Concentrations		✔⊗		✔⊗			✔	WASA	Intake designs, O&M	No data?
								AESD	Irrigation systems design, drip systems etc	No data?
								SLBGA	ditto	No data?
								?	Assessment of erosion and marine deposition	No data?
Water quality (basic) (turbidity, coliforms, TDS etc)				✔				WASA	Supply standards, treatment design, O&M	Yes
								AESD	Crop responses to water qualities, treatment	?
Water quality (advanced) (pesticides, herbicides etc)						✔✤		WASA	Supply standards, treatment design, O&M	Data??
								AESD	Agricultural practices, control and advice	Data??
								SLBGA	Agricultural practices, control and advice	Data??
								Fisheries	Impact on marine fisheries	Data??
								Fisheries	Impact on freshwater fisheries & aquaculture	Data??
								D of Health	Awareness programmes, medical treatment	Data??
As a group::								As applied to all:		
Evaporation		✔	✔		✔			NMS	Weather forecasting	
Temperatures, relative		✔	✔					AESD	Crop requirements and yield predictions	Yes
humidities, dew points etc		✔	✔					SLBGA	Crop needs, agri-practices (spraying etc)	Yes
Wind Speed		✔	✔					WASA	Reservoir condition, water demands	No
Insolation		✔	✔							
Soil Moisture		?						AESD	Irrigation scheduling	Data?
								SLBGA	Irrigation scheduling	Data?
Groundwater	Levels						✔	WASA	Water resources monitoring reponsibilities	No
	Quality						✔	WASA	Water resources monitoring reponsibilities	No

Legend:

✔	Data currently collected
✔✤	Data can be collected/tested on request
✔⊗	Data has been collected in the past, equipment currently out of order
?	Should the organisation be collecting the information?

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organisations who could play a role include the Department of Forestry, departments within the Ministry of Planning and the SLBGA.

3.6 Training programme

Based on an initial assessment of staffing capabilities and capacities within the main organisations with an identified role in the gathering and/or the analysis of hydrometeorological or hydrometric data, it is considered that a training programme is required.

In many of the offices visited, there appeared to be no shortage of good textbooks on watershed management, hydrology, river engineering and associated subjects. This wealth of information should be taken advantage of. There might be a need for more practically orientated training which focuses on studying the problems in the various sectors and a means of training rather than a series of overseas courses which might not yield the 'practical problem solving approach' in a data limited environment.

Overseas courses can be seen as part of an overall training programme, however in-service issue focussed training is considered to be a vital important approach. In order that this is successful, the staff nominated for training need to be granted leave of absence from their posts, or have a reduced 2 day/week input leaving the remainder of the time to work on the 'problem issues' with external guidance.

Overseas of local short courses would be useful in such topics as:

- hydrological data gathering, storage, integrity checking and analysis;
- hydrological analysis linked to solving engineering problems;
- river engineering;
- cross drainage structure design in the context of hydrological analysis, hydraulics and scour;
- water quality sampling, testing and result interpretation and management response;
- overall watershed management.

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Appendix A

Existing Networks and Data in Relation to Water Resources Issues

Appendix A

Existing Networks and Data in relation to Water Resources Issues

A.1 Flood Estimation

In 1984, in the Report 'The Roseau, Dennery and Cul de Sac Drainage and Conservation Project', design flood estimation procedures were presented. The procedure adopted being that of the Rational Method. This relates runoff to catchment area and rainfall intensities in an equation as described in Annex 3.

Rainfall intensity curves were derived for La Caye. The 1:5 year value for a 1 hour duration storm was about 50mm/hr (see Figure 3.5 of the 1984 Report). A table was also presented for the estimation of 'C' the runoff coefficient which varied from 0.18 to 0.95 (Table 3.3 of the Report based on USDA, USCS 1972) with the lower values related to forest areas and 'dense scrub'. The values used in the runoff estimation were not presented. Catchments were divided into sub-catchments and flows estimated. These 1:5 year flows were generally low e.g.

Cul de Sac River downstream of Ravine Souffre - 21.8 m^3/s;
Roseau River downstream of the confluence with the river Millet - 52.5 m^3/s;
Fond d'Or downstream of the confluence with the Derniere Riviere - 40 m^3/s;

The respective channel capacities were given as:

Cul de Sac (slope 0.0012 approx) - 20 m^3/s;
Roseau River (with slope of about 0.0015) - 115 m^3/s;
Fond d'Or downstream of confluence with Derniere Riviere (slope 0.0012) - 42.2 m^3/s;
(although the Dennery Factory Bridge capacity was estimated to be 9.5 m^3/s)

Thus the 1:5 year flood estimates were indicated to be within bank. Note the slope of 0.0012 is equivalent to 1:833 which is shallower than the slopes of the rivers as defined by the recent Phase 1 surveys. A summary of 1984 design discharges is given in **Table A.1**.

Subsequent stages of the same project, in 1986 and 1987 indicated that flood flows were occurring in the Cul de Sac River of a much higher discharge than was indicated by the flood flow analysis which was carried out in 1984. The discharge on 15th of November 1986 being estimated to be 80 m^3/s.

A more recent report by the Institute of Hydrology (UK) have studied in detail the flooding situation in the lower Cul de Sac River (The Impact of Urban Development on Flood Risk in the Cul de Sac Valley, St Lucia, Report for the Ministry of Planning, December 1992). In the lower reaches of the Cul de Sac river, a revised channel slope was estimated, 0.0016 (1 in 625). With a Manning 'n' of 0.035, the estimated in-channel capacity upstream of the main road bridge was estimated to be 53 m^3/s whilst that downstream to be 67 m^3/s.

The Report summarised the 137 current meter gaugings undertaken between August 1985 and January 1991 but pointed out the fact that few large flows were gauged. Apart from one discharge measurement at 16 m^3/s, the others were all below 6 m^3/s with the majority below 1 m^3/s. The stage discharge relationships thereby derived thus giving rise to significant differences when extrapolated for high flow situations. The extrapolations made in the figures included in the report do not appear to allow for the out of channel inflexion point.

The detailed assessment of the flow conditions indicated that the flow of the 15th of November 1987 was

Table A.1

Cul de Sac Catchment Hydrology
1:5 year flood estimates for each sub-catchment

Sub catchment Number	Area ha	Design Discharge m3/s	Equivalent l/s/ha	mm/da	Rational Equation Estimates Tc hrs	i mm/hr	C	Qp m3/s	Design/ Qp
1	523	10.5	20.1	173	4	50	0.25	18.16	0.578
2	160	5.7	35.6	308	4	50	0.25	5.56	1.026
3	58	2	34.5	298	4	50	0.25	2.01	0.993
4	32	2	62.5	540	4	50	0.25	1.11	1.800
5	25	2	80.0	691	4	50	0.25	0.87	2.304
6	38	1.5	39.5	341	4	50	0.25	1.32	1.137
7	34	2.1	61.8	534	4	50	0.25	1.18	1.779
8	109	2.7	24.8	214	4	50	0.25	3.78	0.713
9	21	1.1	52.4	453	4	50	0.25	0.73	1.509
10	75	2.6	34.7	300	4	50	0.25	2.60	0.998
11	25	1.7	68.0	588	4	50	0.25	0.87	1.958
12	51	2.5	49.0	424	4	50	0.25	1.77	1.412
13	835	15.8	18.9	163	4	50	0.25	28.99	0.545
14	22	1.6	72.7	628	4	50	0.25	0.76	2.095
15	49	2.4	49.0	423	4	50	0.25	1.70	1.411
16	28	1.8	64.3	555	4	50	0.25	0.97	1.851
17	11	0.8	72.7	628	4	50	0.25	0.38	2.095
18	46	1.9	41.3	357	4	50	0.25	1.60	1.190
19	58	3.2	55.2	477	4	50	0.25	2.01	1.589
20	9	0.6	66.7	576	4	50	0.25	0.31	1.920
21	24	1.8	75.0	648	4	50	0.25	0.83	2.160
22	151	4.2	27.8	240	4	50	0.25	5.24	0.801
23	38	1.5	39.5	341	4	50	0.25	1.32	1.137
24	223	6.2	27.8	240	4	50	0.25	7.74	0.801
25	28	1.9	67.9	586	4	50	0.25	0.97	1.954
26	66	3.1	47.0	406	4	50	0.25	2.29	1.353
27	21	1.2	57.1	494	4	50	0.25	0.73	1.646
28	32	1.5	46.9	405	4	50	0.25	1.11	1.350
29	60	3.1	51.7	446	4	50	0.25	2.08	1.488
30	88	3.5	39.8	344	4	50	0.25	3.06	1.145
31	254	6.5	25.6	221	4	50	0.25	8.82	0.737
32	37	2.6	70.3	607	4	50	0.25	1.28	2.024
33	14	1.3	92.9	802	4	50	0.25	0.49	2.674
34	34	2.1	61.8	534	4	50	0.25	1.18	1.779
35	16	0.8	50.0	432	4	50	0.25	0.56	1.440
36	51	1.7	33.3	288	4	50	0.25	1.77	0.960
37	66	3	45.5	393	4	50	0.25	2.29	1.309
38	69	2.9	42.0	363	4	50	0.25	2.40	1.210
39	24	1	41.7	360	4	50	0.25	0.83	1.200
40	15	0.6	40.0	346	4	50	0.25	0.52	1.152
Valley floor rainfall-runoff is extra to the above									
	3,520	115	32.7	282 Weighted Average				122.22	
			50	429 Average					1.431

Estimates of Flood Discharges based on 1984 parameter values

Sub-catchment	Area ha	Discharge m3/s	Equivalent l/s/ha	mm/da	Rational Equation Estimates Tc hrs	i mm/hr	C	Qp m3/s	Design/ Qp {ratio}
Cul de Sac (u/s of Ravine Poisson	523	10.5	20.1	173	6	50	0.25	18.16	0.578
Ravine Poisson	160	5.7	35.6	308	6	50	0.25	5.56	1.026
Ravine Souffre	835	15.8	18.9	163	6	50	0.25	28.99	0.545
Cul de Sac (u/s of Ravine Souffre)	1173	15.9	13.6	117	6	50	0.25	40.73	0.390
Cul de Sac (d/s of Ravine Souffre)	2008	21.8	10.9	94	6	50	0.25	69.72	0.313

Source: HTS 1984, The Roseau, Dennery and Cul de Sac Drainage and Conseravtion Project.

Estimates of Flood Discharges based on modified parameter values (based on 1996 information)

Sub-catchment	Area ha	Rainfall Duration hrs	Equivalent l/s/ha	mm/da	Rational Equation Estimates Tc hrs	i mm/hr	C	Qp m3/s
Cul de Sac (u/s of Ravine Poisson	523	4.5	162.5	263	2.5	90	0.65	84.99
Ravine Poisson	160	4.5	162.5	263	2.5	90	0.65	26.00
Ravine Souffre	835	4.5	162.5	263	2.5	90	0.65	135.69
Cul de Sac (u/s of Ravine Souffre)	1173	4.5	162.5	263	2.5	90	0.65	190.61
Cul de Sac (d/s of Ravine Souffre)	2008	4.5	162.5	263	2.5	90	0.65	326.30

File: CUL-FLOW.WK4 (A)

probably closer to 50 to 60 m^3/s than 80 m^3/s since surface velocities had been used for the original estimate. A peak over threshold analysis was undertaken of the period September 1985 to October 1990. Over 40 events had discharges in excess of about 13 m^3/s with only two events in this 6 year period in excess of 30 m^3/s (these on 15/11/87 and 20/09/88).

The available flow record was deemed to be two short to derive a flood of specific recurrent frequency, recourse was made to a rainfall runoff model. This was based on the rainfall at Union Agricultural Research Station. Daily rainfalls between there and Bexon were compared and found to be sufficiently close to enable the use of the more detailed and lengthy records at Union to be employed in the analysis.

Design rainfall profiles were calculated, the 1:50 year event having a specific profile and duration of 5.5 hours. An areal reduction factor of 0.9 was adopted (considered suitable for St Lucia in the absence of actual data) and a unit hydrograph analysis carried out.

In order to calibrate the rainfall runoff model, six rainfall events in 1989 were employed to calibrate the model with flows ranging from 13 m^3/s to 24 m^3/s resulting from daily rainfalls of between 31mm and 123mm. These rainfalls equating to rainfall intensities of 16mm/hr over 7.5 hours to 6 mm/hr for many of the events of different durations. The analysis being undertaken to estimate the initial loss of rainfall through infiltration and the role of antecedent moisture conditions. The analysis yielded 1:50 year flood flows at Ferrands Bridge of 46 m^3/s and a 1:100 year of 50 m^3/s. The 1:50 year event was indicated to be 1.6 times the mean annual flood. It was reported that in Sri Lanka, a similar sort of climate with tropical storms, the ratio is about 9 (this would yield a 1:50 year runoff of 259 m^3/s which is closer to what is currently considered to be the possibility for the Cul de Sac River).

In order to design the unit hydrograph, the time to peak flow from the start of the rainfall event was analysed. Several equations exist, most of the form:

$$T = a\,(L / S)^{b}$$ 'b' being in the range of 0.3 to 0.7

The equation considered as appropriate for the Cul de Sac catchment being given in the Report as:

$$T = 2.24\,(L / S)^{0.5}$$

The characteristics of the Cul de Sac River as evaluated in the report are given in **Table A.2**. The slope being that between 15% and 85% of the distance from the outlet.

Table A.2 Characteristics of the Cul de Sac River Basin

Location	Area (km^2)	L (km)	S_{1085} (m/km)
Ferrand Bridge	26.61	12.4	15.13
Main Road Bridge	33.64	14.9	11.32

Unfortunately, daily rainfall data is only really available post 1985, records back to 1955 have been inspected, however they do not provide confidence, especially the higher rainfall values.

The daily rainfalls used were those from records at Union Research Station. These are reproduced in **Table A.3** with the values also presented as rainfall intensities. For the 1 hour rainfall duration, the

Table A.3

Rainfall Intensities of Different Probabilities of Exceedance

Rainfall Depths for Different Return Periods

Rainfall duration (minutes)

Return Period (years)	5	10	15	30	60	120	360	720
2	8.8	13.4	16.9	23.1	29.8	43.8	64.5	76.9
5	11.5	17.5	21.6	29.1	36.6	54	77.5	92.7
10	13.3	20.3	24.7	33.1	41.1	60.8	86.3	103.2
25	15.5	23.8	28.6	38.2	46.8	69.4	97.3	116.4
50	17.2	26.3	31.5	45.7	51	75.7	105.4	126.2
100	18.9	28.9	34.4	49.4	55.2	82	113.4	135.9

Note: Based on an analysis of the rainfalls for the period 1979 to 1987 inclusive (8 years).
Source: Institute of Hydrology analysis of Union ARS data for a Study of the River Cul de Sac, 1992

Equivalent in terms of Rainfall Intensities (mms/hr)

	5	10	15	30	60	120	360	720
2	105.6	80.4	67.6	46.2	29.8	21.9	10.8	6.4
5	138.0	105.0	86.4	58.2	36.6	27.0	12.9	7.7
10	159.6	121.8	98.8	66.2	41.1	30.4	14.4	8.6
25	186.0	142.8	114.4	76.4	46.8	34.7	16.2	9.7
50	206.4	157.8	126.0	91.4	51.0	37.9	17.6	10.5
100	226.8	173.4	137.6	98.8	55.2	41.0	18.9	11.3
Oct 26th 1996 (Bexon)		102.0	124.0	74.0	53.0	48.5	31.7	19.1
Oct 26th 1996 (Mahaut)		90.0	96.0	88.0	72.0	67.0	36.7	22.8
TSD	165.6	90.0	97.6	96.0	90.0	80.4	43.4	22.5
TSD Modified	165.6	148.2	130.8	96.0	90.0	80.4	43.4	22.5

Modified assuming an intensity of 90mm/hour for a 1 hour duration is a 1:10 year event

Rainfall intensities (mm/hr)

	5	10	15	30	60	120	360	720
2	231.2	176.1	148.0	101.2	65.3	48.0	23.5	14.0
5	302.2	229.9	189.2	127.4	80.1	59.1	28.3	16.9
10	349.5	266.7	216.4	145.0	90.0	66.6	31.5	18.8
25	407.3	312.7	250.5	167.3	102.5	76.0	35.5	21.2
50	452.0	345.5	275.9	200.1	111.7	82.9	38.5	23.0
100	496.6	379.7	301.3	216.4	120.9	89.8	41.4	24.8

Modified assuming TSD (Modified) is Equivalent to a 1:10 year event

Rainfall intensities (mm/hr)

	5	10	15	30	60	120	360	720
2	94.0	83.4	77.3	58.1	57.3	50.7	28.8	14.8
5	122.9	109.0	98.8	73.1	70.4	62.6	34.6	17.9
10	142.1	126.4	113.0	83.2	79.0	70.4	38.5	19.9
25	165.6	148.2	130.8	96.0	90.0	80.4	43.4	22.5
50	183.8	163.8	144.1	114.8	98.1	87.7	47.0	24.3
100	201.9	180.0	157.3	124.1	106.2	95.0	50.6	26.2

File: RF-INTY.WK4 (B)

1;50 year intensity is 51 mm/hr and the 1:100 year is 55 mm/hr, quite a flat relationship. The information is plotted as **Figure A.1**. It is important to compare this with the TSD rainfall intensity of 90 mm/hr and the equivalent of 70mm/hr for the event of October 26th.

The comparison of annual maximum rainfalls at Bexon and Union Research Station was based on 6 values for Bexon and 12 for Union. The largest daily rainfall was for Union at almost 270mm, the Bexon information indicating, from the graph produced lower rainfall characteristics. The opposite might be expected if a longer time series had been available for analysis. The published annual isohyets puts Bexon in the 2,800 mm region with Union in about 2,150mm. Additionally, Barre d'Isle has even higher rainfalls and the upper catchment of Cul de Sac should give a high contribution to the flood discharges. It is thought reasonable to expect the rainfall within the Cul de Sac catchment to be higher than that indicated by Union Research Station records, probably of the order of 30% more although this need not necessarily be reflected in the value of rainfall intensities.

With the updated records for the Union Agricultural Research Station, a new frequency analysis has been carried out of the maximum annual 24 hour rainfall records. This analysis is presented in **Table A.4** and **Figure A.2**. It is interesting to note that the highest 1 day rainfall on record is for 1967, the 1994 event (TSD) is ranked second whilst that of the 26th of October 1996 is only ranked 20th in a 42 year records period. This to a certain extent puts into perspective the reliability of using this data series for flood flow estimation for the central part of the Island. The monthly rainfall was high at Union ARS for September 1967 as it was for October 1970 which has the 3rd highest daily rainfall.

The statistical analysis would indicate that the 1:100 year rainfall based on a Gumbel GEV Type I distribution is about 287mms whilst that for a log Pearson Type III is 264mms. Note, the 24 hour rainfall at Mahaut in the Trumassee Valley on October 26th 1996 was about 280mm.

A similar analysis has been undertaken for Bathe Nursery and is presented in **Tables A.5 to A.7**.

It is interesting to revert to both historic records and local knowledge in the absence of long records of flood levels or flood flows. In the period of 40 years from 1890 to 1930, 5 major floods are on record. In the 30 years from 1930 to 1960 another 5, see **Table A.8**. However in the period 1960 to 1970, 7 major flooding events took place, see **Table A.9**. In all 17 events in 80 years, a recurrence interval of 1 in 5 years! From the limited reports, some of these events will have been as bad if not worse than the floods of October 26th. Bearing in mind the increased population densities these days and the probable fact that perceptions of severity have changed over the years as hardships have reduced, current flooding 'disasters' might not have been deemed worthy of record in the past.

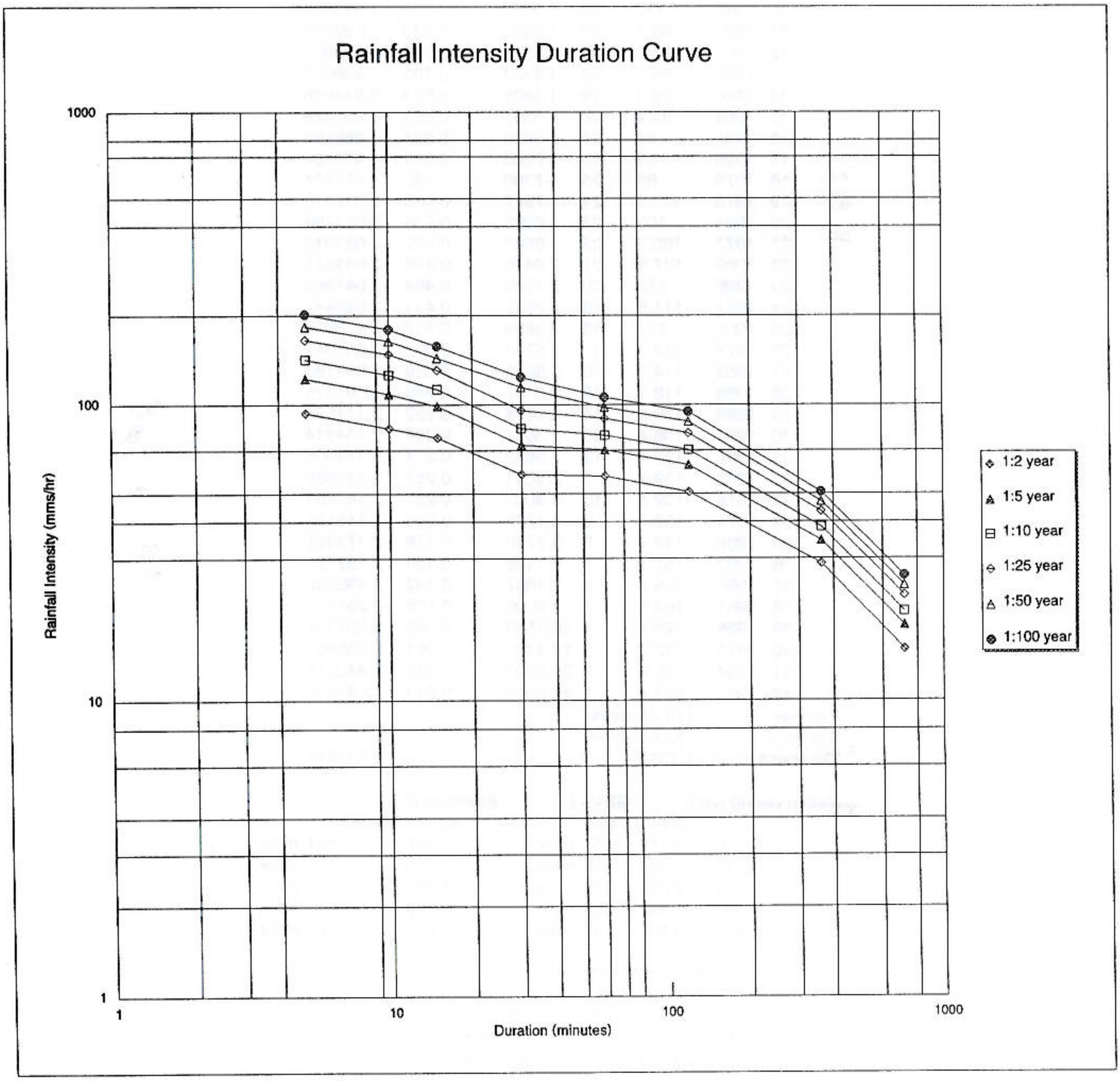
Thus what frequency can one assign to the event of the 26th of October when the Cul de Sac river overtopped the main road bridge? Well outside any normal stage-discharge relation at that point. Perhaps, the October 1996 event was a 1:10 year event, or even a 1:5 ? The estimated discharge down the channel and across the flood plain being over 200 m^3/s.

A.2 Dry Season Flow Estimation and Water Sector Demands

The 37 main river watersheds on the Island have been presented in **Figure 3.1**. The approximate location of the WASA intakes and their estimated catchment areas is given in **Figure A.3**.

Although WASA are the most important user, through their customers, of water. There is some irrigation water being used during the dry season. Reports indicate that there is about 2,000 ha of

Figure A.1



File : RF-INTY.WK4

Table A.4

Frequency Analysis of 24 hour Rainfall at Union Research Station

Record	Year	24 hour Rainfall	Rank	T	P 0.44 Gringorten	Log Rainfall
1	1983	52.6	42	1.0238	0.987	1.720986
2	1959	53.3	41	1.0488	0.963	1.726727
3	1957	66	39	1.1026	0.915	1.819544
4	1958	66	39	1.1026	0.915	1.819544
5	1961	66.3	38	1.1316	0.892	1.821514
6	1973	69.1	37	1.1622	0.868	1.839478
7	1990	72.5	36	1.1944	0.844	1.860338
8	1956	74.9	35	1.2286	0.821	1.874482
9	1993	77	34	1.2647	0.797	1.886491
10	1975	82	33	1.3030	0.773	1.913814
11	1991	85.1	32	1.3438	0.749	1.92993
12	1972	85.9	31	1.3871	0.726	1.933993
13	1985	86.7	30	1.4333	0.702	1.938019
14	1980	88.1	29	1.4828	0.678	1.944976
15	1964	89.4	28	1.5357	0.654	1.951338
16	1955	93	27	1.5926	0.631	1.968483
17	1995	95	25	1.7200	0.583	1.977724
18	1979	95	25	1.7200	0.583	1.977724
19	1978	102.9	24	1.7917	0.559	2.012415
20	1984	105	23	1.8696	0.536	2.021189
21	1977	105.2	22	1.9545	0.512	2.022016
22	1989	107.9	21	2.0476	0.488	2.033021
23	1996	110	20	2.1500	0.464	2.041393
24	1982	111.8	19	2.2632	0.441	2.048442
25	1965	113	18	2.3889	0.417	2.053078
26	1974	114.3	17	2.5294	0.393	2.058046
27	1963	114.6	16	2.6875	0.369	2.059185
28	1966	118.1	15	2.8667	0.346	2.07225
29	1969	129.3	14	3.0714	0.322	2.111599
30	1987	136.4	13	3.3077	0.298	2.134814
31	1986	138.2	12	3.5833	0.274	2.140508
32	1992	139.2	11	3.9091	0.251	2.143639
33	1976	139.4	10	4.3000	0.227	2.144263
34	1971	139.7	9	4.7778	0.203	2.145196
35	1968	149.4	8	5.3750	0.179	2.174351
36	1962	152.1	7	6.1429	0.156	2.182129
37	1960	155.2	6	7.1667	0.132	2.190892
38	1981	160.5	5	8.6000	0.108	2.205475
39	1988	225.3	4	10.7500	0.085	2.352761
40	1970	232.2	3	14.3333	0.061	2.365862
41	1994	275.6	2	21.5000	0.037	2.440279
42	1967	293.4	1	43.0000	0.013	2.46746
Average:		118.25 mms				
Std Devn		53.65 mms				
Skewness		1.6362				0.537914

Return period (yrs)	GEV - I Kt	GEV - I Value	Pearson III Kt	Pearson III Value
5	0.719	157 mms	0.805	161 mms
10	1.304	188 mms	1.326	189 mms
25	2.044	228 mms	1.921	221 mms
50	2.592	257 mms	2.329	243 mms
100	3.136	287 mms	2.712	264 mms

Normal Distribution

	w	z	Value
5	1.7941	0.84	163 mms
10	2.146	1.28	187 mms
25	2.5373	1.75	212 mms
50	2.7971	2.05	228 mms
100	3.0349	2.33	243 mms

Figure A.2

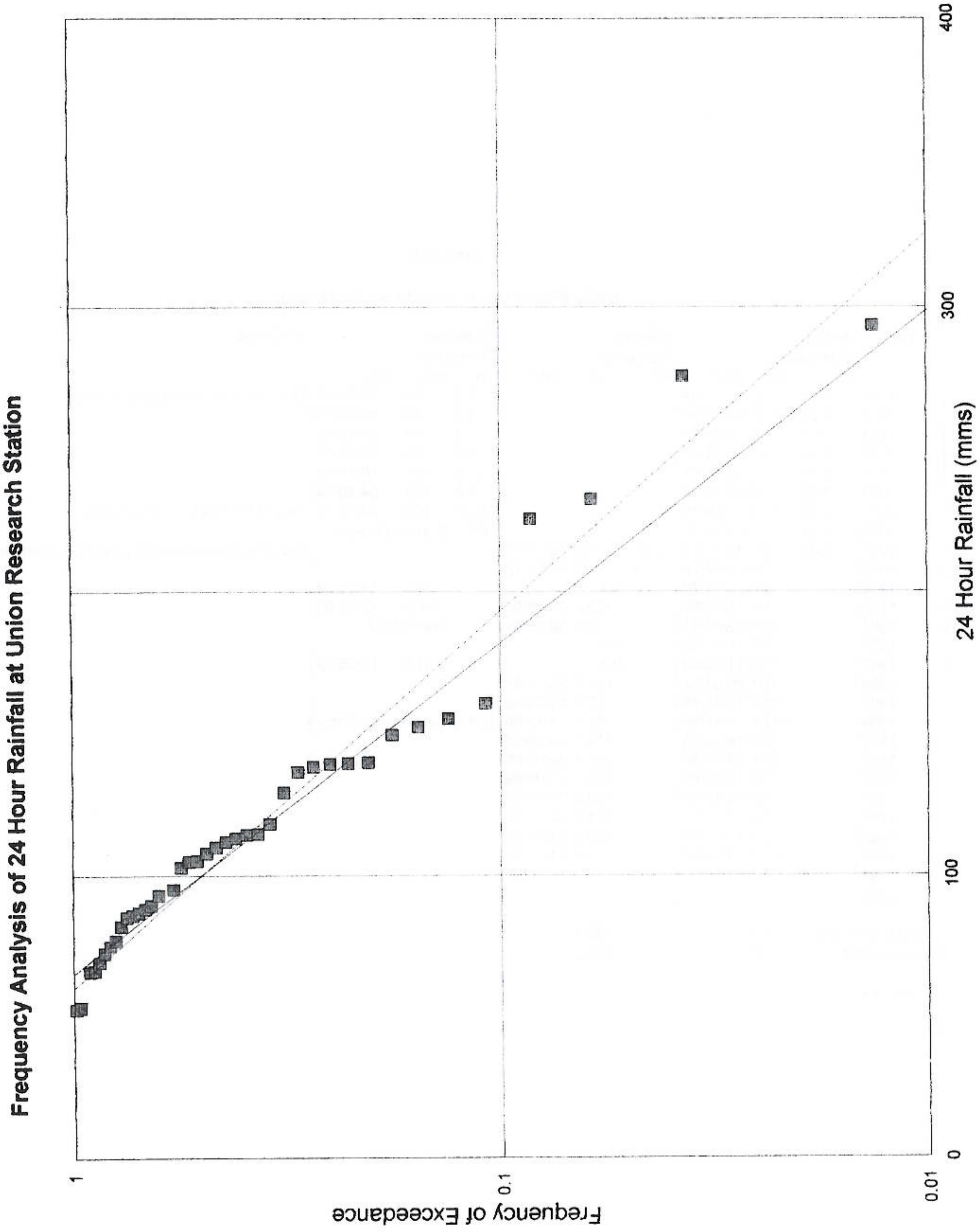

Frequency Analysis of 24 Hour Rainfall at Union Research Station
Frequency of Exceedance
1
0.1
0.01
24 Hour Rainfall (mms)
0
100
300
400

Table A.5

Daily Maximum Rainfalls as Recorded

Year	Bathe Raingauge			Mahaut Raingauge			Quilesse Raingauge			Remarks
	ins	mms	date	ins	mms	date	ins	mms	date	
1969	3.64	92	27/11/69				2.5	64	23/09/69	On 3/10 9.50 inches at Cap Estate
1970	4.23	107	03/10/70				5.5	140	02/10/70	
1971	3.7	94	19/08/71				3	76	30/12/71	
1972	3.55	90	03/11/72				2.5	64	03/11/72	
1973	2.25	57	18/10/73				4.25	108	16/11/73	
1974	3.92	100	03/10/74				6.8	173	04/10/74	
1975	4.48	114	02/09/75				6.23	158	09/11/75	On 2/9 5.68 inches at Quilesse
1976	1.57	40	09/11/76				N/A	Edmund Forest		
1977	2.42	61	31/10/77	4.28	109	30/10/77				Bathe not operational in peak of September
1978		106	07/07/78	3	76	07/07/78				
1979		97	22/11/79		N/A			80.5	14/11/79	
1980		64	16/08/80		129.7	04/08/80		54.3	12/12/80	
1981		130	22/04/81		350	02/05/81		unreliable?		
1982		75	14/11/82		N/A					
1983		111	11/05/83		N/A			113	10/05/83	
1984		183	26/07/84		121.4	25/07/84				
1985		90.5	19/11/85		72.4	12/09/85				
1986		100.4	15/11/86		161.3	14/11/86	104mm in previous 2 days			
1987		72.2	19/11/86		114.5	20/05/86				
1988		311	09/09/88		262.1	09/09/88				
1989		153	15/09/89		165.2	15/09/89				
1990		115	04/10/90		122.5	03/10/90				
1991		80.6	21/11/91		164.5	14/11/91				
1992		133	27/11/92		138.2	24/11/92				
1993		60.7	13/09/93		60.9	24/11/93				
1994										
1995										
Average daily max		105			120.4					
Average 1984-93		130			138.3					

24HRMAX.WK4

Table A.6

Frequency Analysis of 24 hour Rainfall at Bathe Nursery Station

Record	Year	24 hour Rainfall	Rank	T	P 0.44 Gringorten	Log Rainfall
1	1988	311.2	1	26.000	1.018	2.493
2	1984	183	2	13.000	0.518	2.262
3	1989	153	3	8.667	0.305	2.185
4	1992	132.8	4	6.500	0.238	2.123
5	1981	130	5	5.200	0.195	2.114
6	1990	114.7	6	4.333	0.163	2.060
7	1975	114	7	3.714	0.140	2.056
8	1983	111	8	3.250	0.123	2.044
9	1970	107	9	2.889	0.109	2.031
10	1978	106	10	2.600	0.099	2.025
11	1986	100.4	11	2.364	0.090	2.002
12	1974	100	12	2.167	0.082	1.998
13	1979	97	13	2.000	0.076	1.986
14	1971	94	14	1.857	0.071	1.973
15	1969	92	15	1.733	0.066	1.966
16	1985	90.5	16	1.625	0.062	1.957
17	1972	90	17	1.529	0.058	1.955
18	1991	80.6	18	1.444	0.055	1.906
19	1982	75	19	1.368	0.052	1.875
20	1987	72.2	20	1.300	0.050	1.859
21	1980	64	21	1.238	0.047	1.803
22	1977	61	22	1.182	0.045	1.789
23	1993	60.7	23	1.130	0.043	1.783
24	1973	57	24	1.083	0.041	1.757
25	1976	40	25	1.040	0.040	1.601
26	1977					
27	1978					
Average:		105.48 mms				
Std Devn		52.16 mms				
Skewness		2.42				0.54055

Probability Analysis

Return period (yrs)	GEV - I Kt	GEV - I Value	Pearson III Kt	Pearson III Value
5	0.719	143 mms	0.805	147 mms
10	1.304	174 mms	1.326	175 mms
25	2.044	212 mms	1.921	206 mms
50	2.592	241 mms	2.329	227 mms
100	3.136	269 mms	2.712	247 mms

Normal Distribution

	w	z	Value
5	1.794123	0.841457	149 mms
10	2.145966	1.281729	172 mms
25	2.537272	1.751077	197 mms
50	2.79715	2.054189	213 mms
100	3.034854	2.326785	227 mms

File : 24HRMAX.WK4

Table A.7

Frequency Analysis of 24 hour Rainfall at Bathe Nursery Station

Record	Year	24 hour Rainfall	Rank	T	P 0.44 Gringorten	Log Rainfall
1	1988	211.2	1	26.000	1.018	2.325
2	1984	183	2	13.000	0.518	2.262
3	1989	153	3	8.667	0.305	2.185
4	1992	132.8	4	6.500	0.238	2.123
5	1981	130	5	5.200	0.195	2.114
6	1990	114.7	6	4.333	0.163	2.060
7	1975	114	7	3.714	0.140	2.056
8	1983	111	8	3.250	0.123	2.044
9	1970	107	9	2.889	0.109	2.031
10	1978	106	10	2.600	0.099	2.025
11	1986	100.4	11	2.364	0.090	2.002
12	1974	100	12	2.167	0.082	1.998
13	1979	97	13	2.000	0.076	1.986
14	1971	94	14	1.857	0.071	1.973
15	1969	92	15	1.733	0.066	1.966
16	1985	90.5	16	1.625	0.062	1.957
17	1972	90	17	1.529	0.058	1.955
18	1991	80.6	18	1.444	0.055	1.906
19	1982	75	19	1.368	0.052	1.875
20	1987	72.2	20	1.300	0.050	1.859
21	1980	64	21	1.238	0.047	1.803
22	1977	61	22	1.182	0.045	1.789
23	1993	60.7	23	1.130	0.043	1.783
24	1973	57	24	1.083	0.041	1.757
25	1976	40	25	1.040	0.040	1.601
26	1977					
27	1978					
Average:		101.48 mms				
Std Devn		38.20 mms				
Skewness		1.07				-0.05333

Probability Analysis

Return period (yrs)	GEV - I Kt	GEV - I Value	Pearson III Kt	Pearson III Value
5	0.719	129 mms	0.805	132 mms
10	1.304	151 mms	1.326	152 mms
25	2.044	180 mms	1.921	175 mms
50	2.592	200 mms	2.329	190 mms
100	3.136	221 mms	2.712	205 mms

Normal Distribution

	w	z	Value
5	1.794123	0.841457	134 mms
10	2.145966	1.281729	150 mms
25	2.537272	1.751077	168 mms
50	2.79715	2.054189	180 mms
100	3.034854	2.326785	190 mms

File : 24HRMAX.WK4

Table A.8

Disaster History of St Lucia with focus on Storm Events

Earthquake Events	Drought Events	Hurricane/ Flood		Comment on storm event
1832				
1841				
1842				
1843				
1844				
1888				
1889				
1890				
1891	1891	1891		Largely hit Matinique
1893				
1894	1894	1894		Heavy landslides, Soufriere badly hit, 11 dead
	1895			
		1897	11 Sept	14 ins rain Considerable damage
1906	1906			
1907	1907			
1908				
1911				
1914				
1916				
		1921		Considerable damage, 15 dead
1928		1928		Considerable damage in Roseau
	1937			
		1938	Nov	Yearly rainfall 38" above 50 year average, Ravine Poisson hit, 120 dead.
		1939	7 Jan	3 villages destroyed, 100 dead
		1940	7 Aug	Ravine Poisson, L'Abbaye hit, post 1939 works washed away
1946				
1953				
		1954	12 Dec	Yearly rainfall 129", Ravine Poisson badly hit
		1958	4 July	Damage severe in Dennery, Soufriere and Vieux Fort
		1960	10 July	Hurricane 'Abbey', considerable damage (EC$14m+), 6 dead
		1963	24 Sep	Hurricane 'Edith', damage at EC$2m+
		1963	1 Oct	Hurricane 'Flora', mostly affected Grenada
		1965	25 Oct	Worst hit area around Castries (Cul de Sac?)
		1966	June+	Damage in the NE (Mabouya?) EC$0.45m.
		1967	8 Sep	Hurricane 'Beulah' 15" rainfall in 24 hrs, most in 12hrs, damage in NE, 18
	1970	1970	2 Oct	
	1971			
	1972			
	1973			
	1974			
	1975			
				?????????
				?????????
				?????????
		1994	9 Sep	Tropical Storm 'Debbie', 276 mms (10.9") in 24 hrs, 90mm/hr intensity
		1995		
		1996	26 Oct	Storm, 274mms in 24 hrs at Mahaut (Troumassee catchment)

Source historic to 1975: Conway, C. & O'Keefe; 'Natural hazards in the Windward Islands, a survey of available information", August 1975, University of Bradford.

Table A.9

Abstraction of High Rainfalls from published Records

Summary of High Monthly Rainfalls

Station Name	Ref.	1966 Jul	1966 Oct	1966 Nov	1967 Sep	1968 Sep	1969 Aug	1969 Dec	1970 Oct	71	72	73	74	1975 Oct	1975 Nov	76	1977 Aug	1977 Oct	78
Historic 'Overlap'		June			8/9				2/10										
Marquis Estate	4R1	526	248	595	579	238	324	390	611	-	-	-	-	305	285	-	256	295	-
Marquis Babonneau	4R2	519	319	664	604	266	374	441	540	-	-	-	-	295	320	-	257	487	-
La Caye	6R1	488	233	390	493	245	414	141	462	-	-	-	-	317	348	-	258	473	-
Mamiku	9R1	532	288	628	470	349	265	235	N/A	N/	N/	N/	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fond Estate	10R1	445	305	441	415	256	266	282	535	-	-	-	-	351	504	-	335	502	-
Patience	10R2	558	241	507	467	278	249	195	565	-	-	-	-	358	527	-	311	520	-
Troumassee	12R1	570	312	377	383	371	308	N/A	N/A	N/	N/	N/	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mahaut	12R2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/	N/	N/	N/A	N/A	N/A	N/A	589	582	-
Quilesse	12R3	724	521	464	616	318	540	406	641	-	-	-	594	662	715	439	509	676	N/A
Edmond Forest	12R4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/	N/	N/	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Beausejour La Ressource	16R1	459	280	371	456	285	342	167	443	-	-	-	-	310	300	-	183	361	-
Black Bay	17R1	510	246	390	279	361	359	177	N/A	N/	N/	N/	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Balembouche	20R1	465	272	153	390	319	301	291	383	N/	N/	N/	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Park Estate	20R1	457	450	118	276	286	N/A	N/A	N/A	N/	N/	N/	N/A	N/A	N/A	N/A	N/A	N/A	N/A
La Fargue	22R1	393	363	174	393	303	319	N/A	375	-	-	-	-	362	372	-	255	347	356
Bath Nursery	23R2	488	398	246	555	512	399	132	479	-	-	-	-	533	368	-	414	412	398
Barre de L'Isle	33R1	728	434	376	586	N/A	467	289	646	-	-	-	411	375	498	-	441	585	-
Government House	34R1	662	486	233	698	353	412	198	554	-	-	-	-	377	417	-	360	561	-
George Vth Park	34R2	716	410	524	713	347	409	N/A	N/A	N/	N/	N/	N/A	N/A	N/A	-	337	453	-
Bois d'Orange	36R1	508	300	516	443	204	262	218	635	-	-	-	-	382	285	-	282	347	-
Cap Estate	37R1	439	137	447	575	163	267	N/A	513	-	-	-	-	179	N/A	-	205	350	-
Union Agricultural Station	35M1	641	385	565	657	290	364	231	653	-	-	-	-	320	144	-	244	493	-
WINBAN	31M1	707	261	375	466	337	461	199	573	-	-	-	-	364	153	-	352	403	-
Vigie Airport	34M1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	574	-	-	-	-	315	303	-	288	480	-
Hewanorra	14M1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/	N/	N/	-	267	275	-	216	325	-

Station Name	Ref.	1979 Jun	1979 Jul	1979 Oct	1979 Nov	80	1981 Apr	1981 May	82	1983 Jul	84 ??	1985 Oct	1986 Nov	1987 {May}	1988 Sep	1989 Sep	1990 Oct	1991 Nov	1992 Nov	93	1994 Aug	1994 Sep		1995 Aug	1996 Oct
Historic 'Overlap'									Nothing Significant																
Marquis Estate	4R1	336	268	357	272	-	372	263	-	-		349	392	493	375	345	422	388	407		174	334	E	377	
Marquis Babonneau	4R2	429	177	328	289	-	427	364	-	-															
La Caye	6R1	353	154	257	312	-	381	261	-	-		182	394	517	387	467	490	355	513		254	401	M	326	
Mamiku	9R1	N/A	N/A	113	95	-	169	255	-	-			330			508	473	392	495		196	398	E	339	
Fond Estate	10R1	301	166	353	371	-	309	190	-	-											Errard	Errard			
Patience	10R2	289	183	411	369	-	358	N/A	-	-			435			N/A	489	477	588		257	412	E	420	
Troumassee	12R1	N/A	N/A	N/A	N/A	N/	N/A	N/A	N/A	N/A			447			314	391	354	549		262	404	E	368	
Mahaut	12R2	N/A	N/A	N/A	N/A	0	May?	518	N/A	N/A		599	589		541	435	533	673	798		267	539	E	541	
Quilesse	12R3	N/A	N/A	N/A	N/A	N/	N/A	Many	0	0															
Edmond Forest	12R4	440	395	536	487	-	517	487	508	406		774	711		653	656	730	716	771		330	676	E	635	
Beausejour La Ressource	16R1	169	389	235	281	-	298	184	-	-											230	410	M		
Black Bay	17R1	N/A	N/A	N/A	N/A	N/	N/A	N/A	N/A	N/A											Saltibus OK				
Balembouche	20R1	N/A	N/A	N/A	N/A	N/	N/A	N/A	N/A	N/A											252	409			
Park Estate	20R1	N/A	N/A	N/A	N/A	N/	N/A	N/A	N/A	N/A											Delcer OK				
La Fargue	22R1	358	358	N/A	N/A	N/	N/A	N/A	N/A	N/A															
Bath Nursery	23R2	435	339	472	383	-	368	303	-	415		569	554		665	542	549	619	665		405	567	E	532	
Barre de L'Isle	33R1	420	N/A	428	442	-	413	543	N/A	N/A		305	533		483	235	590	525	570		305	667	E	394	
Government House	34R1	438	327	246	247	-	345	282	-	-		283	435		353	363	591	472	308		301	494	M	433	
George Vth Park	34R2	N/A	N/A	N/A	277	N/	N/A	N/A	-	-		445	443		482	331	508	532	443		230	444	E	407	
Bois d'Orange	36R1	N/A	N/A	N/A	N/A	N/	N/A	N/A	N/A	N/A											Soucis OK				
Cap Estate	37R1	252	120	278	235	-	166	242	N/A	N/A		329	238		403	217	350	442	513		246	297	M	328	
																					Bexon OK				
Union Agricultural Station	35M1	349	308	286	335	-	356	367	-	-		334	479		499	323	425	565	596		252	492	M	450	
WINBAN	31M1	406	232	189	304	-	353	169	-	-		285	510		420	404	465	512	439		303	516	E	464	
Vigie Airport	34M1	372	228	216	157	-	339	219	-	-		193	163		532	326	213	88	66		251	465	M	421	
Hewanorra	14M1	157	170	232	216	-	292	154	-	-		359	224		372	480	290	373	452		207	415	M	322	

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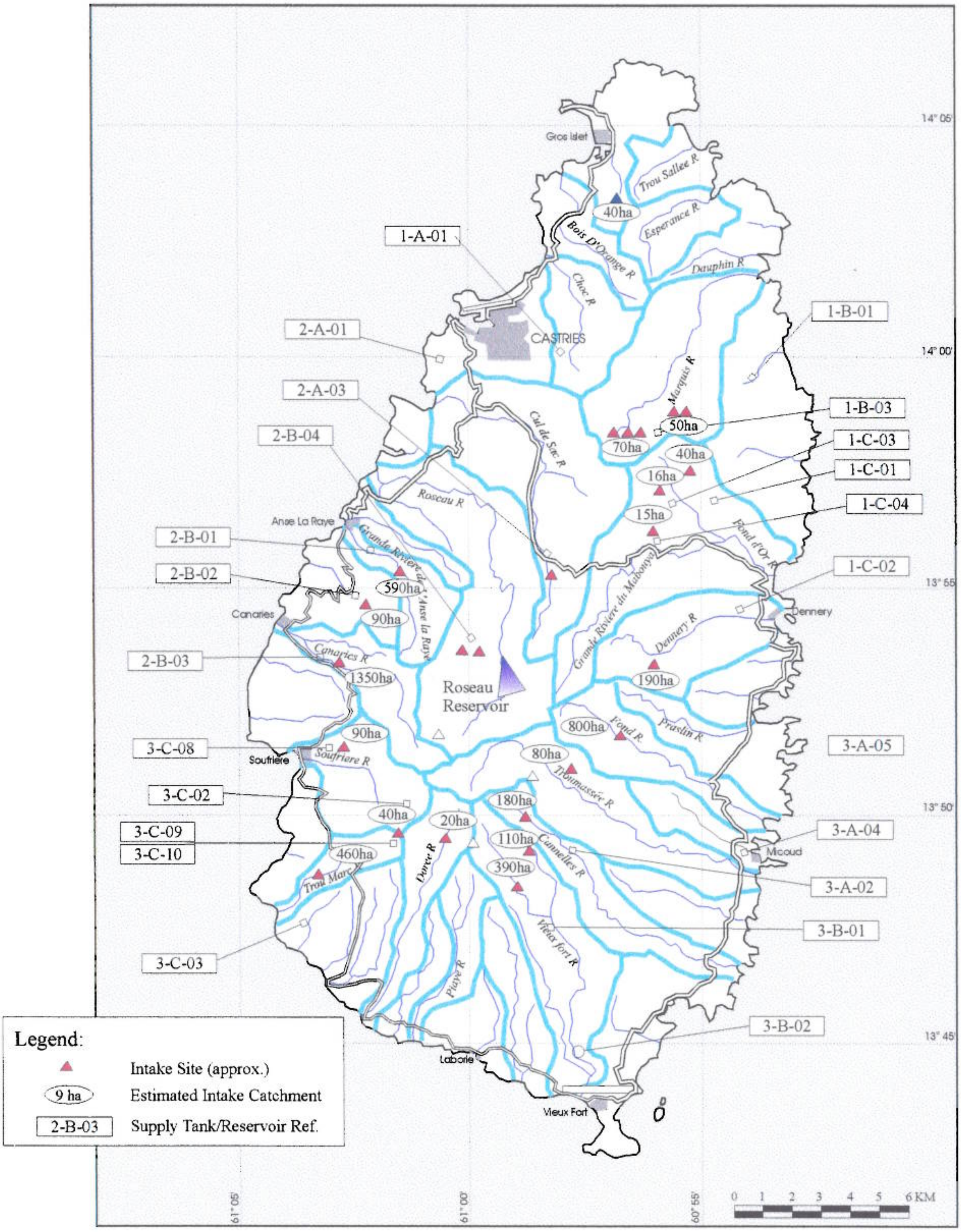
Figure A.3

Main WASA Hydraulic Infrastructure



irrigation, requiring probably about 1 to 1,5 m^3/s of water in the peak of the dry season when stream flows are at their lowest. No inventory of irrigation operators or irrigated farms exists. A constant discharge of this magnitude is not insignificant. However, the magnitude needs to be confirmed.

The domestic and industrial water supply system of St Lucia suffers from intake blockages and high turbidity values in the wet season of June to November and water shortages in the dry season with intakes running dry or the abstraction being all or a large proportion of the base flow in the river leaving probably inadequate ecological releases.

In 1979, total supply volume was estimated to be 4.5 Mm^3/annum with a per capita consumption of 103 litres. By 1989, per capita consumption levels had reportedly increased by 56% (to 152 l/c/d) in parallel with a population increase over the period of 14%. The estimated water demands in 1985 are given in **Table A.10.**

WASA originally only had responsibility for managing the supply of water to the main towns, particularly Castries. In 1987, WASA acquired the responsibility for the supply of water to all the smaller communities on the Island, this having previously been the responsibility of the Ministry of Health.. Problems that existed at that time of typhoid and bilharzia, particularly in the Mabouya and Dennery valleys have now largely been eradicated. The water supply characteristics in 1990, as estimated, are given in **Table A.11**.

In 1992 there were 35 small rural water sources and 4 major plants which included chemical coagulation. Details of 24 of the sources is reproduced in **Table A.12**. The main supply, now from the Roseau Dam is intended to provide water for Castries, which comprises 45% of the population of the Island. The historic supply volumes achieved in 1993, 1994 and 1995 are given in **Table A.13**. The accuracy of the data is unknown, however the information does indicate the variability of supply, it is unlikely that demand changes much.

The rapid development in the banana industry since the 1950s and the increasing use of steeper, less stable soil profiles for cultivation has impacted on water quality, particularly during the wetter months. The increasing importance of tourism added to the increasing indigenous population is placing increasing demands on the water supply system not only in terms of reliability of supply but also quality of water delivered. The population of the Island has more than doubled since 1950.

The document 'A Manual for Developers', produced by the Central Planning Unit indicates that per capita demands should be 35 igpd (160 l/c/d) and in the drier parts of the island, less than 2,000mm annual rainfall, a storage tank of 45m^3 capacity is to be provided. These factors need to be considered in any demand assessment.

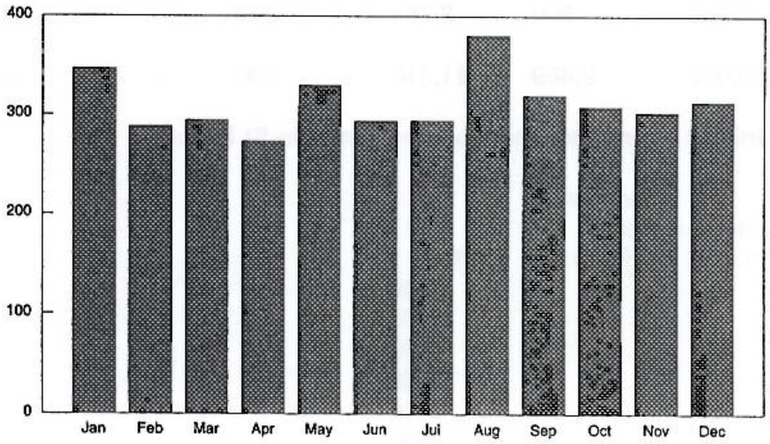
Measurements of dry season flows in the various river systems of the Island has been somewhat sporadic. Measurements were undertaken on many rivers in the period 1984 to early 1986 as part of a UNDP Water Resources Assessment. Subsequently, some measurements have been undertaken, most recently in 1995. These discharge measurements are summarised in **Table A.14**. The flow measurements were undertaken in 1984 and 1985 every 5 to 10 days, normally about 4 times per month, thus giving an indication of base flows during the dry season. A similar approach was used in 1995, but about 2 flow gaugings were made of the selected rivers each month. Sporadic rainfalls in this period for both flow gauging programmes did affect the flow gaugings made. The values given in **Table A.14** are therefore very approximate estimates of the indicative average monthly flow.

Despite these approximations, the results provide a reasonable indication of the base flows likely in each of the river basins. The results are insufficient to enable any evaluation to be made of the

Table A.10

Rural Area Monthly Water Consumption in 1985

Intake	Catch -ment	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals	Maximum Monthly	Maximum month	Average	Maximum/ Average
Monchy	3	1.06	2.27	1.14	1.27	1.36	0.39	0.33	0.65	1.76	0.9	2.32	2.4	15.85	2.4	Dec	1.32	1.82
Boquis	4	0.76	2.27	2.27	0.2	0.18	0.1	1.14	2.03	0.05	0.16	0.73	0.3	10.19	2.27	Feb/Mar	0.85	2.67
Forestiere	4	0.96	0.83	0.68	0.71	0.65	0.47	0.58	0.75	0.9	0.48	0.78	0.62	8.41	0.96	Jan	0.70	1.37
Deriere Riviere	6	39.9	36.2	26.2	8.88	32	25.8	26.4	39.5	31.3	33.2	31.1	36.8	367.2	39.93	Jan	30.60	1.30
Au Leon	6	15.9	6.97	7.6	8.04	9.58	7.47	7.49	10.8	8.89	9.03	8.55	8.96	109.3	15.91	Jan	9.11	1.75
Dennery	7	30.3	28.2	31.8	28.1	35.3	26.6	28.3	31.2	35.6	47.6	38.7	26.8	388.6	47.6	Oct	32.38	1.47
Patience	10	18.2	16.7	17.6	17.5	22	19.2	16.1	21	14.6	15	18.9	17.2	213.8	21.95	May	17.82	1.23
Micoud	12	17.8	16.7	17	18.5	18.6	18.6	17.9	20.2	17.6	15.5	14.4	16.9	209.5	20.16	Aug	17.46	1.15
Desruisseau	14	52	41.8	44.2	41.6	46.3	45.7	40	55.6	44.8	48.2	53.3	52.3	565.6	55.56	Aug	47.14	1.18
Bellevue	16	34.2	29.6	27.6	28.5	28.6	23.6	22.6	33.6	28.3	22.1	33.6	41.2	353.7	41.19	Dec	29.47	1.40
Vieux-Fort	16	18.4	11.1	11.4	12.6	15.6	15.2	14.7	18.5	16.1	15.8	15.4	15.2	179.8	18.48	Aug	14.98	1.23
Saltibus	61	7.85	1.55	6.21	5.76	5.26	5.05	5.65	9.05	7.72	6.52	4.87	11.7	77.17	11.68	Dec	6.43	1.82
Banse	17	8.18	7.77	10	8.18	8.55	0.1	7.56	7.65	5.02	5.39	2.08	6.45	76.95	10.02	Mar	6.41	1.56
Choiseul	21	7.73	8.83	11.8	12.1	11.3	7.55	9.44	12.6	9.93	10.9	10.5	11.5	124.2	12.62	Aug	10.35	1.22
Balice/Paiye	23 (21	1.73	8.32	1.7	3.41	1.36	0.11	1.14	2.61	0.05	0.01	0.46	0.68	21.58	8.32	Feb	1.80	4.63
Delcer	23	25.2	20.6	16.4	18.3	23.9	22.8	17.1	25.7	20.2	8.11	8.28	10.1	216.6	25.68	Aug	18.05	1.42
Fond St Jacques	25	6.76	8.41	7.11	6.9	5	1.19	12	18.4	5.4	6.12	9.97	10	97.24	18.42	Aug	8.10	2.27
Fond St Jacques	25	15.1	15.6	13.3	14.6	17	28.8	27.9	3.34	20.1	17.5	15.8	17.2	206.2	28.77	Jun	17.18	1.67
Soufriere	25	27.1	9.75	25.5	20.9	30.4	18.9	20.5	42.2	33.7	34.1	21.4	4.57	288.9	42.18	Aug	24.07	1.75
Bouton	26	0.23	0.34	0.34	0.23	0.23	8.71	0.34	7.65	0.11	0.23	0.23	0.23	18.87	8.71	Jun	1.57	5.54
Canaries	27	4.32	5.75	5.37	5.42	6.78	6.06	5.11	6.48	5.46	5.73	5.24	6.16	67.88	6.78	May	5.66	1.20
Anse la Raye	29	9.09	5.95	6.77	7.18	6.73	7.53	8.18	7.73	7.27	5.46	5.91	7.27	85.07	9.09	Jan	7.09	1.28
Monier	36	3.72	2.39	2.27	3.66	2.98	3.85	3.36	3.76	5	0.27	0.42	9.32	41	9.32	Dec	3.42	2.73
	Totals	346	288	294	273	330	294	294	381	320	308	303	314	3744	380.91	Aug	311.97	1.22



Source: St Lucia Water Resources, UNDTCD, April 1996.

Table A.11

Water Supply Characteristics in St Lucia (estimated at 1990)

Zone	Supply Centre	Approximate Population	Yearly Average Consumption M g/annum	Ml/annum	Indicated per capita Consumption l/c/d	Possible per capita Consumpti l/c/d	Inferred Supply Volume Ml/annum	Abstraction at assumed loss of : 40%
1	Union	1,080	41.06	186	473	250	99	164
	Monchy	230	3.79	17	205	125	10	17
	Boguis	300	2.03	9	84	84	9	15
	Forestiere	210	1.05	5	62	62	5	8
	Grand Riviere	280	9.46	43	420	125	13	21
	Monier	190	1.19	5	78	78	5	9
	Hill 20	25,100	429.02	1,948	213	250	2,290	3,817
	Sarot	34,000	858.05	3,896	314	250	3,103	5,171
		61,390	1345.65	6,109	273		5,534	9,223
2	Anse la raye	2,860	15.73	71	68	68	71	119
	Anse la Verdue	240	4.7	21	244	125	11	18
	Canaries	2,340	15.11	69	80	80	69	114
	Soufries	5,360	93.2	423	216	125	245	408
	Fond St Jacque	3,010	48.22	219	199	125	137	229
	Bouton	2,650	5.34	24	25	25	24	40
	Delcer	970	53.99	245	692	125	44	74
	Choiseul	6,610	27.26	124	51	51	124	206
		24,040	263.55	1,197	136		725	1,209
3	Thomazo	580	21.97	100	471	125	26	44
	Derniere Riviere	5,089	82.57	375	202	125	232	387
	Dennery	4,022	59.71	271	185	125	184	306
	Patience	3,085	67.7	307	273	125	141	235
	Millet	580	0.51	2	11	11	2	4
	Auleon	4,106	18.81	85	57	57	85	142
		17,462	251.27	1,141	179		671	1,118
4	Micoud	6,980	39.29	178	70	70	178	297
	Desruisseaux	5,660	135.29	614	297	125	258	430
	Belle Vue	3,670	59.42	270	201	125	167	279
	Vieux Fort	9,980	319	1,448	398	125	455	759
	Saltibus	650	28.88	131	553	125	30	49
	Banse	260	26.86	122	1285	125	12	20
		27,200	609	2,764	278		1,101	1,835
	All Zones	130,092	2,469	11,210	236		8,031	13,385

Total Production of Drinking Water and Unaccounted Water in St Lucia

Year	Total Production Mm3	Unaccounted Losses Mm3	%
1979	6.4	1.9	30%
1980	6.9	2	29%
1981	7.7	2.5	32%
1982	8.3	2.5	30%
1983	8.3	2.5	30%
1984	9.3	2.2	24%
1985	9.3	1.9	20%
1986	10.2	2.9	28%
1987	10.5	2.9	28%
1988	12	3.2	27%
1989	11	3	27%

Source: M Phil Thesis, 'Integrating Surface Water Treatment Processes for Rural Communities';
R Eudovique, University of Surrey, 1992

Table A.12

Details of some of the WASA Water Sources

Intake:	Auleon	D/ Rivier	Dennery	Patience	Micoud	Desruissea	Belle Vue	Saltibus
Source type	Stream	Stream	Stream	Stream	Stream	Stream	Stream	Stream
Intake elevation (m)	227	105	98		227	298	274	482
Demand Estimate (m3/day)	455	682	909	405	545	909	545	309
Treatment Type	Cl	Cl	SSF & CL	Cl	SSF & CL	Cl	Cl	Cl
Chlorination system	Gas	Gas	Gas	Gas	Gas	Gas	Gas	Gas
Storage capacity (m3)	227	273	455	227	227	273	None	227
Source demand (l/s)	5.3	7.9	10.5	4.7	6.3	10.5	6.3	3.6
Source catchment (km2)		0.16	1.9	8	0.8	Included	1.8	0.2
Minimum base flow (l/s/km2)		49.33	5.54	0.59	7.88	in Patience	3.50	17.88

Intake:	Anse la Raye	Choiseul	Delcer	Fond St Jacues 1	Fond St Jacues 2	Soufriere	Canaries	Bouton
Source type	Stream	Spring	Stream	Spring	Spring	Spring	River	Spring
Intake elevation (m)		17	229	469	295	114	27	
Demand Estimate (m3/day)	190	455	682	455	136	1023	2341	455
Treatment Type	SSF & CL	Cl	SSF & CL	Cl	Cl	Cl	SSF & CL	Cl
Chlorination system	Gas	Gas	Gas	Gas	Tablets	Gas	Gas	Gas
Storage capacity (m3)	50	291	227	545	455	341	227	55
Source demand (l/s)	2.2	5.3	7.9	5.3	1.6	11.8	27.1	5.3
Source catchment (km2)	5.9	0.2	4.6			0.9	13.5	
Minimum base flow (l/s/km2	0.37	26.33	1.72			13.16	2.01	

Intake:	Forestierre	Monier	Monchy	Boguis	Sarot	Hill 20	Union	Vieux Fort
Source type	Stream	Stream	Stream	Stream	River	River	River	River
Intake elevation (m)	336	83	270		30		30	30
Demand Estimate (m3/day)	91	205	295	45	15455	5455	2273	5455
Treatment Type	Cl	SSF & CL	Cl	Cl	Chemical+Coagulation		Treatment+Chlorination	
Chlorination system	Tablets	Gas	Tablets	Tablets				
Storage capacity (m3)	45	341	45	55	10909	2273	455	4546
Source demand (l/s)	1.1	2.4	3.4	0.5				63.1
Source catchment (km2)				0.5				5
Minimum base flow (l/s/km2)				1.04				12.63

Source: Water Quality Monitoring and Assessment in St Lucia, 1979-92, R Eudovique (WASA)
Regional Workshop on Water Quality Monitoring, Port of Spain, 1993.

Notes: Source estimate, catchment area estimate and base flow requirement estimated under Project
* estimates are very approximate, source linkages not fully clear as of November 1996

WASA-INT.WK4

Table A.12 (Contd)

Details of some of the WASA Water Sources

Intake:	Auleon	D/ Rivier	Dennery	Patience	Micoud	Desruissea	Belle Vue	Saltibus
Source type	Stream	Stream	Stream	Stream	Stream	Stream	Stream	Stream
Intake elevation (m)	227	105	98		227	298	274	482
Demand Estimate (m3/day)	455	682	909	405	545	909	545	309
Treatment Type	Cl	Cl	SSF & CL	Cl	SSF & CL	Cl	Cl	Cl
Chlorination system	Gas	Gas	Gas	Gas	Gas	Gas	Gas	Gas
Storage capacity (m3)	227	273	455	227	227	273	None	227
Source demand (l/s)	5.3	7.9	10.5	4.7	6.3	10.5	6.3	3.6
Source catchment (km2)		0.16	1.9	8	0.8	Included	1.8	0.2
Minimum base flow (l/s/km2)		49.33	5.54	0.59	7.88	in Patience	3.50	17.88

Intake:	Anse la Raye	Choiseul	Delcer	Fond St Jacues 1	Fond St Jacues 2	Soufriere	Canaries	Bouton
Source type	Stream	Spring	Stream	Spring	Spring	Spring	River	Spring
Intake elevation (m)		17	229	469	295	114	27	
Demand Estimate (m3/day)	190	455	682	455	136	1023	2341	455
Treatment Type	SSF & CL	Cl	SSF & CL	Cl	Cl	Cl	SSF & CL	Cl
Chlorination system	Gas	Gas	Gas	Gas	Tablets	Gas	Gas	Gas
Storage capacity (m3)	50	291	227	545	455	341	227	55
Source demand (l/s)	2.2	5.3	7.9	5.3	1.6	11.8	27.1	5.3
Source catchment (km2)	5.9	0.2	4.6			0.9	13.5	
Minimum base flow (l/s/km2	0.37	26.33	1.72			13.16	2.01	

Intake:	Forestierre	Monier	Monchy	Boguis	Sarot	Hill 20	Union	Vieux Fort
Source type	Stream	Stream	Stream	Stream	River	River	River	River
Intake elevation (m)	336	83	270		30		30	30
Demand Estimate (m3/day)	91	205	295	45	15455	5455	2273	5455
Treatment Type	Cl	SSF & CL	Cl	Cl	Chemical+Coagulation		Treatment+Chlorination	
Chlorination system	Tablets	Gas	Tablets	Tablets				
Storage capacity (m3)	45	341	45	55	10909	2273	455	4546
Source demand (l/s)	1.1	2.4	3.4	0.5				63.1
Source catchment (km2)				0.5				5
Minimum base flow (l/s/km2)				1.04				12.63

Source: Water Quality Monitoring and Assessment in St Lucia, 1979-92, R Eudovique (WASA)
Regional Workshop on Water Quality Monitoring, Port of Spain, 1993.

Notes: Source estimate, catchment area estimate and base flow requirement estimated unfder Project
* estimates are very approximate, source linkages not fully clear as of November 1996

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Table A.13

Water Supply Schemes in St Lucia

Intake description Reference	Name	Catch ment	Altitude m	Demand m3/day		River Name	Demand Mm3/annum	Comparable Mm3/annum	1985 Mm3/yr	1993 Mm3/yr	1994 Mm3/yr	1995 Mm3/yr	Percentage supplied 1994	Percentage supplied 1995
1-A-01	Hill 20		-	5455	Rivers	Marquis	1.991			2.1542	1.7971	0.7413		
1-B-01	Desbarrah						0.000			0.0059	0.0087	0.0021		
1-B-02	Desrameau						0.000			0.0156	0.0133	0.0532		
1-B-02	Forestiere	4	336	91	Stream		0.033	0.033	0.008	0.0141	0.0114	0.0052	34%	16%
1-B-03	Riv. Mitang						0.000			0.0011	0.0033	0.0014		
1-B-06	Auleon	6	227	455	Stream		0.166	0.166	0.109	0.0860	0.0707	0.9592	43%	578%
1-C-01	Dennery	7	98	909	Stream	Rav. Saut	0.332	0.332	0.389	0.2381	0.2655	0.2568	80%	77%
1-C-02	D. Riviere	6	105	682	Stream	Rav Cochon	0.249	0.249	0.367	0.3628	0.3350	0.2551	135%	102%
1-C-03	Thomazo						0.000			0.1498	0.1164	0.0392		
1-C-04	Ciceron					Roseau Dam	0.000	7.632		2.1460	4.4148	5.1040	81%	67%
2-A-01	Tete-Chemain						0.000			0.3116	0.0009	0.0000		
2-A-02	Sarot		30	15455	River		5.641			2.8792	0.0689	0.0000		
2-A-03	Anse la Raye	29	-	190	River	Grand Riv.dAl	0.069	0.069	0.085	0.0414	0.0697	0.0862	101%	124%
2-B-01	Ans. L. Verd.						0.000			0.0031	0.0039	0.0041		
2-B-02	Caneries	27	27	2341	Spring?	Canaries	0.854	0.854	0.068	0.0455	0.0491	0.0887	6%	10%
2-B-03	Millet (Old)						0.000			0.0031	0.0008	0.0000		
2-B-04	Union		30	2273	River		0.830	0.830		0.1504	0.0001	0.0000	0%	0%
2-C-01	Belle Vue	16	274	545	Stream		0.199	0.199	0.358	0.4133	0.3288	0.1551	165%	78%
3-A-01	Desruisseau	14	298	909	Stream		0.332	0.332	0.566	0.3867	0.3983	0.3374	120%	102%
3-A-02	Micoud	12	227	545	Stream		0.199	0.199	0.210	0.3406	0.2033	0.0467	102%	23%
3-A-04	Patience	10	-	405	Stream		0.148	0.148	0.214	0.1998	0.1713	0.0648	116%	44%
3-A-05	Grace						0.000			2.2832	1.8086	1.8635		
3-B-01	Vieux-Fort	16	30	5455	River		1.991	1.991	0.180	0.0124	0.5509	0.0672	28%	3%
3-B-02	Bouton	26 ?		455	Spring		0.166	0.166	0.019	0.0066	0.0000	0.0000	0%	0%
3-C-01	Darban						0.000			0.0033	0.0124	0.0038		
3-C-02	Delcer	23	229	682	Stream		0.249	0.249	0.217	0.3795	0.2500	0.1331	100%	53%
3-C-03	Fond St Jac. (N	25	469	455	Spring	Fond	0.166	0.166	0.206	0.2908	0.2855	0.1294	172%	78%
3-C-04	Fond St Jac. (O	25	295	136	Spring		0.050	0.050	0.097	0.0257	0.0607	0.0294	122%	59%
3-C-05	Low. Dia.						0.000			0.0842	0.0418	0.0302		
3-C-07	Ruby						0.000			0.2538	0.3436	0.3009		
3-C-08	Saltibus (H)	16	482	309	Stream		0.113	0.113	0.077	0.0636	0.0348	0.0173	31%	15%
3-C-09	Saltibus (L)						0.000			0.0303	0.0357	0.0000		
3-C-10	Sauzay						0.000			0.0464	0.0735	0.0371		
3-C-11	Up. Diam.						0.000			0.1343	0.1941	0.0861		
	Choiseul?	21	17	455	Spring		0.166		0.124					
	Soufriere	25	114	1023	Spring	Desruisseau	0.373		0.289					
	Monier	36	83	205	Stream		0.075		0.041					
	Monchy	3	270	295	Stream		0.108		0.016					
	Boguis	4	-	45	Stream		0.016		0.010					
							Balice/Paiye	23/21	0.022					
							Banse	17	0.077					
							14.516			13.5626	12.0229	10.8985		

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Table A.14

Dry Season Gauged Flows in the Main River System

River::		Cul de Sac	Mabouya	Dennery	Fond d'Or	Troumasse	Canelles	Vieux Fort	Black Bay	Piaye	Doree	Roseau	Anse la Ra	Canaries	Soufriere	L'Ivrogue	Delcer Canal	Marquis	Derniere	Choc
Station		FerrandsBr.	Mabouya Br.		Factory Br.	Beauchamp	C Road Br	La Retraite								Delcer Canal		Babonneau Br	La Pelle Br.	WASA
Reference		33-A-1	6-A-2		6-W-1	12-A-1	14-W-1	16-A-1			21-A-1					23-W-1		4-W-1	6-W-3	35-A-1
Catchment Area (km2)		26.61	18.88		34.58	27.49	15.97	18.32			10.67					1.41	1.41	7.56	8.38	7.56
Year	Month																			
1995	March	250	200	100	180	410	180	140	55	100	100	200	50	250	180					
	May	160	130	85	130	390	140	100	30	80	150	160	80	180	200					
	Jul	500	140	80	170	520	200	260	100	110	230	1200	180	700	240					
1996	Jan	300	190	110	210	510	210	160	50	80	120	310	50	180	220					
1984	Mar		450		600	950	120	160			140					100		110	55	
	Apr		80		80	280	100	150			120					90	25	90	20	
	May		100		100	500	100	160			100					90	30	70	25	
	Jun		50		50	220	90	140			100					80	15	35	15	
	Jul		200		200	700	120	250			200					70		80	55	
1985	Jan				300	550	200	240			150					100		250	100	70
	Feb		150		220	550	200	220			170					90		120	50	35
	Mar		125		200	400	130	150			110					90		70	50	20
	Apr		60		80	280	150	150			140					80		35	20	10
	May		190		200	600	110	150			125					80		100	50	30
	Jun		50		85	200	90	110			95					70		30	14	10
	Jul		150		190	500	150	170			180					70		100	50	20
1986	Jan	600	270			800	250	500			400					80			120	
	Feb	270	200			400	200	240			140					110			80	
	Mar	260	250			700		220			300					100		75		
	Apr																	85		
Typical dry season flow (l/s)		160	60	80	80	300	100	120	30	80	100	150	50	180	180	70	20	35	20	10
Typical base flow (l/s/km2)		6.0	3.2		2.3	10.9	6.3	6.6			9.4					49.6	14.2	4.6	2.4	1.3

Area wrong

DRYFLOW.WK4

change in base flows between 1985 and 1995 if such have been created by land use changes. A far more comprehensive monitoring programme over the years would have been required. The detailed set of flow measurements would need to have been analysed in relation to the daily rainfall characteristics over the same period.

The base flows, or dry season flows expressed as a flow rate per unit catchment area indicates the low runoff rates. These base flows need to be appreciated. Most of the flows are probably generated in the upper part of the catchments with possible losses down the channel system. In addition, these measurements are made downstream of the WASA intake works and hence the naturalised base flows would need to incorporate those water volumes abstracted by WASA.

Details of some of the WASA intakes are presented in **Table A.12**. A map has been produced in order to define the location of the various intakes in order to relate these to the hydrometric network. This enables an appreciation to be made of the potential needs of an upgraded network system.

Although the continuous flows required to meet demands is relatively small, see **Table A.12**, the estimated yields per hectare are also small and variable when the catchment areas of some of the intakes are taken into consideration. It should be noted that the location of the intake sites needs to be confirmed and consequently the reliability of supply estimates inferred between **Tables A.12** and **Table A.14** should be treated with caution.

The estimated WASA abstractions are presented in **Tables A.12** and **Table A.13**. Again the accuracy of the information is such that these estimates can only be taken as indicative naturalised flows. It is interesting to see the proportion of the flows that may be being abstracted by WASA. In this flow naturalisation estimate, no allowance has been made for the operational characteristics of each particular WASA intake, storage facilities and distribution network. To undertake this would require operational information on the day of each gauging as well as the estimation of travel times between the intakes and the gauging points. This would need to be analysed together with losses and gains in the channel system between the intake and the gauging station.

The foregoing exercise has been undertaken to indicate the uncertainties surrounding the resource estimates since neither are river base flows being measured not the quantity of water being abstracted for irrigation. The water abstracted by WASA should also be considered to be indicative until some of the inconsistencies in the data set are resolved. It highlights a need for better data collection to assist in overall watershed management in the context of water resource management.

A.3 Rainfall Runoff Relationships

Detailed flow measurements have also been undertaken to support the design of the Roseau Dam. The relationship derived by the study (Roseau Basin Water Development Program Stage 1) was presented in Working Paper No 2 as:

$$Q = RO.A / 86.4$$

where Q = discharge in m^3/s
RO = daily unit runoff (mm over the basin/catchment)
A = basin or catchment area in km^2

Rainfall stations used in the estimation of runoff included Quilesse / Edmond Forest, Barre de L'Isle, Union Agricultural, Crown lands and Tete Chemain near Millet.

Correlation analyses were carried out between rainfalls, but on a monthly data set. Monthly runoff was also related to rainfall values through cross correlation or regression analyses of monthly data sets. Various linear and log linear regression relationships were studied, the best correlation being derived from an equation of the form:

$$RO = -8.76 + 1.09\ RL \text{ where } RL = 10^{(0.848 \log Pn + 0.317 \log(Pn-1) - 0.696)}$$

and Pn is the monthly precipitation in mms in a particular month and Pn-1 is that of the previous month to account for antecedent conditions. A correlation coefficient of 0.94 was obtained from 23 data points which was considered acceptable. The rainfall data used being a composite of Quilesse (70%) and Union Research (30%). Linear relationships of various forms were assumed between discharges at the various gauging stations.

Based on the regression analyses, stream flows were generated for the period 1936 to 1986.

The gauging stations used being defined in **Table A.15**. The estimated time to peak (Tp) and the recession coefficient (K) applicable to the recession limb of a storm hydrograph were also defined and estimated to be about 1hr for both, varying between the catchments as defined. For the estimation of flows from the 15 km2 catchment, USDA SCS CN of 74 was assumed with an initial loss of 13mm. {Different values were assumed for PMF estimates (CN of 90)}.

The resulting streamflow gaugings and discharge estimates are given in **Table A.16** with minimum measured stream flows comparable with **Table A.14** when related to a unit area basis.

Based on the information available from the 1985 UNDP Study wherein data sets are presented for daily discharges and daily rainfalls, an comparison has been made of the accumulated discharge values for a particular catchment and compared to the accumulated rainfall considered related to the specific catchment. This is a very simplistic correlation but **Figures A.4** to **A.6** would indicate a reasonable degree of correlation. It is not the objective of this analysis to investigate this relationship in any great detail but purely to assess the potential of relating stream flows to rainfall. The rainfall data set is far more comprehensive than stream flows and hence if stream flows could be reliably derived from daily rainfalls then this would greatly benefit any water resources analysis process. A greater degree of correlation is expected in the wetter months since the impact of abstractions and losses and gains through the river bed will affect dry season correlations.

The instigation of a period of streamflow measurements coupled with good rainfall data analysis would probably enable water resource availabilities to be derived on a probability basis, however, this data collection process needs to be undertaken to meet the analysis requirements.

Table A.15 Characteristics of Catchments as Analysed in the Design of the Roseau Dam

River	Station	Catchment (km2)
Roseau	U/S of proposed dam site	11.05
Roseau	D/S of proposed dam site	15.02
Cul de Sac	U/S of proposed dam site	4.34
Cul de Sac	D/S of proposed dam site	4.75
Millet	Proposed intake site	3.12
Troumassee	Proposed diversion tunnel site	5.85

Source: Roseau Basin Water Development Programme - Stage 1. Working Paper No 2, 1988

Figure A.4

Rainfall Runoff Correlation for the Cul de Sac Catchment, October 1985

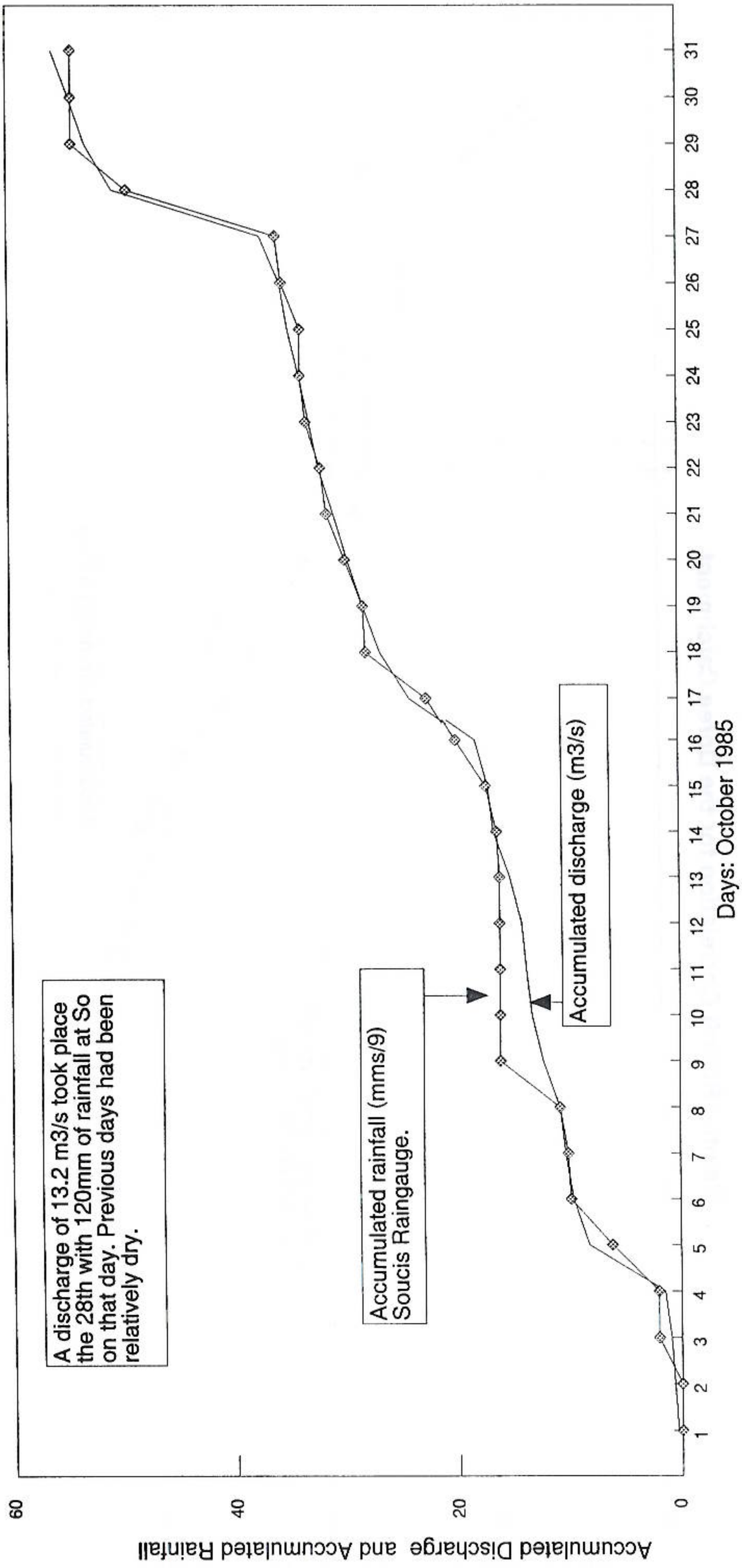


Figure A.5

Rainfall Runoff Correlation for the Doree Catchment

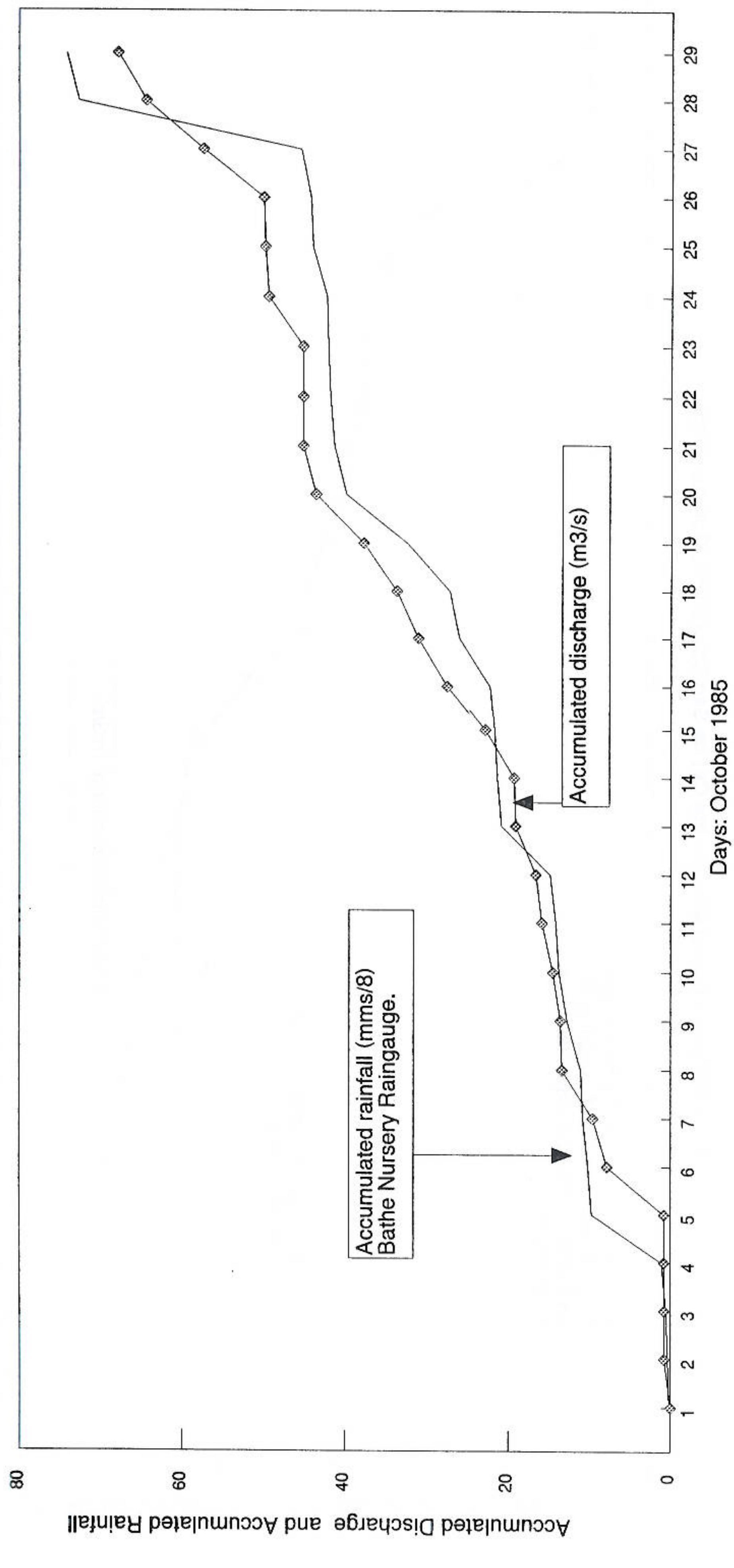
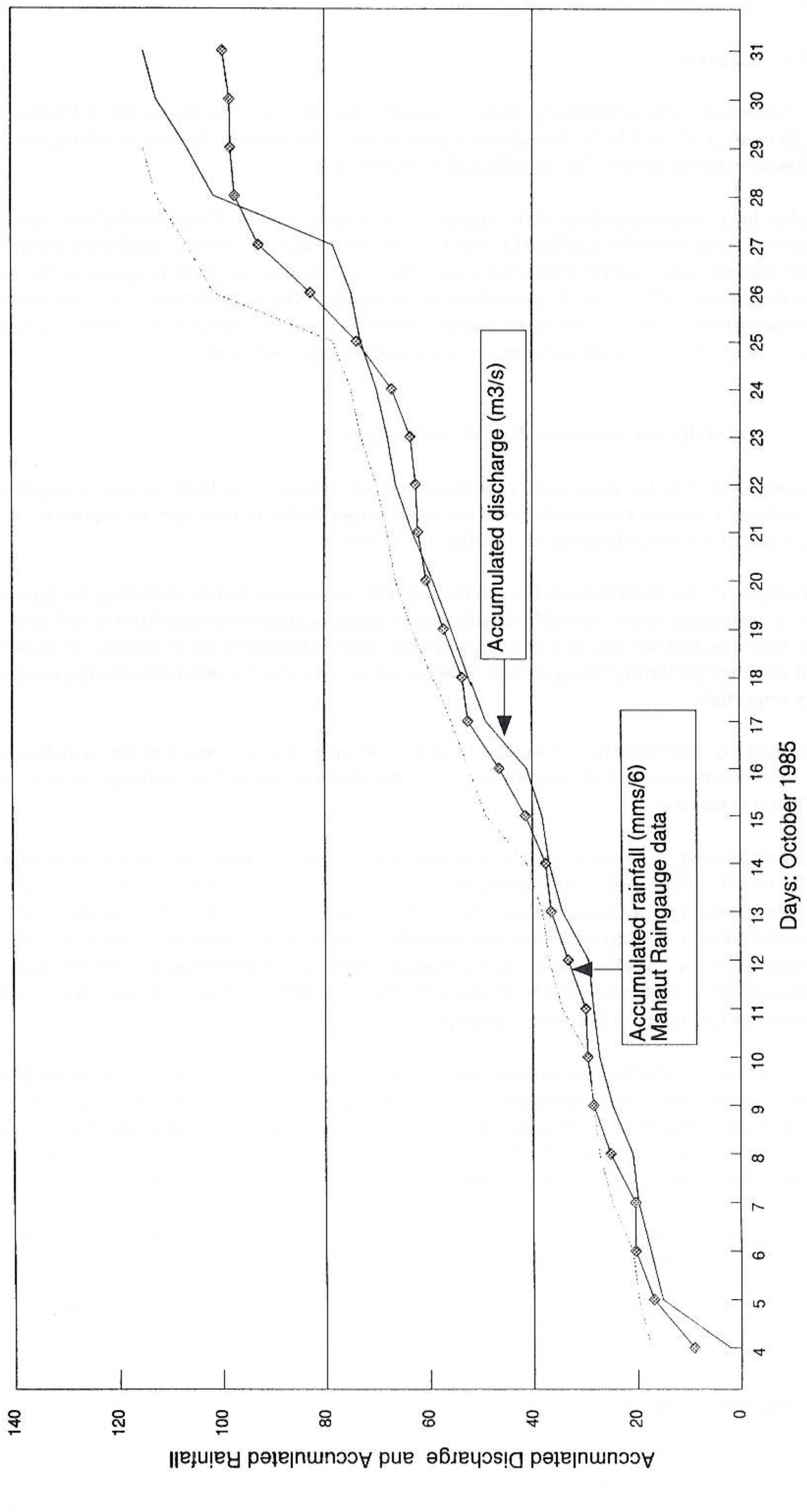


Figure A.6



Rainfall Runoff Correlation for the Troumassee Catchment in October, 1985

A.4 Sediment Transport Estimation

A.4.1 General

The impact of sediment discharge into the marine environment is demonstrated in **Photos 25 and 26.** In the context of coral beds, the estuaries and in-shore areas need to be seen in relation to the main sediment carrying rivers. This is indicated in **Figure 3.8.**

Studies have been undertaken of the deposition of sediment within the several of the coral reefs in the Soufriere Area under the CANARI Project. Twelve (12) sites have been established where deposited sediments are collected and measured every 2 to 3 weeks. This sampling programme has been undertaken since 1989 with the occasional discontinuity. The measurements indicate that sediment pollution of the coral is worse in the months of October and November as would be expected. The impact of the West Coast Road construction has also been evidenced.

A.4.2 Erosivity and Sediment Runoff Assessments

In order to identify the main areas to address in terms of controling land use and/or improvinf agricultural practices and in relation to the desired approaches to drainage, an appreciation is necessary of the controling factors relating to soil loss.

The degree of soil erosion from the ground depends upon many factors including the type of soil, type of vegetation cover, rainfall intensities (and antecedent moisture conditions) and land slope. This indicates that soil loss is a strongly seasonal feature depending upon climatic conditions and land use changes through the year and between years. The effect of extreme climatic events can be very important.

Once soil particles have been detached from the soil mass, the movement of the particles depends on the subsequent processes of rainfall runoff and the characteristics of the drainage network, both in-field and main river.

Factors affecting the erosivity of a soil include both the rainfall intensity and the infiltration capacity of the soil. The latter being affected by the antecedent moisture conditions and the controling soil moisture content prior to and during a storm. The rainfall intensity also relates to the kinetic energy impacting on the soil surface which can itself affect infiltration capacities. This impact effect will be influenced by the 'breaking' effect of the vegetation canopy and the ground cover material (i.e. grass, trash or bare). It is also affected by storm wind effects. Strong winds can increase the kinetic energy of particles by factors of between 1 and over 3.

In St Lucia it is estimated that annual soil loss rates can range from 1 tonne/ha to about 200 tonne/ha depending on the factors described above . Higher and lower rates could apply in very specific circumstances. Research in other countries has shown that soil erosion takes place when rainfall intensities exceed about 25mm/hr. Increasing rainfall intensities resulting in increasing soil erosion although the relationship is not linear, particularly over the 70mm/hr intensity area.

In relation to the slope of the terrain, work by the US Soil Conservation Service has shown that the soil loss per unit area of sloping ground is equivalent to:

$$\text{Soil loss erosion per unit area} \quad \mu = \tan^{m} n \, L^{0.6}$$

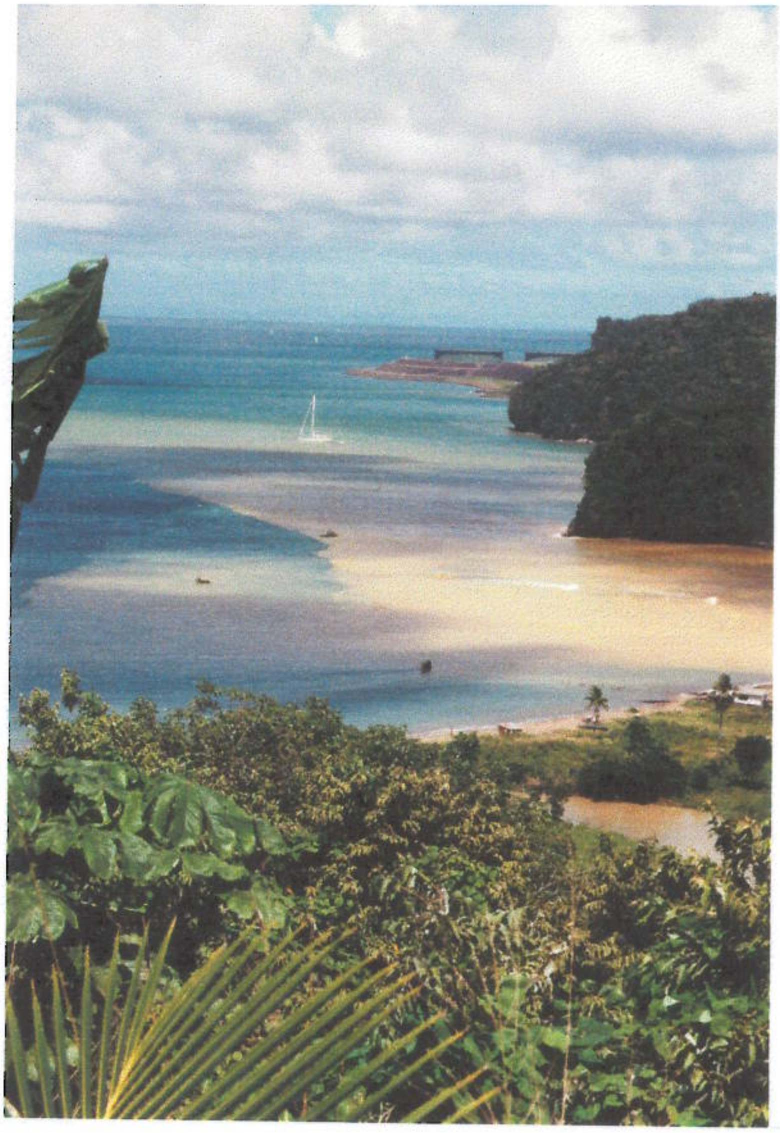


Photo 25 Roseau River Estuary. Sediment laden fresh water entering Bay on 27th October 1996.

Photo 26 Roseau River Estuary. Normal sediment load in estuary, October 19th 1996.

where 'n' is the slope angle and 'L' is the slope length.
'm' was found equal to 1.4 for the US but closer to 2 for tropical conditions akin to St Lucia. However, the value is also related to grain size of the affected soil and does vary with the steepness of the slope ('m' reducing with increasing slope). This yielding a curvilinear relationship.

Ground cover is the other important consideration. This is highlighted by the work carried out many years ago by Hydson and Jackson. A comparison was made between the erosion from two plots of clay loam soils, one plot being covered with a fine wire gauze. Over a 10 year period, the mean annual loss from the open plot was 126.6 t/ha whilst that from the gauze covered plot was only 0.9 t/ha. Similar experiments have been undertaken by others with erosion ratios of between 10 and 100 being found. In general, an exponential decrease in soil loss with increasing percentage interception of rainfall energy and, therefore, increasing percentage canopy cover. This particularly relates to ground coverings of crop residues.

The effectiveness of a plant cover in reducing erosion by raindrop impact depends upon the height and continuity of the canopy and the density of the ground cover. However, raindrops intercepted by leaves will coalesce on the leaves and form larger drops which are more erosive. In particular, the large surface area of bananas can, under high intensity rainfall, form a continuous stream of water which has a highly erosive force on the unprotected soil. It can also tend to remove elements of the ground cover if this is purely crop residues. Thus in addition to to modifying the drop size distribution of the rainfall, the banana leaves, and those of other cultivated crops, can change the spatial distribution of the water impact at the ground surface. [Research on soya crops has shown that rainfall intensities of 25mm/hr were translated into an uneven intensity profile at ground level with 10% of the area being subjected to intensities of 385mm/hr].

The most common means of estimating erosion loss is the application of the Universal Soil Loss Equation. The approach incorporates the 30 minute rainfall intensity value together with values for land/ catchment slopes, crop cover type, erosion control practice

It has been estimated that the sediment transporting capacity of overland varies to the fifth power of the flow velocity, or

$$\text{Sediment Transport Capacity} \propto Q^{5/3} . S^{5/3} \text{ (overland flow) to } Q^{2.1} . S^{2.3} \text{ (+ rainfall effects)}$$

The flowrate is dependent upon the roughness of the ground surface. Increasing the roughness of the ground through encoraging grass growth or through the stabilisation of ground trash/ crop residue reduces flow velocities and reduces the sediment carrying capacity of the sheet flow.

In relation to drainage, the steeper the channel slope the higher the flow velocity and the larger the sediment carrying capacity of the flow. Thus controling channel slopes either through the introduction of structures or through increasing the flow length can reduce the sediment carrying capacities of the drainage channels.

A.4.3 Classification of Erosion Risk.

From the above there are several factors to take into account in the determination of the erosion risk within the catchments of St Lucia. These being:

- storm rainfall intensities;
- soil types and infiltration rates;
- crop or canopy covers (land use patterns);
- ground coverage (land use/ agricultural practices);
- land slope;
- drainage system characteristics; and
- wind effects/exposure.

In relation to rainfall intensities, very little information currently exists in relation to the different rainfall intensities likely to be experienced in different parts of the Island. Information exists for the Union rainfall station on the north of the island, however, that is in arelatively low rainfall area. The recent establishement of new raingauges under the project and the introduction of data loggers has enabled good rainfall intensity information to be obtained for the 1996/97 wet season, notably the rainfall related to the flooding of October 26th 1996.

In the absense of rainfall intensity data, the other approach which has been used to estimate the 'aggressiveness' of rainfall has been been the analysis of the relationship of the highest mean monthly rainfall to the mean annual precipitation. This is analysed in the form p^2/P ('p' being the highest mean monthly rainfall and 'P' the mean annual precipitation).

Work in Peru has derived the following estimation process for estimating sediment yield from a drainage basin:

$$\log (Qs) = 2.65 \log (p^2/P) + 0.46 \log (H) \cdot \tan (S) - 1.56$$

where Qs = mean annual sediment yield (g/m2);
H = mean altitude of the drainage basin;
S = mean slope of the drainage basin in degrees.

Although this does not take into account land use characteristics, the equation can provide an indication of the erosion susceptibility of the different catchments in a region.

A4.4 Land Use Changes

Land use changes affects the rainfall runoff characteristics of a catchment. This relates both to the the severity of flood events and also to the base flow characteristics of the rivers within the catchment. The more effective a catchment becomes at draining storm runoff the greater will be the severity of flooding and the lower the base flows are likely to be during the dry season as less moisture is held in the soild of the catchment.

Only limited research exists in relation to the impact of different soil conservation systems in St Lucia. Work by P Norville for an Msc thesis in 1988 covered the estimation of runoff and soil loss from three different farm layout systems, these being contour drainage, strip cropping and terracing. Some relevant data is contained in the work.

A.4.5 Catchment Sediment Yield

Estimation of sediment yield from the catchments were made in the Study for the Roseau Dam and are summarised in **Table A.16**.

Table A.16

Flow Characteristics in the Upper Catchments of the Cul de Sac, Roseau and Trumassee

Site River	Gauge	Catchment Area km2	Gauged Flows (1983 to 1986) Minimum m3/s	Median m3/s	Mean m3/s	Maximum m3/s
Roseau	U/S Dam site	11.05	0.1	0.38	0.5	4.1
Roseau	D/S Dam Site	15.02	0.14	0.52	0.68	5.6
Cul de Sac	U/S Dam Site	4.34	0.04	0.15	0.2	1.6
Cul de Sac	D/S Dam Site	4.75	0.04	0.16	0.22	1.8
Troumassee	Diversion Tunnel	5.85	0.08	0.29	0.38	3.1
Millet	Intake Site	3.12	0.04	0.15	0.2	1.7

		Equivalent in terms of flows per unit area Minimum l/s/km2	Median l/s/km2	Mean l/s/km2	Maximum l/s/km2
Roseau	U/S Dam site	9.0	34.4	45.2	371.0
Roseau	D/S Dam Site	9.3	34.6	45.3	372.8
Cul de Sac	U/S Dam Site	9.2	34.6	46.1	368.7
Cul de Sac	D/S Dam Site	8.4	33.7	46.3	378.9
Troumassee	Diversion Tunnel	13.7	49.6	65.0	529.9
Millet	Intake Site	12.8	48.1	64.1	544.9

Generated Streamflows 1936 to 1986 Minimum m3/s	Mean m3/s	Maximum m3/s
0.3	0.57	1.05
0.41	0.78	1.43
0.08	0.2	0.39
0.09	0.21	0.43
0.23	0.43	0.79
0.12	0.23	0.42

Equivalent in terms of flows per unit area Minimum l/s/km2	Mean l/s/km2	Maximum l/s/km2
27.1	51.6	95.0
27.3	51.9	95.2
18.4	46.1	89.9
18.9	44.2	90.5
39.3	73.5	135.0
38.5	73.7	134.6

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Sediment transport measurements were made which yielded the following relationships:

For Roseau River and Cul de Sac River catchments - Concentration © = 300 Q mg/l
For Millet River and Troumassee River catchments - Concentration © = 600 Q mg/l
where Q is the channel discharge in m^3/s.

The basis for these relationships was a series of sediment transport measurements which are summarised in **Tables 23 to 27** of the Roseau Dam Report. Working Paper No2, 1988. As for most sediment transport measurements, there was a considerable scatter in the data. Maximum discharges at which sediment concentrations were measured were for about 6.2 m^3/s at the Roseau River cableway. These figures are reproduced in **Figure A.7.** Higher discharges tend to greatly increase sediment transport loadings, hence the linear assumption is not lways correct. However, the data gathered was insufficient to define such a non linear relationship.

Table A.16 Characteristics of Catchments as Analysed in the Design of the Roseau Dam

River	Station	Catchment (km^2)	Annual Estimated Sediment Load (Tonnes)	Yield of each catchment $t/yr/km^2$
Roseau	U/S of proposed dam site	11.05	4,900	443
Roseau	D/S of proposed dam site	15.02	6,700	446
Cul de Sac	U/S of proposed dam site	4.34	1,600	369
Cul de Sac	D/S of proposed dam site	4.75	1,750	369
Millet	Proposed intake site	3.12	4,000	1,282
Troumassee	Proposed diversion tunnel site	5.85	7,500	1.282

Source: Roseau Basin Water Development Programme - Stage 1. Working Paper No 2, 1988

The rivers in St Lucia are typically very steep in the upper reaches of the rivers, the channels being basically ravines, cutting into the rock structure, transitioning into steep channels with wider bed width but with rocks and cobbles forming the channel. The larger rivers have further transition through a steeply sloping stone and gravel bed into a shallower sloped meandering alluvial form. A summary of the different channel forms, braided and meandering channels is presented in the 1984 Report, 'The Roseau, Dennery and Cul de Sac Drainage and Conservation Project'.

The lower reaches of the Cul de Sac River, the Roseau River and the Mabouya river all take on the form of a meandering alluvial channel in their lower reaches. The meander belt width being typically 15 to 20 times the normal flow channel width, as is the case for the Roseau channel. This meander belt width is affected by several factors including the lateral constraints of the valley planform itself.

For determining the regime flow in alluvial channels, several sets of equations have been proposed. These include those of Lacey, Simons and Albertson, Blench and Chang. The majority of these relate to channels which maintain a constant 'design' discharge. The analysis of the equations are useful in appreciating the channel condition for a regime situation.

Sediment Discharge Data (Roseau Dam Studies)

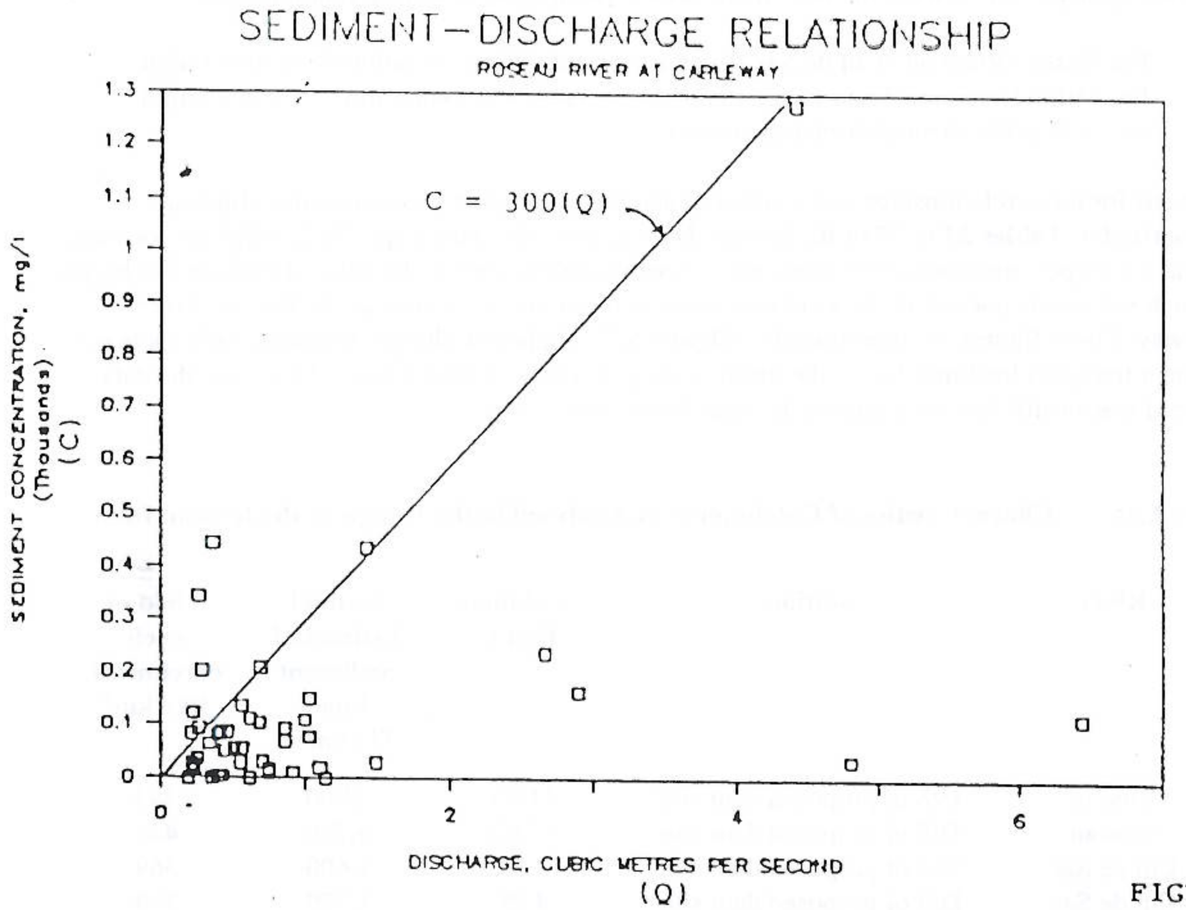

FIGURE 23

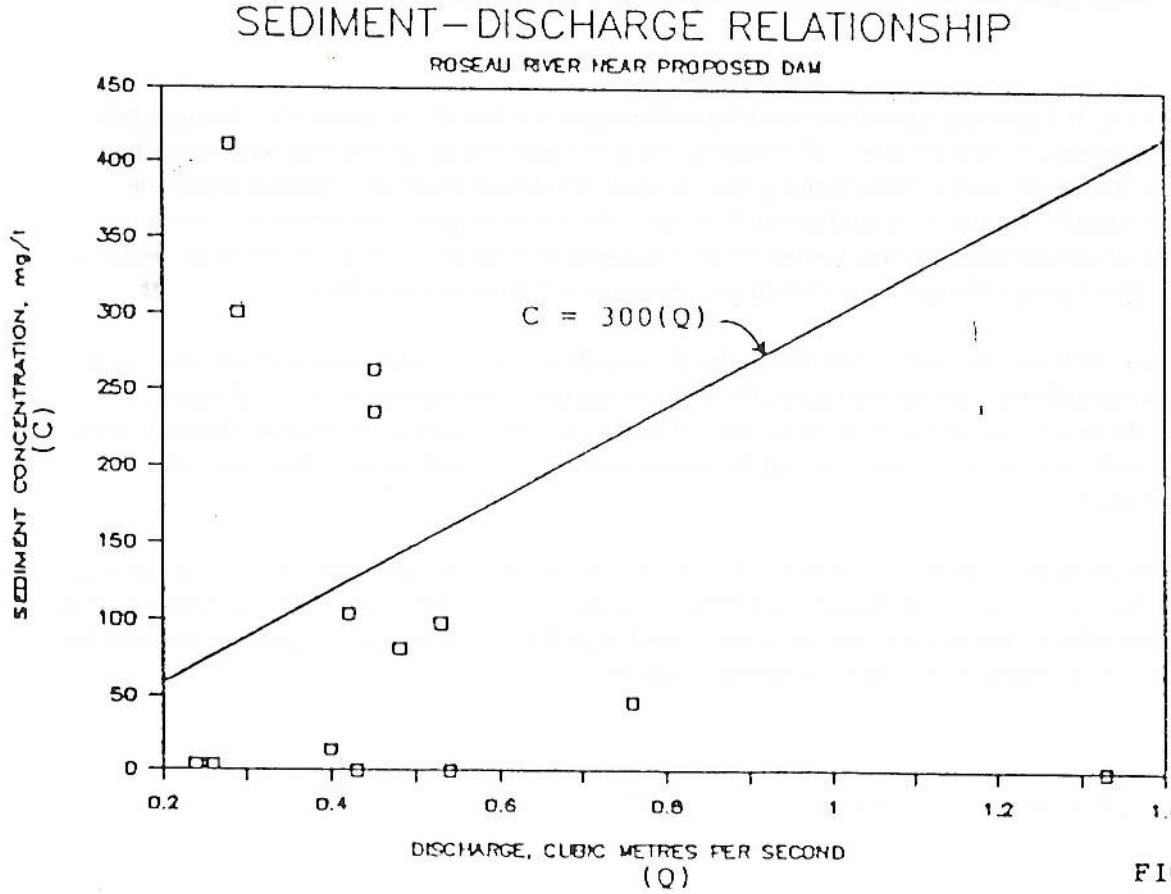

FIGURE 24

Blench developed a regime method which utilises a bed factor, a side factor and a flow resistance value to determine estimates for bed width, depth and slope for a stable channel. The channel form in the Cul de Sac, Roseau area are not considered as yet to be in a very stable form.

The average bed width is given as $B_a = (F_b.\ Q/\ F_s)^{0.5}$

and average depth of $D = (F_s.\ Q/\ F_b{}^2)^{0.333}$

The equation for the stable slope of the channel involves the same co-efficients as above but with parameter defining the sediment concentration also included. This is a more complex equation and has not been presented herein.

For the above equations, F_s is about 0.1 for slightly cohesive banks; and $F_b = 1.9\ (D_{50})^{0.5}$ although the value of F_b increases with sediment concentration.

An alternative method often used is that developed by Chang, **Chang's Rational Method**.

The Chang developed a relationship between slope, particle size and normal discharge. It provides an indication of particle sizes to be expected in bed load form.

In this method, the critical slope for bed load movement is given by:

$$Sc = 0.00238\ Q^{-0.51}(D_{50})^{0.5}$$

or approximately

$$Sc = 0.00238\ (D_{50}/Q)^{0.5}$$

The regime bed width and channel depth being given by the equations

$$B = 4.17\ ((S\text{-}Sc)\ /\ (D_{50})^{0.5})^{\ 0.05}\ Q^{\ 0.5}\ ;\ \text{and}$$

$$D = 0.055\ ((S\text{-}Sc)\ /\ (D_{50})^{0.5})^{\ -0.3}\ Q^{\ 0.3}$$

Whilst in addition an empirical equation was derived for the estimation of bedload related primarily to the difference between the two slopes (the actual channel slope and that critical for bed load movement for a particular bed material defined by the D_{50} value (in mms). The other values in the above equations are in fps units, feet and cusecs). This latter equation is also not given since it is somewhat complex.

Employing these equations enables an estimate to be made of the form of a regime channel for different bed load materials.

For low discharges of about 1 m^3/s and a typical bed material with a D_{50} of 0.25mm, both equations indicate that in a stable channel the bed width would be about 6m with a flow depth of about 0.5m. The channel slope being of the order of 0.0002 (or 1:5000). For a higher discharge of 10 m^3/s, and the same bed material, a much shallower bed slope would be required to prevent sediment movement, two to three times shallower than the stable channel for the $1m^3/s$ flow. Corresponding channel dimensions would be about 17m with a flow depth of about 1m.

These conditions are not those encountered in the channel systems, hence under most conditions the channels are erodible. The degree of erosion during a flood event will however depend upon the sediment carrying capacity of the flow system.

From the equations presented above, at a flow of $10m^3/s$, the estimated sediment load movement is calculated to be between 100 kg/s and 300 kg/s. These relate to sediment concentrations of about 3000ppm and a channel slope of about 0.0025 and a D_{50} of 0.25mm.

For regime relationships in natural channels, these depend upon the planform of the channel. Equations were developed by Chang (1985) for different situations.

In the lower reaches of channels with flat slopes, low sediment loads, and low velocities having a sinuous canal form:

$$B = 5.68\ ((S\text{-}Sc) / (D_{50})^{0.5})^{0.02}\ \dot{Q}^{0.47}\ ;\ \text{and}$$

$$D = 0.83\ \exp[(-0.38\ (S\text{-}Sc) / Sc)^{-0.4}]Q^{0.47}$$

where units are mms, m^3/s and metres where appropriate

For other channels where widths and depths are sensitive to channel slope where the channel oscillates between a sinuous braided form to riffles and pools to maintain slope, different equations have been formulated:

$$B = 278\ Q^{0.93}\ (S / (D_{50})^{0.5})^{0.84}$$

and

$$D_c = [0.112 - 0.0379\ \ln Q - 0.0743\ \ln\ (S / (D_{50})\ ]\ Q^{0.45}$$

In the channel flow conditions defined above, sediment transport estimates based on Engelund and Hansen yields :

$$C = (0.0104\ (S / (D_{50})^{0.5})\ Q^{0.17}\ .\ 10^6\ )^{1.72}\ \text{ppm by weight}$$

and

$$C = (0.137\ (S / (D_{50})^{0.5})\ 10^6)^{1.15}\ \text{ppm}$$

These latter two equations indicate how the sediment load transported by a river is very dependent upon the slope of the channel. Increase the slope of the channel and the sediment carrying capacity increases. This has implications on loop cutting and channel realignment since as the effective channel length is increased, so the slope of the channel increases and therefore the sediment discharge increases thereby carrying more sediment out into the marine environment.

Few actual measurements have been made of sediment loads in the river system. The quantity of sediment transported or moved during a particular event is related primarily to the discharge of the river, it's sectional characteristics and bed roughness and hence the flow velocities. These details should be presented together with any sediment load data set. Information obtained several years ago for the Vieux Fort River are presented in **Table A.18.**

The higher discharges transport a significantly higher volume of sediment be it in suspended form or as bed load movement. Almost all measurements which have been undertaken to date in St Lucia has been related to suspended material, and generally suspended material in the lower more gently sloping reaches of the channel system. However, it is this material which is that which gets transported out into the marine environment, which is an issue of concern in the present Study.

Table A.18 Sediment Transport Loads, River Vieux Fort

River Discharge (m^3/s)	Sediment Load Concentration (ppm)
0.3	11
2.3	100
5.7	240
68.0	4800

Source: UMA 1973 (1984 HTS Report).

During an average flood event of November 21st 1996, water samples were taken in the River Choc, the River Cul de Sac and the River Roseau. No equipment was available hence samples were taken using hand held plastic bottles. Several samples were taken, by necessity from the upper flow area upstream of the three main bridges, two on the West Coast road and the other on the bridge entering the Forestry Department compound/zoo. The Results of these measurements are given in **Table A.19**.

Table A.19 Sediment Sampling on 21st November 1996

River	Estimated Discharge (m^3/s)	Total Suspended Sediment (mg/l)
River Choc	{to be calculated}	3,036
River Cul de Sac		3,330
ditto (same time, location)		3,220
River Roseau		3,515
ditto (same time, location)		4,150
ditto (same time, location)		5,735

The discharge and sediment load given in **Table A.18** would indicate that the sediment load estimates made from the theoretical approach can be considered to be indicative.

In 1985, a study was carried out in the Caribbean region of the hydrology and sediment yield of sample catchments in the region (Quinones 1985). The Troumassee Watershed was selected in the case of St Lucia. The river, of approximate length of 32km was estimated to have an 'average flow' of about 2 m^3/s with an annual rainfall depth of 1,500mm in the lower reaches to 5,000mm per annum in the hills (the latter is probably higher than actual). The suspended sediment was estimated to be in the range of 0 to 654 mg/l over 8.7km reach of the river during heavy rains.

In the upper channel reaches, where slopes are in excess of 1:100 (0.01), boulders of more than 2m diameter have been moved significant distances in the recent floods, notably in the River Troumassee. In the Soufriere river, a very heavy bed load movement took place just upstream of the town with D_{50} boulders of about 0.3m was evident from post flood inspections.

For gravel channels, Parker produced empirical relationships for the flow characteristics

$$B/D_{50} = 4.4\,(Q_*)^{0.5}$$

Where D_{50} is the median particle diameter and Q* is a dimensionless flow parameter

The controlling factor in the relationship being $S (50 / D_{50})^{1.15}$. Complex equations relate bankfull discharge to the above factor and thence to sediment load estimates and mean velocities.

A.5 Water Intakes and Water Qualities

Out of the 24 Sources shown in **Table A.12**, and indicated in **Figure A.3**, 19 are surface sources (Rivers or Streams) 5 are Springs. Out of the 19, five have slow sand filtration; 4 have chemical coagulation (alum and lime) treatment and the remaining 10 have only minimal sedimentation at the storage reservoirs, however, all have chlorine disinfection. Typical Intake sites are shown in **Photos on the next page**.

During and after heavy rain the 10 supplies with minimal treatment are subjected to gross contaminations (turbidity and suspended solids) and consequently shutdown until the turbidity is reduced to an acceptable level determined by an operative. This is not a procedure that WASA would wish to continue and a more appropriate method of treatment, and which is affordable is needed. It should be noted that the four chemical treatment plants supply water to urban areas and also suffer from problems of overload.

The high concentrations of organic debris and sediment resulting from soil erosion create high levels of turbidity particularly during periods of heavy rainfall, with NTUs sometimes over 1,000. {Turbidity levels are measured in terms of Nephelometric Turbidity Units (NTU) }. The World Health Organisation states that high turbidity levels (>5 NTU) can seriously affect the effectiveness of disinfection (treatment - chlorination) of the supply. Slow sand filters as used in some of the plants also have problems dealing with high levels of suspended solids, levels above 10mg/l requiring frequent cleaning. This of course increases operational costs as well as imposing difficulties in ensuring consistent supply reliability and quality. With the introduction of Roseau Dam, the majority of the small intakes are now related to the towns and rural communities in the areas not supplied by the dam.

Pretreatment recommendations include:

20 to 200 NTU	Simple sedimentation;
20 to 150 NTU	Roughing filtration;
50 to 200 NTU	Chemical treatment;
> 1,000 NTU	Storage reservoir;

Regular water quality testing is undertaken by WASA both of the raw water entering storage from an intake and of the eventual treated water. In many places treatment only implies chlorination. Although Table A.12 indicates that most sources are treated with chlorine gas, this information is reportedly out of date and the common treatment of the small supply units is less well controlled

Although WASA do not have the analysis techniques for the chemicals associated with pesticides, they operate fish tanks as a biological monitoring device at the inlet to 3 of the treatment plants (still ??). There have been plans to extend this approach to all intakes but as yet this has not been implemented.

Maintenance of intakes is an important consideration. This not only covers blockages, cleaning filters at the intake, checking on upstream land use activities but also in monitoring discharges in the streams which are not being captured at each intake to enable estimates to be made of future

Photo 27 Dennery Watershed, Ravine Saut Tributary. WASA intake works.

Photo 28 L'Ivrogne River (near Delcer, SW of Island). WASA intake and primary sedimentation.

development potentials or the need to perhaps identify new source locations. The effectiveness of the maintenance can only be assessed through a regular discharge measurement and water quality monitoring programme.

In 1911 piped water supply was installed in Dennery, the population being estimated at that time to be about 1,000. A new source was established in 1967 in the Ravine Saut (98m a.m.s.l.) with a slow sand filter unit at Errard whilst in 1987 another new plant was commissioned. The estimated population in 1981 was up to 6,000 with a relatively high estimated water demand level. Turbidity measurements made on the water from the intake in 1987 ranged from below 5 NTU to over 400 NTU with about 87% of the results being below 50 NTU.

Water quality measurements have been undertaken over a period at the Dennery intake. Analyses have been undertaken to attempt to relate turbidity levels with rainfall volumes. A direct relationship should not be expected since other factors which relate are the distribution of rainfall through the day, the rainfall intensities, the antecedent moisture conditions, the vegetation cover at the time of the rainfall. Only the rainfall factor was analysed and that parameter being related to a monthly total rainfall at a particular fixed point in the catchment. Daily data was available and perhaps the analysis would have yielded better correlation had such been used. There can be also considerable variation in rainfall even within a catchment. The analysis concluded that with a high monthly rainfall, of the order of 500mm, then turbidity levels of 35 to 40 NTU. It is important to relate the turbidity measurements to a particular time and day since it is likely that measured NTUs will vary considerably through the month.

The ODA funded project, 'The Development and Integration of Biotic and Chemical Monitoring with Land Use Assessment for Tropical River Resource Management' (River Surveillance Project) has been in progress for the last couple of years. Sampling programmes have been undertaken on all the major rivers in the Island, approximately 13 in all, requiring 46 sampling stations. Some of these sampling points have been located at the WASA intake sites.

Although the objective of the study is to produce an easy to use ecological classification and surveillance scheme for upland tropical rivers related to the level and categories of upper catchment pollution, it provides a valuable basic network for future water quality monitoring. The location of the sampling sites is given in **Figure A.8**. More details are provided in the Main Report on the conclusions from this study.

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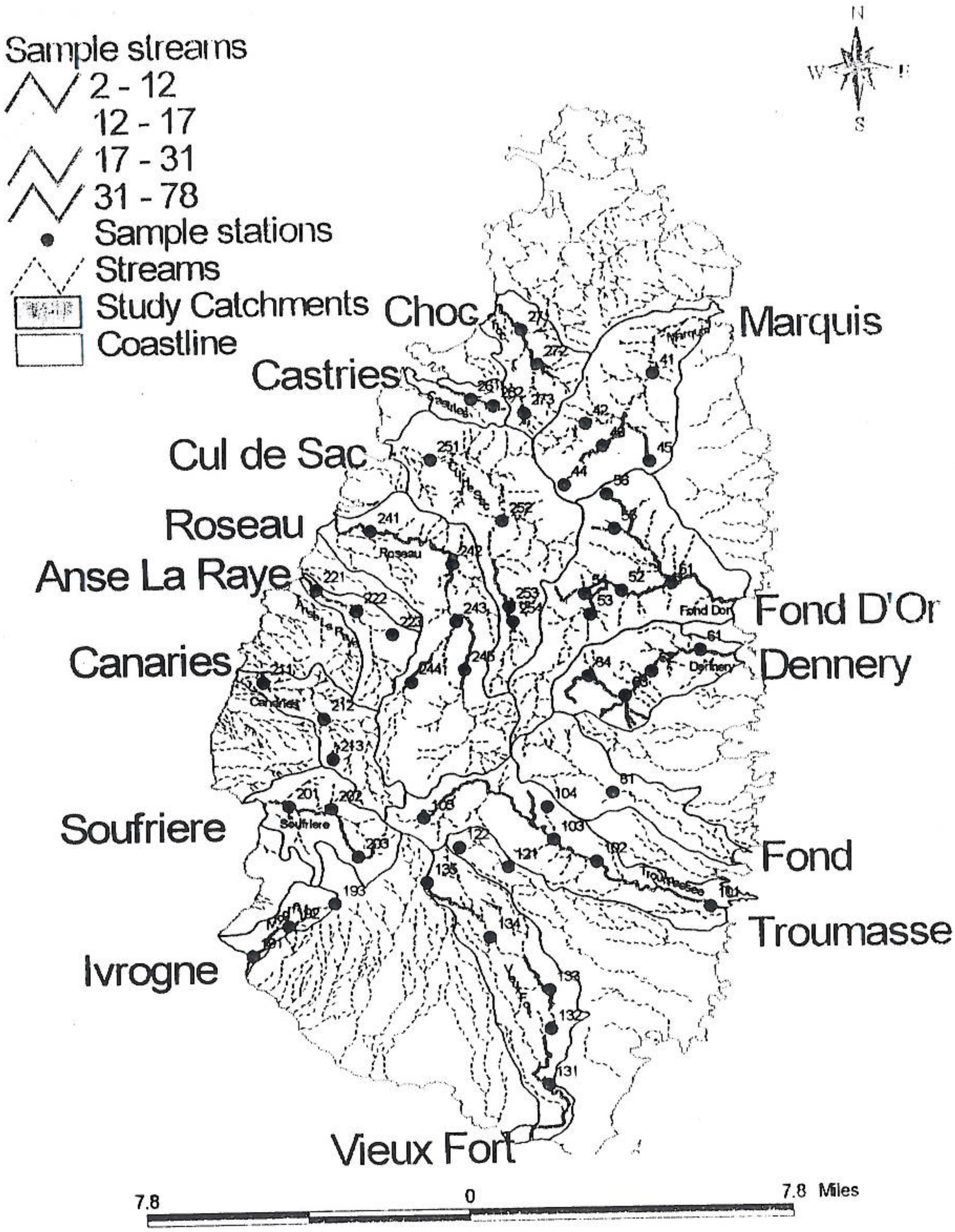
Figure A.8

Streams covered by the Study ' River Surveillance of the Caribbean'
(CEHI/ ODA funded)



Appendix B

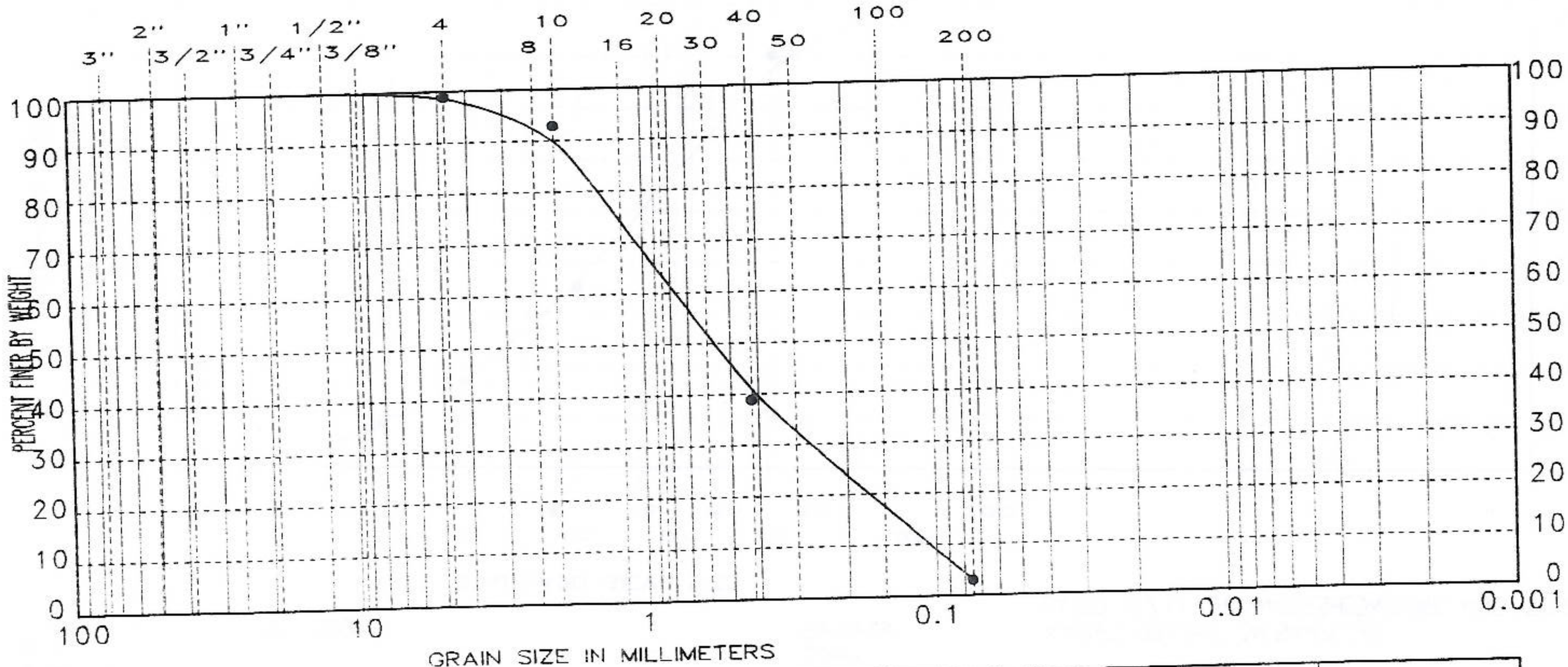
River Bed and Bank Material Particle Size Analyses

River Bed and Bank Material Samples

Sample Number	River	Location
1	Cul de Sac	Immediately downstream of the West Coast Road Bridge {Bed material sample}
2	Cul de Sac	(same location, check sample)
3	Cul de Sac	In river, near supermarket and new fence {Bed material sample}
4	Cul de Sac	Upper L'Abbaye, downstream of bridge {Bed material sample}
5	Mabouya	Immediately d/s of main road bridge (water level recorder site) {Bed material sample}
6	Mabouya	Immediately d/s of main road bridge (water level recorder site) {River bank material, silt depositsed by river}
7	Mabouya	Main road, western bridge. (on map, near 'communal laundary') {Bed material sample}
8	Fond	Downstream of East Coast Road Bridge {Bed material sample}
9	Troumassee	Upstream of East Coast Road Bridge {Bed material sample}
10	Troumassee	2.5 km upstream of East Coast Road Bridge {Bed material sample}
11	Canelles	Downstream of East Coast Road Bridge {Bed material sample}
12	Vieux Fort	Near airport, Sediment deposited by October 26th flood {October 26th flood water deposits}
13	Vieux Fort	Upstream of main river bend near airport {Bed material sample}
14	Vieux Fort	Downstream of bridge near Morne Beausejour {Bed material sample}
15	Roseau	Downstream of West Coast Road Bridge {Bed material sample}
16	Roseau	Channel loop cut section, south of Belair {Bed material sample}
17	Roseau	Channel loop cut section, south of Belair {October 26th flood water deposits}
18	Roseau	Adjacent to Phase I Embankment, north of Vanard crossing {Bed material sample}
19	Cul de Sac	Upstream of Marc Marc Bridge, river bank material {typical river bank material in this section of the river}
20	Marquis	Upstream of Boguis Bridge (old gauging station) {Bed material sample}

SOIL CLASSIFICATION DATA

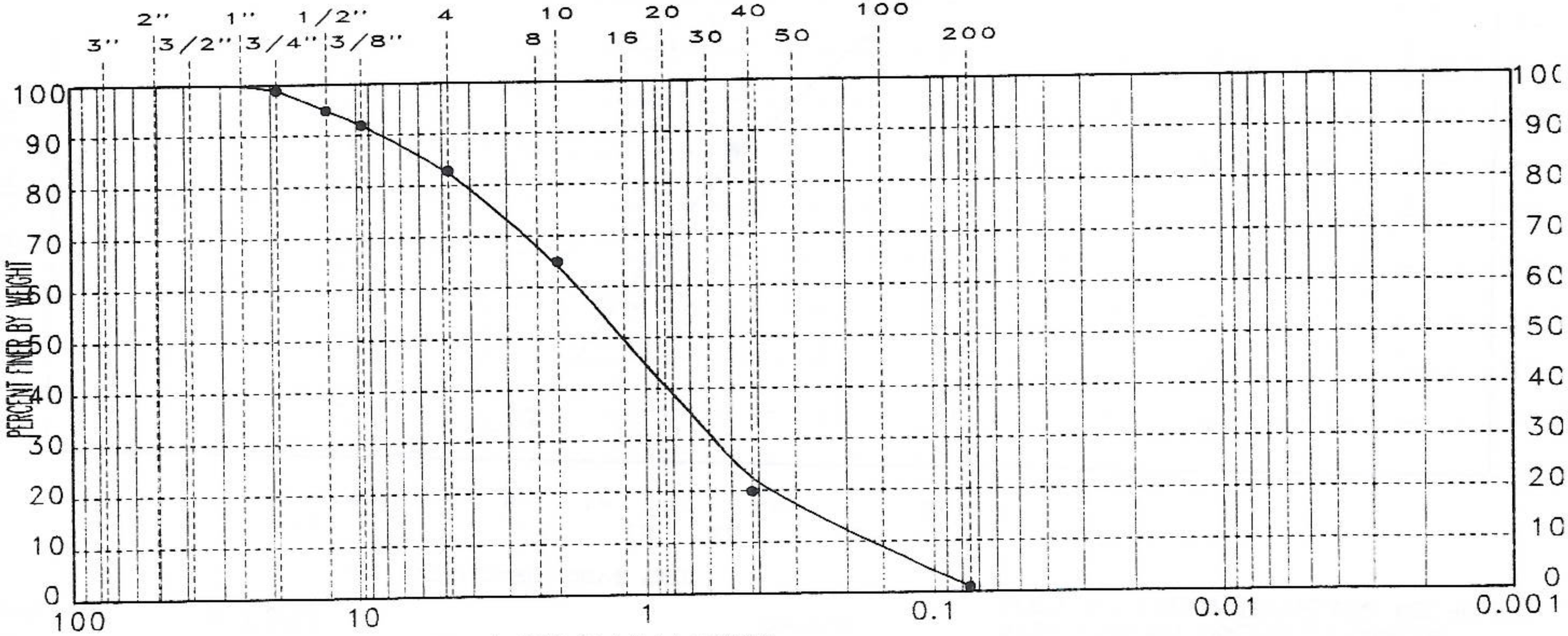
Project No.:	WS ENV M/1	Natural % Moisture:	34
Project Name:	W-SHED & ENVIRONMENTAL MNG PJT	Liquid Limit:	N/A
Boring No.:		Plastic Limit:	N/A
Sample No.:	1.	Plasticity Index:	N/A
Depth:		Color:	
Classification:	ODOT ODOT	Remarks:	WASHED GRADING ANALYSIS ON SAMPLE#1 DATED:16/11/96.WATERSHED&ENV MGE PROJECT.



ASTM D 422	GRAVEL		SAND			SILT	CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE		
AASHTO	COARSE	FINE		COARSE	FINE	SILT	CLAY
	GRAVEL			SAND			

SOIL CLASSIFICATION DATA

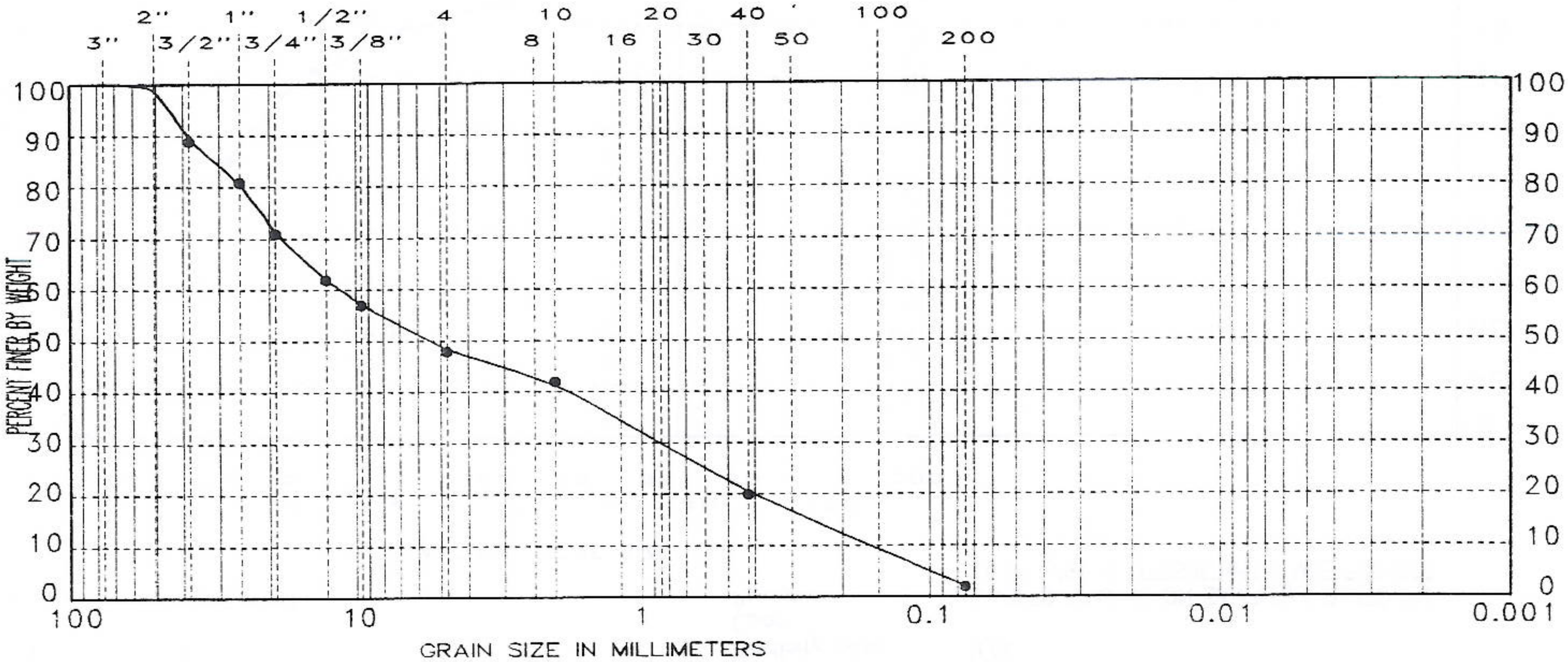
Project No.:	WS ENV M/1	Natural % Moisture:	24
Project Name:	W-SHED & ENVIRONMENTAL MNG PJT	Liquid Limit:	N/A
Boring No.:		Plastic Limit:	N/A
Sample No.:	2.	Plasticity Index:	N/A
Depth:		Color:	
Classification:	ODOT ODOT	Remarks:	WASHED GRADING ON SAMPLE#2 DATED:16/11/96.WATERSHED&EVNRL MGE PRCJE



ASTM D 422	GRAVEL		SAND			SILT	CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE		
AASHTO	COARSE	FINE		COARSE	FINE	SILT	CLAY
	GRAVEL			SAND			

SOIL CLASSIFICATION DATA

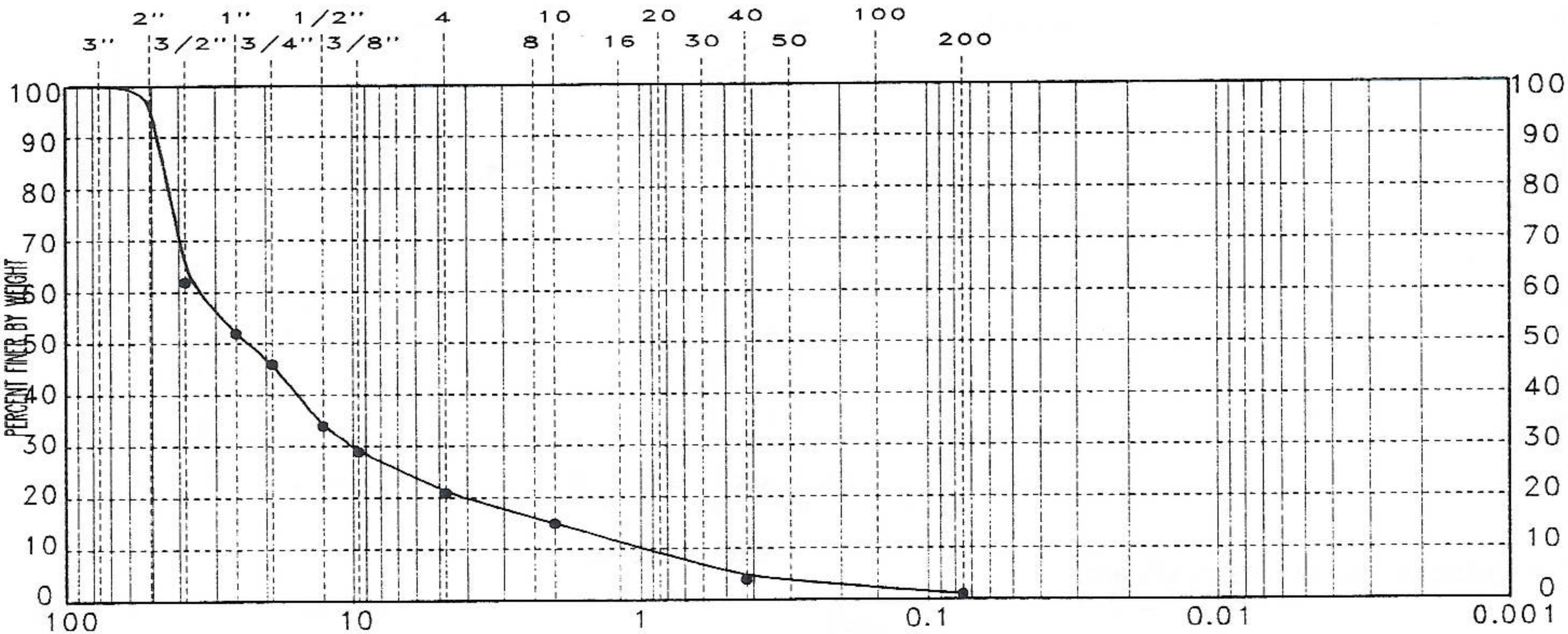
Project No.:	WS ENV M/1	Natural % Moisture:	20
Project Name:	W-SHED & ENVIRONMENTAL MNG PJT	Liquid Limit:	N/A
Boring No.:		Plastic Limit:	N/A
Sample No.:	3.	Plasticity Index:	N/A
Depth:		Color:	
Classification:	ODOT ODOT	Remarks:	WASHED GRADING ON SAMPLE#3.DATED:16/11/96.WATERSHED & ENV MGI



ASTM D 422	GRAVEL		SAND			SILT	CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE		
AASHTO	GRAVEL			SAND		SILT	CLAY
	COARSE	FINE		COARSE	FINE		

SOIL CLASSIFICATION DATA

Project No.:	WS ENV M/1	Natural % Moisture:	10
Project Name:	W-SHED & ENVIRONMENTAL MNG PJT	Liquid Limit:	N/A
Boring No.:		Plastic Limit:	N/A
Sample No.:	4.	Plasticity Index:	N/A
Depth:		Color:	
Classification:	ODOT ODOT	Remarks:	WASHED GRADING ON SAMPLE#4 DATED ON 16/11/96.WATERSHED&ENV MGE PROJECT.



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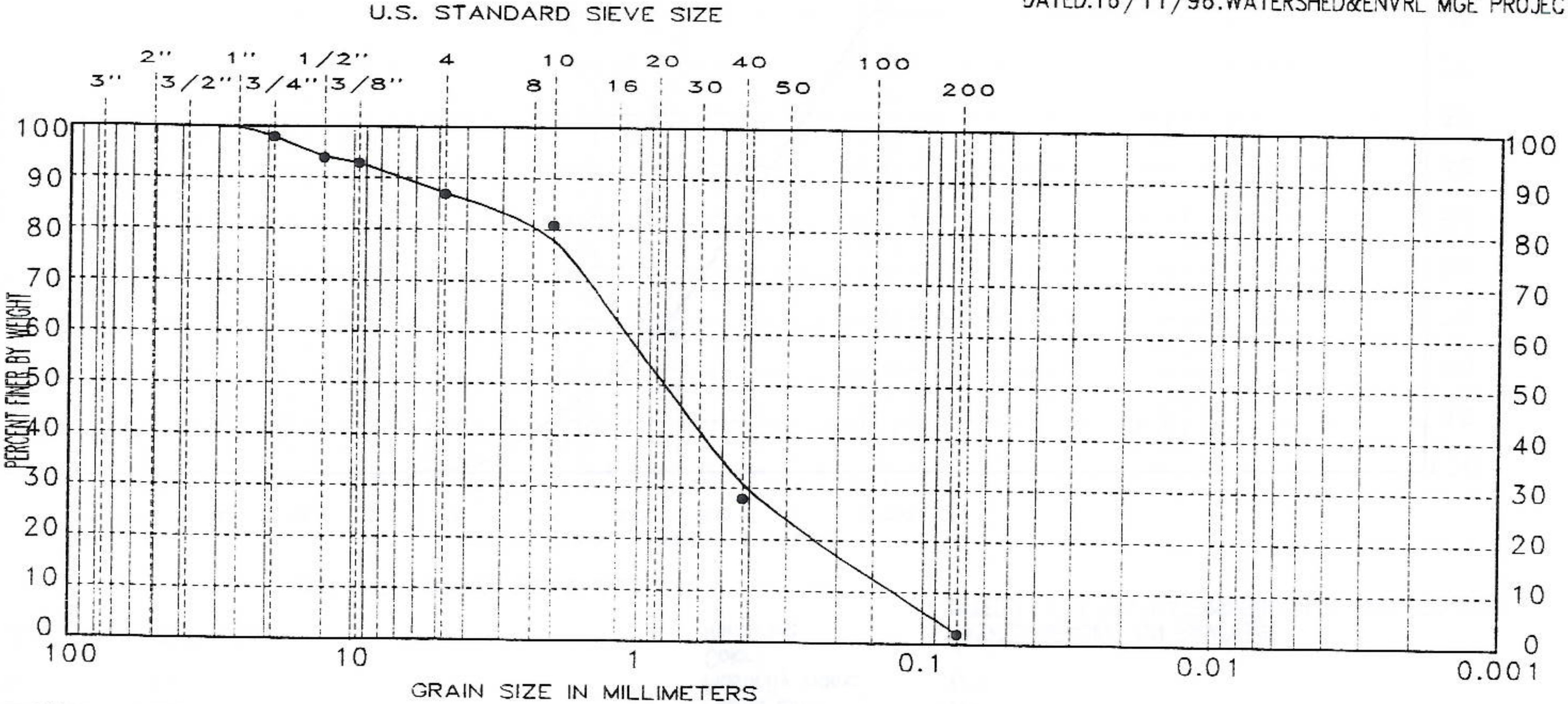
<tr><td>COARSE</td><td>FINE</td><td>COARSE</td><td>MEDIUM</td><td>FINE</td></tr>
<tr><td rowspan="2">AASHTO</td><td>COARSE</td><td>FINE</td><td></td><td>COARSE</td><td>FINE</td><td rowspan="2">SILT</td><td rowspan="2">CLAY</td></tr>
<tr><td colspan="3">GRAVEL</td><td colspan="2">SAND</td></tr>
</table>

SOIL CLASSIFICATION DATA

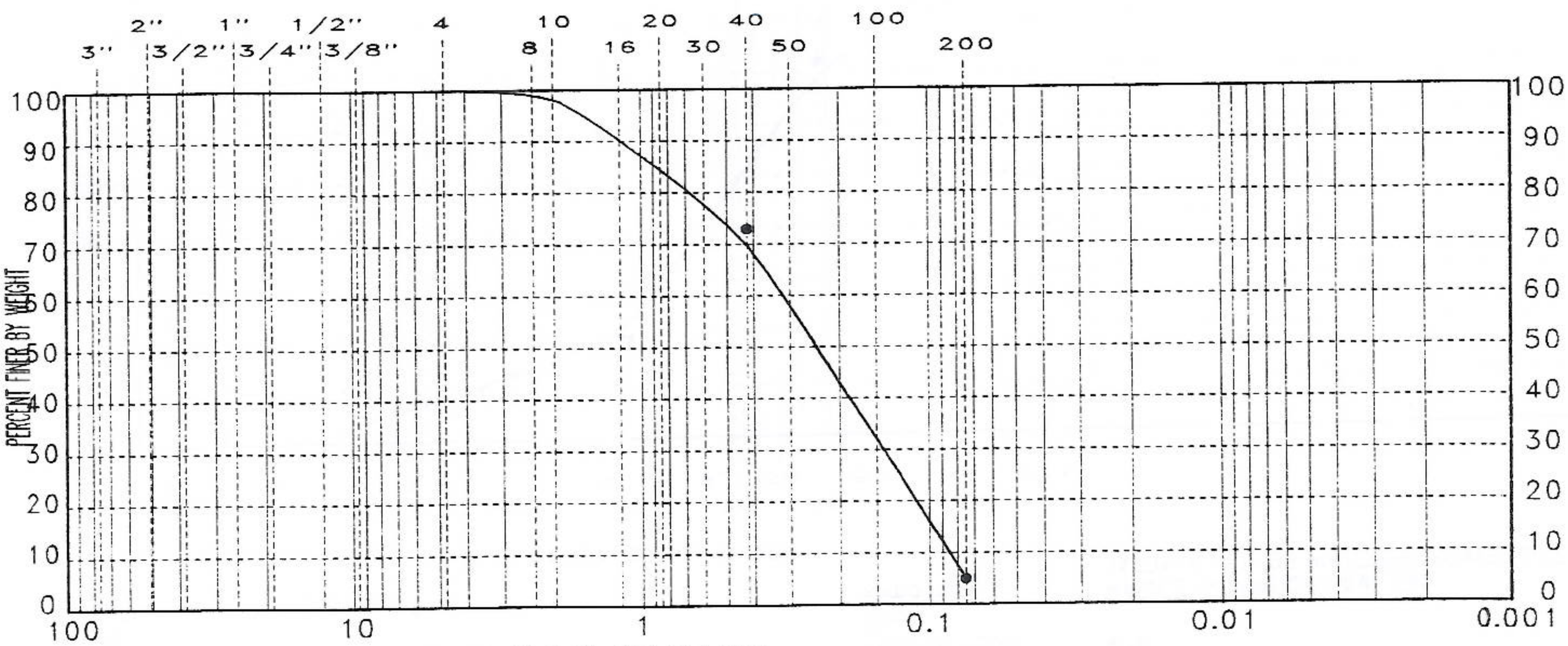
Project No.:	WS ENV M/1	Natural % Moisture:	33
Project Name:	W-SHED & ENVIRONMENTAL MNG PJT	Liquid Limit:	N/A
Boring No.:		Plastic Limit:	N/A
Sample No.:	5.	Plasticity Index:	N/A
Depth:		Color:	
Classification:	ODOT ODOT	Remarks:	WASHED GRADINGON SAMPLE#5 DATED:16/11/96.WATERSHED&ENVRL MGE PROJECT.



	GRAVEL		SAND				
ASTM D 422	COARSE	FINE	COARSE	MEDIUM	FINE	SILT	CLAY
AASHTO	COARSE	FINE	COARSE		FINE	SILT	CLAY
	GRAVEL		SAND				

SOIL CLASSIFICATION DATA

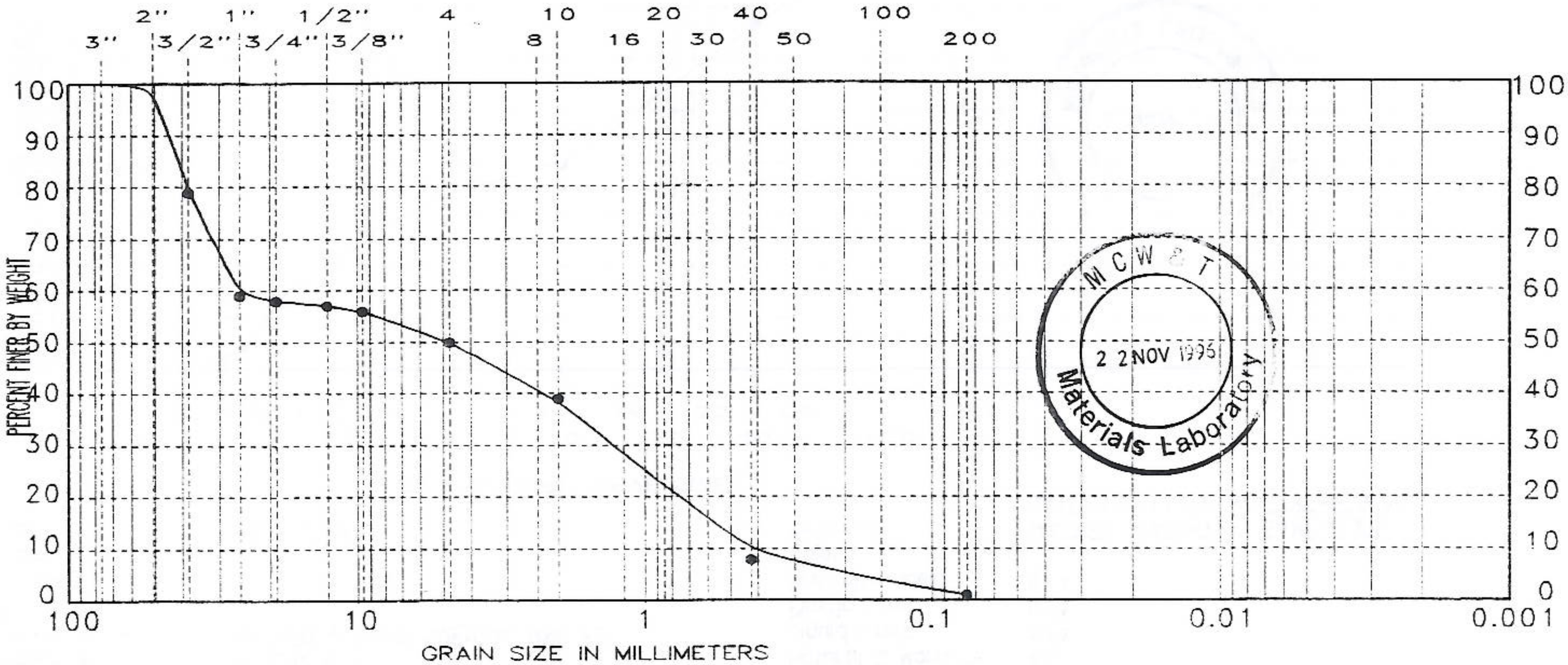
Project No.:	WS ENV M/1	Natural % Moisture:	27
Project Name:	W-SHED & ENVIRONMENTAL MNG PJT	Liquid Limit:	N/A
Boring No.:		Plastic Limit:	N/A
Sample No.:	6.	Plasticity Index:	N/A
Depth:		Color:	
Classification:	ODOT ODOT	Remarks:	WASHED GRADING ON SAMPLE#6 DATED:16/11/96.WATERSHED&ENVRL MGE PROJECT.



ASTM D 422	GRAVEL		SAND			SILT	CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE		
AASHTO	COARSE	FINE		COARSE	FINE	SILT	CLAY
	GRAVEL			SAND			

SOIL CLASSIFICATION DATA

Project No.:	WS ENV M/1	Natural % Moisture:	17
Project Name:	W-SHED & ENVIRONMENTAL MNG PJT	Liquid Limit:	N/A
Boring No.:		Plastic Limit:	N/A
Sample No.:	7	Plasticity Index:	N/A
Depth:		Color:	
Classification:	ODOT ODOT	Remarks:	WASHED GRADING ON SAMPLE #7 DATED:16/11/96.WATERSHED & ENVRL MGE PROJEC

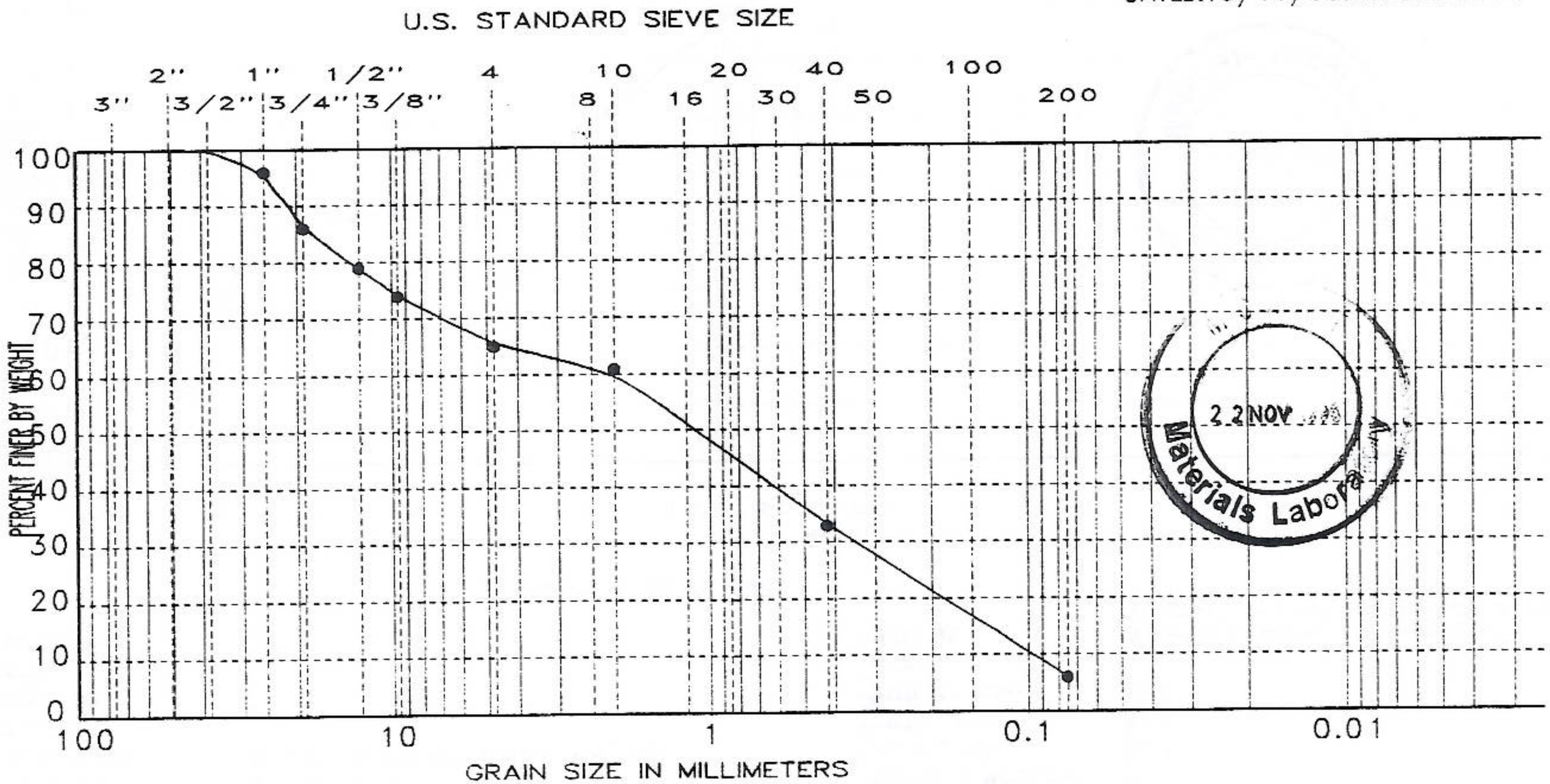


ASTM	GRAVEL		SAND			SILT	CLAY
D 422	COARSE	FINE	COARSE	MEDIUM	FINE		
AASHTO	COARSE	FINE		COARSE	FINE	SILT	CLAY
	GRAVEL			SAND			

SOIL CLASSIFICATION DATA

Project No.: WS ENV M/1
Project Name: W-SHED & ENVIRONMENTAL MNG PJT
Boring No.:
Sample No.: 8.
Depth:
Classification: ODOT ODOT

Natural % Moisture: 45
Liquid Limit: N/A
Plastic Limit: N/A
Plasticity Index: N/A
Color:
Remarks: WASHED GRADING ON SAMPLE #8 DATED:16/11/96.WATERSHED&EN'



ASTM	GRAVEL		SAND			SILT	CLA
D 422	COARSE	FINE	COARSE	MEDIUM	FINE		
AASHTO	COARSE	FINE		COARSE	FINE	SILT	CLA
	GRAVEL			SAND			

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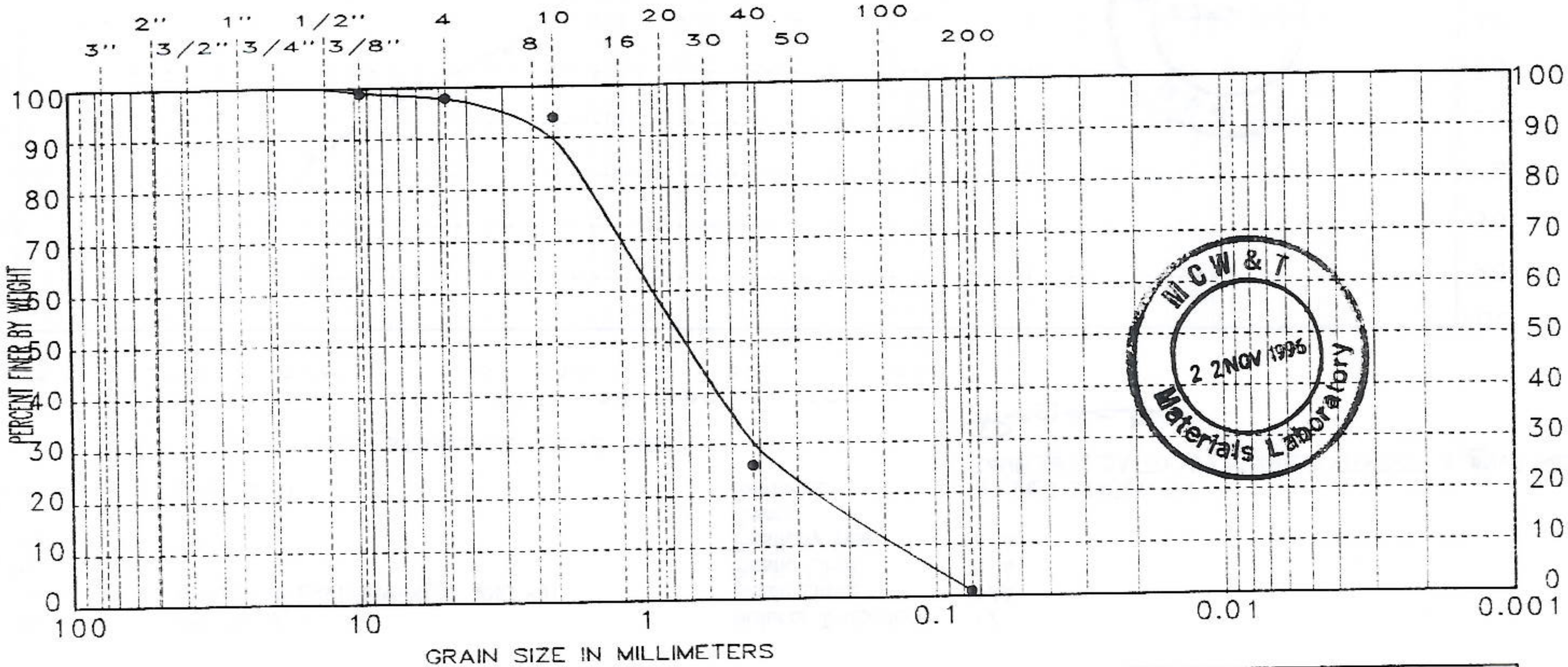
SOIL CLASSIFICATION DATA

Project No.: WS ENV M/1
Project Name: W-SHED & ENVIRONMENTAL MNG PJT
Boring No.:
Sample No.: 9
Depth:
Classification: ODOT ODOT 0

Natural % Moisture: 25
Liquid Limit: N/A
Plastic Limit: N/A
Plasticity Index: N/A
Color:
Remarks: WASH GRADING ON SAMPLE#9 DATED:16/11/96 WA &ENVRL MGE PROJECT.

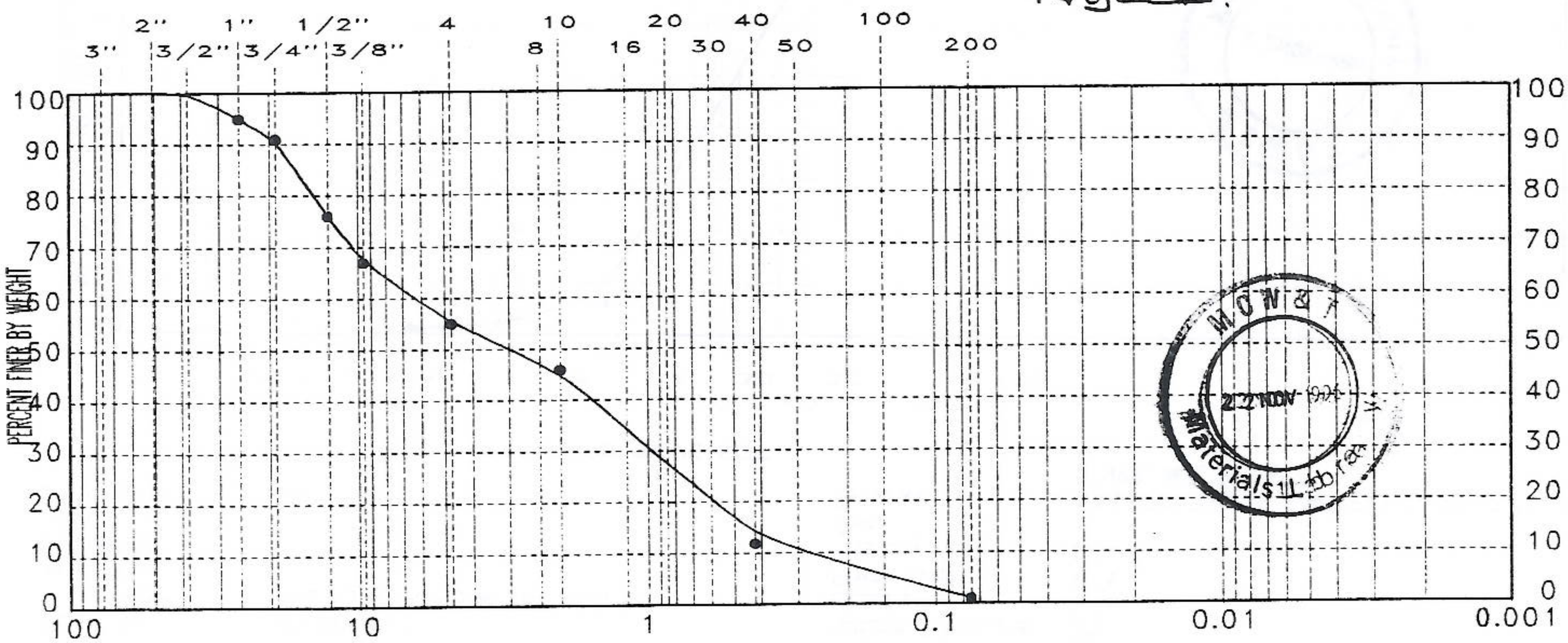


ASTM D 422	GRAVEL		SAND			SILT	CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE		
AASHTO	COARSE	FINE		COARSE	FINE	SILT	CLAY
	GRAVEL			SAND			

SOIL CLASSIFICATION DATA

Project No.:	WS ENV M/1	Natural % Moisture:	17
Project Name:	W-SHED & ENVIRONMENTAL MNG PJT	Liquid Limit:	N/A
Boring No.:		Plastic Limit:	N/A
Sample No.:	10.	Plasticity Index:	N/A
Depth:		Color:	
Classification:	ODOT ODOT	Remarks:	WASHED GRADING ON SAMPLE#10.DATED:16/11/96.WATERSHED & ENVR KGC

Project:

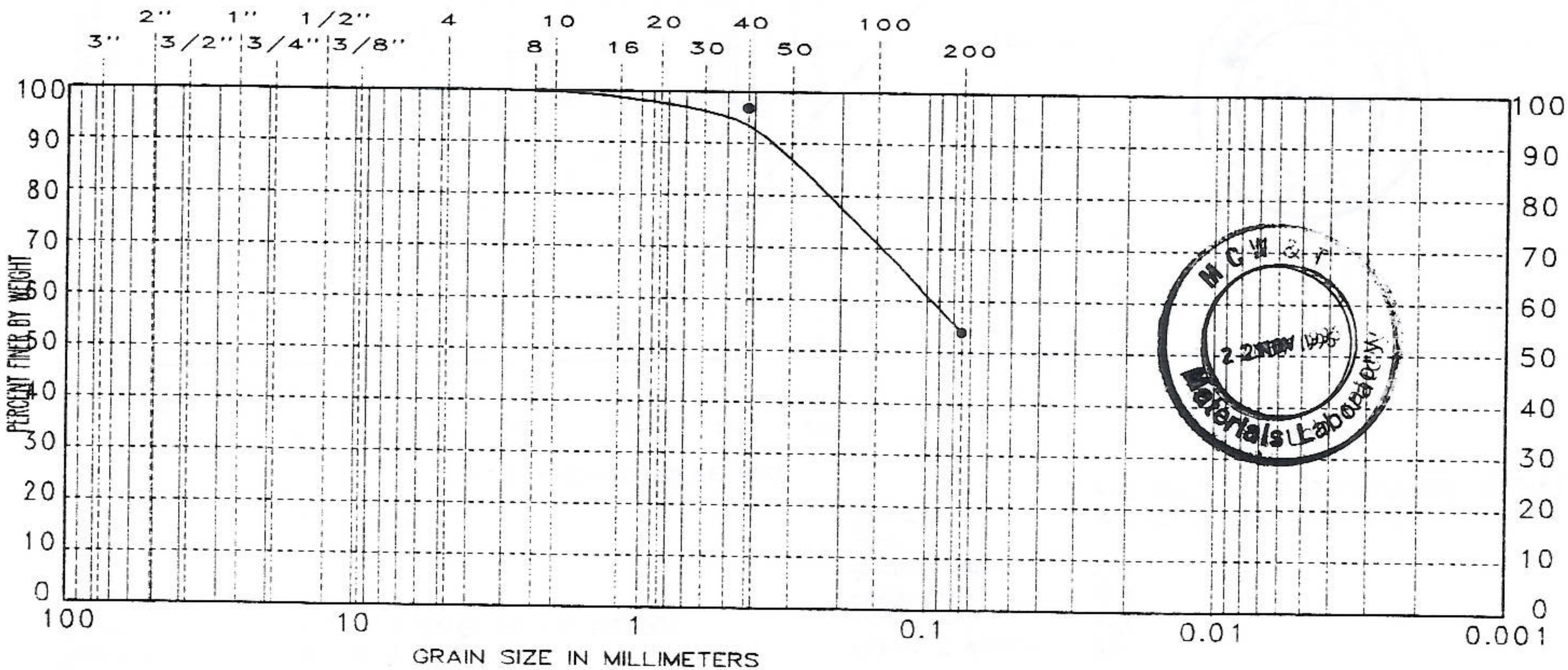


ASTM D 422	GRAVEL		SAND			SILT	CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE		
AASHTO	COARSE	FINE		COARSE	FINE	SILT	CLAY
	GRAVEL			SAND			

SOIL CLASSIFICATION DATA

Project No.: WS ENV M/1
Project Name: W-SHED & ENVIRONMENTAL MNG PJT
Boring No.:
Sample No.: 11.
Depth:
Classification: ODOT ODOT

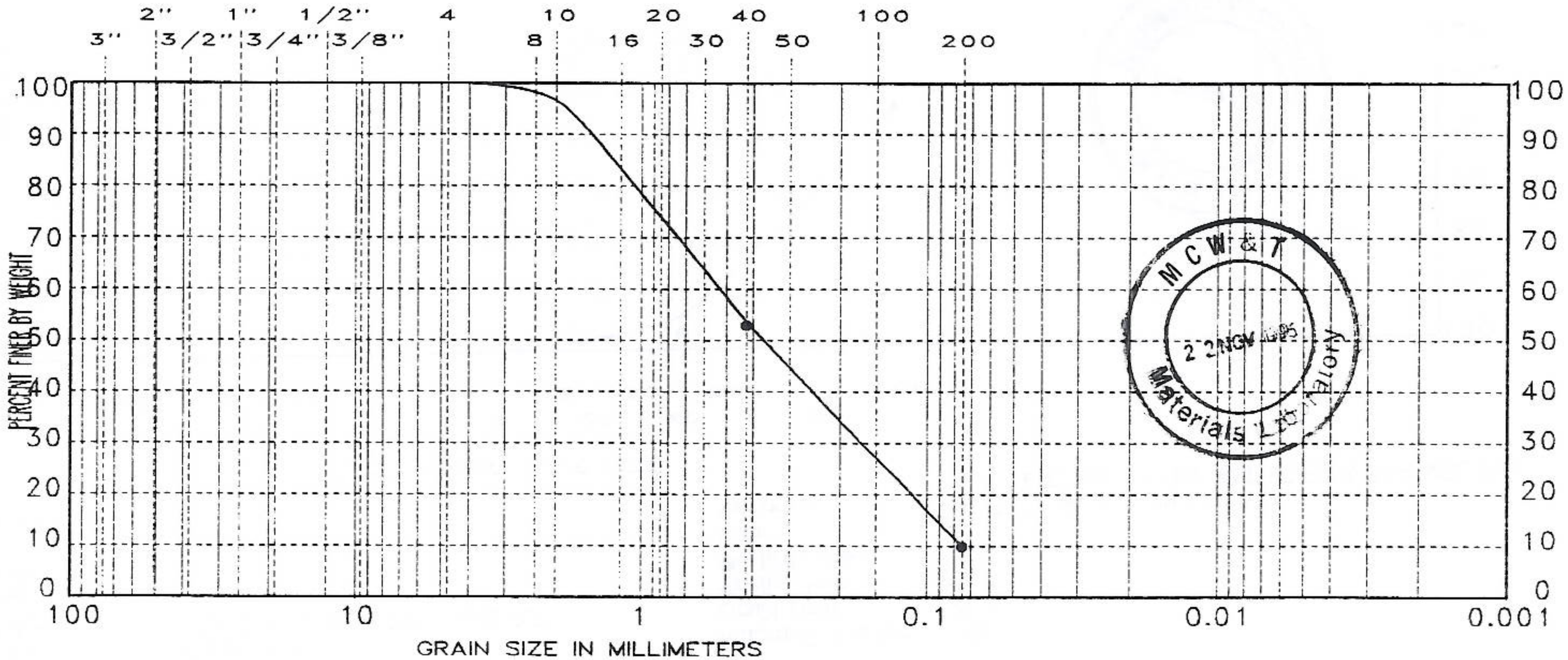
Natural % Moisture: 48
Liquid Limit: N/A
Plastic Limit: N/A
Plasticity Index: N/A
Color:
Remarks: WASHED GRADING ON SAMPLE #11.DATED:16/11/96.WATERSHED &ENVR MGE PRO.



ASTM D 422	GRAVEL		SAND			SILT	CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE		
AASHTO	COARSE	FINE		COARSE	FINE	SILT	CLAY
	GRAVEL			SAND			

SOIL CLASSIFICATION DATA

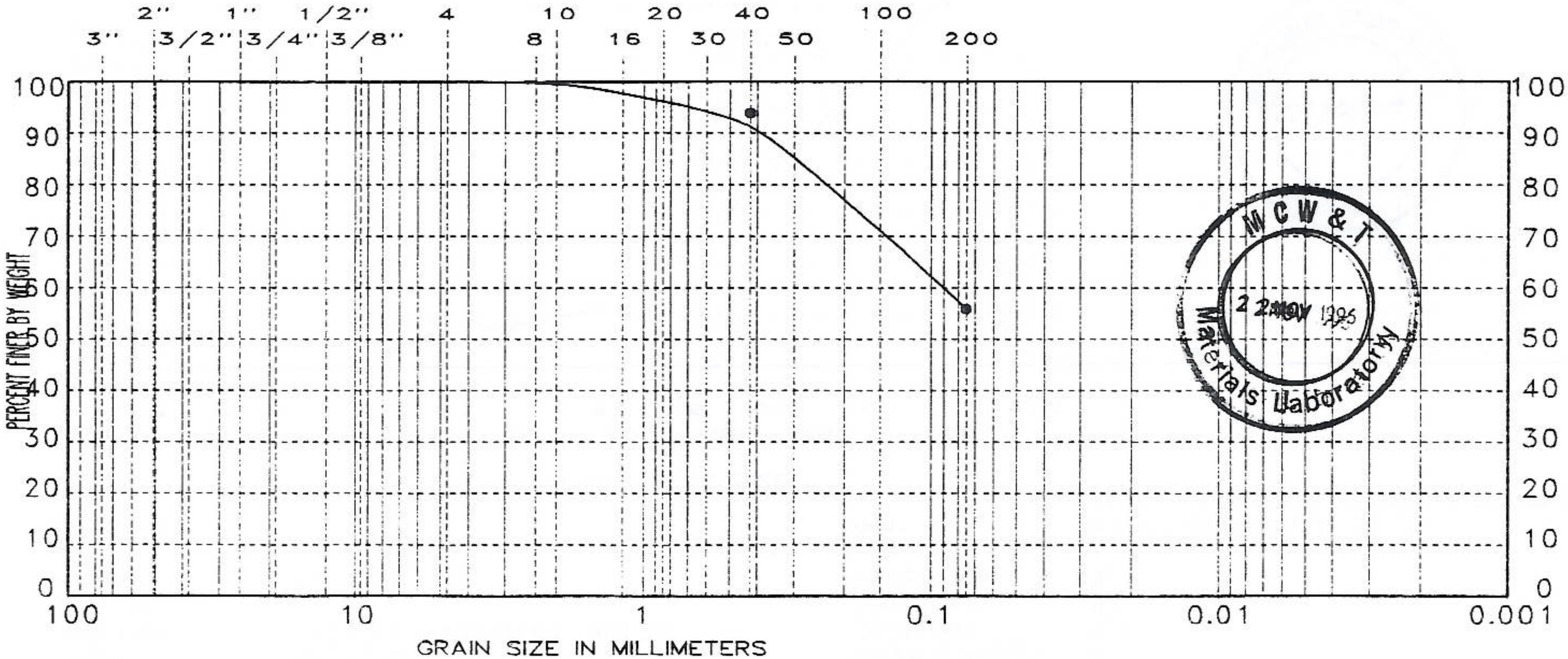
Project No.:	WS ENV M/1	Natural % Moisture:	20
Project Name:	W-SHED & ENVIRONMENTAL MNG PJT	Liquid Limit:	N/A
Boring No.:		Plastic Limit:	N/A
Sample No.:	12.	Plasticity Index:	N/A
Depth:		Color:	
Classification:	ODOT ODOT	Remarks:	WASHED GRADING ON SAMPLE #12.DATED:16/11/96.WATERSHED & ENVR MGE PRC



ASTM D 422	GRAVEL		SAND			SILT	CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE		
AASHTO	COARSE	FINE		COARSE	FINE	SILT	CLAY
	GRAVEL			SAND			

SOIL CLASSIFICATION DATA

Project No.:	WS ENV M/1	Natural % Moisture:	78
Project Name:	W–SHED & ENVIRONMENTAL MNG PJT	Liquid Limit:	N/A
Boring No.:		Plastic Limit:	N/A
Sample No.:	13.	Plasticity Index:	N/A
Depth:		Color:	
Classification:	ODOT ODOT	Remarks:	WASHED GRADING ANALYSIS ON SAMPLE#13 DATED:16/11/96.WATERSHED7ENV MGE PROJECT

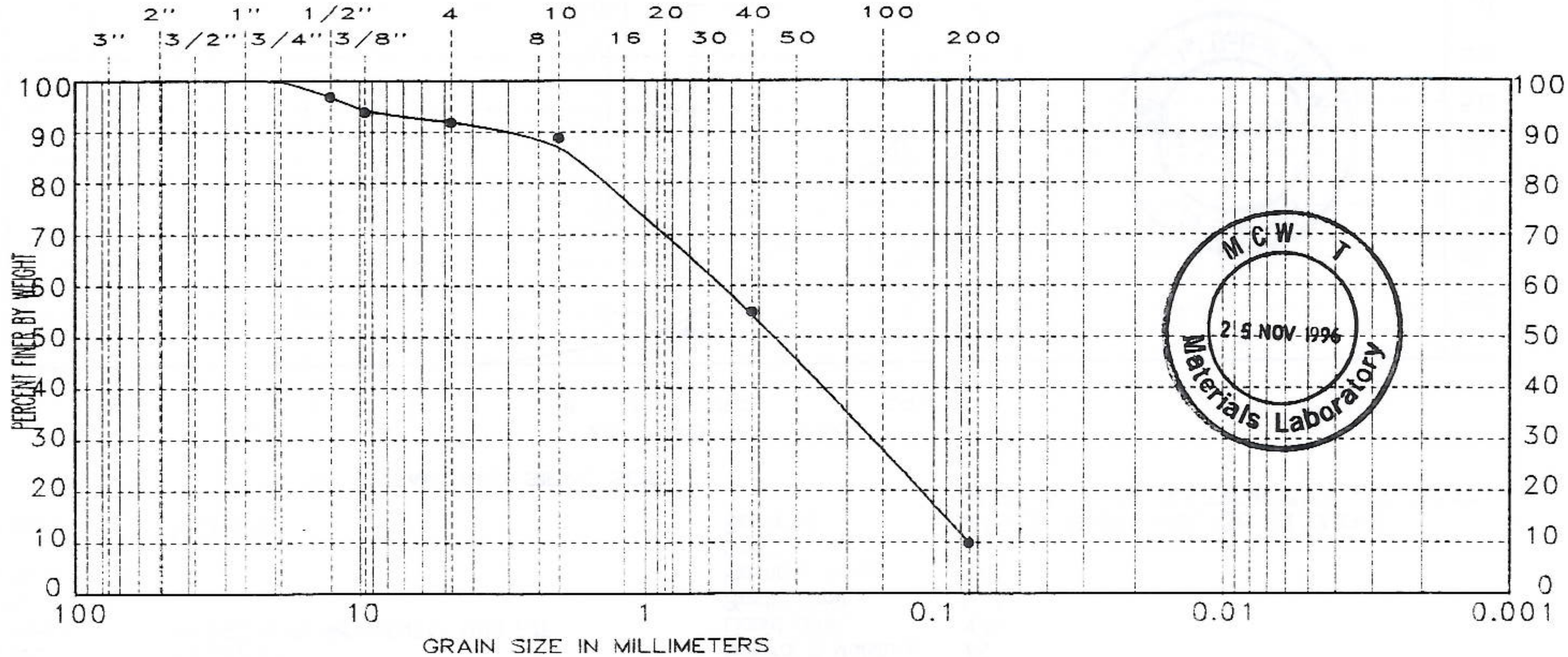


ASTM D 422	GRAVEL		SAND			SILT	CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE		
AASHTO	COARSE	FINE		COARSE	FINE	SILT	CLAY
	GRAVEL			SAND			

SOIL CLASSIFICATION DATA

Project No.: WS ENV M/1
Project Name: W-SHED & ENVIRONMENTAL MNG PJT
Boring No.:
Sample No.: 14.
Depth:
Classification: ODOT ODOT

Natural % Moisture: 46
Liquid Limit: N/A
Plastic Limit: N/A
Plasticity Index: N/A
Color:
Remarks: WASHED GRADING ANALYSIS ON SAMPLE#14.DATED:16/11/96.WATERSHED & ENV M

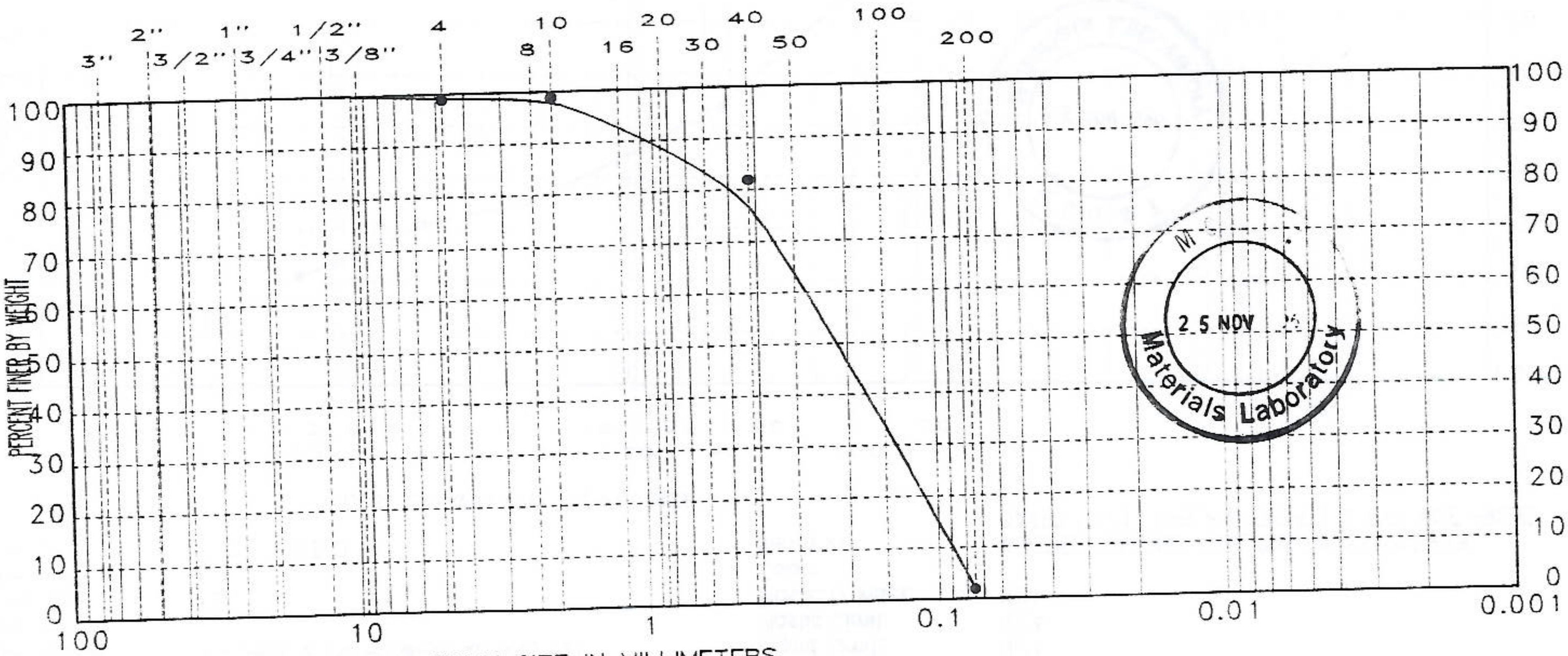


ASTM D 422	GRAVEL		SAND			SILT	CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE		
AASHTO	COARSE	FINE	COARSE		FINE	SILT	CLAY
	GRAVEL		SAND				

SOIL CLASSIFICATION DATA

Project No.:	WS ENV M/1
Project Name:	W-SHED & ENVIRONMENTAL MNG PJT
Boring No.:	
Sample No.:	15.
Depth:	
Classification:	ODOT ODOT

Natural % Moisture:	37
Liquid Limit:	N/A
Plastic Limit:	N/A
Plasticity Index:	N/A
Color:	
Remarks:	

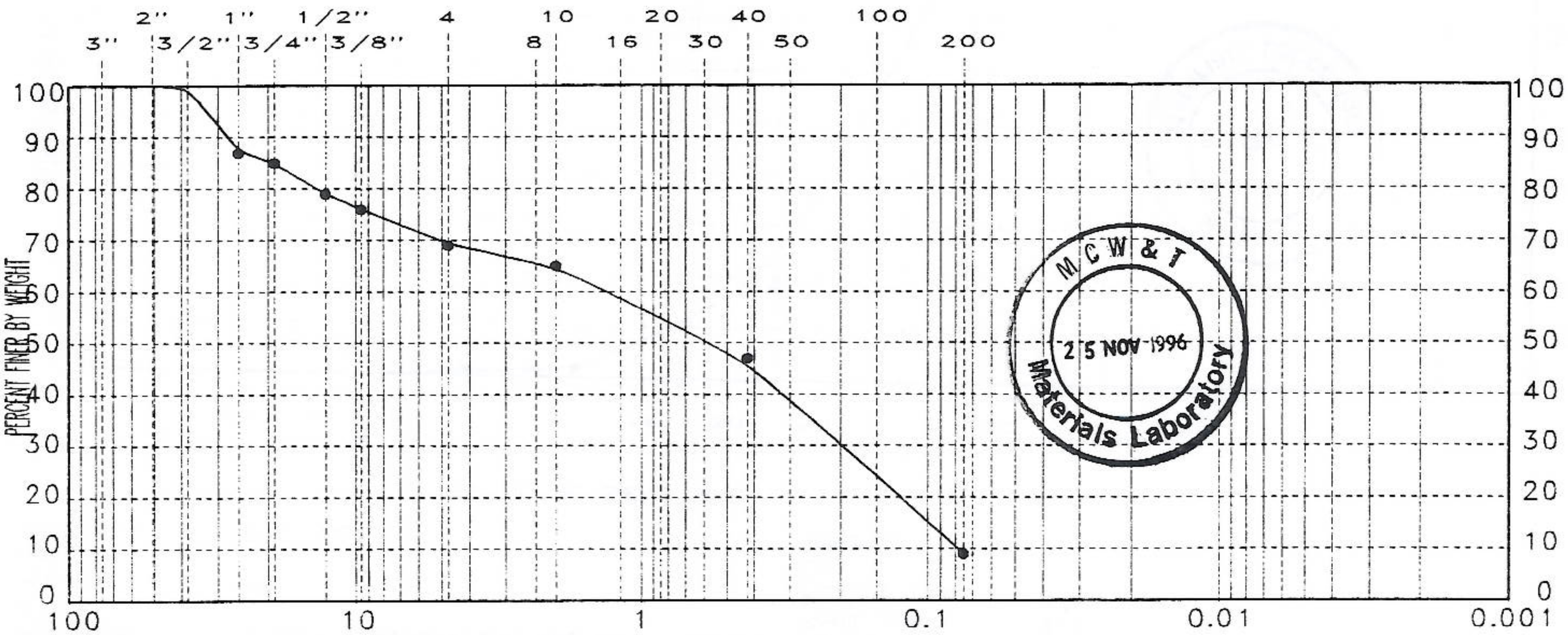


ASTM	GRAVEL		SAND			SILT	CLAY
D 422	COARSE	FINE	COARSE	MEDIUM	FINE		
AASHTO	COARSE	FINE		COARSE	FINE	SILT	CLAY
	GRAVEL		SAND				

SOIL CLASSIFICATION DATA

Project No.:	WS ENV M/1	Natural % Moisture:	26
Project Name:	W–SHED & ENVIRONMENTAL MNG PJT	Liquid Limit:	N/A
Boring No.:		Plastic Limit:	N/A
Sample No.:	16.	Plasticity Index:	N/A
Depth:		Color:	
Classification:	ODOT ODOT 0	Remarks:	WASHED GRADING ANALYSIS ON SAMPLE#16 DATED:16/11/96.WATERSHED & ENV MGE PROJE

U.S. STANDARD SIEVE SIZE



GRAIN SIZE IN MILLIMETERS

ASTM D 422	GRAVEL: COARSE	GRAVEL: FINE	SAND: COARSE	SAND: MEDIUM	SAND: FINE	SILT	CLAY
AASHTO	GRAVEL: COARSE	GRAVEL: FINE		SAND: COARSE	SAND: FINE	SILT	CLAY

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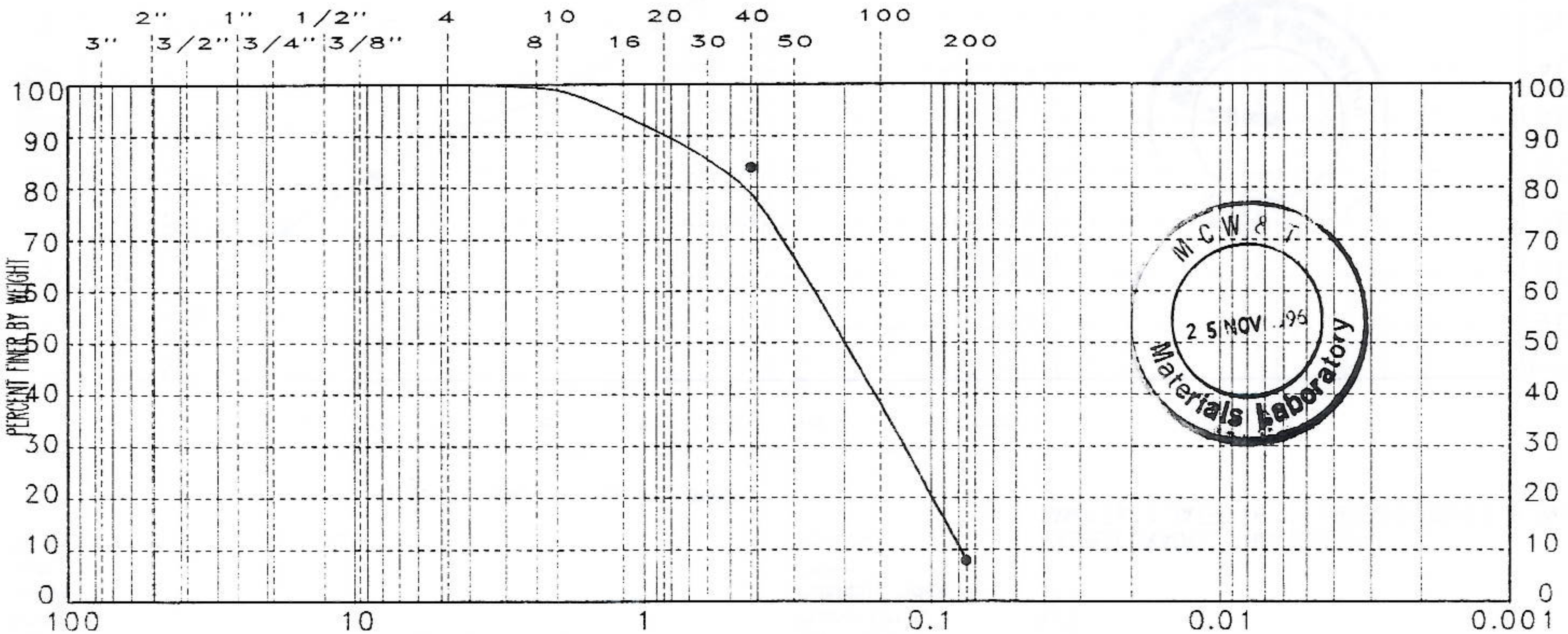
SOIL CLASSIFICATION DATA

Project No.: WS ENV M/1
Project Name: W–SHED & ENVIRONMENTAL MNG PJT
Boring No.:
Sample No.: 17.
Depth:
Classification: ODOT ODOT 0

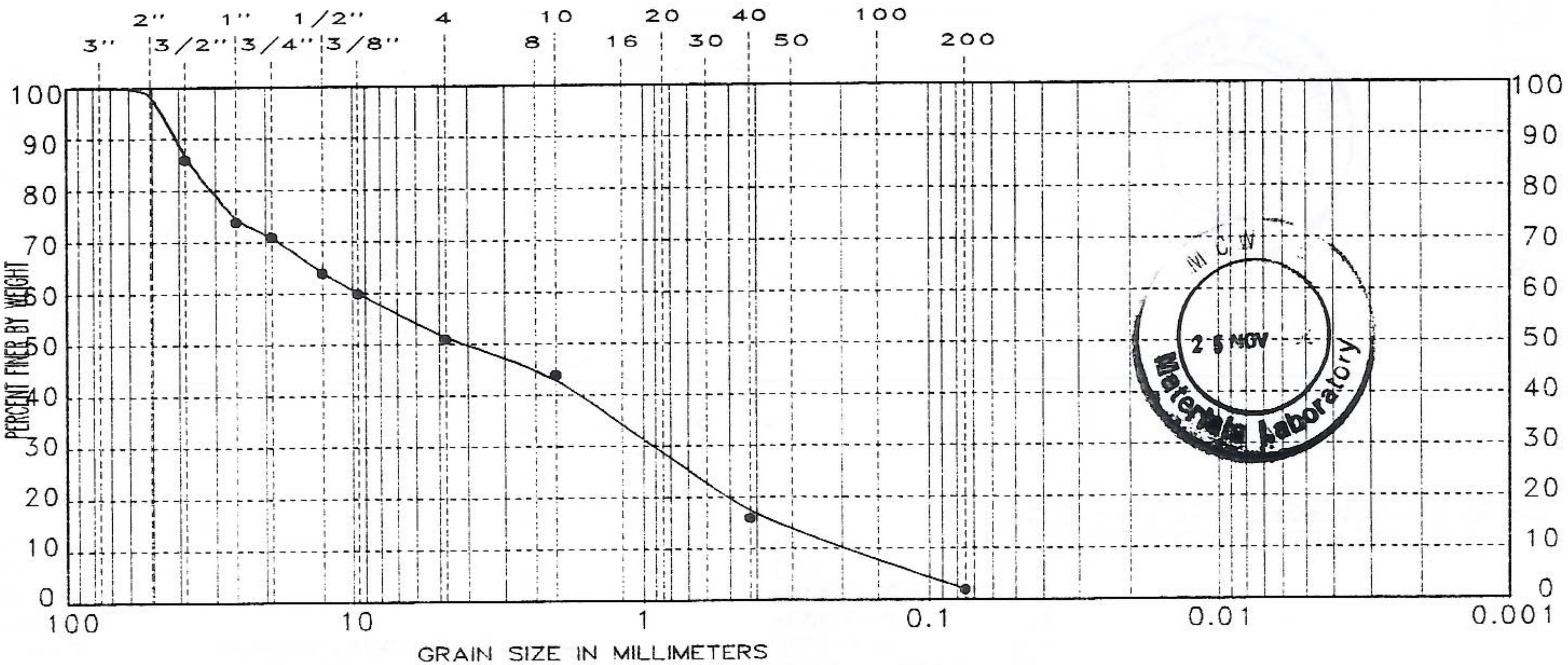
Natural % Moisture: 22
Liquid Limit: N/A
Plastic Limit: N/A
Plasticity Index: N/A
Color:
Remarks: WASHED GRADING ANALYSIS ON SAMPLE#17 DATED:16/11/96.WATERSHED&ENV MGE PROJECT



ASTM D 422	GRAVEL		SAND			SILT	CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE		
AASHTO	COARSE	FINE		COARSE	FINE	SILT	CLAY
	GRAVEL		SAND				

SOIL CLASSIFICATION DATA

Project No.:	WS ENV M/1	Natural % Moisture:	21
Project Name:	W-SHED & ENVIRONMENTAL MNG PJT	Liquid Limit:	N/A
Boring No.:		Plastic Limit:	N/A
Sample No.:	18.	Plasticity Index:	N/A
Depth:		Color:	
Classification:	ODOT ODOT	Remarks:	WASHED GRADING ANALYSIS ON SAMPLE#18.DATED:16/11/96.WATERSHED & ENV M(

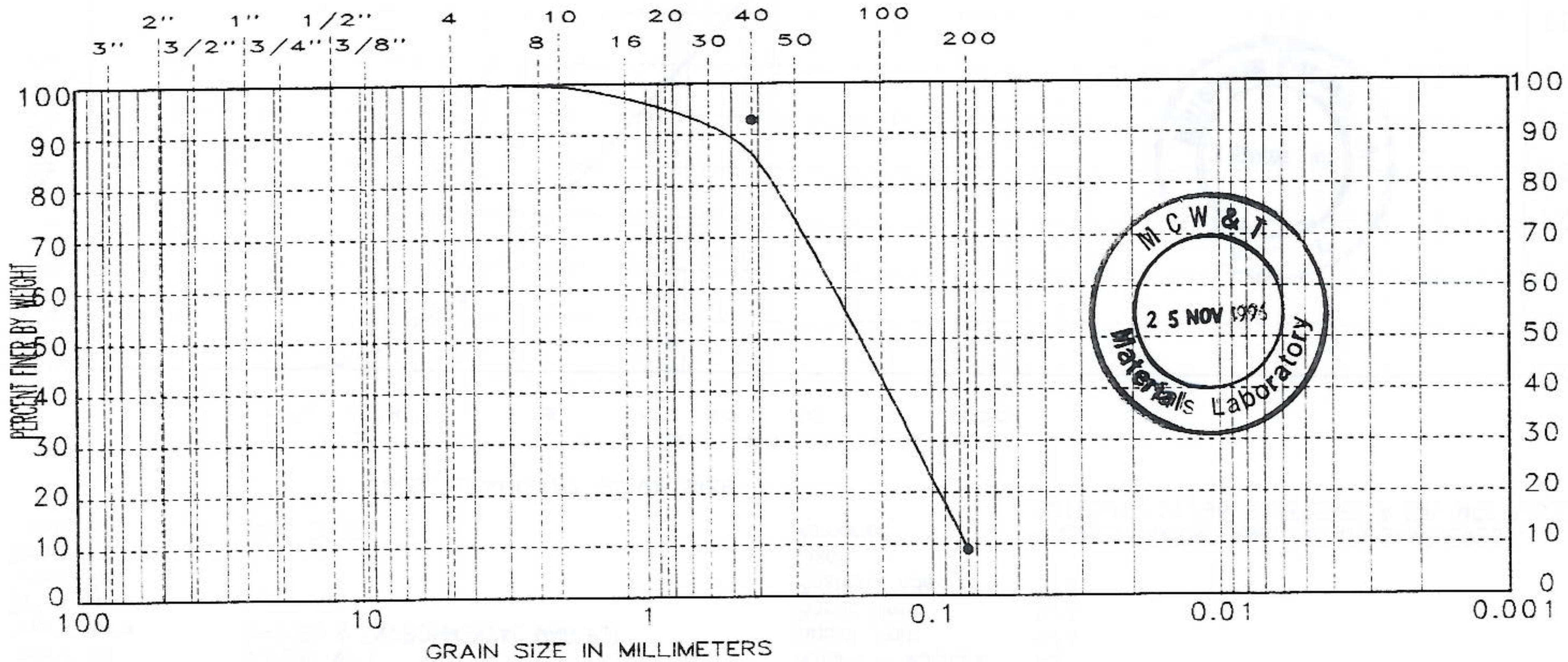


ASTM D 422	GRAVEL		SAND			SILT	CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE		
AASHTO	COARSE	FINE		COARSE	FINE	SILT	CLAY
	GRAVEL			SAND			

SOIL CLASSIFICATION DATA

Project No.:	WS ENV M/1
Project Name:	W-SHED & ENVIRONMENTAL MNG PJT
Boring No.:	
Sample No.:	19.
Depth:	
Classification:	ODOT ODOT

Natural % Moisture:	31
Liquid Limit:	N/A
Plastic Limit:	N/A
Plasticity Index:	N/A
Color:	
Remarks:	WASHED GRADING ON SAMPLE#19.DATED:16/11/96.WATERSHED ENV MGE



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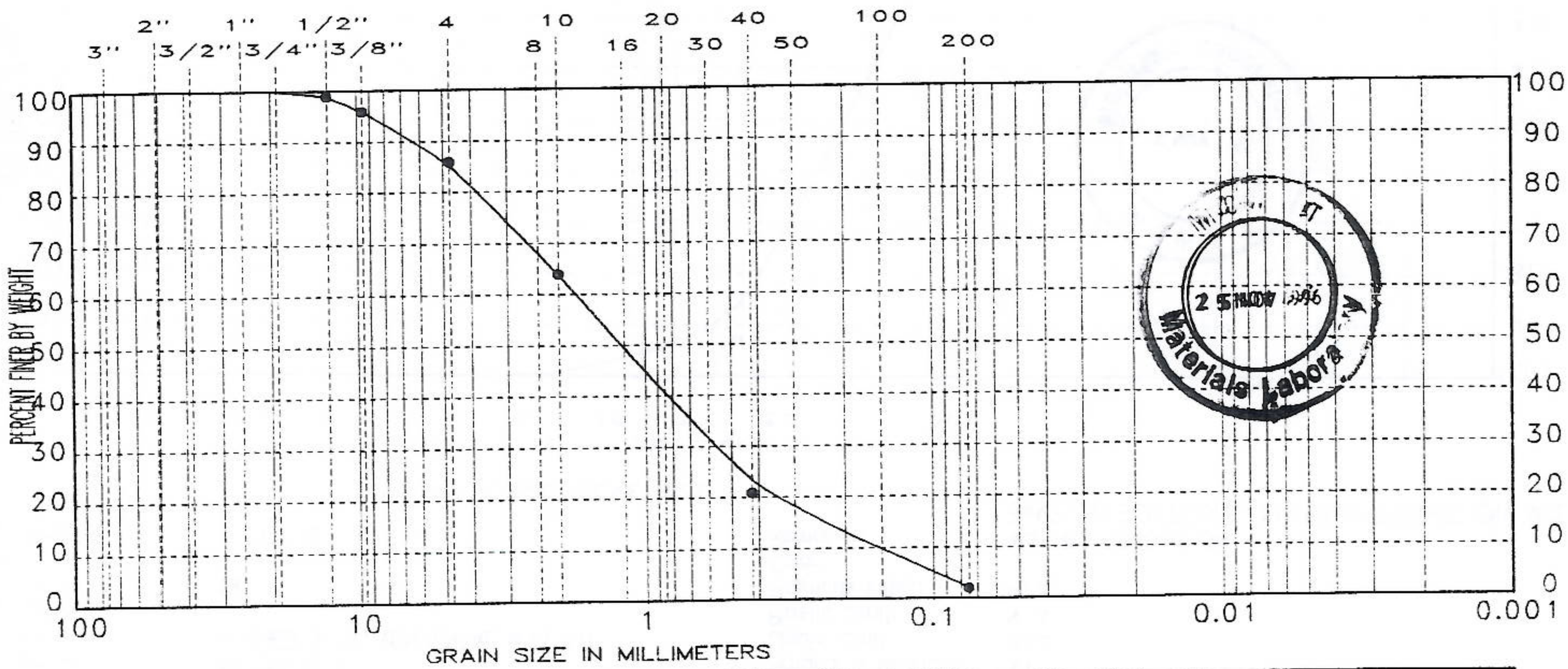
<tr><td rowspan="2">ASTM D 422</td><td colspan="2">GRAVEL</td><td colspan="3">SAND</td><td rowspan="2">SILT</td><td rowspan="2">CLAY</td></tr>
<tr><td>COARSE</td><td>FINE</td><td>COARSE</td><td>MEDIUM</td><td>FINE</td></tr>
<tr><td rowspan="2">AASHTO</td><td>COARSE</td><td>FINE</td><td colspan="2">COARSE</td><td>FINE</td><td rowspan="2">SILT</td><td rowspan="2">CLAY</td></tr>
<tr><td colspan="2">GRAVEL</td><td colspan="3">SAND</td></tr>
</table>

SOIL CLASSIFICATION DATA

Project No.:	WS ENV M/1	Natural % Moisture:	40
Project Name:	W-SHED & ENVIRONMENTAL MNG PJT	Liquid Limit:	N/A
Boring No.:		Plastic Limit:	N/A
Sample No.:	20.	Plasticity Index:	N/A
Depth:		Color:	
Classification:	ODOT ODOT	Remarks:	WASHED GRADING ANALYSIS ON SAMPLE#20 DATED:16/11/96 WATERSHED & ENV MGE PROJE



ASTM	GRAVEL		SAND			SILT	CLAY
D 422	COARSE	FINE	COARSE	MEDIUM	FINE		
AASHTO	COARSE	FINE		COARSE	FINE	SILT	CLAY
	GRAVEL			SAND			

Appendix C

Monthly Rainfall Data

MARQUIS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	48	57	56	181	69	31	144	205	156	349	189	83	1568	349	78
86	71	33	109	57	106	78	79	203	264	127	392	61	1580	392	97
87	60	32	19	7	493	200	190	304	244	253	486	64	2352	493	103
88	66	85	77	73	85	170	200	199	375	308	209	51	1898	375	74
89	109	62	186	146	29	56	235	361	345	175	215	132	2051	361	64
90	122	51	62	93	162	119	170	248	241	**422**	81	132	1903	422	94
91	127	33	68	88	46	76	107	140	210	87	388	75	1445	388	104
92	51	65	36	68	192	245	177	252	407	42	587	91	2213	587	156
93	147	120	109	72	146	124	161	162	201	269	101	26	1638	269	44
94	112	37	40	21	84	61	97	174	**334**	117	62	33	1172	334	95
95	75	31	131	166	93	150	125	377	286	311	147	88	1980	377	72
AVG	90	55	81	88	137	119	153	239	278	224	260	76	1800	278	**43**
1996	72	48	96	91	52	154	265	261	300	**555**	173	81	2148	555	143
1996/AV	80%	87%	118%	103%	38%	129%	173%	109%	108%	248%	67%	107%	119%		

LA CAYE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	92	41	73	70	54	35	145	209	169	182	240	67	1377	240	42
86	67	37	72	81	122	100	116	226	241	125	394	64	1645	394	94
87	90	18	26	6	517	190	135	236	193	277	488	129	2305	517	116
88	56	84	50	33	51	213	172	147	387	321	225	69	1808	387	83
89	71	74	276	134	47	64	210	162	467	140	285	130	2060	467	106
90	119	31	70	74	140	109	237	147	342	**490**	85	108	1952	490	123
91	78	50	40	138	60	25	109	159	190	107	355	88	1399	355	90
92	48	51	35	50	194	175	109	195	278	74	513	95	1817	513	145
93	159	58	132	64	207	93	171	157	219	**194**	137	36	1627	219	29
94	156	67	44	27	61	165	111	254	**401**	167	123	72	1648	401	98
95	61	44	275	148	97	131	92	326	396	311	77	136	2094	396	75
AVG	91	50	99	75	141	118	146	202	298	217	266	90	1794	298	**50**
1996	68	56	76	144	53	88	244	207	264	**474**	284	52	2010	474	112
1996/AV	75%	111%	76%	192%	38%	74%	167%	103%	88%	218%	107%	58%	112%		

CARDI

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85													0		
86	94	64	98	107	147	126	141	248	263	150	411	91	1940	411	87
87	82	33	39	5	577	188	191	352	183	333	561	146	2690	577	124
88	66	87	50	62	64	224	185	239	290	403	247	96	2013	403	81
89	114	118	197	196	57	65	241	256	425	157	250	108	2184	425	83
90	252	107	63	86	148	139	200	185	292	**496**	145	118	2231	496	110
91	112	95	54	124	101	40	147	124	252	107	445	93	1694	445	117
92	83	112	50	64	268	22	133	256	355	129	451	109	2032	451	100
93	231	69	212	78	219	109	184	205	226	202	133	52	1920	231	28
94	165	99	66	59	75	115	143	298	**399**	193	183	112	1907	399	83
95	83	73	336	163	109	156	129	376	417	246	147	188	2423	417	72
AVG	128	86	117	94	177	118	169	254	310	242	297	111	1912	310	**50**
1996	95	75	89	150	63	118	324	230	259	**576**	307	74	2360	576	141
1996/AV	74%	88%	76%	159%	36%	100%	191%	91%	83%	238%	103%	66%	123%		

ERRARD

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85															
86															
87			32	26	528	216	193	255	181	311	623	137	2502	623	155
88	98	105	79	42	85	203	261	203	474	537	276	81	2444	537	118
89	111	104	330	164	66	93	249	282	564	180	274	173	2590	564	123
90	188	118	75	133	174	143	206	169	328	**576**	118	140	2368	576	140
91	174	75	118	87	81	62	183	195	275	129	451	86	1916	451	106
92	69	97	61	83	275	249	116	209	309	168	696	188	2520	696	192
93	198	70	162	41	281	128	198	173	241	201	178	61	1932	281	41
94	176	72	81	23	68	79	155	302	**552**	223	206	161	2098	552	145
95	109	64	164	183	61	158	98	393	393	323	118	201	2265	393	68
AVG	140	88	122	87	180	148	184	242	369	294	327	136	2293	369	**59**
1996	120	81	121	162	75	157	214	218	293	**539**	239	97	2316	539	125
1996/AV	85%	92%	99%	186%	42%	106%	116%	90%	79%	183%	73%	71%	101%		

MAMIKU

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	131	65	43	114	55	24	187	210	164	289	237	66	1585	289	53
86	143	30	94	56	83	139	95	199	267	199	330	85	1720	330	63
87	79	15	25	20	333	147	150	208	181	289	302	112	1861	333	60
88	61	77	39	25	72	180	189	147	371	364	153	53	1731	371	80
89	77	69	265	127	55	41	167	216	508	150	154	146	1975	508	131
90	91	100	32	86	102	97	172	108	230	**473**	71	126	1688	473	133
91	96	67	68	82	63	41	144	138	155	72	392	61	1379	392	111
92	42	51	23	60	111	221	97	133	244	48	495	135	1660	495	148
93	195	43	118	195	43	118	35	214	98	184	131	176	1550	214	30
94	72	33	56	21	59	57	152	196	**398**	149	115	115	1423	398	111
95	70	44	200	155	45	143	55	339	270	238	95	105	1759	339	65
AVG	88	54	92	86	98	116	129	189	273	219	212	114	1670	273	**45**
1996	83	54	94	116	54	92	203	198	220	**447**	211	41	1813	447	110
1996/AV	94%	100%	102%	135%	55%	79%	157%	105%	81%	205%	100%	36%	109%		

PATIENCE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	108	82	56	162	77	51	168	178	228	353	239	99	1801	353	69
86	149	33	110	62	91	136	131	189	314	208	435	121	1979	435	96
87	95	24	33	19	334	174	150	221	183	244	345	115	1937	345	61
88	69	89	62	37	97	198	242	182	336	379	208	81	1980	379	73
90	135	146	50	85	98	105	187	167	227	**489**	100		1789	489	134
91	98	82	73	111	64	43	146	133	193	85	477	53	1558	477	146
92	65	66	26	66	140	308	123	172	275	54	588	132	2015	588	172
93	226	34	166	38	200	110	166	181	150	267	132	46	1716	267	42
94	104	53	38	47	72	74	95	257	**412**	196	182	157	1687	412	101
95	81	64	185	142	94	210	76	420	401	283	115	126	2197	420	80
AVG	111	67	79	68	137	153	148	217	272	250	268	101	1860	272	40
1996	126	70	88	156	62	86	255	202	230	**548**	310	44	2177	548	**138**
1996/AV	113%	104%	111%	229%	45%	56%	172%	93%	85%	220%	116%	43%	117%		

TROUMASSE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	80	53	31	62	44	47	140	168	187	286	195	53	1346	286	61
86	77	31	89	44	72	135	101	163	210	177	447	84	1630	447	123
87	49	11	12	19	223	179	136	272	129	187	269	85	1571	272	47
88	40	86	76	40	12	114	211	169	406	327	144	59	1684	406	98
89	70	61	324	111	16	70	185	109	314	147	167	109	1683	324	62
90	99	124	30	26	97	112	116	145	258	**391**	116	151	1665	391	92
91	86	41	31	99	45	41	117	124	121	25	354	50	1134	354	111
92	57	35	24	55	115	222	122	186	230	60	549	114	1769	549	170
93	165	52	91	29	195	76	162	86	165	154	104	32	1311	195	29
94	80	57	17	23	45	36	147	262	**404**	175	90	93	1429	404	114
95	73	30	145	115	40	165	60	368	331	273	174	113	1887	368	72
AVG	90	53	92	62	71	105	140	181	279	194	212	90	1570	279	**49**
1996	54	75	63	114	33	94	236	216	209	**543**	222	46	1905	543	155
1996/AV	60%	142%	68%	183%	47%	90%	169%	119%	75%	280%	105%	51%	121%		

MAHAUT

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	149	146	131	197	161	89	245	239	295	599	322	168	2741	599	131
86	225	48	167	65	96	238	242	246	434	277	589	226	2853	589	122
87	87	39	34	38	382	225	193	322	290	196	468	184	2458	468	89
88	129	175	123	78	131	288	323	277	541	502	288	119	2974	541	98
89	155	136	374	117	63	74	183	197	435	198	364	229	2525	435	75
90	254	124	109	121	157	180	208	239	385	**533**	132	222	2664	533	107
91	197	90	142	150	94	126	197	166	231	180	673	142	2388	673	190
92	115	94	71	122	285	361	199	271	389	138	20	255	2320	389	65
93	347	82	225	79	185	153	263	201	127	251	259	84	2256	347	53
94	108	110	94	61	129	97	173	267	**539**	274	257	226	2335	539	124
95	80	73	193	111	55	207	104	541	352	315	117	82	2230	541	131
AVG	179	97	166	105	137	186	206	270	375	299	264	170	2462	375	**57**
1996	97	100	87	104	5	87	216	269	316	**545**	345	76	2247	545	132
1996/AV	54%	103%	52%	99%	4%	47%	105%	100%	84%	182%	131%	45%	91%		

EDMUND

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	358	212	204	213	243	136	367	342	351	774	392	288	3880	774	154
86	321	97	250	142	204	400	336	361	530	277	711	318	3947	711	128
87	126	87	61	67	255	264	251	268	265	243	269	278	2434	278	32
88	218	299	153	90	149	381	392	312	653	632	398	208	3885	653	110
89	237	198	502	201	78	190	392	312	656	278	512	301	3857	656	112
90	371	221	143	191	192	333	205	284	414	**730**	200	180	3464	730	154
91	242	142	195	192	127	191	214	255	196	155	716	113	2738	716	187
92	129	163	138	191	305	457	298	401	549	209	**771**	336	**3947**	771	151
93	339	139	302	98	420	155	388	279	316	283	385	131	3235	420	55
94	248	176	162	122	183	157	268	330	**676**	448	272	217	3259	676	140
95	63	142	265	295	113	307	250	635	534	414	241	215	3474	635	116
AVG	233	166	233	173	196	271	301	351	499	394	437	213	3482	499	**72**
1996	191	206	188	196	110	211	443	457	484	**618**	434	139	3677	618	104
1996/AV	82%	124%	81%	114%	56%	78%	147%	130%	97%	157%	99%	65%	106%		

HEWANORRA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	66	54	52	81	43	37	278	150	116	359	193	71	1500	359	86
86	92	38	49	67	52	90	118	115	289	120	224	112	1366	289	61
87	34	35	17	7	147	151	82	167	137	115	294	127	1313	294	66
88	64	75	47	34	35	134	173	140	372	278	168	34	1554	372	89
89	67	71	271	81	9	82	322	234	480	103	134	101	1955	480	118
90	142	92	25	38	134	98	126	161	164	**290**	84	109	1463	290	57
91	85	43	50	81	33	22	112	65	95	36	373	44	1039	373	134
92	45	47	10	48	98	235	145	134	274	91	452	113	1692	452	121
93	144	35	90	37	169	73	152	98	233	192	112	58	1393	233	39
94	104	49	21	27	47	31	105	87	**406**	161	101	96	1235	406	133
95	63	32	184	117	44	148	106	322	286	184	99	56	1641	322	63
AVG	82	52	74	56	74	100	156	152	259	175	203	84	1468	259	**46**
1996	63	48	55	62	29	93	245	162	185	**449**	184	59	1634	449	123
1996/AV	76%	92%	74%	110%	39%	93%	157%	107%	71%	256%	91%	70%	111%		

SALTIBUS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	185	155	166	120	114	96	284	285	219	567	380	185	2756	567	117
86	141	48	185	70	105	229	190	263	370	218	589	185	2593	589	134
87	79	35	27	33	252	244	220	290	277	255	412	210	2334	412	73
88	139	213	127	82	108	296	316	303	**596**	**589**	323	125	**3217**	596	110
89	149	104	260	153	25	99	410	290	538	158	239	223	2648	538	109
90	267	180	90	112	131	217	233	209	374	**477**	172	173	2635	477	86
91	197	99	127	126	82	108	187	169	203	94	658	173	2223	658	195
92	133	94	86	110	218	388	225	281	495	125	889	251	3295	889	240
93	342	116	215	73	204	182	283	190	343	227	227	77	2479	343	47
94	217	144	99	69	121	134	218	336	**605**	376	199	144	2662	605	138
95	93	86	260	233	70	225	161	467	284	342	203	115	2539	467	86
AVG	177	116	149	107	130	202	248	280	391	312	390	169	2671	391	**57**
1996	152	108	108	122	73	218	367	318	354	**546**	361	62	2789	546	107
1996/AV	86%	93%	72%	114%	56%	108%	148%	113%	90%	175%	93%	37%	104%		

DELCER

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	81	87	81	91	46	53	197	205	185	418	271	83	1798	418	97
86	108	23	93	43	74	181	131	168	275	115	441	105	1757	441	111
87	46	19	11	12	148	192	116	179	196	140	188	116	1363	196	28
88	87	88	36	30	33	210	177	192	427	468	177	52	1977	468	111
89	102	96	165	90	14	83	271	186	362	146	148	93	1756	362	75
90	154	64	38	69	62	164	199	151	142	**386**	134	98	1661	386	90
91	120	38	54	41	36	123	132	121	149	23	416	84	1337	416	129
92	60	48	36	56	169	276	137	205	237	52	478	171	1925	478	119
93	181	62	86	11	74	70	204	158	265	141	113	38	1403	265	50
94	129	73	44	11	74	70	101	280	**407**	223	114	37	1563	407	106
95	36	53	108	146	40	199	107	39	348	265	110	76	1527	348	79
AVG	100	59	68	55	70	147	161	171	272	216	235	87	1642	272	**45**
1996	73	49	58	38	25	117	302	250	143	**533**	171	52	1811	533	157
1996/AV	73%	83%	85%	70%	36%	79%	187%	146%	53%	247%	73%	60%	110%		

UNION VALE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	103	92	91	91	56	55	180	232	175	463	320	117	1975	463	109
86	119	40	120	58	84	235	137	216	304	145	367	121	1946	367	69
87	70	18	12	10	179	196	140	206	228	166	202	145	1572	228	33
88	104	121	39	11	52	234	206	235	525	476	204	63	2270	525	121
89	61	93	179	93	8	67	347	212	488	171	244	169	2132	488	112
90	181	64	54	82	71	170	204	192	165	407	173	77	1840	407	90
91	159	52	50	48	41	152	140	144	153	48	431	96	1514	431	123
92	51	51	43	67	167	347	172	234	320	54	504	195	2205	504	115
93	217	65	102	34	119	136	234	183	276	136	168	51	1721	276	44
94	109	66	57	17	85	64	143	321	480	285	111	55	1793	480	128
95	43	56	130	189	33	155	117	468	348	285	110	54	1988	468	110
AVG	111	65	80	64	81	165	184	240	315	240	258	104	1905	315	52
1996	64	57	62	52	42	158	277	345	162	630	201	60	2110	630	188
1996/AV	58%	87%	78%	82%	52%	96%	151%	144%	51%	263%	78%	58%	111%		

BARTHE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	192	163	148	109	110	91	337	314	213	569	385	192	2823	569	115
86	179	64	155	76	116	316	218	270	376	225	554	187	2736	554	112
87	98	40	25	29	259	251	227	336	264	223	374	213	2339	374	60
88	176	198	106	48	112	304	308	343	665	596	316	104	3276	665	135
89	201	165	267	161	22	107	415	296	542	218	360	230	2984	542	98
90	293	155	184	98	137	239	227	259	266	549	245	125	2777	549	109
91	265	95	103	106	72	126	199	215	246	101	619	157	2304	619	166
92	122	111	91	132	233	421	227	283	468	121	665	256	3130	665	141
93	240	81	170	59	210	164	315	202	341	190	242	90	2304	341	50
94	186	153	113	51	148	120	214	405	567	380	208	100	2645	567	122
95	72	121	224	221	70	203	156	532	261	381	195	110	2546	532	111
AVG	184	122	144	99	135	213	258	314	383	323	378	160	2715	383	54
1996	128	114	106	107	83	227	373	376	253	734	321	75	2897	734	186
1996/AV	70%	93%	74%	108%	61%	107%	144%	120%	66%	227%	85%	47%	107%		

WINBAN

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	143	91	79	109	70	69	204	226	179	285	318	161	1934	318	52
86	179	36	143	74	169	149	169	272	418	169	510	165	2453	510	106
87	67	20	26	8	296	205	212	381	218	340	427	90	2290	427	80
88	94	98	60	28	64	244	227	229	420	423	203	87	2177	423	82
89	167	132	224	100	14	63	258	209	404	185	280	214	2250	404	73
90	175	66	79	84	154	170	258	200	305	465	128	132	2216	465	98
91	187	74	61	74	92	114	126	163	268	103	512	125	1899	512	138
92	82	97	37	68	72	278	204	295	473	87	439	149	2281	473	98
93	243	36	176	50	77	129	257	289	229	258	164	51	1959	289	43
94	177	82	97	42	59	110	159	303	516	174	141	117	1977	516	135
95	75	65	128	149	96	124	210	464	269	191	154	77	2002	464	108
AVG	144	72	101	71	106	150	208	276	336	244	298	124	2131	336	53
1996	101	78	80	123	57	117	286	237	226	695	283	68	2351	695	205
1996/AV	70%	108%	79%	172%	54%	78%	138%	86%	67%	285%	95%	55%	110%		

SOUCIS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	213	23	152	173	132	67	207	256	176	366	273	149	2187	366	61
86	161	129	153	72	180	222	170	322	480	263	421	174	2747	480	84
87	66	27	23	8	343	251	216	396	242	308	437	147	2464	437	78
88	96	102	57	66	54	219	260	273	383	442	264	101	2317	442	84
89	157	127	175	146	17	85	287	213	392	83	284	136	2102	392	73
90	241	91	95	102	175	196	258	264	415	**469**	150	111	2567	469	86
91	199	36	57	88	64	149	145	172	268	205	562	134	2079	562	152
92	91	106	47	77	87	258	197	266	199	97	119	188	1732	266	41
93	251	46	185	60	86	138	265	297	237	266	173	78	2082	297	42
94	183	101	111	46	79	122	174	259	**519**	240	168	75	2077	519	130
95	63	53	98	199	92	148	170	431	279	251	157	106	2047	431	91
AVG	152	75	101	90	116	167	214	286	326	272	273	127	2200	326	**48**
1996	83	56	84	119	75	151	349	232	307	**712**	368	107	2643	712	**192**
1996/AV	55%	74%	83%	132%	65%	90%	163%	81%	94%	262%	135%	84%	120%		

BEXON

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85							240	244	180	391	310	151	1516	391	101
86	213	199	180	92	149	175	196	317	490	201	580	168	2960	580	114
87	68	33	42	4	176	284	253	455	296	333	521	171	2636	521	103
88	111	125	84	36	88	267	266	281	320	466	242	103	2389	466	91
89	163	157	312	171	38	68	325	303	511	220	334	255	2857	511	91
90	241	107	118	62	200	176	300	219	475	**570**	166	174	2808	570	116
91	200	87	130	109	119	135	149	194	271	131	630	198	2353	630	169
92	108	146	72	97	168	302	211	346	623	134	560	200	2967	623	131
93	290	98	232	62	217	144	252	333	275	316	226	78	2523	333	44
94	188	107	102	72	94	153	189	330	**617**	272	183	139	2446	617	156
95	53	84	242	184	46	167	210	464	382	216	184	131	2363	464	91
AVG	164	114	151	89	130	187	236	317	404	295	358	161	2605	404	**63**
1996	114	94	104	146	83	212	313	236	326	**836**	342	109	2915	836	240
1996/AV	70%	82%	69%	164%	64%	113%	133%	74%	81%	283%	96%	68%	112%		

BARRE DE L'ISLE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	170	71	107	165	90	55	209	243	213	305	318	117	2063	318	49
86	162	50	140	87	187	147	222	270	395	261	533	138	2592	533	110
87	77	44	47	26	583	213	232	356	204	369	519	158	2828	583	120
88	88	140	107	37	108	235	262	269	483	511	314	108	2662	511	98
89	129	120	353	193	50	114	281	225	235	173	272	143	2288	353	54
90	183	109	76	103	191	158	230	231	414	**590**	152	134	2571	590	135
91	130	93	138	124	121	83	149	239	258	134	525	341	2335	525	118
92	106	112	46	71	292	246	181	299	380	163	570	171	2637	570	123
93	198	70	175	72	290	130	188	204	217	289	221	74	2128	290	40
94	154	108	95	49	99	105	163	305	**667**	276	240	158	2419	667	184
95	101	71	285	194	70	145	170	394	317	342	121	137	2347	394	66
AVG	136	90	143	102	189	148	208	276	344	310	344	153	2443	344	**48**
1996	105	92	103	142	64	115	280	215	344	**634**	355	106	2555	634	157
1996/AV	77%	102%	72%	139%	34%	78%	135%	78%	100%	204%	103%	69%	105%		

GOVERNMENT HOUSE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	114	85	69	30	67	47	146	237	191	283	219	117	1605	283	50
86	139	45	116	72	110	168	120	243	350	199	435	122	2119	435	89
87	60	21	12	7	336	199	192	388	195	305	438	122	2275	438	84
88	66	145	25	71	75	135	172	269	353	356	191	71	1929	356	66
89	161	101	184	109	29	79	198	181	363	88	330	63	1886	363	70
90	172	80	60	94	108	175	213	252	306	**591**	85	160	2296	591	152
91	146	61	110	75	66	157	119	153	197	103	472	138	1797	472	124
92	58	75	37	67	106	289	149	302	341	52	308	189	1973	341	59
93	19	40	133	21	179	142	73	165	289	261	144	41	1507	289	55
94	131	87	57	55	67	112	141	301	**494**	190	144	134	1913	494	128
95	64	28	141	176	105	112	176	433	213	184	125	106	1863	433	101
AVG	103	70	86	71	113	147	154	266	299	237	263	115	1924	299	**47**
1996	75	58	92	83	56	181	303	292	197	**607**	239	103	2286	607	161
1996/AV	73%	83%	107%	118%	49%	123%	196%	110%	66%	256%	91%	90%	119%		

GEORGE V

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	122	92	65	76	86	44	215	200	187	445	207	139	1878	445	105
86	166	44	117	68	94	182	122	295	366	183	443	128	2208	443	89
87	57	27	13	9	386	237	247	351	236	289	473	71	2396	473	93
88	104	124	63	36	78	179	188	266	482	301	226	100	2147	482	108
89	150	102	202	153	58	110	250	269	331	120	297	242	2284	331	48
90	175	84	79	90	107	153	201	262	319	**508**	101	133	2212	508	117
91	140	48	95	79	79	141	114	122	217	71	532	96	1734	532	163
92	78	83	40	61	131	252	165	199	188	96	443	180	1916	443	102
93	154	48	103	55	148	94	199	135	280	219	117	48	1600	280	49
94	120	80	35	42	88	113	123	230	**444**	182	99	61	1617	444	122
95	18	28	131	169	84	91	145	407	211	192	135	98	1709	407	97
AVG	117	69	86	76	122	145	179	249	296	237	279	118	1973	296	**45**
1996	63	55	77	78	59	122	221	148	227	**516**	280	89	1935	516	138
1996/AV	54%	80%	90%	102%	48%	84%	123%	60%	77%	218%	100%	76%	98%		

VIGIE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	96	118	63	79	58	63	46	190	185	193	339	168	1598	339	72
86	97	105	38	75	63	151	135	117	274	328	163	420	1966	420	90
87	118	57	18	12	8	325	225	190	338	230	315	383	2219	383	66
88	103	86	99	35	46	52	148	165	212	532	360	187	2025	532	140
89	90	114	97	168	90	24	49	272	237	326	107	278	1852	326	57
90	214	181	69	91	75	109	165	190	230	**213**	604	107	2248	604	162
91	145	126	47	64	62	72	119	110	151	219	88	511	1714	511	152
92	116	71	74	37	63	98	269	207	307	346	66	423	2077	423	86
93	150	190	41	132	35	146	109	231	161	222	189	154	1760	231	30
94	123	76	56	39	70	98	116	251	**465**	207	130	117	1748	465	124
95	65	33	111	151	93	135	159	421	236	195	168	103	1870	421	95
AVG	120	105	65	80	60	116	140	213	254	274	230	259	1916	274	**39**
1996	70	52	84	89	52	169	335	277	195	**641**	245	76	2285	641	180
1996/AV	58%	49%	130%	111%	86%	146%	239%	130%	77%	234%	107%	29%	119%		

UNION

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	126	79	93	86	79	36	192	239	172	334	219	122	1777	334	63
86	123	49	101	66	136	130	110	248	341	185	479	118	2086	479	110
87	62	28	28	15	402	240	214	343	269	300	499	96	2496	499	100
88	97	130	57	41	73	169	243	257	499	378	208	82	2234	499	111
89	126	82	209	117	60	63	312	261	323	145	278	107	2083	323	50
90	215	81	89	124	125	149	243	248	260	**425**	112	140	2211	425	82
91	143	65	93	71	84	163	115	141	190	150	565	112	1892	565	169
92	66	95	60	74	120	291	201	272	384	69	596	145	2373	596	150
93	221	37	158	69	112	126	204	181	280	259	154	66	1867	280	42
94	143	91	67	58	94	102	126	252	**492**	247	105	126	1903	492	127
95	88	40	150	189	108	171	144	450	240	233	168	103	2084	450	97
AVG	128	71	100	83	127	149	191	263	314	248	308	111	2091	314	**47**
1996	85	58	106	116	57	185	382	304	263	**591**	309	95	2551	591	137
1996/AV	66%	82%	106%	140%	45%	124%	200%	116%	84%	239%	100%	86%	122%		

TROUYA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	73	60	66	47	82	27	165	175	124	372	196	73	1460	372	95
86	128	35	62	68	139	112	112	242	270	160	370	80	1778	370	77
87	43	20	10	16	301	190	203	206	191	237	396	49	1862	396	84
88	58	94	46	67	66	120	168	259	425	248	183	67	1801	425	100
89	91	57	111	99	53	82	218	220	302	112	229	119	1693	302	54
90	125	56	91	48	143	164	158	189	201	**393**	103	80	1751	393	**88**
91	101	45	65	76	69	176	100	74	175	48	455	62	1446	455	143
92	62	58	41	71	84	192	191	183	393	58	565	74	1972	565	162
93	139	27	70	16	105	102	172	155	208	194	167	36	1391	208	31
94	76	35	47	122	85	81	105	285	**317**	161	96	86	1496	317	67
95	112	40	164	153	99	131	127	371	197	186	133	76	1789	371	77
AVG	92	48	70	71	111	125	156	214	255	197	263	73	1676	263	**41**
1996	66	24	85	86	30	158	303	257	215	**453**	148	121	1946	453	105
1996/AV	72%	50%	121%	121%	27%	126%	194%	120%	84%	230%	56%	166%	116%		

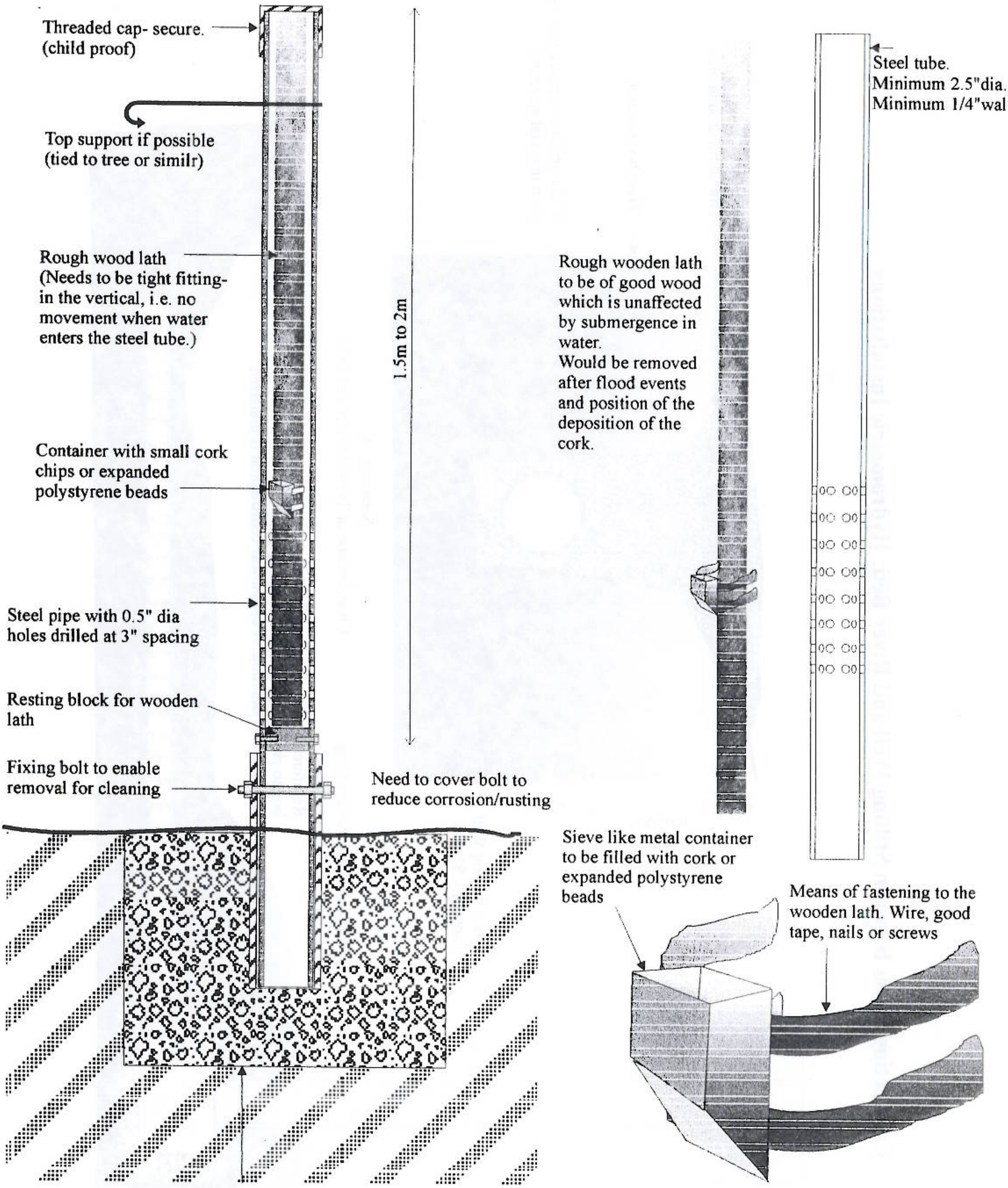
CAP ESTATE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Max	p2/P
85	61	31	27	49	28	25	109	151	134	329	187	82	1213	329	89
86	91	19	35	99	195	57	71	75	210	141	238	60	1291	238	44
87	44	18	9	3	392	136	191	183	184	258	387	84	1889	392	81
88	75	51	56	19	63	105	151	218	403	258	126	65	1590	403	102
89	67	41	155	106	11	67	236	199	217	80	203	107	1489	236	37
90	127	39	66	35	167	96	109	194	155	**350**	51	107	1496	350	82
91	62	41	69	110	46	42	65	86	162	37	442	57	1219	442	160
92	39	39	23	24	150	244	135	159	247	38	513	79	1690	513	156
93	103	20	87	20	135	51	165	101	269	184	76	18	1229	269	59
94	81	20	29	69	73	65	71	246	**297**	197	109	117	1374	297	64
95	92	32	160	165	49	179	91	328	169	163	62	54	1544	328	70
AVG	77	32	65	64	119	97	127	176	222	185	218	75	1457	222	**34**
1996	50	26	70	66	29	123	236	220	256	**489**	140	162	1867	489	128
1996/AV	65%	81%	108%	104%	24%	127%	186%	125%	115%	264%	64%	215%	128%		

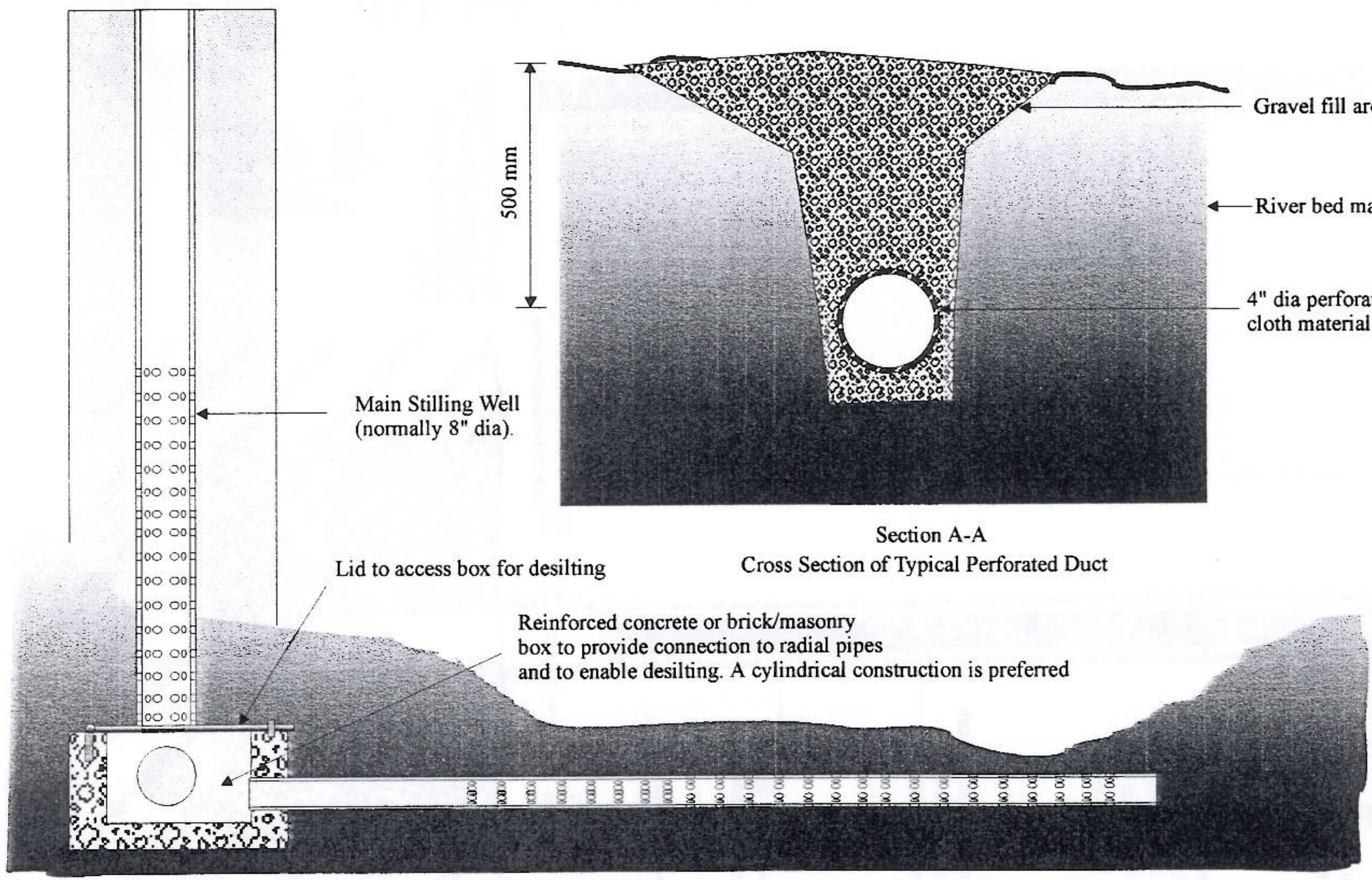
Appendix D

Additional Hydrometric Installation Guidelines

Crest Level Gauge (for estimation of flood peak levels)



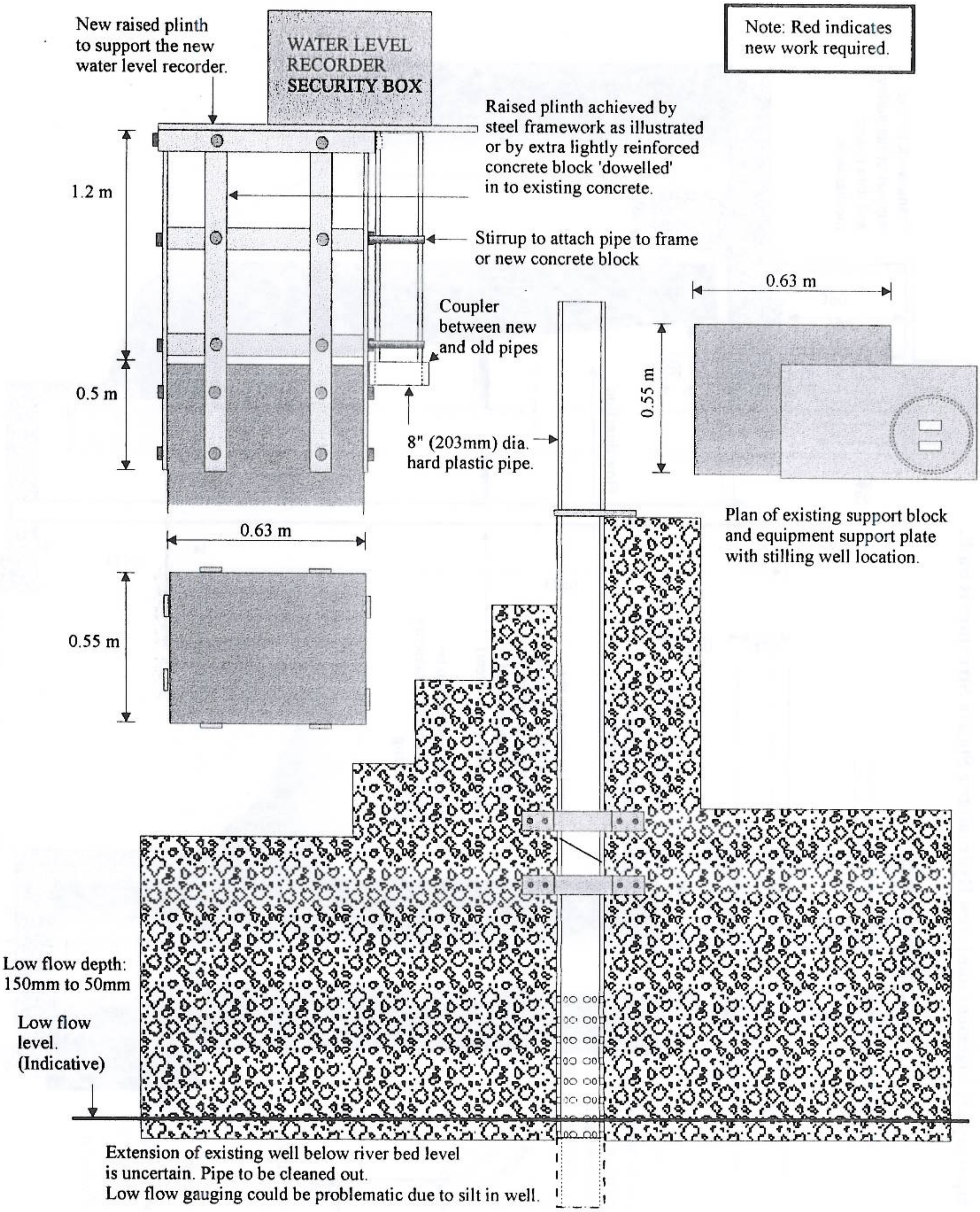
Connecting Ducts between Stilling Well and River Bed: Hydrometric Installations



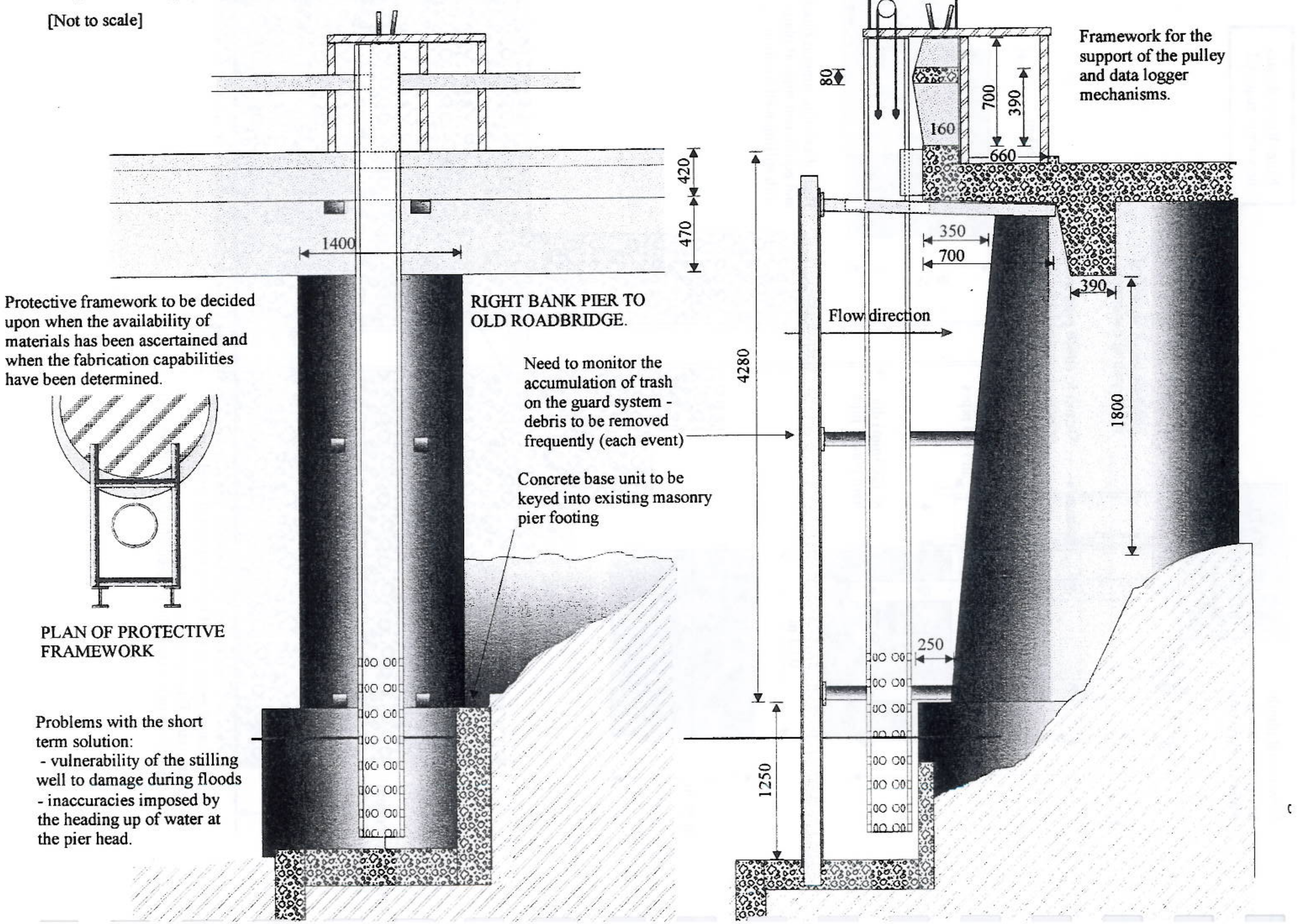
Section A-A
Cross Section of Typical Perforated Duct

Troumassee Hydrometric Station

Rehabilitation of the Hydrometric Gauge at Beauchamp Estate



Cul de Sac River Gauging Station. :
Proposed Temporary arrangement until New Hydrometric Station Structure is built.



Annex 3

Floods and Flood Plain Hazard Mapping

ANNEX 3

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Appendices:

A. Notes on the use of the Flood Report Site and Questionnaire Forms
B. Flood Report for Tropical Storm Debbie (TSD)
C. Flood Report for the Storm of 26th October 1996

St Lucia: Watershed and Environmental Management Project

Final Report
Annex 3

Floods and Flood Plain Hazard Mapping

Chapter 1

Introduction

1.1 Preamble

It was stated in the World Bank Review Mission Report, December 1994 that:

"For the planning and preparation of watershed management projects in Phase 2, more basic data on rivers are needed to supplement the sparse information currently available. A survey is required to establish permanent benchmarks and their co-ordinates along the priority rivers. From these benchmarks, cross sectons at fixed points can be measured to study and monitor the rivers' physical and hydrological characteristics and changes with time. While the surveys are being carried out, flood marks established for TSD should be levelled at the same time. The project implementation plan should specify that the surveys in priority watersheds be completed in time for the relevant Phase 2 project preparation work, which would benefit greatly from an early procurement of the data."

1.2 Background

Flood plain zoning and mapping is a relatively standard procedure undertaken in several countries. The information normally required to undertake this task can be summarised as:

- historic water level information at several locations in each river system covering many flood events. Ideally a record length of about 50 years is desirable;

- flood reports associated with the historic floods, reporting the properties damaged, the flood levels at the properties or infrastructure and the duration of flooding;

- socio-economic surveys of the affected populations, be they household surveys or sample group interviews;

- good topographic information in the main flood prone areas with contour intervals of about 0.3m (1ft).

In addition, work being undertaken extensively in the UK by the Consultant entails the use of hydrodynamic modelling techniques to simulate design storms down the river network. This is undertaken where historic water level information is not very extensive or perhaps periods of record are not long. The process requires topographic surveys of the river network with river cross sections at about 200m intervals with the cross sections extending through the flood plain. The resulting modelling of storm inflow hydrographs of 1:100 year return periods enables assessments to be made of the likely extent of flooding during such events. It is also possible to change river geometry, introduce flood protection embankments and new developments on the flood plain to evaluate their impact on the flooding regime.

Unfortunately, in St Lucia very little of the above data is available. Although subject to serious flooding on a relatively regular basis, water level records in the river system ~~is~~ at best sparse. Water level recorders operational in the past ~~has~~ been primarily related to gauging dry season flows. Stage discharge relationships have been derived for low flows with uncertain extrapolations used to relate stage to flood discharges. During serious flood events, gauges have often been damaged or washed away.

The peakiness of flood flows is such that normal staff gauges read manually one or twice a day would not necessarily produce peak flow water levels unless the staff gauge reader was exceptionally diligent and was willing to record levels on a ½ hourly basis during a flood event, day or night.

Flood Reports have not been produced, hence this source of valuable information is not available. This situation should be rectified in the future with the automatic production of a well structured flood report document following each serious flood event. Even after TSD, there is not known to be any structured watershed by watershed quantified statement of peak flood levels and flood extents. Flood marks based on trash marks were painted on various trees and power/ telephone poles, but only several weeks after the event when trash marks could have been disturbed.

In terms of topographic information, several map series do exist. The 1:25,000 and the 1:10,000 series have contours shown but only at a minimum interval of 25 feet (7.6m). This is inadequate for reliable flood plain or hazard zone mapping. There is a limited coverage of 1:2,500 maps with contours at 10 feet (3m).

Topographic surveys were carried out during Phase 1 of many of the main river systems where flooding is particularly a problem. This included the Cul de Sac, Roseau, Mabouya, Troumassee and the Canelles River. However, the surveys undertaken only covered the main river channel and a distance of about 20m either side of the river, often less. Hence, there is little opportunity of accurately determining flood extent from this data. Benchmarks were put in place and it might be possible to re-activate the surveying exercise to extend the cross sections beyond the flood plain.

In the light of the above, recourse has had to be made to that information available from TSD and the extent of flooding evidenced on October 26th of this year (1996). Within the scope of the Consultancy it has not been possible to undertake a comprehensive Flood Report for the October 26th event, however, many of the affected areas have been visited by the River Engineer and this 'experience' information has been incorporated into the flood zone hazard mapping which has been carried out. **{Note: ODA/ DFID have funded the input of an engineering hydrologist in the summer of 1997 to undertake comprehensive 'flood reports' for both TSD and the event of October 26th. These are incorporated in Appendix A and B to this Annex}.**

In the UK, flood extent mapping is often carried out for 1:10 year, 1:20, 1:50 and 1:100 year floods. With the accuracy of the mapping available it has not been possible to provide such 'accurate' information even on an indicative basis. It is considered that to do so would be misleading. Even the Flood Zone Hazard Map should be treated with caution.

Another feature of flood zone hazard mapping is the necessity to undertake socio-economic surveys and limited questionnaire approaches in areas subjected to flooding to elicit the opinions of the affected population on their perception of the severity, cause and response mechanisms to flooding. The impact on their livelihoods needs to be understood and quantified.

The main requirement for a more detailed Flood Hazard Zoning Map is the execution of a detailed topographic survey in, and just beyond, the areas provisionally identified by the mapping as being at risk.

As flood level estimates are in future obtained from the water level recorders which are planned to be installed, hence the Flood Hazard Zoning Map can be refined from the current relatively crude assessment.

Apart from the flood extent mapping, it has been considered desirable to also identify particular infrastructure which is at risk from serious flood events. However, this should not be taken as being a 'fully comprehensive identification'. In the vicinity of cross drainage structures, flood damage risks exist for adjacent and downstream properties should this cross drainage structure become blocked during a flood event.

Information on the design capacity of cross drainage structures should also be incorporated in the assessment. A road structure inventory adequate to enable this to be carried out does not currently exist. The susceptibility of each cross drainage structure to blockage should likewise be assessed together with an assessment of the likely flow path should a blockage occur. These details would be incorporated within a catchment management planning process.

The following two sections present an analysis of the flood events of TSD and of the 26th October. This has been carried out in considerably more detail than is warranted by the Terms of Reference for the River Engineer under Phase 2 Consultancy Contract for several reasons:

i. To provide a more detailed comprehensive assessment of TSD bringing together individual, small, papers and notes on the incident {the flood mark summary is also recorded prior to the departure of N Ermissee whose was party to their positioning};

ii. To similarly provide a quantified assessment of the flood of the 26th October to put the event in the context of TSD and in the context of frequency of occurrence;

iii. To provide an example for the use of the information now available from the new data loggers which have been installed under Phase 1;

iv. To provide a example for the assessment of the value of the existing hydrometric data base and the need for new or expanded hydromet networks (reference to Section 3.1)

Chapter 2

Flood Events

2.1 Flooding Resulting from TSD

Estimates of the flood flows during TSD are few. No water level recorders were in operation either being damaged during the storm or previously in-operative.

Some flood marks were recorded for the TSD but these have not been recorded nor integrated into any flood extent mapping of TSD although some of the trash marks have been used to estimate flood flow discharges. It should be pointed out that the flood marks recorded must be considered to be 'flood levels due to runoff and channel blockages' rather than the conventional flood level as a result of runoff and normal cross drainage structure and channel capacity effects. See **Plates 27** and **28.**

Visits were made in November 1996 to record the TSD flood marks as identified in the period post TSD. These have been plotted on the 1:10,000 maps and photographs taken of what were considered to be the more important marks. In many instances it was difficult to locate the marks owing to the damage caused to trees and electricity poles during the recent flood events. It should be noted that the survey was originally undertaken almost 2 months after TSD, hence the reliability of some of the marks could be questionable. In addition, the impact of debris on flood levels must be taken into account when assessing the implications of the flood levels estimated from the trash marks. However, the floods experienced recently are in places only slightly lower than the TSD marks, leaving a new trash set as indicators. In summary the extent of TSD marks visited include:

Cul de Sac Valley:

- on an electricity pole outside a supermarket in Bexon some 0.7m above road level {indications from the workers in the supermarket indicated that levels were probably lower, the recent floods having been almost as bad as TSD}.
- on an electricity pole near Ferrands Bridge and the Texaco Filling Station, about 1.3 m above main road level.

Roseau Valley:

- on an electricity pole downstream of the main West Coast Road bridge (left bank), level almost with the hand railing of the bridge, some 0.8m above road level;
- on an electricity pole downstream of the Vanard culvert crossing (left bank), two marks exist tieing in with two pronounced trash mark levels;

{Note the impact on trash marks in the Roseau valley caused by the large volume of debris which passed down the channel from the minor dam break from the Roseau Dam Site}.

Mabouya - Fond d'Or Valley:

- several TSD marks on the road to the north of the channel near to La Pelle. Some 2m above surrounding land and hence about 5m above channel bed level;
- top of railing/ girder of the main river bridge at the Dennery Factory site. This was 5.4m above the river level (13th Nov 1996) with an estimated depth of flow of 1m.
- on an electricity pole about 50 m due west of the turn off from the main road to La Resource, on the northern side of the road.

Dennery Valley:

- several trash marks on trees adjacent to the road which runs up the valley from the main road.

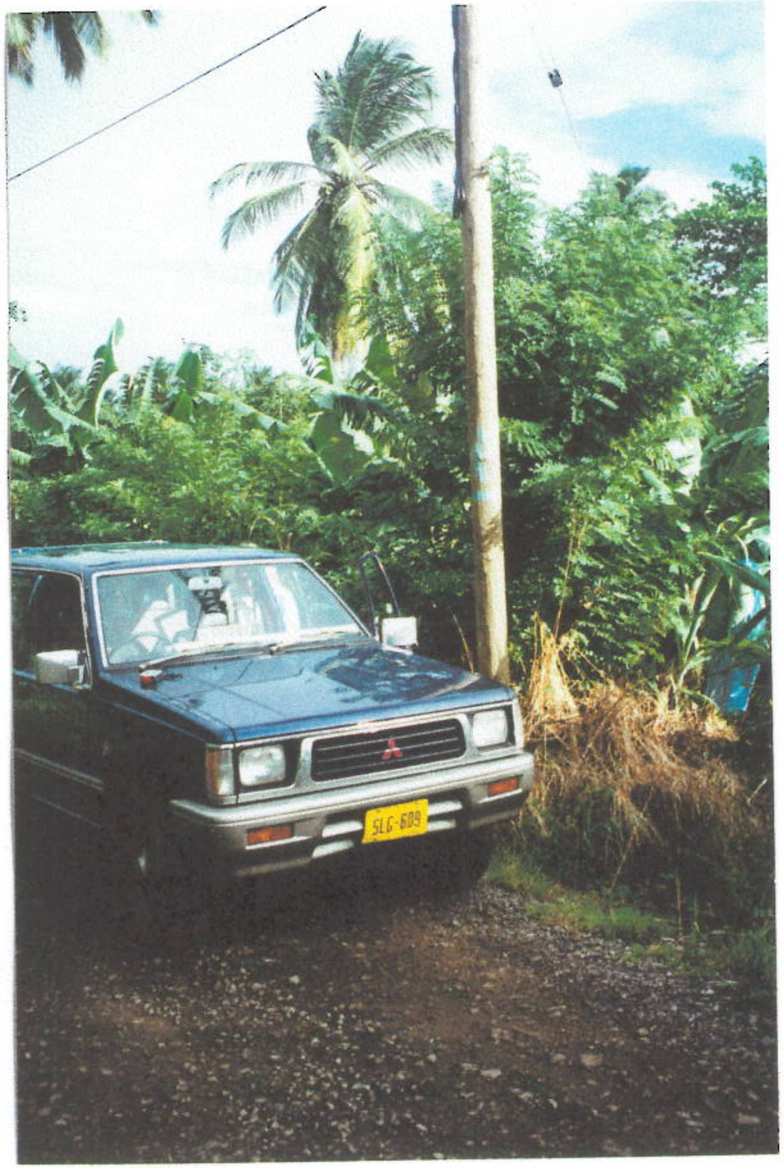


Photo 28 Dennery River, TSD Mark on pole above car roof. Level 6.5m above river bed.

Photo 27 Vieux Fort River, La Retraite Bridge. TSD Flood Mark (on th

The marks indicate that the flow was on average about 1.3m above the road surface and about 6.5m to 7m above the bed of the channel (See **Photo 28**);

- a mark on an electricity pole on the road down into Dennery town, adjacent to the Dennery flood protection bund which is currently under construction, this being about 1m above adjacent road level.

Troumassee Valley:

- marks on several trees up the track on the right bank of the River Troumassee due west of the main road. All marks indicated a TSD flow depth some 1.5 above the track or about 6.5m above river bed level. Flood plain width is limited on the right bank (where the track is located) but quite wide on the left bank. Trash marks from the recent floods were some 0.5m lower than TSD marks;
- TSD trash mark indicator on a tree on the left bank of the channel downstream of the Mahaut road crossing. This being about 5m to the bed of the channel.

Canelles Valley:

- marks on several trees on the track on the right bank of the River Canelles due west of the main road. Marks indicated that TSD flood water levels were 1.6m to 1.8m above the level of the track. One mark being easily measurable above the channel water level on the 13/11/96, being 4.3m above with a flow depth of about 0.8m. Another site had the TSD mark at 4.65m above the river water level.
- at a site upstream near De Mailly, the TSD mark was about 2.9m above the water level in the channel (culvert crossing), thus about 3.3m above bed level. Trash indicated that the recent floods were about 0.8m lower than this.

Vieux Fort:

- La Retraite Bridge. TSD flood mark corresponded to the top of the hand railing of the bridge, or about 7.9m above the water level on the 13/11/96 where bed level was estimated to be about 1.2m lower than this. The height from the top of the hand railing to road level is 1.2m. The main channel is about 20m wide at normal flow with a bridge width of about 30m. (Note downstream bridge near the mouth of the river has a water way width of about 33m). The recent floods indicated a flood level at the deck level of the bridge, i.e. about 1m lower than TSD; See **Photo 27**;
- Bridge across the river on the way to Hope Estate. TSD marks some 7m above river bed level. Water will have passed over the bridge during TSD and the recent floods although the recent levels indicated by the trash marks were about 1.5m lower than the TSD marks;
- Culvert across the river just south of Plut. Culvert badly damaged by the recent floods although mainly the upstream approach track.. Nearby landslips into the channel could have aggravated the recent floods.

Soufriere Valley:

- No marks were left. River bed upstream from the town of Soufriere after the recent floods showed more extensive debris and stone/ rock accumulation than had been evidenced during TSD.

These represent the major channels on the Island. These lead from the larger catchments which originate in the central higher rainfall zones and are thus expected to experience the most sever and aggressive floods. Small valleys generally do not have extensive flood plains and hence their flows are normally contained within the main flow channel and away from most habitation and human activities.

Serious floods in all the river catchments are the result of high intensity rainfalls of short duration, of the order of 1 to 3 hours. Analysis of rainfall runoff relationships during flood events has been hampered by the lack of reliable rainfall intensity information and the paucity of flood level estimation.

A paper produced by Ms N Eernisse for a Workshop in July 1996 provided some indications of river discharges during the event. In the paper, 'Role of climatic factors in soil conservation', the rainfalls leading up to the storm event and on the 9th September 1994 were presented. These are given in **Table 2.1.**

Table 2.1 Rainfall leading up to and during TSD

Date	Union	Saltibus	Delcer	Hewan	Soucis
September 3	28.3	61.7	35.5	54.6	37.0
September 4	29.2	14.3	11.0	25.7	35.9
September 5	18.0	7.3	2.7	2.1	58.3
September 6	13.7	13.6	4.2	6.8	12.3
September 7	18.1	30.7	22.0	7.6	2.2
September 8	6.2	7.9	9.3	1.5	19.0
Total	113.5	135.5	84.7	98.3	164.7
September Mean	260.0	379.0	222.0	220.0	288.0
September 9-Debbie	275.6	320.8	244.9	212.0	230.0

The rainfall analysis for Union indicated a rainfall intensity of 90mm/hour for a 1 hour duration (see **Table 2.2**). {The WB Consultant's Report of December 1994 indicated a 1 day rainfall at Bexon of 427.9mm}.

Based on the Rational Formula, discharge estimates were made for the River Cul de Sac at Bexon and at Ferrand's Bridge.

$Q = C.i.A.\ 0.278\ m^3/s$ where

C= Runoff Coefficient (taken as 0.7)

I = Rainfall intensity (mm/hr)

A= Catchment Area, 9.4 for Bexon and 30 for Ferrands Bridge.

This yielded 164.6 m^3/s at Bexon and 525.4 m^3/s at Cul de Sac. It was noted that the normal baseflow at Ferrands Bridge is 0.18 m^3/s. The average flood runoff was estimated to be about 20$m^3/s/km^2$ and was estimated to have about a 1:100 year return period.

A detailed assessment of the implications of TSD on the design of the Roseau Dam was undertaken in 1994. The Report, 'Tropical Storm Debbie, Report on Hydrology, Roseau Dam and Ancillary Works, Stanley & Klohn Leonoff, November 1994' provides the details of the analysis and also presents a good summary of the characteristics of the storm as it moved across the Caribbean.. A study was made of all the rainfall recorders deemed to be operational leading up to and during TSD was undertaken. The resulting rainfall depths and intensities for specific return periods are summarised in **Table 2.3**. An analysis of the variation in rainfall intensities with altitude was undertaken although some altitude discrepancies exist in the computations in relation to the altitudes assumed. {The Roseau Dam spillway crest is set at 101.5 m whilst the average elevation for the Dam catchment is about 270m whilst the catchment area of the reservoir is 15.2 km^2}.

Table 2.2

Rainfall Intensity Information for St Lucia
Union Agricultural Station

Rainfall Depths for Different Return Periods

Return Period (years)	Rainfall duration (minutes): 5	10	15	30	60	120	360	720
2	8.8	13.4	16.9	23.1	29.8	43.8	64.5	76.9
5	11.5	17.5	21.6	29.1	36.6	54	77.5	92.7
10	13.3	20.3	24.7	33.1	41.1	60.8	86.3	103.2
25	15.5	23.8	28.6	38.2	46.8	69.4	97.3	116.4
50	17.2	26.3	31.5	45.7	51	75.7	105.4	126.2
100	18.9	28.9	34.4	49.4	55.2	82	113.4	135.9

Note: Based on an analysis of the rainfalls for the period 1979 to 1987 inclusive.
Source : IoH, Report on Cul de Sac Industrial Area

Maximum Rainfall Depths in Different Durations (mms)

	1995	5 minutes	10 minutes	15 minutes	30 minutes	60 minutes	120 minutes	180 minutes	360 minutes	720 minutes
Jan		7.4	9.4	11.4	24.3	28.8	36.6		36.8	36.9
Feb		2.9	2.9	2.9	4.5	5.5	5.9		6.7	7.6
Mar		6.2	8.7	9.7	14.8	22.6	26.6		32.2	37.2
Apr		9.5	9.9	12.0	19.3	30.8	31.9		49.2	60.9
May		7.0	8.0	10.4	18.1	19.2	23.2		53.5	64.5
Jun		6.3	10.5	20.0	26.6	29.6	30.9		42.1	54.4
Jul		5.0	7.0	8.2	10.2	10.7	12.9		14.4	24.2
Aug		6.5	9.5	21.5	27.3	34.3	44.8		66.2	71.2
Sep		5.5	8.7	12.9	13.1	19.1	34.2		37.4	38.2
Oct		5.4	7.5	12.9	16.2	20.7	30.7		43.4	49.1
Nov		7.4	11.7	15.9	23.3	27.9	30.2		30.2	30.8
Dec		7.4	9.5	13.5	13.5	13.5	13.5		14.0	16.0
Maximum		9.5	11.7	21.5	27.3	34.3	44.8		66.2	71.2
	1991	7.5	14.6	17.0	28.3	37.5	38.3	41.3	50.0	85.1
	1992	12.0	15.0	25.0	30.0	30.0	66.7	69.8	91.2	110.0
	1993	8.0	12.0	17.5	30.0	46.0	52.0	53.5	62.5	77.0
	1994	7.6	11.7	13.8	21.5	24.0	37.2		46.4	46.5
Debbie		13.8	15.0	24.4	48.0	90.0	160.8		260.6	269.5

Source: 'Role of climatic factors in soil conservation', Ms N Eernisse, AESD, MoA.
{Workshop on Soil and Water Conservation, Ministry of Agriculture, July 1996}

For October 26th:

	5	10	15	30	60	120	180	360	720
26th Oct '96:Bexon mms		17	31	37	53	97		190	229
26th Oct '96:Mahaut mms		15	24	44	72	134		220	274

Maximum Rainfall Intensities in Different Durations (mms/hr)

	1995	5 minutes	10 minutes	15 minutes	30 minutes	60 minutes	120 minutes	180 minutes	360 minutes	720 minutes
Jan		89	56	46	49	29	18		6	3
Feb		35	17	12	9	6	3		1	1
Mar		74	52	39	30	23	13		5	3
Apr		114	59	48	39	31	16		8	5
May		84	48	42	36	19	12		9	5
Jun		76	63	80	53	30	15		7	5
Jul		60	42	33	20	11	6		2	2
Aug		78	57	86	55	34	22		11	6
Sep		66	52	52	26	19	17		6	3
Oct		65	45	52	32	21	15		7	4
Nov		89	70	64	47	28	15		5	3
Dec		89	57	54	27	14	7		2	1
Maximum		114	70	86	55	34	22		11	6
	1991	90	88	68	57	38	19	14	8	7
	1992	144	*90*	100	60	*30*	33	23	15	9
	1993	96	72	70	60	46	26	18	10	6
	1994	91	70	55	43	24	19		8	4
October 26th'96 (Bexon)			**102**	**124**	**74**	**53**	**49**		**32**	**19**
October 26th'96 (Mahaut)			**90**	**96**	**88**	**72**	**67**		**37**	**23**
Debbie (Union)		**166**	***90***	**98**	**96**	**90**	**80**		**43**	**22**

Note: Figures in Italics indicate values are probably not the maxima.

File : RF-INTY.WK4

Table 2.3

Tropical Storm Debbie, Maximum Recorded Rainfall and Calculated Intensities

Rainfall Station	Maximum Recorded Rainfall in Specific Durations (mms) 15 min	30 min	1 hr	2 hr	3 hr	6hr	12 hr	24 hr
Union Research	27	48	89	167	212	257	272	286
Bexon			100	185	247	306	339	347
Soucis			51	98	122	181	215	231
Errard			125	225	265	317	349	372
Delcer			61	99	151	221	251	258
Saltibus			72	122	172	280	320	337

Rainfall Station	Maximum Intensities for Specific Duarations (mm/hr) 15 min	30 min	1 hr	2 hr	3 hr	6hr	12 hr	24 hr
Union Research	**108**	**96**	**89**	**83.5**	**70.7**	**42.8**	**22.7**	**11.9**
Bexon			100	92.5	82.3	51.0	28.3	14.5
Soucis			51	49.0	40.7	30.2	17.9	9.6
Errard			125	112.5	88.3	52.8	29.1	15.5
Delcer			61	49.5	50.3	36.8	20.9	10.8
Saltibus			72	61.0	57.3	46.7	26.7	14.0

Maximum Intensity TSD {estimated for 270m elevation}	157.5	147.4	140.9	125.2	92.1	54.1	29.7	16.3
1,000 year Storm	226.8	166.8	119	70.3	54.1	37.8	29.7	19.2
PMP	490	367.6	272	203.7	166.5	105.5	64.5	39.8

Source: Tropical Storm Debbie, Report on Hydrology, November 1994
Roseau Dam and Ancillary Works, Stanley & Klohn Leonoff.

In addition to the rainfall analysis, estimates were made of flood flows passing the dam structure based on trash marks and estimated roughness coefficients and channel slopes related to the flow. The problems of uncertainty in the analysis owing to data availability and the impact of trash and debris was highlighted. None the less, the Report indicated that the 'best estimate of the flood discharge at the Roseau Dam is 260 to 375 m^3/s ', whilst the 'peak flood at the Roseau Dam, prior to breaching, on September 10, 1994, was estimated to be in the range of 240 to 290 m^3/s' with a modelled maximum outflow of 270 m^3/s. {The storm maximisation analysis 'confirmed the design parameters and design storm and flood used for the Roseau Dam and spillway capacity'}.

The scale of these discharges are not considered to be too dissimilar to the estimates made of the TSD flows at the main road bridge near the WINBAN establishment.

A separate analysis has been carried out of the estimated flood flows in the Cul de Sac, Roseau and Dennery Rivers during TSD has been carried out utilising channel slope estimates based on the Phase I surveys in conjunction with estimating main channel and flood plain flows as separate components with separate flow boundary roughness values. The results are given in **Table 2.4**. These are not dissimilar to the values estimated earlier.

Historic rainfall data has been obtained for the raingauge at Bexon in the Cul de Sac Valley. The maximum daily, maximum 3 day rainfall and the monthly totals have been plotted in **Figure 2.1**. The 1994 maximum daily is significantly larger than other years. The middle plot is of the daily rainfalls at Soucis and Bexon over the month of September 1994. The period 3rd to the 6th providing water to meet soil moisture requirements such that the intensive rainfall of the 9th primarily translated into runoff. The lower series gives the time series of maximum daily rainfall at Bexon (9:00 am to 9:00 am). Two events of about 300mm are within a 30 year period. However, as mentioned earlier, it is the rainfall characteristics through the day which is important to flood flows. Only the Union Agricultural Station has had hourly intensity data which has been considered as usable. The station is outside the high annual rainfall area which also correlates with high monthly rainfalls in October and November the main wet months.

2.2 Flooding of the 26th of October

The main damage zones resulting from the heavy rainfall during the morning of the 26th of October 1996 were:

Soufriere:
The Phase 1 gabion mattress training walls stood up well, however there was a footbridge downstream of the main works (d/s of the lower bend) which has a low soffit level which it is considered caused most of the damage in the town itself. It blocked or partially blocked and caused overspilling into Soufriere damaging the adjacent road which was being resurfaced, damaging construction vehicles etc.

Canaries:
The main river was reported to have carried a very high discharge as a result of heavy rains in the upper catchment. A retaining wall built as part of the Phase 1 works was undermined and collapsed taking half the small road leading up the valley with it. The downstream gabion work was badly damaged and earth behind it washed away. The main Dennery bridge right abutment was also undermined and collapsed, the Bailey type deck dropping at that end by about 2m.

Table 2.4

Estimation of Peak Flood Flows during the TSD

River	Location	Estimation of Runoff by the Rational Formula					Channel Conveyance Capacity at Peak Water Level									
		Catchment Area km2	Rainfall Intensity mm/min	Runof Coeff.	Unit Coeff.	Estimated Discharge m3/s	Mannings 'n'	Channel Slope	Flow Area m2	Wetted Perimeter m	*Nominal Dimensions* *Width* m	*% on flood plain*	*Depth F* m	*Depth C* m	Flow Velocity m/s	Estimated Discharge m3/s
Roseau	W 60-59-35 N 13-55-45	22.8	1.66	0.7	16.7	**441.6**	0.025 Slope 1 in	0.0072 139	134	127	120	90%	0.9	2.1	3.52	**472.6**
Cul de Sac	Bexon W 60-58-40 N 13-57-10	9.4	1.66	0.7	16.7	**182.1**	0.035 Slope 1 in	0.0061 164	125	172.6	160	90%	0.6	3	1.80	**225.5**
Cul de Sac	Bexon W 61-00-20 N 13-59-00	40.9	1.66	0.7	16.7	**792.3**	0.025 Slope 1 in	0.0004 2500	750	470	230	90%	1.5	4	1.09	**819.5**
Dennery	W 60-64-45 N 13-47-30	12.1	1.66	0.7	16.7	**234.4**	0.03 Slope 1 in	0.0019 526	120	91	55	50%	1.5	4.2	1.75	**209.7**
Dennery	W 60-55-35 N 13-53-45	6.93	1.66	0.9	16.7	**172.6**	0.05 Slope 1 in	0.021 48	63	41	35	30%	0.65	3.5	3.86	**243.2**

Comments on file:

1. For the Second Dennery estimate:
   The channel was probably blocked with debris, hence flow level evidenced was caused by backing up of the flow
   Rational Formula run-off coefficient increased to 0.9 for mountain streams
2. Rainfall intensity is equivalent t 99.6 mm/hr {note, most estimates are of 90 mm/hr, hence possible overestimate above of about 10%}.
3. Rational Formula used : Q= 16.67 C.i.A.
4. Flow areas and wetted perimeters derived from field inspection and trash marks

{all as estimated by Ms N Eernisse and Humberto Verasquez Rodrigues shortly after the event}

File: DEBBIE-F.WK4

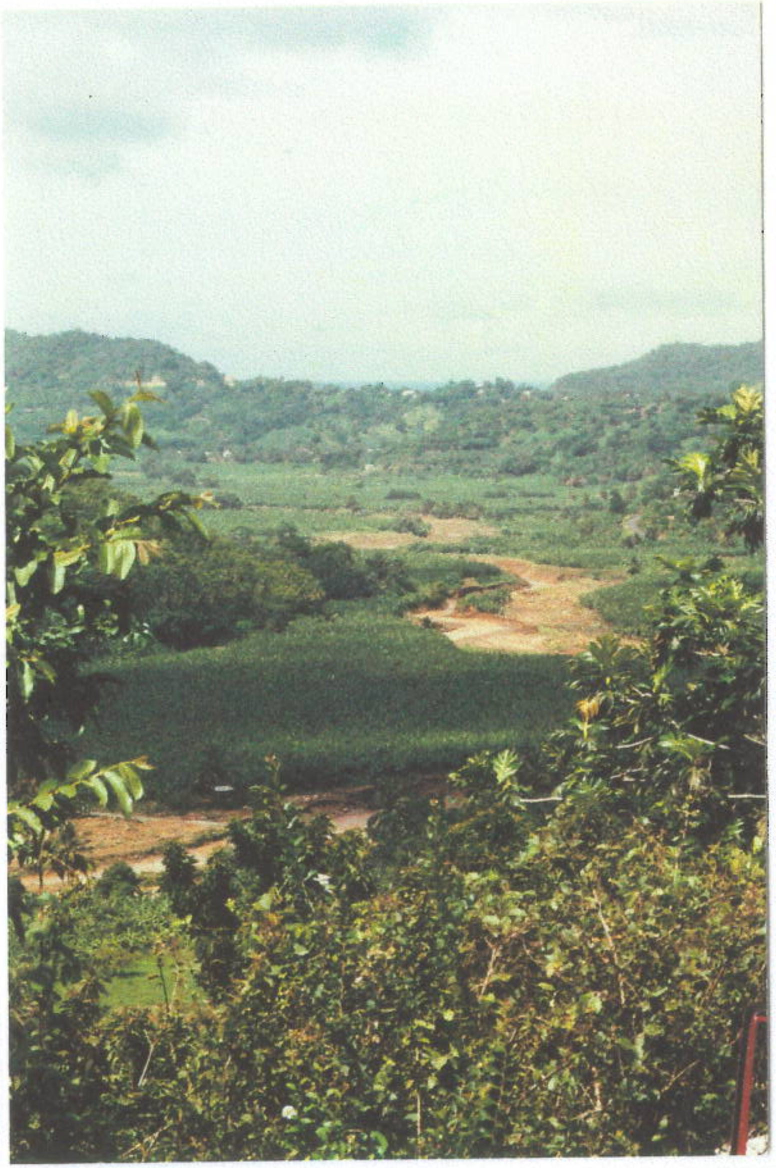


Photo 29 Cul de Sac Valley. Main west coast road looking south during flooding of 26th October

Photo 30 Roseau Valley. After October 26th event showing main channel and active flood plain.

Photo 31 Cul de Sac River: Upstream of West Coast Bridge. Flood waters during October 26th.

Photo 32 Cul de Sac River. As Photo 31 October 27th. Debris in need of removal. Maintenance?

Photo 33 Cul de Sac River : Footbridge access to new Bexon School. Pre October 26th.

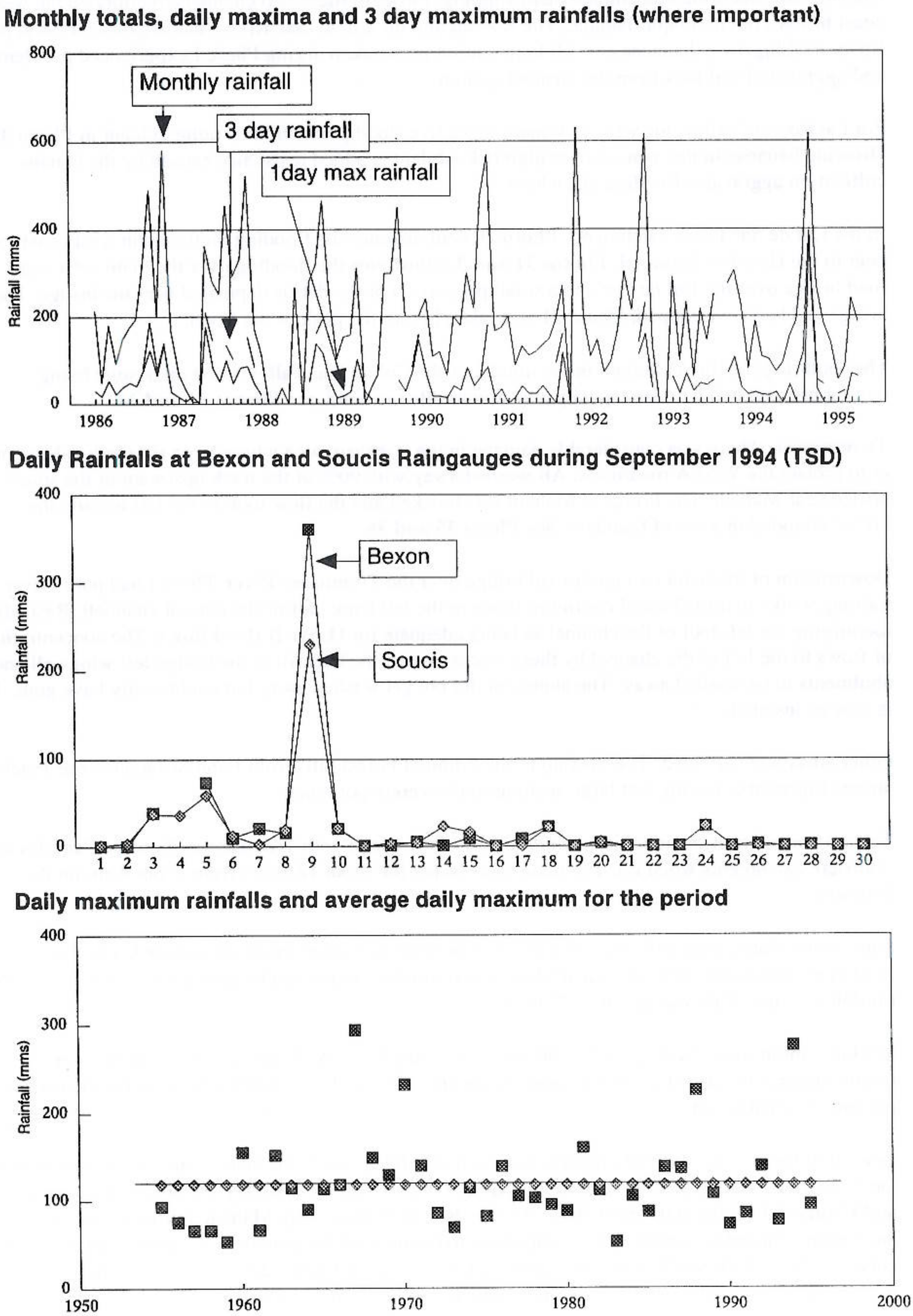
Photo 34 Cul de Sac River : As Photo 33. Oct. 26th. Undercapacity footbridge, floodplain zone.

Photo 35 Troumassee River at Mahaut: After 26th October. Bridge blocked by debris then stones.

Photo 36 Troumassee River at Mahaut:Novemebr 13th. Bridge reinstated with rip rap protection.

Figure 2.1

Cul de Sac Valley : Rainfall Characteristics



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Roseau and Cul de Sac:
Considerable scouring and embankment slipping. Flows in these two channels overtopped the west coast bridges but no major damage. The Roseau and the Cul de Sac Rivers had significant flood plain flows washing away bananas etc. All loop cutting undertaken during Phase I experienced problems and aggravated soil loos from the channel system.

For the Roseau Valley due west of Vanard the active flood plain width is quite evident in **Photo 30.** Growing bananas in this zone carries high risk whilst the added resistence caused by the banana cultivation aggravates flooding elsewhere.

In the Cul de Sac lower catchment, **Photo 29** demonstrates the flooding on the main west coast road near to the Hess Oil Terminal. **Photos 31 and 32** illustrates the flooding over the main west coast road bridge over the Cul de Sac and a small proportion of the debris deposited near the bridge. The bridge had been overtopped, **Photo 31** was taken before the peak of the flood.

The footbridge at Bexon School in the middel of the Cul de Sac Valley stood up despite being overtopped and being under capacity and structurally unsound, **see Photos 33 and 34.**

Troumassee: There was considerable damage in the upstream area where large rip-rap had been put in to protect the WASA road/track. All washed away with 90% of the track upstream of the small bridge near Mahaut. The bridge at Mahaut was blocked and the flow took to the left leaving the bridge stranded in a sea of boulders. See **Photo 35 and 36.**

Downstream of the main east coast road bridge over the Troumasee River, Phase I had put in river training works in mid channel confining flows to the left bank half of the natural channell. Basically identifying the left half of the channel as being adequate for (1:5yr ?) flood flows. The concentration of flows to the left of the channel by these works caused the backfill to the bridge left wingwall and abutments to be washed away. The abutment did not get washed away but could easily have gone. It is now re-instated.

Other areas were affected. The road up to the Edmund Forest hills from Fond St Jacques was made almost impassable having lost large sections and severely pot holed.

The storms and rains mainly hit the middle part of the island with Troumassee, Roseau, Canaries and Soufriere catchments worst hit. The main rains lasted for about 12 hours from about 4 am on the Saturday.

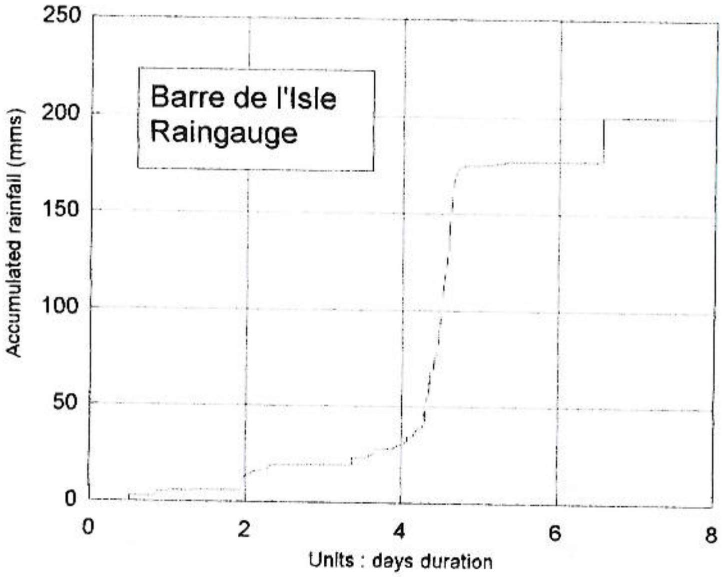
Some of the data logger information which has been down loaded has been analysed. The days rainfall at Bexon was 229mm, that at Mahaut (Troumassee upper catchment) it was 274mm. (Debbie rainfall at Union Vale was given as 270mm).

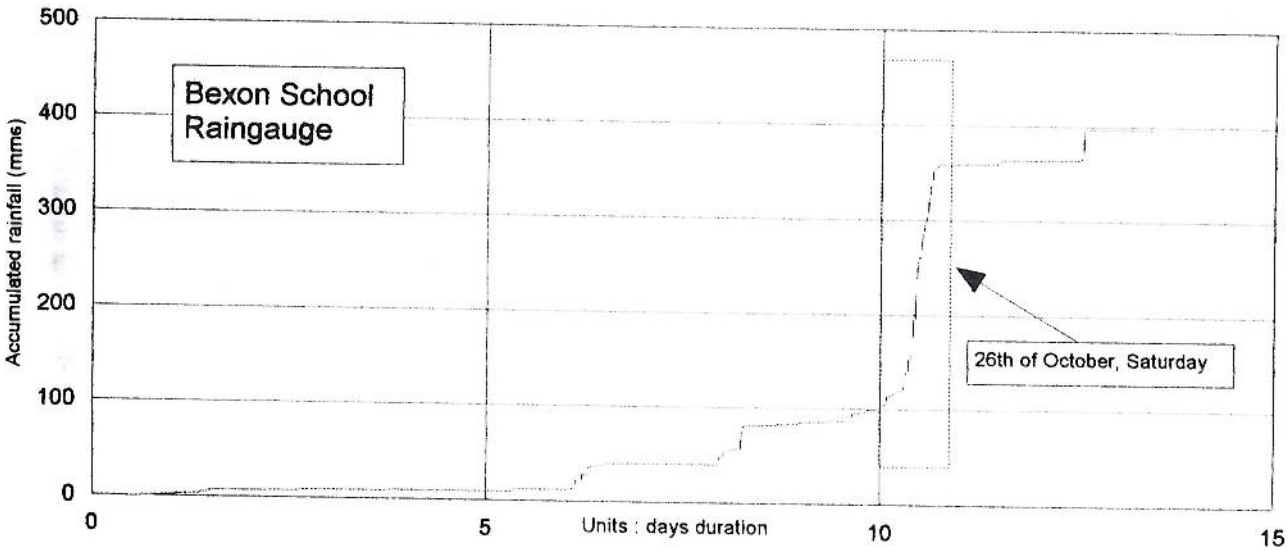
Debbie rainfall intensity is quoted as 90mm/hr at Union Vale. At Bexon it was 53mm/hr over 60minutes and at Mahaut 72 mm/hr over 60 minutes. The daily rainfall information for the period is presented in **Table 2.5.**

Several of the new rainfall data loggers had been installed prior to the heavy rains. This information has been down loaded and the rainfall records associated with this data is presented in **Figures 2.2** and **Figure 2.3** for the stations of Barre d'Lisle, Bexon, Soucis, Cap, Mahaut and Troumassee. These have been adjusted to enable direct comparison to be made of the growth in the accumulated rainfall curves in the Cul de Sac Watershed, **Figure 2.4** and others in **Figure 2.5.** To enable rainfall intensities to be clearly visible, these are again plotted in **Figures 2.6** and **2.7.**

Cul de Sac River Valley

Long term accumulated rainfall during storm event of late October 1996





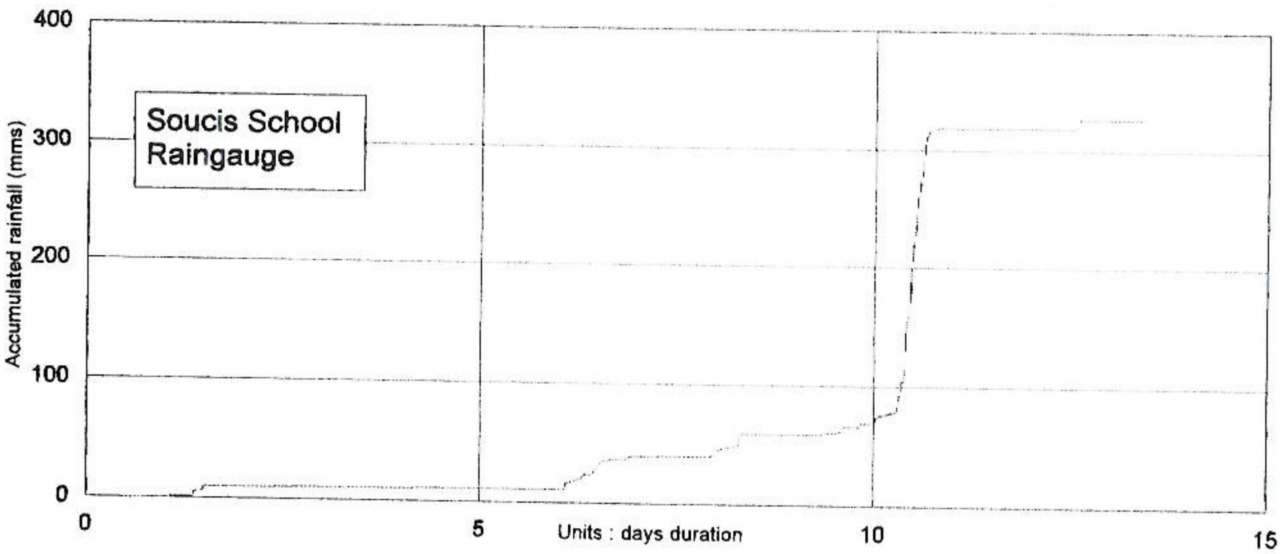


Table 2.5 Daily Rainfalls on 25th/26th October 1996

Station Name	Number	Friday 25th Oct. (to 9:00 am 26th)	Saturday 26th Oct. (to 9:00 am 27th)	Total for 2 days (mms)
Bexon		65.4	207.0	272.4
Soucis		43.8	214.6	258.4
Barre de l'Isle	333	45.0	108.8	153.8
Troumassee		43.8	104.2	148.0
Mahaut		55.4	239.4	294.8
Union	351			
Saltibus	211			
Hewanorra	151			

Use has been made of a unit hydrograph flood generation process to estimate the response of the Cul de Sac Watershed to different rainfall volumes distributed differently through the day. This is intended to demonstrate the importance of the duration of heavy rainfall in the creation of a flood. These generated flows are presented in **Figures 2.8 to 2.12**. The results, taking into account the rainfall growth characteristics experienced on the 26th of October would indicate flood flow of about 250 to 300 m^3/s.

The analyses were based on the random generation of rainfall data to match the approximate daily rainfalls experienced on October 26th and TSD. **Figure 2.8** relates to an 263mm rainfall depth evenly spread across the 24 hour period. A relatively low flood peak results.

The random rainfall generation is then modified to create a more intensive rainfall period between 6 hrs to 8 hrs. Over this period the rainfall intensity ranges from about 35 mm/hr to 45 mm/hr. The resultant flood peaks range from 240 m^3/s to 310 m^3/s, see **Figures 2.9 and 2.10**.

Adopting the catchment area of 33.6 km^2 and a runoff coefficient of 0.7 and the empirical runoff relationship, Q = C.i.A. 0.278 m^3/s yields, Q = 261 m^3/s at i= 40 mm/hr. It is possible that for run-off from the upper catchments values of 'C' of 0.8 +/- 0.05 will probably apply. In these upper areas rainfall intensities are also likely to be higher.

Using the same unit hydrograph characteristics and randomly distributing a very high daily rainfall of 366 mms through the 24 hour period only results in a relatively row runoff. This is illustrated by **Figures 2.11 and 2.12** which only differ by the randomisation of the rainfall depth within the 24 hour period.

These estimates are intended to illustrate the importance of rainfall intensity distribution through the day in the context of flood flows in St Lucia. Hence, the high value to be placed on the installation and operation of the network of data logger rainfall recorders which have now been installed across the Island. Previously, the few autographic rainfall recorders which had been installed were rarely analysed in relation to rainfall intensities. The analysis of rainfall-runoff relationships has therefore not been undertaken in the past. It is accepted that the spatial variability of rainfall intensities might be high, however, experience from the records of October 26th are that useful information is obtainable.

Figure 2.7

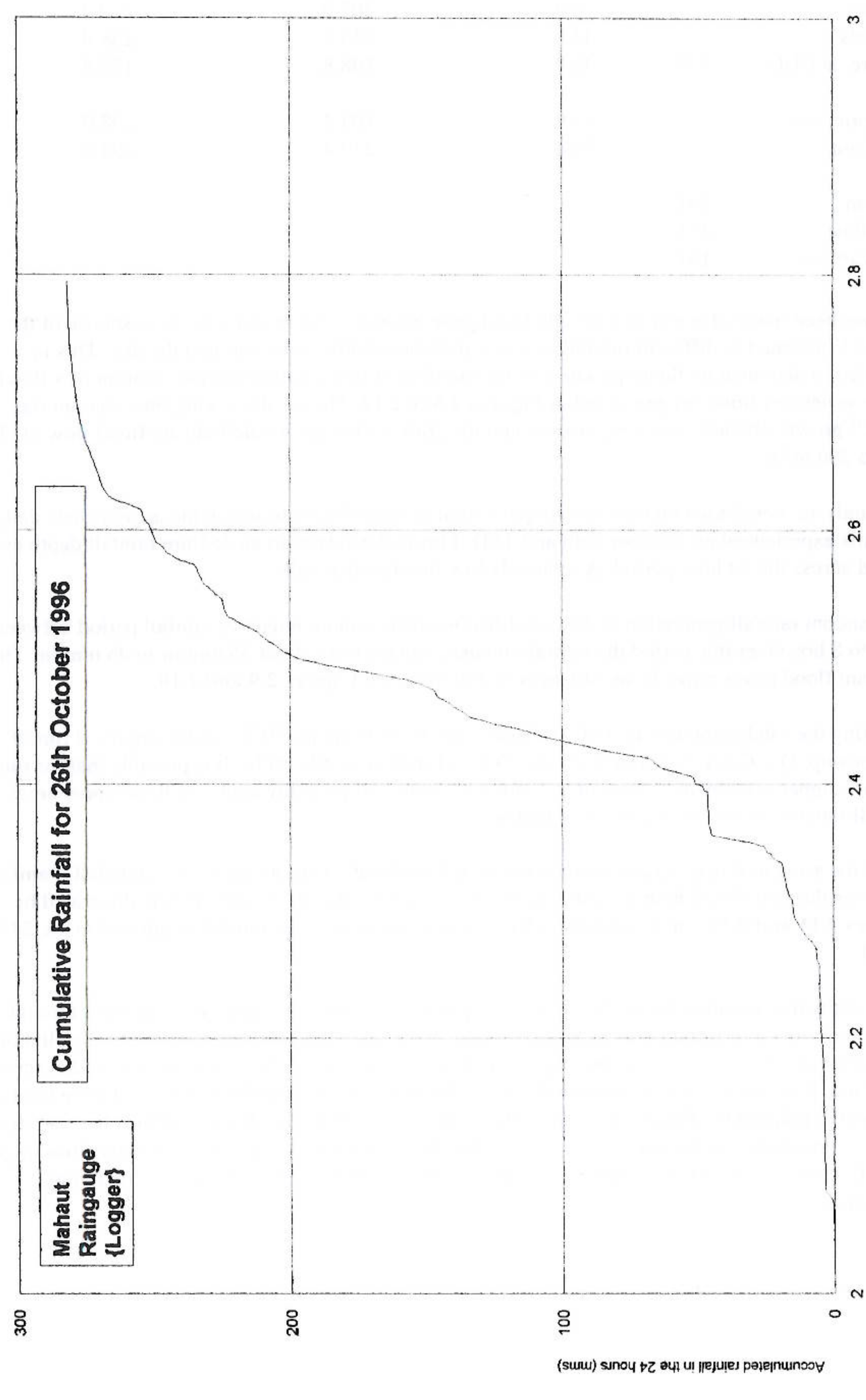
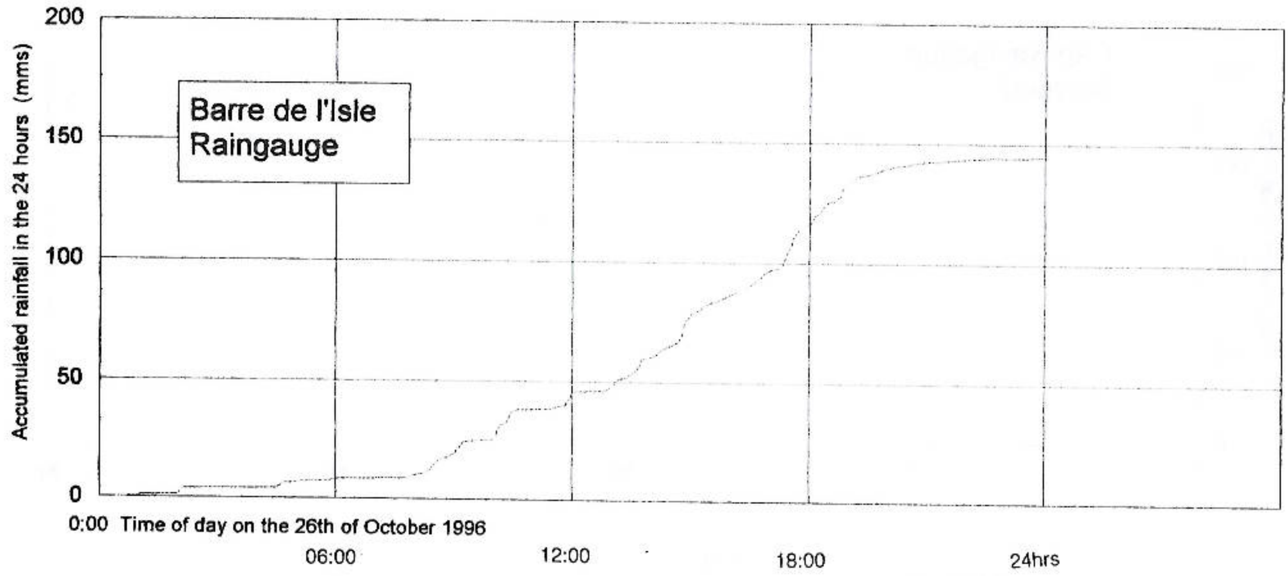
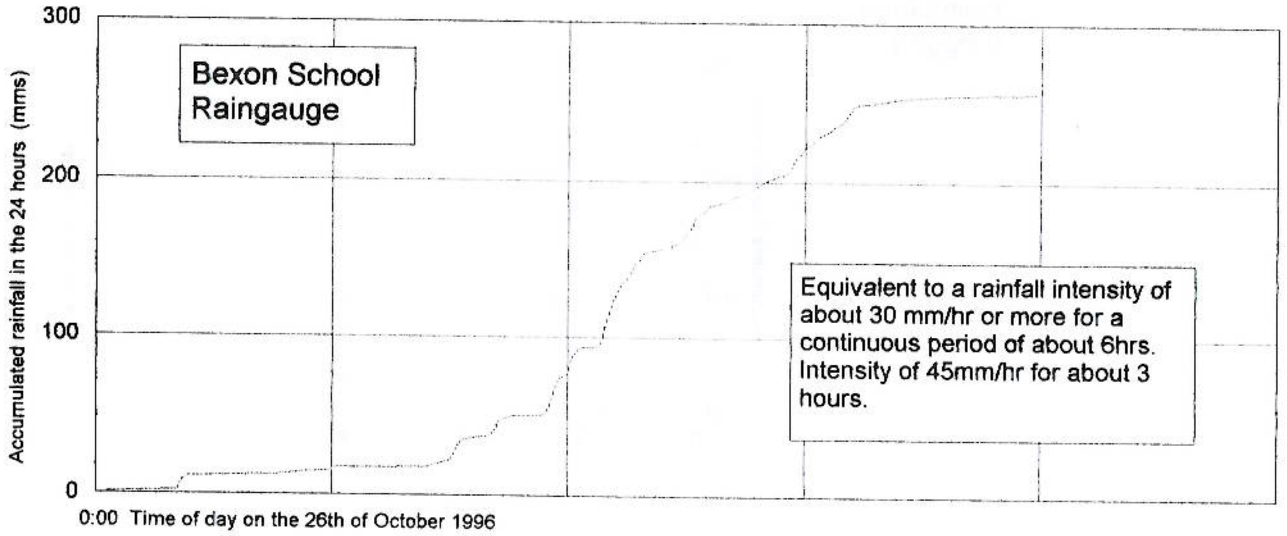

Cumulative Rainfall for 26th October 1996
Mahaut
Raingauge
{Logger}
Accumulated rainfall in the 24 hours (mms)
300
200
100
0
2
2.2
2.4
2.6
2.8
3

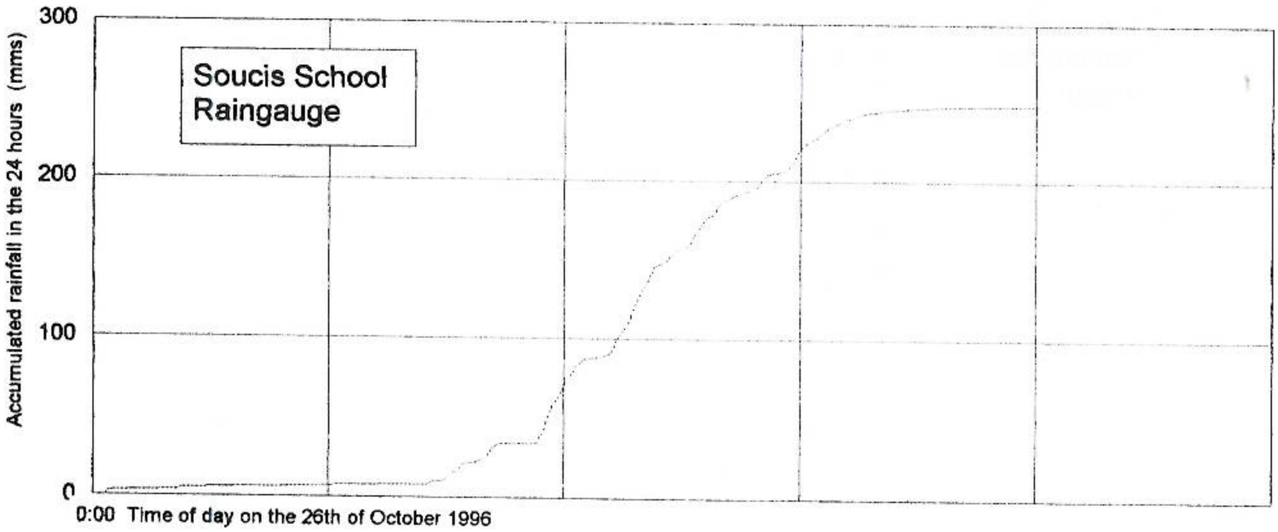
Figure 2.4

Cul de Sac River Valley

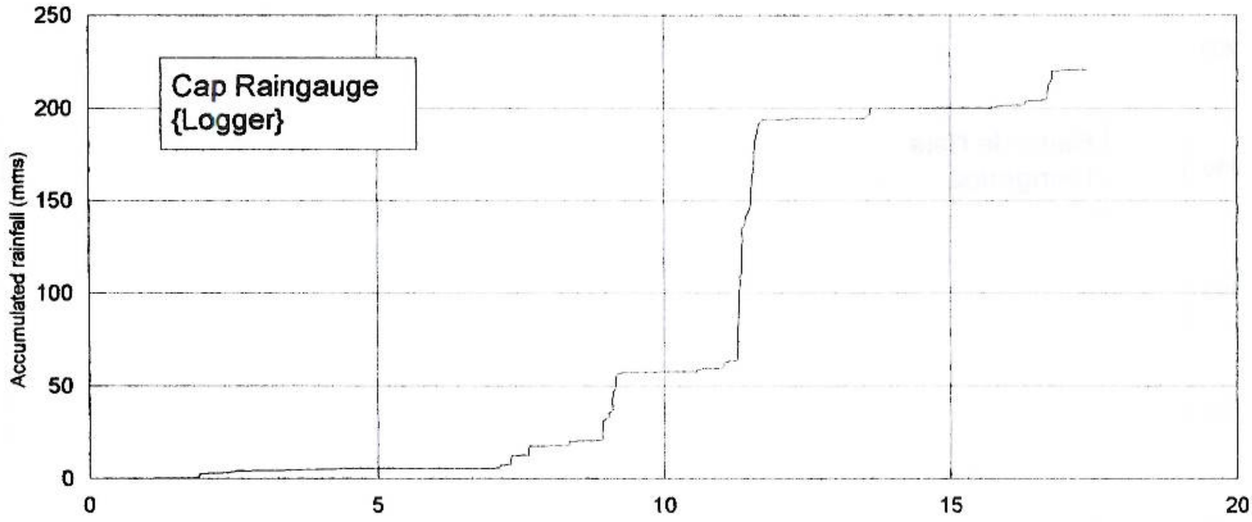
Rainfall of 26th of October 1996 from data loggers

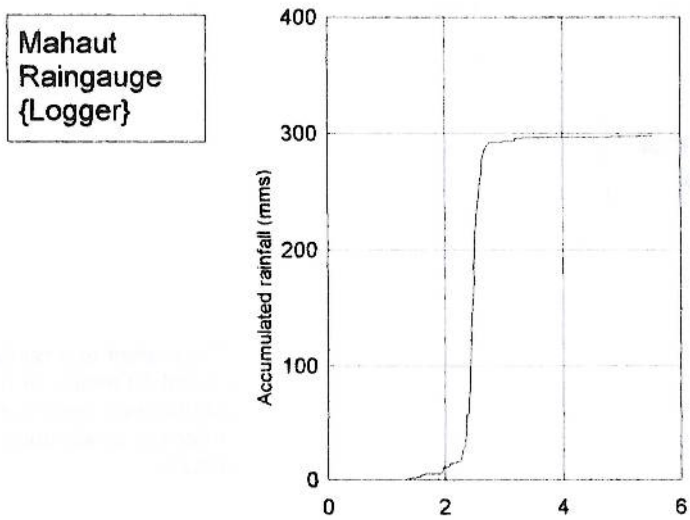






Long Term Accumulated Rainfall leading up to the event of 26th October 1996





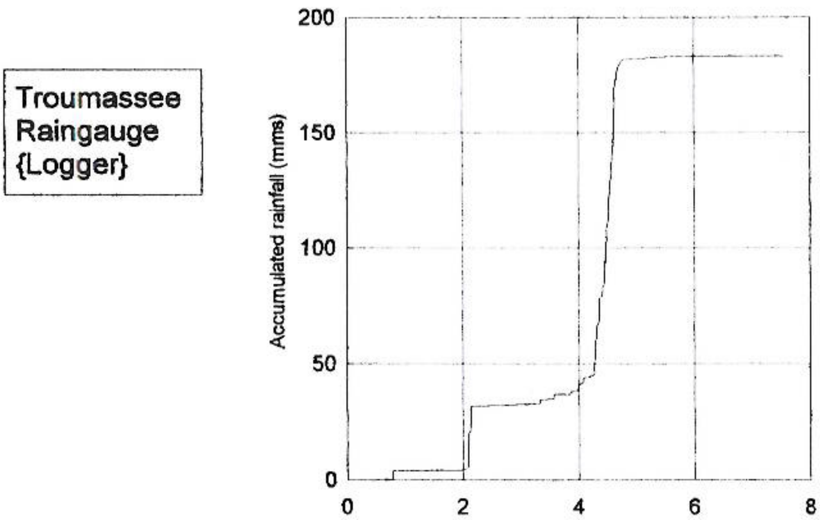
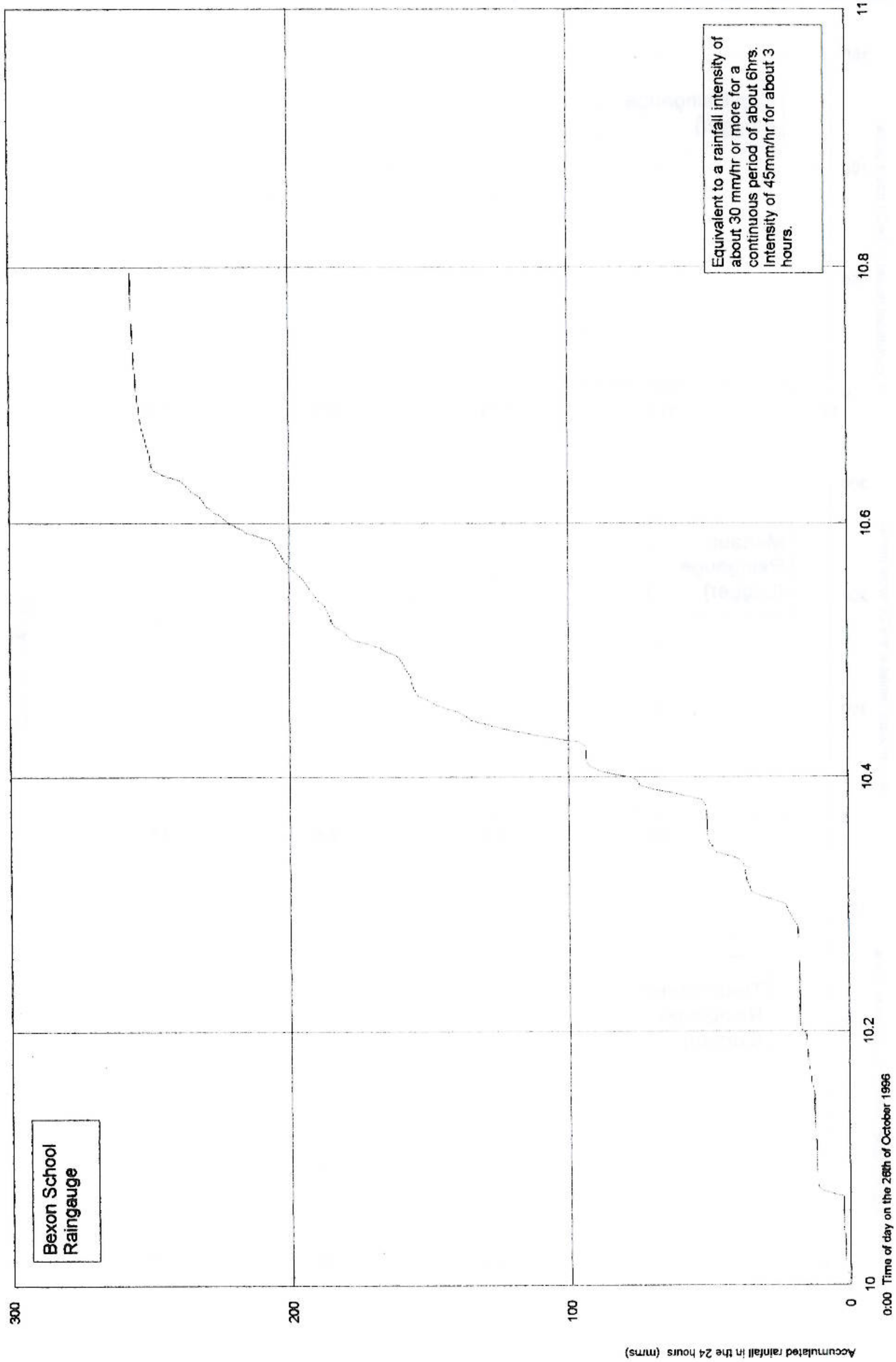
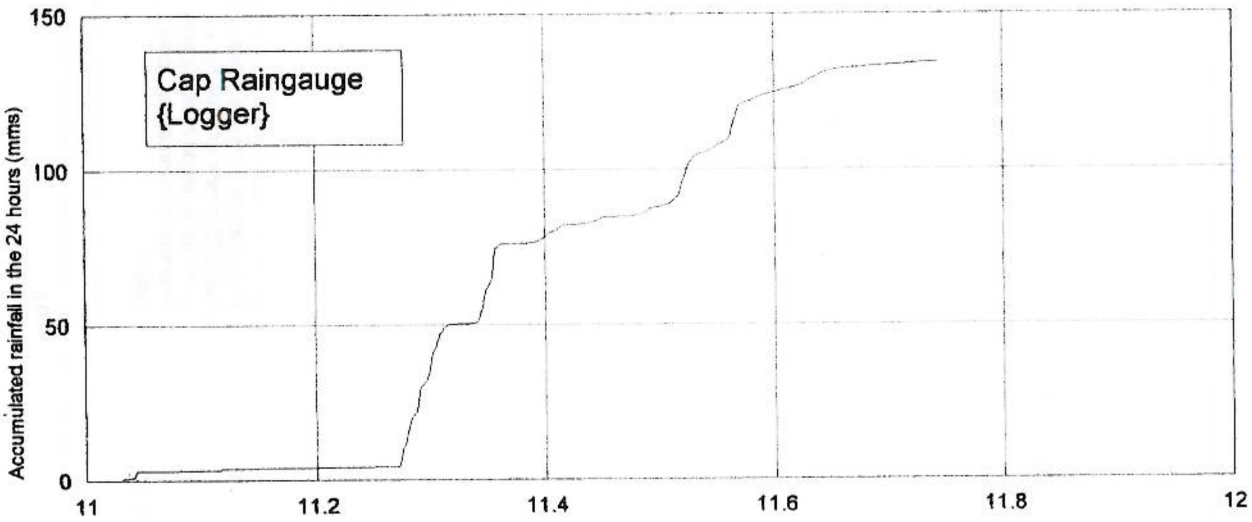


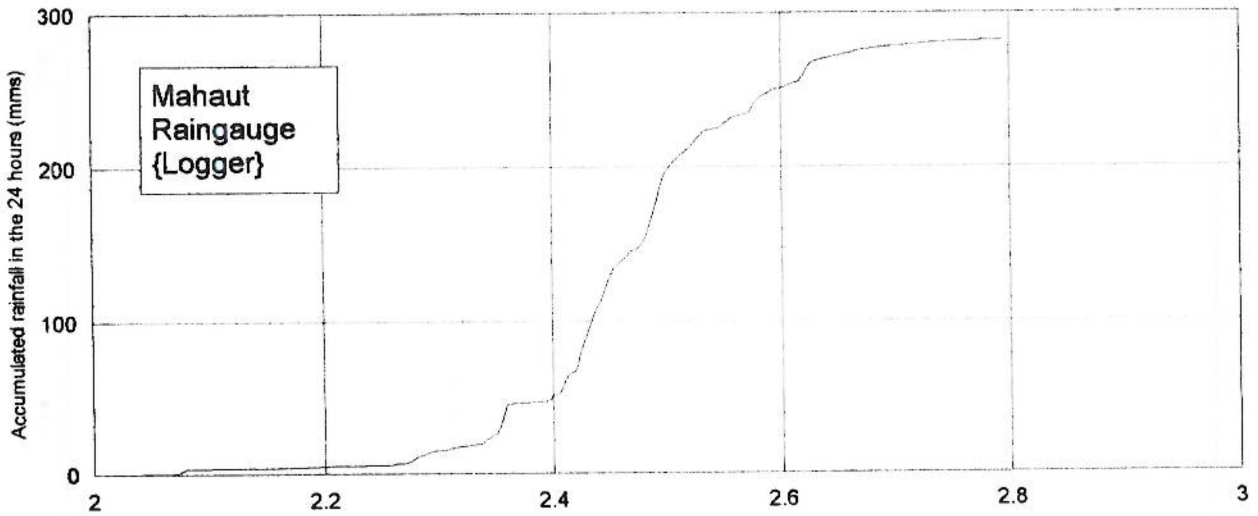
Figure 2.6

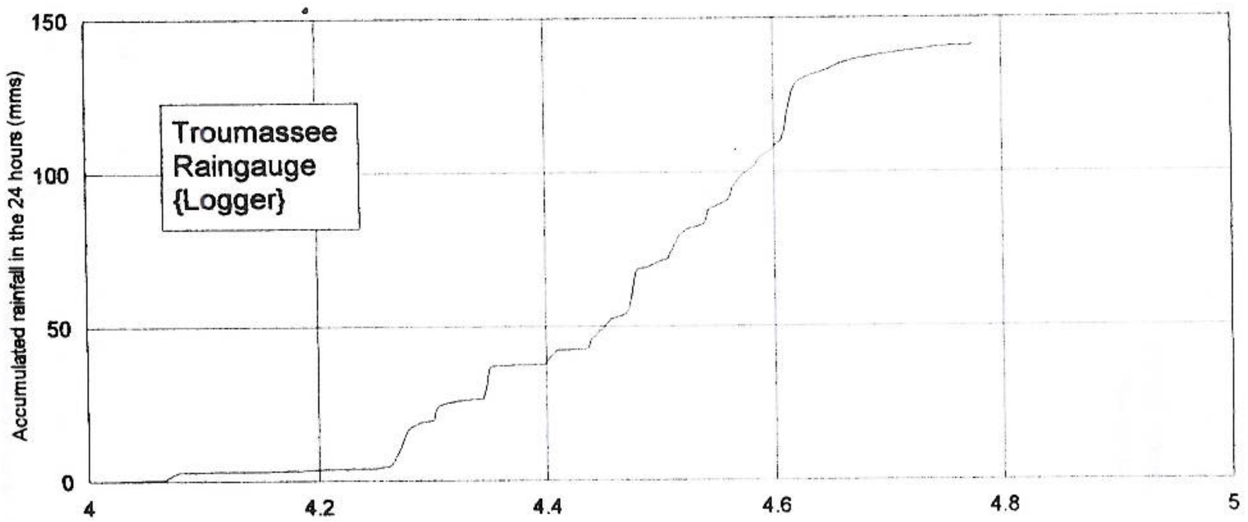


Bexon School
Raingauge
Equivalent to a rainfall intensity of about 30 mm/hr or more for a continuous period of about 6hrs. Intensity of 45mm/hr for about 3 hours.
Accumulated rainfall in the 24 hours (mms)
0
100
200
300
10
10.2
10.4
10.6
10.8
11
0:00 Time of day on the 26th of October 1996

Rainfall Characteristics during and up to the Storm Event of 26th October 1996







Estimated Runoff Characteristics from the Cul De Sac Catchment
October 26/27 1997

Catchment Area (km2)	33.64	Tp or time to peak of hydrograph	2.57 hrs
24 hour rainfall total (mms)	263	Tl or the lag time of the rainfall runofl	0.72 hrs

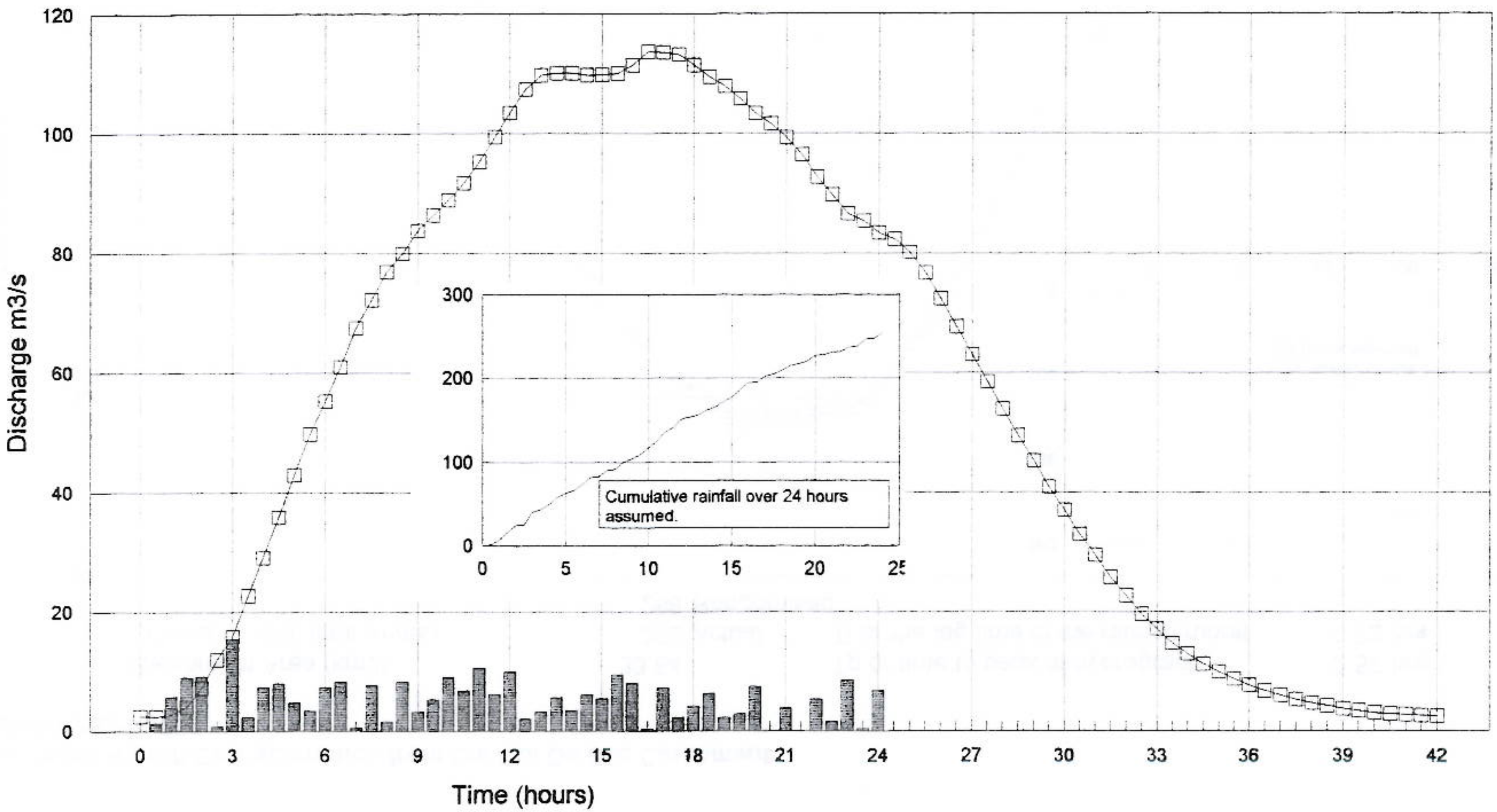


Figure 2.8

Estimated Runoff Characteristics from the Cul De Sac Catchment
October 26/27 1997

Catchment Area (km2)	33.64	Tp or time to peak of hydrograph	2.57 hrs
24 hour rainfall total (mms)	263 Actual	Tl or the lag time of the rainfall runofl	0.72 hrs
	268 Randomised		

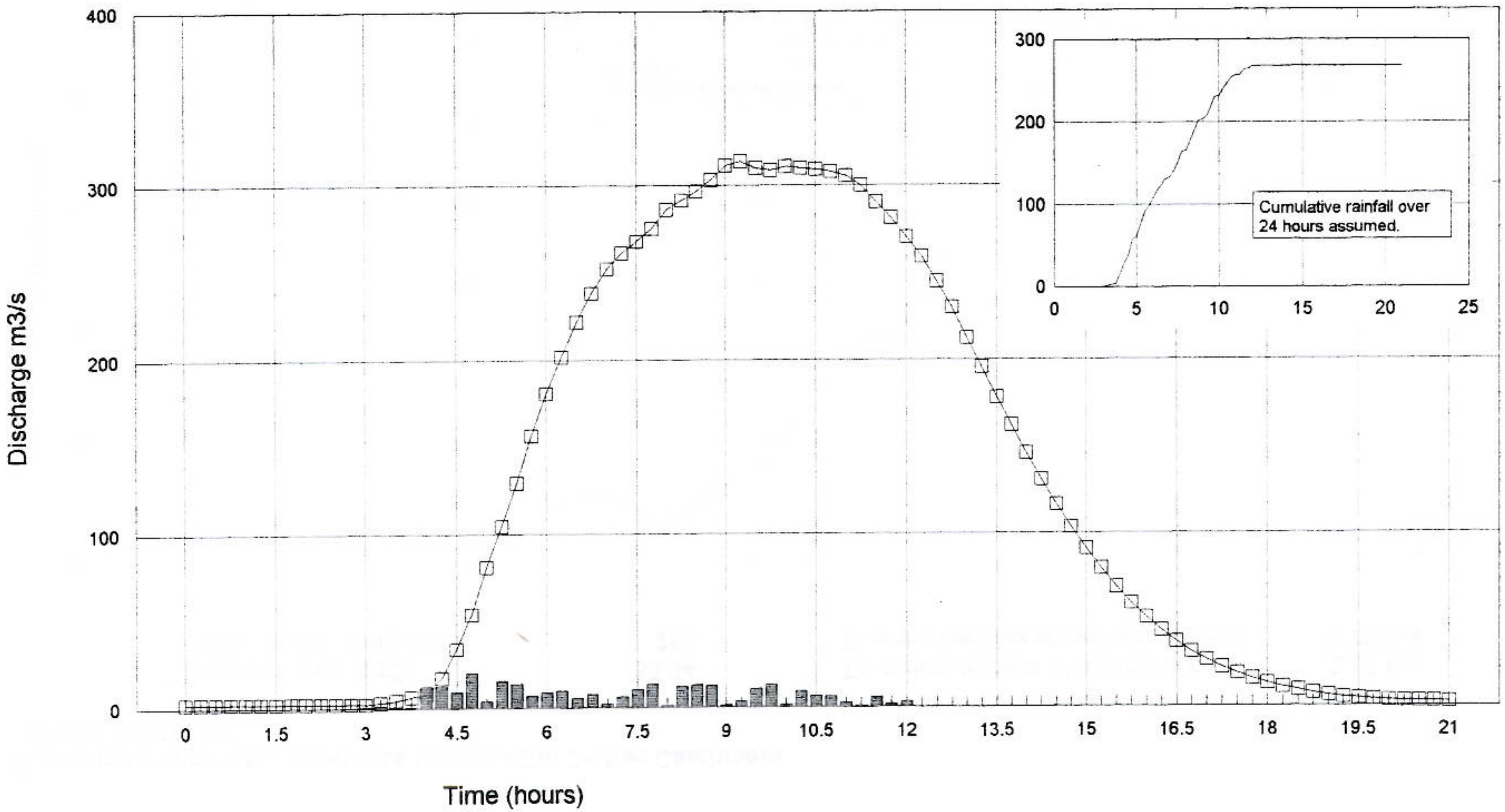


Figure 2.9

Figure 2.10

Estimated Runoff Characteristics from the Cul De Sac Catchment
October 26/27 1997

Catchment Area (km2)	33.64	Tp or time to peak of hydrograph	2.57 hrs
24 hour rainfall total (mms)	263 Actual 257 Randomised	Tl or the lag time of the rainfall runoff	0.72 hrs

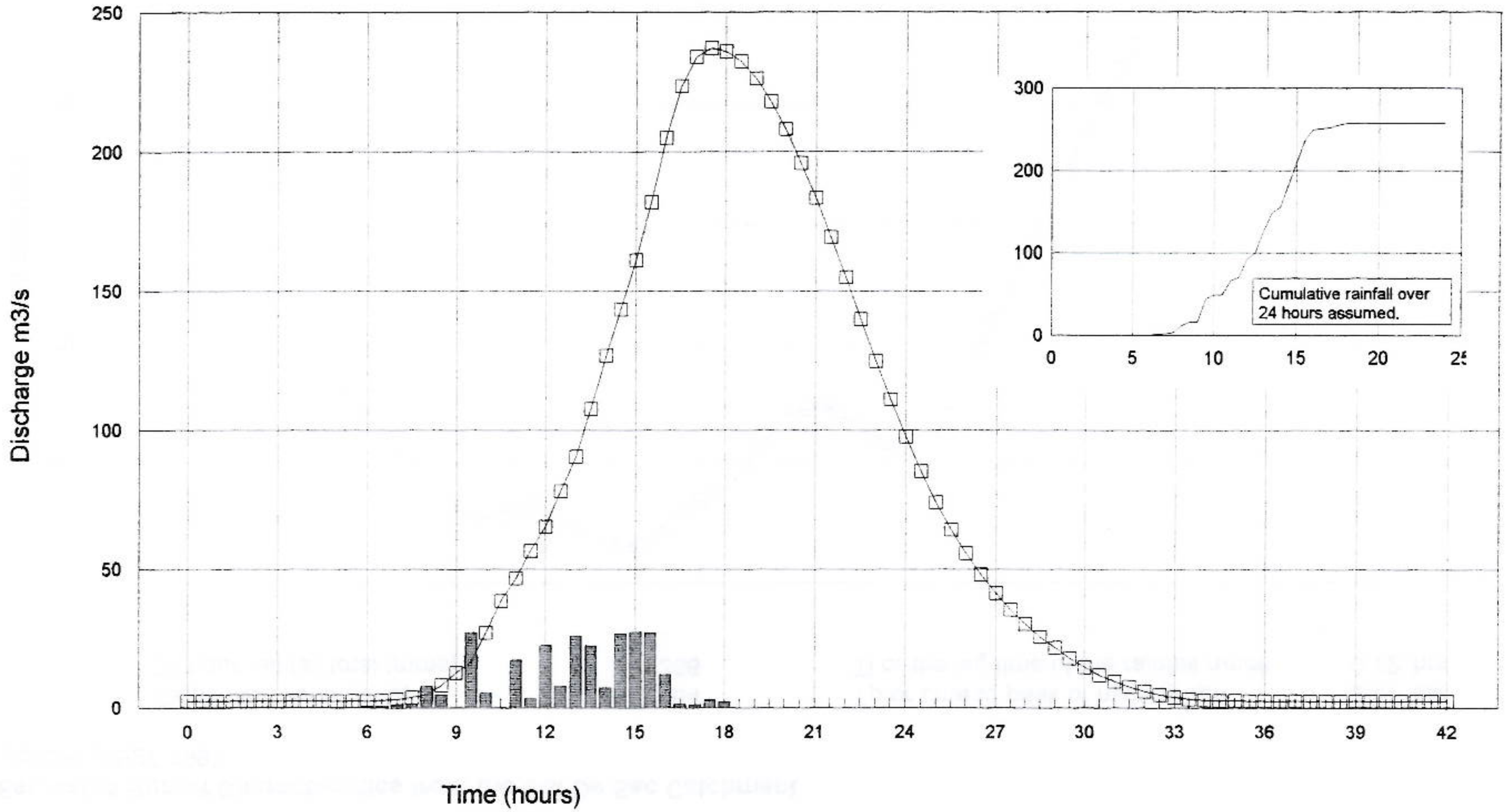
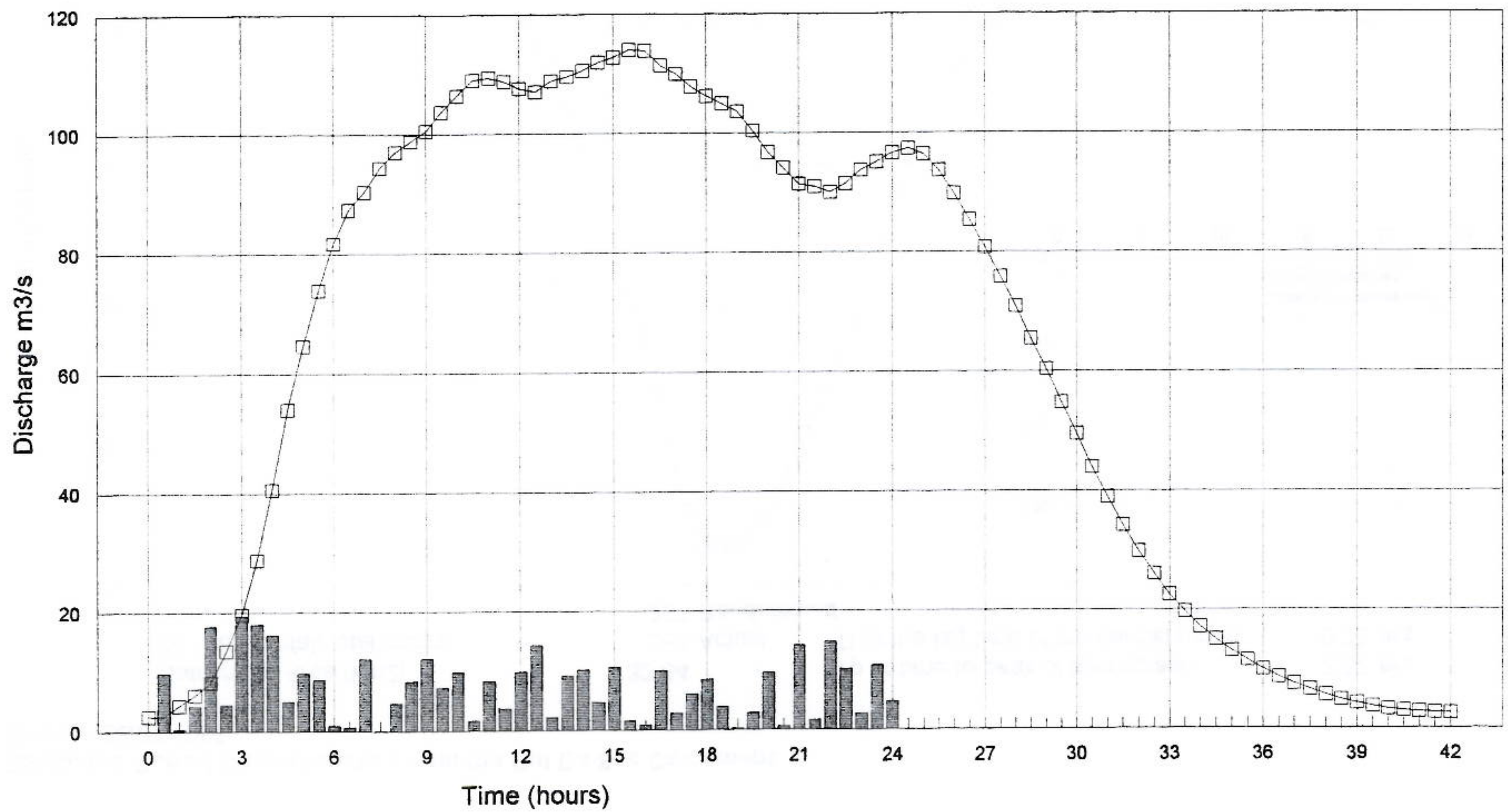


Figure 2.11

Estimated Runoff Characteristics from the Cul De Sac Catchment
October 26/27 1997

Catchment Area (km2)	33.64	Tp or time to peak of hydrograph	2.57 hrs
24 hour rainfall total (mms)	366	Tl or the lag time of the rainfall runofl	0.72 hrs



Estimated Runoff Characteristics from the Cul De Sac Catchment
October 26/27 1997

Catchment Area (km2)	33.64	Tp or time to peak of hydrograph	2.57 hrs
24 hour rainfall total (mms)	366	Tl or the lag time of the rainfall runofl	0.72 hrs

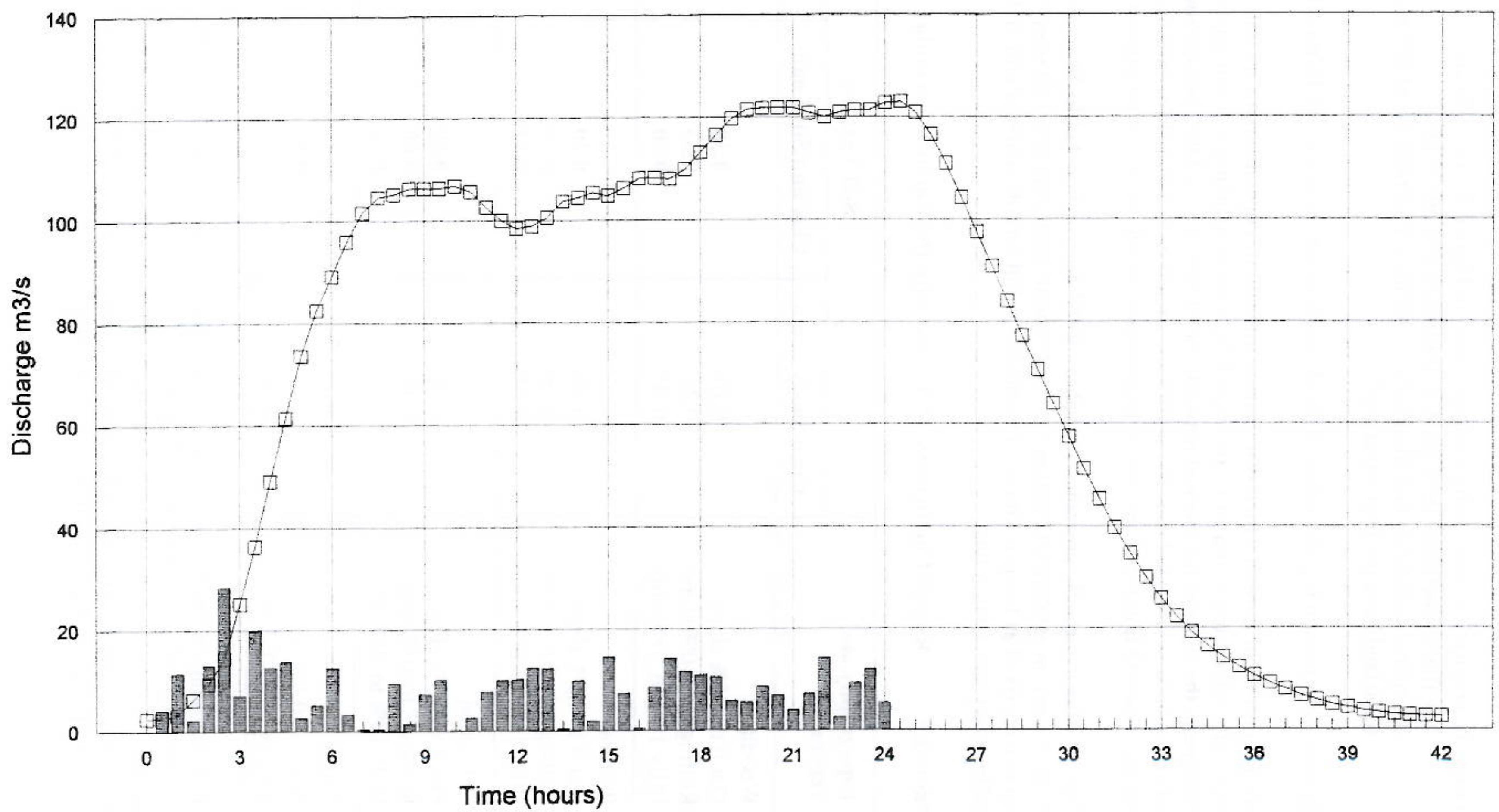


Figure 2.12

An indicative relationship for the estimation of flood flows across the Island is presented in **Figure 2.13**.

It must be emphasised that the information given in **Figure 2.13** is indicative, since, to date

- few flood flows have been gauged or estimated in any manner;
- the spatial variability and frequency of occurrence of rainfalls of different intensities across the island have not been measured.

As more information is gathered on these elements, improvements will be possible to the figure.

The proportion of rainfall which is translated into runoff depends on the assumed value for 'C' and physically relates to catchment factors which include the land use and soil type characteristics of the catchment, the slope of the channel network and of the land, and the configuration of the drainage network. An area weighted run-off coefficients should be calculated for each catchment, hence the values given in **Figure 2.13** are very indicative and should be used with caution.

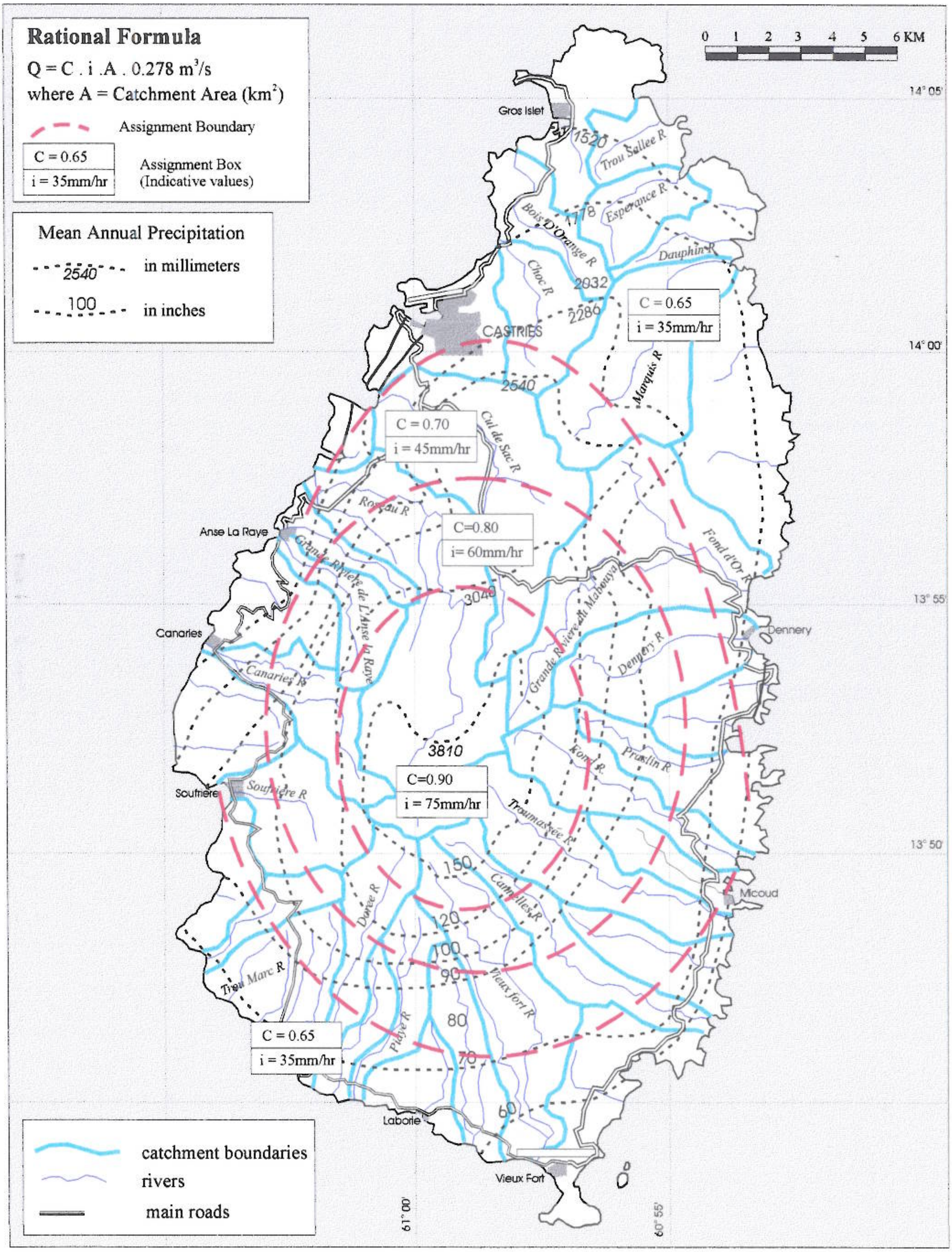
Typical values normally presented for values of 'C' are given in **Table 2.6** and were developed for North American catchments. Values for Caribbean tropical climates with steeply sloping land have not been derived as far as is known. The storm rainfall run-off analyses undertaken above provides a rudimentary first step in this.

Table 2.6 Runoff Coefficients 'C' for use with the Rational Formula

Topography and Vegetation	**Soil Texture**		
	Open Sandy Loam	**Clay and Silt Loam**	Tight Clay
Woodland			
Flat 0 to 0.5% slope	0.10	**0.30**	0.40
Rolling 5 to 10% slope	0.25	**0.35**	0.50
Hilly 10% to 30% slope	0.30	**0.50**	0.60
Pasture			
Flat 0 to 0.5% slope	0.10	**0.30**	0.40
Rolling 5 to 10% slope	0.16	**0.36**	0.55
Hilly 10% to 30% slope	0.22	**0.42**	0.60
Cultivated			
Flat 0 to 0.5% slope	0.30	**0.50**	0.60
Rolling 5 to 10% slope	0.40	**0.60**	0.70
Hilly 10% to 30% slope	0.52	**0.72**	0.82
Urban	30% impervious	50% impervious	70% impervious
Flat 0 to 0.5% slope	0.40	0.55	0.65
Rolling 5 to 10% slope	0.50	0.65	0.80

The topography of the island and the relatively direct flow paths in the drainge network would indicate the need to adopt relatively high run-off coefficients for the estimation of peak flows. This has been indicated by the analysis of the estimated discharges which occurred on October 26th. Allowances should be made for the areas where the slopes are >30% since the method is generally only applicable to slopes less than this and to small watersheds (<1,000 ha or 10 km^2).

ESTIMATION OF INDICATIVE 1:20 YEAR PEAK FLOOD DISCHARGES BY THE RATIONAL FORMULA



Hence, for a specific site, a careful assessment of the above factors should be made in the determination of design flood flows. The issues raised in the following section should also be taken into consideration.

More detailed analyses can be undertaken using the USDA Soil Conservation Service Method which takes many more catchment characteristics into account. Ideally, the catchment size should be less than 1,000 ha.

An analysis of the runoff from the Cul de Sac catchment using the SCS method is presented in **Figures 2.14 and 2.15**. The estimated flood flows are similar to those estimated by the rational method and the basic unit hydrograph approach. A better approach is to subdivide the catchment into smaller units where the catchment characteristics can be better defined. The subcatchments can have more homogeneous characteristics, the flows from each sub-catchment should then be routed through the drainage network to the site in question.

The difference between the hydrographs presented in **Figures 2.14** and **2.15** is the value assigned to the CN value for bananas. In **Figure 2.14** a CN value of '70' has been adopted whilst **Figure 2.15** this has been reduced to '60' to estimate the potential impact on peak flood levels. The indication is a reduction in flood peak of about 10%. The different CN values are presented to illustrate the possible effects of improved farm drainage and soil conservation measures. The area assigned to bananas in the estimate is relatively high to enable the scale of the impact on a flood peak to be estimated. Although the impact on flood peak is not large, it will have a greater impact on the reduction in sediment carrying capacity.

2.3 Experience from TSD and the event of October 26th 1996

Various short reports and notes were produced in the aftermath of TSD. The conclusions presented in these reports are worth recording since they have relevance both to the development of the Flood Plain Hazard Zoning Maps as well as the development of Watershed and Environmental management Plans.

A report was produced shortly after TSD by H.V Rodriguez (November 30th 1994), 'Water Resources Management and Development in St Lucia - Post Tropical Storm Debbie'. The contributing factors which resulted in damage were stated to be:

- *The soil was practically saturated by the precipitation of the days preceding the storm event.*
- *The high rainfall during the storm, nearly 300 m(m) in 24 hours and particularly the high intensities reaching 100mm/hr.*
- *The relative size and gradient of the watershed, which given their 'smallness' and steepness mean that the runoff from rainfall reaches (and of a high percentage) at the lower levels of the river basin quite quickly, resulting in quick accumulation of runoff.*
- *Inadequate capacity of the civil works, such as bridges, on river courses.*
- *The inadequacy of river channel alignment and cross sectional area, since at numerous sections and along river stretches huge quantities of sedimentation and debris were deposited as a result of accelerated land erosion on cultivated areas of steep slopes with no appropriate soil conservation measures.*
- *The cultivation of banana on riverbanks and side slopes which provides very little protection and only serve as an obstacle to river flow.*
- *Lack of periodic river channel maintenance.*
- *The absence of control structures in the upper reaches of the river basin.*

Figure 2.14

US SCS Estimated Flood Disharges in the Cul de Sac River : Existing

US: SCS Runoff Estimates - Cul de Sac Storm Runoff

>	US Soil Group			C			
	Moderately high runoff potential						
>	Antecedent Moisture Conditions			II			
	Catchment Characteristics	CN	Area(ha)	%	CN'		
>	Low forest scrub	60	500	13%	7.5		
>	Tropical rainforest	65	1000	25%	16.3		
>	Coconuts	65	600	15%	9.8		
>	Bananas	70	1700	43%	29.8		
>	Fallow	85	100	3%	2.1		
>	Urban	90	100	3%	2.3		
			4000	ha	67.6		
		A	40	km2			
	Time of concentration:	Tc		min	248	4.1	hr
>	Maximum length of flow		8000	m			
>	Watershed gradient		0.0014	m/m			
	Time to peak	Tp		min	179	3.0	hr
>	Duration of rainfall excess [hourly step]	D	60	min			
	Time of recession	Tr		min	298	5.0	hr
	Hydrograph base time	Tb		min	477	8.0	hr
	Potential difference Rf-RO	S		mm	122		
>	Rainfall Intensity considered	Ri	60	mm/hr			
>	Critical storm duration	Sd	4	hrs			
	Storm Rainfall Depth	I		mm	240		
	Depth of surface runoff	Q		mm	8.09		

Time Step	Rainfall event (mms/hr)	Cum Rf mm	RO mm	Incr mm	Qp m3/s	Qp x incr
1	60	60	8.1	8.09	2.79	22.6
2	60	120	42.1	34	2.79	95.1
3	60	180	87.4	45.3	2.79	126.5
4	60	240	137.9	50.5	2.79	141.1
5	15	255	151.1	13.1	2.79	36.7
6	5	260	155.5	4.41	2.79	12.3
7	5	265	159.9	4.43	2.79	12.4

Time from start (hrs)	Time to peak (hrs)	Time to end (hrs)
0	3.0	8.0
1	4.0	9.0
2	5.0	10.0
3	6.0	11.0
4	7.0	12.0
5	8.0	13.0
6	9.0	14.0

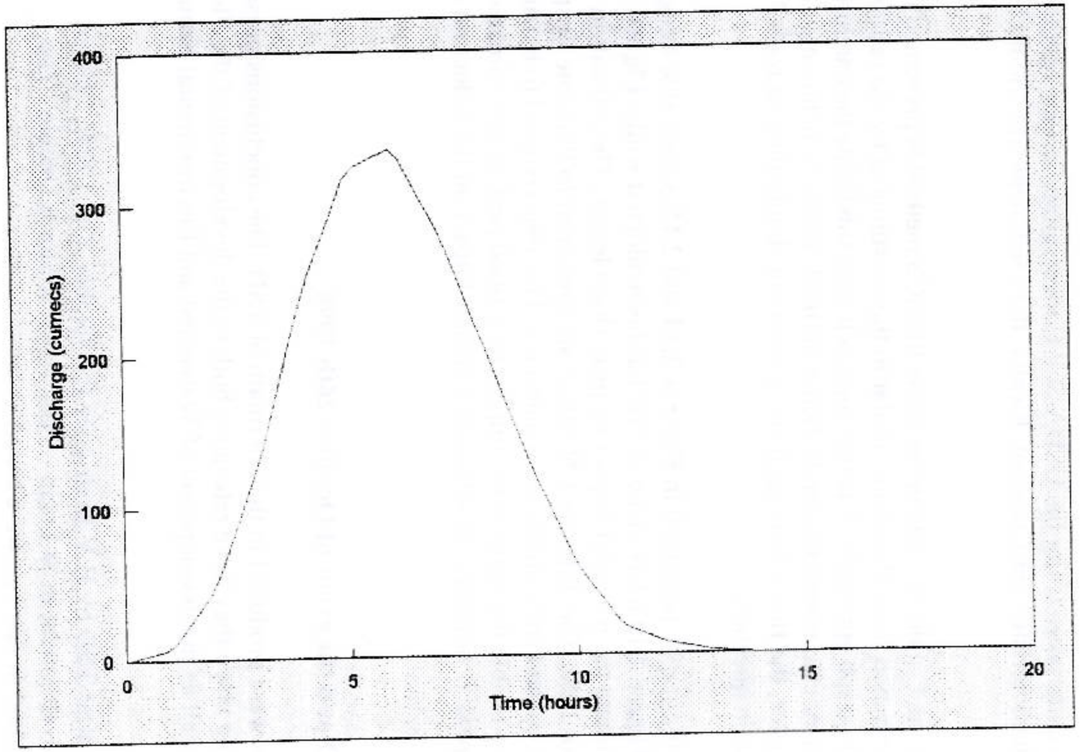


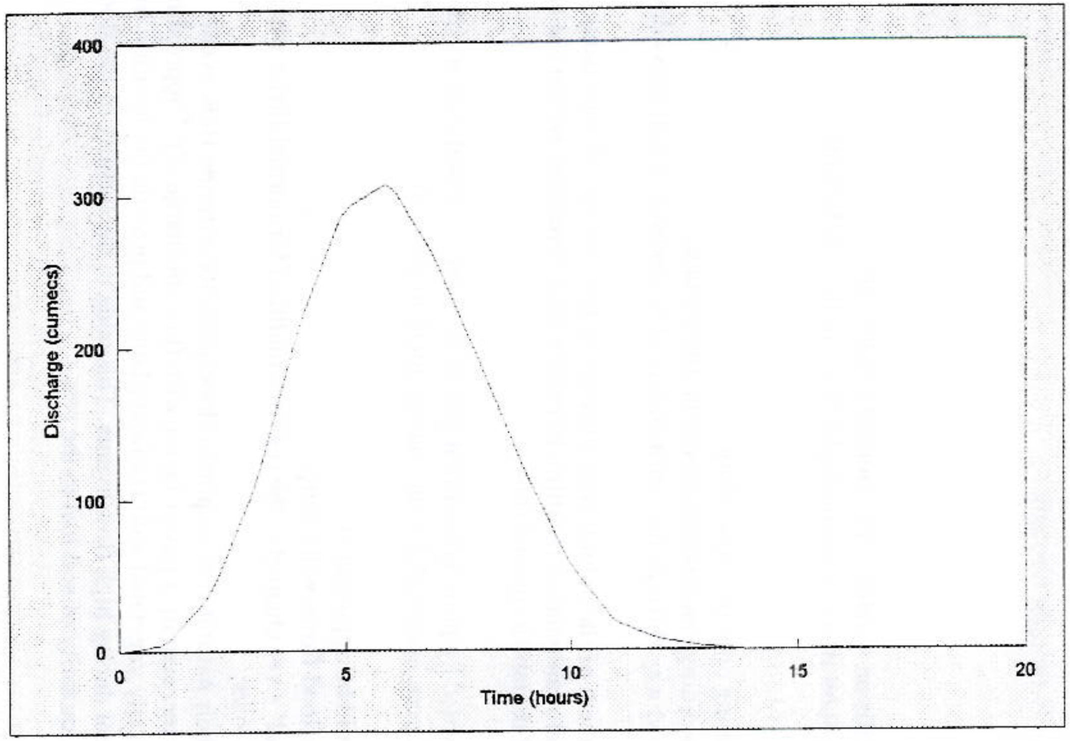
Figure 2.15

US SCS Estimated Flood Disharges in the Cul de Sac River : Modified Banana Cultivation

US: SCS Runoff Estimates - Cul de Sac Storm Runoff

>	US Soil Group		C				
	Moderately high runoff potential						
>	Antecedent Moisture Conditions		II				
	Catchment Characteristics						
		CN	Area(ha)	%	CN'		
>	Low forest scrub	60	500	13%	7.5		
>	Tropical rainforest	65	1000	25%	16.3		
>	Coconuts	65	600	15%	9.8		
>	Bananas	60	1700	43%	25.5		
>	Fallow	85	100	3%	2.1		
>	Urban	90	100	3%	2.3		
			4000 ha		63.4		
		A	40 km2				
	Time of concentration:	Tc	min		248	4.1 hr	
>	Maximum length of flow		8000 m				
>	Watershed gradient		0.0014 m/m				
	Time to peak	Tp	min		179	3.0 hr	
>	Duration of rainfall excess [hourly step]	D	60 min				
	Time of recession	Tr	min		298	5.0 hr	
	Hydrograph base time	Tb	min		477	8.0 hr	
	Potential difference Rf-RO	S	mm		147		
>	Rainfall Intensity considered	Ri	60 mm/hr				
>	Critical storm duration	Sd	4 hrs				
	Storm Rainfall Depth	I	mm		240		
	Depth of surface runoff	Q	mm		5.29		

Time Step	Rainfall event (mms/hr)	Cum Rf mm	RO mm	Incr mm	Qp m3/s	Qp x incr
1	60	60	5.3	5.29	2.79	14.8
2	60	120	34.6	29.3	2.79	81.9
3	60	180	76.3	41.7	2.79	116.5
4	60	240	124.1	47.8	2.79	133.6
5	15	255	136.7	12.6	2.79	35.1
6	5	260	140.9	4.23	2.79	11.8
7	5	265	145.2	4.25	2.79	11.9



Modified to show impact of change in banana cultivation practice on flood peak
SCS CN number changed from 0.70 to 0.60
[This is considered to be a significant change on what is considered to be a high gross area planted]

Time from start (hrs)	Time to peak (hrs)	Time to end (hrs)
0	3.0	8.0
1	4.0	9.0
2	5.0	10.0
3	6.0	11.0
4	7.0	12.0
5	8.0	13.0
6	9.0	14.0

The nature of flooding, the causes, the impacts and damage characteristics all have to be understood in an integrated environment. Similarly, any 'reaction' to flood events in terms of flood protection and control needs to be carefully thought through.

Factors which relate are:

Cause of flood flows:

- high intensity rainfalls on small steeply sloping catchments;
- possible impact on flood flows of changing land use in the catchments.

Cause of flood damage:

- agriculture encroaching onto the flood plain;
- infrastructure and buildings encroaching onto the flood plain;
- throttling of the flood way through the construction of 'economic' small cross drainage structures;
- imprudent re-alignment of the natural river channel or resectioning of the channel;
- lack of river channel maintenance resulting in reduce flow capacities within the channel section and potential destabilisation of flow;

The above situation is aggravated by poor agricultural practices in terms of soil conservation, poor farm waste management and poor household waste management in general.

Natural processes which should be appreciated:

- the inevitability that flood flows will occur;
- the fact that a 'normal' river channel is the regime condition for normal flows which also accommodates low flows;
- almost all rivers in their natural state require a flood plain for extreme flow events;
- sediment discharges increase by a power factor with flow discharge ($Q^{2.5}$ approximately);
- flood plains are naturally vegetated with resilient plants and provide the location for the deposition of sediment during high flow events. This adds to the fertility of the flood plain and helps reduce the quantity of soil lost to the sea.

Human intervention factors and their impact:

- poor hydrological, hydraulic and engineering design can both throttle river flows and destabilise rivers during flood events;
- changes in land use in the upper catchments can increase the erosivity conditions increasing sediment flows in the river and out into the coastal areas;
- changes in land use in the upper catchments can increase the runoff rate for a particular rainfall event thus aggravating flooding downstream;
- cultivation of bananas in the upper catchment and in the lower catchment near to the main channel of a river increases the risk of bananas being damaged and washed away. When washed away they increase the debris flow in the river system which can block cross drainage structures (road bridges, culverts etc) downstream. They can also accumulated against trees which have fallen across the river channel through undercutting or storm winds;
- the existence of bananas and deep drainage ditches over most of the flood plain increases the frictional resistance of the flood plain over what it would naturally be. This increased roughness impairs flood plain flow increasing water levels and hence flood extent and damage extent. The increased water level can increase the pressure head against a structure (possibly already clogged with debris) causing it to fail/ collapse.

The flood hazard level of a particular location will therefore depend upon external factors, not just rainfall intensity (recurrence frequency etc) and topographic characteristics. Factors which could be addressed through prudent catchment management include:

- controlling upper catchment development and land use practices;
- controlling and undertaking proper design of cross drainage structures;
- controlling and where possible preventing infrastructure and building development on the flood plain if negative impacts can be proven;
- controlling agricultural use of the flood plain, reducing the encroachment towards the river channel and making sure that drainage systems are comparable with flood plain flooding;
- most rivers possess active and passive flood plain areas, these need to be identified in the control process;
- maintaining river channels and identifying and removing potential vegetation or other material which could fall or be swept into a channel during a storm event;
- establishment of a river berm both for increased conveyance capacity, improved bank stability following rapid drawdown of river water levels at the end of a flood and to assist in providing at least a small buffer zone with no banana cultivation;
- maintaining cross drainage structures for a clear flow way;
- undertaking river engineering works only where essential and where economically justified i.e. to protect major infrastructure. Where modifications to a channel is undertaken, careful consideration needs to be given to ecological issues.

2.4 Flood Plain Hazard Zoning Mapping

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 the entry of fallen trees or small embankment slips into the channel.

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 general land levels in and around the flood plain.

Topographic maps are available for most of the river basins but have too course a topographic detail (contour information) to provide the desired base map. No alterative exists to the 1:10,000 maps hence these have been used as the base map for the current project. More detailed topographic surveys are recommended in order to refine the mapping.

Some reports have estimated flood flows in the river network of the different river basins. The 1984 Report by Hunting Technical Services have to date provided the main source of such information. The Phase 1 Final Report, Section 5.2.5 indicates that the June 1984 Report was the prime 'basis for flood flows in the design process. The report gives estimates of the 5 year return period design peak flood flows for the Roseau .... other catchments were estimated by reviewing their relative catchment areas and characteristics........' (for the Phase 1 works).

More detailed analysis has recently been carried out in relation to flood flows in the Cul-de Sac River (IoH) which provides an alternative estimation. This and other reports have been reviewed.

There is clearly a need to review this rainfall runoff relationship since it is important in the estimation of river training work requirements, cross drainage structure design and sediment run-off estimates. The correct perception of probable recurrence interval of floods of different degrees of severity needs to be established. Some improved approaches are presnted in this report.

Limited water level information exists. Some river basins being without any form of river gauging. 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.

A detailed approach to the issue of flood plain hazard mapping is presented in **Chapter 3**.

2.5 Flood hazard warning

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 sever 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. Weather radar has advanced considerably over recent years with incresing computer power and decreasing prices. Modern doppler radar systems and dual polarisation systems provide improved images and the ability to place rainfall intensities into many bands however one of the largest problems is the calibration of the system. {Note, systems in the London Area work to 208 levels of rainfall intensity on a 2km grid resolution}. In the terrain of St Lucia and with the changing weather systems calibration could be difficult. However, the introduction of the new raingauges provides a relatively good station density. One problem with radar systems is both their capital cost and recurrent costs. A station might cost in the order of £700,000 with recurrent costs of £20,000. Cheaper systems are believed to exist and indicative costs will be obtained in the coming months. Such systems are beyond the scope of the current project.

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 potential linkage of the newly installed rainfall data loggers through the WASA SCADA system will be investigated. A direct link to the NMS and AESD might be possible.

Flood Hazard Warning needs to be most effective where the danger of flooding is more severe. However, planning regulations should be such that properties and infrastructure are kept out of flood hazard (and land slide hazard zones) wherever possible. Section 3.4 of the *Manual for Developers* prepared by the Development Control Authority states that 'If an area possesses characteristics and is located in an area where life and property may be in constant threat if the area is developed, a Development Order may be issued to prevent development of the area'. This course of action should be implemented by the Planning Authority, not only to prevent individuals putting themselves at risk but also to avoid flood plain encroachment.

2.6 Surveys to Support Flood Hazard Mapping

In order to facilitate the production of flood hazard mapping, it is important that the follwoing surveys are undertaken during the coming months:

i. Topographic surveys across the flood plains on the Cul de Sac, Roseau and Mabouya valleys, picking up the bench mark levels put in place during the Phase 1 works. Cross sections would ideally be provided at least at 1km intervals up the valleys where the flood plains are evident. Priority should be given to the Cul de Sac and Dennery Flood plain areas since these have been selected as the Pilot Catchments and will be investigated in more detail. The Dennery Flood plain is defined as the main town area, taken to be defined by a contour equivalent to the design bank top level of the newly constructed river embankment. {It is understood that these surveys will be undertaken through the Project funds and managed by engineers of the MWC&T}.

ii. Socio-economic surveys of the flood prone areas of the Cul de Sac and Dennery Watersheds to elicit information in relation to the impact of flooding on the communities, the economic losses incurred and the current preparation (flood proofing?) and response of individuals, families and communities to flooding. This needs to be evaluated in the context of different social groups, affluence levels, and property and crop ownership in the context of the flood plain. The Disaster Preparedness Organisation in each area would also be addressed on this issue.

Chapter 3

Flood Reporting and Floodplain Mapping

3.1 Introduction

A vital tool in comprehensive and reliable hydrological and flood analysis is the study of historic events. Data collected from such events can be used in the analysis of catchment response to rainfall and therefore the development and calibration of catchment (rainfall-runoff) and hydraulic models from which design flows and water levels may be derived. Further uses of such study include;

- identification of land, property and infrastructure at risk from flooding, i.e. flood risk areas, and consequently the identification of areas that may benefit from flood defence schemes,
- assessment of the discharge capacity of existing infrastructure and the identification of locations where the channel is throttled (e.g. an undersized bridge) which results in blockage or raised upstream water levels and hence avoidable flooding,
- evaluation of the performance of existing flood defence/alleviation schemes and the river maintenance program,
- provision of data useful in the engineering design of future infrastructure and the design and determination of the economic viability of proposed schemes.

The collection of data following a significant flood event should be undertaken in a systematic manner such that no potentially useful information is missed. The data gathered, the results of the analysis undertaken and a description of the flooding should then be presented in a clear and usable format that provides an easily digestible and comprehensive report of the flood event for future reference.

The definition of a significant flood event, and therefore one for which a full report should be produced, is subjective. Following any flooding brief analysis should be undertaken of the damage caused and the need for channel clearance or repair. This preliminary analysis should provide an indication of the extent of the damage, the significance of the event and therefore whether a full flood report is required. It is anticipated that flood events justifying a full report are likely to occur approximately every five years although lesser reports concentrating on specific locations (particularly urban areas) are likely to be required more frequently.

Floodplain maps indicate either the area flooded during a historic event or the areas considered likely to flood during an event of a given return period. They are useful in determining areas at risk from flooding as well as a variety of other associated uses such as development control and flood defence analysis. Flooded area maps should be produced in association with a flood report.

This document outlines a methodology for collecting relevant flood data following a significant event and proposes a standardised format for a flood report. It then outlines a methodology for floodplain mapping.

3.2 Flood Data Collection

3.2.1 Hydrometeorological Data

Hydrometeorological data, rainfall and river flow in particular, are essential for a detailed analysis of a significant flood event. Such data will enable the development and calibration of catchment and hydraulic models and will enable the hydrologist to assess the relative significance (or return period) of the event.

The general mechanisms for the collection of hydrological data within St. Lucia are already established. The Agricultural Engineering Services Division (AESD) under the Ministry of Agriculture, Lands, Fisheries and Forestry (MoALFF) is responsible for the data gathering from most of the existing autographic and daily total raingauges and the same department will also undertake the responsibility of data collection from the flow gauging network that is currently being designed and installed.

The importance should be stressed of autographic or continuous readings of rainfall and river flow given the short lag time between rainfall and runoff and the resulting flashy nature of the catchments on the island. It is therefore essential that a program of regular inspection and maintenance of such hydrometric equipment is introduced.

Additional hydrological information (e.g. rainfall at Hewanorra and Vigie airports and flow measurements at water supply off-takes) should be available from the National Meteorological Services Division (NMSD) under the Ministry of Communications, Works and Transport (MoCWT) and from WASA respectively. This information should also be collected as a matter of course by AESD from relevant counterpart staff member following a significant event.

AESD also currently collect and publish climatological data (Agromet Bulletins). This may be of use in the determination of the condition of the soil prior to the event.

3.2.2 Flood Extents, Depths and Damage

The extents and depths of flooding and the damage caused during a measured/gauged event constitute extremely useful information when relating the results of a mathematical model to physical ground conditions, in the identification of flood risk areas and in post-flood evaluation of remedial/defence measures required. This information is also of prime importance in delineating floodplain maps for the event.

The data collection for this set of information is best undertaken through site inspections by trained engineering/hydrological staff (either from AESD or MoCWT). The concept of the site visit is to gather as much physical evidence of the flood extents, depths and damage caused as possible. This can be done using a number of methods.

- Discussions with local residents and workers who were present at a flood location during the event can furnish the engineer with a great deal of information concerning;
    - flood extents and depths,
    - the timing of the peak of the flood and the rate of the rise in water level,
    - the volume of debris carried by the floodwaters,
    - the duration of flooding (e.g. period during which a road was impassable),
    - blockage by debris of bridges, narrow channel sections, etc,
    - damage caused.

Flood depths or extents indicated by local people should be photographed and their location and height above ground level noted (see Appendix A). The levels should be surveyed to national datum either during the site visit or whenever possible afterwards as staff resources become available. This also applies to peak water levels identified using the other methods given below.

- Inspection of trash marks. The rivers of St. Lucia carry a large volume of debris when in flood (e.g. blue banana bags), some of which is left on the ground or caught on trees, rails, poles, etc. as the flood waters recede. The stranded debris and flattened vegetation are good indicators of the peak flood water level. Sediment deposition is another indicator of flooded areas.

- If the site visit may be *safely* undertaken during the flood event then photographs of flood extents may be taken showing flood levels and extents. If this is not the case, as is likely, then enquiries may be made as to whether any local residents took photographs during the event which may be copied and returned.

The inspection should be undertaken as soon after the flood event as staff resources and personal safety permit. This will maximise the likelihood that marks left by the flood are still visible and have not been moved. The flood will also be fresh in peoples' minds and hence reports of the flooding derived from conversations with locals are more likely to be accurate.

Appendix A contains a sample Flood Report Site Form (and Additional Information Sheet) along with guidance notes on the method of use. The form should assist the inspecting engineer/technician in the undertaking of a comprehensive site inspection and provides a standardised format for noting observations and flood details. It is recommended that a separate form is completed for each flooding location visited. The forms may then be used as a reference for compiling the flood report and should either be included as an appendix to the report or be filed in a readily accessible location.
A sample Flood Event Questionnaire Form is also provided in Appendix A. These may be circulated to local authorities and other institutions with an interest in the effects and prevention of flooding either following an event or once the flood reporting mechanisms have been established such that the authorities and institutions will complete and submit the forms as a matter of course following flooding within their area of concern.

The questionnaire form is intended to *supplement* the information collected during the site inspections following major events and should *not* be used as an alternative as they will provide a significantly reduced level of information. They may however be used to report localised flooding during minor events as a means of identifying blockages, particular problem locations at structures or along a river channel and the need for river clearance and maintenance.

3.3 Flood Report Format

3.3.1 Introduction

The introduction to the flood report should summarise the main findings of the report, i.e. rainfall distribution, totals and peak intensities at key gauges, a brief description of the flooded extents and the damage caused, peak flows and levels at key points, the estimated return period of the event, the need for channel clearance or repair, the performance of, or need for, flood defences, etc.

3.3.2 Rainfall Analysis

All rainfall data collected pertaining to the event and technical details of the rainfall analysis should be included within the report as an appendix. This is so that the report is a complete and stand-alone documentation of the flood from which all relevant details may be derived during future reference.

The rainfall analysis section within the core of the report should provide the reader with an overview of the nature and significance of the rainfall event. The section should contain the following information where available;

- general meteorological details of the event, e.g. the nature of the storm (cyclonic, orographic, etc.),
- details of flood warnings issued before or during the event,
- anteceedant rainfall depths and catchment moisture content prior to the event,
- a table of the total event rainfall depths at all operative gauges,
- details of the peak rainfall intensities with estimates of the event return period at various locations for a range of durations,
- an analysis of the temporal and spatial variability including an isohyetal map of the event rainfall distribution across the country (if possible).

3.3.3 Flood Extents

The information relating to flooded areas collected during the site inspections should be reviewed and then summarised within the core section of the report. A description of the flooding of agricultural land (including estimates of areas) and details of urban flooding (depths and levels at given locations and names of flooded roads/properties) should be given providing the reader with an overview of the extent of both rural and urban flooding. This may be given on a catchment by catchment basis.

Flood maps are a simple means of conveying large amounts of information. They can however involve considerable work and therefore should only be produced where this is justifiable according to:

- the level of information available,
- the significance of the event,
- the location concerned.

With respect to the first of the criteria, a flood map should only be produced where the extents may be drawn with an acceptable level of confidence. Incorrect delineation of the flood extents is not desirable as it may result in over/under design of flood defences, unnecessary prevention of development or permission being granted for unprotected development in an area that is at risk from flooding.

Criteria two and three are inter-related. The flood extents for any area need not be mapped for minor events involving localised ponding adjacent to the river channels. Similarly, flooding across agricultural land need not be mapped unless the flood event is of particular significance (return period of 10 - 50 years or more), the extents are unprecedented (e.g., due to blockage by flood debris as occurred during TSD), or unless there is a specific reason for delineating extents for given lower order return periods. However, urban flooding for middle as well as higher order events (return period of approximately 5 years or more) should be mapped. This is to provide information to enable benefit-cost analysis to be carried out for flood defence schemes which requires flood extents and depths over a range of return periods.

General flood maps of agricultural areas may be produced at a scale of 1:10 000 while urban flooding should be mapped at a scale no greater than 1:2 500. The maps may be folded (or reduced) and included in the report where a limited number have been produced. Masters should also be referenced and filed.

3.3.4 Flood Damage

Flood damage identified during and subsequent to the site inspections should be outlined within this section of the report. Particular points to note include;

- description and initial cost estimate of damage to property, infrastructure and agriculture,
- damage to the river channels, e.g. bank failure and erosion,
- performance of and damage to flood defence schemes,
- damage caused by the sediment load including river siltation and blockage and damage to the marine environment,
- location, scale and effect of landslips (not always directly caused by flooding but likely to occur during flood events and therefore should be included).

A table listing damaged and destroyed properties, roads and bridges is recommended for inclusion either within the core of the report or as an appendix.

It should be noted that although an initial cost estimate of the resultant damage may be made, this should not involve significant work as the estimate will invariably be adjusted as further detail and information comes to light.

3.3.5 Hydrological Analysis

For the same reasons given in Section 3.2 of this report, all relevant flow data and technical details of the hydrological analysis should be included within the flood report as an appendix. The hydrological section within the core of the report should provide the reader with an overview of the hydrological results. The section should contain the following information where available (with the analysis and calculations given in an appendix);

- a summary of the available flow data including details of gauging stations which were inoperable or failed to function throughout the full range of the event,
- a summary of the pre-event soil conditions with reference to moisture content and antecedent rainfall, gauged peak flows and lag times,
- estimated peak flows in ungauged catchments,
- a summary of the estimated return period of the flood event in gauged and ungauged catchments,
- a description of the significance of the event in relation to previously observed floods and its effect, if any, on previously calculated flood frequency curves.

3.3.6 Conclusions

The concluding section of the report should summarise the important findings of the previous sections and clearly list any recommendations for further study and/or field work (e.g. urgent river clearance, changes to river maintenance/management procedures, defence works, bridge repair, etc.).

3.4 Production of the Flood Report

The overall responsibility for the production of a flood report should lay with AESD which includes management of the collection of all relevant data and ensuring the prompt performance of relevant tasks allocated to other departments.

Specific AESD responsibilities will include:

- site inspection and collection of questionnaires provided to statutory bodies (although this task could be undertaken by MoCWT staff should this be necessitated by the distribution of available staff resources),
- interpretation of data collected through site inspection,
- collection of rainfall, discharge and climatological data from field equipment and from other bodies holding such information (NMSD and WASA).
- rainfall and hydrological analysis of the event,
- production of the report.

Responsibilities of other divisions and authorities include:

MoCWT Surveying of peak flood levels if this could not be undertaken during the site inspections,

MoCWT Inspection and evaluation of flood damage to roads and property and determination of the extent and cost of remedial works (this may be undertaken following notification of damage locations by the site inspection team).

NMSD/AESD collection and provision of relevant rainfall and climatological data,

WASA/AESD collection and provision of relevant flow data.

Should the institutional arrangements change with the creation of an Environmental Authority then all of the responsibilities currently resting with AESD will be transferred to the authority. In addition, assuming that a skeleton labour staff is maintained by the authority (for the purposes of ongoing river maintenance and the undertaking of minor works) then they should also be able to undertake any surveying of flood levels required.

3.5 Floodplain Mapping

3.5.1 Introduction

Floodplain or flood extent maps indicate areas at risk from flooding. They may be used for a variety of purposes including development control, development of flood warning systems, identification of structures or earthworks increasing the risk and extent of flooding, identification of areas potentially in need of flood defence and the determination of the economic viability of a flood defence scheme.

There are two principal types of floodplain maps which are fundamentally different but similar in format and may indeed be presented on the same drawing:

- historical, or observed, event flood extent maps,
- design event flood extent maps.

Observed flood extent maps show the areas of land inundated during a specified event, for example, Tropical Storm Debbie. They are based entirely on observations made during or after the event and are hence factual representations of an historical occurrence. Design flood extent maps on the other hand indicate the areas of land that are *expected* to flood should an event occur of a given return period. They are estimates of what is likely to happen under given circumstances and are based upon two estimates (or calculations); the estimated peak flow for the given return period and the flood extents estimated to occur due to the given peak flow. Historical extent maps will clearly assist with the production of design extent maps.

For design extent maps in particular there is inevitably going to be variation in the level of confidence that may be attributed to the location of a flood extent line. For example, a historic extent line that has been plotted using aerial photographs of the flooding may be afforded a high level of confidence, whereas only a low level of confidence may be afforded a design extent line that has only the estimated peak flow and a site inspection as source data. A proposed method of attributing levels of confidence to the flood extent lines is given in Section 3.5.2.

Also detailed in this section is the recommended methodology used in producing flood extent maps (historical and design) and suggestions concerning the presentation format.

3.5.2 Methodology

The methodology outlined below is that which has been built up through experience of mapping flood extents in the UK. It is intended to be used as a basis from which mapping in St. Lucia can be undertaken and then amended, if required, to suit local needs and resources.

3.5.2.1 Data Collection

Historical Extent Mapping

Data collection for historical extent mapping is the same process as flood report data collection (Section 2 of this document) as they are both investigating an historical occurrence, although for mapping purposes it is depth and extent information that is clearly of prime importance.

Site inspections provide the engineer with a feel for the area, allows interviews with local residents to be undertaken and the engineer to make his/her own preliminary assessment of the likely flood extents. It is strongly recommended that site inspections are always undertaken as part of the mapping process.

Design Extent Mapping

All information collected for historical extent mapping will also be useful in design extent mapping and should therefore be researched.

The first step in determining the flood extents for design extent maps is to derive an estimate of the peak flow for the return period under consideration. This may be done through a variety of means using meteorological, statistical and hydrological analysis and modeling. Other texts should be referred to for further details (e.g., Ref; Shaw, 1988).

Where large storage areas and/or reservoirs are involved then some data concerning the event duration is also required to determine how full the area/reservoir will become and whether the contained waters will overflow and spill into other areas. Useful information concerning the design standard of the storage facility, maximum capacities, embankment crest levels, safety outlets, design outflows, etc., under flood conditions should be obtainable from the engineer's report for the structure.

In addition to any data collected for historical flood extent mapping, an extremely useful source of information, if available, are the results from hydraulic modeling studies. Models are usually run using design inflows and should therefore provide design water levels and in some instances, extents.

3.5.2.2 Data Analysis

Introduction

The level of confidence that may be attributed to the plotted flood extents, in particular design extents, depends on the quality and quantity of information on which the extent location has been based. Each piece of data should therefore be assessed in terms of its likely accuracy and then the pool of data for a given location assessed to determine the level of confidence that may be attributed to a flood extent line.

Assessment of the Quality of Information

Set out below is a guide to which information may be considered as high quality, or *primary*, information and which is likely to less accurate and therefore considered as *secondary*. Primary information must be based upon a reliable source, such as *recorded* observation or detailed calculation, but must also be relevant, e.g., of a similar return period to that of a mapped design extent. Secondary information is usually of a more general descriptive nature or is based on memory.

PRIMARY

- Previously drawn maps of historic flood extents (principally of use in design extent mapping but may also be used in historic extent mapping for comparative purposes),
- Photographic records or video footage (aerial or land based) of historic and significant flood extents,
- Information from engineer=s reports (e.g., accurately calculated design water levels, recorded historic water levels, etc.),
- Results from hydraulic models.
- Accurate flood marks (e.g., accurately placed flood level indicators, stained walls, precisely identified flood depths, etc.).

SECONDARY

- Estimates of likely flood extents made during site visits,
- Photographic records or video footage (aerial or land based) of minor flooding,
- General reports of flooding,
- Detailed press reports,
- General information derived from interviews with local residents.
- Rough flood marks (e.g., paint marks made long after the event)

Some data gathered such as vague press reports, while of general use in providing further description of the flood, will probably be of no practical use in determining flood extents.

Whilst normally secondary data, the estimates of flooding extents made during site visits may be considered primary data if it is believed that the flood extents can be estimated on-site with a high degree of certainty, e.g., where the channel runs through a flat floodplain with clearly defined edges in a steep-sided valley. It is understood that this is subjective but to avoid doing so may cast unnecessary, and unwarranted, doubt on the indicated flood extent.

All data gathered should be quality controlled through cross-checking for contradictions and comparison with the engineer's estimates made during the site visit.

3.5.2.3 Determination of Levels of Confidence

Three levels of confidence are proposed depending on the type of information available for a particular reach. The definition and information requirements for each level are given below.

Level of Confidence	High (design event)
Information Requirements	At least one item of primary data supported by secondary data from one or more source.
Level of Confidence	Medium (design event)
Information Requirements	Secondary data from more than one source that are mutually supportive or one unsupported item of primary data.
Level of Confidence	Low (design event)
Information Requirements	Secondary data from only one source.
Level of Confidence	Observed or historical event (high)
Information Requirements	Site inspection incorporating interviews with local residents and observations of flood marks, etc. (Should be undertaken shortly after the event).

It should be noted that all estimates of the flood extents will have at least one source of secondary data (and therefore at least low confidence) as a site inspection should have been undertaken and an initial estimate of the extents made by the engineer.

3.5.2.4 Flood Extent Mapping Techniques

The first step in delineating the flood extents is a review of all available data (that has been accepted as accurate) which should then be notated on topographical maps of an appropriate scale (no greater than 1:10,000 , preferably 1:2,500 or less). The engineer should then undertake a site inspection (as soon as possible after the event in the case of observed flood extent mapping) during which he/she should:

- Interview local residents about flood depths and extents,
- Check the sites where information is available to ensure the data is realistic,
- Look for and photograph any flood marks,
- Assess the channel capacity and floodplain topography and delineate preliminary flood extents according to the available information and his/her subjective opinion of the likely flood limits.

There are two approaches to the delineation of flood extents.

- Mapping of extents based on flooded areas,
- Mapping on extents based on water levels.

The former is a more direct and simplistic approach where the engineer attempts only to determine which areas flooded and which did not. No consideration is given to the peak water levels. This approach is open to error as it is rare that information concerning the exact extent is available; usually information is only available to say that point A flooded and point B did not, but it is unknown exactly where the flood extent limit was between the two points. This method may only be used for the mapping of historic flood extents.

The latter attempts to determine the flood extents using the peak water levels at given points. Water levels at a given section perpendicular to the direction of flow should be constant across the section (with the exception of local eddies, sharp meanders and other areas of turbulence). Having derived a peak water level at a point, it may therefore then be extrapolated across the floodplain (perpendicular to the direction of flow) to intercept the valley sides. The interception point is the flood extent. This method will make use of a greater volume of data and is theoretically more reliable than the first approach but relies heavily on the accuracy of the basemap contours and the engineer=s site inspection (extrapolation across the floodplain should be undertaken on site rather than by relying solely on the map contours).

Ideally the peak water levels gathered or calculated would be levels to datum. They must often be derived however from depths above ground level which introduces potential error as the ground level is often not known. In this situation extrapolation across the floodplain is likely to more accurate if undertaken on site rather than relying on contours and spot heights from maps. Similarly if the maps available only have contours at widely spaced intervals (>5m) then flood extent delineation is more likely to be accurate if undertaken on site.

The first method may be used in conjunction with the second in the mapping of historic extents by determining known flooded areas and establishing minimum elevations for peak flood levels.

Both of the methods will establish short reaches or points of Aknown@ flood extent. The engineer must then interpolate between these reaches to fill in the extents along the remainder of the river reach under study. This interpolation should generally assume a constant water surface gradient between the points although allowance should be made for changes in river bed gradient and the occurrence of flow restrictions and flow area contractions and expansions.

For design flood extents, hydraulic models are the most useful tool as they calculate design water levels at regular intervals from which relatively accurate extents may be derived (assuming the design inflows are accurate and the model has been correctly calibrated). Such models are however relatively expensive to set up and can rarely be justified for the sole purpose of flood plain delineation except in urban areas. They are however frequently used in determining flood risk areas in feasibility studies for flood alleviation schemes. The engineer should investigate whether any such models have been used along the river reaches under study.

In the absence of hydraulic modeling results, design flows should be compared to recorded or estimated flows of historic events. The historic extents should then be used as a basis for delineating the design extents based on the relative return periods (if historic extents have been mapped for 20 and 60 year events for example then the 50 year design flood extents will lie between them).

Where no historic extents have been mapped then the engineer must rely on reports of flooding incidents, information derived from interviews with local residents and his/her subjective opinion of the likely flood extents for the given return period based on the calculated design flow and his/her assessment of the channel capacity and floodplain characteristics.

3.5.3 Mapping Formats

The format of the maps is entirely a matter of preference for the user. However, it is advisable that a common format that is agreed upon by all potential users is employed nation-wide to avoid confusion over what a given line-type or shading represents. Given below are suggestions for formats for the various lines and symbols that may be used.

Design flood extent lines (with appropriate return period attached):

High confidence -	Solid line
Medium confidence -	Chain dotted line
Low confidence -	Dashed line

Observed/historic extent lines:	Solid line with date of event attached.
Note or Comment:	Circle with reference number. The notes or comments should then be included within the appropriate flood report linked to the map by the map number and reference number.
Flooded areas:	Blue shading

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Appendix A

Notes on the use of the Flood Report, Site and Questionnaire Forms

Appendix A

NOTES ON THE USE OF THE FLOOD REPORT SITE AND QUESTIONNAIRE FORMS

A1. INTRODUCTION

An important component in the analysis of a catchment and river system is calibration data against which to compare predicted flows and levels produced by hydrological and hydraulic models. Without calibration, estimates of design flood flows and levels (upon which flood defence and infrastructure works are designed) cannot be afforded a high level of confidence. This is likely to result in either unnecessary over design of the works (resulting in additional cost) or under design (which may result in failure of the works).

The Flood Report Site Forms provide a means of collecting flood event data in a standardised format that may facilitate the calibration process. A site inspection should be undertaken by an engineer or technician as soon as possible following a flood event during which the Site Form should be completed. They will then form the basis for a flood report and should be kept on file for reference or included as an appendix to the report. A separate form should be completed for each site visited where flooding has occurred.

The form has been designed for detailing fluvial flooding information for hydrological purposes. They should not be used in instances where urban storm water drainage systems become overloaded or blocked or where rainfall is unable to drain and has ponded in local low spots.

A2. FORM COMPLETION

A2.1 General Information

The general information section of the report form provides outline details of the site inspection and the flood event.

Flood Inspector
The name of the engineer or technician undertaking the site inspection.

Date of Inspection
The date (including year) on which the site inspection took place.

Flooding Location
The name of the town or village where the inspection is being undertaken. Further details of location (e.g. the streets, houses or fields effected) should be provided under the flooding information section.

Flood Event Date
The date (including year) on which the flooding occurred.

Grid Reference
The grid reference of the location given above.

Watercourse
The name of the river or stream from which the flooding occurred.

A2.2 Flooding Information

Flooding Extents
This section should detail the extent of the flooding, with specific streets and houses named and lengths/areas effected included where possible. A sketch of the flood extents should be drawn on an Additional Information Sheet where appropriate

Description of Flood Damage
Details of flood damage to any property or infrastructure. An estimate of the cost of the damage is not required at this stage.

Cause of the Flooding
Details of the likely cause of the flooding, e.g. undersized bridge or blockage by debris. This information may enable prevention of similar flooding in the future.

Duration of Flooding
The duration of the flooding of property or infrastructure, e.g. the length of time a house was inundated or a road was impassable.

Time of Flood Peak at Location
This information may be obtained during the site inspection by consulting local residents or workers. The information will be useful in the determination of the hydrological characteristics of the catchment and river..

Observed Flood Levels/Depths
Observed depths of flooding derived from trash marks, observations of local residents/workers, photographs taken during the flooding, etc. The depths should be related to fixed and identifiable landmarks or locations, e.g. road level at a specified point, the deck level of a bridge or a height up an identified telegraph pole.

Flood Levels to Datum
The above flood levels should be surveyed and a peak water level given to national datum. It is understood that this is not always possible during the initial site inspection, but should be undertaken at a later date as this information is of considerable importance in the calibration of hydraulic models and in floodzone hazard mapping.

Source of Information
This section should identify the source of the information obtained, e.g. the name of local residents/workers providing assistance/information.

Photograph Reference Numbers
Photographs should be taken during the site inspection showing flood extent/ level marks and any damage caused. These photographs and any others taken during the event should be filed for future reference. This is of particular importance where flood water levels have not been surveyed to national datum during the site inspection. The photographs should be given a reference number which will allow future identification of the date of the event, the flood location and any other pertinent information.

A3 ADDITIONAL INFORMATION SHEETS

These sheets should be used where it is not possible to fit all the available information onto the Site Form, e.g. sketches of flood extents, diagrams of damaged bridges or detailed descriptions of complex flooding.

The number of additional sheets used should be noted on the Site Form as a check measure to ensure that the user is aware of all the available information.

A4 FLOOD REPORT QUESTIONNAIRE FORMS

A4.1 Introduction

Questionnaires may be sent to local authorities and other institutions with an interest in the effects and prevention of flooding (e.g. WIBDECO) as a means of supplementing the flood extent and damage information gathered during the post-flood site inspections. It must be stressed that use of the questionnaires should not be an alternative to the site inspections as they will provide a significantly reduced level of information.

As a trial, the questionnaires may be sent to the relevant authorities following a major flood incident with guidance notes on their completion (see below). The level of cooperation and the information provided should then be evaluated to determine whether the questionnaires are a viable method of data collection and whether the proposed format may be improved. A number of questionnaires may then be sent to each of the authorities with a request that they should be completed as a matter of course following any flood event. A list should be kept of the authorities involved.

The questionnaire may additionally be used as a means for the authorities to report minor flooding incidents and problems along river channels to AESD and/or the MoCWT.

A4.2 Guidance Notes for Completion of the Questionnaires

Questionnaire Form Reference Number
This is for use by AESD to reference and files the returned questionnaires.

A4.2.1 General Information

Flood Event Date
The date (including year) on which the flooding occurred.

Reporting Date
The date (including year) on which the questionnaire was completed.

Name
The name of the person completing (or responsible for the completion) of the questionnaire.

Authority/Institution
The name of the authority or institution which the person completing the questionnaire represents.

A4.2.2 Flooding Information

Number of Houses/Buildings Flooded
The number of houses and other buildings flooded during the event and, if available, the maximum depths and duration of flooding. Specific properties effected should be listed if possible, else identified on an annotated map of appropriate scale.

Roads Flooded
Details of which roads were effected by the flooding and, if available, the extents and maximum depths of flooding and the duration during which a road was rendered impassable to vehicles.

Area of Agricultural Land Flooded
The areas of land flooded should be identified, preferably through the use of annotated maps.

Description of Flooding Extents and Damage
The authority should provide as much detail as possible concerning the flooding extents and damage caused. This should include wherever possible specific details of which houses, roads and areas of land were effected, depths, duration and the time of the flooding and detailed description of the damage to property, infrastructure and agricultural land.

Suggested Cause of Flooding
The authority should be encouraged to put forward their ideas as to why the flooding at a particular location occurred, e.g., an undersized bridge, lack of river maintenance, etc. This should identify for AESD/MoCWT maintenance/capital works that may need to be undertaken.

MINISTRY OF AGRICULTURE, FISHERIES, FORESTRY AND ENVIRONMENT
AGRICULTURAL ENGINEERING SERVICES DIVISION

FLOOD REPORT SITE FORM

Site Form Reference No: FR/SF/

GENERAL INFORMATION

Flood Inspector		Date of Inspection	
Flooding Location		Flood Event Date	
Grid Reference		Watercourse	

FLOODING INFORMATION

Flooding Extents:
Description of Flood Damage:
Cause of the Flooding:
Duration of Flooding:
Time of Flood Peak at Location:
Observed Flood Levels/Depths:
Flood Levels to Datum:
Source of Information:
Photograph Reference Numbers:

Attach additional pages for further detail where necessary
No. of additional pages:

SITEFORM.WK4

MINISTRY OF AGRICULTURE, FISHERIES, FORESTRY AND ENVIRONMENT
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FLOOD REPORT SITE FORM - ADDITIONAL INFORMATION SHEET

Site Form Reference No: FR/SF/ Additional Page No.

SITEFORM.WK4

MINISTRY OF AGRICULTURE, FISHERIES, FORESTRY AND ENVIRONMENT
AGRICULTURAL ENGINEERING SERVICES DIVISION

FLOOD REPORT QUESTIONNAIRE FORM

Questionnaire Form Reference Number	FR/QF/

GENERAL INFORMATION

Flood Event Date		Reporting Date	
Name		Authority/Institution	

FLOODING INFORMATION

Number of Houses/Buildings Flooded (and depths and duration of flooding within):
Roads Flooded (length of road effected and duration and depth of flooding):
Area of Agricultural Land Flooded:
Description of Flooding Extents and Damge (including flood depths, duration and time of flooding, etc.) (Please attach sketches/drawings of flood extents/damage on an additional sheet)
Suggested Cause of Flooding (e.g. debris blocking a bridge, inadequate storm drainage):

Appendix B

Flood Report for Tropical Storm Debbie (TSD)

The Flood Report is intended to stand alone, hence some duplication of data and information will be found with the main sections of the Annexes.

Appendix B

FLOOD REPORT
TROPICAL STORM DEBBIE - 9/10 SEPTEMBER 1994

1 INTRODUCTION
1.1 Flood Summary

In September, 1994, St. Lucia was struck by Tropical Storm Debbie (TSD). For several days a tropical wave had been monitored from satellite observations but there had been no reason to believe that it could develop into a full storm. However, during the night of the 9th/10th September, when the wave reached St. Lucia, it developed rapidly from a tropical wave to a depression and then to a tropical storm. Unfortunately standard procedures at the Meteorological Services made it impossible to keep track of such rapid developments and no specific warnings could be issued to the population.

The most devastating part of TSD was not so much the wind-speed, although some wind-related damage did occur, but rather the very high intensity rainfall that accompanied it. In particular, in the early hours of the 10th September, heavy rainfall was experienced in the interior parts of the country.

Six rainfall gauging stations were operational throughout the storm, with recorded 24 hour totals ranging from 230 to 360 mm. Maximum recorded 1 hour rainfall intensities reached 89 mm/hr at Union Research Station with an estimated peak 1 hour intensity in the upper Roseau Valley of 141 mm/hr.

The short duration, high intensity rainfall experienced during TSD forms the most critical storm profile type for many of St. Lucia's small, steep catchments. This, in combination with the already saturated soil conditions due to antecedent rainfall, resulted in high discharges in the rivers, in particular in those whose catchments drain the steep slopes of the central Mt. Gimie highlands (Cul-de-Sac, Roseau, Mabouya, Dennery, Fond, Troumassee, Vieux-Fort, Soufriere and Canaries). The devastating effect of the resulting floods was aggravated by large volumes of debris and sediment that came down the rivers, principally derived from extensive landslides that occurred on steep slopes (both cultivated and under natural forest). The debris blocked channels and structures, raising flood water levels and increasing the extents of the flooded areas.

Large areas of agricultural land were submerged under significant depths of flood water, most notably the flat floodplain areas in the lower reaches of some of the catchments. Urban centres were also severely flooded with many properties damaged or destroyed and extensive damage caused to infrastructure.

The floods caused four deaths, 24 persons were injured, six people were reported missing, 37 were made homeless and 500 displaced persons had to be accommodated in temporary shelters. The cost of the damage caused is estimated at EC$112 million.

The return period of the event has been estimated in the order of 50 to 100 years in the Cul-de-Sac valley at Ferrand's Bridge and in excess of 1000 years at Roseau Dam. Estimates are difficult to verify due to the general lack of hydrological data available within the country and the specific lack of event flow data due to damage to the gauging sites.

1.2 Flood Reporting

This report has been produced almost 3 years after TSD. It is therefore heavily reliant on extracts and information from previously published reports and papers. Specific references to the documents are only made within this text where assumptions have been made or analyses/calculations have been undertaken.

Rainfall and hydrological analysis of the event has been undertaken at various levels for the above mentioned documents. The information used, methods applied and results obtained have been collected and summarised within this report. No checking has been undertaken of the data used in the documents referred to.

Site visits were undertaken in July 1997 during which interviews were conducted with local residents, administrators and engineers to derive information concerning flood extents, depths and damage that might compliment the previously available data. The information derived is given in Section 3.1 of the report and summarised on the flood extent maps.

2 RAINFALL ANALYSIS

2.1 Meteorological Description of Tropical Storm Debbie

The following section has been extracted from the memorandum concerning the impact of TSD on Roseau Dam (Ref; Stanley/Klohn Leonoff, 1994). The original meteorological description was provided by Mr. John Miller.

On 8th September 1994, an easterly tropical wave crossing the southern North Atlantic was located approximately 1300 km to the east of the Lesser Antilles, closing to 200 km by late afternoon of the 9th September. A tropical depression developed as the wave moved through the Lesser Antilles, with couterclockwise circulation first beginning to form just north of Barbados. The depression then moved on a west-northwest track with the centre passing over Hewanorra Airport between 10 p.m. and midnight on the 9th. The storm continued on a west-northwest track and developed into Tropical Storm Debbie by the morning of the 10th. By the afternoon of the 10th the storm had moved sufficiently far to the west that its effects over St. Lucia had ceased.

Rainfall over the island began during the early part of the 9th as the tropical wave approached. The rainfall was generally light with occasional heavy showers until near midnight, after which it significantly increased in intensity. The heaviest rainfall occurred between approximately 3 a.m. and 9 a.m. on the 10th as TSD continued to strengthen and its counter clockwise rotation continued to bring moisture onto St. Lucia from the northeast.

2.2 Flood Warning

The office of the National Meteorological Services Department (NMSD) is under the Ministry of Communications, Works and Transport (MoCWT&PU). It operates a station at each of the two airfields, Hewanorra and Vigie. From satellite images it was known that a tropical wave was approaching on the 9th September, but due to insufficient facilities and staffing at the time, no warnings were issued to relevant authorities or to the public.

2.3 Rainfall Data

At the time of TSD a total of 34 rain gauges were in place, although only 25 were operational prior to the event (**see Table 2.1**). Following TSD, 9 rainfall charts were recovered although only 6 were usable for analysis, the other 3 having failed during the storm. None of the storage rain gauges could yield results as they either overflowed or were lost.

TABLE 2.1

Rainfall Station Network

Catchment Name	Rainfall Ref.Nr.	Station Name	Date of Installation	Elevation (m)	Avg. Annual Rainfall (mm)	Years of Record	Latitude N			Longitude W			Type	Oper- -ational Y/N '94
							o	'	"	o	'	"		
Marquis (4)	4-R-1	Marquis Estate	1908	35	1906	70	14	1	26	60	54	36	RR	Y
	4-R-2	Marquis Babonne	1958	46	1873	28	14	0	11	60	55	17	RG	N
Fond D'or (6)	6-M-1	CARDI La'Resource	1980	14			13	56	38	60	53	11	RR+EP	Y
	6-R-1	La Caye	1907	25	1884	71	13	55	46	60	54	8	RR	Y
Dennery (7)	7-R-1	Errand Estate	1986	70	2100	0	13	53	2	60	55	29	RG	Y
Mamiku Patience (9)	9-R-1	Mamiku Estate	1907	8	1802	71	13	51	57	60	54	10	RR	Y
Fond (10)	10-R-1	Fond Estate	1907	50	1841	60	13	50	18	60	54	35		N
	10-R-2	Patience Estate	1951	92	1904	35	13	50	53	60	54	49	RR+RG	Y
Troumasse (12)	12-R-1	Troumasse Estate	1982	17	1762	63	13	48	47	60	54	16	RR+RG	Y
	12-R-2	Mahaut Estate	1952	129	2593	9	13	50	26	60	57	2	RR+RG	Y
	12-R-3	*Quilesse*	1935	320	3683	44	13	51	7	60	58	57		
	12-R-4	*Edmund Forest*	1979	490	3697	7	13	50	18	60	59	53	RR	Y
Roarne Rugeine (15)	15-M-1	Hewanorra Airport	1974	10	1386	12	13	44	2	60	57	6	RR+RG	Y
Vieux-Fort (16)	16-R-1	Beausejour (Vieux F)	1975	16			13	44	37	60	57	30	RR	y
Doree (21)	21-M-1	Saltibus	1985	274		1	13	48	13	61	0	43	RG	Y
Choiseul (22)	22-R-1	Delcer School	1982	206	1807	4	13	48	0	61	3	18	RR+RG	Y
L'Ivrogne (23)	23-R-1	Union Vale	1923	242	1968	35	13	48	38	61	3	18	RR+RG	Y
	23-R-2	Bathe Nursery	1948	367	2558	38	13	49	3	61	1	55	HMS	Y
Soufriere (25)	25-R-1	*Belfond Soufriere*	1983	495			13	49	39	61	2	30		N
Canaries (27)	27-R-1	Canaries	1985	54		0	13	54	19	61	3	53		N
	27-R-2	Desraches	1986	620		0	13	50	55	61	1	5		N
Roseau (31)	31-M-1	Roseau Winban	1966	5	2158	20	13	57	20	61	1	9	RR+RG	Y
	31-R-1	*Roseau Yard*	1970	5	2149	46	13	57	7	61	1	26		N
	31-R-3	Millet Tete Chemin	1983	260	2964	3	13	53	58	60	59	44		N
Cul De Sac (33)	33-R-1	Soucis	1908	9	2432	71	13	58	43	60	59	47	RR	Y
	33-R-2	Bexon School	1985	23	N.A.	0	13	57	8	60	58	37	RR+RG	Y
	33-R-3	Barre de L'Isle	1984	290	2980	1	13	55	30	60	57	28	RR+RG	Y
Castries (34)	34-M-1	Vigie Airport	1970	3	1815	16	14	1	9	60	59	35	RR+RG	Y
	34-R-1	Government House	1945	137	1880	41	14	0	22	60	59	48	RR+RG	Y
	34-R-2	George V Park	1890	6	2342	89	14	3	38	60	59	10	RR+RG	Y
Choc (35)	35-M-1	Union Agric. Stat.	1923	11	2040	63	14	1	21	60	57	32	RR	Y
Bois D'Orange (36)	36-M-1	*Marisule*	1984	61		2	14	3	33	60	58	1		N
	36-R-1	Trouya	1977	15	1736	8	14	3	42	60	58	2	RR	Y
Cap (37)	37-R-1	Cap Estate	1982	23	1307	34	14	5	41	60	56	10	RR	Y

{Note: those in italics not operational at time of report}

2.3.1 Antecedent Rainfall

TSD occurred following a period of heavy rain as shown in **Table 2.2**. It can be seen that between a third and over a half of the mean monthly total rainfall for September, and between three and six times the annual six-day average rainfall, fell during the six days preceding TSD.

The high intensity rain of TSD therefore fell on very wet, if not saturated, soil leading to a very high percentage runoff.

Table 2.2 Antecedent Rainfall to Tropical Storm Debbie (mm)

Date	Rainfall Station Union	Bexon	Delcer	Errard	Saltibus	Soucis
Sept 3	28.3	38.6	35.5	0.0	61.7	37.0
Sept 4	29.2	27.0	11.0	45.1	14.3	35.9
Sept 5	18.0	46.4	2.7	46.8	7.3	58.3
Sept 6	13.7	9.7	4.2	20.1	13.6	12.3
Sept 7	18.1	20.5	22.0	6.4	30.7	2.2
Sept 8	6.2	15.5	9.3	7.2	7.9	19.0
Total	113.5	157.7	84.7	125.6	135.5	164.7
Average 6 Day Rain	33.6	43.0	N/A	37.3	N/A	29.7
Monthly Mean (Sept)	260	404	222	369	379	288

2.3.2 Total Rainfall Depths

As described in Section 2.1, none of the storage gauges could provide useful data having either overflowed or been washed away. Total event rainfall depths could however be derived from the chart recorders (**Table 2.3**), although some of the data has had to be estimated (as indicated with an asterisk).

Comparing **Table 2.3** with the mean monthly total rainfall given in **Table 2.2**, it may be seen that the recorded rainfall depths of 9th September are similar, and in some cases exceed, the average September total.

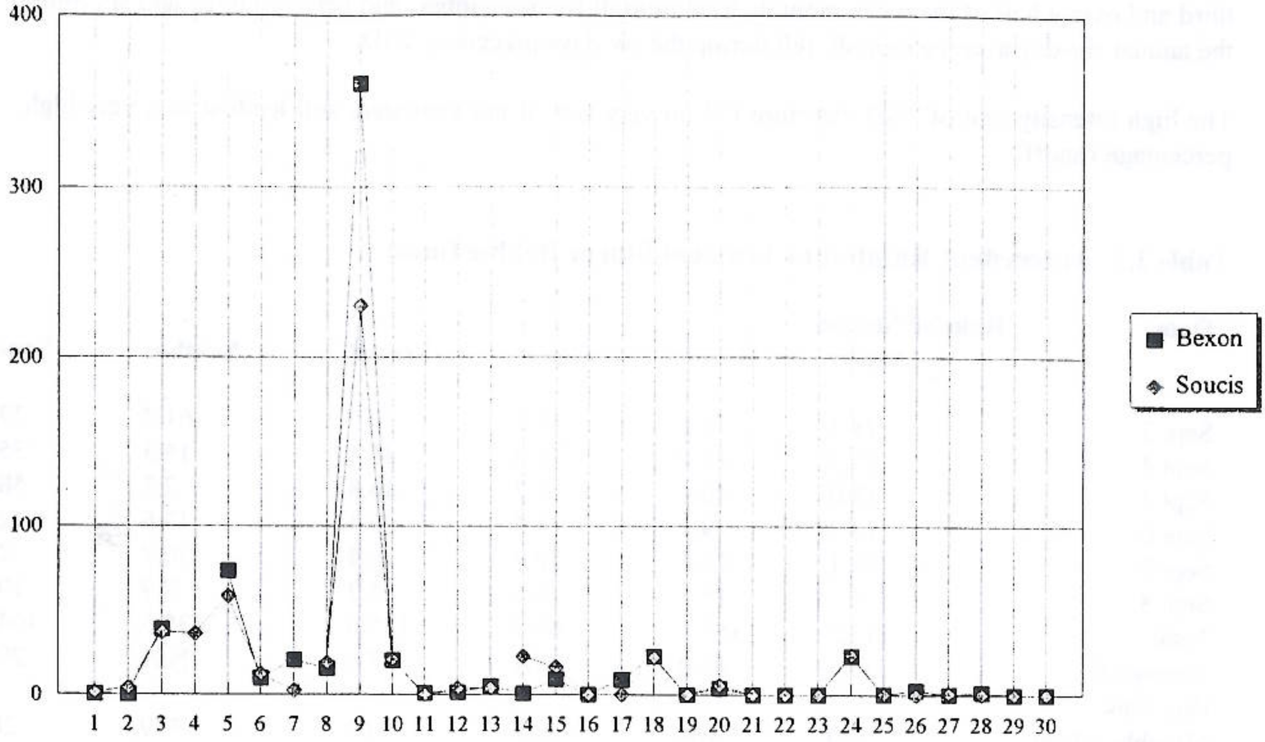
Figure 2.1 shows the daily rainfall depths recorded through September at Bexon and Soucis raingauges.

Table 2.2 Total Rainfall Depths during Tropical Storm Debbie

Rainfall Station	Station Elevation (m)	Rainfall Depth (mm) 9 September
Union	3	275.6
Bexon	23	360.4
Delcer	76	244.9
Errard	177	323.6
Saltibus	260	320.8
Soucis	230	230.0

FIGURE 2.1

Daily Rainfall Totals - September 1994



2.3.3 Rainfall Intensities

All of the rainfall recorders used weekly charts except for Union which had a daily chart. The charts were photo-enlarged and analysed to derive intensities for a range of durations. Due to the scale, only Union could provide reliable intensities for durations less than one hour.

Figure 2.2 shows the 1 hour intensity recorded at each of the stations during the passage of the storm while **Figure 2.3** shows the short duration (up to one hour) intensities recorded at Union.

It can be seen from **Figure 2.2** that low intensity rainfall occurred for the first 18 hours of the day (beginning at 9 a.m.). The intensity then increased between 3 and 5 a.m. (10^{th} September) before reaching its maximum (up to 90 mm/hr) between 6 and 8 a.m. During the last hour of the day only 9 mm were recorded.

The maximum recorded rainfall intensities for a range of durations are given in **Table 2.4**.

Table 2.4 Maximum Recorded Rainfall Intensities for Tropical Storm Debbie

Rainfall Station	Maximum Intensities (mm/hr) for Specific Durations							
	15 min	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr
Union	108	96	89	83.5	70.7	42.8	22.7	11.9
Bexon	N/A	N/A	100	92.5	82.3	51.0	28.3	14.5
Delcer	N/A	N/A	61	49.5	50.3	36.8	20.9	10.8
Errard	N/A	N/A	125	112.5	88.3	52.8	29.1	15.5
Saltibus	N/A	N/A	72	61.0	57.3	46.7	26.7	14.0
Soucis	N/A	N/A	51	49.0	40.7	30.2	17.9	9.6

2.4 Spatial Rainfall Variability

Significant spatial variation in rainfall was observed during Debbie. Residents of towns and villages at the outfall of many of rivers were not expecting such ferocious flooding as the rainfall at lower elevations was significantly less than that experienced in the mountainous centre of the island, particularly over the slopes of Mount Gimie.

Spatial variations in total rainfall depths may be explained by the direction of the moisture laden winds bringing in the storm and the topography of the island. These factors induce heavier rainfall over the windward east side of the island and over the high land in the centre. An effective rainshadow is caused, reducing the rainfall over the towns and low-lying land along the leeward west coast (explaining the phenomenon mentioned above).

The above phenomenon is demonstrated by the high rainfall recorded at the Errard and Saltibus gauges which are situated in the central highlands compared to the lower recorded depth at Soucis gauge which is at a similar elevation but on the leeward west coast.

Significant variability is also observed within the maximum short duration intensities observed. These may also be explained by the reasons given above as well as the natural temporal variability of the precipitation within a given storm.

FIGURE 2.2

1 hour Rainfall intensities - 10 September, 1994

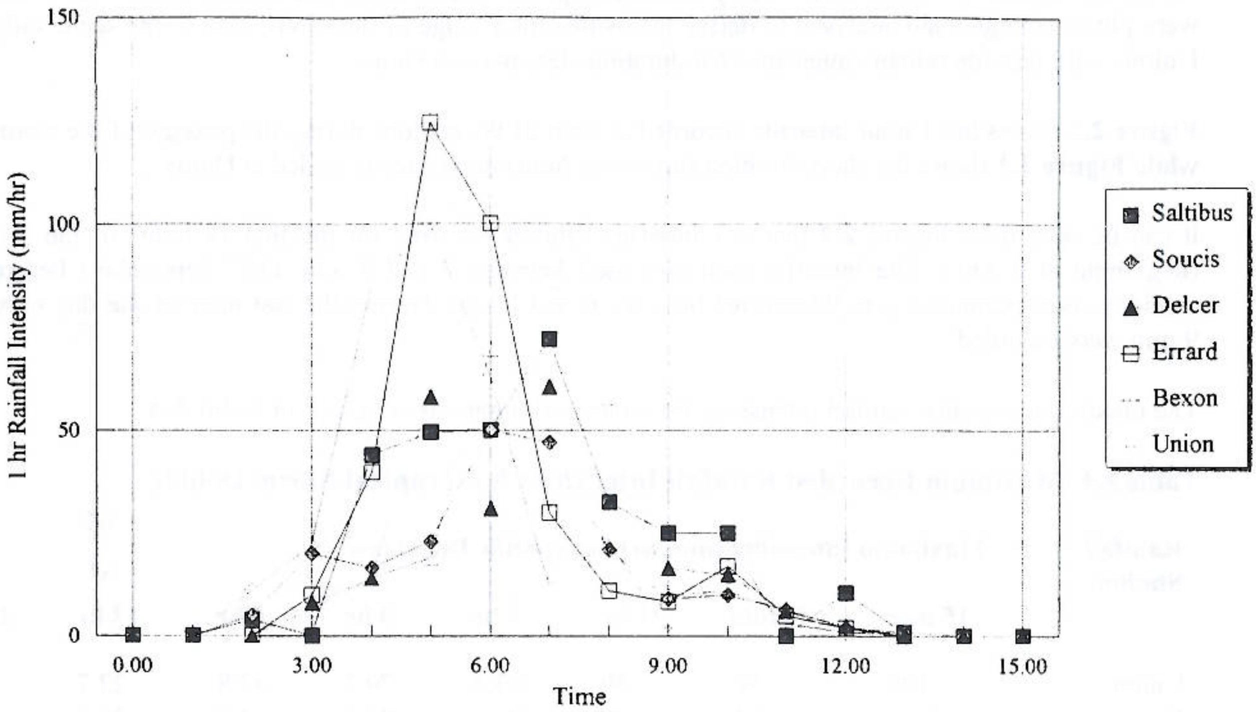
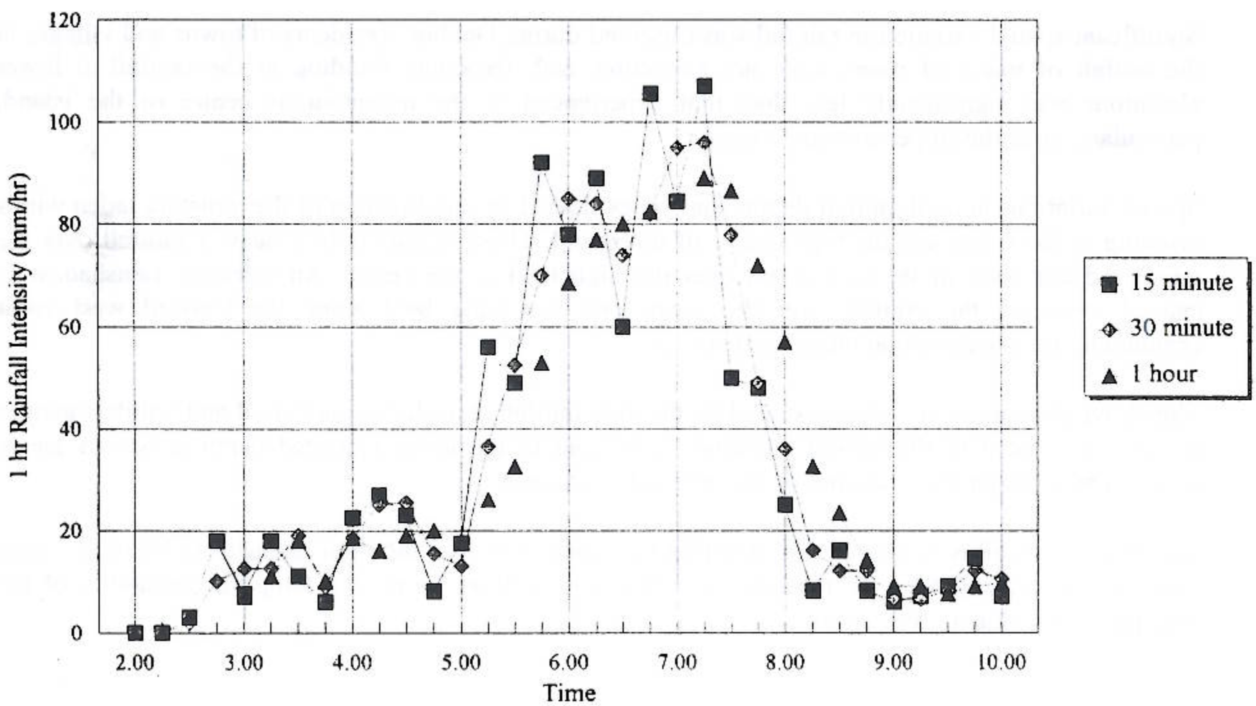


FIGURE 2.3

Rainfall intensities at Union Station - 10 September, 1994



2.5 Rainfall Data Analysis

Some general analysis of short duration and 1-day rainfall depths and return periods has been undertaken under the WEMP II study. Details of the study and results are provided in Appendix A of the flood report on the event of 26th October 1996 (Ref; HTS/MML 1997).

Given in **Table 2.5** are the rainfall intensities for a range of return periods and durations for the raingauge at Union Agricultural station. The corresponding intensities recorded during TSD and their estimated return periods are given at the bottom of the table.

Table 2.5 Frequency of Rainfall Intensities at Union

Return Period(years)	**Rainfall Intensities (mm/hr) for Given Duration (minutes)**							
	5[1]	**10[1]**	**15[1]**	**30[1]**	**60[2]**	**120[2]**	**360[2]**	**720[1]**
2	106	80	68	46	26.9	19.6	10.2	6.4
5	138	105	86	58	30.9	22.7	12.3	7.7
10	160	122	99	66	35.2	26.1	13.6	8.6
25	186	143	114	76	41.3	30.8	14.7	9.7
50	206	158	126	91	53.6	39.9	16.0	10.5
100	227	173	138	99	67.6	50.2	16.9	11.3
Debbie	**166**	**N/A**	**108**	**96**	**89**	**83.5**	**42.8**	**22.7**
Return Period	**15**	**N/A**	**15**	**75**	**>100**	**>100**	**>100**	**>100**

Note 1 From analysis of rainfall 1979-87, Ref; IoH, 1992
2 From HTS/MML, 1997.

The corresponding frequency-duration curves and the intensity-duration curves for TSD are shown in **Figures 2.4 and 2.5** respectively.

It can be seen from **Table 2.5** that while the short duration intensities are not extraordinary (return period of approximately 15 years), the storm had an estimated return period well in excess of 100 years at Union station for durations of 1 hour or more. It should however be remembered that some of the frequency analysis undertaken was done with only 9 years' data and the estimated intensities may therefore be inaccurate for the larger return periods. Estimated return periods for some of the stations are given in **Table 2.6** for a range of rainfall durations.

Table 2.6 Estimated Return Periods (years) for TSD Rainfall Event

Station	**Estimated Return Period (years) of Event for Given Duration**			
	1 Hour	**2 Hour**	**6 Hour**	**24 Hour**
Union	>100	>100	>100	75
Bexon	>100	>100	>100	75
Errard	N/A	N/A	N/A	100
Soucis	25	75	>100	40

NOTE: These values should not be used for any purpose other than as approximate first estimates.

FIGURE 2.4

Rainfall Intensity Duration Curves - Union Station

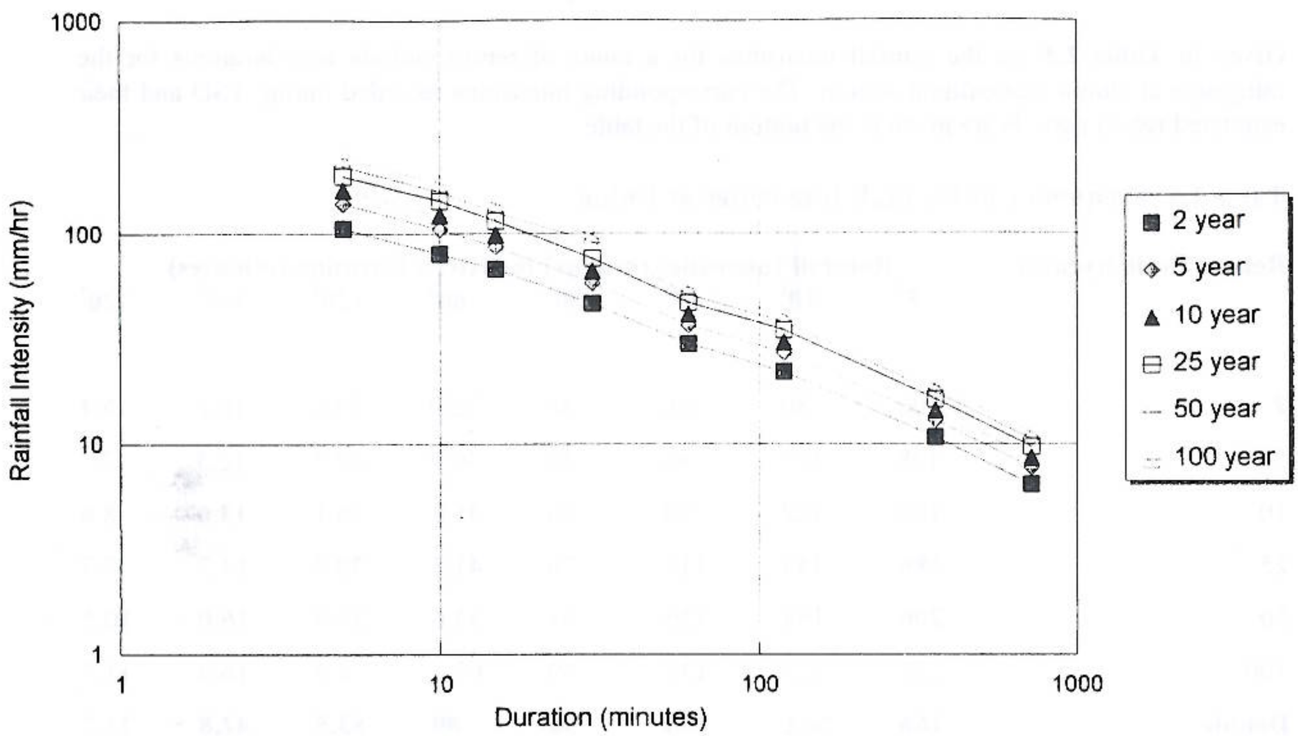
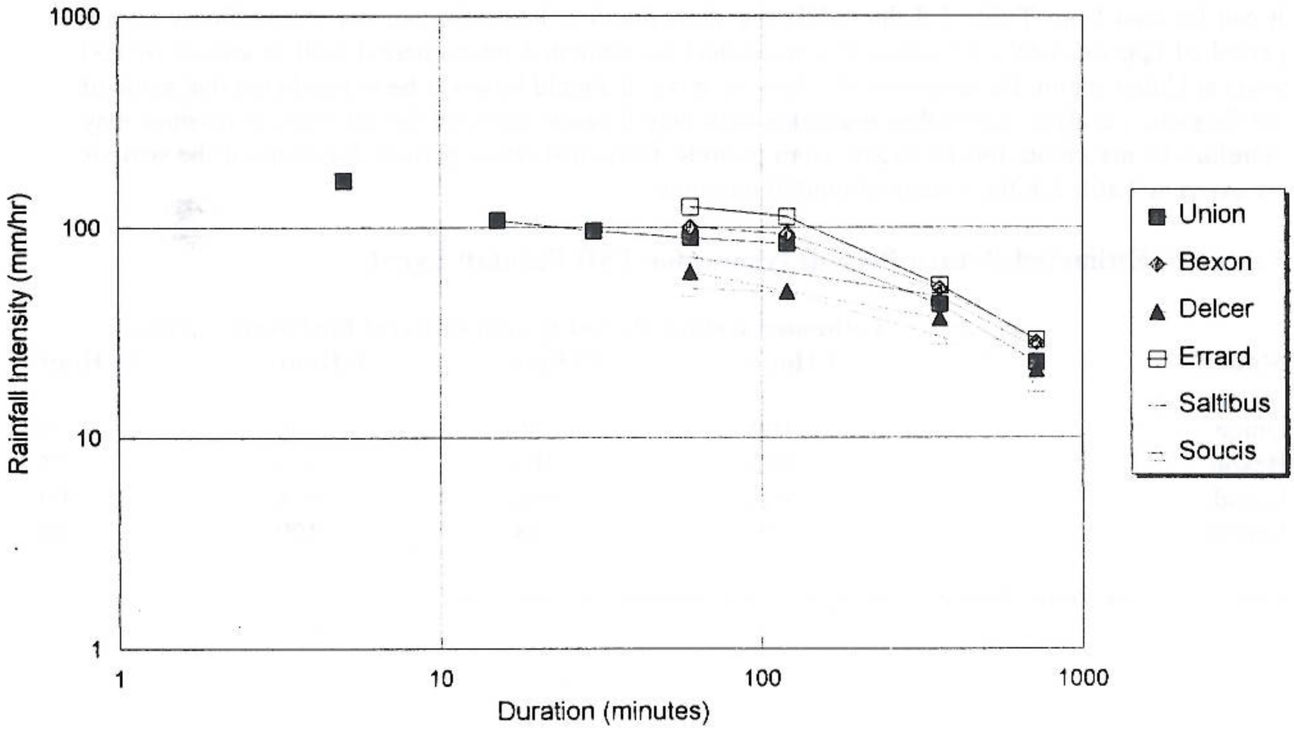


FIGURE 2.5

Rainfall Intensity Duration Curves - TSD



It is interesting to note that the intensities recorded at Union station during TSD are approximately average of the set given in **Table 2.4**, although no firm conclusions may be drawn from this observation as no frequency analysis has been undertaken for the other stations.

3 FLOOD EXTENTS

The flooding caused by TSD effected large tracts of land, particularly in the flat, low-lying floodplains of the major river systems (e.g. Roseau, Cul-de-Sac, Mabouya and Dennery).

Based on painted flood marks, information gathered during site visits, previous reports and a video made immediately following the event, the flood extents have been mapped for some of the most seriously effected areas (Section 3.2). A full set of the maps for this and other events are kept at the AESD office.

3.1 Flood Marks and Depths

Listed below are the flood marks and depths used in the determination of the flooded extents. Flood marks were made of peak water levels, usually painted onto telegraph/electricity poles, during a survey undertaken two months after TSD. Their locations have been identified on the flood extent maps.

Given the delay in making the marks, the levels indicated may be erroneous. It should further be noted that exceptionally large volumes of debris were carried down the rivers during Debbie and the levels indicate the peak water level due to runoff and channel blockages (of which there were many) rather than just normal channel flow. The levels should therefore not be used for calculation of peak discharge except with extreme caution.

The flood depths given are principally those based on the interviews conducted during the site visits undertaken in July 1997.

Cul-de-Sac Valley

Flood Marks

- Approximately 0.7m above main road level on an electricity pole outside a supermarket in Bexon. Workers at the supermarket however reported that the water only reached about 1 foot above the shop floor (a lower level than that indicated on the pole).
- Approximately 1.3m above main road level on an electricity pole near Ferrand's Bridge and the Texaco Filling Station.

Flood Depths

The majority of the banana plantations along the valley floor were flooded to between 0.5 (lower reaches) and 2m (upper reaches). The main road between Castries and Dennery-Vieux Fort which runs along the valley was flooded to a depth of about 0.5m all along the lower part of the valley and was made impassable (flooding up to 2m deep) at various locations in the upper part.

Roseau Valley

Flood Marks

- Approximately 1.0m above road level on a pole by the culvert crossing upstream of Vanard.
- Approximately 1.0m above road level (2-3m above the bridge deck) on a pole on the left bank approximately 40m from the bridge on the Vanard to Sarot road.
- Approximately 0.75m above road level on an electricity pole downstream of Vanard.
- Approximately 1.0m above road level on a pole by the Morne D'Or Learning Centre.
- Approximately 0.8m above road level (almost level with the bridge hand rail) on an electricity pole downstream of the main West Coast Road bridge.

Flood Depths

Roseau valley was flooded to significant depths principally due to the breaching of the Roseau Dam at the top of the river. The effects of the dam burst were significant near the top of the valley (fields flooded to in excess of 3m) but were obviously attenuated further downstream and the lower part of the valley (downstream of Vanard) was flooded to a depth of approximately 1m. A portable office at the WINBAN station was floated and washed out to sea indicating significant depths even in the wide part of the valley near to the outfall of the river.

Mabouya - Fond D'Or Valley

Flood marks

- Approximately 1.0 m above road level on a telegraph pole on the main road at the end of the village of Riche Fond.
- There is a flood stain at about road level on the side wall of one of the houses by the crossroads between La Pelle and La Resource.
- There are several marks on telegraph poles on the left bank of the Fond D'Or river near La Pelle, approximately 2 to 2.25 m above road level.
- The flood waters reached the top rail of the bridge at the Dennery Factory Site.

Flood Depths

- The banana boxing plant at Grande Riviere flooded to a depth of approximately 1.5 m.
- The shop on the north side of the main road near the turning to Morne Panache flooded to a depth of approximately 0.5 to 0.75 m. The main road at this location was flooded to approximately 0.2 m.
- The house by the turning to the school downstream of Grand Riviere flooded to a depth of approximately 0.5 m. Some marks are still visible.
- The road at the junction of the main road to La Resource flooded to approximately 1.5 m above road level. The water was over the counter of the shop by the junction and approximately 0.4 m deep in the adjacent house.
- The community centre at La Resource was flooded but the school and church were not.
- The bridge by the nursery gardens near Grande Ravine was flooded to approximately 0.3 m.
- The road by La Pelle was flooded to a depth of approximately 1.0 m.

Dennery Valley

Flood Marks

- There are several flood marks on telegraph poles on the road that runs along the left bank of the Dennery river upstream of the Dennery Garment Factory. The marks range from approximately 0.3 to 2.5 m above road level. The banana boxing plant beside the road on this reach was not flooded.
- Approximately 0.6 m above road level on a telegraph pole outside the Dennery Garment Factory.
- Approximately 1.6m above road level on a pole 200 m downstream of Dennery Garment Factory.
- Approximately 1.4 m above road level on a pole 300 m upstream of the main east coast road bridge over the river.

Flood Depths

Flood depths above road level upstream of the main east coast road bridge vary significantly depending on the floodplain width and level of the road relative to the river. Downstream of the bridge, the land is flat and flooded almost uniformly to a depth of approximately 1 to 2 m. Locations where flood depths were given during the site visit include:

- 1.2 m above ground level at MoCWT&PU garage,
- 1.0 m above ground level at the new Dennery schools,
- 2.0 m above ground level at the church and community centre,
- 1.0 m above road level at the old primary school,
- 0.6 m above road level at the petrol station near the river outfall,
- 0.75 m above road level at the bridge over the outfall of Ravine Trou a L'Eau.

Troumassee Valley

Flood Marks

- On several trees up the track on the right bank of the river due west of the main road, all approximately 1.5 m above road level or 6.5 m above river bed level,
- Trash mark indicator on a tree on the left bank of the river downstream of the Mahaut road crossing, approximately 5 m above river bed level.

Flood Depths

No other details concerning flood depths in the Troumassee valley have been collected.

Canelles Valley

Flood Marks

- There are marks on several trees on the track on the right bank of the river due west of the main east coast road, approximately 1.6 to 1.8 m above road level.
- Approximately 3.3 m above river bed level near De Mailly.

Flood Depths

No other details concerning flood depths in the Cannelles valley have been collected.

Vieux Fort

Flood Marks

- A house in the downstream end of Joyeaux is stained from TSD at a level of approximately 4 m above road level.
- Approximately 2.5 m above road level on a banana tree on the road to Hope Estate/Joyeaux, 150 m upstream of La Retraite bridge.
- Blue mark approximately 3 m above bridge deck level on pole downstream of bridge.
- Approximately 1.2 m on pole on left bank by La Resource bridge (reportedly 0.3 m below actual peak level which was 0.3 m above top rail of the bridge).

Flood Depths

- There is a mark on a tree at the upstream end of Joyeaux. TSD was reported to have reached approximately 1.5 m above this line.
- Peak water levels are reported to have been 1.5 to 2 m above the Coolie Town bridge deck.
- The banana boxing plant on the left bank downstream of La Retraite bridge was flooded to approximately 1.5 m, covering cars that were parked there.
- Buildings at Harlel Integrated Farming Project were flooded to approximately 1.5 m (or 0.5 m above the painted colour change on the concrete posts of the first building).
- Taxi stand building at Hewanorra Airport was flooded to approximately 1 m.
- The cricket field at Vieux Fort flooded to a depth of approximately 1.0 m.
- The track into the shanty town on the east side of Vieux Fort flooded to a depth of approximately 0.5 m.
- Properties on the west side of Vieux fort near to the outfall of the original river course flooded to a depth of approximately 2.0 m.

Soufriere

Flood Marks

No flood marks were observed in Soufriere.

Flood Depths

- The road at the junction to the restaurant north-west of the new bridge was flooded to a depth of approximately 1 m.
- The damaged house on the right bank downstream of the new bridge was flooded to approximately 0.75 m.
- The housing area on the left bank upstream of the school was flooded to between 0.5 and 1.0 m.
- The school was flooded to a depth of approximately 2 m.
- The housing area on the right bank downstream of the school was flooded to up to 1 m.

- The deck of the main west coast road bridge over the river was overtopped by 0.3 m but the bridge was not destroyed.
- The church was flooded to a depth of 0.6 m.
- The road junction outside the old school (now a Court's shop) was flooded to 0.6 m.

Canaries

Flood Marks

No flood marks were observed in Canaries.

Flood Depths

- Houses on Valley Road by and upstream of the sharp left-hand bend in the river at Riverside were flooded to a shallow depth, i.e., flood waters approximately 0.3 m above road level,
- School was flooded to approximately 0.3 m.
- House upstream of the main road bridge on the left bank was flooded to approximately 1 m.
- The main west coast road through the town was flooded to a depth of approximately 1 m.
- Police station was flooded to approximately 0.3 m.
- The junction of High and Cork Street was flooded to a depth of approximately 0.3 m.

Anse La Raye

Flood Marks

No flood marks were observed in Anse La Raye.

Flood Depths

- The main West Coast Road flooded to 1.5 m at the bridge over the Petite Riviere de Anse La Raye. Houses in the St. Laurent Estate were flooded to a similar depth.
- Flooding in the car park at the Health Centre by the main road rose to approximately 2 m above ground level.
- The playground of the school on the right bank of the Grand Riviere de Anse La Raye upstream of the town was flooded to a depth of approximately 1 m.
- The community centre on the right bank of the Grand RiviPre flooded to 1.5 m.
- The area upstream of the main road flooded to depths of up to 2 m above road level.
- The main road was flooded to 1 - 1.25 m deep.
- The church and immediate surrounding land were not flooded as the water flowed down St. Louis and Market Streets to the sea.
- The north end of Front Street was flooded to a depth of approximately 2 m above road level.

3.2 Flood Extent Mapping

Based on the previous reports, the information obtained during the site visits and given in Section 3.1, and the topographical data provided on the 1:2 500 maps, peak water levels were derived along the rivers and the corresponding flood extents marked for the following areas:

- Cul-de-Sac Valley (Ravine Poisson to outfall),
- Roseau Valley (Durandeau to outfall),
- Anse La Raye (urban areas),
- Canaries (urban areas),
- Soufriere (urban areas),
- Mabouya-Fond D'Or (La Resource, Grande Ravine and Grande Riviere to outfall),
- Dennery (Ravine Chien to outfall),
- Vieux-Fort (Beausejour Agricultural Station to outfall).

The maps have been drawn at a scale of 1:2 500 but due to the current lack of digital bases at this scale, they have been produced at 1:10 000 using enlargements of the 1:25 000 digital bases. The 1:2 500 digital bases should become available in 1998 when map production at this scale can be undertaken.

It should be noted that the flood extents have been plotted based principally on flood marks which must be assumed to be of dubious precision and accuracy, and on verbal reports of the flood extents and depths provided during the site visits in July 1997. The extents should therefore be considered as indicative of the areas flooded during the event rather than definitive.

4 FLOOD DAMAGE

Tropical Storm Debbie caused extensive damage throughout St.Lucia to infrastructure, property and agricultural land. Preliminary estimates of the total cost of the damage (GoSL, 4 October 1994) were in the order of EC$209 million (18.9% of 1993 GDP). More recent estimates place the losses at EC$112.

4.1 Damage to Infrasructure

The principal damage to the country's infrastructure was to water systems, bridges and roads although power and telephone services were also disrupted.

Floodwater and siltation caused extensive damage to all water intakes which are run-of-river intakes with varying forms of diversion weirs.

Six bridges were totally swept away (e.g., Soufriere) and four others suffered significant damage.

While the surfaces of most major roads were unaffected by the storm, landslides resulted in some shoulders collapsing (see Section 4.4) including those of the two main roads (Barre D'Isle and west coast roads).

The Hewanorra international airport runway and terminal building were flooded. The airport was closed for five days due to the silt deposited on the runway. Some ports experienced siltation which also adversely effected the coral reefs and marine environment.

Roseau Dam was under construction at the time of TSD and suffered significant damage when the works were overtopped and consequently breached. It is estimated that 30% of the completed works were lost at a cost of approximately EC$15 million. The floodwave caused by the breach aggravated the flood problem downstream. A video of the damage to the dam was taken shortly after the event. A copy is available in St. Lucia from Mr. Keith Compton (Tel: 452 8134).

4.2 Damage to Property

Approximately 200 houses were damaged by flooding during TSD of which around 100 were completely destroyed. Particularly severely hit were the towns of Soufriere where most of the town was inundated although only one property was rendered uninhabitable, Anse La Raye where 24 properties were damaged including four which were destroyed, and Dennery which was also extensively flooded with damage caused to 58 properties. Seven houses were also totally destroyed at Vieux Fort.

4.3 Damage to Agriculture

Losses to the agricultural sector were the most significant with the cost of the damage initially estimated at EC$134.9 million although later reduced by approximately 30%. Fertile soils were lost, crops damaged and land eroded and covered by landslides.

The banana industry is the primary employer and exporter on the island and it is estimated that 55% of the crop was either completely destroyed or severely damaged at an initially estimated direct cost of EC$76.6 million. More recent estimates from the industry (SLBGA and GEEST) show that before TSD production forecasts were 102,000 tons (taking account of the drought), while post-TSD production forecasts were 90,000 tons indicating an immediate drop of 12% (EC$10 million). Total crop production losses were estimated at EC$28 million (WINCROP).

Replanting and rehabilitation costs for all crops were initially estimated at EC$1 million at farm level, but vary considerably between crops depending on the amount of damage sustained. Many farmers rehabilitated their crops within a few months and also desilted blocked drains as part of their normal annual drain clearance regime. Others waited for works by the Government on the river and drainage system to ensure the viability of on-farm drainage systems.

4.4 Landslides

More than 400 landslides were reported to have occurred as a result of TSD resulting in the loss of soil, trees and crops which contributed to the debris and sediments which choked rivers and damaged adjoining farmland.

The economic costs of lost soil and forest resources and of permanently damaged valley farmland has not been evaluated.

An assessment of the landslide hazard zones was initiated following Debbie which is currently being undertaken as part of the WEMP II project. The main observations of the preliminary report relating to TSD are given below.

More than 90% of the landslides occurred in the upper reaches of the watersheds with landslides occurring in every main drainage area in some catchments (e.g. Fond D'Or and Troumassee). In other catchments (e.g. Soufriere and Marquis) a high density of slides occurred in isolated pockets. The density of slides in some areas (e.g. Quilesse Forest Reserve, Roseau) was between 12 and 20 per square kilometer.

A large proportion (87% of those examined by December 1994) were shallow debris flows, 10 to 20 m in width, originating close to ridge crests. Debris and rock slides occurred principally along roads (e.g. Barre de L'Isle, road between Canaries and Soufriere) and the east road south of Micoud).

4.5 Damage to the Marine Environment

Sediment flowing into the sea buried some coral reefs and marine fishery habitats. The cost of reduced fish catches and the adverse effect on tourism resulting from the loss of some coral reefs has not been quantified.

5 HYDROLOGICAL ANALYSIS

5.1 Flow Data

Although river gauging stations with chart recorders were in place and generally operative prior to Debbie (**Table 5.1** lists the stations active in 1992), they were unable to record the flood peak as all of the stations were flooded and some of the stilling wells and recorders were destroyed during the event. Therefore no discharge data is available for the event.

Table 5.1 River Gauging Stations in 1992

River	Gauging Site	Operator (in 1992)	Installation Date
Choc	Treatment Plant	LWUU[1]	1985
Cul-de-Sac	Ferrand's Bridge	LWUU	1985
Cul-de-Sac	Ravine Poisson	WASA	1983
Doree	Coast Road Bridge	LWUU[2]	1984
Fond D'Or	Mabouya Bridge	LWUU	1984
Marquis	Marquis Bridge	LWUU[3]	1986
Millet	Bridge	WASA	1983
Roseau	Cable	WASA	1983
Troumassee	Beauchamp Estate	LWUU	1984
Vieux Fort	La Retraite Bridge	LWUU[4]	1985

NOTE: 1 Poorly sited next to water intake
2 Catchment now heavily pumped
3 No reliable rating curve
4 Vandalised

5.2 Estimates of Peak Flow

Although no flow data is available for Debbie, various estimates have been made of the peak flow at a range of locations. The estimates are presented together in **Table 5.2**.

Rodriguez (1994) estimated the peak flows at four locations based on both Manning's Formula (using high water level marks and surveyed channel/floodplain cross-sections) and the Rational Formula ($Q_p = 0.278CiA$) using a runoff coefficient, C, of 0.7 except in the upper Dennery catchment where a value of 0.9 was considered more appropriate. Rainfall intensity was assumed to be 99.6 mm/hr, a 10% increase over more frequently used estimate of 90 mm/hr.

Stanley and Klohn Leonoff (1994, (ii)) reviewed the impact of TSD on the Roseau Dam and calculated the peak discharge prior to, and after, the breach occurred. This analysis confirmed the design parameters and storm and flood used in the calculations for the Roseau Dam and spillway capacity.

Ms N Eernisse (1996) calculated peak flows for the event for the Cul-de-Sac river at Bexon and Ferrands Bridge based on the Rational Formula ($Q_p = 0.278CiA$) using a runoff coefficient, C, of 0.7.

Table 5.2 Estimated Peak Flows during Tropical Storm Debbie

Location of Flow Estimate			Estimated Q_p (m^3/s)			
River	Site	Area (km^2)	Rational Method[1]	Rational Method[2]	Manning Method[1]	Avg.
Cul-de-Sac	nr. outfall	40	792.3		819.5	805.9
Cul-de-Sac	Ferrand's Bridge	30		525.4		525.4
Cul-de-Sac	Bexon	9.4	182.1	164.6	225.5	190.7
Dennery	Upper catchment	6.93	172.6		243.2[3]	207.9
Dennery	Upper catchment	12.1	234.4		209.7	222.1
Roseau	Middle catchment	22.8	441.6		472.6	457.1
Roseau	Dam	15.2				270[4]

Notes:
1. As applied by Rodriguez (1994)
2. As applied by Eernisse (1996)
3. Water level believed to have been significantly raised by channel blockage, resulting in a probable over-estimate of the flow.
4. Methodology applied by Stanley-Klohn Leonoff not specified. Estimated maximum discharge from dam in the range of 260-375 m^3/s with peak flood to dam prior to breaching in the range of 240-290 m^3/s.

The estimated flows at each location may be considered to be in reasonable agreement; the maximum variation of any estimate from the average is less than 20%.

Table 5.3 gives the runoff per km^2 at each location based on the flows calculated using Manning's method as applied by Rodriguez and on the derived average. With the exception of the estimate for the upper Dennery catchment, the values are approximately equal, averaging 18-19 $m^3/s/km^2$, equivalent to a percentage runoff during peak flow of approximately 75%.

Table 5.3 Estimated Peak Runoff

Catchment	Location	Estimated Peak Runoff ($m^3/s/km^2$)	
		Manning's Method	Average
Cul-de-Sac	nr. Outfall	20.0	19.7
Cul-de-Sac	Ferrand's Bridge	N/A	17.5
Cul-de-Sac	Bexon	24.0	20.3
Dennery	Upper 1	35.1	30.0
Dennery	Upper 2	17.3	18.4
Roseau	Middle	20.7	20.1
Roseau	Dam	N/A	17.1[1]

Notes 1. Estimated by Stanley and Klohn Leonoff

5.3 Significance of Flood Event

The Institute of Hydrology (IoH) in the UK estimated the Mean Annual Flood and 50 year return period flood on the Cul-de-Sac river at Ferrand's Bridge as 28.8 and 46.1 m^3/s respectively using a rainfall-runoff model with 6 years of flow data (Ref; IoH, 1992). Using the growth curve generated by IoH, the estimate of Q_p at Ferrand's Bridge for TSD given in **Table 5.2** would give the event a return period significantly in excess of 1000 years with a growth factor (Q_P/Q_{MAF}) of almost 20.

During Hurricane 'Beulah' in 1967, 378 mm of rain fell in 24 hours of which most fell within 12 hours. The resulting flood is considered to be of comparable magnitude to TSD (Ref; AESD, 1994). Other events that *may* have been of a similar magnitude occurred in 1897 and 1938 (i.e., similar events have occurred at approximately 30 year intervals prior to TSD). A list of major floods effecting St. Lucia are listed in Appendix A.

A lesser, but significant, flood event occurred only two years after TSD (26th October, 1996) for which the peak flow at Ferrand's Bridge is estimated at almost 300 m^3/s (Ref; HTS/MML, 1997).

It may be concluded from the frequency of apparently extreme storms that the IoH predictions of design flows might be erroneous. This is probably due to the absence of long flow records and the reliance on a data series of only 9 year which did not include four major events that have occurred during the last 30 years.

The time of concentration to urbanised locations within most of the catchments is estimated to be in the order of one to three hours (although this is to be confirmed once reliable catchment models have been constructed). The rainfall intensities for these durations are in excess of the *estimated* 100 year intensities (Section 2.5) which, combined with the likely saturated soil conditions prior to the storm, would result in flood flows of extreme rarity.

In summary, the rainfall intensities over the critical durations would indicate a return period in excess of 100 years as would the estimated peak flows assuming the IoH design flows to be correct. It should be remembered however that Hurricane 'Beulah', an event thought to be similar in magnitude to TSD, occurred in 1967, less than 30 years before and that other events that *may* have been of a similar magnitude occurred in 1897 and 1938 (i.e., at approximately 30 year intervals prior to TSD). It may therefore be assumed that the event has a return period in the order of 30 to over 100 years.

6 CONCLUSIONS AND RECOMMENDATIONS

Tropical Storm Debbie comprised extreme intensity rainfall over durations of 1 to 6 hours (return periods in excess of 100 years). The estimated return period of the 1 day rainfalls is 50 to 100 years. The event occurred over significantly wetter than normal soil conditions.

The resulting floods covered most low-lying flat areas to a depth of up to, and in some cases in excess of, 2 m resulting in extensive damage to agriculture, infrastructure and property.
Event peak flows have been produced that may be considered to be of acceptable reliability for an initial estimate but no return period may be attached to the estimates given the general absence of flow data and reliable design discharges. An event of similar magnitude occurred approximately 30 years ago with other events possibly of similar magnitude having occurred at thirty year intervals prior to this.

It is concluded that TSD flood event has a return period in the order of 30 to in excess of 100 years.

WEMP Phases I and II are currently implementing works to reduce the flood risk to many areas and cover the majority of the recommendations that might have been made. The project is also assisting in the implementation of the expansion of the hydrometric network. Recommendations made below are therefore restricted to hydrological work and do not cover practical flood alleviation measures.

It is recommended that a full review, data check and analysis of historical rainfall records is undertaken, in particular of short duration (0.5 to 6 hour) rainfall intensities. This would be a major study requiring approximately two man-months of engineer/technician time. The study should also include detailed analysis of 6 day rainfall depths on a wet-season only basis.

Flood marks for this and other significant events should be surveyed to provide flood level data to datum. This will be useful in the production of flood maps, the estimation of peak flows at non-gauged locations, the design of flood defence and infrastructure works and in the calibration of hydraulic models should they be built.

For the same reasons as the recommendation above, crest gauges should be installed as far as resources permit to monitor peak water levels.

A review should be undertaken of the available hydrological information from neighbouring islands and a brief study undertaken to investigate any similarities in physical conditions and rainfall patterns.

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APPENDIX A
MAJOR HISTORICAL STORMS AND HURRICANES TO EFFECT ST. LUCIA

Given below are outline details of the major storms and hurricanes that have effected St. Lucia over the last 100 years. It should be noted that it is not always clear whether the damage detailed is caused by flooding or high winds.

1894	Heavy landslides and 'incalculable damage to crops'. 45 houses washed away in Soufriere. 11 killed.
1897 (11 Sept)	353 mm of rain. 'Hundreds of peasant properties in total ruin'. Cocoa crops swept away.
1921 (10 Sept)	Cocoa crop, communications and ships damaged. 15 killed.
1928 (19 Sept)	Crops and road destroyed and fish market and jetty washed away at Roseau.
1938 (21 Nov)	'Worst storms in living memory'. Annual rainfall 960 mm above average, 242 mm in 24 hours at Barre De L'Isle. 120 killed, mainly through landslides.
1939 (7 Jan)	Three villages destroyed. 100 killed and 250 missing.
1940 (7 Aug)	Extensive damage to crops. Roads swept away. Cul-de-Sac valley particularly badly hit.
1954 (12 Dec)	3250 mm of rainfall recorded for the year. Ravine Poisson badly hit by landslides, whole crop destroyed.
1960 (10 July)	Hurricane 'Abbey'. Damage to roads, bridges and electricity supply. 6 killed.
1963 (24 Sept)	Hurricane 'Edith'. 60% of banana trees destroyed in effected areas (mostly north and east). Estimated damage EC$4 million.
1965 (25 Oct)	40% of all banana crop effected. Castries area worst hit.
1967 (8 Sept)	Hurricane 'Beulah'. 378 mm of rain in 24 hours, most of which fell within 12 hours. 18 killed. 'Collapse of road system - millions of tons of top soil washed away'. (Event similar in magnitude to TSD in terms of rainfall and probably flooding)
1979	Hurricane 'David'.
1980	Hurricane 'Allen'.
1988 (10 Sept)	Hurricane 'Gilbert'. Over 200 mm of rain in 24 hours at Union.
1989 (18 Sept)	Hurricane 'Hugo'.
1994 (10 Sept)	Tropical Storm Debbie. Maximum rainfall intensity approximately 90 mm/hr with 276 and 372 mm of rain in 24 hours at Union and Errard respectively. 4 killed, 100 homes destroyed + 100 damaged. Total damage estimated at EC$112 million.

The information above was principally derived from AESD, 1994 and IoH, 1992.

Appendix C

Flood Report for the Storm of 26th October 1996

The Flood Report is intended to stand alone, hence some duplication of data and information will be found with the main sections of the Annexes.

Appendix C

FLOOD REPORT
EVENT OF 26 OCTOBER 1996

1 INTRODUCTION

1.1 Flood Summary

On the morning of Saturday 26th October, 1996, heavy rain fell over the island of St. Lucia as a result of a tropical wave. The rainfall recorded varied greatly across the island with the greatest depths recorded in the south-east and at points along the west side of the island.

The 24 hour rainfall depth recorded during the event varied between approximately 100 and 350 mm, with the greatest depths recorded at Bathe Nursery and Union Vale (south east of Soufriere), Mahaut (in the upper reaches of the Troumassee valley) and at Bexon and Soucis (Cul-de-Sac Valley). Most of the rain fell within 6 hours and 1 hour rainfall intensities reached 73 mm/hr at Mahaut. The rainfall event is considered to have a return period of between 2 and 60 years (2 hour duration).

The resulting high flows (estimated at almost 300 m^3/s in the Cul-de-Sac valley at Ferrand's Bridge) caused significant damage to infrastructure, property and crops. Particularly badly effected were the Troumassee, Roseau and Cul-de-Sac valleys and the towns of Anse La Raye and Canaries. No lives were lost although 2 houses were destroyed.

Many of the Phase I works undertaken as part of the Watershed and Environmental Management Project (Ref; GoSL, 1994), initiated following Tropical Storm 'Debbie' (TSD) that had devastated the island on 10th September 1994, were also damaged. The works significantly reduced the impact of the flood at certain locations (e.g. Soufriere) while at other locations they may have had a negative impact causing increased erosion and loss of land.

All of the river flow gauges were damaged during TSD and had not been repaired since. There are therefore no flow records for the event. The peak flows have however been estimated at approximately 370 m^3/s at the outfall of the Cul-de-Sac valley and as 325 m^3/s at Durandeau in Roseau Valley.

1.2 Flood Reporting

This report has been compiled almost a year after the event. Site visits were undertaken in July 1997 during which interviews were conducted with local residents, administrators and engineers to derive information concerning flood extents, depths and damage that might compliment previously available data. The information derived is given in Section 3.1 of the report and summarised on the flood extent maps which have been produced for certain locations.

The rainfall analysis has been undertaken using all available data provided by AESD and NMSD. Flow estimates have been made using the rational method. Further estimates of peak flows may be made using Manning's slope-discharge equation once the WEMP II survey work has been completed.

2 RAINFALL ANALYSIS

2.1 Meteorological Description

No details of the meteorological conditions that led to the storm have been collected.

2.2 Flood Warning

No specific flood warnings were issued to either the public or relevant authorities although the movement of the tropical wave had been monitored and reported on radio and television weather forecasts.

2.3 Rainfall Data

2.3.1 Antecedent Rainfall

The event of 26 October 1996 occurred after a period during which the country received variable rainfall. Parts of the island had remained comparatively dry with less than 10 mm having fallen (Bathe Nursery, Saltibus and Union Vale) while other locations received approximately twice the annual six day average (Bexon, Troumassee).

Rainfall depths for the antecedant (6 day) period are given in **Table 2.1** along with the annual average 6 day and September monthly rainfall depths.

Table 2.1 Antecedent Rainfall to 26 October (mm)

Date	Raingauge Station					
	Bexon	Bathe Nursery	Cap Estate	Saltibus	T'massee	Union Agri'tl
19 Oct	0.4	1.3	0.0	4.6	14.1	0.5
20 Oct	2.8	0.1	0.0	0.0	0.0	0.0
21 Oct	24.6	1.2	7.2	2.5	8.1	21.4
22 Oct	3.4	0.7	7.6	0.5	3.4	3.0
23 Oct	41.0	0.3	37.4	0.0	28.0	19.2
24 Oct	6.0	5.1	0.0	0.0	2.8	2.1
Total	78.2	8.7	52.2	7.6	56.4	46.2
Average 6 Day Rainfall	43.0	N/A	23.5	N/A	28.3	33.6
Average Monthly Total	295	323	185	312	194	248

NOTE: The six day average rainfall depths are calculated annually rather than considering only the wet season. Details of calculation of average 6 day rainfalls given in Appendix A, Section A8.

2.3.2 Total Rainfall Depths

Given in **Table 2.2** are the total rainfall depths that occurred on the 25th and 26th October. It should be noted that heavy rainfall began at around 6 a.m. on the 26th and would hence have been included on the rainday of the 25th. **Table 2.3** gives the 24 hour rainfall depths for a selection of stations starting at 00:00 hrs on the 26th. Comparison of **Tables 2.2** and **2.3** reveal that over 95% of the combined normal daily rainfall totals (25th and 26th) fell during the 24 hour period following 00:00 hrs on the 26th.

The depths given in **Table 2.3** are generally lower than those experienced during Tropical Storm Debbie (1994) by about 30-50%. At Soucis gauge however a greater depth was recorded than during TSD, and almost 350 and 300 mm fell at Bathe Nursery and Mahaut respectively of which 95% probably fell during 12 hours.

Table 2.2 Total Rainfall Depths during Event of 26 October, 1996

Raingauge Station	Station Elevation (m)	Rainfall Depth 25 October(mm)	Rainfall Depth 26 October (mm)
Bexon	23	65.4	207.0
Barre de L'Isle	290	45.0	108.8
Bathe Nursery	367	75.4	272.9
Cap Estate	23	78.2	59.0
Errard	70	58.2	91.0
George V Park	6	26.7	91.7
La Caye	25	38.6	59.8
La Resource	14	50.2	60.4
Mahaut	129	55.4	239.4
Mamiku	N/A	49.2	82.8
Patience	92	17.0	122.1
Saltibus	282	37.0	168.3
Soucis	9	43.8	214.6
Troumassee	17	43.8	104.2
Union Agri. Stn.	11	92.1	70.0
Union Vale	242	54.8	250.7

NOTE: Rain days start at 9 AM on the given data.

Table 2.3 24 Hour Rainfall Totals from 00:00 hrs, 26th October

Raingauge Station	24 hr Rainfall Depth (mm)
Bexon	256.6
Barre de L'Isle	144.8
Cap Estate	134.4
Mahaut	281.6
Soucis	248.4
Troumassee	141.0

2.3.3 Rainfall Intensities

Six of the rainfall recorders were operative during the storm of 26th October. The data from these stations has been analysed and the peak intensities for a range of durations calculated. Plots from the logger data are given at the back of Appendix A.

Intermittent rainfall had occurred during the night of the 25th/26th October. The intensity of the rain began to increase from about 6 a.m. (on the 26th), steadily rising to a peak between 10 a.m. and 12 noon. The intensity then gradually decreased over the afternoon, petering out at around 6 p.m. **Figures 2.1 to 2.3** show the 1, 2 and 3 hour rainfall intensities recorded at the six operative rainfall recorders. Peak rainfall intensities are given for a range of durations in **Table 2.4** and shown graphically in **Figure 2.4**.

Table 2.4 Maximum Recorded Rainfall Intensities for 26 October 1996

Rainfall Station	Maximum Intensities (mm/hr) for Specific Durations (minutes)							
	5	10	15	30	60	120	180	360
Bexon	106	106	104	81.2	60.6	50.8	40.9	31.5
Barre de L'Isle	76.8	55.2	49.6	34.4	27.4	21.6	19.1	16.2
Cap Estate	115	73.2	66.4	52.0	45.0	33.5	24.5	15.5
Mahaut	130	110	106	91.2	73.0	66.5	56.3	38.0
Soucis	98.4	84.0	78.4	68.4	56.4	43.7	41.1	33.4
Troumassee	96.0	75.6	64.8	42.0	28.0	23.1	19.7	15.9

2.4 Spatial Rainfall Variability

It can be seen from **Tables 2.2 and 2.4** that the peak intensities and total rainfall depths during the storm varied significantly across the island. The heaviest rainfall fell over the central highlands around, and particularly to the south of, Mount Gimie (e.g. Bathe Nursery, Union Vale, Mahaut and along Cul-de-Sac valley) with stations at lower elevations recording lower depths.

During TSD, there was a distinct east-west pattern in the rainfall depths recorded with the stations in the rainshadow along the west coast recording lower depths than may have been expected given their altitude. This phenomenon was not observed during the event of the 26th October and, with the exception of Soucis, all coastal stations recorded below average rainfall depths.

2.5 Rainfall Data Analysis

Some general analysis of short duration and 1-day rainfall depths and return periods has been undertaken. Details of the study and results are provided in Appendix A and are outlined below.

Daily rainfall records for eight stations have been collected from the HYDATA database at AESD. The annual maxima series were extracted for each station for years were the data set was considered to be adequate. The series were then cross-correlated and missing values in-filled where appropriate. Frequency distributions were then fitted to each of the series (Sections A1 to A4).

Frequency analysis was undertaken on the series to determine design 1 day rainfall depths (Section A5.1 and A9).

FIGURE 2.1

1 Hour Rainfall Intensities - 26 October, 1996

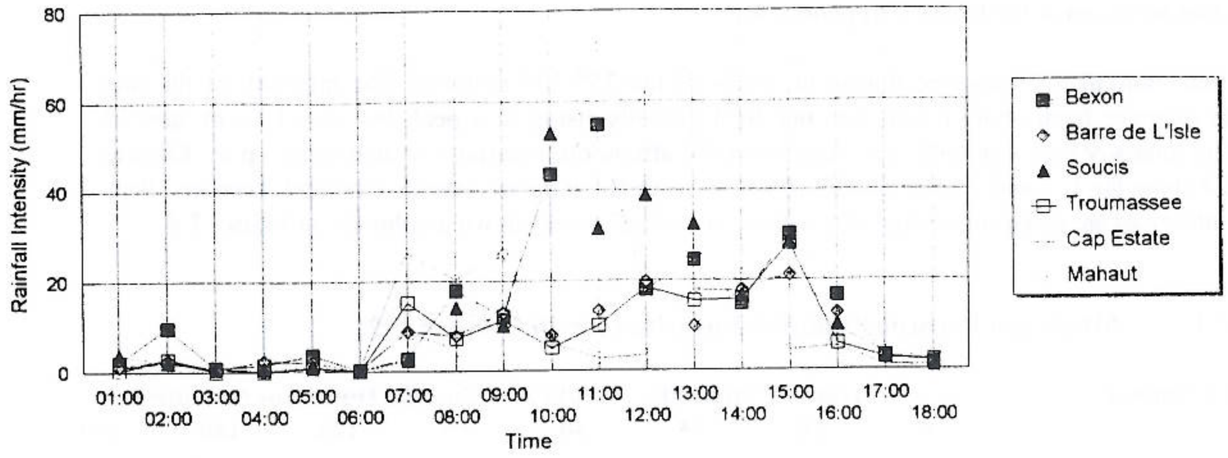


FIGURE 2.2

2 Hour Rainfall Intensities - 26 October, 1996

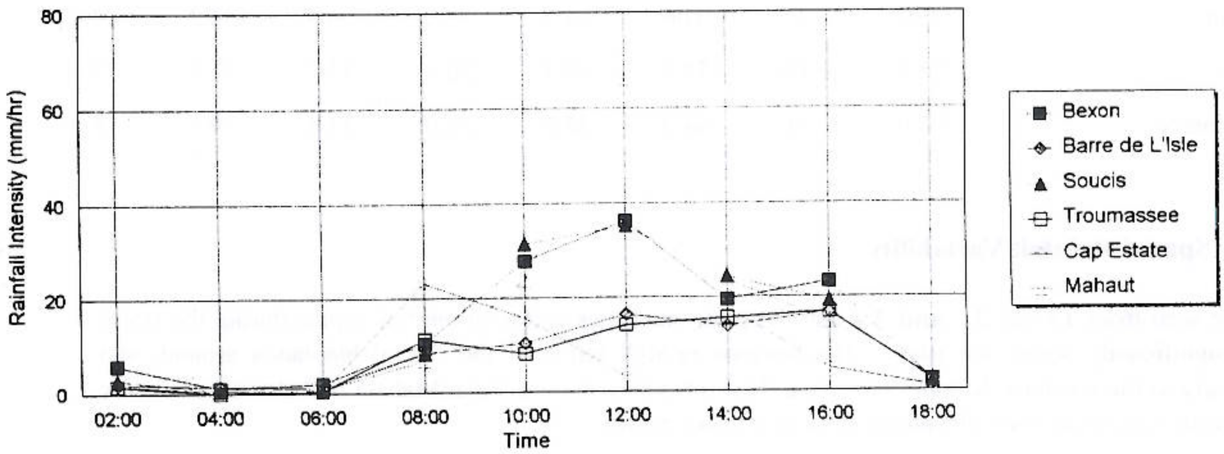
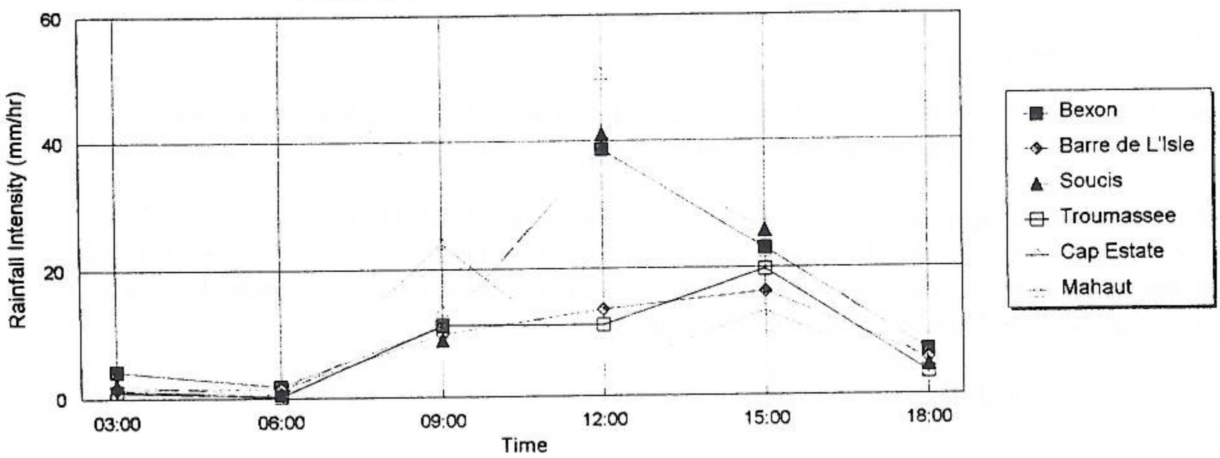


FIGURE 2.3

3 Hour Rainfall Intensities - 26 October, 1996



Frequency-duration curves have not been derived for any rainfall gauges except for that at Union Agricultural Centre. For comparative purposes the frequency-duration-intensity curves for the gauge at Union Agricultural Station is produced in **Figure 2.5**. The GEV Type-II distribution fitted to the Union data was applied to other stations using ratios of mean annual daily rainfalls and their relative growth factors to produce estimates of design rainfalls for 1, 2 and 6 hour durations (Section A5.2).

If, after further analysis, the distributions adopted prove to be applicable, then the rainfall event of the 26th October would have a return period at each gauge as given in. **Table 2.5.**

Table 2.5 Estimated Return Period (years) of Rainfall Event of 26th October

	Estimated Return Period (years) of Event for Given Duration			
Station	**1 Hour**	**2 Hour**	**6 Hour**	**24 Hour**
Bexon	50	60	>100	20
Barre de L'Isle	<2	<2	2	2
Cap Estate	2	2	<2	2
Mahaut	50	60	>100	100
Soucis	30	40	>100	50
Troumassee	<2	2	2	2

NOTE: These values should not be used for any purpose other than as approximate first estimates.

Clearly there is a significant variation in estimated return period which may be due to natural variations in the rainfall depth falling during the storm, but is also likely to be due to the inapplicability of the Union statistics to the gauges in the central highlands.

3 FLOOD EXTENTS

The flooding caused by the heavy rainfall during the event effected large tracts of land, particularly in the flat, low-lying floodplains of the major river systems (e.g. Roseau, Cul-de-Sac, Mabouya and Dennery).

Photographs of the flood extents and levels were taken during and immediately after the event. Site visits were further undertaken in July 1997 when local residents, administrators and engineers were interviewed to obtain further details concerning flood extents, depths and the damage caused by the event.

The photographs and information derived were subsequently analysed and the flooded areas mapped out at 1:2 500 scale for urban areas and severely effected rural valleys. A full set of the maps for this and other events are kept at the AESD office at Union.

3.1 Flood Description and Depths

Summarised below are the descriptions of the flooding and the flood depths reported during the site visits undertaken in July 1997. No painted flood marks of peak water levels were located for this event.

Cul-de-Sac Valley

- The river remained in-bank at the bridge in Ravine Poisson.
- Flooding occurred over low spots on the road upstream and downstream of the community centre in Bexon making the road impassable (flood depth approximately 1 m)
- Flooding over the road occurred to a depth of approximately 1 m at .
- Flood waters reached 0.3 m above the supermarket floor in Bexon.

FIGURE 2.4

Rainfall Intensity Duration Curves - 26 October, 1994

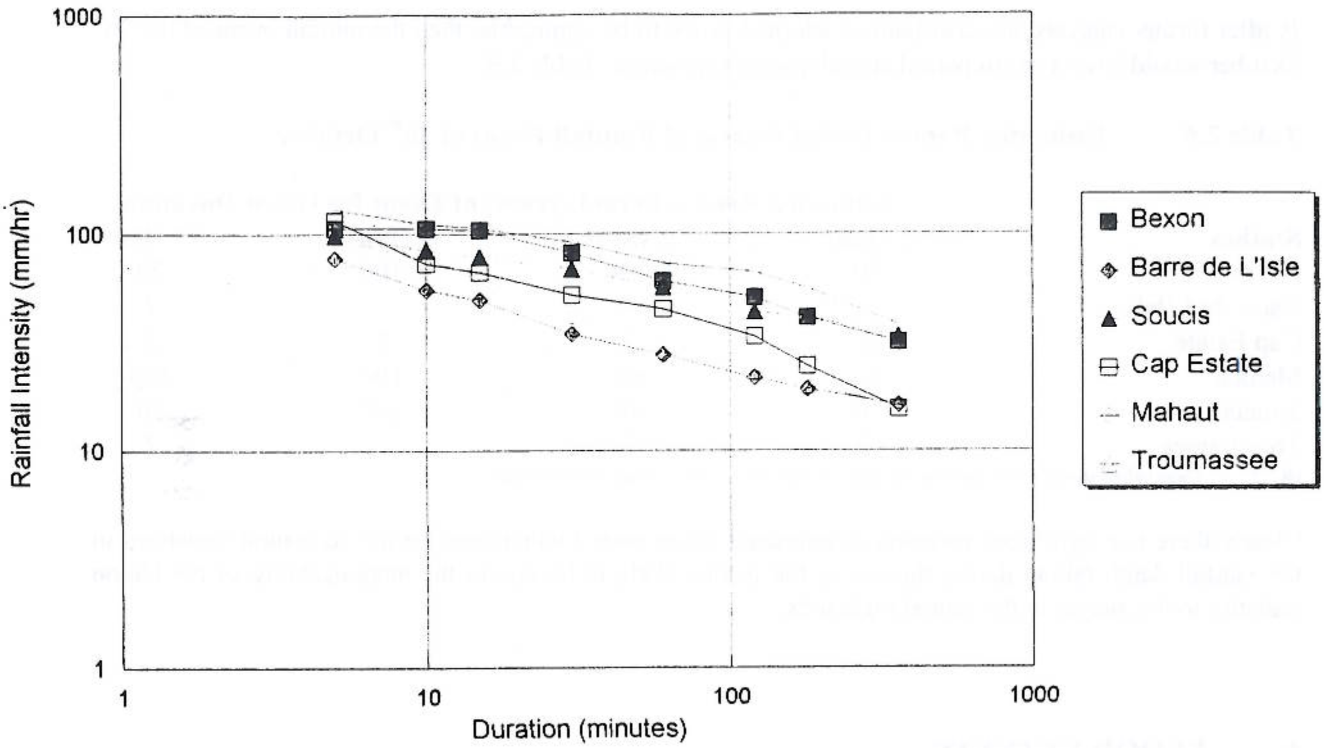
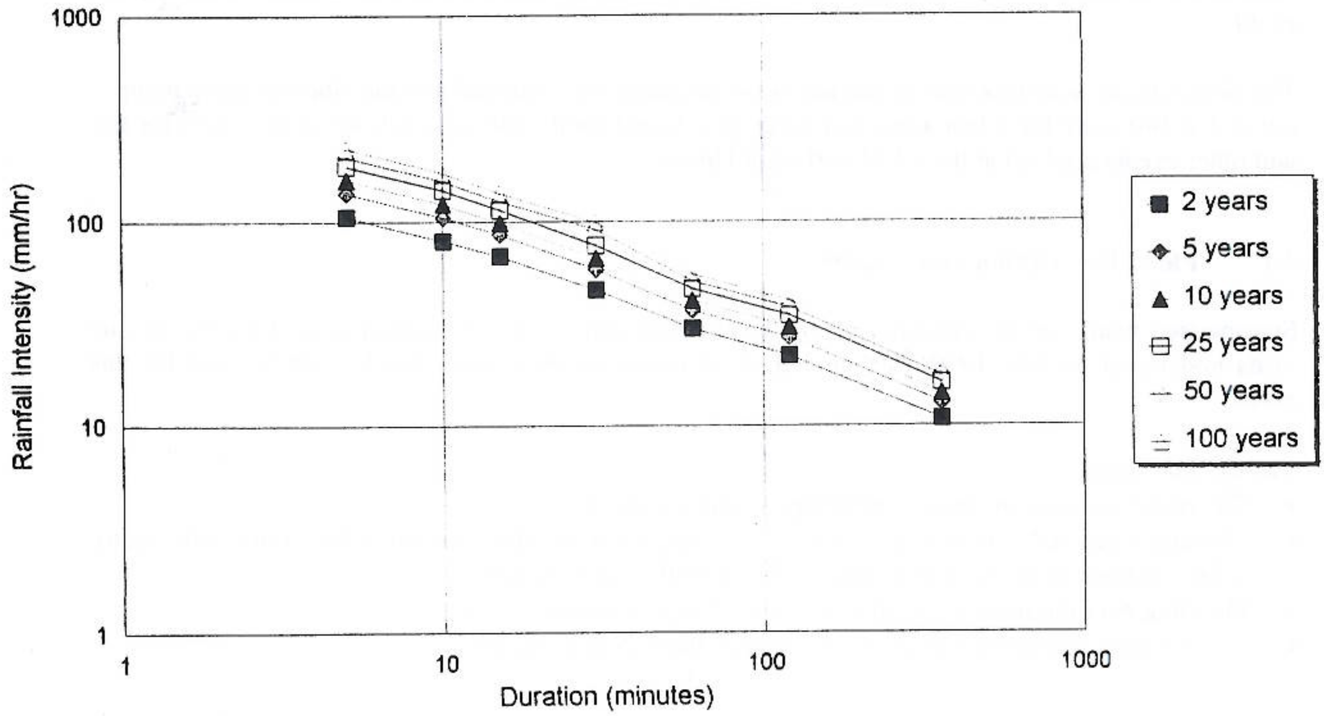


FIGURE 2.5

Frequency-Intensity-Duration Curves - Union Agricultural Station



- The land south and west of the road between Deglos Junction and Bexon flooded with water over the road to a depth of 0.1 - 0.3 m.
- The road adjacent to the revetment works undertaken as part of WEMP II downstream of Bexon was flooded to a depth of 0.1 m.
- The road through the lower reaches of the valley flooded up to 0.5 m deep. The bridge carrying the main road to Bexon was overtopped as was the west coast road.

Roseau Valley

- The water level reached approximately 0.1 m above the deck of the bridge upstream of Durandeau that was destroyed during the event.
- The road over the culvert at Vanard flooded to a depth of approximately 0.1 m.
- The flood waters reached approximately 1.5 m above the deck of the bridge on the Vanard to Sarot road.
- The road at Morne D'Or flooded to approximately 0.5 m.
- The houses near the Roseau Factory flooded to a depth of approximately 1.0 m.

Mabouya - Fond D'Or Valley

- The banana boxing plant at Grande Riviere flooded to a depth of approximately 0.75 m.
- The shop on the north side of the main road near the turning to Morne Panache flooded to a depth of approximately 0.3 m. The main road at this location was not flooded.
- The house by the turning to the school downstream of Grand Riviere flooded to a depth of approximately 0.2 m.
- The road at the junction of the main road to La Resource flooded to approximately 0.3 m.
- No buildings at La Resource were flooded but the road outside the community centre was.

Dennery Valley

The WEMP Phase I works (including a flood embankment along the left bank of the river downstream of the main road) was almost complete at the time of the event. Some gabion baskets had not yet been placed at the upstream end of the defences and consequently water spilled over the left bank but returned to the river 200 - 300 m downstream. No properties were effected.

Troumassee Valley

Trash marks indicated that flood depths in Troumassee valley were approximately 0.5 m below those experienced during TSD upstream of the main east coast road bridge. Depths along the right bank are therefore estimated to have been approximately 1.0 m above track level or 6.0 m above river bed level.

Canelles Valley

Trash marks indicated that flood levels near De Mailly were approximately 0.8 m below TSD levels, i.e., approximately 2.5 m above river bed level.

Vieux Fort

- There is a mark on a tree at the upstream end of Joyeaux. The flood level was reported to have reached approximately half way between the ground and this line (about 1.0 m above the bridge deck).
- Flood levels reached approximately 2.5 m above the deck of La Retraite bridge.
- The banana boxing plant on the left bank downstream of La Retraite bridge was flooded to approximately 1.0 m (red mark on tree opposite TSD mark in same location).
- Buildings at Harlel Integrated Farming Project were flooded to approximately 1.5 m (where the painted colour changes on the concrete posts of the first building).
- Taxi stand building at Hewanorra Airport was flooded to approximately 0.5 m.
- The track into the shanty town on the east side of Vieux Fort flooded to a depth of approximately 0.5 m.

- Properties on the west side of Vieux Fort near to the outfall of the original river course flooded to a depth of approximately 1.0 m.

Soufriere
- The WEMP phase I channel improvements had been completed and the river remained in-bank through the upper part of the town.
- The footbridge connecting the school to Desmond Avenue was inadequate to pass the flow and became blocked causing flooding of the left bank.
- The road outside the hospital was flooded to a depth of approximately 0.5 m.

Canaries
The village of Canaries was severely flooded during the event, more so than during TSD. This is reportedly due to heavy siltation of the river bed during TSD which has caused a significant reduction in the channel capacity.
- Houses along Valley Road on the left bank upstream of the village were flooded to up to 1 m deep.
- Flood waters were approximately 1 m deep outside the house at the top of Badal Road.
- The playing field flooded to a depth of approximately 1.5 m.
- The house on the left bank immediately upstream of the bridge was flooded to approximately 1.5 m.
- Flooding over the main road through the village (on the right bank) was approximately 1 m deep.
- The road outside the police station (High Street) was flooded to a depth of approximately 0.75 m.
- Flooding over the junction of Cork Street and the High Street was approximately 1.5 m deep.

Anse La Raye
Flooding during this event through Anse La Raye was similar in depth and extent to that experienced during TSD.
- The main west coast road flooded to 1.5 m at the bridge over the Petite Riviere de Anse La Raye. Houses in the St. Laurent Estate were flooded to a similar depth.
- Flooding in the car park at the Health Centre by the main road rose to approximately 2 m above ground level.
- The playground of the school on the right bank of the Grand Riviere de Anse La Raye upstream of the town was flooded to a depth of approximately 1 m.
- The community centre on the right bank of the Grand Riviere flooded to 1.5 m.
- The area upstream of the main road flooded to depths of up to 2 m above road level.
- The main west coast road was flooded to 1 - 1.25 m deep.
- The church and immediate surrounding land were not flooded as the water flowed down St. Louis and Market Streets to the sea.
- The north end of Front Street was flooded to a depth of approximately 2 m above road level.

3.2 Flood Extent Mapping

Based on the information given in Section 3.1, topographical data provided on the 1:2 500 maps and photographs taken during and after the event, peak water levels were derived along the rivers and the corresponding flood extents marked (where significant and markedly different from those experienced during TSD).

The maps have been plotted at a scale of 1:2 500 but due to the current lack of digital bases at this scale, they have been produced at 1:10 000 using enlargements of the 1:25 000 digital bases. The 1:2 500 digital bases should become available in 1998 when map production at this scale can be undertaken.

It should be noted that the flood extents have been plotted a year after the event based principally on verbal reports of the flood extents and depths provided during the site visits in July 1997. The extents should therefore be considered as indicative of the areas flooded during the event rather than definitive.

4 FLOOD DAMAGE

The flooding of the 26th October caused some damage to infrastructure, property and agricultural land. Two properties were destroyed during the event. Estimates of the cost of the damage and crop losses have not been made.

4.1 Damage to Infrastructure

Although many roads were temporarily impassable due to high water levels, little permanent damage was sustained.

In the Soufriere watershed, large sections of the road up to the Edmund Forest Hills from Fond St. Jacques in were lost and the road was left severely pot-holed along the Migny River. The top section of the gabion work, constructed as part of the WEMP Phase I works, collapsed on the left bank of the Soufriere River immediately downstream of the bridge destroyed during TSD. In the town, Desmond Avenue on the left bank, which was being resurfaced at the time of the flood, was damaged along with construction vehicles on the site.

In Canaries, a retaining wall built as part of the WEMP Phase I work was undermined and collapsed resulting in the loss of a section of the adjacent Valley Road. The gabion work downstream was also badly damaged as the backfill was scoured out and washed away. The main West Coast Road bridge right abutment was also undermined and collapsed, dropping the Bailey type decking at that end by approximately 2 m.

Significant scouring and embankment slippage occurred along the channel of the Roseau River, particularly at the new channel sections where loop cutting had been undertaken as part of the WEMP Phase I works. The main west coast road bridge was overtopped but not damaged while the bridge upstream of Durendeau was overtopped causing the deck to collapse into the river.

Scouring and embankment slippage also occurred along the channel of the Cul-de-Sac River. Gabion defence to a property upstream of Bexon constructed as part of the WEMP Phase II works partially collapsed following scouring out of the backfill caused by the misalignment of the works. The west coast road bridge was overtopped but not damaged. The undersized footbridge over the Cul-de-Sac river by Bexon School was also overtopped but not damaged. This bridge is considered to be structurally unsound and consideration should be given to its replacement.

The road to the WASA intake in the upper Troumassee valley was washed away with the rip-rap that had been placed along the channel to protect it. The bridge at Mahaut downstream was blocked but and overtopped but did not collapse. Downstream of the main east coast road bridge river training works had been placed in the middle of the channel (assuming that the left half the channel had the required design capacity) as part of the WEMP Phase I works. The resulting concentration of flows to the left of the channel caused the backfill to the bridge left wingwall and abutments to be washed away. The abutment itself survived and has since been reinstated.

4.2 Damage to Property

One property on the left bank of the Roseau River downstream of the destroyed bridge was washed away and another was destroyed by the bridge over the Petite Riviere in Anse La Raye.

4.3 Damage to Agriculture

The flat valley bottoms of most of the larger catchments were flooded to depths of up to 2 m. Roseau in particular was badly effected and the banana fields along the valley suffered severe damage. No estimate of the losses incurred has been made.

4.4 Landslides

The event was not generally noted for an exceptional frequency of landslides although, as described in Section 4.1, considerable slippage occurred along the channels of the Roseau and Cul-de-Sac rivers. This was in part due to the destabilisation of the river bed both in terms of long-section and planform, the creation of very steep sided trapezoidal sections and the failure to plant stabilising growth on the banks.

4.5 Damage to the Marine Environment

Unlike TSD, the event of 26th October was not noted for extreme volumes of debris and sediment and so damage to the marine environment is unlikely to have been exceptional.

5 HYDROLOGICAL ANALYSIS

5.1 Flow Data

All of the islands' river flow gauging stations were destroyed during Tropical Storm Debbie (1994) and had not been repaired before the event of the 26th October. There are therefore no flow records for the event.

5.2 Estimates of Peak Flow

Unlike during TSD, the rivers in flood during the event of 26th October did not carry vast volumes of debris and although some channel/structure blockage did occur, the peak water levels were generally due to the high flows. Consequently the errors in estimates of flood flow based on peak water levels (using Manning's equation) are likely to be less significant. Relevant cross-sections and water levels were however not available at the time of writing and so this analysis has not yet been performed.
Estimates of the peak flows at various points have been made using the rational formula,

$$Q_p = 0.278 * C * i * A,$$

where C Runoff coefficient (a value of 0.7 has been used),
i Average rainfall intensity (mm/hr),
A Catchment area (km^2).

The durations specified for the determination of the intensities are based on the estimated time of concentration of the catchment to that point (Table 5.1) using Kirpich's formula (Ref; Shaw, 1988),

$$Tc = 0.00025 * (L/(S)^{0.5})^{0.8}$$

where L Length of catchment along main channel (m),
S Overall catchment slope (m/m).

The areas used are those given in the calculation of the runoff during TSD (Ref; Eernisse (1996) and Rodriguez (1994)). Stream lengths and overall catchment slopes were measured from the relevant 1:25 000 scale maps.

Table 5.1 Times of Concentration to Points of Flow Estimation

River	Location	Length (m)	Slope (m/m)	Time of Concentration (hrs)
Cul-de-Sac	Bexon School	8000	0.057	1.0
Cul-de-Sac	Ferrand's Bridge	13500	0.035	1.9
Cul-de-Sac	nr. Outfall	16100	0.029	2.4
Dennery	nr. Water intake	4400	0.10	0.5
Dennery	nr. Bazile Rd junction	7100	0.06	0.9
Roseau	Dam	5400	0.16	0.5
Roseau	Durandeau	9800	0.09	1.0

The derived intensities (based on those calculated in Appendix A) and the resultant peak flow estimates are given in **Table 5.2.**

Table 5.2 Estimated Peak Flows using the Rational Formula

River	Location	Intensity (mm/hr)	Area (km^2)	Peak Flow (m^3/s)
Cul-de-Sac	Bexon School	60	9.4	110
Cul-de-Sac	Ferrand's Bridge	50	30.0	292
Cul-de-Sac	nr. Outfall	46	40.9	366
Dennery	nr. Water intake	91	6.9	123
Dennery	nr. Bazile Rd junction	75	12.1	177
Roseau	Dam	91	15.2	269
Roseau	Durandeau	73	22.8	324

5.3 Significance of 26^TH October Flood Event

The Institute of Hydrology (IoH) in the UK estimated the Mean Annual Flood and 50 year return period flood on the Cul-de-Sac river at Ferrand's Bridge as 28.8 and 46.1 m^3/s respectively using a rainfall-runoff model with 6 years of flow data (Ref; IoH, 1992). Using the growth curve generated by IoH, the estimate of Q_p at Ferrand's Bridge for the event of 26th October given in **Table 5.2** would give the event a return period significantly in excess of 100 years with a growth factor (Q_P/Q_{MAF}) of over 10.

During Hurricane 'Beulah' in 1967, 378 mm of rain fell in 24 hours of which most fell within 12 hours. The resulting flood is considered to be of comparable magnitude to TSD (1994, Ref; AESD, 1994) during which 360 mm fell at Bexon. Other major rainfall events of a similar magnitude to the event of 26th October occurred in 1970 and 1988. A list of major floods effecting St. Lucia are listed in Appendix B.

Given the unexceptional antecedant rainfall and 2-hour rainfall intensities with return periods no greater than 60 years, it is highly unlikely that the event of 26th October has a flood return period in excess of 100 years, especially given that four other rainfall events of similar or greater magnitude have occurred during the last 30 years. It is therefore likely that the IoH estimates of high return period design flows are underestimated. A return period for the flood event between 2 and 50 years (depending on the location) is more likely.

6 CONCLUSIONS AND RECOMMENDATIONS

The event of 26th October 1996 comprised, at some locations, extreme intensity rainfall over durations of 1 to 24 hours (return periods in excess of 100 years). The estimated return period of the 1 day rainfalls varies between 2 and 100 years. The event occurred after a period of spatially variable rainfall with some areas receiving approximately twice the average 6 day rainfall depth while others were relatively dry. The storm therefore fell over variable soil conditions.

The resulting floods covered most low-lying flat areas to a depth of up to, and in some cases in excess of, 1 m resulting in significant damage to agriculture with some minor damage also inflicted on infrastructure and property.
Event peak flows have been produced that may be considered to be of acceptable reliability for an initial estimate but no return period may be attached to the estimates given the general absence of flow data and reliable design discharges. Four other event of similar or greater magnitude have occurred during the previous 30 years.

It is concluded that the 26th October 1996 flood event has a return period in the order of 50 years in some areas (e.g., Cul-de-Sac and Troumassee valleys) but much lower in others (e.g., Cap, Union and Choc areas).

WEMP Phases I and II are currently implementing works to reduce the flood risk to many areas and cover the majority of the recommendations that might have been made. The project is also assisting in the implementation of the expansion of the hydrometric network. Recommendations made below are therefore restricted to hydrological work and do not cover practical flood alleviation measures.

Further estimates of the peak flows should be calculated using Manning's equation once the surveyed cross-sections become available.

It is recommended that a full review, data check and analysis of historical rainfall records is undertaken, in particular of short duration (0.5 to 6 hour) rainfall intensities. This would be a major study requiring approximately two man-months of engineer/technician time. The study should also include detailed analysis of 6 day rainfall depths on a wet-season only basis.

A review should be undertaken of the available hydrological information from neighbouring islands and a brief study undertaken to investigate any similarities in physical conditions and rainfall patterns.

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APPENDIX A
RAINFALL ANALYSIS
A1. Introduction

Given below is a description of the rainfall analysis undertaken during the preparation of this report. It is not intended to be an exhaustive study as that is beyond the scope of this report, but merely to provide estimates of the return period, and therefore the significance, of the event of the 26th October 1996. As such, data searches and checking have been brief. It is therefore considered that while the derived results are acceptable for the purposes of this report, they should not be used elsewhere except for comparison.

A2 Data Collection
26th October 1996

Daily rainfall was collected from the rainfall ledger maintained by AESD. Autographic data was downloaded from the operative rainfall recorders shortly after the event and was available for this study in digital, but unprocessed, format.

Historical Data

AESD maintain a hydro-meteorological database, HYDATA, on which is stored the daily and monthly rainfall records for St. Lucia. Although some of the older rainfall data is yet to be entered into the database, the available (more recent) records were considered to be adequate for the purposes of this study.

Annual maximum short duration (< 1 day) rainfall series (1979 - 1987) from Union Agricultural Station are provided in the IoH (1992) report. No additional search was undertaken to extend the series.

A3 Data Checking

Only a brief check of the reliability of the collected rainfall data has been undertaken (described below).

HYDATA was used to view each year of the daily rainfall data for each station. A year for a station was rejected where *significant* sections of the data was missing. If the missing section was not long or occurred during the dry season, then the record was compared to complete records from other stations to look for major events during the missing period. If none were noted then the year was included in the series. It is understood that this method carries the risk of including years where the annual maximum value is missing, but given the checking procedure, this risk is considered to be small.

The annual maximum series for each station was then reviewed and compared to the others. Unusually large or small values were noted and the daily series inspected for missing or accumulated data.

Data provided in other publications and the autographic rainfall data for 26th October has not been checked during this study.

A4 Extension of Data Series

Eight annual maxima series were derived from the collected data. The series for each station was correlated with those of other stations over coincident periods of significant length. Missing values in the series were then in-filled (using the derived regression equation) from the series showing the greatest level of correlation. Series that showed inadequate correlation with those of any other station were not extended. Figures A1 to A5 show the regression plots for the correlations considered to be

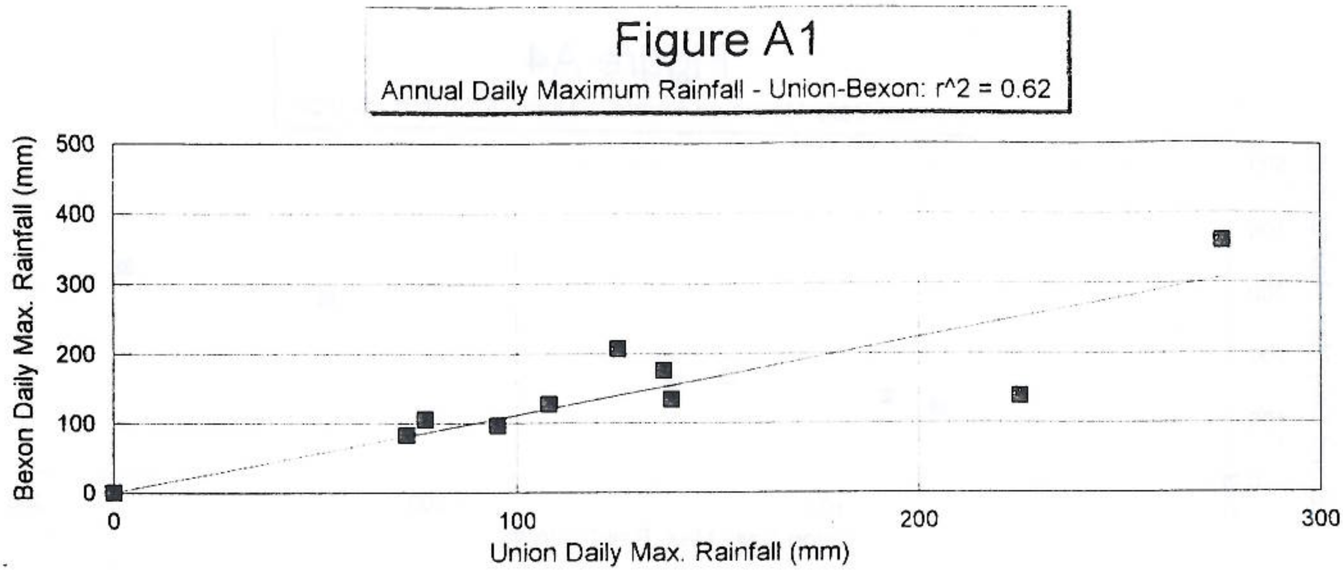


Figure A1
Annual Daily Maximum Rainfall - Union-Bexon: r^2 = 0.62
Bexon Daily Max. Rainfall (mm)
500
400
300
200
100
0
0
100
200
300
Union Daily Max. Rainfall (mm)

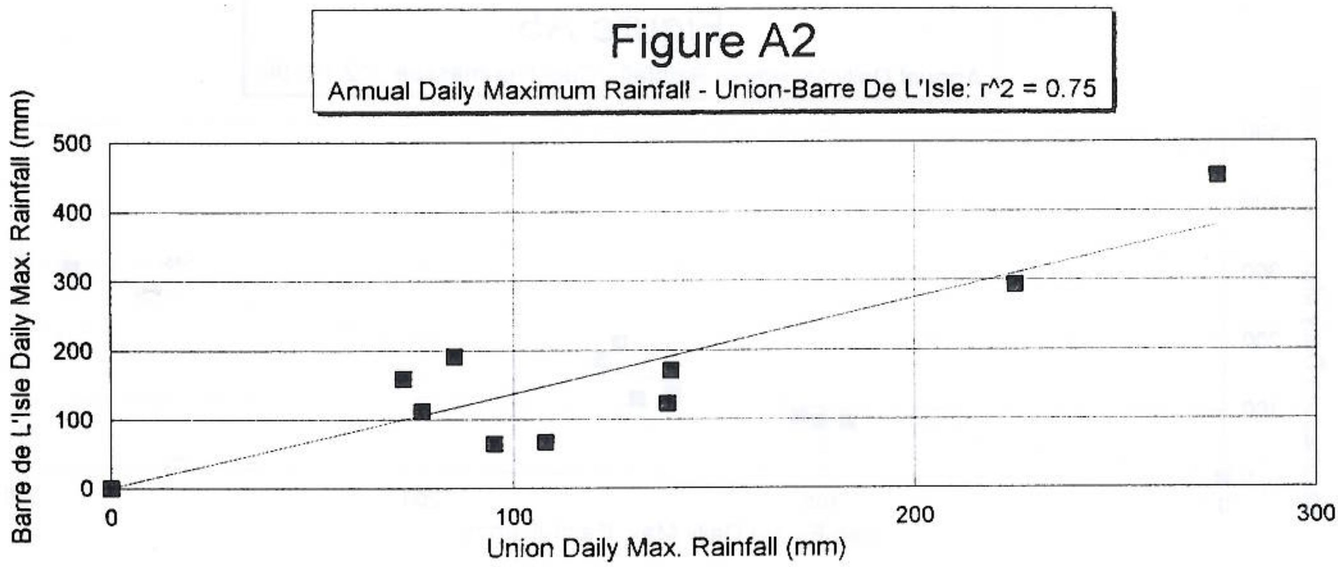


Figure A2
Annual Daily Maximum Rainfall - Union-Barre De L'Isle: r^2 = 0.75
Barre de L'Isle Daily Max. Rainfall (mm)
500
400
300
200
100
0
0
100
200
300
Union Daily Max. Rainfall (mm)

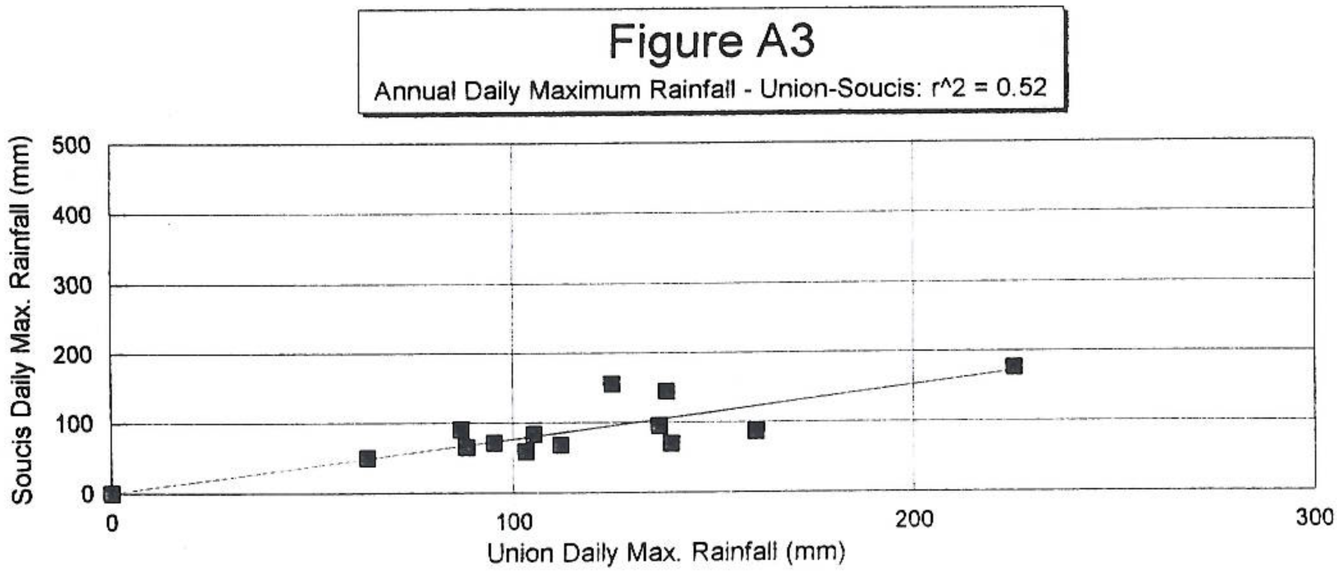


Figure A3
Annual Daily Maximum Rainfall - Union-Soucis: r^2 = 0.52
Soucis Daily Max. Rainfall (mm)
500
400
300
200
100
0
0
100
200
300
Union Daily Max. Rainfall (mm)

Figure A4

Annual Daily Maximum Rainfall - Union-Errard: r^2 = 0.94

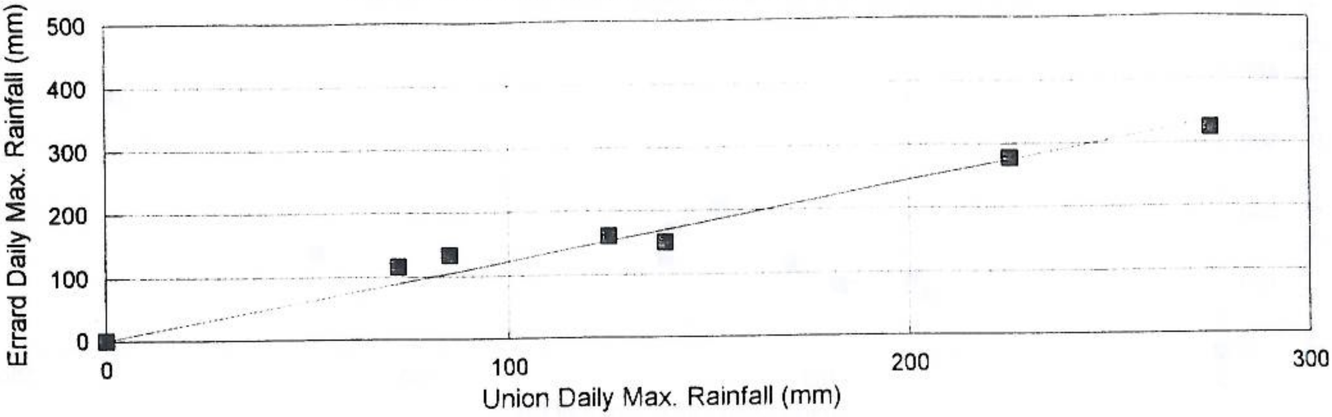
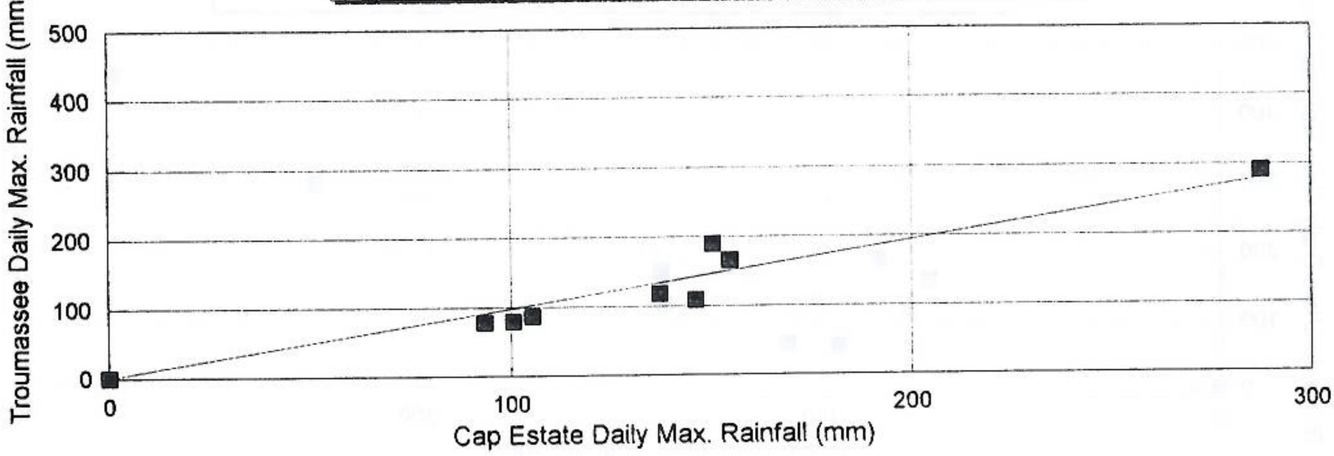


Figure A5

Annual Daily Maximum Rainfall - Cap-Troumassee: r^2 = 0.88



acceptable. The extended series are provided in **Table A1**.

A5 Frequency Analysis

A5.1 Daily Maximum Rainfall

The series were run through a frequency analysis program which fits a GEV distribution to the data. The estimated daily rainfalls for each of the stations for a range of return periods are given in **Table A2**. The distributions and growth factors for six of the stations are plotted in **Figures A6 and A7** respectively.

Table A2 Design 1 Day Rainfalls (mm)

	Return Period (years)					
Station	**2**	**5**	**10**	**20**	**50**	**100**
Union	108.7	151.2	183.9	219.2	271.5	316.2
Bexon	121.5	168.8	205.6	245.9	306.0	358.0
Barre de L'Isle	149.5	214.5	260.9	308.2	373.7	426.1
Soucis	80.5	117.1	149.0	186.8	249.2	308.4
Errard	134.7	185.7	223.9	264.3	322.4	370.9
Mahaut	139.8	186.9	218.0	247.9	286.6	315.5
Trou-massee	112.0	153.8	187.4	224.9	282.5	333.6
Cap Estate	127.9	172.0	201.2	229.2	265.5	292.6

The GEV Type-II was found to be the most suitable for all of the stations (except Mahaut where a Type-III was best fitted) with an average shape parameter, k, of -0.122. There is however significant variation between the distributions, with growth factors for the 100 year event ranging from 1.84 to 2.91. The analysis results are given in Section A9. The greatest value of each series is less than three times the mean and are therefore not considered to be outliers that should be excluded from the anlysis.

The relatively close agreement between Bexon, Barre de L'Isle, Errard and Soucis might have been expected as a significant proportion of the series was derived from the Type-II Union Series. To determine the influence of the in-filling, frequency analysis of the unextended series for these stations was undertaken. This, however, also showed strong Type-II characteristics (except for Errard to which a Type-I curve was fitted). The unextended (and extended) series (except for that of Errard) include the major events of 1994 (TSD) and 1996 (26th October) which given the short series length (6 to 13 years) would skew the distribution towards the Type-II curve.
An EVI distribution was fitted to the annual maximum daily rainfall series for Union Agricultural Station for 1979 - 1987 (Ref; IoH, 1992) which estimated the 10 and 100 year daily rainfalls as 139 and 265 mm respectively. These values are lower than those predicted during this study. The Type-II curve derived here (based on 37 values) is considered more appropriate.

A GEV frequency distribution was fitted to the 1 day Union series used in the IoH study and a Type-III curve was calculated (k = 0.250). The discrepancy between this and the Type-II distribution (k = -0.162) calculated using the 37 year series highlights the potential dangers in using annual maxima series of short length in determining design values of even low return periods (the estimated 10 year 1 day precipitation calculated using the 9 year series was 140 mm compared to 184 mm; a difference of almost 25%). It may be noted that the 1979-87 series excludes the four greatest rainfall values included in the 37-year series.

TABLE A1
Extended Annual Maximum Daily Rainfall Series

Year	Union	Bexon	Barre De L'Isle	Errard	Soucis	Mahaut	Trou-massee	Cap Estate
1996	125.0	207.0	171.6	160.2	214.6	239.4	104.2	104.7
1995	95.0	96.7	64.8	115.7	72.0	124.8	85.4	105.3
1994	275.6	360.4	450.0	323.6	208.9		184.1	185.0
1993	77.0	105.3	111.8	93.8	58.4	95.4	77.2	93.2
1992	139.2	154.9	170.4	150.0	105.5	137.2	112.9	120.9
1991	85.1	94.7	191.0	133.0	64.5	164.5	95.7	102.5
1990	72.5	83.0	158.9	114.9	55.0	122.5	165.4	154.8
1989	107.9	127.0	67.1	131.4	81.8	132.9	189.1	150.4
1988	225.3	137.6	292.8	277.0	176.0	262.1	291.1	287.5
1987	136.4	176.0	187.3	166.1	94.7	114.5	117.7	137.1
1986	138.2	134.2	122.7	168.3	144.0	161.3	108.0	146.1
1985	86.7	96.5	119.0	105.6	90.1	72.4	78.5	100.5
1984	105.0	116.9	144.2	127.9	82.9	174.7		
1983	63.5	70.7	87.2	77.3	49.5			
1982	111.8	124.4	153.5	136.2	67.1			
1981	160.5	178.6	220.4	195.5	85.7			
1980	88.1	98.1	121.0	107.3	63.8	129.7		
1979	95.0	105.7	130.4	115.7	70.5			
1978	102.9	114.5	141.3	125.3	57.7			
1977	124.7	138.8	171.2	151.9	154.3			
1976	139.4	155.2	191.4	169.8	69.0			
1975	82.0	91.3	112.6	99.9	62.2			
1974	114.3	127.2	156.9	139.2	86.6		110.1	117.9
1973	69.1	76.9	94.9	84.2	52.4		129.5	138.7
1972	85.9	95.6	117.9	104.6	65.1		67.3	72.1
1971	139.7	155.5	191.8	170.2	105.9		71.9	77.0
1970	232.2	258.4	318.8	282.8	176.0			
1968	149.4	166.3	205.1	182.0	113.2			
1967	293.4	326.6	402.8	357.4	222.4		199.4	200.4
1966	118.1	131.4	162.2	143.8	89.5		154.7	155.5
1965	113.0	125.8	155.1	137.6	85.7		135.9	136.6
1964	89.4	99.5	122.7	108.9	67.8			
1963	114.6	127.5	157.3	139.6	86.9			
1962	152.1	169.3	208.8	185.3	115.3			
1960	155.2	172.7	213.1	189.0	117.6			
1959	53.3	59.3	73.2	64.9	40.4			
1958	66.0	73.5	90.6	80.4	50.0			
Data Infilling Station:		Union	Union	Union	Union	N/A	Cap Estate	Trou-massee

Missing value infilled

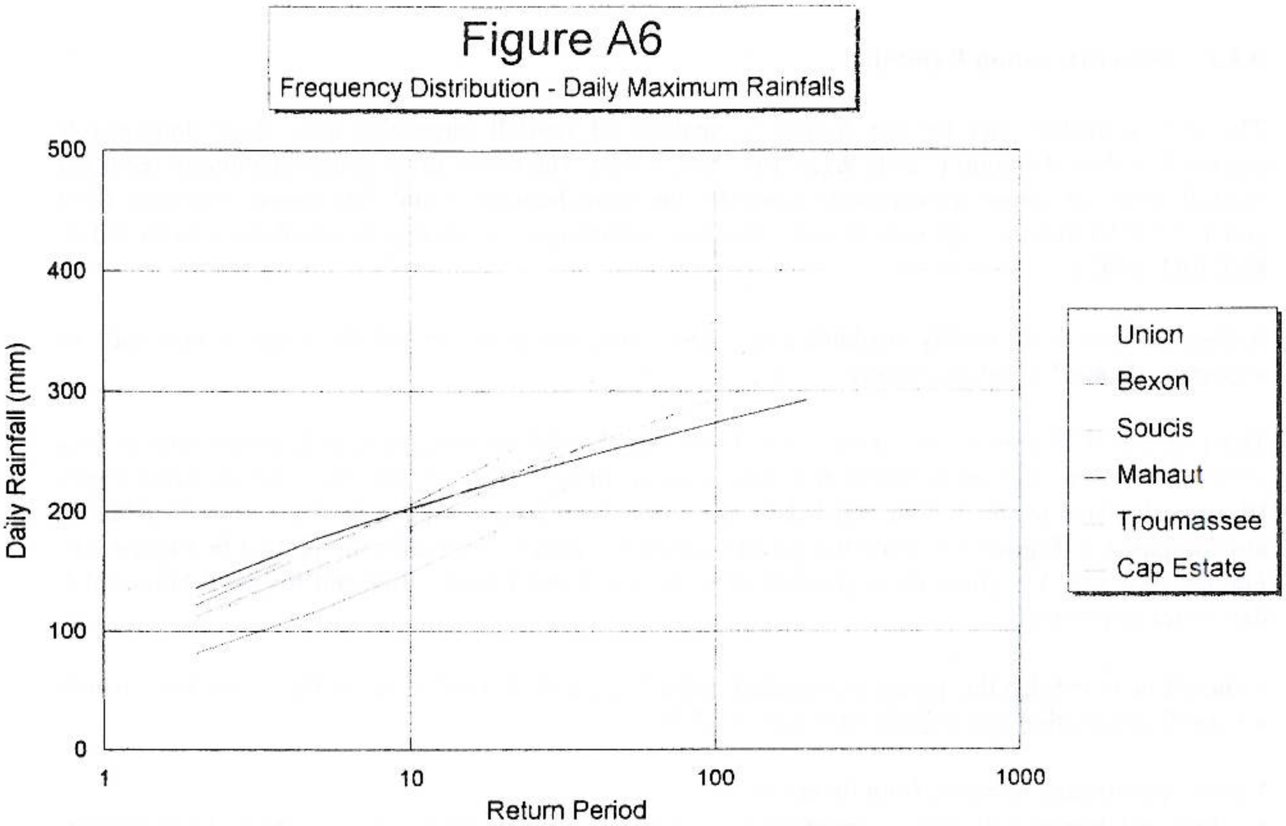


Figure A6
Frequency Distribution - Daily Maximum Rainfalls
500
400
300
200
100
0
Daily Rainfall (mm)
1
10
100
1000
Return Period
Union
Bexon
Soucis
Mahaut
Troumassee
Cap Estate

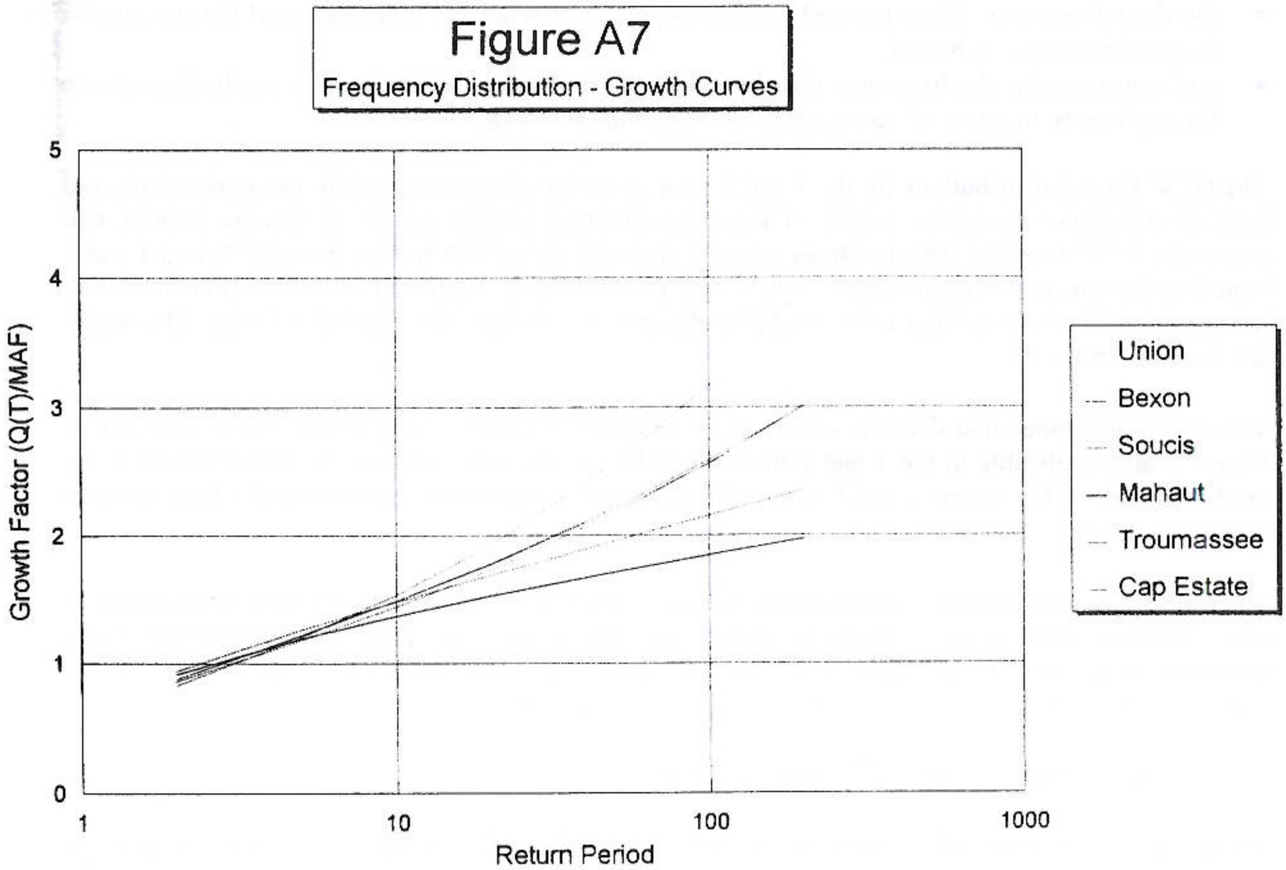


Figure A7
Frequency Distribution - Growth Curves
5
4
3
2
1
0
Growth Factor (Q(T)/MAF)
1
10
100
1000
Return Period
Union
Bexon
Soucis
Mahaut
Troumassee
Cap Estate

A5.2 Short Duration Rainfall

The only available data for the frequency analysis of rainfall intensities over short durations is provided in the IoH report (**Table 9.1.1**, Ref; IoH, 1992). The report gives annual maximum recorded rainfall depths at Union Agricultural Station for durations between 5 and 720 minutes between 1979 and 1987. EVI distributions were fitted to the data and design rainfall depths calculated (**Table 9.1.2**, Ref; IoH, 1992).

Additional data is not readily available and it was considered to be beyond the scope of this study to undertake detailed detail processing.

The 1, 2, 6 and 24 hour series for this period were run through the frequency analysis program to fit a GEV distribution. A Type-II distribution was found to fit best for the 1 and 2 hour series while Type-III was calculated for the 6 hour and 1 day series. The Type-I and II curves for the 1 hour distribution are compared in **Figure A8** while the growth curves for each of the series are plotted in **Figure A9**. Figures A10 and A11 show the regression plots for the 1 and 2 hour series and for the 6 hour and 1 day series respectively.

It should be noted that this period is included in the 37 year daily rainfall series for Union from which a Type-II distribution was calculated (Section A5.1).

Various points may be noted from these results:

- first and foremost is that, as mentioned in section A5.1, the results derived from the frequency analysis of a short series of annual maxima should be treated with caution,
- there is a strong correlation between the 1 and 2 hour series and between the 6 hour and 1 day series (1979-87 data set),
- the short duration (< 2 hour) annual maxima appear to be relatively independent of the maxima for longer durations (> 6 hours),
- and consequently, the frequency distribution of the 24 hour/1 day series may not be appropriate for application to series of very short duration rainfall maxima.

The GEV Type-II distributions for the 1 and 2 hour series have been adopted for use in this study and used to determine the return period of the short duration rainfall depths at various stations that occurred on 26th October. This has been done by applying the growth factors from the Union 1 and 2 hour distributions to the mean annual 1 and 2 hour rainfall depths calculated for each station according to the ratio of the mean annual 1 day rainfall at the station over the 1 day rainfall at Union. The results are given in **Table A3**.

This method assumes that the ratio of the mean annual 1 day rainfall at a given station over that at Union is also applicable to the 1 and 2 hour rainfalls, i.e., the ratio between the mean annual 1 day rainfall at Bexon (for example) and Union is the same as that between the mean annual 1 hour rainfalls at the two stations.

It is further assumed that the frequency distribution for the 1 and 2 hour series at Union is applicable to other stations. There is no evidence to support or repress this assumption as, although the 1 day distributions between stations agree to a reasonable extent, the distributions for 1 and 2 hour rainfall series have been shown to be independent of the 1 day distribution.

A6 Return Period of the 26TH October Event

The estimated return period for the event at each of the stations for a range of durations are given in **Table A4**. It can be seen that the return period of the storm varies significantly with location. The storm was approximately a 2 year event over the north and east coast while in the centre, west and south of the island the storm had a return period of between 30 and 100 years depending on duration.

Figure A8

Frequency Distribution 1 Hour Rainfall - Union (1979-1987)

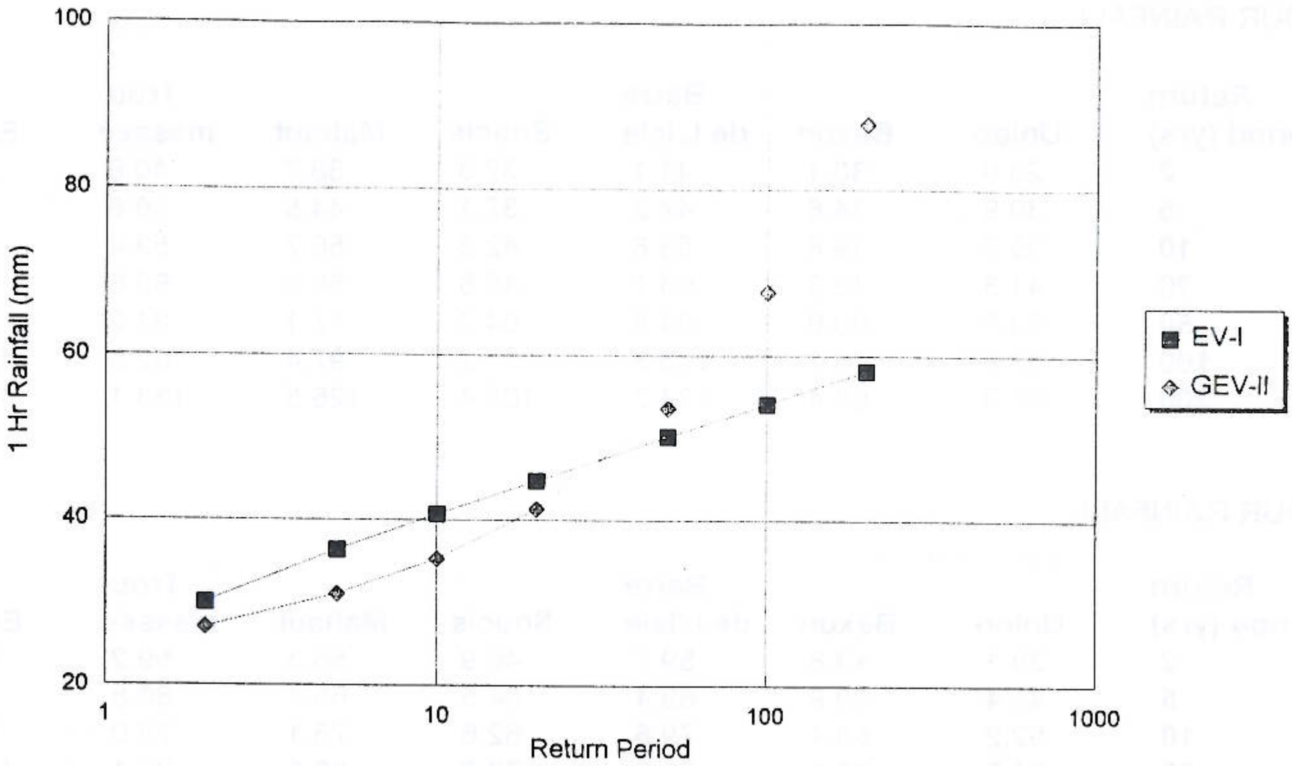


Figure A9

Growth Curves - Union (1979-1987)

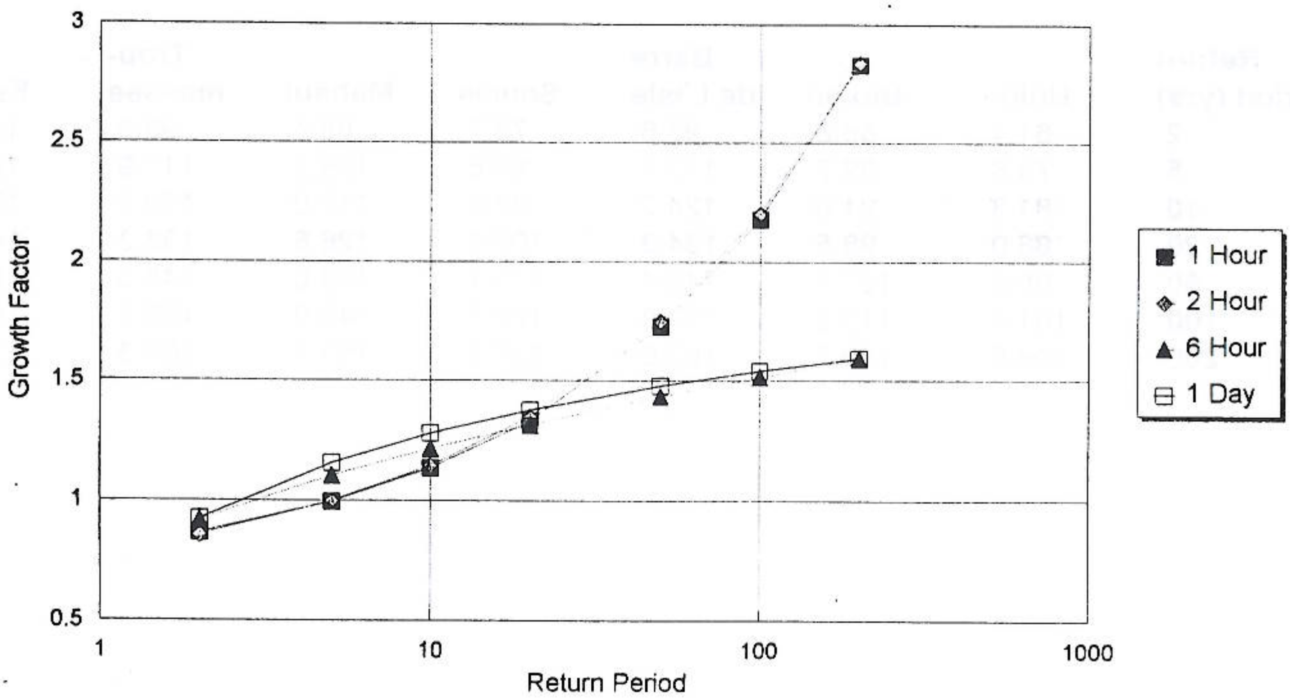


TABLE A3
Short Duration Design Rainfall Depths

1 HOUR RAINFALL

Return Period (yrs)	Union	Bexon	Barre de L'Isle	Soucis	Mahaut	Trou-massee	Cap Estate
2	26.9	30.1	41.1	32.3	38.7	40.8	44.8
5	30.9	34.6	47.2	37.1	44.5	46.8	51.5
10	35.2	39.4	53.8	42.3	50.7	53.4	58.6
20	41.3	46.3	63.1	49.6	59.5	62.6	68.8
50	53.6	60.0	81.8	64.3	77.1	81.2	89.2
100	67.6	75.7	103.3	81.2	97.4	102.5	112.6
200	87.9	98.4	134.2	105.4	126.5	133.1	146.2

2 HOUR RAINFALL

Return Period (yrs)	Union	Bexon	Barre de L'Isle	Soucis	Mahaut	Trou-massee	Cap Estate
2	39.1	43.8	59.7	46.9	56.3	59.2	65.0
5	45.4	50.9	69.4	54.5	65.4	68.8	75.6
10	52.2	58.4	79.6	62.6	75.1	79.0	86.8
20	61.5	68.8	93.8	73.8	88.5	93.1	102.3
50	79.8	89.3	121.8	95.8	114.8	120.9	132.8
100	100.4	112.4	153.3	120.5	144.5	152.1	167.1
200	129.6	145.0	197.8	155.5	186.5	196.3	215.6

6 HOUR RAINFALL

Return Period (yrs)	Union	Bexon	Barre de L'Isle	Soucis	Mahaut	Trou-massee	Cap Estate
2	61.4	68.8	93.8	73.7	88.4	93.0	102.2
5	73.8	82.7	112.7	88.6	106.3	111.9	122.9
10	81.3	91.0	124.2	97.6	117.0	123.2	135.3
20	88.0	98.5	134.3	105.6	126.6	133.3	146.4
50	95.9	107.4	146.4	115.1	138.0	145.3	159.6
100	101.4	113.5	154.8	121.7	145.9	153.6	168.7
200	106.5	119.2	162.6	127.8	153.3	161.3	177.2

The exception to the above is Barre De L'Isle in the centre of the island which only recorded a 2-year event. This is possibly due to natural spatial variation within the storm or it is possible that the recorder was either partially blocked or did not function correctly.

Table A4 Estimated Return Period of Rainfall Event of 26th October 1996

	Estimated Return Period (years) of Event for Given Duration			
Station	**1 Hour**	**2 Hour**	**6 Hour**	**24 Hour**
Bexon	50	60	>100	20
Barre de L'Isle	<2	<2	2	2
Cap Estate	2	2	<2	2
Mahaut	50	60	>100	100
Soucis	30	40	>100	50
Troumassee	<2	2	2	2

NOTE: The design 24 hour rainfall event for a given return period will be greater than that of a 1 day event (where the start and end times are fixed). This has been taken into account in estimating the event return periods given above.

A7 Significance of the Event

Frequency analysis has been undertaken on the extended series given in **Table A1** with the 1996 value removed. This is done to determine the effect of the event on the frequency distribution and the estimated rainfall depths for given return periods.

As may have been expected, the removal had an insignificant effect on the distributions at Union, Barre De L'Isle, Cap Estate and at Troumassee where the event only had an estimated return period of approximately 2 years. The removal only had a minor effect on the distributions of the other stations where the return period of the event is estimated to be in the order of 30 to over 100 years. This is due to the presence of three other major events; those of 1967, 1988 and TSD, 1994, all of which were of the same order or greater than 26th October.

A8 6 Day Average Rainfall

The daily rainfall used in the annual maximum daily rainfall analysis was summed to calculate 6 day rainfall totals. The averages for each station were calculated and are given in **Table A5** with the standard deviation assuming an normal distribution.

Table A5 Average 6 Day Rainfall Totals

Station	Annual Average Rainfall (mm)	6 Day Average Rainfall (mm)	Standard Deviation (mm)
Barre De L'Isle	2980	48.0	51.6
Bexon	2472[1]	43.0	45.8
Cap Estate	1307	23.5	33.0
Errard	2100	37.3	43.7
Mahaut	2593	42.2	41.9
Soucis	2432	29.7	33.0
Troumassee	1762	28.3	36.8
Union Agri.	2040	33.6	36.9

NOTE 1: Estimated from daily rainfall values used in frequency analysis.

It may further be seen from **Table A5** that there is significant correlation (r2 = 0.76) between the annual average and 6 day average rainfalls at each station.

It should be noted however that the above 6 day rainfall depths have been calculated on an annual basis, i.e., include wet and dry season rainfall. Given that major floods are far more likely to occur during the wet season (June to November/December) then analysis of the wet-season only 6 day rainfall depths would be required for a more accurate estimation of the relative antecedent wetness conditions for a given event.

A9 Results of Frequency Analysis

Given in the following pages are the output files from the frequency analysis undertaken on the annual maximum 1 day rainfall records; extended and natural. It is reiterated that the data check undertaken was not exhaustive.

Figure A10

Regression Plot 1 and 2 Hour Rainfall - Union (1979-1987)

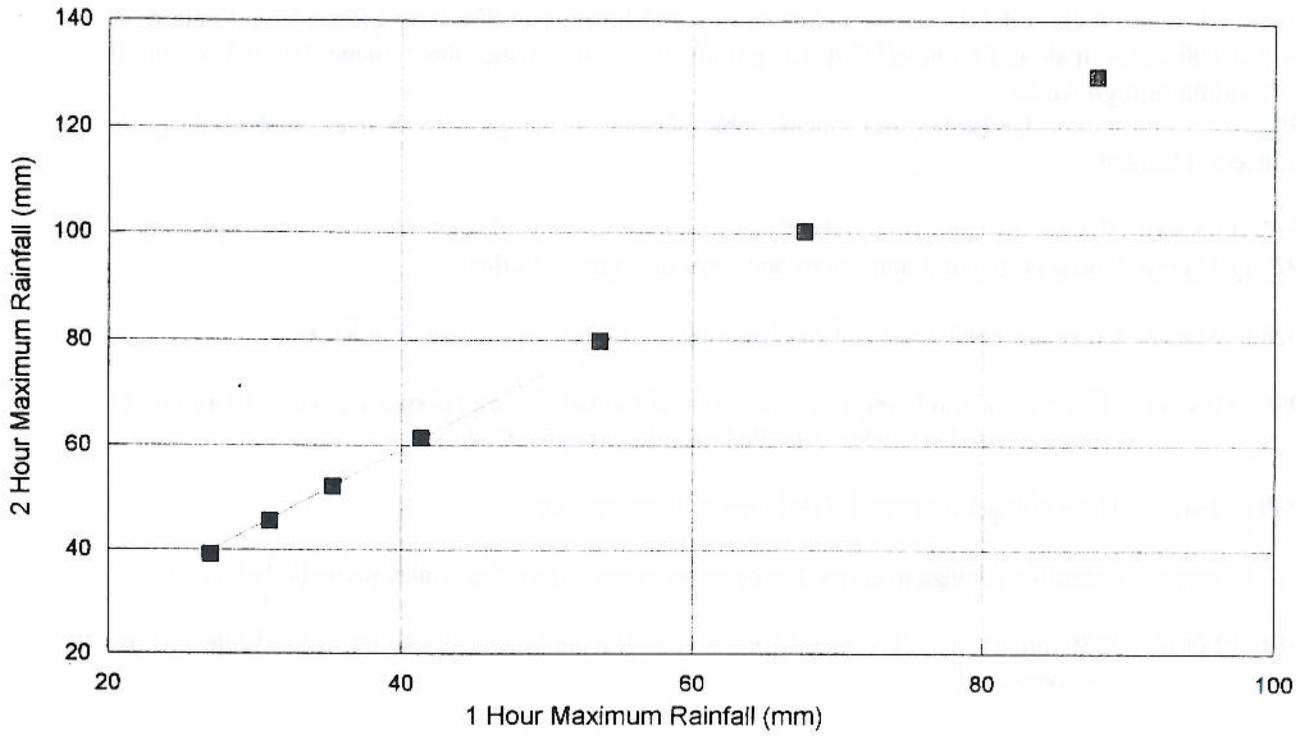
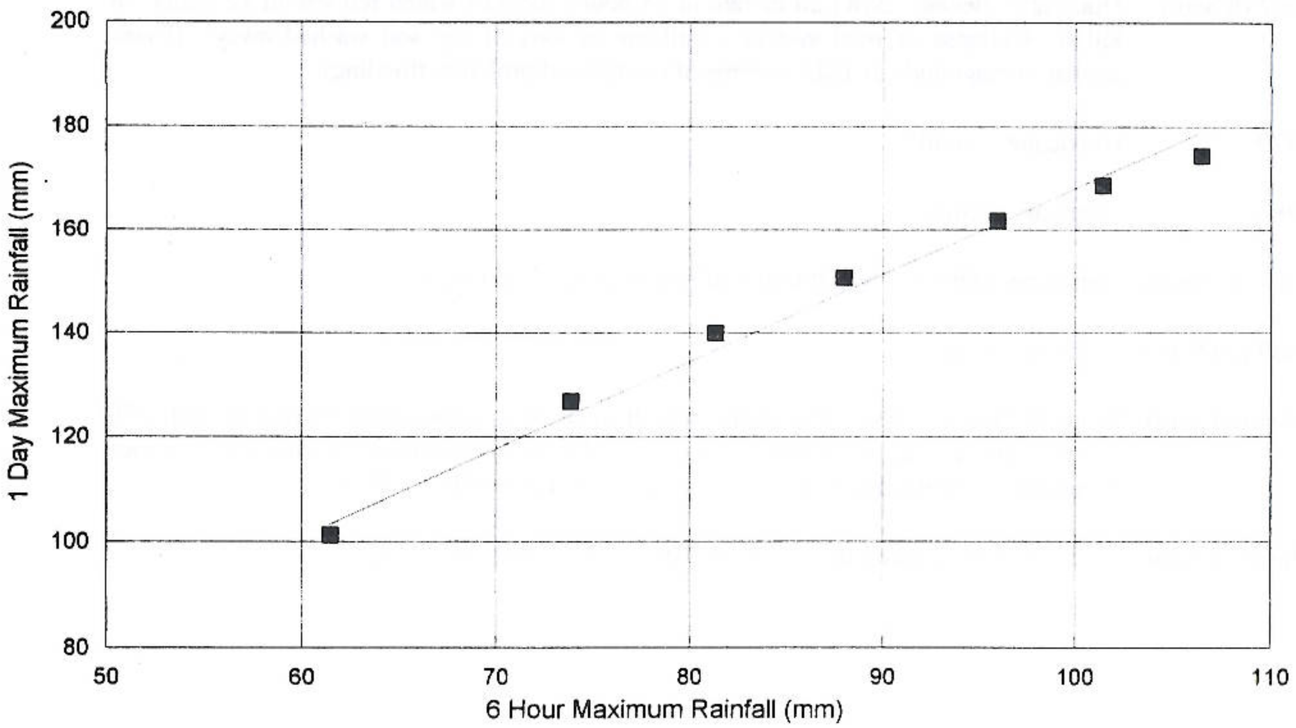


Figure A11

Regression Plot 6 Hour and 1 Day Rainfall - Union (1979-1987)



APPENDIX B
MAJOR HISTORICAL STORMS AND HURRICANES TO EFFECT ST. LUCIA

Given below are outline details of the major storms and hurricanes that have effected St. Lucia over the last 100 years. It should be noted that it is not always clear whether the damage detailed is caused by flooding or high winds.

1894 Heavy landslides and 'incalculable damage to crops'. 45 houses washed away in Soufriere. 11 killed.

1897 (11 Sept)	353 mm of rain. 'Hundreds of peasant properties in total ruin'. Cocoa crops swept away.
1921 (10 Sept)	Cocoa crop, communications and ships damaged. 15 killed.
1928 (19 Sept)	Crops and road destroyed and fish market and jetty washed away at Roseau.
1938 (21 Nov)	'Worst storms in living memory'. Annual rainfall 960 mm above average, 242 mm in 24 hours at Barre De L'Isle. 120 killed, mainly through landslides.
1939 (7 Jan)	Three villages destroyed. 100 killed and 250 missing.
1940 (7 Aug)	Extensive damage to crops. Roads swept away. Cul-de-Sac valley particularly badly hit.
1954 (12 Dec)	3250 mm of rainfall recorded for the year. Ravine Poisson badly hit by landslides, whole crop destroyed.
1960 (10 July)	Hurricane 'Abbey'. Damage to roads, bridges and electricity supply. 6 killed.
1963 (24 Sept)	Hurricane 'Edith'. 60% of banana trees destroyed in effected areas (mostly north and east). Estimated damage EC$4 million.
1965 (25 Oct)	40% of all banana crop effected. Castries area worst hit.
1967 (8 Sept)	Hurricane 'Beulah'. 378 mm of rain in 24 hours, most of which fell within 12 hours. 18 killed. 'Collapse of road system - millions of tons of top soil washed away'. (Event similar in magnitude to TSD in terms of rainfall and probably flooding)
1979	Hurricane 'David'.
1980	Hurricane 'Allen'.
1988 (10 Sept)	Hurricane 'Gilbert'. Over 200 mm of rain in 24 hours at Union.
1989 (18 Sept)	Hurricane 'Hugo'.
1994 (10 Sept)	Tropical Storm Debbie. Maximum rainfall intensity approximately 90 mm/hr with 276 and 372 mm of rain in 24 hours at Union and Errard respectively. 4 killed, 100 homes destroyed + 100 damaged. Total damage estimated at EC$112 million.

The information above was principally derived from AESD, 1994 and IoH, 1992.

DAILY MAXIMUM RAINFALL
Union Agricultural Station

THE STATISTICS OF THE ANNUAL SERIES

MAXIMUM VALUE	2.934E+02
MINIMUM VALUE	5.330E+01
RANGE OF VALUES	2.401E+02
MEAN OF 37 VALUES	1.239E+02
STANDARD ERROR	9.096E+00
STANDARD DEVIATION	5.533E+01
COEFFICIENT OF VARIATION	0.45
SKEWNESS	2.72E+05
COEFFICIENT OF SKEWNESS	1.60
STANDARD ERROR	0.39
KURTOSIS	5.76

the parameters of a type 2 distribution

location	96.59
scale	32.13
shape	-0.162

THE DISTRIBUTION ESTIMATES FOR GIVEN PROBABILITIES OF EXCEEDENCE

PROBAB. EXCEED.	RETURN PERIOD	REDUCED VARIATE	ESTIMATED MAXIMA	CONFIDENCE LIMITS UPPER	LOWER
0.990	1.01	-1.53	53.12	78.90	27.34
0.980	1.02	-1.36	57.27	81.15	33.39
0.950	1.05	-1.10	64.29	85.29	43.30
0.900	1.11	-0.83	71.53	90.03	53.02
0.800	1.25	-0.48	81.88	97.88	65.88
0.500	2.00	0.37	108.73	125.09	92.37
0.200	5.00	1.50	151.16	178.72	123.60
0.100	10.00	2.25	183.86	221.08	146.64
0.050	20.00	2.97	219.20	266.22	172.18
0.020	50.00	3.90	271.52	331.57	211.47
0.010	100.00	4.60	316.24	386.20	246.29
0.005	200.00	5.30	366.14	446.03	286.24
0.001	1000.00	6.91	505.80	608.87	402.74
0.000	5000.00	8.52	686.97	813.30	560.64
0.000	10000.00	9.21	780.78	917.15	644.41

DAILY MAXIMUM RAINFALL
Union Agricultural Station

rank	year	recorded maxima	return period a	b
1	1967	293.40	66.29	70.84
2	1994	275.60	23.79	53.43
3	1970	232.20	14.50	25.41
4	1988	225.30	10.43	22.40
5	1981	160.50	8.14	6.12
6	1960	155.20	6.68	5.46
7	1962	152.10	5.66	5.10

8	1968	149.40	4.91	4.81
9	1971	139.70	4.34	3.89
10	1976	139.40	3.88	3.87
11	1992	139.20	3.52	3.85
12	1986	138.20	3.21	3.76
13	1987	136.40	2.96	3.62
14	1996	125.00	2.74	2.82
15	1977	124.70	2.55	2.80
16	1966	118.10	2.39	2.43
17	1963	114.60	2.24	2.26
18	1974	114.30	2.11	2.24
19	1965	113.00	2.00	2.18
20	1982	111.80	1.90	2.13
21	1989	107.90	1.81	1.97
22	1984	105.00	1.72	1.86
23	1978	102.90	1.65	1.78
24	1979	95.00	1.58	1.54
25	1995	95.00	1.51	1.54
26	1964	89.40	1.45	1.40
27	1980	88.10	1.40	1.37
28	1985	86.70	1.35	1.34
29	1972	85.90	1.30	1.32
30	1991	85.10	1.26	1.31
31	1975	82.00	1.21	1.25
32	1993	77.00	1.18	1.18
33	1990	72.50	1.14	1.12
34	1973	69.10	1.11	1.09
35	1958	66.00	1.07	1.06
36	1983	63.50	1.04	1.05
37	1959	53.30	1.02	1.01

return periods estimated from:

a: gringorten plotting position
b: fitted type 2 distribution

DAILY MAXIMUM RAINFALL
Bexon (Extended)

THE STATISTICS OF THE ANNUAL SERIES

MAXIMUM VALUE	3.604E+02
MINIMUM VALUE	5.930E+01
RANGE OF VALUES	3.011E+02
MEAN OF 37 VALUES	1.387E+02
STANDARD ERROR	1.058E+01
STANDARD DEVIATION	6.435E+01
COEFFICIENT OF VARIATION	0.46
SKEWNESS	5.17E+05
COEFFICIENT OF SKEWNESS	1.94
STANDARD ERROR	0.39
KURTOSIS	7.50

the parameters of a type 2 distribution

location	108.06
scale	35.40
shape	-0.175

THE DISTRIBUTION ESTIMATES FOR GIVEN PROBABILITIES OF EXCEEDENCE

PROBAB. EXCEED.	RETURN PERIOD	REDUCED VARIATE	ESTIMATED MAXIMA	CONFIDENCE LIMITS UPPER	LOWER
0.990	1.01	-1.53	60.60	90.58	30.61
0.980	1.02	-1.36	65.08	92.86	37.31
0.950	1.05	-1.10	72.71	97.12	48.29
0.900	1.11	-0.83	80.58	102.10	59.06
0.800	1.25	-0.48	91.89	110.50	73.28
0.500	2.00	0.37	121.46	140.49	102.43
0.200	5.00	1.50	168.76	200.82	136.71
0.100	10.00	2.25	205.64	248.94	162.35
0.050	20.00	2.97	245.86	300.55	191.17
0.020	50.00	3.90	306.01	375.86	236.17
0.010	100.00	4.60	357.96	439.32	276.59
0.005	200.00	5.30	416.40	509.33	323.48
0.001	1000.00	6.91	582.42	702.30	462.55
0.000	5000.00	8.52	802.11	949.04	655.17
0.000	10000.00	9.21	917.45	1076.06	758.84

DAILY MAXIMUM RAINFALL
Bexon (Extended)

rank	year	recorded maxima	return period a	b
1	1994	360.40	66.29	103.12
2	1967	326.60	23.79	66.45
3	1970	258.40	14.50	24.49
4	1996	207.00	10.43	10.25
5	1981	178.60	8.14	6.04
6	1987	176.00	6.68	5.75
7	1960	172.70	5.66	5.40

8	1962	169.30	4.91	5.05
9	1968	166.30	4.34	4.77
10	1971	155.50	3.88	3.86
11	1976	155.20	3.52	3.84
12	1992	154.90	3.21	3.81
13	1977	138.80	2.96	2.78
14	1988	137.60	2.74	2.72
15	1986	134.20	2.55	2.54
16	1966	131.40	2.39	2.41
17	1963	127.50	2.24	2.24
18	1974	127.20	2.11	2.23
19	1989	127.00	2.00	2.22
20	1965	125.80	1.90	2.17
21	1982	124.40	1.81	2.11
22	1984	116.90	1.72	1.84
23	1978	114.50	1.65	1.77
24	1979	105.70	1.58	1.52
25	1993	105.30	1.51	1.51
26	1964	99.50	1.45	1.39
27	1980	98.10	1.40	1.36
28	1995	96.70	1.35	1.33
29	1985	96.50	1.30	1.33
30	1972	95.60	1.26	1.31
31	1991	94.70	1.21	1.30
32	1975	91.30	1.18	1.24
33	1990	83.00	1.14	1.14
34	1973	76.90	1.11	1.08
35	1958	73.50	1.07	1.06
36	1983	70.70	1.04	1.04
37	1959	59.30	1.02	1.01

return periods estimated from:

a: gringorten plotting position
b: fitted type 2 distribution

DAILY MAXIMUM RAINFALL
Bexon

THE STATISTICS OF THE ANNUAL SERIES

MAXIMUM VALUE	3.604E+02
MINIMUM VALUE	8.300E+01
RANGE OF VALUES	2.774E+02
MEAN OF 9 VALUES	1.586E+02
STANDARD ERROR	2.833E+01
STANDARD DEVIATION	8.499E+01
COEFFICIENT OF VARIATION	0.54
SKEWNESS	1.20E+06
COEFFICIENT OF SKEWNESS	1.95
STANDARD ERROR	0.72
KURTOSIS	7.95

the parameters of a type 2 distribution

location	105.97
scale	29.57
shape	-0.407

THE DISTRIBUTION ESTIMATES FOR GIVEN PROBABILITIES OF EXCEEDENCE

PROBAB. EXCEED.	RETURN PERIOD	REDUCED VARIATE	ESTIMATED MAXIMA	CONFIDENCE LIMITS UPPER	LOWER
0.990	1.01	-1.53	72.33	152.63	-7.96
0.980	1.02	-1.36	75.01	149.40	0.62
0.950	1.05	-1.10	79.80	145.18	14.41
0.900	1.11	-0.83	85.05	142.69	27.41
0.800	1.25	-0.48	93.17	143.01	43.33
0.500	2.00	0.37	117.65	168.62	66.69
0.200	5.00	1.50	167.08	252.91	81.24
0.100	10.00	2.25	214.84	330.78	98.90
0.050	20.00	2.97	276.61	423.07	130.15
0.020	50.00	3.90	388.75	575.81	201.70
0.010	100.00	4.60	505.52	723.42	287.62
0.005	200.00	5.30	659.99	908.84	411.14
0.001	1000.00	6.91	1240.44	1561.46	919.41
0.000	5000.00	8.52	2356.97	2750.46	1963.47
0.000	10000.00	9.21	3113.96	3538.72	2689.19

DAILY MAXIMUM RAINFALL
Bexon

rank	year	recorded maxima	return period a	b
1	1994	360.40	16.29	40.85
2	1996	207.00	5.85	9.02
3	1987	176.00	3.56	5.77
4	1988	137.60	2.56	2.96
5	1986	134.20	2.00	2.78
6	1989	127.00	1.64	2.41
7	1993	105.30	1.39	1.56
8	1995	96.70	1.21	1.33

9	1990	83.00	1.07	1.09

return periods estimated from:

a: gringorten plotting position
b: fitted type 2 distribution

DAILY MAXIMUM RAINFALL
Barre De L'Isle (Extended)

THE STATISTICS OF THE ANNUAL SERIES

MAXIMUM VALUE	4.500E+02
MINIMUM VALUE	6.480E+01
RANGE OF VALUES	3.852E+02
MEAN OF 37 VALUES	1.690E+02
STANDARD ERROR	1.374E+01
STANDARD DEVIATION	8.356E+01
COEFFICIENT OF VARIATION	0.49
SKEWNESS	1.03E+06
COEFFICIENT OF SKEWNESS	1.77
STANDARD ERROR	0.39
KURTOSIS	6.85

the parameters of a type 2 distribution

location	129.75
scale	53.10
shape	-0.081

THE DISTRIBUTION ESTIMATES FOR GIVEN PROBABILITIES OF EXCEEDENCE

PROBAB. EXCEED.	RETURN PERIOD	REDUCED VARIATE	ESTIMATED MAXIMA	CONFIDENCE LIMITS UPPER	LOWER
0.990	1.01	-1.53	53.50	92.44	14.57
0.980	1.02	-1.36	61.20	97.27	25.13
0.950	1.05	-1.10	74.02	105.72	42.32
0.900	1.11	-0.83	86.93	114.88	58.99
0.800	1.25	-0.48	104.96	129.13	80.80
0.500	2.00	0.37	149.50	174.21	124.79
0.200	5.00	1.50	214.46	256.08	172.84
0.100	10.00	2.25	260.89	317.10	204.67
0.050	20.00	2.97	308.17	379.19	237.16
0.020	50.00	3.90	373.65	464.34	282.95
0.010	100.00	4.60	426.08	531.73	320.42
0.005	200.00	5.30	481.36	602.03	360.70
0.001	1000.00	6.91	622.14	777.80	466.49
0.000	5000.00	8.52	782.51	973.30	591.72
0.000	10000.00	9.21	858.31	1064.27	652.36

DAILY MAXIMUM RAINFALL
Barre De L'Isle (Extended)

rank	year	recorded maxima	return period a	b
1	1994	450.00	66.29	135.60
2	1967	402.80	23.79	73.84
3	1970	318.80	14.50	23.29
4	1988	292.80	10.43	16.00
5	1981	220.40	8.14	5.46
6	1960	213.10	6.68	4.90
7	1962	208.80	5.66	4.60

8	1968	205.10	4.91	4.35
9	1971	191.80	4.34	3.58
10	1976	191.40	3.88	3.56
11	1991	191.00	3.52	3.54
12	1987	187.30	3.21	3.36
13	1996	171.60	2.96	2.69
14	1977	171.20	2.74	2.67
15	1992	170.40	2.55	2.64
16	1966	162.20	2.39	2.36
17	1990	158.90	2.24	2.26
18	1963	157.30	2.11	2.21
19	1974	156.90	2.00	2.20
20	1965	155.10	1.90	2.15
21	1982	153.50	1.81	2.11
22	1984	144.20	1.72	1.87
23	1978	141.30	1.65	1.81
24	1979	130.40	1.58	1.59
25	1964	122.70	1.51	1.47
26	1986	122.70	1.45	1.47
27	1980	121.00	1.40	1.44
28	1985	119.00	1.35	1.42
29	1972	117.90	1.30	1.40
30	1975	112.60	1.26	1.33
31	1993	111.80	1.21	1.32
32	1973	94.90	1.18	1.16
33	1958	90.60	1.14	1.13
34	1983	87.20	1.11	1.11
35	1959	73.20	1.07	1.05
36	1989	67.10	1.04	1.03
37	1995	64.80	1.02	1.03

return periods estimated from:

a: gringorten plotting position
b: fitted type 2 distribution

DAILY MAXIMUM RAINFALL
Barre De L'Isle

THE STATISTICS OF THE ANNUAL SERIES

MAXIMUM VALUE	4.500E+02
MINIMUM VALUE	6.480E+01
RANGE OF VALUES	3.852E+02
MEAN OF 9 VALUES	1.811E+02
STANDARD ERROR	4.086E+01
STANDARD DEVIATION	1.226E+02
COEFFICIENT OF VARIATION	0.68
SKEWNESS	2.77E+06
COEFFICIENT OF SKEWNESS	1.51
STANDARD ERROR	0.72
KURTOSIS	6.16

the parameters of a type 2 distribution

location	100.22
scale	24.68
shape	-0.726

THE DISTRIBUTION ESTIMATES FOR GIVEN PROBABILITIES OF EXCEEDENCE

PROBAB. EXCEED.	RETURN PERIOD	REDUCED VARIATE	ESTIMATED MAXIMA	CONFIDENCE LIMITS UPPER	LOWER
0.990	1.01	-1.53	77.45	193.26	-38.36
0.980	1.02	-1.36	78.86	186.15	-28.43
0.950	1.05	-1.10	81.56	175.87	-12.75
0.900	1.11	-0.83	84.78	167.92	1.65
0.800	1.25	-0.48	90.29	162.17	18.40
0.500	2.00	0.37	110.58	184.09	37.07
0.200	5.00	1.50	167.24	291.05	43.44
0.100	10.00	2.25	240.45	407.67	73.23
0.050	20.00	2.97	360.12	571.36	148.88
0.020	50.00	3.90	644.50	914.29	374.71
0.010	100.00	4.60	1026.53	1340.81	712.25
0.005	200.00	5.30	1658.01	2016.94	1299.09
0.001	1000.00	6.91	5198.26	5661.28	4735.24
0.000	5000.00	8.52	16593.13	17160.67	16025.58
0.000	10000.00	9.21	27412.26	28024.91	26799.62

DAILY MAXIMUM RAINFALL
Barre De L'Isle

rank	year	recorded maxima	return period a	b
1	1994	450.00	16.29	28.65
2	1988	292.80	5.85	14.13
3	1991	191.00	3.56	6.51
4	1992	170.40	2.56	5.19
5	1990	158.90	2.00	4.50
6	1986	122.70	1.64	2.55
7	1993	111.80	1.39	2.05

8	1989	67.10	1.21	1.00

DAILY MAXIMUM RAINFALL
Soucis (Extended)

THE STATISTICS OF THE ANNUAL SERIES

MAXIMUM VALUE	2.224E+02
MINIMUM VALUE	4.040E+01
RANGE OF VALUES	1.820E+02
MEAN OF 37 VALUES	9.738E+01
STANDARD ERROR	7.985E+00
STANDARD DEVIATION	4.857E+01
COEFFICIENT OF VARIATION	0.50
SKEWNESS	1.55E+05
COEFFICIENT OF SKEWNESS	1.35
STANDARD ERROR	0.39
KURTOSIS	4.14

the parameters of a type 2 distribution

location	71.03
scale	24.50
shape	-0.292

THE DISTRIBUTION ESTIMATES FOR GIVEN PROBABILITIES OF EXCEEDENCE

PROBAB. EXCEED.	RETURN PERIOD	REDUCED VARIATE	ESTIMATED MAXIMA	CONFIDENCE LIMITS UPPER	LOWER
0.990	1.01	-1.53	40.83	63.46	18.20
0.980	1.02	-1.36	43.45	64.42	22.48
0.950	1.05	-1.10	48.02	66.45	29.59
0.900	1.11	-0.83	52.89	69.13	36.64
0.800	1.25	-0.48	60.14	74.19	46.09
0.500	2.00	0.37	80.51	94.87	66.14
0.200	5.00	1.50	117.14	141.33	92.94
0.100	10.00	2.25	148.97	181.65	116.30
0.050	20.00	2.97	186.81	228.08	145.53
0.020	50.00	3.90	249.19	301.91	196.47
0.010	100.00	4.60	308.40	369.81	246.99
0.005	200.00	5.30	380.69	450.83	310.56
0.001	1000.00	6.91	616.87	707.35	526.40
0.000	5000.00	8.52	994.27	1105.17	883.37
0.000	10000.00	9.21	1219.94	1339.66	1100.23

DAILY MAXIMUM RAINFALL
Soucis (Extended)

rank	year	recorded maxima	return period a	b
1	1967	222.40	66.29	34.71
2	1996	214.60	23.79	30.97
3	1994	208.90	14.50	28.44
4	1970	176.00	10.43	16.62
5	1988	176.00	8.14	16.62
6	1977	154.30	6.68	11.11
7	1986	144.00	5.66	9.04

8	1960	117.60	4.91	5.05
9	1962	115.30	4.34	4.79
10	1968	113.20	3.88	4.55
11	1971	105.90	3.52	3.81
12	1992	105.50	3.21	3.78
13	1987	94.70	2.96	2.88
14	1985	90.10	2.74	2.56
15	1966	89.50	2.55	2.52
16	1963	86.90	2.39	2.36
17	1974	86.60	2.24	2.34
18	1965	85.70	2.11	2.28
19	1981	85.70	2.00	2.28
20	1984	82.90	1.90	2.13
21	1989	81.80	1.81	2.07
22	1995	72.00	1.72	1.62
23	1979	70.50	1.65	1.56
24	1976	69.00	1.58	1.51
25	1964	67.80	1.51	1.47
26	1982	67.10	1.45	1.44
27	1972	65.10	1.40	1.38
28	1991	64.50	1.35	1.36
29	1980	63.80	1.30	1.34
30	1975	62.20	1.26	1.30
31	1993	58.40	1.21	1.21
32	1978	57.70	1.18	1.20
33	1990	55.00	1.14	1.15
34	1973	52.40	1.11	1.10
35	1958	50.00	1.07	1.07
36	1983	49.50	1.04	1.07
37	1959	40.40	1.02	1.01

return periods estimated from:

a: gringorten plotting position
b: fitted type 2 distribution

DAILY MAXIMUM RAINFALL
Soucis

THE STATISTICS OF THE ANNUAL SERIES

MAXIMUM VALUE	2.146E+02
MINIMUM VALUE	4.950E+01
RANGE OF VALUES	1.651E+02
MEAN OF 14 VALUES	1.014E+02
STANDARD ERROR	1.346E+01
STANDARD DEVIATION	5.035E+01
COEFFICIENT OF VARIATION	0.50
SKEWNESS	1.52E+05
COEFFICIENT OF SKEWNESS	1.19
STANDARD ERROR	0.60
KURTOSIS	3.96

the parameters of a type 2 distribution

location	70.87
scale	23.69
shape	-0.294

THE DISTRIBUTION ESTIMATES FOR GIVEN PROBABILITIES OF EXCEEDENCE

PROBAB. EXCEED.	RETURN PERIOD	REDUCED VARIATE	ESTIMATED MAXIMA	CONFIDENCE LIMITS UPPER	LOWER
0.990	1.01	-1.53	41.71	79.85	3.58
0.980	1.02	-1.36	44.24	79.57	8.91
0.950	1.05	-1.10	48.65	79.70	17.59
0.900	1.11	-0.83	53.34	80.72	25.97
0.800	1.25	-0.48	60.35	84.02	36.67
0.500	2.00	0.37	80.03	104.24	55.82
0.200	5.00	1.50	115.50	156.27	74.73
0.100	10.00	2.25	146.39	201.45	91.32
0.050	20.00	2.97	183.14	252.70	113.58
0.020	50.00	3.90	243.85	332.69	155.01
0.010	100.00	4.60	301.55	405.04	198.06
0.005	200.00	5.30	372.10	490.29	253.91
0.001	1000.00	6.91	603.12	755.59	450.66
0.000	5000.00	8.52	973.43	1160.31	786.54
0.000	10000.00	9.21	1195.33	1397.07	993.59

DAILY MAXIMUM RAINFALL
Soucis

rank	year	recorded maxima	return period a	b
1	1996	214.60	25.21	33.11
2	1988	176.00	9.05	17.65
3	1977	154.30	5.52	11.74
4	1986	144.00	3.97	9.52
5	1987	94.70	3.10	2.95
6	1985	90.10	2.54	2.61
7	1981	85.70	2.15	2.32

8	1984	82.90	1.87	2.16
9	1979	70.50	1.65	1.57
10	1976	69.00	1.48	1.51
11	1982	67.10	1.34	1.45
12	1980	63.80	1.22	1.34
13	1978	57.70	1.12	1.19
14	1983	49.50	1.04	1.06

return periods estimated from:

a: gringorten plotting position
b: fitted type 2 distribution

DAILY MAXIMUM RAINFALL
Errard (Extended)

THE STATISTICS OF THE ANNUAL SERIES

MAXIMUM VALUE	3.574E+02
MINIMUM VALUE	6.490E+01
RANGE OF VALUES	2.925E+02
MEAN OF 37 VALUES	1.518E+02
STANDARD ERROR	1.079E+01
STANDARD DEVIATION	6.562E+01
COEFFICIENT OF VARIATION	0.43
SKEWNESS	4.56E+05
COEFFICIENT OF SKEWNESS	1.62
STANDARD ERROR	0.39
KURTOSIS	5.83

the parameters of a type 2 distribution

location	119.76
scale	39.81
shape	-0.131

THE DISTRIBUTION ESTIMATES FOR GIVEN PROBABILITIES OF EXCEEDENCE

PROBAB. EXCEED.	RETURN PERIOD	REDUCED VARIATE	ESTIMATED MAXIMA	CONFIDENCE LIMITS UPPER	LOWER
0.990	1.01	-1.53	64.64	95.22	34.07
0.980	1.02	-1.36	70.02	98.34	41.70
0.950	1.05	-1.10	79.07	103.96	54.17
0.900	1.11	-0.83	88.30	110.25	66.36
0.800	1.25	-0.48	101.39	120.37	82.42
0.500	2.00	0.37	134.71	154.11	115.30
0.200	5.00	1.50	185.74	218.42	153.05
0.100	10.00	2.25	223.93	268.07	179.79
0.050	20.00	2.97	264.26	320.02	208.49
0.020	50.00	3.90	322.43	393.65	251.21
0.010	100.00	4.60	370.91	453.87	287.94
0.005	200.00	5.30	423.81	518.56	329.06
0.001	1000.00	6.91	566.53	688.77	444.30
0.000	5000.00	8.52	742.53	892.35	592.70
0.000	10000.00	9.21	830.49	992.23	668.76

DAILY MAXIMUM RAINFALL
Errard (Extended)

rank	year	recorded maxima	return period a	b
1	1967	357.40	66.29	82.93
2	1994	323.60	23.79	50.88
3	1970	282.80	14.50	27.07
4	1988	277.00	10.43	24.65
5	1981	195.50	8.14	5.98
6	1960	189.00	6.68	5.31
7	1962	185.30	5.66	4.96

8	1968	182.00	4.91	4.67
9	1971	170.20	4.34	3.76
10	1976	169.80	3.88	3.73
11	1986	168.30	3.52	3.63
12	1987	166.10	3.21	3.48
13	1996	160.20	2.96	3.13
14	1977	151.90	2.74	2.69
15	1992	150.00	2.55	2.60
16	1966	143.80	2.39	2.33
17	1963	139.60	2.24	2.17
18	1974	139.20	2.11	2.16
19	1965	137.60	2.00	2.10
20	1982	136.20	1.90	2.05
21	1991	133.00	1.81	1.94
22	1989	131.40	1.72	1.89
23	1984	127.90	1.65	1.79
24	1978	125.30	1.58	1.72
25	1979	115.70	1.51	1.49
26	1995	115.70	1.45	1.49
27	1990	114.90	1.40	1.48
28	1964	108.90	1.35	1.36
29	1980	107.30	1.30	1.34
30	1985	105.60	1.26	1.31
31	1972	104.60	1.21	1.30
32	1975	99.90	1.18	1.23
33	1993	93.80	1.14	1.16
34	1973	84.20	1.11	1.08
35	1958	80.40	1.07	1.06
36	1983	77.30	1.04	1.04
37	1959	64.90	1.02	1.01

return periods estimated from:

a: gringorten plotting position
b: fitted type 2 distribution

DAILY MAXIMUM RAINFALL
Errard

THE STATISTICS OF THE ANNUAL SERIES

MAXIMUM VALUE	3.236E+02
MINIMUM VALUE	1.149E+02
RANGE OF VALUES	2.087E+02
MEAN OF 6 VALUES	1.931E+02
STANDARD ERROR	3.499E+01
STANDARD DEVIATION	8.572E+01
COEFFICIENT OF VARIATION	0.44
SKEWNESS	6.00E+05
COEFFICIENT OF SKEWNESS	0.95
STANDARD ERROR	0.85
KURTOSIS	4.38

the parameters of a type 1 distribution

location	154.54
scale	66.83

THE DISTRIBUTION ESTIMATES FOR GIVEN PROBABILITIES OF EXCEEDENCE

PROBAB. EXCEED.	RETURN PERIOD	REDUCED VARIATE	ESTIMATED MAXIMA	CONFIDENCE LIMITS UPPER	LOWER
0.990	1.01	-1.53	52.47	151.65	-46.70
0.980	1.02	-1.36	63.38	155.26	-28.51
0.950	1.05	-1.10	81.21	161.97	0.45
0.900	1.11	-0.83	98.80	169.99	27.61
0.800	1.25	-0.48	122.73	184.29	61.18
0.500	2.00	0.37	179.03	241.99	116.08
0.200	5.00	1.50	254.79	360.81	148.76
0.100	10.00	2.25	304.94	448.14	161.74
0.050	20.00	2.97	353.05	533.94	172.15
0.020	50.00	3.90	415.32	646.36	184.28
0.010	100.00	4.60	461.98	731.12	192.84
0.005	200.00	5.30	508.47	815.84	201.10
0.001	1000.00	6.91	616.17	1012.69	219.66
0.000	5000.00	8.52	723.76	1209.79	237.74
0.000	10000.00	9.21	770.09	1294.74	245.44

DAILY MAXIMUM RAINFALL
Errard

rank	year	recorded maxima	return period a	b
1	1994	323.60	10.93	13.06
2	1988	277.00	3.92	6.76
3	1996	160.20	2.39	1.66
4	1992	150.00	1.72	1.52
5	1991	133.00	1.34	1.34
6	1990	114.90	1.10	1.20

return periods estimated from:

DAILY MAXIMUM RAINFALL
Mahaut

THE STATISTICS OF THE ANNUAL SERIES

MAXIMUM VALUE	2.621E+02
MINIMUM VALUE	7.240E+01
RANGE OF VALUES	1.897E+02
MEAN OF 13 VALUES	1.486E+02
STANDARD ERROR	1.476E+01
STANDARD DEVIATION	5.323E+01
COEFFICIENT OF VARIATION	0.36
SKEWNESS	1.54E+05
COEFFICIENT OF SKEWNESS	1.02
STANDARD ERROR	0.62
KURTOSIS	4.44

the parameters of a type 3 distribution

location	122.13
scale	39.61
shape	0.082

THE DISTRIBUTION ESTIMATES FOR GIVEN PROBABILITIES OF EXCEEDENCE

PROBAB. EXCEED.	RETURN PERIOD	REDUCED VARIATE	ESTIMATED MAXIMA	CONFIDENCE LIMITS UPPER	LOWER
0.990	1.01	-1.53	57.67	99.51	15.82
0.980	1.02	-1.36	64.94	103.71	26.18
0.950	1.05	-1.10	76.64	110.72	42.57
0.900	1.11	-0.83	87.93	117.97	57.89
0.800	1.25	-0.48	102.90	128.88	76.93
0.500	2.00	0.37	136.43	162.99	109.87
0.200	5.00	1.50	178.02	222.75	133.29
0.100	10.00	2.25	203.49	263.91	143.08
0.050	20.00	2.97	226.49	302.81	150.17
0.020	50.00	3.90	254.30	351.78	156.83
0.010	100.00	4.60	273.79	387.34	160.24
0.005	200.00	5.30	292.12	421.80	162.44
0.001	1000.00	6.91	330.76	498.05	163.47
0.000	5000.00	8.52	364.56	569.61	159.51
0.000	10000.00	9.21	377.79	599.14	156.44

DAILY MAXIMUM RAINFALL
Mahaut

rank	year	recorded maxima	return period a	b
1	1988	262.10	23.43	65.63
2	1996	239.40	8.41	30.28
3	1984	174.70	5.13	4.60
4	1991	164.50	3.69	3.59
5	1986	161.30	2.88	3.33
6	1992	137.20	2.36	2.03
7	1989	132.90	2.00	1.88

8	1980	129.70	1.74	1.78
9	1995	124.80	1.53	1.65
10	1990	122.50	1.37	1.59
11	1987	114.50	1.24	1.42
12	1993	95.40	1.13	1.17
13	1985	72.40	1.04	1.04

return periods estimated from:

a: gringorten plotting position
b: fitted type 3 distribution

DAILY MAXIMUM RAINFALL
Troumassee

THE STATISTICS OF THE ANNUAL SERIES

MAXIMUM VALUE	2.911E+02
MINIMUM VALUE	6.730E+01
RANGE OF VALUES	2.238E+02
MEAN OF 19 VALUES	1.304E+02
STANDARD ERROR	1.291E+01
STANDARD DEVIATION	5.627E+01
COEFFICIENT OF VARIATION	0.43
SKEWNESS	2.46E+05
COEFFICIENT OF SKEWNESS	1.38
STANDARD ERROR	0.52
KURTOSIS	5.60

the parameters of a type 2 distribution

location	100.44
scale	30.35
shape	-0.207

THE DISTRIBUTION ESTIMATES FOR GIVEN PROBABILITIES OF EXCEEDENCE

PROBAB. EXCEED.	RETURN PERIOD	REDUCED VARIATE	ESTIMATED MAXIMA	CONFIDENCE LIMITS UPPER	LOWER
0.990	1.01	-1.53	60.70	97.29	24.12
0.980	1.02	-1.36	64.37	98.27	30.48
0.950	1.05	-1.10	70.65	100.45	40.86
0.900	1.11	-0.83	77.20	103.46	50.93
0.800	1.25	-0.48	86.69	109.40	63.98
0.500	2.00	0.37	112.00	135.22	88.78
0.200	5.00	1.50	153.81	192.92	114.70
0.100	10.00	2.25	187.40	240.23	134.58
0.050	20.00	2.97	224.91	291.64	158.18
0.020	50.00	3.90	282.54	367.76	197.31
0.010	100.00	4.60	333.61	432.89	234.33
0.005	200.00	5.30	392.39	505.77	279.01
0.001	1000.00	6.91	565.86	712.13	419.60
0.000	5000.00	8.52	807.65	986.93	628.36
0.000	10000.00	9.21	939.25	1132.78	745.72

DAILY MAXIMUM RAINFALL
Troumassee

rank	year	recorded maxima	return period a	b
1	1988	291.10	34.14	56.55
2	1967	199.40	12.26	12.60
3	1989	189.10	7.47	10.34
4	1994	184.10	5.37	9.37
5	1990	165.40	4.19	6.40
6	1966	154.70	3.44	5.10
7	1965	135.90	2.91	3.38

8	1973	129.50	2.53	2.93
9	1987	117.70	2.23	2.26
10	1992	112.90	2.00	2.04
11	1974	110.10	1.81	1.92
12	1986	108.00	1.65	1.84
13	1996	104.20	1.52	1.70
14	1991	95.70	1.41	1.45
15	1995	85.40	1.31	1.23
16	1985	78.50	1.23	1.13
17	1993	77.20	1.15	1.11
18	1971	71.90	1.09	1.06
19	1972	67.30	1.03	1.03

return periods estimated from:

a: gringorten plotting position
b: fitted type 2 distribution

DAILY MAXIMUM RAINFALL
Cap Estate

THE STATISTICS OF THE ANNUAL SERIES

MAXIMUM VALUE	2.875E+02
MINIMUM VALUE	7.210E+01
RANGE OF VALUES	2.154E+02
MEAN OF 19 VALUES	1.361E+02
STANDARD ERROR	1.145E+01
STANDARD DEVIATION	4.989E+01
COEFFICIENT OF VARIATION	0.37
SKEWNESS	1.97E+05
COEFFICIENT OF SKEWNESS	1.58
STANDARD ERROR	0.52
KURTOSIS	6.97

the parameters of a type 1 distribution

location	113.66
scale	38.90

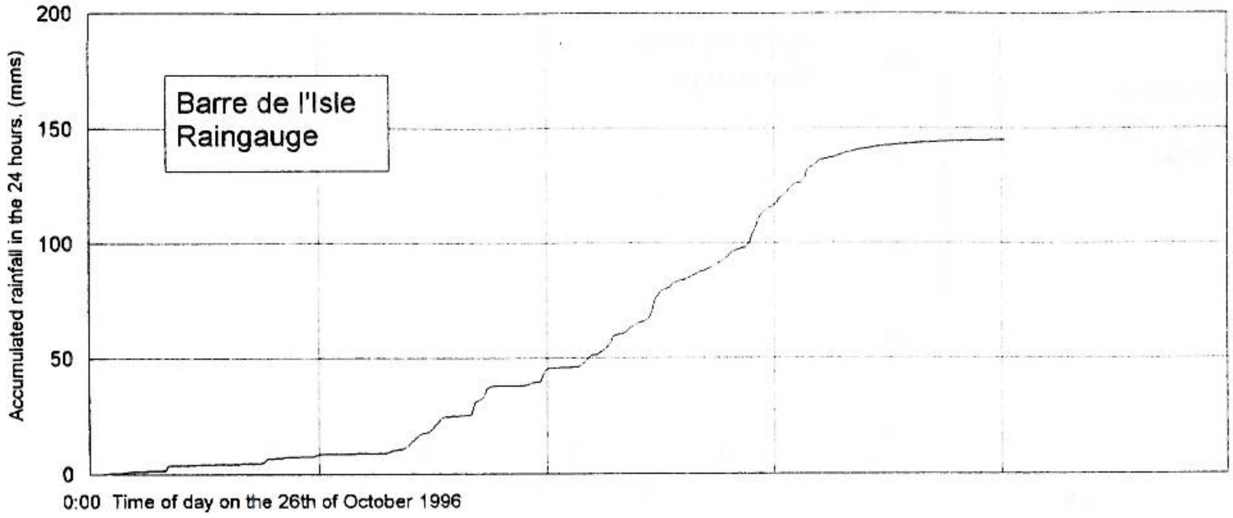
THE DISTRIBUTION ESTIMATES FOR GIVEN PROBABILITIES OF EXCEEDENCE

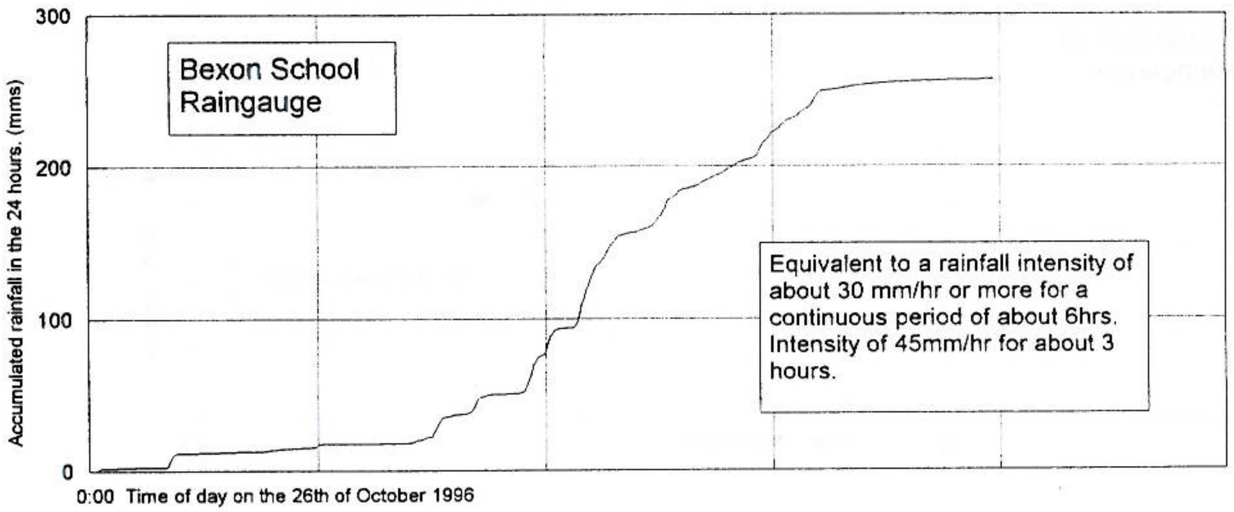
PROBAB. EXCEED.	RETURN PERIOD	REDUCED VARIATE	ESTIMATED MAXIMA	CONFIDENCE LIMITS UPPER	LOWER
0.990	1.01	-1.53	54.25	86.69	21.81
0.980	1.02	-1.36	60.60	90.65	30.54
0.950	1.05	-1.10	70.98	97.40	44.56
0.900	1.11	-0.83	81.22	104.50	57.93
0.800	1.25	-0.48	95.15	115.28	75.01
0.500	2.00	0.37	127.92	148.51	107.33
0.200	5.00	1.50	172.01	206.69	137.33
0.100	10.00	2.25	201.20	248.05	154.36
0.050	20.00	2.97	229.21	288.38	170.04
0.020	50.00	3.90	265.45	341.03	189.88
0.010	100.00	4.60	292.62	380.65	204.58
0.005	200.00	5.30	319.68	420.22	219.14
0.001	1000.00	6.91	382.37	512.06	252.67
0.000	5000.00	8.52	444.99	603.97	286.01
0.000	10000.00	9.21	471.96	643.57	300.34

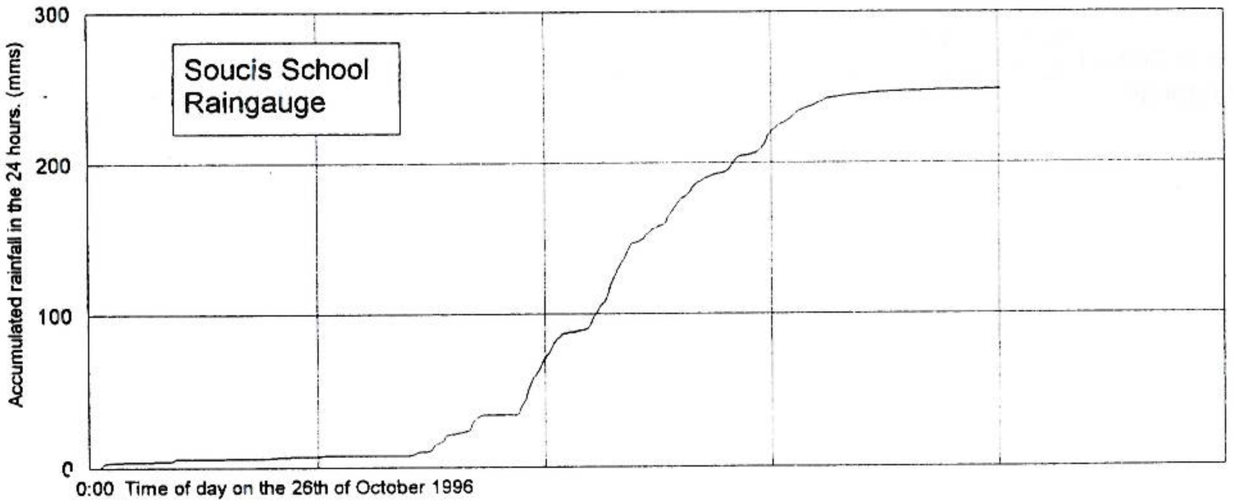
DAILY MAXIMUM RAINFALL
Cap Estate

rank	year	recorded maxima	return period a	b
1	1988	287.50	34.14	87.74
2	1967	200.40	12.26	9.81
3	1994	185.00	7.47	6.77
4	1966	155.50	5.37	3.46
5	1990	154.80	4.19	3.41
6	1989	150.40	3.44	3.10
7	1986	146.10	2.91	2.84
8	1973	138.70	2.53	2.45

Cul de Sac River Valley
Rainfall of 26th of October 1996 from data loggers

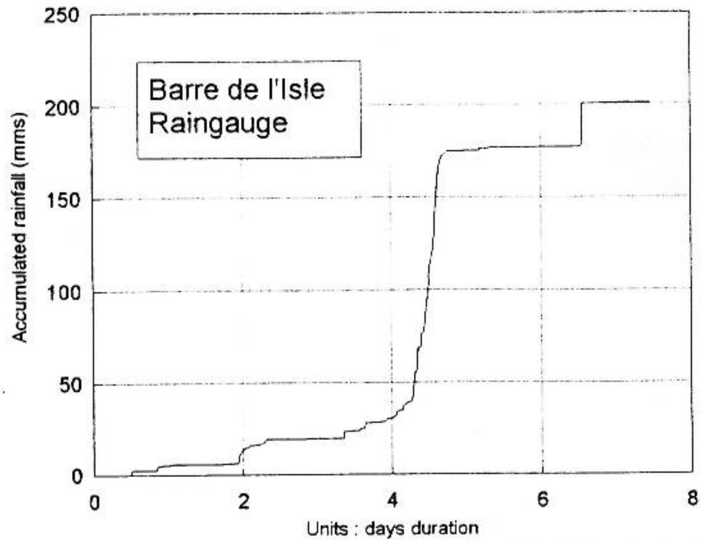


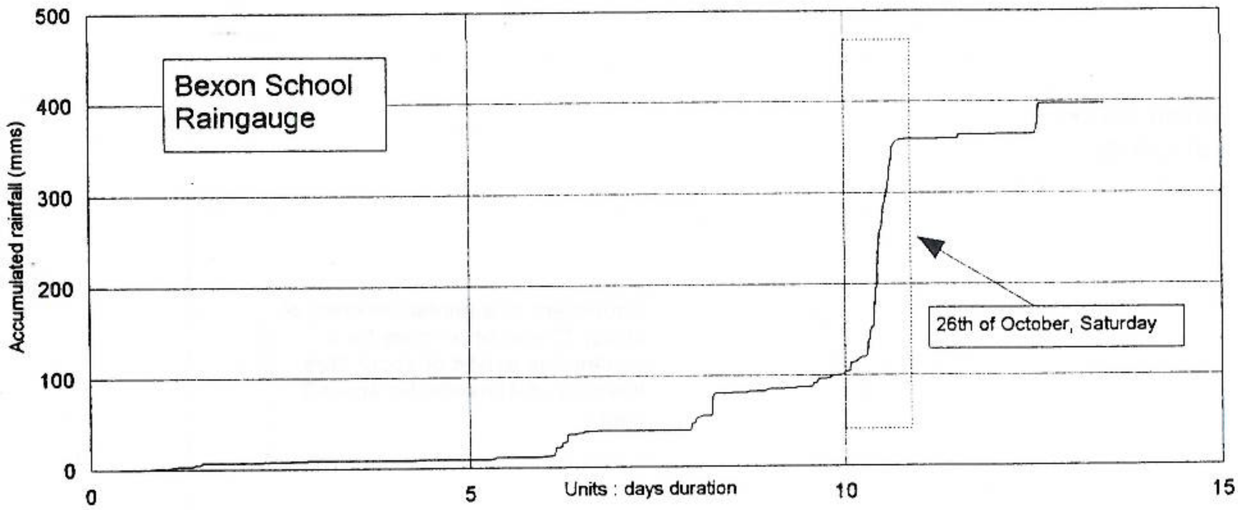


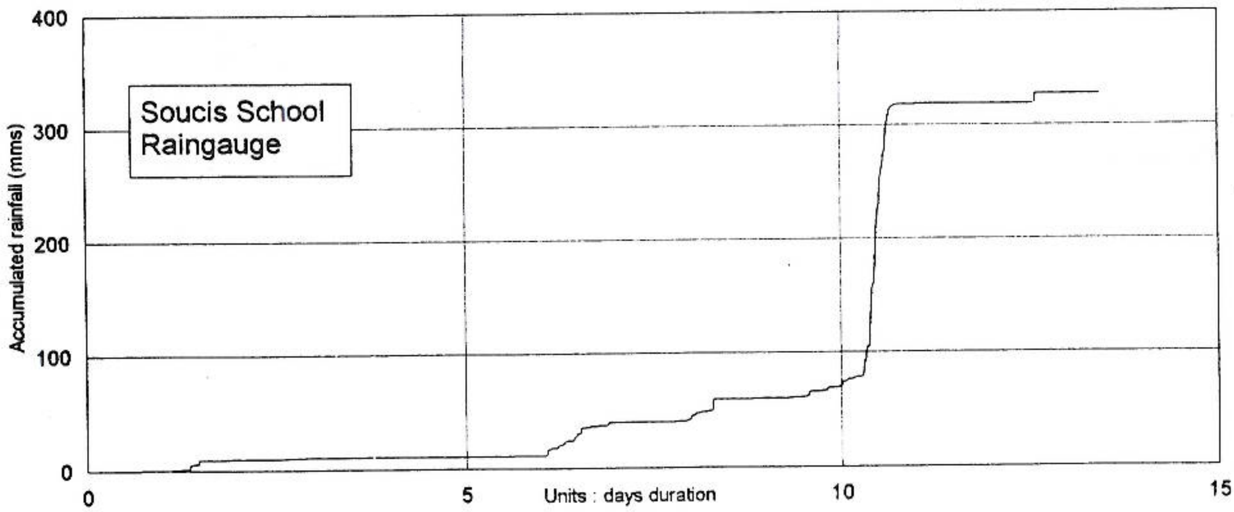


Cul de Sac River Valley

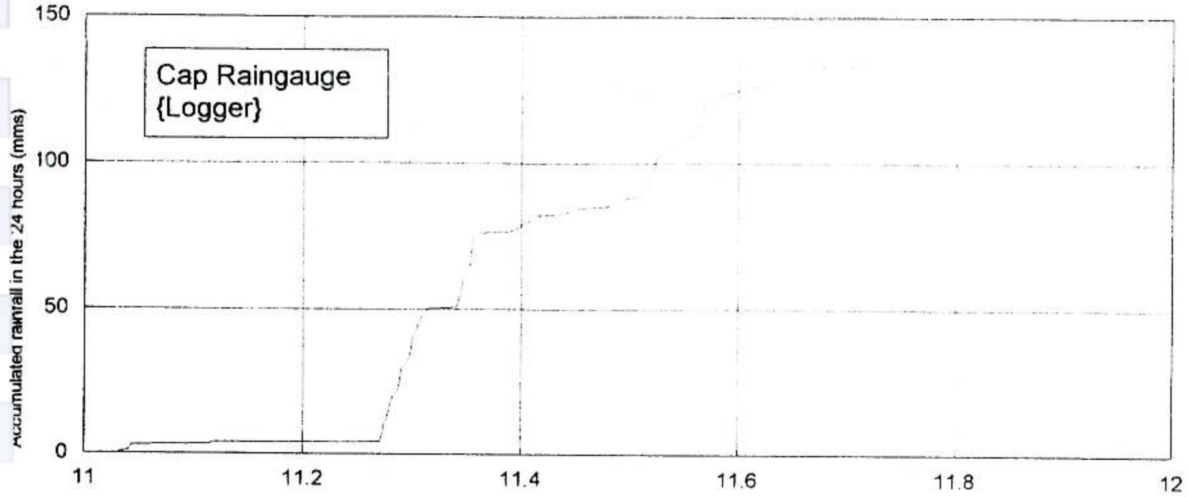
Long term accumulated rainfall during storm event of late October 1996

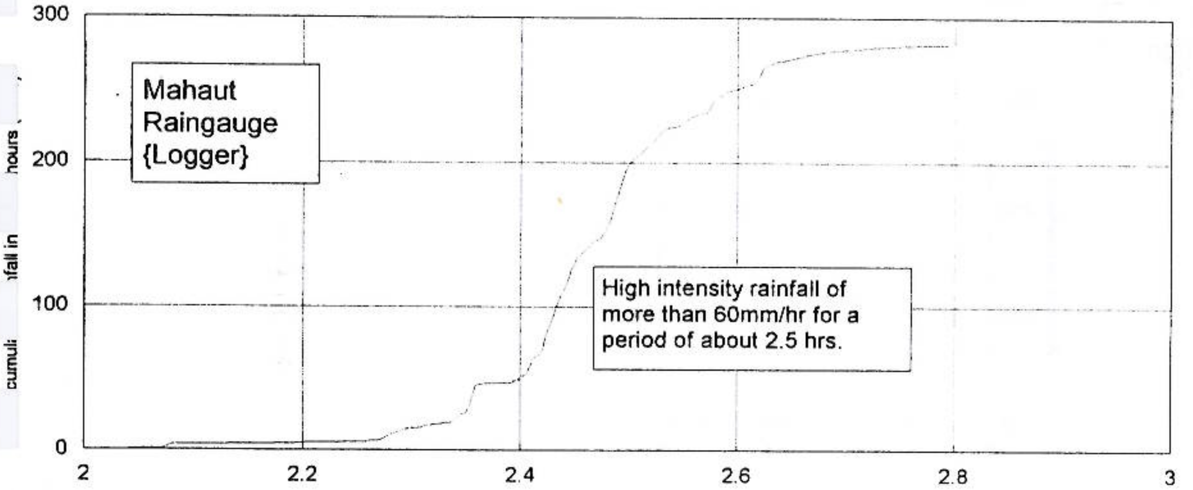


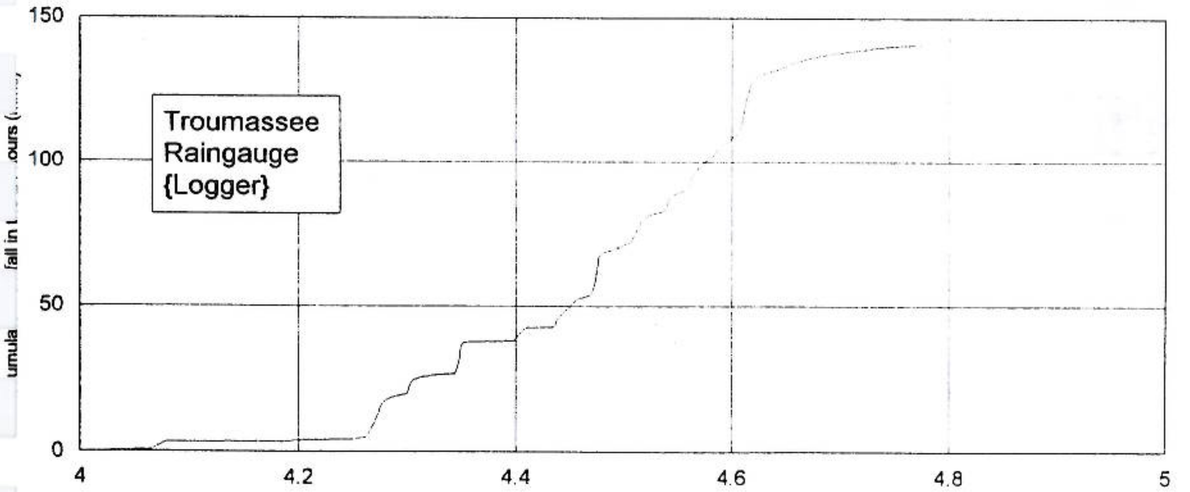




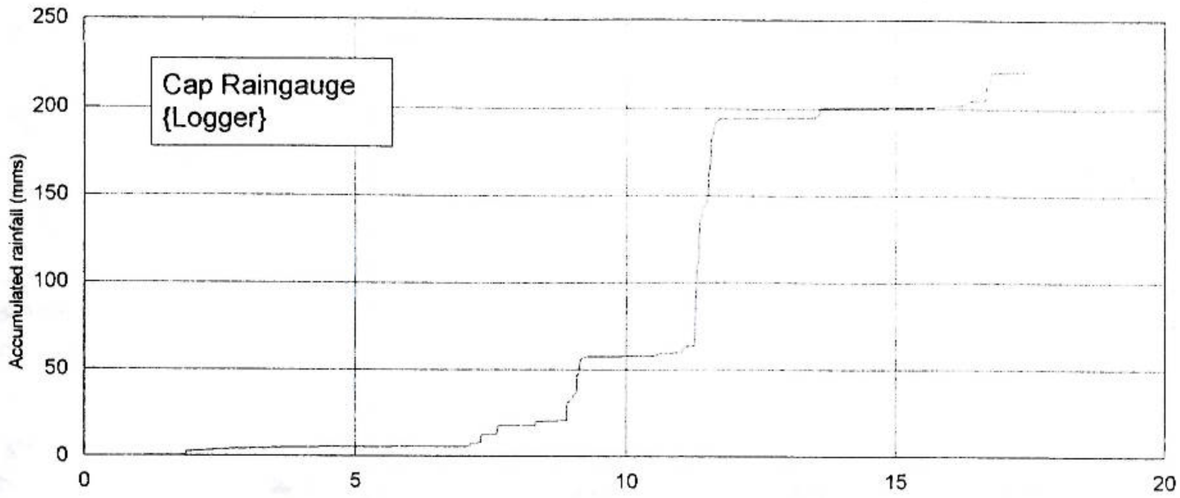
Rainfall Characteristics during and up to the Storm Event of 26th October 1996

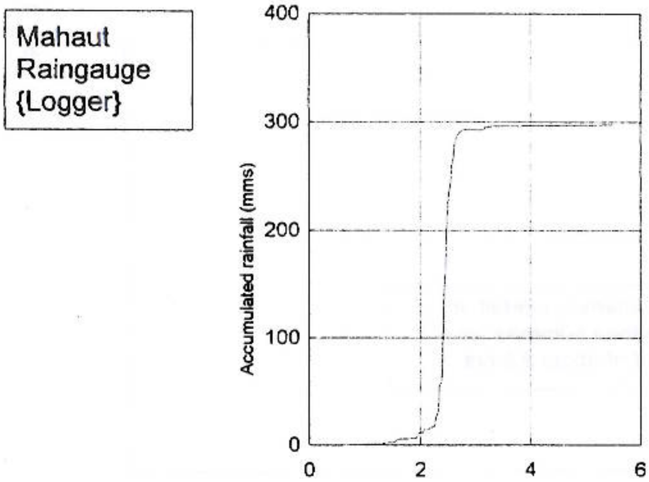


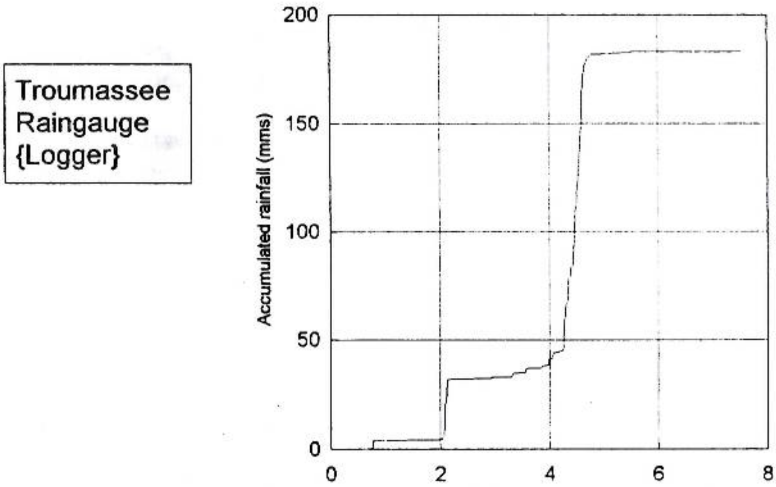




Long Term Accumulated Rainfall leading up to the event of 26th October 1996







APPENDIX B

MAJOR HISTORICAL STORMS AND HURRICANES TO EFFECT ST. LUCIA

Given below are outline details of the major storms and hurricanes that have effected St. Lucia over the last 100 years. It should be noted that it is not always clear whether the damage detailed is caused by flooding or high winds.

1894	Heavy landslides and 'incalculable damage to crops'. 45 houses washed away in Soufrière. 11 killed.
1897 (11 Sept)	353 mm of rain. 'Hundreds of peasant properties in total ruin'. Cocoa crops swept away.
1921 (10 Sept)	Cocoa crop, communications and ships damaged. 15 killed.
1928 (19 Sept)	Crops and road destroyed and fish market and jetty washed away at Roseau.
1938 (21 Nov)	'Worst storms in living memory'. Annual rainfall 960 mm above average, 242 mm in 24 hours at Barre De L'Isle. 120 killed, mainly through landslides.
1939 (7 Jan)	Three villages destroyed. 100 killed and 250 missing.
1940 (7 Aug)	Extensive damage to crops. Roads swept away. Cul-de-Sac valley particularly badly hit.
1954 (12 Dec)	3250 mm of rainfall recorded for the year. Ravine Poisson badly hit by landslides, whole crop destroyed.
1960 (10 July)	Hurricane 'Abbey'. Damage to roads, bridges and electricity supply. 6 killed.
1963 (24 Sept)	Hurricane 'Edith'. 60% of banana trees destroyed in effected areas (mostly north and east). Estimated damage EC$4 million.
1965 (25 Oct)	40% of all banana crop effected. Castries area worst hit.
1967 (8 Sept)	Hurricane 'Beulah'. 378 mm of rain in 24 hours, most of which fell within 12 hours. 18 killed. 'Collapse of road system - millions of tons of top soil washed away'. (Event similar in magnitude to TSD in terms of rainfall and probably flooding)

1979 Hurricane 'David'.

1980 Hurricane 'Allen'.

1988 (10 Sept) Hurricane 'Gilbert'. Over 200 mm of rain in 24 hours at Union.

1989 (18 Sept) Hurricane 'Hugo'.

1994 (10 Sept) Tropical Storm Debbie. Maximum rainfall intensity approximately 90 mm/hr with 276 and 372 mm of rain in 24 hours at Union and Errard respectively. 4 killed, 100 homes destroyed + 100 damaged. Total damage estimated at EC$112 million.

The information above was principally derived from AESD, 1994 and IoH, 1992.

Appendix D

Floodplain Maps and River Surveys

Annex 3

Appendix D

Flood Plain Mapping and River Surveys

1. Flood Plain Mapping

Site inspections and floodplain extents have been delineated for TSD (and for the flood event of 26th of October 1997 where the extent of flooding differed significantly) for the following main flood prone areas:

- Cul de Sac Valley (Ravine Poisson to estuary)
- Roseau Valley (Durandeau to outfall)
- Anse La Raye (urban area)
- Canaries (urban area)
- Soufriere (urban area)
- Mabouya - Fond D'Or (La Resource, Grande Ravine and Grande Riviere to estuary)
- Dennery (Ravine Chien to estuary)
- Vieux Fort (Beausejour Agricultural Station to estuary)

The flood extents on the left and right banks have been marked on paper copies of the 1:2,500 scale maps (1982, Directorate of Overseas Surveys, UK). The maps having contours at a vertical interval of 10m are the best maps available for the flood extent mapping process, unfortunately a 10m contour interval places limitations on the accuracy of the interpretation and mapping of flood extents. The maps are annotated with the positions of flood extent limits based on the questioning which took place of local residents. These are marked '③' indicating the reference to the report.

A list of the map sheets employed for each river basin is presented in **Table D.1**. These map sheets have been bound and handed over to the Acting Chief Engineer AESD for safe keeping and future reference.

A process of digitization has been undertaken to produce digital .DXF files through the Autocad software package. The digitization has been carried out by staff at MCWT&PU. The current status of .DXF coverage is given in the figure sheets on the following pages and illustrates the problems which have been encountered during the process. The digitizer available within the MCWT&PU was only of about A4 size necessitating considerable map adjustment and loss of position. Nevertheless, they illustrate the process which can be followed which would enable the marked up 1:2,500 maps to be imported into the GIS environment.

It is recommended that when local staff time is available that the 1:2,500 sheets should be re-digitized using a A1 or preferably A0 digitizer. There is suitable digitizing equipment available at CEHI and it is believed also at the Ministry of Finance, Planning, Information Services and Public Services.

A printout from the CEHI GIS at 1:10,000 using the digitized flood extent mapping was to be presented at the end of this Appendix, unfortunately this was not possibble due to a lack of functioning pens in the plotter. The CEHI GIS, like that at the MFPIS&PS is based on the digitized 1:25,000 mapping series. There is thus a degree of 'crudeness' when output plots are produced at 1:10,000. A more detailed GIS base is required to match the flood plain mapping which has been undertaken.

It is reported that a company in the US is currently producing a set of 1:2,500 maps covering the whole island and should hand over the digital bases some time in 1998. It is intended that these are then used as bases for the maps although this will have to be undertaken at some time in the future.

Table D.1

Maps Used for Flood Extent Mapping (Scale 1:2,500)

River Name	1:2,500 Maps with Flood Extents (TSD) Marked
Cul de Sac	0645, 0646, 0844, 0845, 0846, 1041, 1042, 1043, 1044, 1045
Dennery	1837, 2037
Mabouya/ Fond D'Or	1439, 1440, 1441, 1639, 1640, 1641, 1838, 1839, 1840, 2039
Vieux Fort	1017, 1018, 1217, 1218, 1219, 1417, 1418
Soufriere	
Canaries	0036, (0037)
Anse La Raye	0240, 0241
Roseau	0441, 0442, 0443, 0641, 0642, 0643, 0840, 0841, 0842

{Note: All the above original paper maps with marked up flood extents have been deposited in the AESD Office}.

2 River Surveys

As part of the Phase 1 works, many surveys were undertaken of the main river system in advance of the engineering works which were undertaken at that time. The surveys only covered the main river course in the lower reaches and only extended at most about 20m out from either bank. In addition, no permanent, or clearly identifiable temporary benchmarks were established. The data for the longitudinal profiles of various rivers presented in Annex 1 was derived from this work.

A need identified during the World Bank Mission in 1994 was for a number of river cross sections to be surveyed to form known sectional profiles extending across the flood plain to enable future checks to be made in relation to river morphological changes which might be taking place owing to the erosion and sedimentation process. In other words, were the lower reaches of rivers aggrading or eroding.

Historic river cross sections only exist at the major river gauging sites (see Annex 2). It is important for the analysis of planform stability and bed level accretion that the cross sections surveyed are always tied in to a common temporary benchmark or fixed level point.

In many of the river valleys, only one gauging site has suitable records. A programme of additional river surveys were therefore initiated during Phase 2 to augment the number of 'control sections' for regular checking. These were identified for the Roseau Valley, Dennery, Cul de Sac and Mabouya. These surveyed sections were also intended to serve as potential locations for the siting of crest level gauges to measure flood peaks. In the future, the RMU should undertake similar exercises on other main rivers on the island.

Unlike Phase 1, the majority of 'special work' has been undertaken through the Government system. A surveyor was identified by MCWT&PU in January 1997 to undertake the above work and a briefing held with the Consultants. It was estimated the survey work would take a couple of weeks. A contract was arranged by MCWT&PU, however, progress has been very slow.

The contract surveyor has undertaken his tasks for the Cul-de-Sac and Roseau river valleys (channel and floodplain cross-section surveys including any floodmarks identified, preparation of cross-section plots, installation of bench marks and preparation of plans indicating the surveyed sections and the location and elevation of the bench marks). There have been delays in the work due to payment approvals but it is expected to resume soon.

Once completed, the cross-sections and surveyed flood levels may be used also to verify the flood extent maps produced and to make estimates of peak flows using Manning's equation. The cross-sections should also be added to the flood extent maps. {The sections should also be used as locations for the installation of crest level gauges}.

On November 14th 1997, a 1:10,000 map of the Roseau Valley was handed over to the Consultants by the Surveyor together with one of the six cross sections located in the Valley. Work on the Cul de Sac surveys is being processed. (This is all too late for inclusion in the current reporting but should be followed up by staff of AESD/ MCWT&PU).

Additional Survey Needs:

River flow gauging stations are planned for some rivers not included in the above work. Benchmarks to datum need to be set where these are not already available (some were put in during the WEMP Phase 1 works).

A large number of floodmarks have been identified during the flood mapping process. The marks, listed in the flood reports for Tropical Storm Debbie and the event of 26th October 1996, should be surveyed to obtain levels to datum. This information may then be used to verify the flood extent maps and as reference in any future assessment of flood risk or in the design of flood defences.

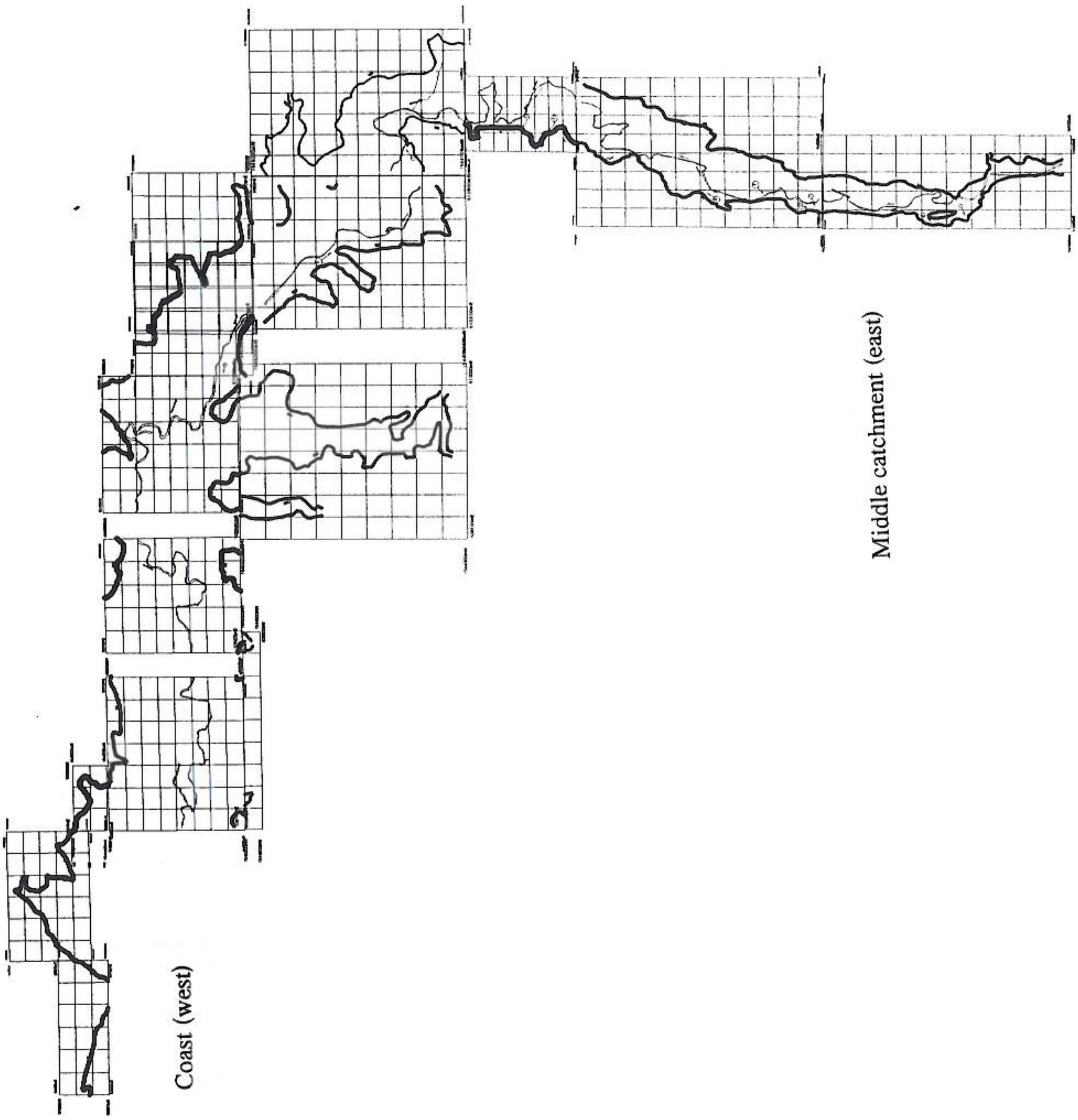
Ideally, channel sections at the completed works for the engineering trials should be surveyed (channel sections, preferably to datum) to obtain as-built levels and dimensions. Each section should be taken between two identifiable markers (e.g., a telegraph pole or stake driven into the ground) in order that the exact location of each section is known. Further surveys should then be taken (identical sections as the as-built survey) either following major flood events or after a given time lapse to determine whether any movement of the works or river channel has occurred. This survey will also provide data concerning siltation/erosion rates.

The experience of contracting surveyors during Phase 2 has not been encouraging for the furtherance of river level information retrieval in the future. Technicians within the future RMU should be able to undertake topographic levelling work to fix flood levels and datums for crest level gauges and hydrometric stations. These are essential tasks in any flood hydrology situation.

......

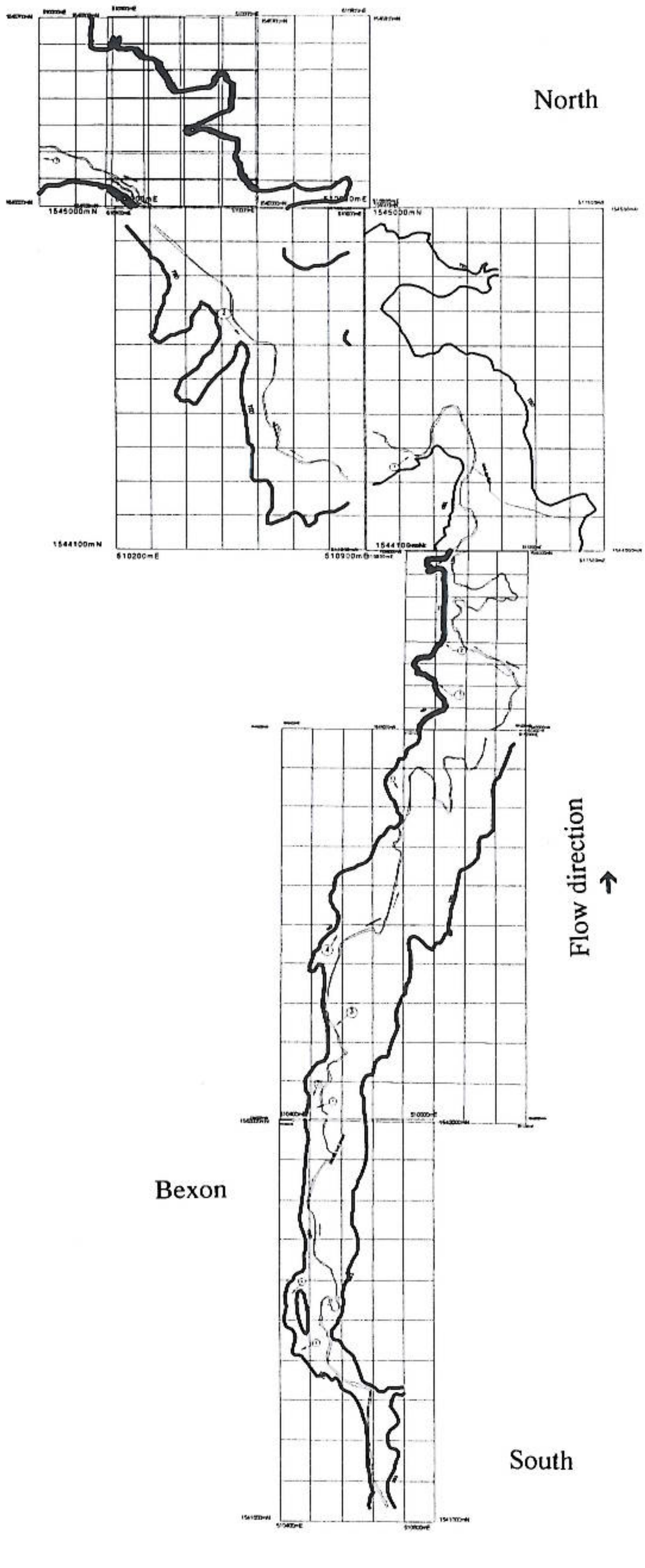
Cul de Sac

Layout of the Autocad .DXF files created showing the extent of flooding



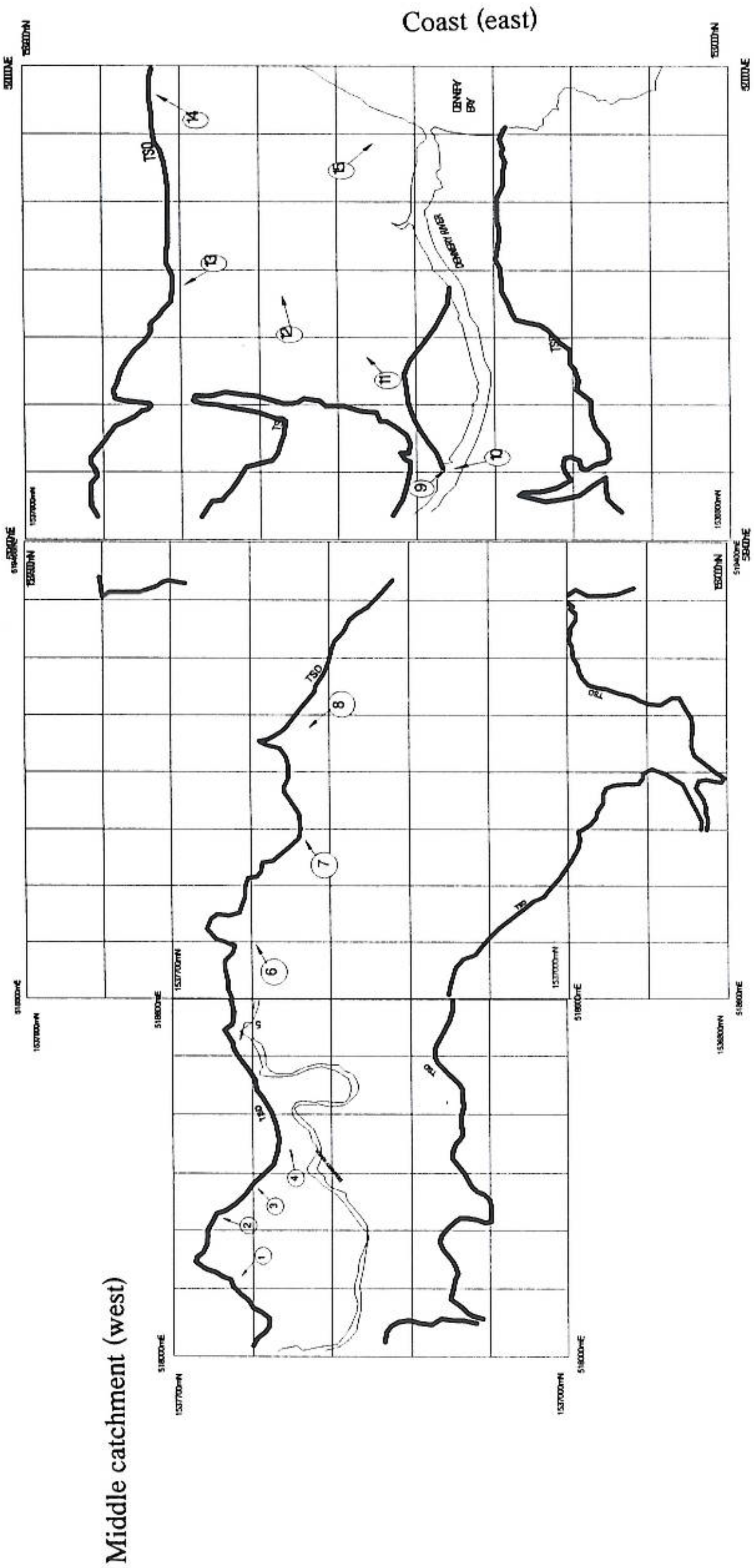
Cul de Sac (Bexon Area)

Layout of the Autocad .DXF files created showing the extent of flooding



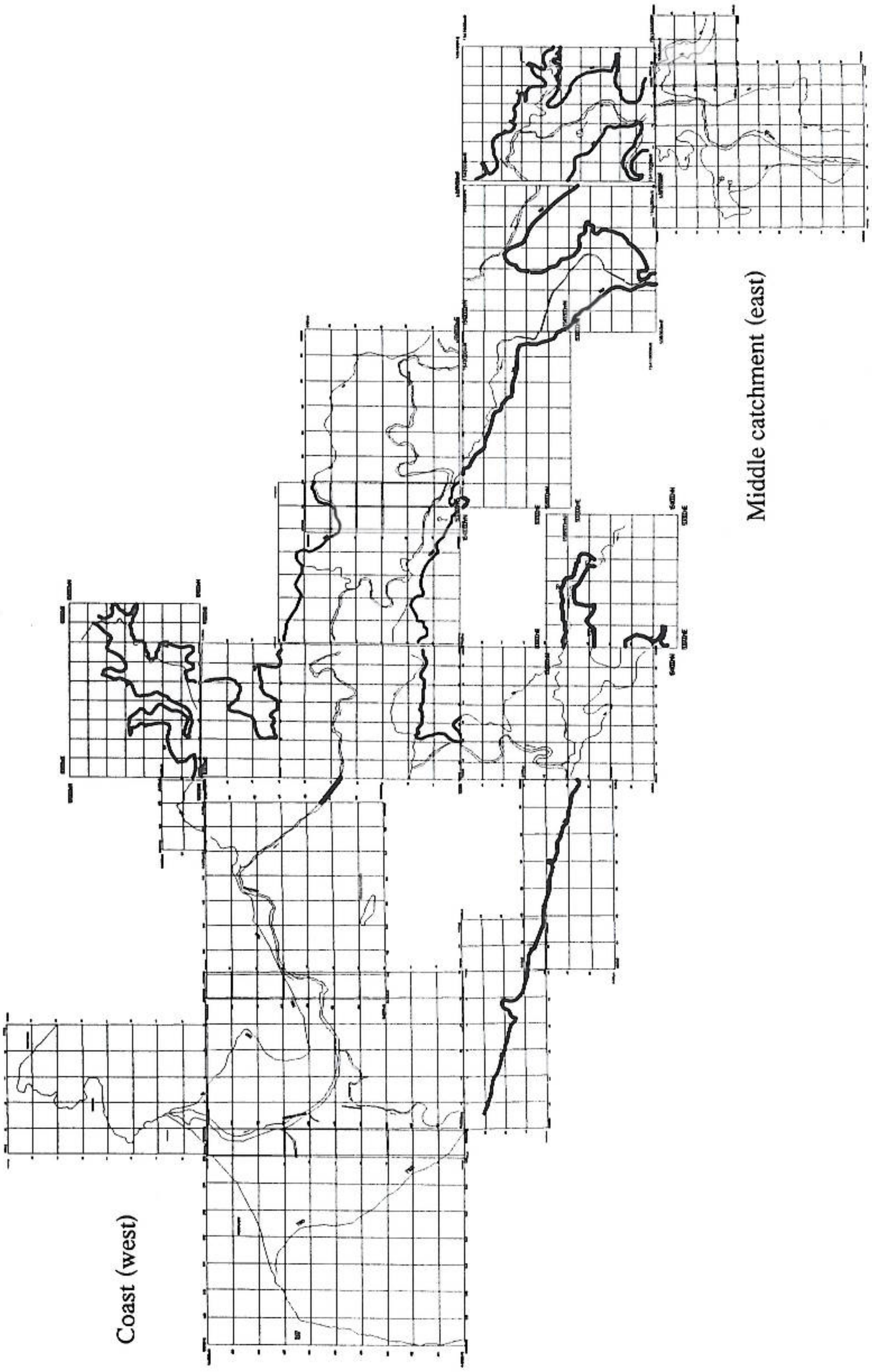
Dennery

Layout of the Autocad .DXF files created showing the extent of flooding



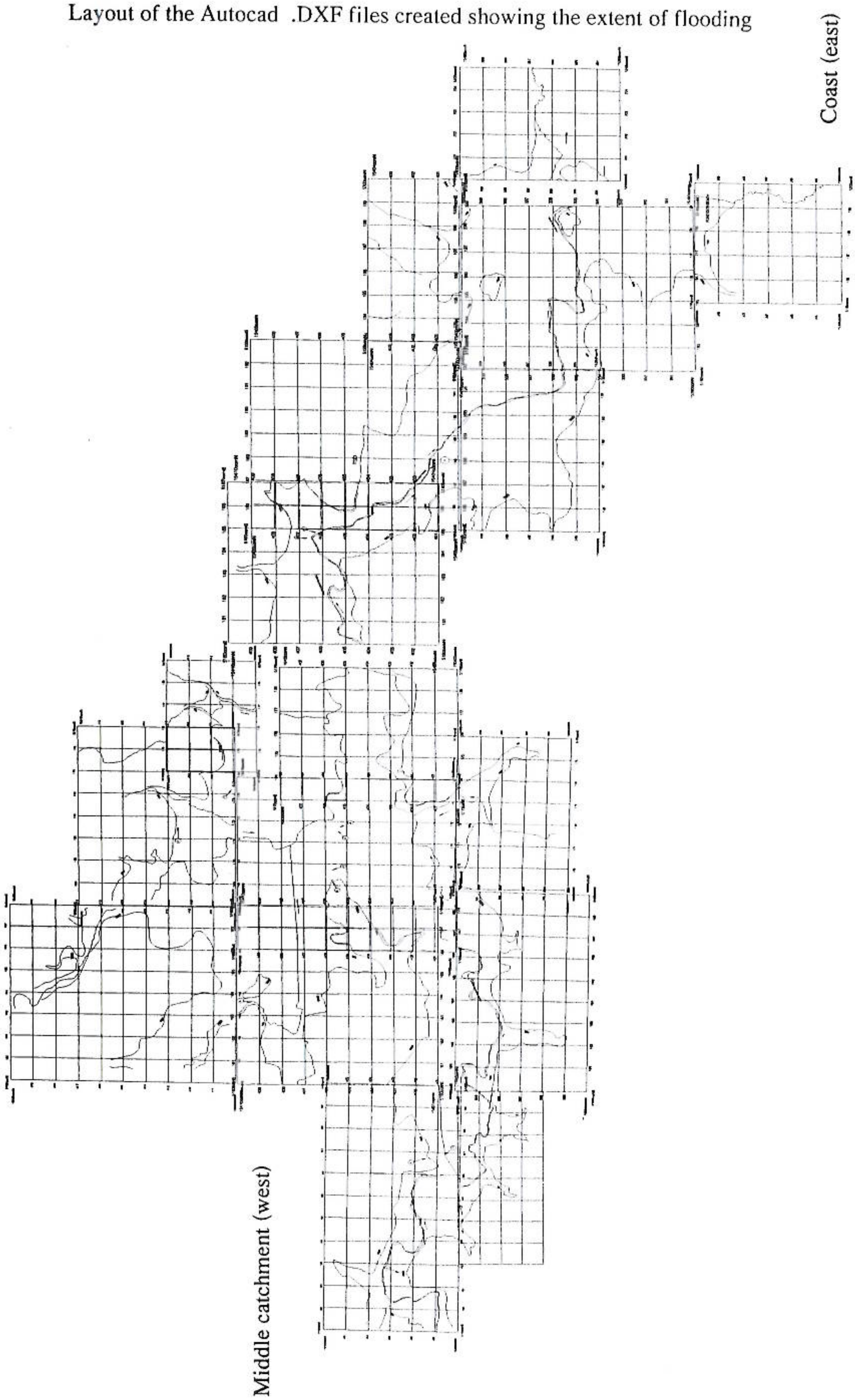
Roseau

Layout of the Autocad .DXF files created showing the extent of flooding



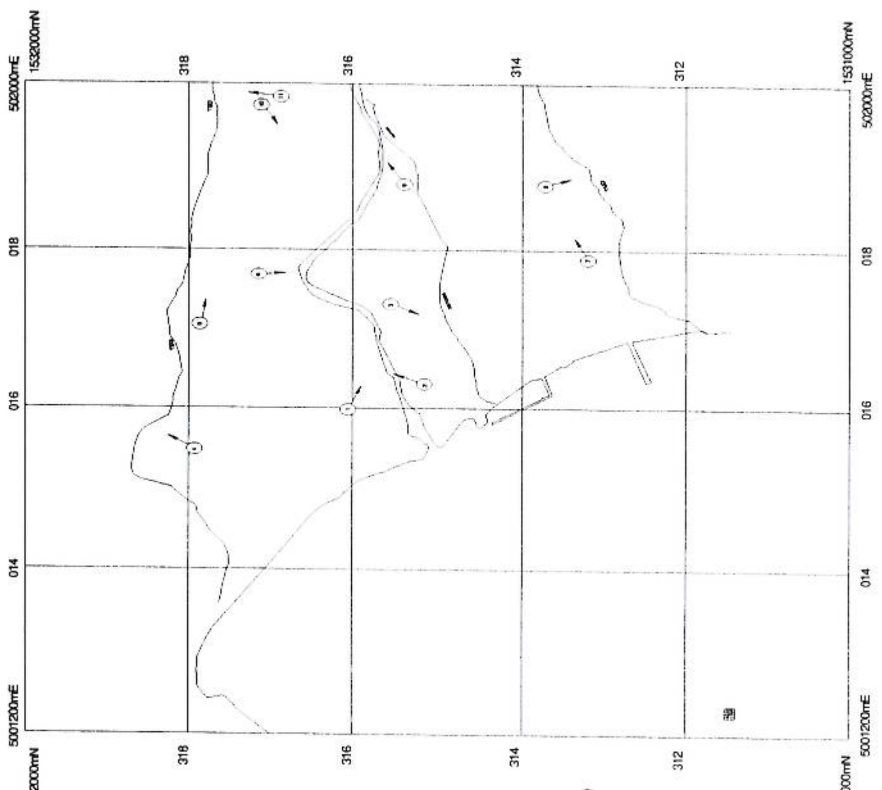
Mabouya / Fond d'Or

Layout of the Autocad .DXF files created showing the extent of flooding



Soufriere

Layout of the Autocad .DXF files created showing the extent of flooding

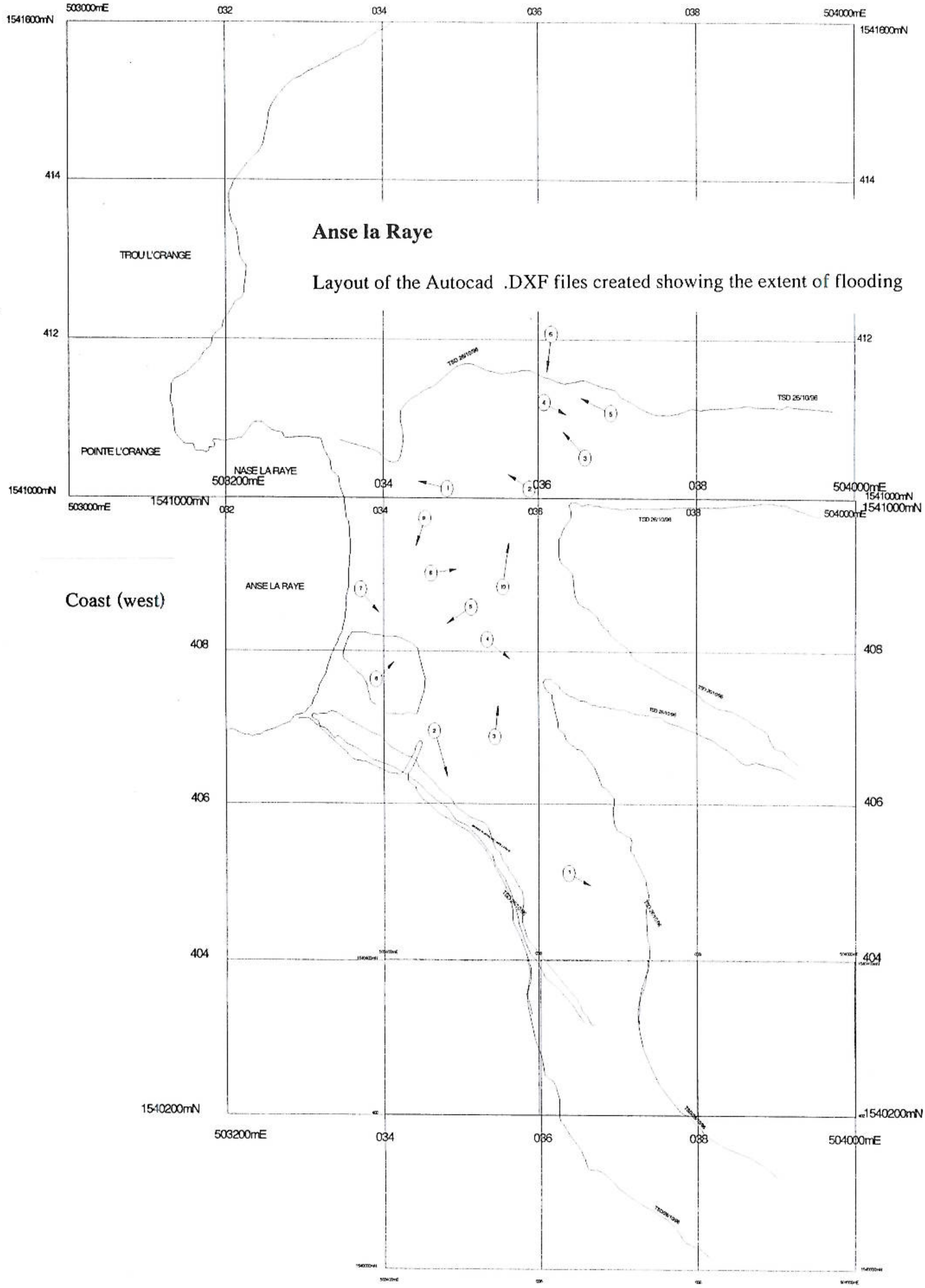


Coast (west)

Anse la Raye

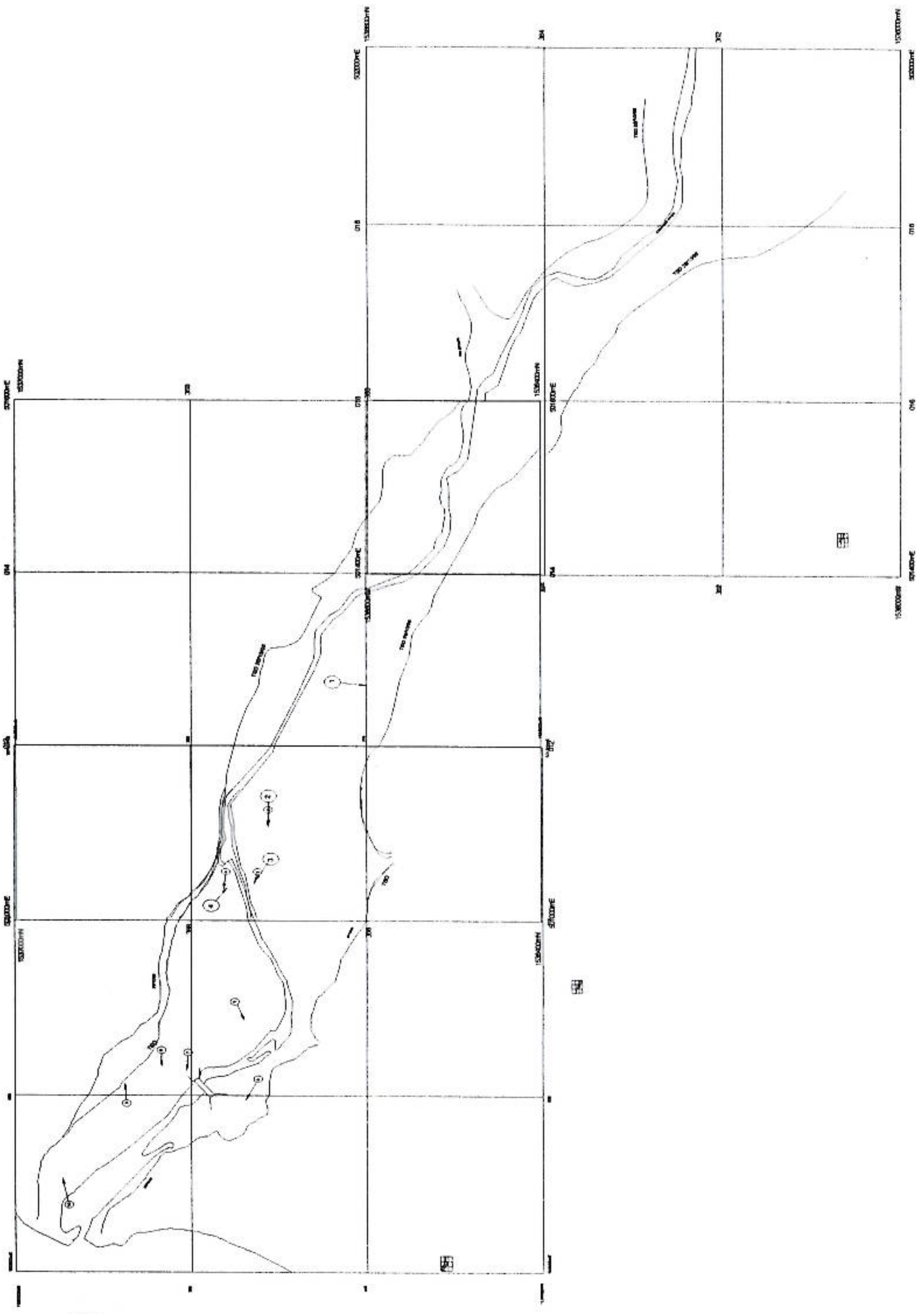
Layout of the Autocad .DXF files created showing the extent of flooding

Coast (west)



Canaries

Layout of the Autocad .DXF files created showing the extent of flooding



Coast (west)

Vieux Fort

Layout of the Autocad .DXF files created showing the extent of flooding