A hydrological assessment and watershed management plan for the Talvan water catchment

Christopher Cox

November 2004

iied
International Institute for Environment and Development

DFID Department for International Development

Contacts:
Christopher Cox • P.O. Box GM682 Castries, St. Lucia • Tel: +758 458-1595 • Fax: +758 453-7116 • Email: ctcox@candw.lc

Caribbean Natural Resources Institute (CANARI) • Tel: +868 626 6062 • Fax: +868 626 1788 • Email: info@canari.org • Website: www.canari.org.

Forestry and Land Use, Natural Resources Group, International Institute for Environment and Development, 3 Endsleigh Street, London WC1H 0DD, UK • Tel: +44 (0)20 7388 2117 • Fax: +44 (0)20 7388 2826 • Email: ivan.bond@iied.org

Citation:
Cox, C. (2004) *A hydrological assessment and watershed management plan for the Talvan water catchment*, *Marquis watershed, St. Lucia.* Caribbean Natural Resources Institute (CANARI), Laventille, Trinidad and Tobago and International Institute for Environment and Development, London, UK.

Developing markets for watershed protection services and improved livelihoods

Based on evidence from a range of field sites the IIED project, ‘Developing markets for watershed services and improved livelihoods’ is generating debate on the potential role of markets for watershed services. Under this subset of markets for environmental services, downstream users of water compensate upstream land managers for activities that influence the quantity and quality of downstream water. The project purpose is to increase understanding of the potential role of market mechanisms in promoting the provision of watershed services for improving livelihoods in developing countries.

The project is funded by the UK Department for International Development (DFID).

Table of contents

Acronyms and abbreviations

a.s.l.	Above sea level
AEZ	Agro-ecologic zoning
CANARI	Caribbean Natural Resources Institute
CEHI	Caribbean Environmental Health Institute
CIDA	Canadian International Development Agency
DEM	Digital Elevation Model
DFID	Department for International Development
EPA	United States Environmental Protection Agency
ET	Evapotranspiration
FAO	The UN Food and Agriculture Organization
FMP	Forestry Management Project
GIS	Geographical Information System
GOSL	Government of St. Lucia
HTS	Hunting Technical Services Ltd.
IIED	International Institute for Environment and Development
LCC	Land capability class
LMR	Land management regimes
LUT	Land utilisation types
MAFF	Ministry of Agriculture, Forestry and Fisheries
mdys/yr	Man days per year
NRMU	Natural Resources Management Unit
NTU	Nephelometric turbidity unit
OAS	Organization of American States
OECS-ESDU	Organization of Eastern Caribbean States – Environmental Sustainable Development Unit
PMAs	Priority Management Areas
PRF	Poverty Reduction Fund
TWCG	Talvan Water Catchment Group
WASCO	Water and Sewerage Company
WEMP	Watershed and Environment Project
WRMU	Water Resources Management Unit

Executive summary

This report is a product of an action learning research project to examine and test the use of markets and incentives to improve the quality and delivery of watershed services, such as water production, soil erosion, landslide and flood control, and biodiversity protection, for the purpose of improving local livelihoods, especially for the poor. The project, called 'Who Pays for Water? Preparing for the use of market-based mechanisms to improve the contribution of watershed services to livelihoods in the Caribbean', is implemented by the Caribbean Natural Resources Institute (CANARI).

The project focuses on five countries: Grenada, Jamaica, St. Lucia, St. Vincent and the Grenadines, and Trinidad and Tobago. Project activities include action learning projects in St. Lucia and Jamaica to value watershed services and to test the usefulness of markets and incentives in addressing critical watershed management issues. They also include the establishment of an Action Learning Group to validate and critique project findings and results. Research is being conducted on the potential effects of water sector privatisation and of the incentive opportunities from the tourism sector for watershed protection services. Training activities relating to land use and hydrology tools have also been conducted.

Project research is carried out in collaboration with the Sustainable Economic Development Unit of the University of the West Indies (UWI) and the forestry departments of St. Vincent and the Grenadines, Jamaica, St. Lucia, Grenada, and Trinidad and Tobago.

'Who Pays for Water?' is the Caribbean component of a global project*, 'Developing Markets for Watershed Protection Services and Improved Livelihoods',* which is being implemented by the International Institute for Environment and Development with financial support from the United Kingdom Department for International Development. The initiative includes activities in India, Indonesia, South Africa, China and Bolivia in addition to the Caribbean.

One component of the 'Who Pays for Water?' project was a two-year research and testing activity to assess the feasibility of compensating community groups in St. Lucia for management interventions aimed at improving water quantity and/or quality. The activity focused on the ongoing work of the Talvan Water Catchment Group (TWCG).

The author of this paper conducted a hydrological assessment of the Talvan water catchment in order to consider the past and current land use practices, and the extent of watercourse degradation and its impact on water quality and quantity in the Talvan catchment. The assessment also considered the impact of the intervention activities of the Talvan Water Catchment Group[1]. This paper presents a watershed and hydrology assessment along with an integrated management plan for the catchment, in support of determination of the value of watershed protection services towards the eventual development of market-based incentives for watershed management.

[1] The author would like to express thanks to the persons who assisted in providing information, or otherwise assisted in completion of this study. The following are hereby acknowledged: Deborah Bushell, Water Resources Management Project, MAFF; Aloysius Bartholomew, Water Sector Reform Project; Adrian Teobald, Water and Sewerage Company; Shanta King, Water and Sewerage Company; Mary Flortin, Water and Sewerage Company; Lucien Alexander, Water and Sewerage Company; Cornelius Isaac, Forestry Department, MAFF; David Lewis, Forestry Department, MAFF; Peter Vidal, Forestry Department, MAFF; Leroy Ambroise, Fisheries Department; Herold Gopaul, Caribbean Environmental Health Institute; Festus George, Agricultural and Engineering Services Division, MAFF; and Lyndon John, Caribbean Natural Resources Institute.

This work also represents an evolution of the previous assessment conducted in advance of the Organization of Eastern Caribbean States (OECS), and the Poverty Reduction Fund (PRF)-financed initiatives and contains data related to the geophysical environment, land capability, and recommended land management regimes, along with cost estimates for remedial works. A proposed monitoring regime for the watershed is also presented.

The Talvan water catchment is a 320 ha watershed located within the Marquis watershed and is the principle source of water to the Hill 20 Water Treatment Plant which supplies water to the communities of Babonneau, Fond Assor, Cacao and their environs. The watershed has been degraded over the years primarily due to agricultural activity, which included intensive banana cultivation on relatively steep slopes, and livestock rearing to a lesser extent. Housing has gradually expanded along the watershed divides and the potential for household waste water contamination is no doubt increasing.

Quality tests on raw water at the intake confirm high levels of pollution and underscore the dire need for corrective action to the undertaken. In an ideal circumstance the watershed should be under protected forest by statute, whether state or privately owned. Acquisition of the watershed by the government is now a very costly option given the level of development. Although the catchment may have to be abandoned as a water source in the long-term if the water quality does not improve, the Water and Sewerage Company (WASCO, the sole water company in St. Lucia) notes that the source will be operated at least in the medium-term, and affirms the need to implement remedial measures to enhance water quality.

To date, a few initiatives aimed at rehabilitation of the watershed have been undertaken, and the focus has been on stabilisation of the riverbanks, and establishment of forest cover. Some attention has also been paid to upland erosion control within farms through installation of drainage, and other soil and water conservation measures.

The Talvan watershed is not instrumented and consequently there is no long-term record of stream flow. There have been sporadic spot measurements made by various agencies, and an attempt was made to estimate the relative variation between dry season and wet season flows. An analysis of the current land use based on imagery obtained in April 2004 revealed that just less than 28% of the watershed is under intensive agriculture and settlement. These land-use categories are likely the largest main contributors to non-point source pollutant loading within the watershed. A significant proportion of the area previously under intensive banana cultivation is now abandoned; it is likely that surface erosion has declined from these areas. A GIS-assisted analysis of land capability and associated recommended land management regimes was conducted, and the result compared against current land use to assess the extent of conflictive land use within the watershed. It was estimated that just over 36% of the land area was being utilised unsustainably based on recommended land management. A field reconnaissance exercise revealed a few areas within the catchment that are likely significant point sources for pollutants, namely households, livestock production units, and farm access roads.

A hydrologic and pollutant loading monitoring programme is being recommended to assess change in water quality in response to implementation of rehabilitation measures. The watershed outlet – just upstream of the intake – should be an instrumented primary monitoring station to provide a continuous log of stream flow, and when triggered by a rain event, to sample the stream flow for pollutants. Three secondary monitoring stations located on major tributaries are also recommended to assess the spatial distribution of contributing sources in the watershed to pollutant loads. These stations should be ‘spot-monitored’ during heavy rains.

Implementation of the proposed watershed management strategy should serve to ameliorate the water quality to the intake. It must be stressed however, that the trend in decline in flow volume may not be a reversible phenomenon in the short-term, in spite of rehabilitation of the watershed. Such a change may only be attainable in the very long-term, perhaps over 50 years, if there is complete reforestation of not only the Talvan catchment but also the surrounding upper reaches of the Marquis and Cul de Sac watersheds.

1. Introduction

The Talvan water catchment extends over approximately 320 ha within the south eastern reaches of the Marquis watershed. The Marquis watershed is the major drainage basin in the northern portion of the island, draining a total of 3,059 ha into the Atlantic at Marquis Bay. The Talvan catchment area has historically been an important water catchment area as it was among the earliest sources of water to Castries and its environs. The catchment forms part of a wider network that includes gravity sources at Forestiere (Piton, Joseph, and Louisy intakes), the eastern branch of the Marquis River (Marquis intake) and gravity sources within the Castries Waterworks Forest Reserve in the foothills of La Sorcière (La Sorcière intakes 1 and 2). These sources all feed into the Hill 20 Treatment Plant at Cacao.

Hill 20 water supply sources

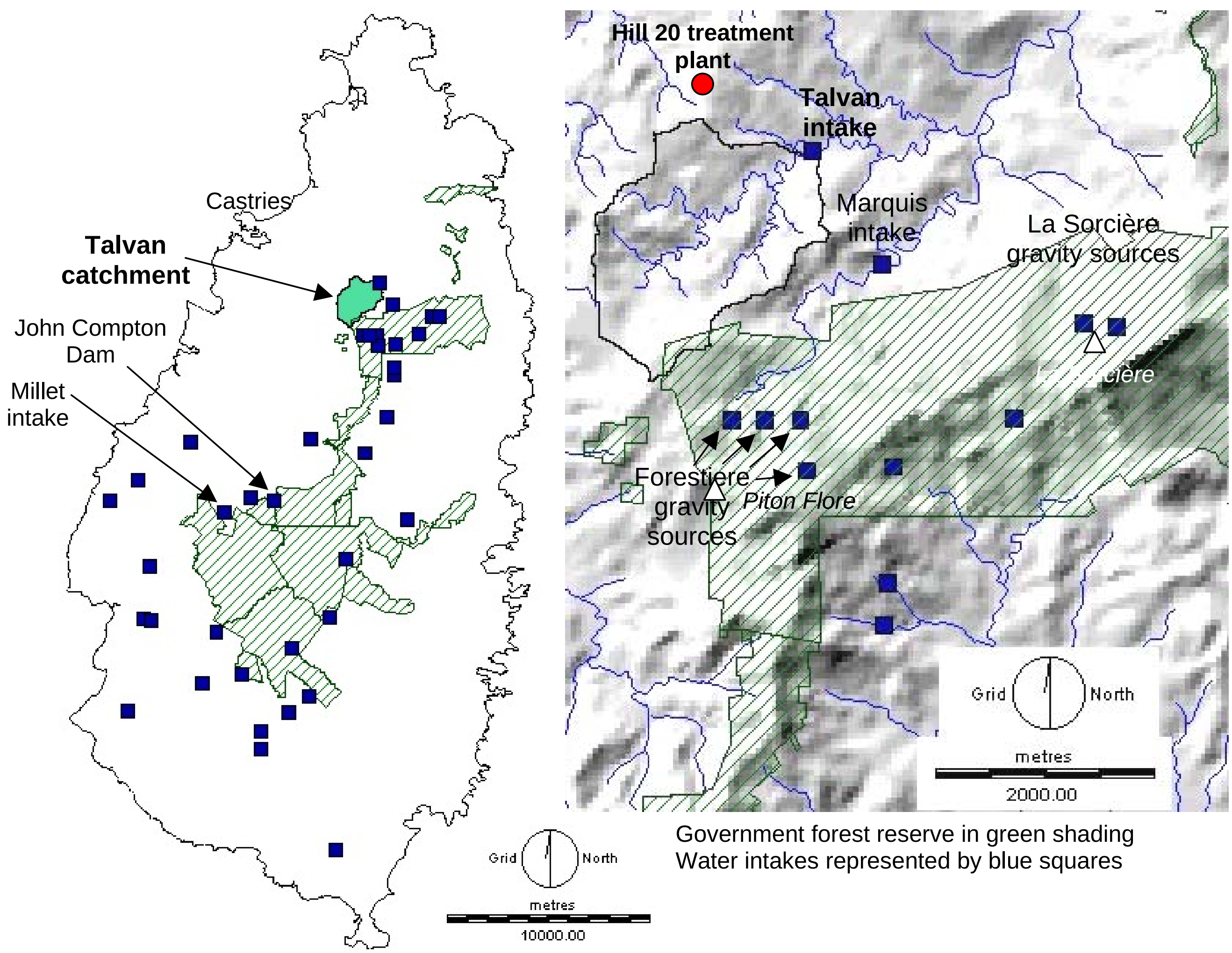


Figure 1: The island-wide water intake network and location of the Talvan catchment and intake sources

Figure 2: Talvan intake (abstraction location indicated by arrow; pump house at right; note bananas on riverbank)

Figure 3: WASCO's Hill 20 Water Treatment Plant

Based on data from 2002 to April 2004, average monthly water production from Hill 20 ranged between 22 and 34 million gallons (100,000 and 154,600 m^3) (production for June 2003 was unusually low, affecting the mean). This is the key supply to approximately 10,000 people in Babonneau and its environs, through to Forestiere, Bocage, and Bagatelle. The Hill 20 system augments the supply from the Millet intake/Roseau Dam which forms part of the Ciceron treatment station distribution network. The Talvan catchment itself accounts for approximately 40-50% of the water to Hill 20 (WASCO 2004).

Table 1: Water production from the Hill 20 Treatment Plant (million gallons)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total
2002	28	26	28	27	31	27	30	30	30	30	31	33	349
2003	33	26	26	20	20	18	26	31	31	29	30	35	323
2004	32	31	28	30									
Mean	31	28	27	25	25	22	28	30	30	29	30	34	31

The Talvan catchment lies within a key agricultural area and has seen significant expansion in agricultural activity over the years. Bananas has been the dominant crop cultivated within the catchment and in some areas this continues to be carried out on lands that are generally unsuitable for the crop on account of steep terrain and/or unstable soils. In many locations in the catchment area, bananas and other short-term crops are cultivated along the edges of watercourses, increasing the likelihood of chemical (fertilizer and pesticide) contamination. It must be noted however, that with the recent downturn in the banana industry, there has been significant abandonment of cultivation in the catchment with a likely reduction in pollutant contamination potential. On the other hand, there has been some increase in production of non-traditional crops, particularly in the lower reaches of the catchment around Talvan and Cacao, the main crops including lettuce, cabbage and tomato.

Livestock rearing is a relatively minor activity but there are at least three piggeries within the catchment at En Poix Doux and Combat which are potentially significant pollutant contributors. Cattle are permitted to graze unrestrained and contribute to degradation through denudation of the riverbanks, physical soil disturbance and waste discharge. There is also an aquaculture operation at Combat, with some possibility for release of contaminants, although adverse environmental impact is considered minimal (Ambroise 2004).

There has been significant urban expansion in the catchment in recent years. The main settlements are confined to the southern and western periphery of the basin, with Forestiere at the headwaters in the south, Guesneau and Cacao along the western divide, and Talvan near the drainage basin outlet. The increased urbanisation is likely contributing to the potential for pollution through grey water and sewerage discharge. At Talvan, there are at least 13 households (visible in the aerial photo, Figure 10) in relatively close proximity to the main channel from which pollutants may be posing a risk. Washing of vehicles and bathing in the river add to potential contamination, and disposal of solid waste is an ever-present problem. Although not quantified, the amount of refuse observed in the river channel in the reconnaissance exercise seems to suggest an improvement over a few years ago, perhaps attributable to enhanced community awareness.

The influence of land use and other practices on the water quality at the intake has been clearly manifested. A study carried out by the Caribbean Environmental Health Institute (CEHI) between December 2003 and May 2004 revealed that the raw water quality from Talvan was generally poor. Talvan had consistently elevated turbidity, nitrate, and fecal colliform levels as compared to the other tested sources. During heavy rains the intake must be closed due to heavy sedimentation (Figure 4), although recent modifications to the intake structure have permitted abstraction to minimise sediment uptake.

Figure 4: Raw water to Hill 20 Treatment Plant following heavy rain. (The highly turbid Talvan catchment supply is to the left and the adjacent Marquis catchment supply is on the right.)

As is the case with many of the water catchment areas on the island, the majority of the land area is under private ownership. In the case of Talvan, only 6 ha within the extreme southern area falls within the Government Forest Reserve, hence some 314 ha are therefore ‘unprotected’. Although there is provision for the designation of the area as Protected Forest under Section 21 sub-section (c) of the *Forest, Soil and Water Conservation Ordinance* (1964, Amendment 1983), this has not been pursued.

Extenuating factors are primarily related to cost implications in terms of compensation to land owners, and the rationalisation of investments by the government in land acquisitions for the purpose of watershed protection. In recent years the government made substantial investments in compensation to land owners in the John Compton (Roseau) Dam development project and the Grace/Woodlands catchment (supply source to Vieux Fort and Laborie and their environs) acquisition. In the context of acquisition, the development of Roseau Dam as the major supply to the north relegated potential acquisition of lands within Talvan to secondary priority. Current priority in terms of watershed acquisition is pointing towards the Tonesse catchment, earmarked to be the future major supply to the critically water-scarce communities in the Mabouya Valley. The relatively large area of the Talvan catchment and the high level of agricultural and urban development suggest the cost of acquisition would be considerable.

The short- to medium-term management strategy for the Talvan catchment has therefore focused on changing management practices within the catchment using participatory approaches involving stakeholders (farmers, householders) within the catchment, and beneficiaries (water consumers) to a lesser extent. The Forestry Department has been engaged in a long-running management process with the Fond Assor and Talvan communities in promoting sustainable land management practices. Under a Canadian International Development Agency (CIDA)-financed Forestry Management Project (FMP) that ended in 1992, significant investment was made in community forestry approaches island-wide. Out of that initiative a community forestry group emerged, whose primary aim was the introduction and promotion of agroforestry regimes to farmers in the catchment area. These activities – carried out in the early 1990s – resulted in the establishment of forest and tree crops along the main river channel upstream of the Talvan intake, and in other areas within the Marquis watershed. More recently, financing from the OECS-NRMU (now ESDU) and the Poverty Reduction Fund (PRF) facilitated the installation of soil and water conservation measures by the Talvan Water Catchment Group (TWCG) with focus on riverbank rehabilitation (Lewis 2002). The Forestry Department provided the technical support to these initiatives.

2. The physical environment

2.1 Topography

The headwaters of the catchment fall within the Forestiere area along the divide between the Marquis and Cul de Sac watersheds. The highest elevation within the catchment is 365 metres above sea level. The elevation at the watershed outlet (intake) at Talvan is approximately 60 metres. Slopes within the basin range from gentle within the lower water course near Talvan, to in excess of 30 degrees in the more rugged areas, particularly around En Poix Doux and Cacao (Figure 5).

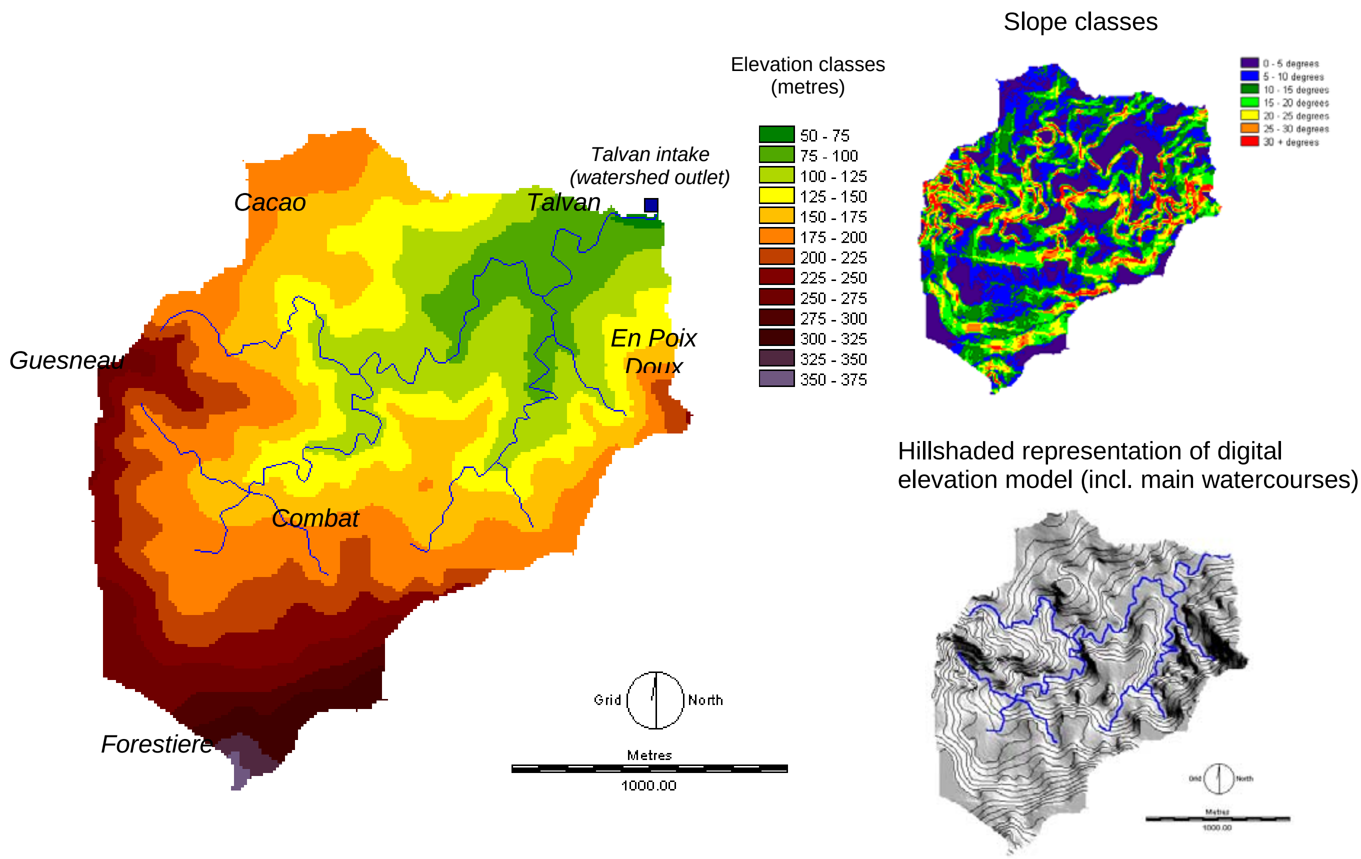


Figure 5: Topography of the Talvan catchment

2.2 Geology and soils

The geology of the area is characterised by andesitic ash formation (OAS 1987) with eight soil associations occurring within the catchment, according to Stark et al. (1966). The dominant soils in terms of map unit areal extents are Anse, Moreau and Warwick clays (it must be noted that map units may consist of more than one soil series; refer to Stark et al. (1996) for more detail). The map unit dominated by Anse clay accounts for 106 ha within the central portion of the basin over the lower elevations. This soil is classed as a vertisol (USDA soil order nomenclature) with kaolinitic and montmorillonitic mineralogy, and tends to be highly erodible. The southern area of the catchment is dominated by Moreau clay (accounting for 97 ha), and is characterised by kaolinitic mineralogy. It is moderately stable in terms of erosion hazard. Warwick clay dominates the upper south west area (accounting for 58 ha) and is a stable inceptisol, characterised by an allophonic mineralogy. The minor soil series in the basin include Garrand clay loam, Panache silty clay loam, Bocage stony clay, Canelles clay, and Assor clay. For further reference, the *Watershed and Environmental Management Project Report* – Volume 3; Annex 4 (Hunting Technical Services Ltd. 1997) provides a good review of St. Lucia soil characteristics based on integration of studies in St. Lucia and the neighboring French speaking islands.

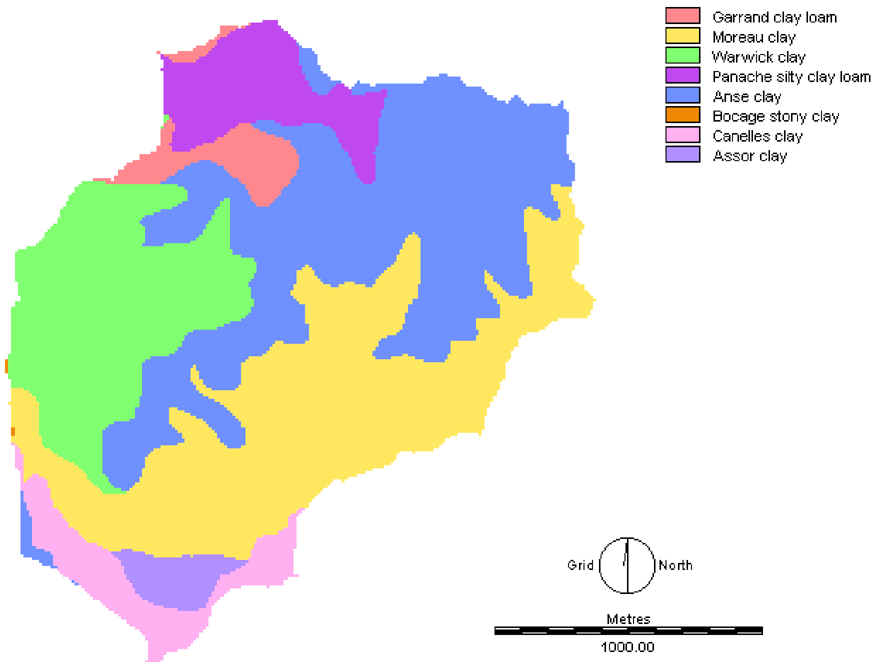
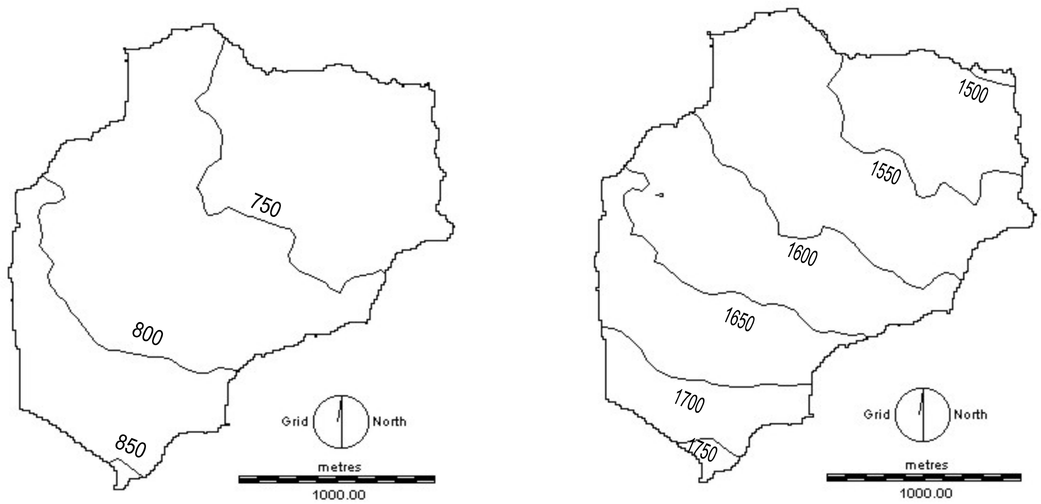


Figure 6: Dominant soil series in the Talvan catchment

2.3 Rainfall and water availability

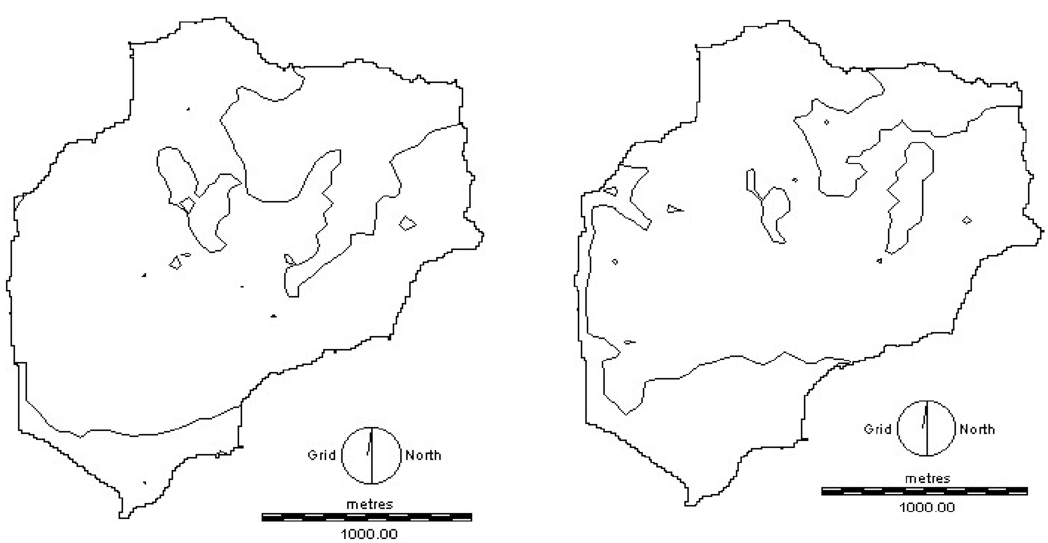
Mean annual rainfall over the watershed is approximately 2,380 mm, ranging from 2,200 mm in the vicinity of the watershed outlet to 2,600 in the highest elevations (Cox 2003). Estimated long-term mean rainfall for March (statistically the driest month) averages 100 mm over the watershed, and 314 mm for October (the wettest), based on geo-statistical spatial analyses (Cox 2003). The estimated cumulative dry season rainfall between January and June averages 770 mm over the watershed, while the wet season cumulative rainfall from July to December approximates 1,610 mm. Figure 7 shows the spatial variation in the dry and wet season cumulative rainfall.



(A) Dry season (Jan-Jun) mean rainfall (mm) (B) Wet season (Jul-Dec) mean rainfall (mm)

Figure 7: Seasonal variability in mean rainfall within the Talvan catchment

Reference evapotranspiration (ET_o) was estimated by Cox (2003) using the FAO Penman-Monteith method (FAO 1996) to determine spatial variability in water availability for agro-ecologic zoning for St. Lucia. The results of this analysis revealed that ET over the catchment varies little over the year due to the narrow variability in temperature, the most critical parameter influencing ET. Evapotranspiration losses are slightly higher during the dry months as compared to the wet months; the average over the watershed is 730 mm and 720 mm for the dry and wet seasons respectively.



(A) Dry season (Jan-Jun) ET_o (mm) (B) Wet season (Jul-Dec) ET_o (mm)

Figure 8: Seasonal variability in mean reference evapotranspiration within the Talvan catchment

Water availability over the catchment shows strong seasonal variation. In the dry months abstraction at the intake is often near 100% of flow and the system needs to be shut down periodically when the flow becomes exceedingly low. The seasonal variation in flow can be explained by the corresponding rainfall regime; however there has been a noticeable but unquantified trend over the past several decades in terms of declining flows, not only within this catchment but across the island in general. In discussion with community members, many recall the lower watercourse characterised by large deep pools fed by steady year-round flow.

There are two factors that may explain the declining flow regimes in St. Lucia's watersheds; long-term climatic variation and change in land use. More research needs to be conducted using historic rainfall data to determine whether rainfall has in fact been declining. In the case of land use it seems likely that the conversion of the forested upper reaches of many watersheds in the island to agriculture has caused changes in the watershed hydrologic response, whereby runoff following rainfall events tends to be greater with relatively less moisture retained in the basin to recharge baseflow.

No long-term systematic monitoring of flows at the Talvan intake has ever been undertaken. However spot discharge data has been collected by WASCO and the WRMU since 2002. At the time of writing the only other data retrieved was contained in a study by Oelsner (1981) under an OAS study of the country's water resources. The discharge measurements in that case dated back to the early 1960s. Annex 2 contains the observations from WASCO, the WRMU, and the Oelsner study.

These discharge measurements were plotted against the relative time of year the observations were made (Annex 2). A crude trend analysis was carried out in an attempt to observe the general temporal variation in flow over the year. Obvious outliers were removed from the data set and a trend line fitted. The line of best fit and the relative clustering of points suggest that the dry season flows vary between 30 and 40 l/s and the wet season flows varied between 40 to 80 l/s (Annex 2). It must be noted however that no data exists for January or December therefore the trend line may be yielding underestimates or overestimates towards the start and end of the year. It is also noted that the data set is assumed to represent 'normal' flow condition. Table 2 summarises the findings.

Table 2: Estimated seasonal discharge at the Talvan catchment outlet

Discharge range		Seasonal (6-month) discharge (m^3)	Depth over 320 ha area (mm)
(l/s)	(m^3/day)		
(a) dry season (181 days)			
30	2,592	469,152	147
40	3,456	625,536	195
(b) wet season (184 days)			
40	3,456	635,904	199
80	6,912	1,271,808	397

Based on the above, the annual discharge may vary between 1,105,056 and 1,897,344 m^3. WASCO estimates that approximately 50% of the production from Hill 20 is from the Talvan catchment, where total production was 1,587,771 and 1,469,345 m^3 in 2002 and 2003 respectively. Assuming the 50% contribution by Talvan and minimal loss at the plant or along the pipeline, the abstraction ratios may range between 42 and 71% for 2002, and 39 and 66% for 2003. Taking an average of these ratios, it may be further assumed that approximately 50% of the natural flow is being abstracted over the course of the year.

Using the estimated discharge an attempt was made to derive the water balance for the watershed. The water balance model can be expressed as;

$$P = ET + R + S \qquad [1]$$

P = Precipitation
ET = Evapotranspiration
S = Storage
R = Runoff

The most significant components of the water balance equation in the case of relatively small mountainous catchments in St. Lucia are the *ET* and *R* components. The storage component is small and considered negligible. Leonce (1978) explains that deep percolation and storage in these steep environments is low because of reduced infiltration opportunity as compared to flat terrain. In steep terrain the horizontal component of interflow is greater than the vertical component resulting in increased delivery of water to the surface or the channel as runoff. The water balance equation is therefore reduced to:

$$P = ET + R \qquad [2]$$

As noted above, the dry and wet season cumulative rainfall (*P*) approximates 770 and 1,610 mm respectively. The observed runoff component (*R*) ranges between approximately 150 and 200 mm, and between 200 and 400 mm for the cumulative dry and wet season flows, based on discharge observations. The potential ET for the area has been calculated by Cox (2003) and Leonce (1978) using the FAO Penman-Monteith and Blaney-Criddle methods respectively, with close results. Cumulative dry season ET approximates 730 mm (using both methods) and wet season ranges between 690 mm (Leonce 1978) and 720 mm (Cox 2003).

Substituting these values into the water balance equation [2] yielded the following:

A. Dry season water balance:
   i. lower range: 770 = 730 + 50; *R* and/or *ET* overestimated by 10 mm
   ii. upper range: 770 = 730 + 200; *R* and/or *ET* overestimated by 160 mm

B. Wet season water balance (i&ii - applying Cox's ET estimate; iii&iv – applying Leone's ET estimate):
   i. lower range: 1610 = 720 + 200; *R* and/or *ET* underestimated by 690 mm
   ii. upper range: 1610 = 720 + 400; *R* and/or *ET* underestimated by 490 mm

   iii. lower range: 1610 = 690 + 200; *R* and/or *ET* underestimated by 720 mm
   iv. upper range: 1610 = 690 + 400; *R* and/or *ET* underestimated by 520 mm

The results of the water balance suggest that more data is required to properly estimate the seasonal variability in the runoff component. This data must be collected continuously so as to adequately capture large volume flows that contribute significantly to runoff, particularly in the wet season. There may also be some basin storage influences that may explain the relatively high runoff with respect to the water balance model in the dry season. The ET estimates are less likely the source of the error, as ET observations from the metrological stations (pan ET) are in the approximate range of the estimates, which are also similar to reported data in various studies from St. Lucia (HTS 1997) and other islands (Schellekens and Buuijnzeel 2000; Amarakoon et al. 2000).

3. Land management

3.1 Land tenure

The current land registry record indicates a total of 422 parcels falling within the catchment area. The majority of land parcels fall in the 1 to 5 ha category. Only 9 parcels are greater than 5 ha in area. Typical house lot sizes vary between 0.04 ha (4,300 sq.ft) and 0.12 ha (13,000 sq.ft). Figure 9 illustrates the parcels within the catchment area.

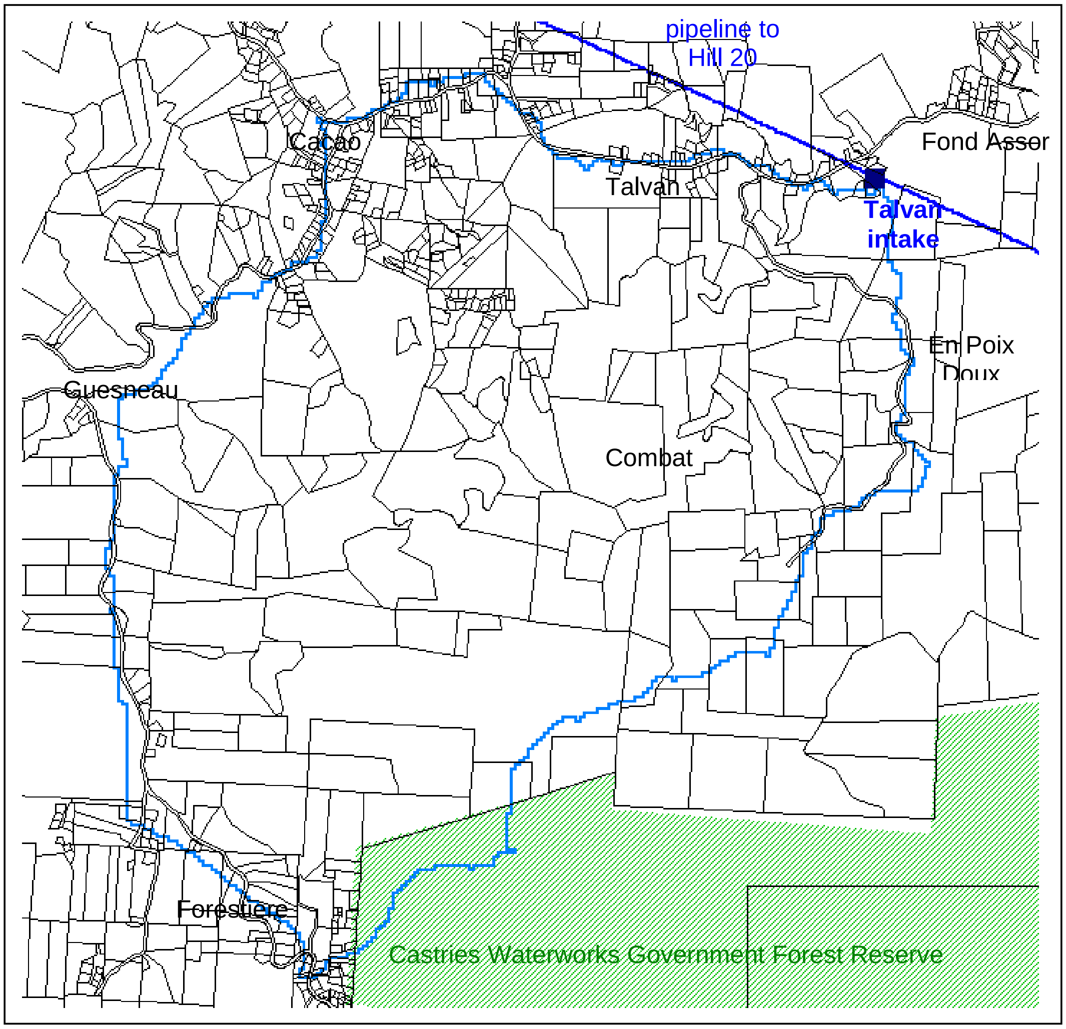


Figure 9: Land parcels within the Talvan catchment (mutations as at July 2004)

Table 3 contains the frequency and areal distribution for parcel areas falling within the catchment boundaries. This data was derived using GIS analyses.

Table 3: Frequency and areal distribution of land parcels within the Talvan catchment

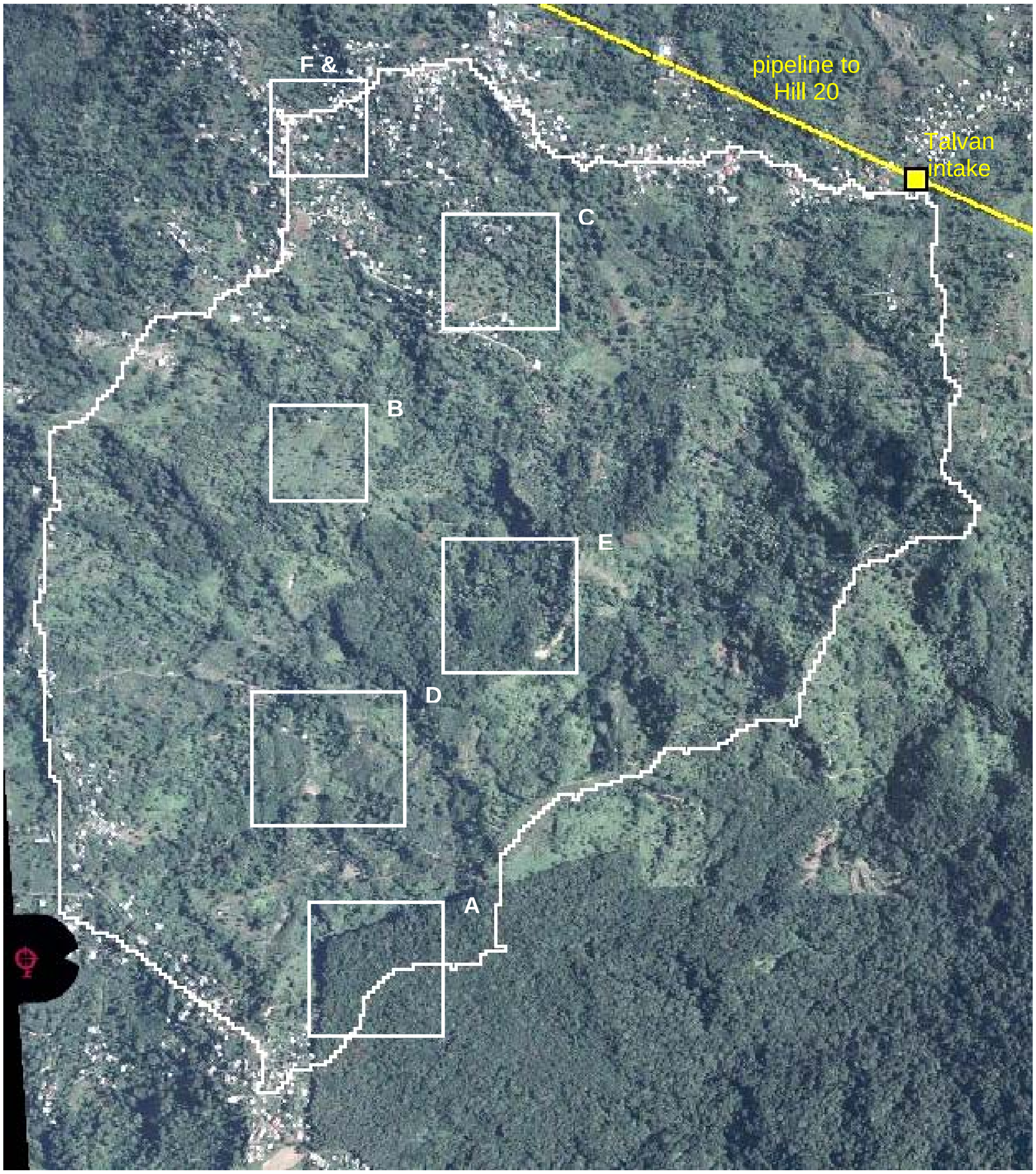
Size category (ha)	Number parcels	Acreage (ha)	Proportion of catchments area (%)
0 – 1	332*	62.9	20
1 – 5	81	175.2	55
5 – 10	7	45.4	14
10 +	2	32.8	10

*Note: 61 of the 322 parcels were represented by 1 and 2 pixels in the GIS raster representation. These were likely not entire parcels as the typical smallest lot size is 0.04 ha. They therefore generally constitute only the portions of larger lots that fell within the periphery of the catchment boundary.

3.2 Land use

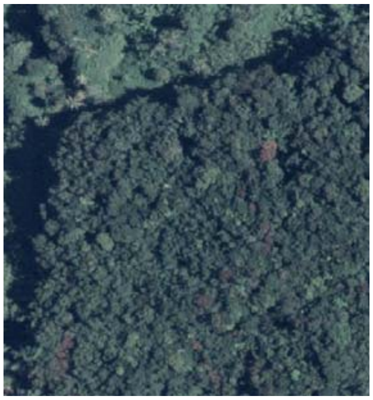
Given the historical importance of this area for agriculture most of the original vegetation has been substantially modified. According to the life zone assessment presented by OAS (1986) and Isaac and Bourque (2001), the natural vegetation based on the Holdridge system of life zone classification would be described as sub-tropical moist/wet forest. This life zone is characteristic of elevations between 0 and 200 metres a.s.l. where the moisture regime is between 2,000 and approximately 2,700 mm per annum, and the biotemperature is 26^{o} C.

Aerial photos acquired in April 2004 by the Ministry of Physical Development, Environment and Housing reveal the status of land utilisation within the catchment. A digital representation of the air photo of the area with a pixel resolution that corresponded to a 0.5 m ground distance was used to extract land cover classes within the study area, using a GIS. The classification used in this application was based on the most recent land use classification of the island, derived from the *Forestry Management Plan* (GOSL 1992). Figure 10 is the aerial photograph of the study area with the catchment boundary superimposed. Figures 11a. and 11b. are larger-scale detailed views of the typical land uses found in the catchment that were used to guide the differentiation of the transitional boundaries between the various land use classes.



A: Primary (including plantation) forest.
B: Abandoned cultivation / fallow lands.
C: Mixed farming; temporary crops with tree crop overstorey.
D: Intensive hillside cultivation; predominantly bananas.
E: Densely vegetated tree crops and residual (secondary) forest.
F: Intensive vegetable cultivation.
G: Rural settlement.
Views within numbered boxes are expanded in photos on following pages.

Figure 10: Aerial photo of the Talvan Catchment with catchment boundary superimposed. (Source: aerial photo taken in April 2004 at 1:25,000 scale .Digital TIFF file format – pixels correspond to 0.5 m ground resolution.)



CLASS A: Primary (including plantation) forest. Photo shows sharp divide between cultivated areas and the Castries Waterworks Forest Reserve at Forestiere.

CLASS B: Abandoned cultivation / fallow lands. Dominated by regenerating vegetation and scattered tree crops; mango, breadfruit, coconut.

CLASS C: Mixed farming; temporary crops (bananas, vegetables) with tree crop overstorey (mango, breadfruit, coconut) along with fragments of secondary forest.

CLASS D: Intensive hillside cultivation; predominantly bananas and vegetable production (fish ponds are visible in the upper right corner of the photo).

Figure 11a. Land use cover characterisation

CLASS E: Densely vegetated low-intensity agriculture, dominated by tree crops (mango, breadfruit, coconut, others) and dense residual (secondary) forest cover.

CLASS F: Intensive vegetable cultivation; backyard gardens.

CLASS G: Rural settlement.

Figure 11b: Land use cover characterisation

To determine the areal extents of the various land-use classes in the catchment, and to facilitate further spatial analytical applications, the digital aerial photo had to be processed using a GIS. The photo was first geo-rectified using a rubber-sheet transformation or re-sampling process (Eastman 1999) to assign British West Indies grid geographic coordinates. Using a 'heads-up' or on-screen digitising utility in the GIS, polygons were then drawn around the various land classes (visible in the aerial photo in Figure 10 on the computer screen) and unique identifiers corresponding to the land-use class polygon assigned. It is noted that some degree of positional error resulted from the re-sampling process. In general, alignment between the aerial photo and the cadastral land parcel map was best at locations with common features in the land parcel map (e.g. road junctions) and the aerial photo. Figure 12 is the resultant classified land use.

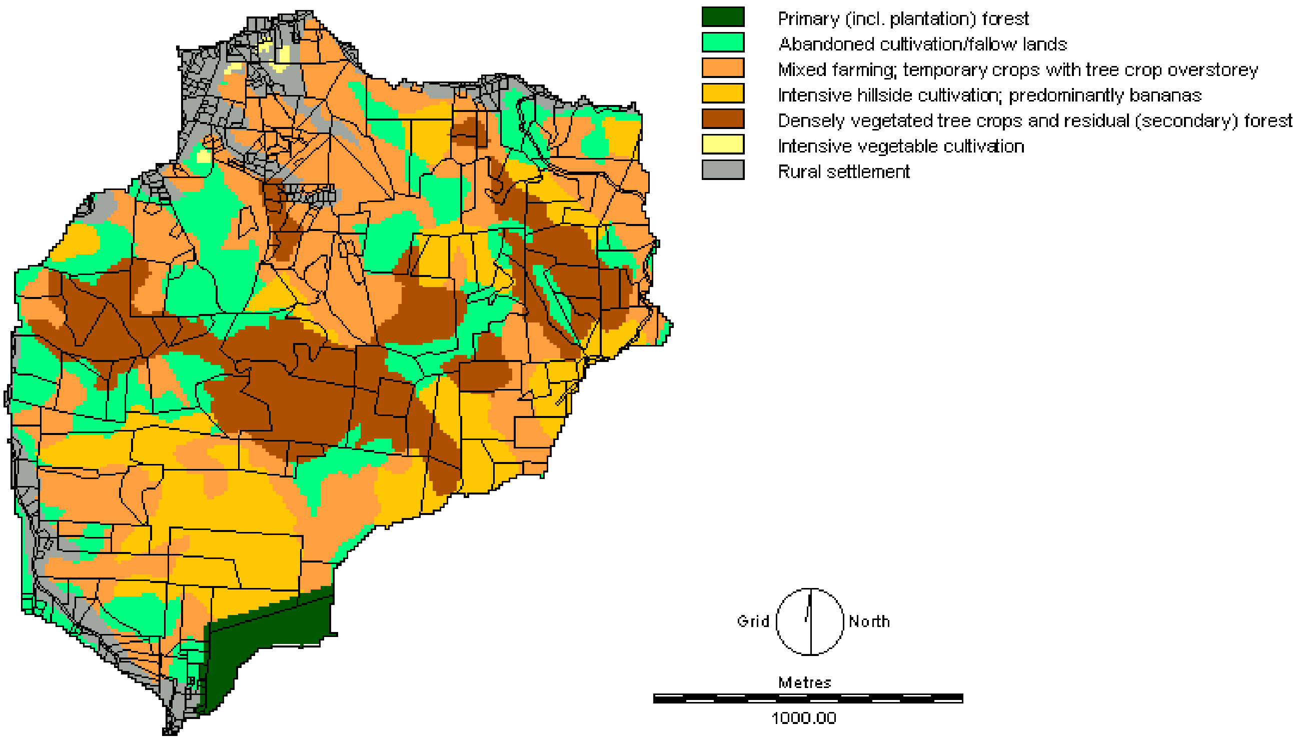


Figure 12: Classified land use within the Talvan catchment

The dominant land-use classes in the watershed derived from the GIS spatial analysis were mixed farming, followed by densely vegetated tree crops/residual forest, and intensive hillside agriculture. The basin can be categorised as an agricultural watershed although the intensity of utilisation may be described as low to moderate over most of the area.

The largest contiguous area of relatively intensive agriculture is concentrated in the south-western region, just north of the forest reserve. Banana is the dominant crop interspersed with tree crops such as coconuts, mango and breadfruit. Under the Banana Emergency Recovery Programme, fields are being rehabilitated with improved planting stock and enhancements to agronomic practices. There are also fish pond operations in this area. Smaller pockets of relatively pure banana stands are scattered over the remainder of the watershed south of Fond Assor and Combat.

The land use over the remainder of the watershed is reflective of reduced agricultural productivity, resulting from the downturn in the banana industry. The mixed agriculture class is generally characterised by tree crop overstorey with short-term vegetable crops and/or bananas cultivated at varying levels of intensity. In many areas, cultivation has been abandoned entirely, overrun with vines (lien-douce), grasses and secondary forest regeneration. This pattern is dominant in the western portion of the watershed in the vicinity of settlement areas. The densely vegetated agriculture class occurs as a discontinuous band across the central region of the watershed. This class is dominated by tree crops and forest fragments. From the ground reconnaissance it appears that some areas have remained relatively undisturbed and contain significant tracts of natural forest species in varying stages of regeneration. This is particularly the case within scattered pockets on the steeper slopes along the eastern and west-central divides.

Settlement areas are confined to the northern to north-western divides (Talvan and Cacao communities) and western divides (Guesneau and Forestiere communities) of the watershed basin. The land use in the vicinity of settlement areas can be characterised as low intensity agriculture where tree crops and small backyard vegetable plots are typical. In some locations these plots are operated commercially (see Annex 1 for photos).

Table 4 contains the data on GIS-derived acreages and provides descriptions of the land-use classes.

Table 4: Land use within the Talvan catchment

Map unit	Land use class description	Area (ha)	%
1	Primary (incl. plantation) forest.	8.3	2.6
5	Abandoned cultivation / fallow lands. Dominated by regenerating vegetation (grasses and vines) and scattered tree crops: mango, breadfruit, coconut (comparable to 'Grassland and open woodland' land-use class in 1992 land use mapping).	60.6	18.9
6	Mixed farming, temporary crops (bananas, vegetables) with tree crop overstorey (mango, breadfruit, coconut) along with fragments of secondary forest.	98.7	30.8
7	Intensive hillside cultivation; predominantly banana and vegetable production. Scattered tree crops common with some forest fragments.	58.1	18.1
8	Densely vegetated low-intensity agriculture. Dominated by tree crops (mango, breadfruit, coconut, others) and dense residual (secondary) forest cover.	63.6	19.9
9*	Intensive vegetable cultivation (back-yard gardens and small commercial plots). Considered comparable to the level of operational intensity associated with the 1992 land-use class 'Flatland intensive farming'.	0.9	0.3
11	Rural settlement.	30.0	9.4
	Total	**320.2**	**100.0**

* There may be a greater acreage in this category depending on time of year when plots are activated; in addition, some acreage in this class may also be accounted for within class 7.

4. Watershed degradation assessment

A rapid reconnaissance exercise was carried out to determine the extent of degradation along the major river channels and within the upland areas in the watershed. This activity was conducted in conjunction with analysis of the aerial photography which was at a sufficiently high resolution to generally permit the assessment without having to physically inspect all the river channels.

Site visits were conducted on September 25th, October 19th and 21st, 2004 The consultant assessed the main channel along its length to the Cacao bridge, the length of the Fond Assor-Combat road, and community and farm access roads in the Cacao, Guesneau and Forestiere areas. As noted previously, the decline in land use intensity within the catchment suggest that pollutant loads to the watershed outlet may have also declined over the past few years. However, in discussion with WASCO technicians at the Hill 20 Treatment Plant there still are contributing sources to sediment loads within the watershed.

A major sediment source noted by both WASCO and Forestry Department personnel was a road cut at the Cacao Bridge (Figure 13C). During the October 21st site visit, which coincided with a two-hour thunderstorm event, runoff and gullying over this road surface was observed. The road remains in an un-motorable state. Another likely source is the area in the vicinity of a vehicle yard and cut hill slope at Guesneau, which fall within the headwaters of a major tributary draining the western reaches of the watershed. During the October 21st assessment, the flow in that tributary was heavily sediment-laden. Other areas of concern include road crossings over tributaries in the upper Combat area and in all areas under banana cultivation.

As was typically the case, there was little evidence of conservation measures within the cultivated areas. Poorly maintained field drains and minor ravines serve as conduits for erosive channelised flow and are no doubt significant sediment contributors (Figure 13D). This is a concern particularly within the excessively steep banana plantations along the Combat access road.

As noted previously, many of the active banana cultivations that existed during previous project phases have been abandoned, or are in varying states of abandonment. As a result grasses and running vines (lien douce) have proliferated under the banana mats, likely contributing to reduction in erosion and the quantity of sediment that can be transported in overland flow to the river channels.

The lower 0.5 km of the main channel upstream of the intake may potentially be most vulnerable to direct pollutant loading (sewerage and grey water) from households which are in relatively close proximity to the river channel. Along the main Fond Assor road which runs roughly parallel to the river there are 13 households; the septic system of one of these households appears to lie within 5 metres of the river channel. Under the OECS-funded rehabilitation initiative, one ventilated improved pit (VIP) latrine was installed for one of the homes. There are a large number of homes in the Cacao area, and although somewhat removed from the main channel and tributaries, these may contribute to pollutant loads particularly under saturated conditions when the likelihood of increased surface runoff is higher.

A: Damaged road culvert along Combat Road (R1 – Figure 14)
B: Overland erosive flow on road cut during heavy rain (R3 – Figure 14)
C: Sediment-laden flow upstream of Cacao Bridge during heavy rain (R3 – Figure 14)
D: Rapid erosive flow during heavy rain in farm drain

Figure 13: Erosion sources and sediment transport in the Talvan watershed.

During the field visits, two livestock pens were observed although WASCO and Forestry Department technicians informed of a third in the upper reaches in the catchment in the Combat area. The pen at En Poix Doux is relatively small with a few swine and sheep. It is located some distance away from any watercourse hence the risk of direct discharge into the river is likely low. Both livestock units at Combat are commercial piggeries. The unit at L2 (Figure 14) is relatively close to the watercourse and further investigations to determine pollutant risk should be undertaken. The second unit not visited by the consultant is evidently of serious concern (L. Alexander undated) and the owner has been in discussion with Ministry of Health and WASCO officials regarding containment of outflow and eventual relocation of the pen.

Table 5 summarises observed potential pollutant sources within the watershed and Figure 14 illustrates their approximate locations.

Table 5: Potential pollutant point sources within the Talvan watershed (refer to Figure 14)

Location	Description	Remarks
Crop cultivation: there were a few areas visited and locations visible from the aerial photo where significant soil exposure and cultivation along the riverbanks will contribute to sediment loading. The degree of degradation is likely higher on steeper slopes.		
C1	Root crop cultivation – Talvan	This activity is on the edge of the river channel, although the bank itself is grassed. There is potential for sediment discharge given the close proximity to the channel.
C2	Steep banana cultivation in tributary headwaters – Combat	Area too steep for bananas. Soil conservation measures generally lacking. Potential sediment pollution source.
C3, C4, C5	Large clearings visible on aerial photo	These clearings are in relatively close proximity to the main watercourses. Likely significant contributors to sediment load.
Livestock production: there are a few production units in the catchment. They are likely sources of effluent and need to be monitored to determine the severity of the problem.		
L1	Small livestock pen – En Poix Doux	Few swine and sheep. May be a potential source of pollutants under saturated conditions.
L2	Commercial piggery - Combat	Unit contains several adult swine. Likely source of sewerage discharge due to its close proximity to watercourse.
L3	Commercial piggery - Combat (precise location unknown)	Unit contains several adult swine. Likely source of sewerage discharge due to its close proximity to watercourse.
L4	Fish ponds – Combat	Inoperative at time of assessment. Site should be investigated to determine level of risk. Owner claims that he has 7 ponds. Aquaculture specialist from the Fisheries Department notes that the risk of contamination is usually low but should be investigated.
Road infrastructure: where the road traverses watercourses the continual disturbance due to vehicular traffic contributes to sediment discharge to the river channel. In addition, the roads themselves act as conduits for overland flow where drainage is not installed, as is the case with virtually all the access roads in the catchment.		
R1	Damaged culvert – Combat	Concentrated erosion around structure.
R2	River crossing	Increased erosion potential.
R3	Road cut – Lower Cacao	Unsurfaced road cut into steep incline; no drainage. Overland sediment-laden runoff (gullying) being observed directly discharged into main river.
Industrial/commercial: there is a large equipment yard that was carved out of the embankment at Guesneau and the spoil may still be stabilising. There are several locations in the urban areas where vehicular repairs are carried out and may be contributors to pollution. These were not precisely located in this study and should be investigated.		
I1	Equipment yard – Guesneau	Hillside cut with high soil exposure. Also cut slope along headwater of tributary.
Households: the households in the Talvan, Cacao and Forestiere areas will contribute to pollutant loading to the watershed, particularly during heavy rains when the soil is at high antecedent moisture condition. Most of the homes are not directly adjacent to the main channels; therefore discharge may have greater opportunity to infiltrate and immobilise, thereby reducing contamination potential somewhat.		
H1	Household with septic tank near main channel – Talvan	Potential for direct sewerage contamination. Needs to be investigated.

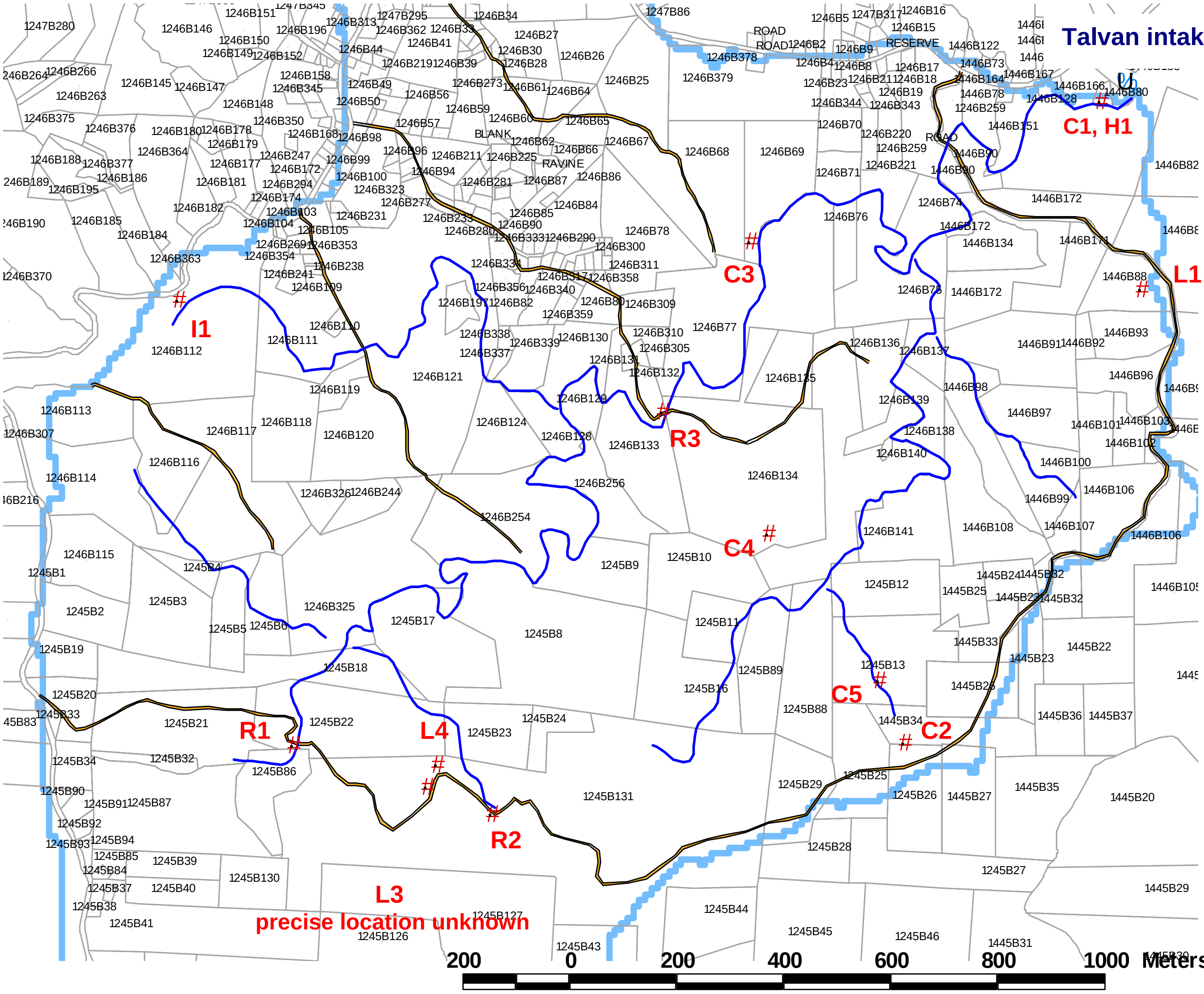


Figure 14: Approximate locations of pollutant sources within the Talvan Watershed (parcels [block and parcel numbers] overlain for reference)

5. An integrated watershed management strategy for Talvan

An integrated watershed management strategy for the watershed is presented in two parts. In the first part, GIS analytical tools will be used to map recommended land management regimes for the watershed based on land capability. The recommended land management regimes will be evaluated against the current land use in order to map the spatial extents of conflictive land uses. In the second part, appropriate soil and water conservation measures will be outlined.

5.1 Land capability and recommended land management assessment

Land capability is the capacity of the land to support particular management regimes sustainably with minimal environmental impact. Ahmad (1989) proposed a land capability classification scheme to guide agricultural land planning on St. Lucia. Local agronomists and other agricultural technical personnel consider this classification system more applicable to St. Lucia given the relatively steep terrain of the island, as compared to the previously applied USDA classification scheme (OAS 1987).

Two criteria define land capability in the Ahmad scheme: soil aggregate stability and slope steepness. In the classification, all soils in St. Lucia are categorised in three classes based on relative resistance to erosion; (i) stable, (ii) less stable and (iii) fragile. Most andisols, alfisols, and some inceptisols and mollisols are classified as stable, while soils classified as less stable include some inceptisols and most mollisols. Fragile soils are predominantly vertisols. Slopes are classed into six 5-degree slope classes with a seventh for slopes in excess of 30^{o}. Each soil and slope class combination yields a unique land capability class to yield nine land capability classes (LCCs).

Each LCC has an associated recommended land management regime (LMR). LCCs characterised by relatively stable soils, and flat to gentle slopes, can be subject to more intensive agricultural LMRs than capability classes characterised by less stable and more fragile soils on relatively steep slopes. Areas designated Priority Management Areas (PMAs), which include water catchment areas, riparian zones, and ecological areas, should be subject to more restrictive or conservative LMRs in the context of conserving soil, water and biological resources. The LMRs for water catchment areas therefore tend toward agroforestry and forestry systems (Cox 2003). Table 6 details the criteria combinations to yield LCC and associated LMRs.

Table 6: Land capability and corresponding land management regimes (adapted from Ahmad 1989)

<table>
<tr><th rowspan="3">Slope range</th><th colspan="3">Capability classes / Recommended land management regimes</th></tr>
<tr><th>Stable soil aggregates</th><th>Moderately stable soil aggregates</th><th>Fragile soil aggregates</th></tr>
<tr><td>Soil series: 1,2,3,4,5,7,8, 9,11,12,13,14,15,18,20,21, 22,24,26,27,30,36,37,40,41, 49,50,51.</td><td>Soil series: 6,10,19,23,25, 31,32,38,39,46,47,48.</td><td>Soil series:16,17,28,29,42,43, 44,45,52.</td></tr>
<tr><td>0 – 5°</td><td rowspan="4">A1
Agroforestry

Alley cropping – annual crops and tree crops.</td><td rowspan="2">B1
Agroforestry

Alley cropping – annual crops and tree crops.</td><td>C1
Agroforestry

Alley cropping – annual crops and tree crops.</td></tr>
<tr><td>5 – 10°</td><td>C2
Agroforestry / Forestry

Tree crops with high crown cover in shelter wood system over annual crops; tree orchard, natural or plantation forest.</td></tr>
<tr><td>10 – 15°</td><td rowspan="2">B2
Agroforestry / Forestry

Tree crops with high crown cover in shelter wood system over annual crops; tree orchard, natural or plantation forest.</td><td rowspan="5">C3
Production forestry

Timber plantations, tree crop orchard, forest enrichment, non-mechanised selective harvesting, interpretive activities.</td></tr>
<tr><td>15 – 20°</td></tr>
<tr><td>20 – 25°</td><td rowspan="2">A2
Agroforestry / Forestry

Tree crops with high crown cover in shelter wood system over annual crops; tree orchard, natural or plantation forest.</td><td rowspan="3">B3
Production forestry

Timber plantations, tree crop orchard, forest enrichment, non-mechanised selective harvesting, interpretive activities.</td></tr>
<tr><td>25 - 30°</td></tr>
<tr><td>30° +</td><td>A3
Production forestry

Timber plantations, tree crop orchard, forest enrichment, non-mechanised selective harvesting, interpretive activities.</td></tr>
</table>

Within riparian and forest reserve buffers, (defined as 50-metre wide reserves), the recommended LMRs assigned to capability classes that fall within these zones are more conservative than adjacent areas, given their special sensitivity (Table 7).

Table 7: Recommended land management regimes within riparian and forest reserve buffer zones (Source: Cox 2003)

<table>
<tr><th>Capability class</th><th>Riparian (river) buffer LMRs</th><th>Forest reserve buffer
LMRs</th></tr>
<tr><td>A1, B1, C1</td><td rowspan="2">AF/F
Agroforestry/Forestry</td><td rowspan="2">F1
Production Forestry</td></tr>
<tr><td>A2, B2, C2</td></tr>
<tr><td>A3, B3, C3</td><td>F1
Production Forestry</td><td>F2
Protection Forestry</td></tr>
</table>

LCCs for the Talvan watershed were derived in a GIS environment. A digital elevation model (DEM) with a grid resolution of 10x10 metres was used to generate slope steepness and the watershed was subsequently reclassified into seven 5^o slope categories. Soil series (Figure 6) were grouped into the three stability categories according to Ahmad (1989) and the land capability classes generated in the GIS using a cross-classification operation. The LCCs were subsequently assigned respective LMRs as per Table 6. Figures 15 and 16 illustrate the resultant land capability classification and recommended management regimes for the watershed. The land parcels are superimposed on the outputs so as to translate the analysis as the basis for development of farm management plans.

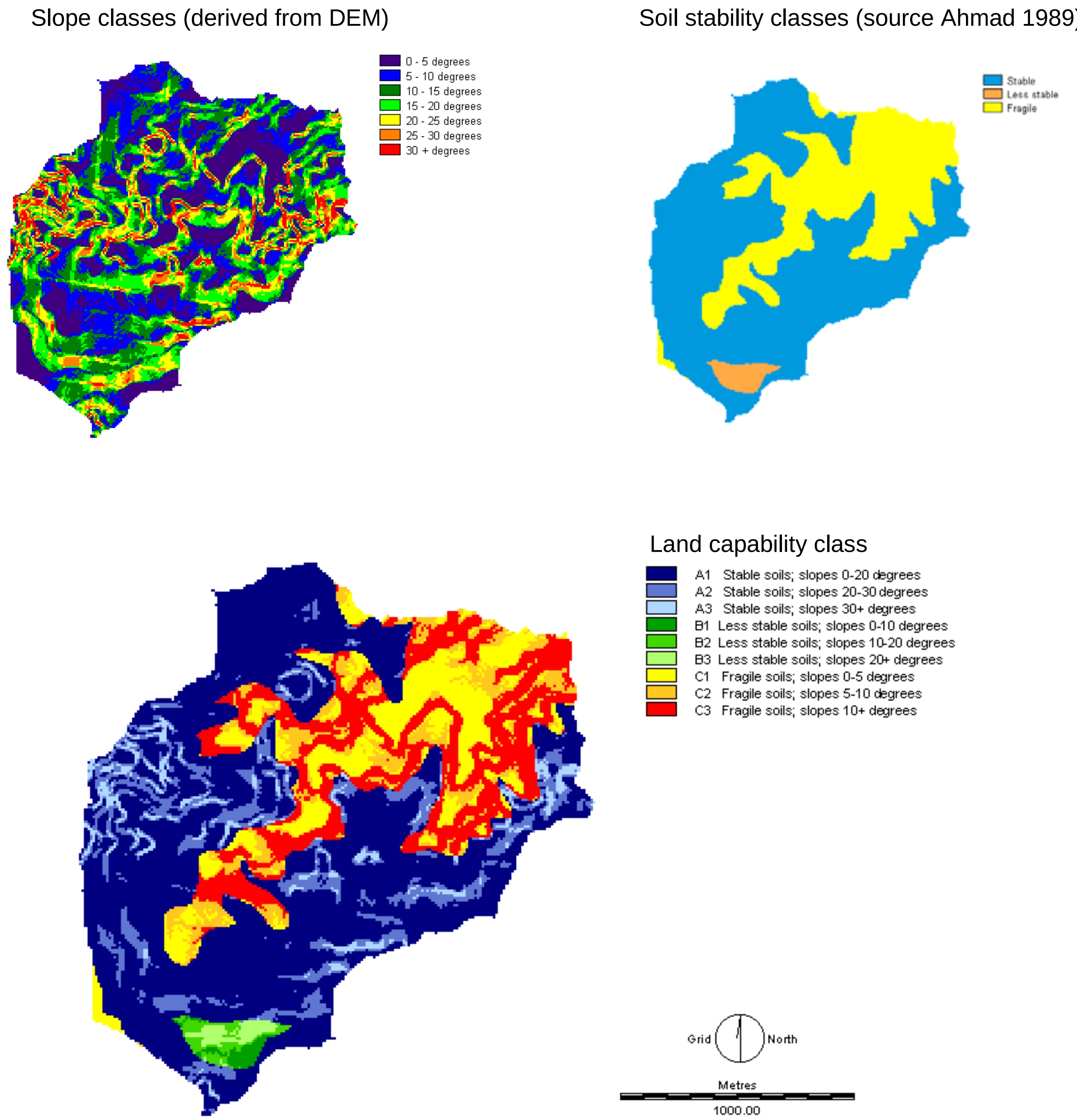


Figure 15: Land capability classification (LCC) for the Talvan catchment

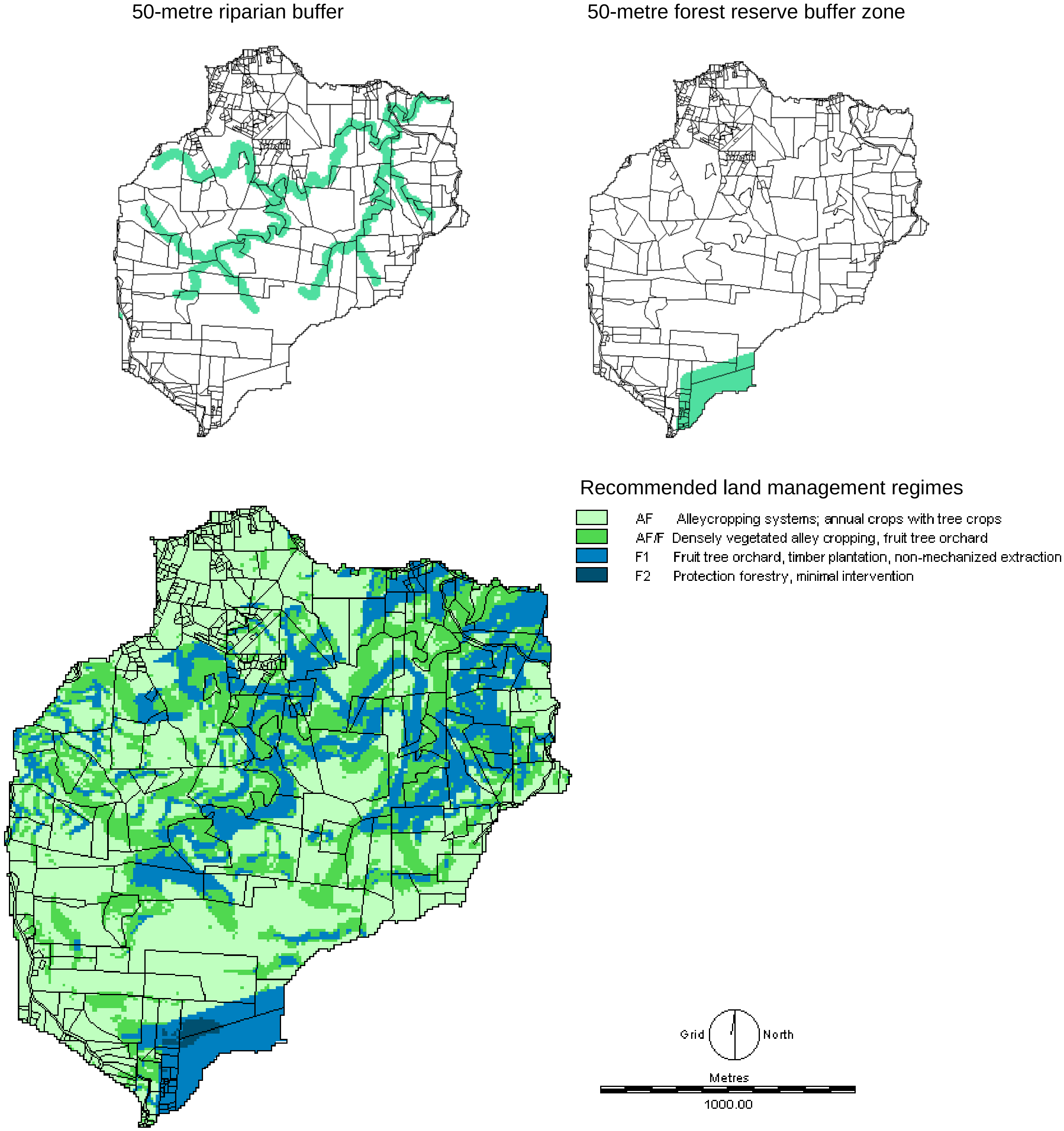


Figure 16: Recommended land management regimes (LMRs) within the Talvan catchment (land parcels superimposed)

The dominance of relatively stable soils (Warwick and Moreau clays) in the watershed yielded an A1 LCC over 162 ha, representing approximately 50% of the watershed. The C3 LCC constituted the second largest areal coverage with 49 ha or 15% of the watershed area. C1 and C2 LCCs dominated the remainder of the lower elevations of the watershed. The B series LCCs constituted a relatively small proportion of the watershed as the associated soil series made up only a minor fraction of the watershed area, mainly in the southern region.

In the evaluation, 162 ha were assigned the agroforestry LMR within LCCs A1, B1 and C1; 85 ha were assigned the agroforestry/forestry LMR, within the 50-metre riparian and forest reserve buffers, and the A2, B2 and C2 LCCs. The forestry F1 and F2 LMRs associated with the A3, B3 and C3 LCCs and the riparian and forest reserve buffers accounted for just under 73 ha. Table 8 summarises the spatial coverage of each capability class and associated LMRs over the watershed.

Table 8: Spatial extents of land capability and land management regime classes over the Talvan catchment

Capability class (incl. riparian & forest reserve buffer)	Recommended land management regime	Area (ha)	% total watershed
A1	Agroforestry (AF) Alley cropping – annual crops and tree crops	161.7	50.5
B1			
C1			
A2	Agroforestry / Forestry (AF/F) Tree crops with high crown cover in shelter wood system over annual crops; tree orchard, natural or plantation forest	85.1	26.6
B2			
C2			
Riparian and forest reserve buffer			
A3	Production Forestry (F1) Timber plantations, tree crop orchard, forest enrichment, non-mechanised selective harvesting, interpretive activities	71.4	22.3
B3			
C3			
Riparian and forest reserve buffer			
Forest reserve buffer	Protection Forestry (F2) Minimal intervention	1.5	0.005

5.2 Land use compatibility assessment

A comparative analysis was conducted to assess the compatibility of present land use within the watershed in the context of recommended LMRs, based on similar analyses presented by Rojas et al. (1988) and in the 10-year *Forest Management Plan* (GOSL 1992). At locations where recommended LMRs were highly divergent from the current land use, the lands were either being exploited unsustainably, or not being used to their full potential. Where the LMRs were similar to the current land management regime, the lands were characterised as being utilised sustainably. A 7-point nominal scale was applied to rank land-use compatibility, where ‘1’ suggested that the land was being underutilised based on present land use, to ‘7’, which suggested that the land was being highly unsustainably managed or over-exploited. The mid-point value of 4 implies that the current land use is optimal relative to recommended LMRs. A conflict matrix – adapted from Cox (2003) – in Table 9 contains the compatibility ratings.

Table 9: Conflict matrix to determine compatibility of current land uses within the Talvan watershed with recommended land management regimes

Present land use	Recommended land management regimes			
	AF	AF/F	F1	F2
Natural and plantation forest	2	3	4	4
Grass/open woodland (abandoned cultivation)	4	5	6	6
Mixed agriculture	5	6	7	7
Intensive hillside farming	5	6	7	7
Densely vegetated agriculture	4	4	5	5
Flatland intensive farming	6	7	7	7

Key:
1 = underutilised
2 = somewhat underutilised
3 = somewhat optimal
4 = optimal/sustainable
5 = somewhat unsustainable
6 = unsustainable
7 = highly unsustainable

Refer to Cox (2003) for the expanded land-use compatibility matrix for other land-use classifications.

The compatibility coverage was generated in the GIS by first cross-classifying the recommended land management and current land use layers. The current land use/recommended management combinations in the cross-classified coverage were assigned compatibility ratings (Table 9) to yield the final map layer (Figure 17).

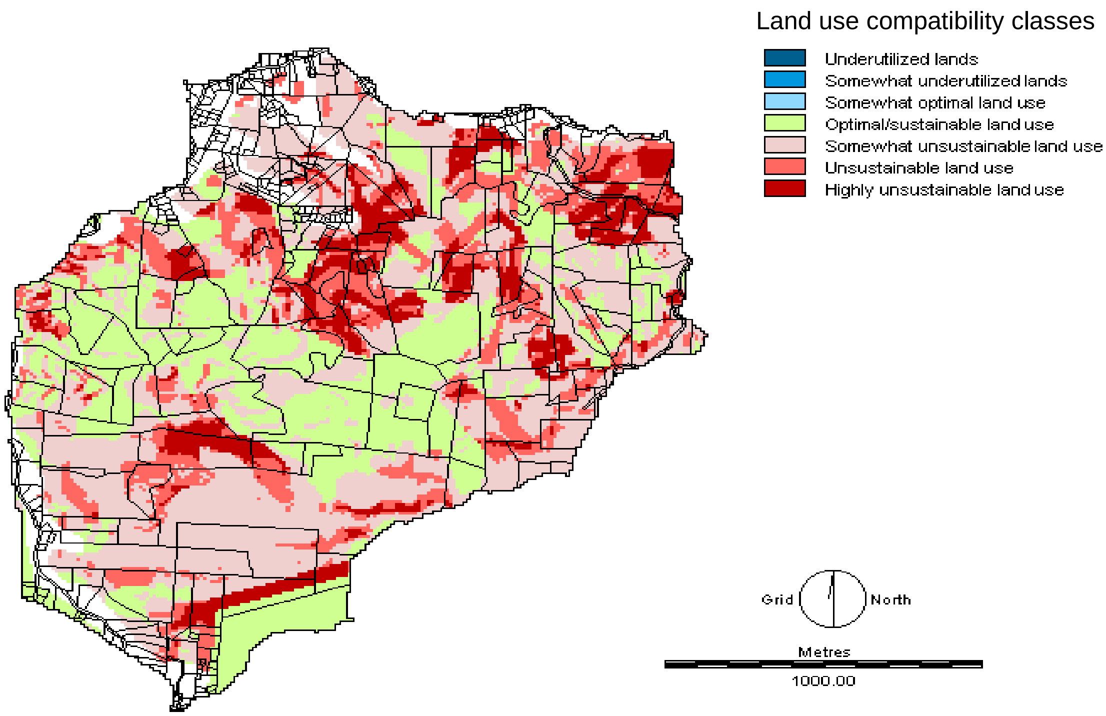


Figure 17: Land use compatibility assessment for the Talvan catchment (land parcels superimposed)

A spatial analysis of the results revealed that the majority of lands, or approximately 64% of the total area in the watershed, were under management regimes that varied between sustainable to somewhat unsustainable. In view of the fact that the catchment area is considered environmentally sensitive, any land management that tends toward heavily vegetated – or even abandoned (with heavy cover) – is considered to have less of an environmental impact in the context of soil and water conservation. Approximately 10% of the area was evaluated to be under highly unsustainable land management regimes. These areas included the forest buffer zone, which does not actually exist as the forest has been cleared for intensive agriculture up to the boundary line. The main areas of highly conflictive land use were clustered primarily in the lower reaches of the watershed along the relatively steep valley slopes of the main channel where the fragile soils warranted a C3 land capability class. The north eastern divide was another area where steep slopes with fragile soils were being unsustainably farmed. Table 10 provides a summary of the areal land use compatibility analysis.

Table 10: Areal extents of land use compatibility classes in the Talvan catchment

Land use compatibility category	Area (ha)	% of total
Optimal/sustainable land use	84.0	26.3
Somewhat unsustainable land use	121.0	37.8
Unsustainable land use	51.6	16.1
Highly unsustainable land use	32.9	10.3

5.3 Agro-ecologic zoning and crop suitability evaluation

Cox (2003) carried out GIS-based analyses to assess spatial variability in relative suitabilities for annual and perennial rain-fed crop production based on water availability and soil suitability criteria, adapting the FAO methodology for agro-ecological zoning (FAO 1996). For each recommended LMR, crop class suitabilities were assigned based on the environmental conditions, to derive agricultural and forestry land utilisation types (LUTs). In that investigation a total of 14 LUTs were defined for St. Lucia. The LUTs provide further guidance to land management planners, and agricultural and forestry officers in recommending the most appropriate crop combinations within the various LMRs.

Four perennial crop classes were modelled in the AEZ evaluation primarily on the basis of annual rainfall requirements.

- Group A perennial crops are those that are optimally productive in an environment where average annual rainfall is relatively high, ranging upward from 2,500 mm/yr. This includes crops such as cocoa, mango, avocado and breadfruit.

- By comparison, Group D perennial crops (such as cashew) are more optimally suited to drier environments where the rainfall varies between 1,500 to 2,000 mm/yr (HTS 1997; Cox 2003).

Spatial variability in suitability for annual crops was modelled based on a similar approach as for perennial crops; however the mean annual water deficit was used as the key parameter that determined suitability at any given location.

Soil suitability characteristics were also incorporated in the analyses; these were fertility, acidity and drainage. The soil and rainfall/water deficit factors were combined using a weighted linear combination procedure in the GIS (Eastman 1999).

Three suitability classes were derived for annual (short crop) cultivation based on relative suitability scores derived from the weighted linear combination evaluation.

- Class S1 suitability for annual crops represented optimal suitability for rain-fed annual crops on account of relatively good soil characteristics and relatively low water deficit.

- Class S3 suitability on the other hand, represented relative low suitability on account of the adverse soil characteristics and relatively high moisture deficits.

The evaluation was carried out for the entire island at a 50x50 m^2 grid resolution (Cox 2003). The results were extracted for the Talvan catchment (Figure 18).

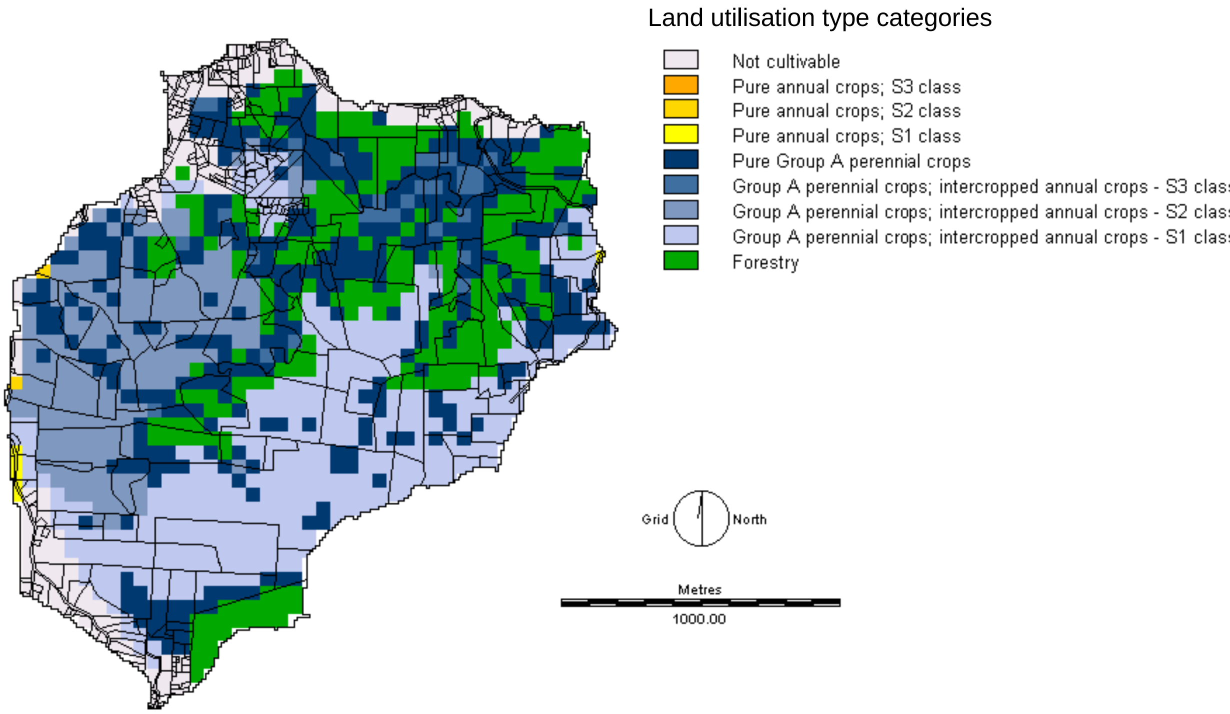


Figure 18: Agricultural and forestry land utilisation types within the Talvan catchment

Within the lower elevations of the watershed the forestry LUT was assigned corresponding to the F1 management regime, which was in turn associated with the C3 land capability class. The forestry LUT can include pure forestry plantation, natural forest, tree crop orchard or a combination of any of the three. Pure tree crop LUTs were associated with the AF/F LMR along the riverbanks and within the forest reserve buffer zone. In the south-western region of the watershed the dominant LUT was the Group A perennial tree crop intercropped with S2 class annual crops. The relative lower suitability (S2 class) for annual crops was on account of the soil characteristics associated with Warwick clay. Warwick clay tends to have a low natural fertility and is very acidic, although it is relatively well drained (Stark et al. 1966). The LUT associated with the AF LMR within the south-eastern region of the watershed varied from the western area in terms of the annual crop assignment which was class S1, suggesting more optimal suitability for annual crop production. This was due to the more favourable soil characteristics associated with Moreau clay which is better drained, has a slightly higher natural fertility, and is less acidic.

In Figure 18 there are three small areas on the western periphery of the watershed that were classified as pure annual crops – S1 class. This was due to the coarser resolution of the AEZ analysis (50x50 m) and actually corresponded to the LUT assignment in the adjacent watershed basin.

5.4 Soil and water conservation measures

This section details rehabilitation measures that may be installed within the watershed in accordance with the spatial land management regimes identified in the previous section.

5.4.1 Riverbank conservation measures

Conservation strategies within water catchment areas should, as a matter of priority, seek to mitigate the transmission of pollutants, (whether they be sediment, agro-chemicals, or other liquid and solid waste) into the watercourses. The most effective measure is the installation of vegetated buffer zones along the entire length of the water channels, along with the installation of appropriate control systems to stabilise and settle out contaminants from farms and households. However in St. Lucia the present legislative framework to safeguard riparian zones is weak, and land owners are not mandated to adopt appropriate soil and water conservation measures along water channels that may traverse their holdings. In previous initiatives, land owners have participated in the installation of the conservation measures along the main channels. The recommendations presented below build on previous strategies.

In the previous initiatives, approximately 2.2 km or just under 50% of the 4.6 km main channel upstream of the intake was rehabilitated with a combination of tree planting and bio-engineering slope stabilisation measures. The bio-engineering measures included installation of gliricidia (*Gliricidia sepium*) wattles (fascines) (see Annex 3) to arrest surface sediment wash into the watercourse and to stabilise the bank to prevent it from further collapse. Geo-textile fabric was used to cover small exposed areas along the riverbanks that had collapsed. Tree crops, primarily cocoa and mango, along with timber species such as Honduras mahogany (*Swietenia macrophylla*) were planted as needed.

It is proposed that the existing measures be augmented, particularly along riverbank segments that are still undergoing degradation – possibly in the upper reaches of the watershed that had not been treated. As a frontline measure of defence, a 25-metre vegetated buffer strip is recommended along each side of the riverbank from the intake structure, upstream to the upper reaches of the watershed. Currently the vegetated buffer (where established) is limited to a single row of trees, however more rows is desirous, not only from the standpoint of maximising the riparian protection function but also from the standpoint of establishing economically productive cultivation.

This vegetated buffer can be established from natural vegetation, tree crops, or commercially important timber species. Land owners however tend to favour tree crops, and given the prevailing agro-ecologic conditions in the area, mango, breadfruit or cocoa may be suitable alternatives. In instances where the farmer already has temporary or annual crops established along the waterway, these may be intercropped with tree crops or timber species, anticipating gradual succession and some degree of economic return until pure stand tree cover is established.

Annex 3 contains agrological data for selected tree crops with good commercial potential for both domestic and export markets.

In areas where concentrated degradation is occurring the strategy will require installation of various control measures so as to ‘armour’ the riverbank to enhance resistance to continued erosion. In the worst-case scenario, where the banks are relatively steep (in excess of 30^o) with a high degree of soil exposure, the installation of vegetative wattles (fascines) and grass barriers will provide the ‘frontline’ defence to retard the rate of overland transport of sediment to the channel. The number of rows of wattles and grass barriers will depend on the steepness and length of the riverbank slope. Geo-textile fabric should be installed along sections where the soil is completely exposed. The fabric should be staked in direct contact with the soil surface using propagative material such as gliricidia or bamboo. Where the bank is being undercut, sandbags may be installed, staked into position using propagative stakes and planted with grass (Note: bamboo, maho-mang and other propagative planting material may be experimented with). Clark and Hellin (1996) provide an excellent review of practical bio-engineering techniques that can be applied for slope stabilisation which can be adapted for this application. Figure 19 illustrates typical configurations for various riverbank stabilisation measures.

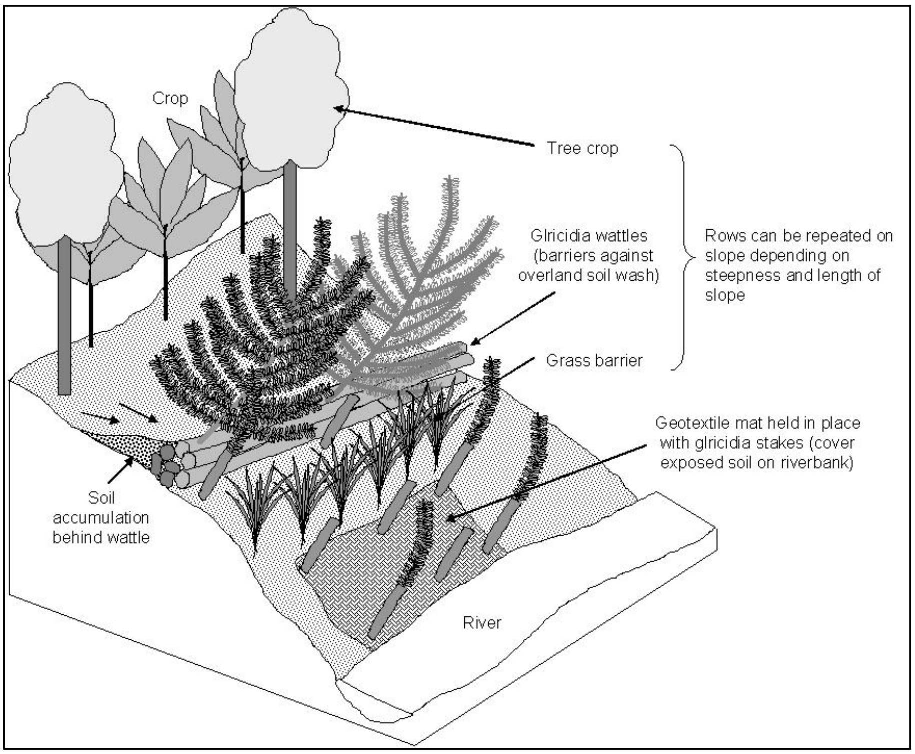


Figure 19: Detail of riverbank soil conservation measures.

Based on the field reconnaissance and the land use/conflictive land use analysis derived from the high resolution aerial photos, at least 38 parcels adjacent to major watercourses will likely require riverbank rehabilitation measures (Table 12). Considering the fhe fact that not all watercourses (smaller ravines and ephemeral streams) were assessed, it is likely that there are channel segments excluded from the evaluation that may require remedial works. It is anticipated that such areas may be assessed for rehabilitation during follow-up implementation.

5.4.2 Upland (on-farm) erosion mitigation measures

Measures to control upland erosion seek to reduce the effects of channel (gully) and inter-rill (surface or sheet) erosion. Gullying is accelerated detachment and transport of soil aggregates that become entrained in flow within farm drains or ravines after stabilising vegetation has been removed. In large storms significant quantities of material can be lost due to gully erosion. Sheet erosion is the dislodgement and transport of soil particles due to raindrop impact and overland flow under conditions when the rainfall exceeds the soil infiltration capacity, usually under saturated soil moisture conditions. The problems of erosion are aggravated over steep terrain, particularly where soil aggregates are loosely consolidated (relatively low clay and organic matter content), and where land management regimes (inadequate vegetation and residue cover, and poor drainage) leave the soil exposed to rain drop impact and subject to unimpeded runoff.

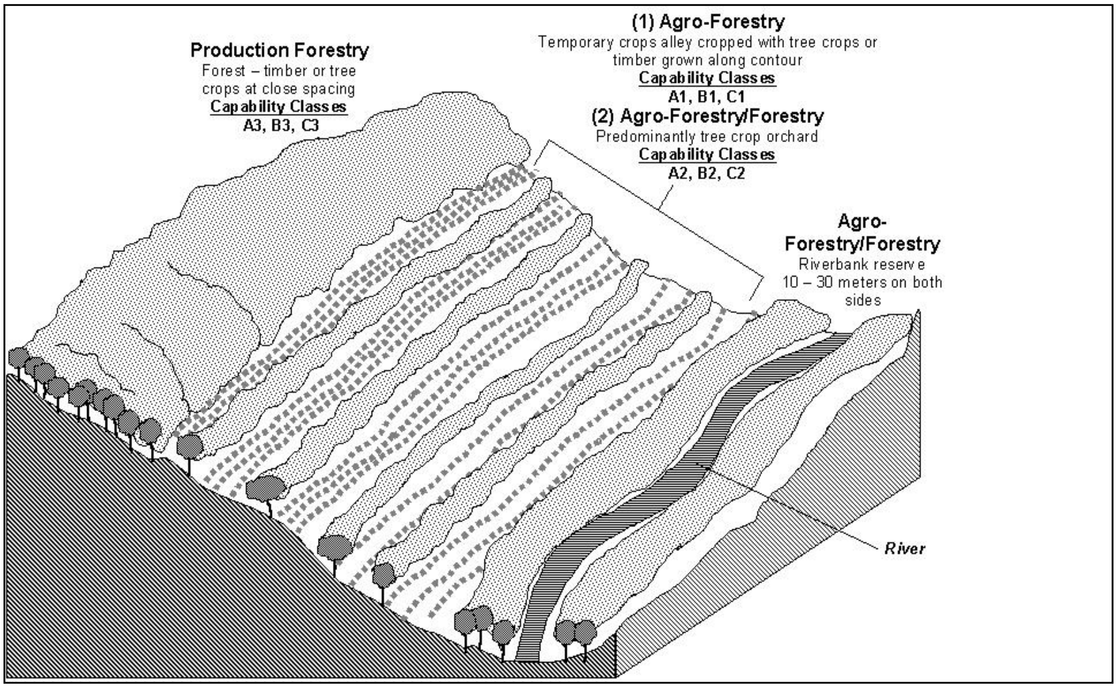


Figure 20: Arrangement of recommended land management regimes on a hillside within a water catchment area

In agricultural watersheds, frontline strategies to mitigate erosion centre around effective vegetation cover management and drainage. Tree crops, commercial timber, or natural tree species are favoured in steep areas given their extensive root networks that enhance soil permeability to reduce runoff, and serve to bind surface and sub-surface soil aggregates to reduce landslide risk. In agroforestry management regimes, trees are intercropped with annual (or temporary) crops – typically along the contour– so as to improve slope stability and reduce soil surface exposure. Incorporation of vegetative residue such as stems, branches and leaves as trash lines along the contour not only shields exposed soil but also increase surface roughness. These organic residues act as physical retardants to the movement of sediment in runoff downslope and enhance infiltration capacity through their incorporation in the soils. Grass barriers perform a similar role in retarding flow but also in terms of soil stabilisation, on account of their root network. Whatever the vegetative management strategy, this must be complemented with proper drainage to manage potential erosive flows and conserve moisture within the soil horizons. Figure 20 illustrates a typical configuration of a hillside agroforestry land management regime based on the land capability class. Annex 3 contains more details on typical soil and water conservation measures that may be employed.

On site visual assessments, along with the aerial photo analysis, yielded a tentative identification of the parcels that will likely require rehabilitation measures in the upland areas. Upland conservation measures are also recommended for parcels that bound with the Government Forest Reserve (with respect to the 50-metre forest buffer zone). Some 16 parcels require upland conservation measures of which 5 are adjacent to the forest reserve.

Ten parcels will require both riverbank and upland conservation measures. The data is contained in Table 11.

Table 11: Land parcels in the Talvan catchment requiring priority rehabilitation measures

Block	Parcel	Location class			Block	Parcel	Location class		
		Riverbank	Upland	Forest buffer			Riverbank	Upland	Forest buffer
1245B	6	✓			1246B	119	✓		
1245B	13	✓	✓		1246B	121	✓		
1245B	18	✓			1246B	128	✓		
1245B	22	✓	✓		1246B	129	✓		
1245B	23	✓			1246B	130	✓	✓	
1245B	43			✓	1246B	132	✓		
1245B	47			✓	1246B	133	✓	✓	
1245B	57			✓	1246B	136	✓	✓	
1245B	58			✓	1246B	138	✓		
1245B	86	✓			1246B	139	✓		
1245B	88	✓			1246B	141	✓	✓	
1245B	89	✓			1246B	149			
1245B	117			✓	1246B	221	✓		
1245B	131	✓	✓		1246B	256	✓		
1246B	69	✓	✓		1246B	259	✓		
1246B	71	✓			1246B	325		✓	
1246B	74	✓			1445B	34	✓		
1246B	75	✓			1446B	90	✓		
1246B	76	✓			1446B	98	✓		
1246B	77	✓			1446B	106		✓	
1246B	78		✓		1446B	107	✓	✓	
1246B	111	✓			1446B	108	✓	✓	
1246B	112	✓			1446B	134		✓	
1246B	113		✓		1446B	151	✓		
1246B	114		✓		1446B	172	✓		

Note: Parcel identification based on field reconnaissance, aerial photo analysis, and derivatives – specifically land use and conflictive land use analysis. Refer to Figure 21.

5.5 Costs

The following are estimated unit costs for installation of soil conservation measures.

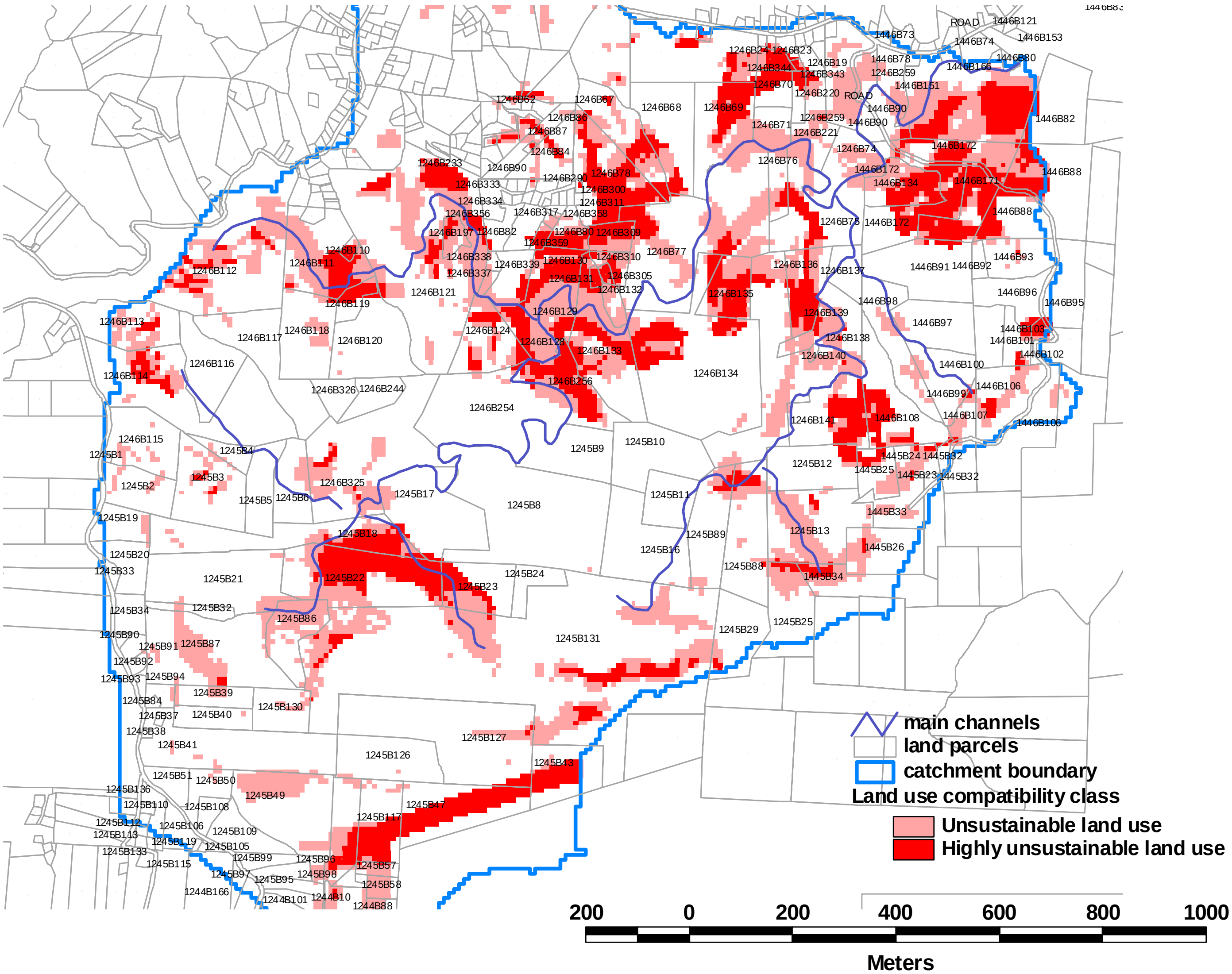
Table 12: Installation costs for typical soil conservation measures (Sources: Festus George, Engineering Services Division, MAFF; Cornelius Isaac, Forestry Department, MAFF)

Measure	Specifications	Installation cost range EC$
Interceptor drains	Bed width 0.8 – 1.2 m Depth 0.5 – 1.0 m	\$5 - \$7/m
Collector drains	Bed width 0.5 – 0.8 m Depth 0.5 – 0.7 m	\$3 - \$5/m
Lateral drains	Bed width 0.3 – 0.5 m Depth 0.3 – 0.5 m	\$3- \$4/m
Grass barriers	0.2 x 0.15 m spacing	\$5 - \$10/m^2
Trash barriers	Width 0.6 m Height 1.0 m	\$2 - \$5/m
Soil berms	Width 0.3 m Height 0.6 m	\$4 - \$7/m
Wattles	Length 2.0 – 3.0 m (6 to 8 bundles)	\$14 - \$20/m*
Tree crops	Refer to Annex 2 for spacings for various tree crops	\$50 - \$300/ha**

* Based on EC \$41.00 per wattle used in prior conservation initiatives within Talvan watershed. Cost included material procurement (cutting and transport), bundling, manual delivery to site, and installation.

** Estimate derived based on planting of 200 seedlings per day at EC\$50 per man-day. This may vary depending on the distance to planting site and terrain.

Figure 21: Areas under conflictive land use in the Talvan watershed targeted for land conservation measures



6. Water quality monitoring

6.1 Water quality parameters

In view of the fact that the watershed will likely continue to be an important water supply for communities in the north of the island, and is a possible demonstration site area for watershed management practices, a long-term hydrologic monitoring programme is being recommended. Parameters to be monitored should include:

- Discharge – assess hydrologic regime of the watershed.
- Rainfall – assess rainfall depth, duration and intensity; correlate pollutant loading (erosion) to storm intensity.
- Fecal colliform – assess levels of sewerage contamination.
- Turbidity (suspended solids) – assess severity of soil erosion; both channel and sheet.
- pH – indicator of possible chemical loadings (for further detailed analysis).
- Temperature – indicator of possible chemical loadings (for further detailed analysis).
- Macro-organism aquatic diversity – presence or absence are indicative of general water quality.

Presently there are no established raw water (streamflow) standards for St. Lucia. Some benchmarks established by the United States Environmental Protection Agency may be used as a guide (refer to EPA Quality Criteria for Water (1976), on-line source at: www.epa.gov/waterscience/criteria/redbook.pdf).

6.1.1 Fecal colliform bacteria

In the case of fecal colliform levels the EPA notes that the type of bacteria present will determine tolerable limits as some organisms are more virulent than others. The criterion adopted is that detection should not exceed a log mean of 200 organisms per 100 ml sample based on a minimum of 5 samples taken over 30 days. Alternatively, no more than 10% of the total samples extracted during any 30-day period should exceed 400 organisms per 100ml.

6.1.2 Turbidity

In the case of turbidity, which is measured in terms of nephelometric turbidity units (NTUs), there are no standard guidelines. Tolerable levels of turbidity will depend on the purpose for which the water is being used. In the case of drinking water there are limits to which the treatment infrastructure can handle suspended solids. WASCO technical personnel advised that NTU levels in excess of 1,000 verify possible problems for the treatment plant. The EPA defines clear water as having an average NTU measurement of less than 25; water of intermediate clarity has an NTU of between 25 and 100; and muddy water has an NTU level exceeding 100. The EPA criteria for turbidity is that settleable and suspended solids should not reduce the depth of the compensation point for photosynthesis activity by more than 10% from the seasonably established norm for aquatic life. A national standard for St. Lucia may be considered along similar criteria, although research will need to be undertaken to establish an appropriate benchmark.

6.1.3 Acidity

The pH for water should range around neutrality. The EPA standard for surface waters is between 6.5 and 9.0.

6.1.4 Other parameters

Other quality standards may be considered, and presence/absence detection of micro and macro flora and fauna may be important indicators of the health of aquatic ecosystems. In higher elevations within the watershed, freshwater shrimp are indicators of relatively clean non-polluted waters. Likewise, the presence of algae often indicates signs of eutrophication where nutrient loadings due to agricultural and sewerage runoff, and decay of organic material, favour their proliferation. Other important clues to water quality status include the presence of solid waste and oil-based pollutants.

6.2 Monitoring infrastructure

The watershed outlet (at the intake) should be the primary sampling point for the watershed, with secondary sampling locations on tributaries within the watershed to capture the effects of spatial variation in land use and its impact on water quality. The primary monitoring station should be capable of continuous recording (of discharge) with systematic sampling of pollutant loading. The secondary monitoring stations should be sampled for discharge and pollutant loading generally during and after relatively large rainfall events where practical. It is recommended that a continuous recording rainfall station be installed at the WASCO Hill 20 Treatment Plant to permit analysis of runoff and pollutant loading relationships based on rainfall characteristics.

To determine the possible locations of the secondary stations, the DEM was analysed using the GIS to disaggregate the area into four major hydrologic response units based on the major tributaries (Figure 22). The southern basin drains 130 ha in the upper Combat area, the western basin drains approximately 33 ha in the Cacao area and the eastern basin drains 64 ha over the eastern Combat and En Poix Doux areas. These sub-basins represent just less than 71% of the total watershed area.

6.2.1 Primary monitoring station (watershed outlet)

Stream flow is monitored using ‘primary’ measuring devices, but secondary devices may also be installed to capture flow data, either mechanically or electronically. Primary measuring devices are physical modifications to the stream channel itself, to alter the flow to obtain a stable water level to flow rate (discharge) relationship. There are two main types of primary measuring devices; weirs and flumes. A weir is a dam with a notch installed at the crest of the dam wall through which the flow is directed. The shape of the notch determines the depth or ‘head’ of flow just upstream of the notch where the discharge is computed, based on specific formula depending on the weir profile (typical profiles are rectangular, V-notch, and trapezoidal). Flumes are precisely shaped channel segments that constrict and stabilise the flow through the channel so that the water level at a particular location within the flume is directly related to the discharge. With both weirs and flumes, once the discharge is calibrated against the water level as it flows through the section it is possible to directly read the discharge from a staff gauge (calibrated rule) installed on the side of the device. (See Annex 4 for details.)

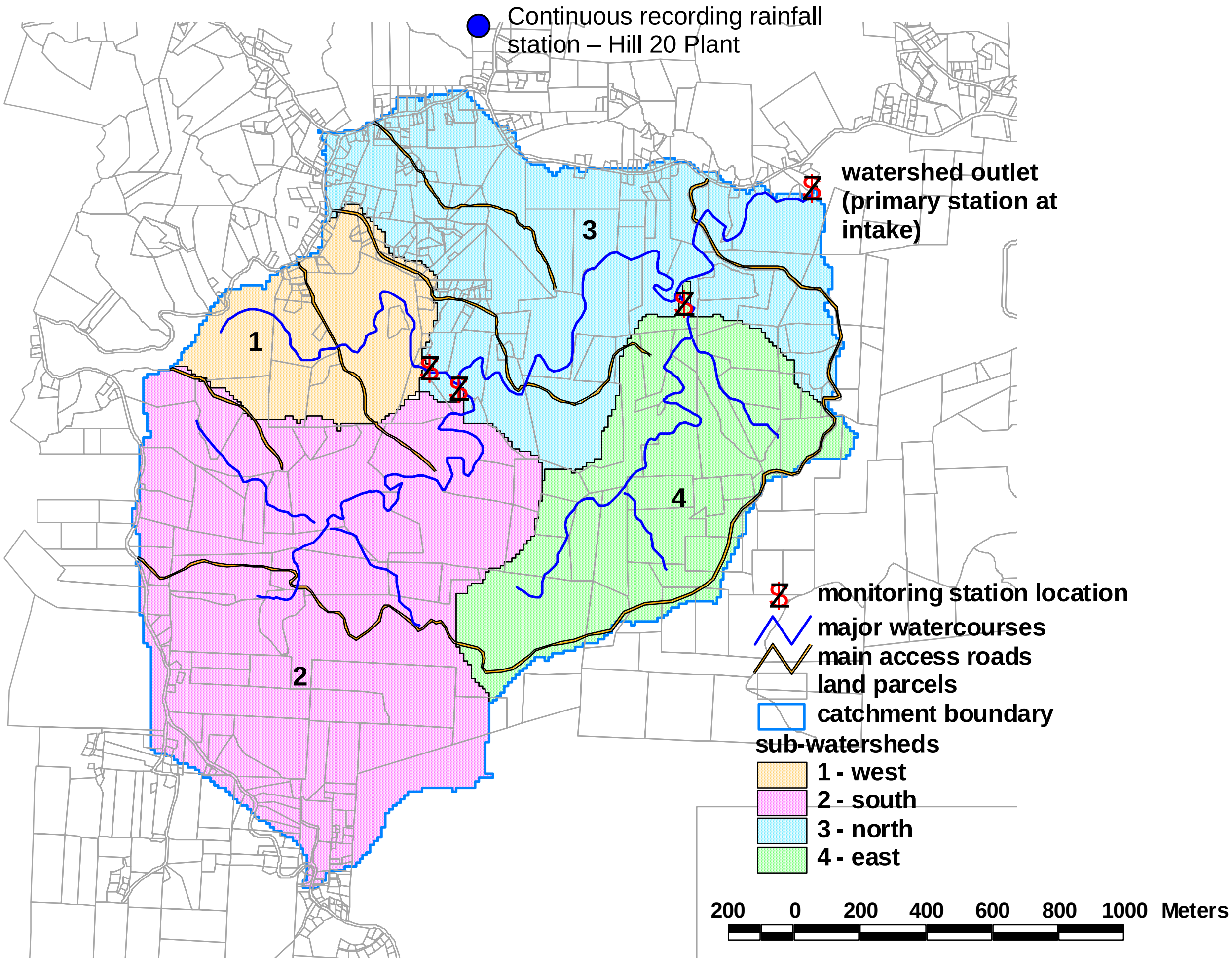


Figure 22: Proposed hydrologic monitoring network for the Talvan watershed

For the watershed outlet it is recommended that a weir be installed just upstream of the abstraction point. Weirs are typically cheaper to install than flumes and yield accurate results, although debris accumulation upstream of the weir requires occasional maintenance. Flumes are expensive to install and do not yield accurate results under high flow conditions. The approach and downstream ends of the structure must be stabilised using rip rap, gabions and vegetation as appropriate. The WEMP Report (1997) should be consulted for further design specifications related to channel stabilisation.

There are various options in selection of the secondary measuring device. Mechanical recorders use a float that contacts the water level (in an isolated chamber next to the weir or flume called a stilling well) and moves a pen arm against a revolving chart. Electronic devices sense the water level and pulse a signal to a data logger for conversion to discharge measurements based on a rating curve (the rating curve is the mathematical relationship that translates water level to discharge). Pressure transducers and ultrasonic devices fall in this category. (See Annex 4 for details.)

An automated water sampler should be installed to extract water samples from the flow based on a ‘trigger’ water level in response to runoff events which contribute to increased pollutant loading. Extracted water samples collected over the duration of a runoff event are stored in bottles contained within the sampler and can be removed for subsequent analysis (see Annex 4). The sampler and the flow measuring device are usually housed in an equipment shed in close proximity to the weir or flume.

6.2.2 Secondary monitoring stations

The stations on the other tributaries are proposed to be basic monitoring stations, with data collected primarily during heavy rains to ascertain the contribution of upstream areas to sediment and other pollutant loadings. Since these stations will be monitored only intermittently, they do not need to be continuous-recording. Weirs (as described above) can be installed across the stream channels with staff gauges mounted on the side wall of the structures. It is recommended that the stream bed and approach to the weir be stabilised using rip-rap, gabions or other reinforcement as appropriate.

6.3 Sampling regime management

Flow data derived from the primary automatic station at the watershed outlet should be downloaded on a monthly basis. If a water sampler is installed, samples will need to be collected after large flow events. Since the sampler will be extracting sequential samples over time during the flow event it will be possible to chart the change in pollutant loading with respect to flow. At the secondary stations readings can be taken directly from the staff gauges and water samples collected by hand. The rainfall data from the proposed station at Hill 20 should be downloaded on a monthly basis.

It is recommended that the Ministry of Agriculture, through the Water Resources Management Unit (Water Resources Agency, post-WRM project), be assigned primary responsibility for implementing the monitoring regime in partnership with WASCO, CEHI, and – importantly – the community, specifically the Talvan Water Catchment Group and the Babonneau Secondary School.

With appropriate training, the TWCG – in partnership with the Babonneau Secondary School – can operate the proposed monitoring system under technical oversight by the WRMU. This will involve the collection of water samples from both the automated sampler at the primary station and directly from streamflow at the secondary stations. Using basic field test kits the samples can be analysed on the spot; should more sophisticated tests be desired, the samples may be sent to CEHI for analysis. It is envisaged, however, that the electronic data downloads from the flow logger at the primary station and the rainfall station be carried out by the WRMU/WRA as part of routine monitoring.

It is recommended that validation checks with CEHI be made, perhaps once every 6 months, so as to ensure consistency in data quality. Other key partner agencies in the programme should include the Environmental Health Unit of the Ministry of Health, and the Forestry and Fisheries Departments (MAFF).

6.4 Costs

The costs presented below are estimates, particularly with respect to installation of the primary measuring device (weir), as detailed design specifications are required to derive final costs. The data are presented in terms of capital and recurrent cost related to operation and maintenance.

Table 13: Estimated costs for establishment of monitoring infrastructure and annual maintenance ($EC)

Item	Unit	Qty	Unit cost	Total Cost	Remarks
Capital costs (East Caribbean $): weir construction/equipment shed					
1. Primary station		1	15,000	15,000	Station in proximity of Talvan intake
2. Secondary stations		3	8,000	24,000	On main tributaries
Automatic water sampler		1	16,000	16,000	
Flow meter		1	10,000	10,000	Ultrasonic sensor and logger
Automatic rainfall station		1	2,000	2,000	Tipping bucket rain gauge and logger
Computer (laptop)		1	6,000	6,000	For data download
Propeller meter		2	500	1,000	To calibrate discharge
Field test kits		4	400	1,600	
			Sub-total	75,600	
Annual recurrent costs (East Caribbean $): weir maintenance					
1. Labour	mdys/yr	24	50	1,200	Maintenance cycle - once every 3 months, 2 men @ EC$50/day for 3 days/cycle
2. Materials				2,500	Stone, cement, tools
Equipment maintenance				500	Electronic maintenance as required
Sample analysis (CEHI)				1,000	For validation of test results
Field test kit reagent replacement	yr	1	500	500	
Data collection	mdys/yr	20	40	800	Additional paid resources if necessary
Training				1,000	For community group, schools
			Sub-total	7,500	
			TOTAL	83,100	

7. Summary and recommendations

The Talvan watershed is a highly degraded catchment that is a primary source of water to the Hill 20 Treatment Plant distribution network. Recent studies have revealed that the raw water from Talvan is more polluted than most other sources on the island. The high turbidity and other pollutants – fecal colliform in particular – raise serious health concerns, and have a significant cost implication in terms of water treatment. The supply from Talvan is frequently interrupted due to quality problems, which results in distress to communities that rely primarily on Hill 20. A field investigation revealed that the watershed is not as intensively cultivated as it was five years ago and therefore it is likely that the severity of sediment loads from agricultural fields may have declined. On the other hand, the proliferation of households may be contributing to increased levels of sewerage and solid waste contamination. A GIS analysis of land use compatibility suggested that approximately 26% of the land area is under land uses that are incompatible with the recommended land management regimes.

Rehabilitation works should be maintained in the watershed given the catchment's importance as a water supply to communities in the north of the island. Acquisition of the watershed and reversion to forest may be an option; however, due to the fact that the watershed is highly developed in terms of agriculture, housing, and infrastructure, this will be very costly. In addition, investment in the John Compton Dam as the main water supply to the north relegates acquisition of the Talvan catchment to lesser importance. Notwithstanding this, the watershed should be maintained as a demonstration site for experimental soil and water conservation techniques and general watershed best management practices. To assess the viability and effectiveness of management interventions, a monitoring regime must be installed to measure key water quality indicators.

The following are the major recommendations from this study:

A. Install a hydrologic monitoring network for the watershed, with a continuous recording streamflow station at the watershed outlet, and secondary non-recording stations on major tributaries to assess spatial variability in pollutant source contributions.

B. Continue rehabilitation measures along degraded segments of the main watercourse and within upland cultivated areas.

C. Assess the pollutant risk from the livestock production units and develop control measures to minimise such risk.

D. Assess the pollutant risk from households, particularly those in close proximity to the main channel at Talvan, and develop control measures to minimise such risk.

E. Establish national raw water standards so as to set appropriate benchmarks against which effectiveness of watershed remedial measures can be assessed.

F. Build capacity within the Talvan Water Catchment Group to undertake monitoring of the watershed and to play a lead role in undertaking rehabilitation works in conjunction with land owners.

References

Ahmad, N. (1989) *A treatment oriented land classification for St. Lucia*. Unpublished. Dept. of Soil Science, University of the West Indies, St. Augustine, Trinidad.

Alexander, L., Water and Sewerage Company (undated) personal communication.

Ambroise, L., Fisheries Department (2004) personal communication.

Amerakoon, D., A. Chen and P. McLean (2000) 'Estimating daytime latent heat flux and evapotranspiration in Jamaica' in *Agric. For. Meteorol.,* 102: 113-124.

Caribbean Environmental Health Institute (2004) *Certificate of Analysis, Report 20030473, Compilation of Reports 20030473 and 20040030*. Prepared for the Water Sector Reform Project, c/o the Water and Sewerage Company, St. Lucia.

Cox, C.A. (2003) *Integrated watershed management planning for St. Lucia.* PhD thesis, McGill University, Montreal.

Eastman, J.R. (1999) *IDRISI32 Guide to GIS and Image Processing Vols. 1 & 2*. Clark Labs, Clark University, Worcester, Massachusetts, USA.

Food and Agriculture Organization (1996) *Agro-ecological zoning: Guidelines*. FAO Soils Bulletin 73. UN-FAO, Rome, Italy.

Government of St. Lucia (1992) *Forest Management Plan (1992 – 2002). Vols. 1 and 2.* Prepared by Roche lteé., Quebec. Ministry of Agriculture, Castries, St. Lucia.

Government of St. Lucia (1997) *WEMP Phase II Final Report*. Ministry of Planning and Development. St. Lucia.

Grant, D.M. and B.D. Dawson (1997) *Isco Open Channel Flow Measurement Handbook*. Isco Inc., Lincoln, New England, USA.

Hunting Technical Services Ltd. 1997. *Watershed and Environmental Management Project, Final Report.* Vol. 3. Hemel Hempstead, UK.

Isaac, C. and C.P.A. Bourque (2001) 'Ecological Life Zones of St. Lucia' in *Global Ecology and Biogeography* 10: 549-566.

Leonce, L.M. (1978) *A Preliminary Study of the Potential Water Requirements, Collection and Storage in St. Lucia*. MSc thesis, McGill University, Montreal, Canada.

Lewis, D. (2002) *Talvan Rapid Riverbank Rehabilitation and Soil Conservation Project Report*. Submitted to the Poverty Reduction Fund. Forestry Department, Ministry of Agriculture, Forestry and Fisheries, Saint Lucia.

Organization of American States (1987) *Saint Lucia Development Atlas*. Department of Regional Development, Organization of American States, Washington, D.C.

Oelsner, J. (1981) *Natural Resources and Agricultural Development, Water Resources.* General Secretariat of the Organization of American States, Washington, D.C.

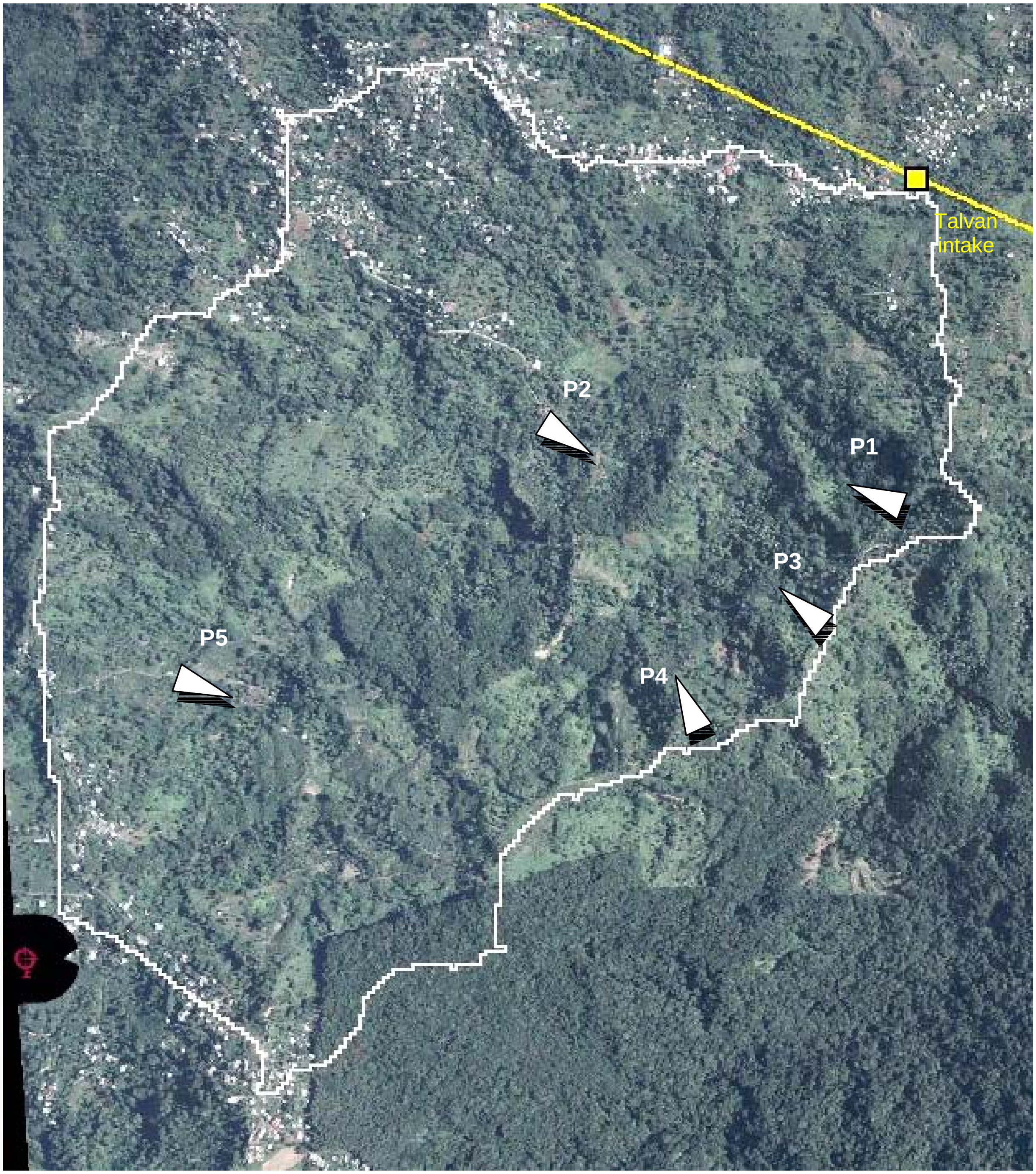
Rojas, E., R. M. Wirtshafter, J. Radke and R. Hosier (1988) 'Land conservation in small developing countries: Computer assisted studies in Saint Lucia' in *Ambio*. 17(4): 282-288.

Schellekens, J., L. A. Bruijnzeel, F. N. Scatena, N. J. Bink and F. Holwerda (2000) ‘Evaporation from a tropical rain forest, Luquillo Experimental Forest, eastern Puerto Rico’ in *Water Resour. Res*. 36(8): 2183-2196.

Stark, J., P. Lajoie and A. J. Green (1966) *Soil and land-use surveys, No. 20, St. Lucia*. University of the West Indies.

Appendix 1: Photographs

Index map. The approximate position of the photo location and direction of view indicated by arrows



P1: Abandoned cultivation at En Poix Doux

P2: Woodland area at lower Cacao

P3: Mixed and abandoned cultivation and fragmented woodlands in the lower reaches of the Talvan watershed

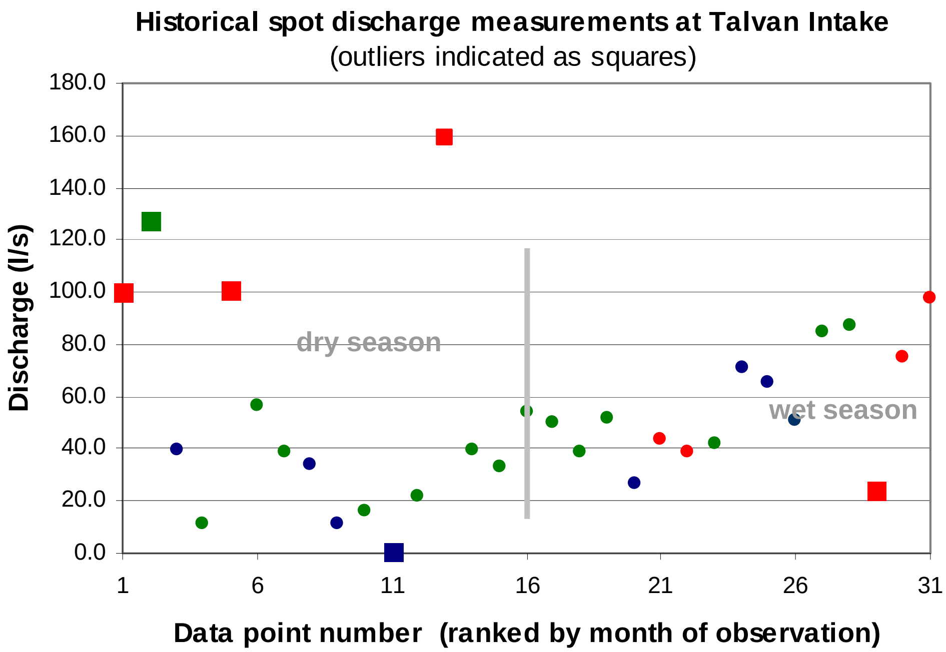
P4: Steep hillside banana cultivation at Combat

P5: Intensive banana production at Combat adjacent to the Government Forest Reserve (La Sorcière is visible in distance at left; the summit of Piton Flore visible to the right)

Appendix 2: Historical discharge measurements at the Talvan intake

Obs #	date	l/s	sources
1	16-Jan-04	100.00	WASCO, 2004
2	21-Jan-04	127.50	WRMU, 2004
3	18-Feb-04	39.81	WRMU, 2004
4	19-Feb-64	11.00	Oelsner, J. 1981
5	10-Mar-04	101.00	WASCO, 2004
6	25-Mar-04	56.29	WRMU, 2004
7	26-Mar-03	38.83	WRMU, 2004
8	10-Apr-03	33.54	WRMU, 2004
9	17-Apr-63	11.00	Oelsner, J. 1981
10	27-Apr-61	16.00	Oelsner, J. 1981
11	25-May-60	1.00	Oelsner, J. 1981
12	26-Jun-02	21.64	WRMU, 2004
13	Jul-02	159.00	WASCO, 2004
14	4-Jul-02	39.19	WRMU, 2004
15	10-Jul-02	33.15	WRMU, 2004
16	24-Jul-02	53.93	WRMU, 2004
17	28-Jul-03	50.26	WRMU, 2004
18	2-Aug-02	38.97	WRMU, 2004
19	17-Aug-64	52.00	Oelsner, J. 1981
20	20-Aug-02	26.90	WRMU, 2004
21	27-Aug-03	43.55	WRMU, 2004
22	Aug-02	39.00	WASCO, 2004
23	Aug-03	42.00	WASCO, 2004
24	6-Sep-63	71.00	Oelsner, J. 1981
25	2-Oct-61	65.00	Oelsner, J. 1981
26	18-Oct-02	51.13	WRMU, 2004
27	23-Oct-60	85.00	Oelsner, J. 1981
28	28-Oct-03	87.12	WRMU, 2004
29	Oct-03	24.00	WASCO, 2004
30	Nov-03	75.00	WASCO, 2004
31	Nov-02	98.00	WASCO, 2004

Graphic plot



Colour code:
red – WASCO, discharge measurements 2002 - 04
green – WRMU, discharge measurement 2002 - 04
blue – Oelsner (1981), discharge measurements in 1960s

Appendix 3: Land (riverbank and upland) degradation assessment and soil / water conservation measures

Part 1: Procedure for assessment and documentation of the nature and extent of land degradation.

A. Watercourse degradation assessment

Important contributors to sediment and pollutant loads in the watershed system include eroding riverbanks (successive bank collapse), livestock grazing areas, outlets from livestock pens, household sewerage outflows points, and farm drainage outflows. These 'point-sources' of contaminants should be locationally referenced to the land registry cadastre. Land registry maps (1:2,500 scale) for the corresponding area can be obtained from the Land Registry by official request. The map sheet is used in conjunction with an assessment form on which the nature and extent of degradation is compiled. The assessment form is the primary tool used to determine the nature of conservation measures required along the various segments of the riverbanks. The following are the parameters that need to be collected.

1. Land owner / farmer data

I. Land Parcel Number – referenced to LRTP Block and Parcel number
II. Land owner – registered owner(s)
III. Farmer name – common name used by farmer
IV. Status of farmer – owner or tenant

2. Status of riverbank

I. Map reference location – identify approximate position of degraded area(s) on LRTP sheet with number or letter
II. Crop(s) cultivated on riverbank
III. Length of degraded section of riverbank
IV. Relative coverage by trees – rate how much canopy coverage is afforded to the riverbank in terms of the amount of exposure of the riverbank to direct sunlight.
    a) Low: 0-30% canopy coverage
    b) Moderate: 30-60% canopy coverage
    c) High: 60%+ canopy coverage
V. Relative degree of soil exposure – rate the extent of coverage of ground vegetation or low shrubbery in terms of degree of soil exposure
    a) Low exposure: 0-30% soil exposed
    b) Moderate exposure: 30-60% soil exposed
    c) High exposure: 60%+ soil exposed
VI. Relative riverbank steepness – determine and categorise the slope of the riverbank above the stream water level. Low slope steepness: 0-10 degrees; moderate slope steepness: 15-30 degrees; high slope steepness:30+ degrees.
VII. Livestock grazing – record the presence or absence of grazing in proximity of the watercourse.

3. Recommended treatments (see Part 2)

These are based on observations vis. riverbank status assessment. The assessment form presented below may be modified as appropriate to include additional fields for treatments (as appropriate), or they can be entered separately.

Riverbank Degradation Assessment
Talvan Watershed / Riverbank Rehabilitation

Compiled by: *B. Henry*

Date: *June 20 2004*

(1) Land owner / Farmer Data					(2) Status of riverbank														(3) Recommended Treatments							Remarks
Land Parcel no.	Registered land owner	Farmer			Map reference location	Crop(s) cultivated on adjacent riverbank	Degraded section length (feet)	Relative tree cover			Relative degree of soil exposure			Relative bank steepness			Livestock grazing		Tree crops / timber required		Wattles	Geotextile	Grass barriers		Other (specify)	
		Name	Tenant	Owner				High	Mod	Low	High	Mod	Low	High	Mod	Low	Yes	No	Qty	Type	Qty	Qty (m)	Type	Qty (cormbs)		
1246B / 134	John Smith	"Ray"	✓		A	Bananas	75		✓			✓		✓			✓		100	Mango	25	15	cus-cus	50		irrigation dam in vicinity
1246B / 136	Rose Peters	same		✓	B	Dasheene	30			✓	✓					✓		✓	50	Gmelina	---	20	---	---		

Notes:____

B. On-farm (upland) degradation assessment

Following a similar approach as the watercourse assessment, degraded areas within farm holdings (and urban areas if observed) should be noted on the assessment forms and on the LRTP map sheets, thereby referencing these locations to land parcels. The data to be captured in the assessment sheet is primarily a written narrative on the type and severity of erosion at particular locations. The parameters that need to be collected are:

1. Land owner / farmer data

I. Land Parcel Number – referenced to LRTP Block and Parcel number
II. Land owner – registered owner(s)
III. Farmer name – common name used by farmer
IV. Status of farmer – owner or tenant

2. Status of riverbank

I. Crop(s) cultivated on riverbank
II. Map reference location – identify approximate position of degraded area(s) on LRTP sheet with number or letter
III. Nature of degradation – record the type of degradation processes that are occurring at that location within the land parcel

3. Recommended treatments (see Part 2)

These are based on observations vis. riverbank status assessment. The assessment form presented below may be modified as appropriate to include additional fields for treatments (as appropriate), or they can be entered separately.

On-farm Degradation Assessment
Talvan Watershed / Riverbank Rehabilitation

Compiled by: F. Raymond

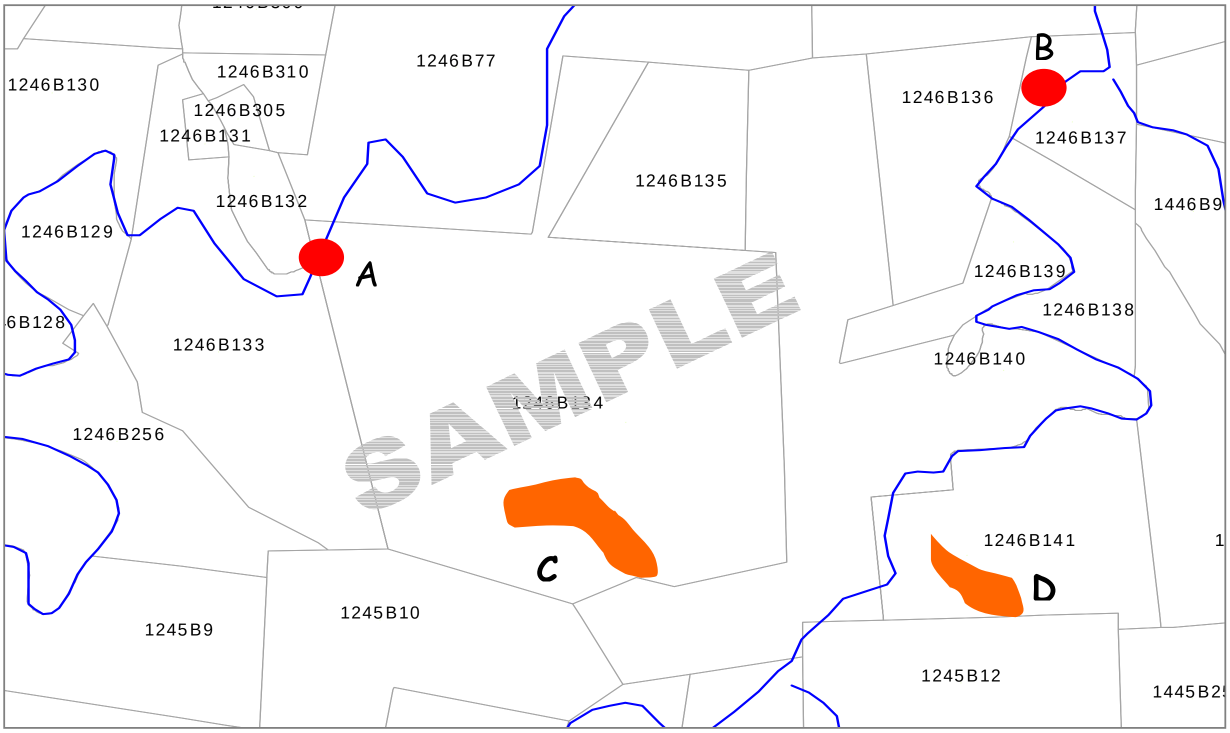
Date: June 20 2004

Land owner / Farmer Data					**Status of farm holding**			**Recommended Treatments**							**Remarks**
Land Parcel no.	**Registered land owner**	**Farmer**			**Crop(s) cultivated**	**Map reference location**	**Nature of degradation**	**Tree crops / timber**		**Wattles**	**Geotextile**	**Grass barriers**		**Other** (specify)	
		Name	Tenant	Owner				Qty	Type	Qty	Qty (m)	Type	Qty cormbs		
1246B 134	John Smith	"Ray"	✓		*Bananas*	C	General sheet erosion over most areas	100	Mango	25	15	cus-cus	50		
1246B 141	Mary Jones	same		✓	*Dasheene*	D	Deep gorge near south corner, general sheet erosion over area	50	Gmelina	---	20	---	---		

Notes:____

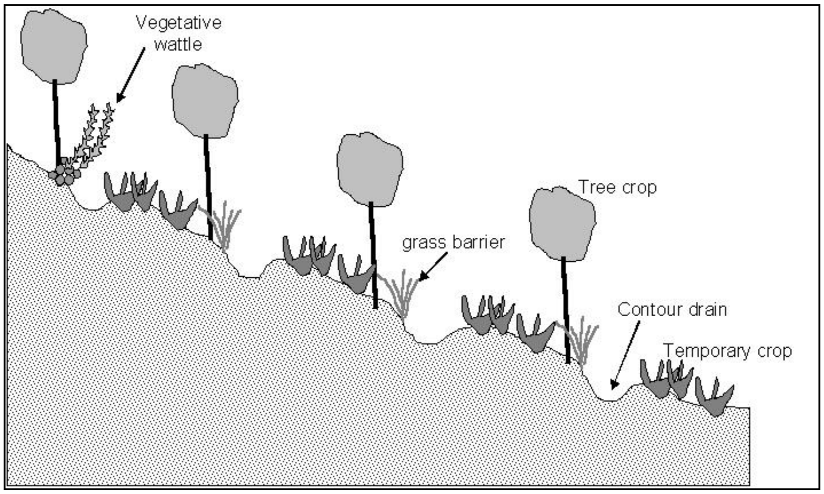
Accompanying assessment (LRTP) map sheet

The symbols denoting approximate location of degraded sites are best illustrated on a map showing the land parcels so as to provide a frame of reference to accompany the assessment sheets. The orange areas indicate approximate extents of upland degraded areas and the red dots indicate locations of degraded riverbank segments.



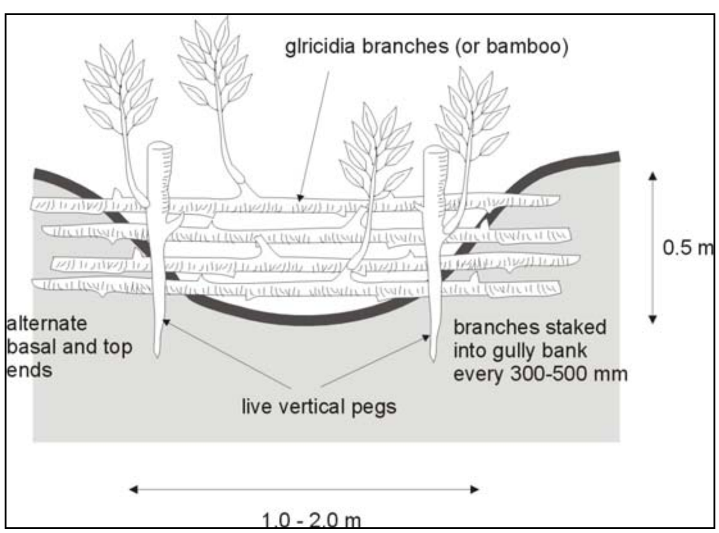
Part 2: Typical soil conservation techniques (and specifications) that can be installed to stabilise riverbanks and minimise sediment discharge from farm drains. (Refer to the reference by Clark and Hellin, *Bio-engineering for Effective Road Maintenance in the Caribbean* (1996) for details.)

A. Upland soil conservation measures: On sloping lands it is recommended that vegetation cover and drainage works be aligned along the contour.



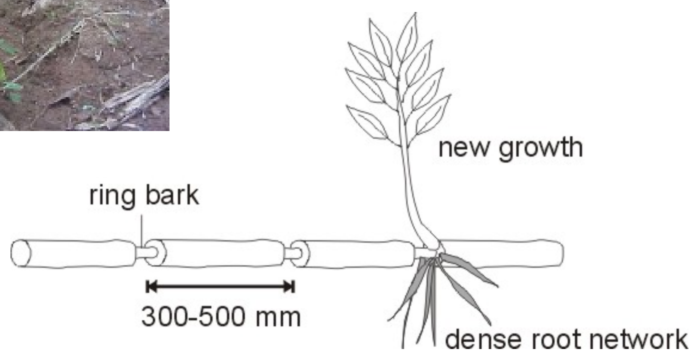
On steep hillsides, non-woody annual crops (vegetables, root crops, bananas) should be intercropped with tree crops, augmented by grass barriers to armour the slope and trap sediment moved in surface runoff. Grass barriers also assist in maintaining the integrity of drainage works. Lateral drains are installed along the contour and drain into collector drains installed at the margin of the cultivated beds for transport of runoff downslope. Interceptor drains are usually larger drains installed at the head of the slope to evacuate runoff upslope of the cultivated area. The configuration of soil conservation measures in an area will vary depending on site conditions and it is recommended that technical staff form the Agricultural Engineering Services Division of the Ministry of Agriculture provide assistance in assessment, planning and installation.

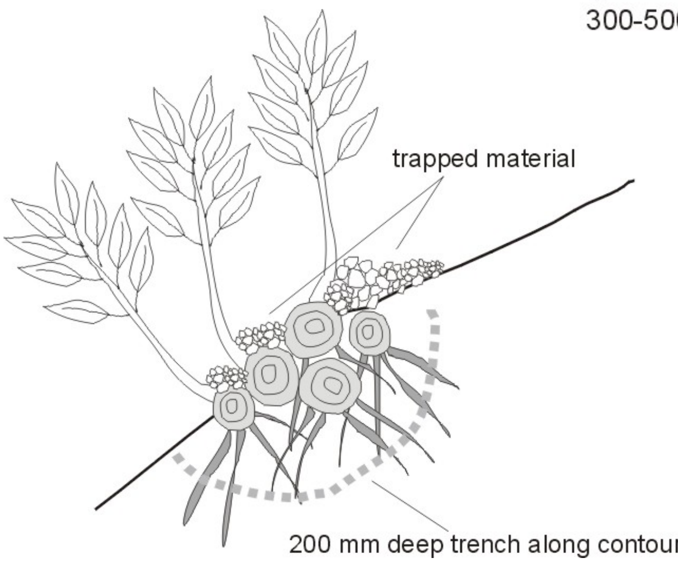
B. Live mini check dams: These are installed within collector drains and gullies to decrease the velocity of runoff downhill in order to minimise erosive force and serve to trap sediment before discharge into the stream. These should be installed 2 to 3 m apart. Common materials recommended include gliricidia and bamboo.



C. Wattles (fascines): A wattle or fascine is a bundle of live woody stems which, when placed along the contour in direct contact with the ground, propagates to produce a dense hedgerow. This measure serves to arrest surface wash of eroded material upslope behind the wattle. A variety of plant material can be used; gliricidia and bamboo among the species that can be easily used for this purpose. Wattles have been installed along the main river at Talvan as a frontline defence to reduce sediment wash from adjacent cultivations.

Gliricidia wattle installed under banana cultivation at Talvan in alignment with the riving bank





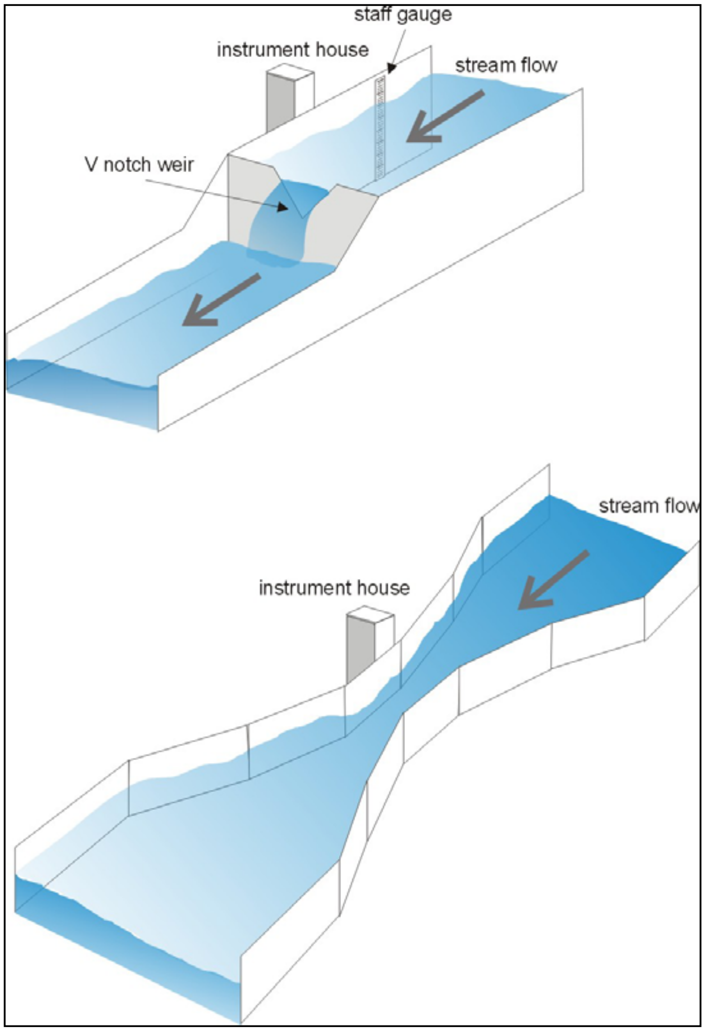
Recommended tree crops and agronomic specifications (Source: HTS 1997)

Crop	Years to bearing	Spacing (m)	Density (plants/ha)	Target yield (t/ha)	Input requirement	
					Fertilizer	Pesticide
Cocoa	4	3x3	1,111	1.0 – 1.8	mod	mod-high
Mango	5 - 9	8x10	125	12 - 18	mod	mod
Breadfruit	3 - 6	10x12	83	50 - 80	mod	v. low
Avocado	5 - 6	7x12	119	7 - 8	mod	low
Citrus (g. fruit)	4	7x10	143	10 - 15	mod-high	mod-high

Appendix 4: Hydrologic monitoring

The following are suggested stream monitoring measuring devices that can be installed at the watershed outlet, just upstream of the water intake. Weirs and flumes are examples of ‘primary devices’ that are installed within the river channel. They are constructed to precise specifications such that the stream flow level through the device is a direct function of discharge. Mechanical or electronic sensing equipment (known as ‘secondary devices’) can also be installed within these primary devices to record and log the flow rate. There are a variety of texts and internet online sources available on the subject. Material presented in this study was derived from *Isco Open Channel Flow Measurement Handbook*, Grant and Dawson (1997).

A. Primary measuring devices



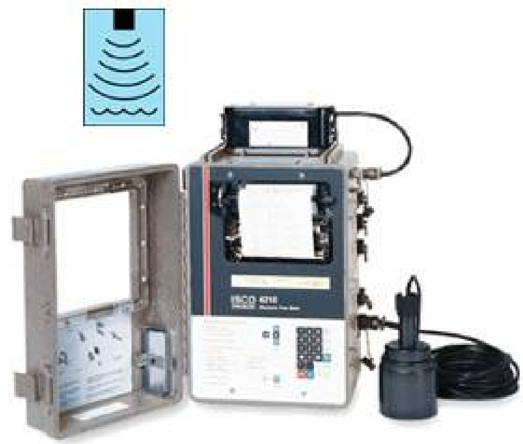
Weir: These may be of different configurations depending on the shape of the opening through which the water flows. Weir types include rectangular, V-notch (triangular), trapezoidal, etc. The flow rate can be measured by reading the water level from a staff gauge mounted on the wall of the weir structure or derived from a recording device that automatically logs discharge. Weirs are relatively inexpensive to install but must be maintained to reduce build-up behind the dam wall.

Flume: These may be of different configurations depending on the shape of structure. The channel base of the flume must also be constructed. Flumes are generally more expensive to construct, but have the advantage of being self-cleaning owing to the constriction of the flow through the structure. Secondary devices may also be installed.

B. Secondary measuring devices

There are various types of secondary devices that are commonly used. Pressure transducers are submerged in the flow and measure discharge based on the pressure exerted by the water volume in the channel stream. Float-operated flow meters utilise a float within a stilling well which translates to a recording of height of flow and discharge.

Ultrasonic sensors are non-contact devices. They are mounted above the flow stream, and transmit a sound pulse that is reflected by the surface of the flow. The elapsed time between sending a pulse and receiving an echo determines the level in the channel. This sensor requires minimal maintenance since it does not contact the flow and is not affected by suspended solids or other pollutants in the flow (source: ISCO Product Website at htttp://www.isco.com/).



For monitoring the Talvan catchment an ultrasonic sensor is recommended.

C. Water sampling devices

There is a variety of automatic pumping samplers that can be programmed to extract water samples from the stream flow, either on a time-based interval or on flow-paced intervals (usually to coincide with runoff events associated with rainfall). Samplers like the one illustrated (ISCO sampler at right) are outfitted with a removable bottle chamber that rotates to obtain sequential samples. The sampler is usually installed, along with the flow meter instrumentation, in the equipment shed adjacent to the weir or flume.