SUPPORTING REPORT

PART H

FOREST AND SOIL EROSION

THE STUDY ON WATERSHED MANAGEMENT AND FLOOD CONTROL FOR THE FOUR MAJOR VITI LEVU RIVERS IN THE REPUBLIC OF FIJI ISLANDS

SUPPORTING REPORT
PART H, FOREST AND SOIL EROSION

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

B/C	: Benefit Cost Ratio
BOD	: Biological Oxygen Demand
COD	: Chemical Oxygen Demand
D&I	: Drainage and Irrigation Division, MAFF
DO	: Dissolved Oxygen
DOE	: Department of Environment, MUDHE
DOF	: Department of Forest, MAFF
EIA	: Environmental Impact Assessment
EIRR	: Economic Internal Rate of Return
FAO	: Food and Agriculture Organization of the United Nations
FEA	: Fiji Electricity Authority
FMS	: Fiji Meteorological Service, MTCA
FSC	: Fiji Sugar Corporation
GDP	: Gross Domestic Product
GIS	: Geographical Information System
IEE	: Initial Environmental Examination
INR	: Institute of Natural Resources
JICA	: Japan International Cooperation Agency
MAFFA	: Ministry of Agriculture, Fisheries, Forests and ALTA
MAFF	: Ministry of Agriculture, Fisheries, and Forests
MPWIT	: Ministry of Public Works, Infrastructure and Transport
MRD	: Mineral Resources Department
MTCA	: Ministry of Tourism and Civil Aviation
MUDHE	: Ministry of Urban Development, Housing and Environment
NLTB	: Native Land Trust Board
NPV	: Net Present Value
PWD	: Public Works Department, MPWIT
SOPAC	: South Pacific Applied Geoscience Commission
SPC	: South Pacific Commission
SS	: Suspended Solids
TH	: Total Hardness
TN	: Total Nitrogen
TOR	: Terms of Reference
TP	: Total Phosphorus
UNDP	: United Nation Development Programme
USP	: University of the South Pacific
WHO	: World Health Organization

CHAPTER 1 FACTORS CAUSING SOIL EROSION

1.1 Topographic Features

Topographic features are one of determinant factors of soil erosion. The sources of target rivers are Nadrau plateau and Rairaimatuku plateau whose altitude is more than 900 m above the sea level.

Slope of riverbeds is very gentle from the mouth to the middle reach and abruptly gets very steep in the upper reach as shown in Fiugure-H1.1 (longitudinal profiles of four major rivers). At river mouths of Rewa and Ba rivers, large deltas are formed where agriculture is the main land use. River mouths of Nadi and Sigatoka rivers are affected by the tidal current and the deltas are less developed. Alluvial land is formed along Sigatoka river in the middle reach where vegetables are farmed. The topography is generally undulating except the delta and the alluvial land of Sigatoka river, and steep lands (slopes greater than 18°) form 67 % of Viti Levu island. Thus, much of the surface runoff after heavy rain over steep slopes increase eroding effect remarkably. Steep slopes also lead to frequent landslides after heavy rain.

1.2 Climate

From the view point of erosion, the most important climatic factors are wind and rainfall. Viti Levu island is divided into two major rainfall zones by Nadrau plateau. One is the south-eastern part having the trade wind all year round known as the "wet zone" and another is the north-western part known locally as the "dry zone". According to isohyetal map of mean annual rainfall (refer to Part C "Meteorology and Hydrology" of Supporting Report), most part of the Rewa watershed is in "wet zone". In particular, a part of watersheds of Waimanu and Waidina tributaries in south has more than 4,000 mm of annual rainfall. The area around Waidalau creek in north belongs to the "dry zone". Most parts of the Sigatoka, Nadi and Ba watersheds are in the "dry zone".

1.3 Soil

Erodibility degrees of different soil classes are shown in Figure-H1.2 based on the GIS data of soil type and soil erodibility provided by the Management Services Division. "Erodibility" here referred is the erodibility determined by natural properties of soil. However, soil type comes to change for a long period resulting from the topography and land use. For example, Latosolic Soil, which is the tropical soil formed after most of the dissolved has been taken away due to weathering for a long time, turns into Ferruginous Latosol by accumulation of the undissolved like iron on the surface because of much more intense weathering.

Soil erodibility of the Rewa watershed is generally "high". The erodibility of the grassland and the beef scheme area along Wainibuka river in the upper reach, is "severe". The erodibility of deltas is "low" to "moderate". Soil erodibility of the Sigatoka watershed is "severe" except the low land along the river and a part of Nausori highland. Also that of the Nadi and Ba watershed is "severe" except the plain and a part of the forest.

Detailed soil classification was made in "Soil Map of Fiji (1961)", based on soil erodibility set by Land Use Section, MAFFA, as follows:

Table-III.1 Soil Erodibility by Type of Soil

Soils	Soil erodibility
Recent Soils from Coastal Sands	moderate
Recent Soils from Alluvium	low
Nigrescent Soils from Limestones	high
Nigrescent Soils from Other	severe
Latosolic Soils	moderate
Humic Latosols	high
Ferruginous Latosols [Talasiga]	severe
Red-yellow Pedsolic Soils	high
Gley Soils	moderate
Organic Soils	severe
Saline Soils of the Marine Marsh	high

Source: Management Services Division (Department of Forestry)

1.4 Land Use

Land use is another factor which determines the volume of soil erosion. For example, forests generally enhance the effective role to control erosion by the following mechanism compared with cultivated land, bare land or grassland. And also forests contributes to control of landslide.

- effect to reduce impact of raindrops on the soil by litter
- effect to control formation of rill or gully by the network of litter and roots
- effect to absorb the first stage raindrops by crown , litter and boles
- effect to form soil which has the high capability to hold water

1.5 Forest

Man-caused soil erosion in the forest is made by commercial logging, logging for conventional and subsistence farming or unintentional and intentional fire, which expose the soil surface to direct raindrop and disturb the soil surface by plowing. The quantity of soil erosion will increase by the time that the forest will be recovered.

Pine plantation stations have been established in the grassland widely extended over the "dry zone" of Viti Levu, and reforestation with mahogany has been implemented for the logged out areas in the "wet zone". Nevertheless, the total area of the forest has been steadily decreasing. The reason is probably due to logging for conventional and subsistence farming and unintentional or intentional fire, though little is known about the actual conditions. The most remarkably decreasing area of forest is the divide of the Sigatoka and Ba watersheds. The details of the forest are described in the Chapter 5.

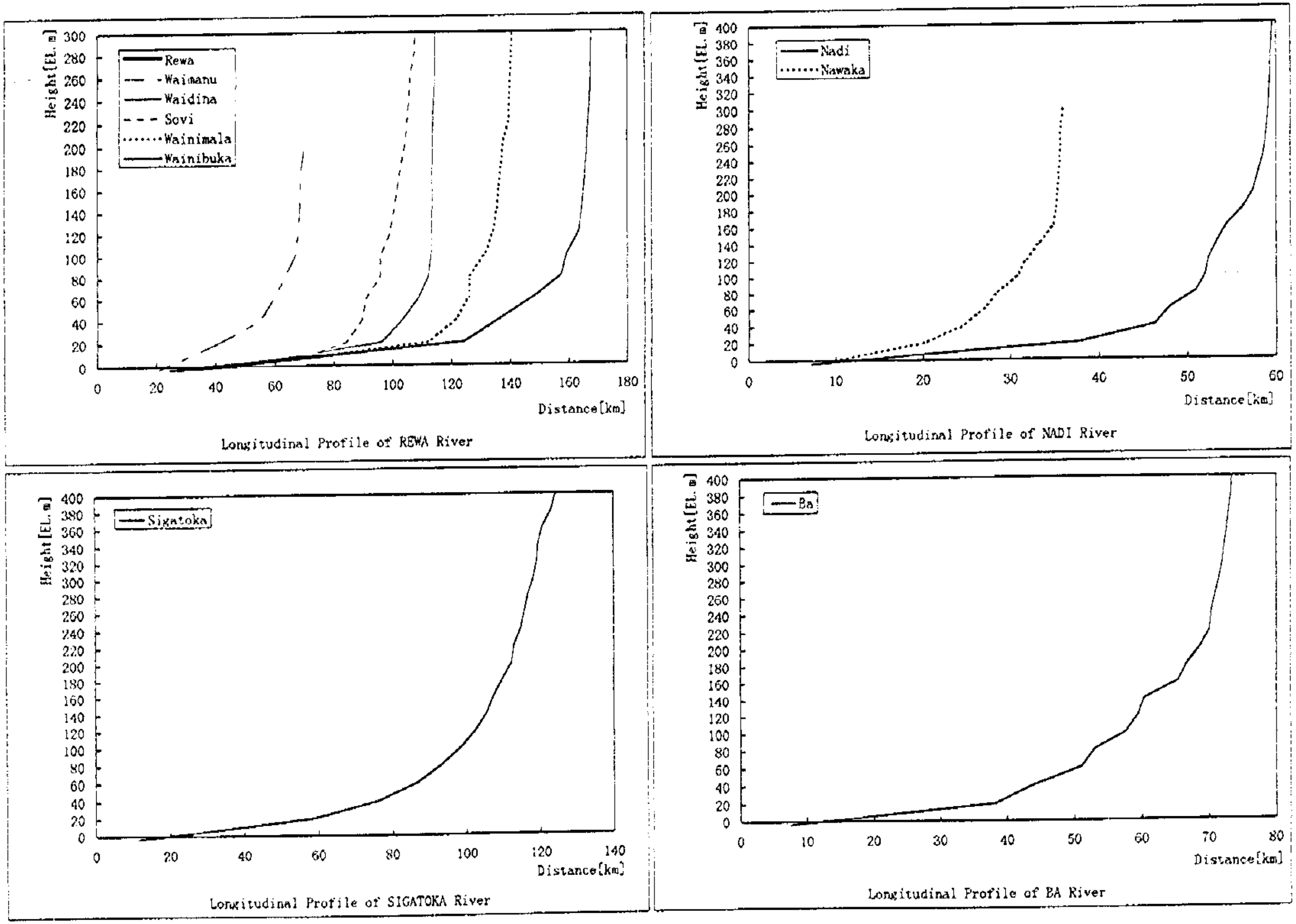


Figure-H1.1 Longitudinal Profiles of Four Major Rivers

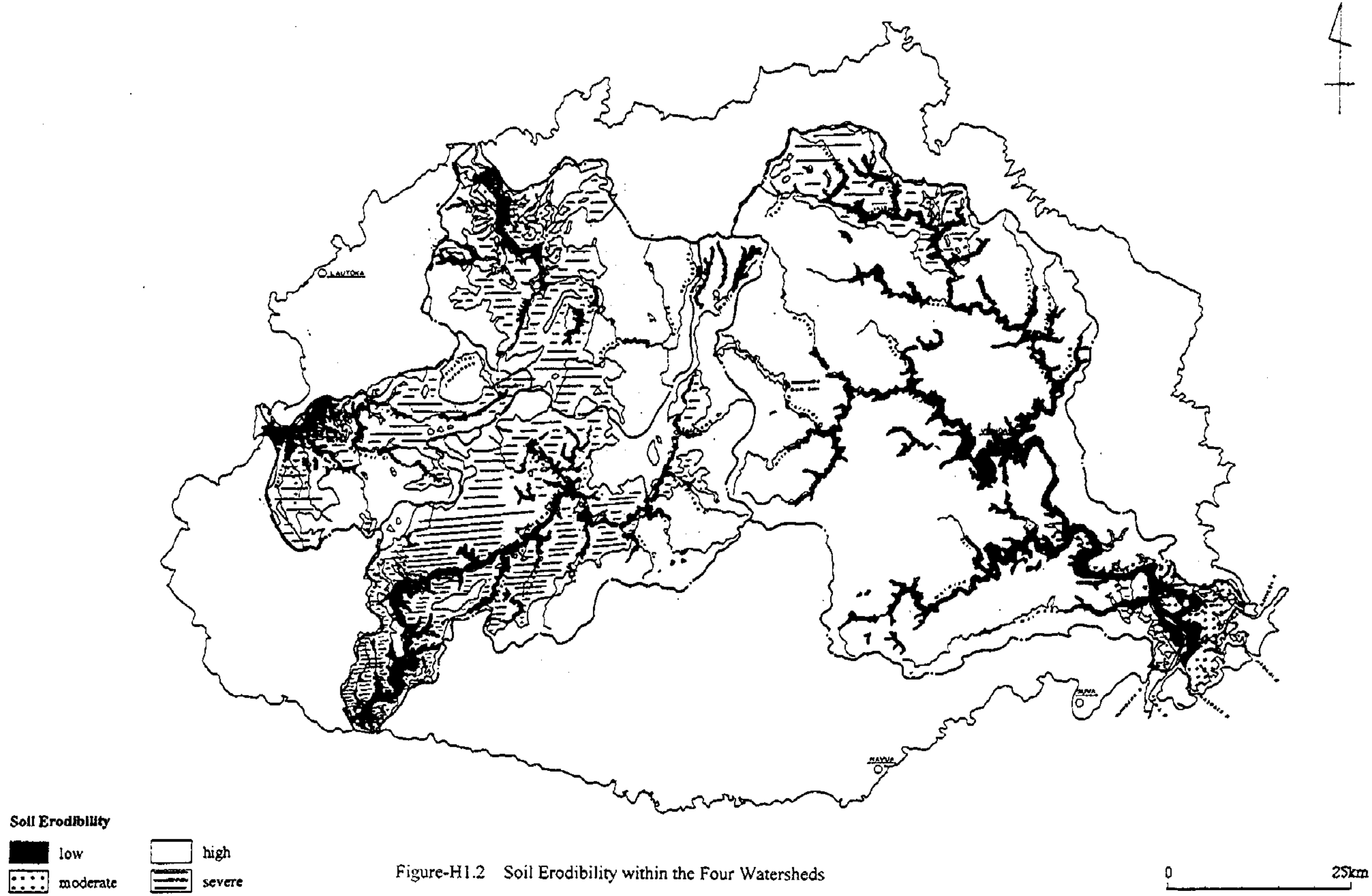


Figure-H1.2 Soil Erodibility within the Four Watersheds

Source: Management Service Division (Department of Forestry)

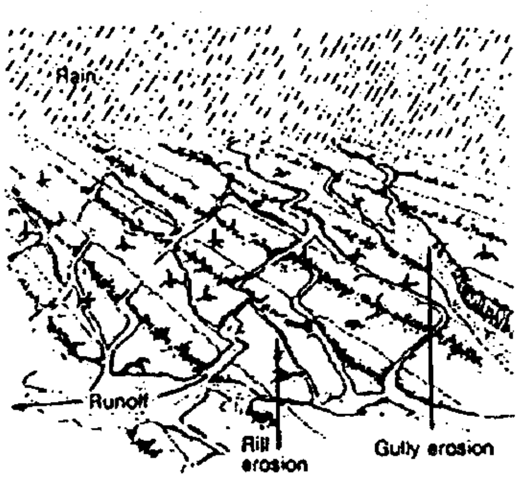
CHAPTER 2 FACTORS AND PRESENT CONDITION OF SEDIMENTATION

Factors causing sedimentation are largely classified into erosion and landslide.

"Erosion" is wearing away of rocks or soil by the action of water, ice, or wind. Erosion by water is classified into sheet erosion, rill erosion and gully erosion (Figure-H2.1). Stream-bank erosion is placed between landslide and erosion.

"Landslide" is the sliding of a large mass of rocks and soil down the slope. Landslide is classified into several types by material and speed of movement as shown in Figure-H2.2.

These are the phenomena caused naturally by weathering of rocks and rainfall, while they are expanded and escalated by the human action such as logging, development of farms and occasional burning.



Source: Government of Fiji and IUCN (1992)
Figure-H2.1 Form of Erosion

2.1 Landslides

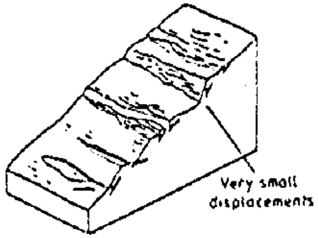
Landslides in Viti Levu are caused mainly by cyclones and storms. The records of landslides are limited to the disasters caused by landslides. Although there is no study on the quantitative relation between rainfall and soil movement, it is considered that landslides are causes for sedimentation of rivers, especially in the wet zone.

Figure-H2.3 shows location of the landslides by the storm in April 1986 in the watershed of Waimanu river which is a tributary of Rewa river. The landslides occurred even in forests and much of landslides were observed near farmlands. Number of the landslides amounts to 620 and 570,000 m^3 of soil was estimated as flowed down.

1. SLIDES

Movement is along continuous shear surface(s) within the soil or rock substance or along existing defects.

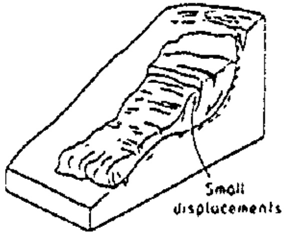
VERY SLOW MOVEMENT



SOIL CREEP

a. Shear failure and plastic deformation along numerous small surfaces.

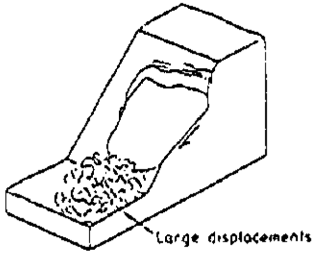
MODERATE TO SLOW MOVEMENT



SLUMP

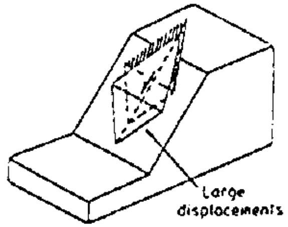
a. Initial shear failure along concave - upwards surface.
b. Material not greatly deformed at head, but approaches plastic deformation at toe.
c. Backward tilting at head.

RAPID MOVEMENT



PLANE FAILURE

a. Initial shear failure along planar surface (defect such as a joint)
b. Failure direction is true dip of surface.



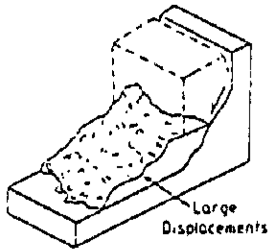
WEDGE FAILURE

a. Initial shear failure along two intersecting surfaces (defects such as joints).
b. Failure direction is line of intersection of two surfaces.

2. FALLS

Soil or rock mass collapse along steep embankment or cutting. Movement is predominantly by free fall and rolling. No sliding surface forms.

RAPID MOVEMENT



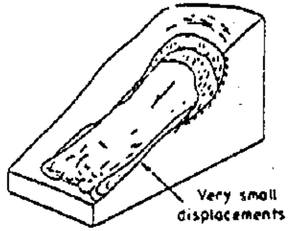
FALL

a. Failure involves collapse of near - vertical soil or rock mass due to reduction in shear strength or increase in shear stress and is often preceded by the development of extensive tension cracks.

3. FLOWS

Movement of soil or rock particles resembles that of a viscous fluid. Slip surfaces are destroyed by the moving mass.

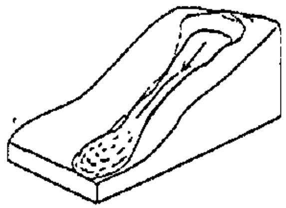
VERY SLOW MOVEMENT



EARTHFLOW

a. Initial shear failure is along circular, planar or irregular surface.
b. Basal and lateral shear/striated surfaces are typical.
c. Plastic deformation occurs at the toe.

RAPID MOVEMENT

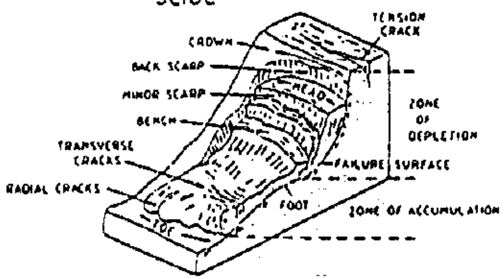


DEBRIS FLOW

a. Initial shear failure is along circular, planar or irregular surfaces typically during wet periods.
b. The mass deforms plastically and liquefies as it mixes with rainwater and moves down slope.
c. The mass is deposited at reduction in slope.

LANDSLIDE TERMINOLOGY

SLIDE



LANDSLIDE: Downward and outward movement of slope forming materials composed of natural rock, soils, artificial fills, or combinations of these materials (Varnes 1958)

CROWN: Slope immediately behind the landslide, undisturbed apart from tension cracks.

BACK SCARP: Steep surface in undisturbed ground left exposed by movement of the landslide; the exposed part of the basal failure surface.

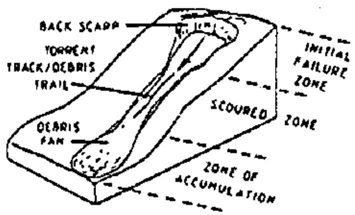
HEAD: The upper part of the landslide along the contact with the main scarp.

MINOR SCARP: Steep surface(s) within landslide formed by differential movement within sliding mass.

FOOT: Intersection between lower part of failure surface and original ground surface.

FLANK: Side of landslide

FLOW



FAILURE SURFACE: Single or composite surface along which the initial shear failure occurred.

TENSION CRACK: Defect opened by tensional failure during differential movement within or adjacent to the landslide.

BENCH: Surface within slide bound by scarps.

TOE: Leading edge of the moving mass.

DEBRIS: Soil, earth and vegetation forming the slide or flowing mass.

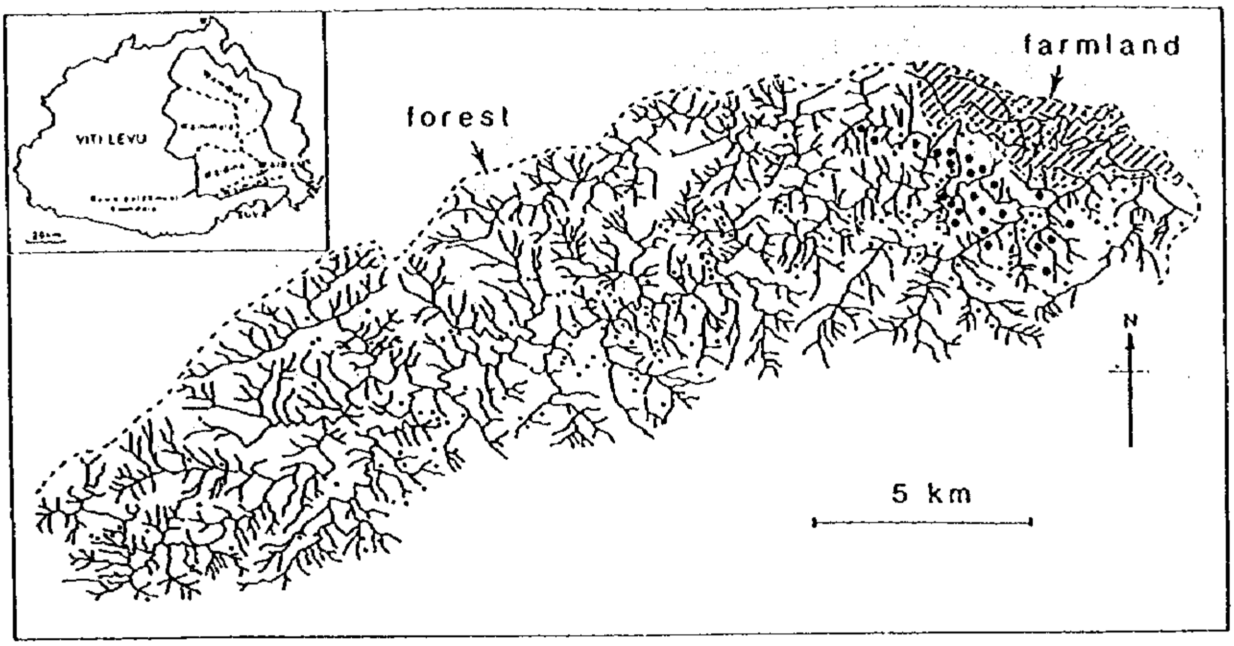
TORRENT TRACK / DEBRIS TRAIL: Track along which sliding or flowing mass moves down slope; generally scoured with scattered debris.

DEBRIS FAN: Debris deposited at or near base of slope.

SCAR: Bare stretch of landscape left at source of landslide; often also taken to include torrent track.

Source: T. Lawson (1993)

Figure-H2.2 Landslide Classification and Terminology



Notice: Small dots indicate single landslides; large dots indicate a cluster of ten landslides.
Source: Patrick D. Nunn (1990)

Figure-H2.3 Distribution of Landslides in the Northern Part of Waimanu Watershed by Rainstorm in April, 1986

Major disasters by landslides are shown in Table-H2.1 indicating the date, the cause of landslide and the location.

Table-H2.1 Major Landslides

Date	Cause	Place
21-27 February 1931	Hurricane	Western Fiji, Lautoka
6 February 1952	Hurricane	Namosi
14 September 1953	Earthquake	West-Southwest of Suva
5 May 1979	Storm	Southeastern Fiji
1-5 April 1980	Cyclone Wally	Whole Fiji
24 November 1980	Storm	Serua Hills (Korovou)
16 June 1984	Storm	Namosi Road and Talenaua
16-21 April 1986	Storm	Southeastern Fiji

Source: T.Lawson (1993)

2.2 Soil Erosion

Although only a little data is available on soil erosion, the relation between soil erosion and land use has been studied.

2.2.1 Forest

In Fiji emphasis in studies on soil erosion is placed on prevention of the soil loss from cultivating land. Therefore, there is no experimental study on soil erosion in forests which soil loss is considered small and economic loss does not occur. Change of soil erosion in the cycle of logging, planting and reforestation is left unknown.

Morrison (1981) estimated the soil loss in the typical closed rainforests as 14.6 ton/ha/year in the eastern part of Viti Levu island based on the Universal Soil Loss Equation.

Glatthaar (1988) estimated the average soil loss in the Waimanu watershed at 50 ~ 55 ton/ha/year, where shift to cultivation and logging was progressing, using the data of sediment load of Wainamu river.

Nelson (1987) estimated the soil loss of each land unit classified in the Rewa and Ba watersheds using the Universal Soil Loss Equation (Table-H2.2). The soil loss was comparatively large in lands for grazing and sugarcane farming in the Wainibuka watershed located in the Rewa watershed, and was also large in lands for commercial and subsistence farming in the river valley and lowland of the Wainimala and the Waidina watershed located in the Rewa watershed. The soil loss of most land units in the areas covered by forests was estimated at less than 13 ~ 15 ton/ha/year, the permissible range not to damage productivity of land in the tropical zone. The land in the Ba watershed had high level of soil loss except the plain and the stream terrace lands. The loss of the U5 unit was estimated at 50.9 ton/ha/year, where Lololo Pine Plantation and grazing land formed 75 % and 25 % of the total area respectively. The average soil loss of the Ba watershed was 68.3 ton/ha/year.

Well developed forests work suitably for soil erosion reduction as mentioned before. Therefore, main factors of sedimentation from the forest area are landslide, mud flow and river erosion. For example, in the Waimanu watershed, which Glatthaar (1988) roughly calculated the soil loss as 50 ~ 55 ton/ha/year, forests have been gradually disappearing by rapid cultivation development for commercial farming production such as ginger. On the other hand, mean annual rainfall in the upper reach of the Waimanu is more than 3,500 mm and this large rainfall causes many landslides as shown in Figure-H2.3.

2.2.2 Ginger Cultivation Area

Ginger cultivation is concentrated in the Rewa river valley and lowlands between Wainimala and Waimanu rivers. Ginger is suitable to be cultivated in well drained slopes and planted alternately with dalo (taro) and cassava intervened in by a fallow in most cases. The ginger cultivation on slopes causes severe soil erosion which leads land degradation and losses in agricultural productivity. Farmers give up the low productive land and start to cultivate a new land in a nearby forest causing deforestation; however, the figures of extent of deforestation is unknown. To cope with this problem, a experimental study has been carried out by the Land Use Section of Koronivia Research Station and the Agroforestry Section of the Extension Division, with such measures as *vetiver* grass or pineapple hedgerow or *calliandra* inter-planting.

Table-H2.2 (1/2) Characteristics of Land Units

Rewa Watershed's Land Unit		Location	Land Use	Area (ha)	Soil Loss (t/ha/yr)	Sediment Delivery rating	Landslide hazard	Slope gradient, degrees
N1	Main Ridge Crests	Extreme North end of Watershed. Head of Wainibuka.	Little use. Some areas planted with pine. Cattle grazing on lowerslopes. No villages.	9,113	31.1	Moderate	Moderate	20-25
N2	Basin Hill Slopes	Upper Wainibuka Valley.	Mainly grazing with small spots of subsistence agriculture in West. Sugarcane in east end of valley.	18,053	82.0	Low	Low	10-20
N3	Basin Lowlands	Upper Wainibuka, Savusavu - Vunisea area.	Most of population, villages, roads in upper Wainibuka are here. Dominant commercial crops including sugar cane but gardens also.	4,933	12.0	High	Low	2-5
N4	Parallel Ridge and Valley System	Southern tributaries of Lawaki and Adjacent Wainibuka areas.	Subsistence agriculture and tree cutting for local use.	20,024	20.6	Moderate	Low	10-20
N5	Bottom land terraces and toe slopes	Lawaki and Upper Wainibuka River bottoms.	Commercial, subsistence crops, grazing.	3,407	16.3	High	Low	2-5
N6	Ridge Systems	Mainly in Wainiboa, Waisomo creeks drainages.	Subsistence farming (20 %). Some commercial ag. near villages < 3 %.	13,419	61.3	High	Moderate	5-30
C1	Low Ridge system	South central part of Rewa catchment, Waimanu to Wainimala.	Forest -90 %, Subsistence agriculture 10 % along river ways. Terrace of commercial agriculture in Waimanu area.	60,843	13.2	High	High	15-40
C2	High Ridge Crests	Ridge between Waindina and Wainimala catchments.	Natural forest, brush.	6,878	7.2	Moderate	High	25-35
C3	Mountain Ridges	Mendrausatha and Korombasabasanga Ranges between Wainimala and Waindina catchments.	Forest with subsistence agriculture in less than 2 percent of the area.	16,263	8.7	Moderate	Moderate	25-80
C4	Plateau Breaklands	Margin of Rairaimatuka - Nadarau plateaus.	Subsistence Ag. = 10 %; Lightly used open forest = 90 %.	13,768	19.7	Moderate	Low	5-30
C5	Main Canyon Slopes	Along Middle Wainimala Area.	Subsistence Ag. = 20 %; Grazing = 10 %; remainder is in forest.	5,753	35.6	High	High	20-35
C6	Bottom Alluvial Lands	Mostly on Middle and Upper Wainimala.	Village sites on higher terraces, pasture on lower terraces and in flood plains. Subsistence agriculture on toe slopes.	7,687	2.4	High	Low	1-2.5
L1	Low Relief Dissected Surface	Both sides of Rewa River Valley including Lomaivuna Agricultural Subdivision.	Commercial agriculture dominates - Subsistence agriculture is minor.	10,976	15.4	Low	Low-mod	10-20
L2	Deeply Dissected Plain	Rewa River Valley and Lowlands between Wainimala and Waindina Rivers.	Commercial agriculture = 25 %; Subsistence agriculture = 20 %; Forest = 50 %.	25,631	153.0	High	High	20-40
L3	Moderate Relief Ridge Systems	In the "Y" made by the Lower Wainibuka and Wainimala.	Subsistence agriculture = 5 %.	29,634	14.3	High	Moderate	10-35
L4	Upland Surface	Isolated area forming head of Waisomo, Waikonavono tributaries of the Wainimala.	Subsistence agriculture = 5 %; Forest = 95 %.	5,898	8.1	Low	Low	5-15
L5	Rewa Valley and Terrace Lands	At Junction of Wainimala and Wainimbuka Rivers and along Rewa River.	Commercial crops = 50 %; Pasture = 20 %; Shell fishing.	9,920	9.8	High	High	0-20
P1	Steep Ridge Crests	Centred in Tominivi (Mt. Victoria).	Currently in forest.	9,144	4.9	Low	High	30-75
P2	Low Relief Uplands	Rairaimatuku and Nadarau Plateau.	Little use. Pastures and subsistence farms along openings. Some logging in past.	8,115	1.1	Low	Low	3-15
P3	Dissected Uplands	Tominivi areas of Rairaimatuta Plateau.	Closed forest, minor subsistence agriculture.	9,466	2.7	Low	Low	3-20
Total				288,925	-			
Average				-	32.3			

Source: Nelson (1987)

Table-H2.2 (2/2) Characteristics of Land Units

Ba Watershed's Land Unit		Location	Land Use	Area (ha)	Soil Loss (t/ha/yr)	Sediment Delivery rating	Landslide hazard	Slope gradient, degrees
L10	Flood Plain	Low reach Ba River Valley.	90% cultivated mainly sugarcane.	1,711	6.8	High	Low	< 2
L11	Lowland Hills	Lower Ba Valley.	Commercial agriculture with emphasis on sugarcane.	10,732	112.0	Moderate	Low-mod	5-17
L12	Stream Terrace Lands	Adjacent to Lower Ba River and its Main tributaries.	Commercial crops.	3,504	10.4	Low	Low	0-4
L13	Foot Slopes	East and West Margins of Ba Valley.	Grazing, commercial agriculture in valleys.	4,716	84.5	Moderate	Low	7-25
U1	Ridge Lands	The Ridges of the Sides and Upper half of the Ba drainage.	Subsistence agriculture on lower slopes. Some areas grazed but most not used.	48,542	54.0	Low	Moderate	15-32
U2	Basin Floor	Valley of Navuniyasa Creek near Navala.	Grazed grassland with subsistence and commercial agriculture in drainage ways. Developed is in pockets adjacent to road.	2,855	57.7	Low	Moderate	5-30
U3	Upper Ridge Slopes	On the Edge of Eastern part of the Watershed. Particularly in the Nanoko and the Nadarivatu areas.	Forestry 70%; Subsistence agriculture 5%; Remainder is forest.	12,920	100.1	High	Moderate	10-30
U4	Ridge and Basin Land	Namau area Southeast of Ba.	Commercial agriculture 30%; Grazing 40%; Wasteland 30%.	2,879	146.5	Moderate	Moderate	20-30
U5	Lower Ridge Slopes	Main Ridge on the West side of the Lower Ba Valley.	Forestry 75%; Grazing 25%	4,806	50.9	Moderate	Moderate	10-25
Total				92,665	-			
Average				-	69.0			

Source: Nelson (1987)

The soil loss in ginger farm is estimated by an empirical method using the Universal Soil Loss Equation and by an experimental method analyzing the data of the experiment farms. Morrison (1981) estimated 85.7 ton/ha/year of the soil loss for the typical ginger cultivation in the eastern Viti Levu by the Universal Soil Loss Equation.

In the Waibau experiment farm in the Waimanu watershed, soil loss of ginger, dalo, cassava and fallow rotation has been measured with the following cultivation method;

- Farmer's practice
- Farmer's practice, but with pineapple contour row
- Farmer's practice, but with *vetiver* grass contour row

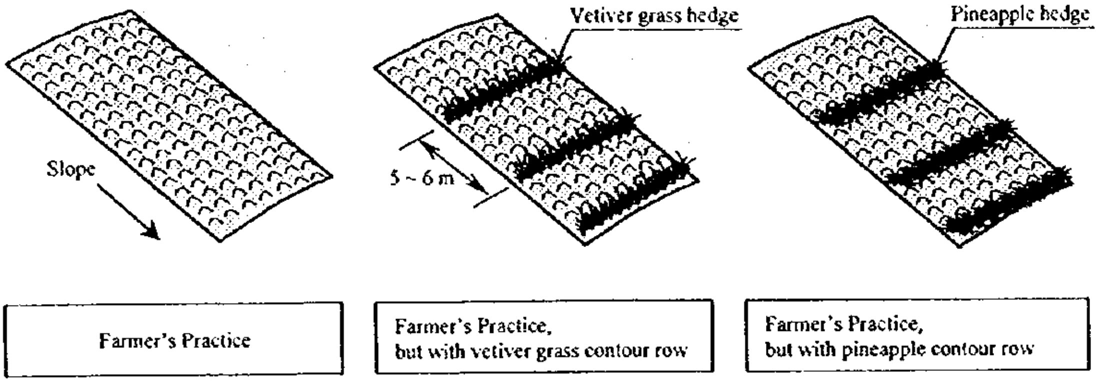


Figure-H2.4 Cultivation Method in Waibau Experiment Farm

Soil loss by crop and by cultivation method is shown in Table-H2.3. Soil erosion can be drastically reduced by arranging the contour row of *vetiver* grass and pineapple in a cultivating land compared with farmer's practice. Techniques to reduce soil erosion in a cultivating land are almost established. However, extension and training to farmers has just started.

Table-H2.3 Soil Loss Measured in Waibau Experiment Farm

(ton/ha/year)

	1991 - 1992	1992 - 1993	1993 - 1994	1994 - 1995		Average
Ginger/Vetiver Contour	0.27			0.42		0.35
Ginger/Farmer's Practice	0.53			22.60		11.57
Ginger/Pineapple Contour	0.11			0.64		0.38
Cassava/Vetiver Contour		0.13	0.11	0.02		0.09
Cassava/Farmer's Practice		0.28	1.17	1.92	0.13	0.88
Cassava/Pineapple Contour		0.09	0.18	0.02	0.06	0.09
Taro/Vetiver Contour	0.08	0.13				0.11
Taro/Farmer's Practice	0.04	2.60				1.32
Taro/Pineapple Contour	0.04	0.21				0.13
Fallow/Vetiver Contour			0.14	0.31		0.23
Fallow/Farmer's Practice			0.61	0.66		0.64
Fallow/Pineapple Contour			0.06	0.88		0.47

Notice: Annual rainfall (1994 Aug. - 1995.Jul.) is 2584 mm
Source: Koronivia Research Station

2.2.3 Sugarcane Field

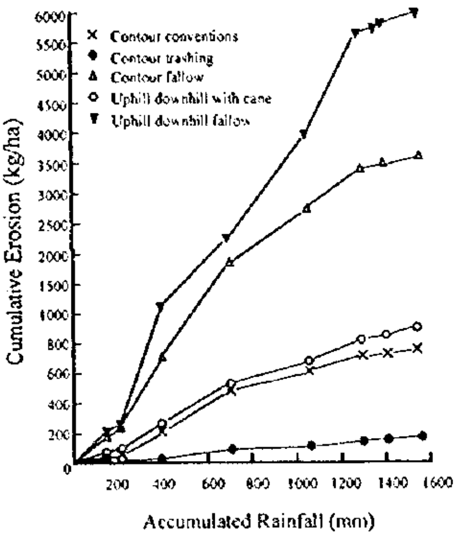
More than 70 % of the total land of 72,500 ha currently used for sugarcane cultivation in Fiji are hilly lands with slopes, steeper than 3 %. Soil loss from sugarcane cultivation on steep lands is expanding with increase of sugarcane production and development; however, the awareness of soil erosion by the farmers is generally low. In the cultivation lands on steep slopes, soil loss is so serious resulting in extension of abandoned land, but area of such lands is unknown. And burning after the harvest of sugarcanes causes the acceleration of weathering and soil loss.

Study on soil erosion in sugarcane fields and its reduction methods has a long history. In 1930's, contour cultivation had been studied in a demonstration farm, and in 1950's, Land Conservation Board has been established. First of all, mechanical method such as terracing was adopted but no result exists. Then the method to prevent soil erosion by the hedgerow of *vetiver* grass was employed but this was not accepted for the reason that the terraced fields by hedgerow made truck mobility in harvest season difficult.

At present, Fiji Sugar Corporation has been conducting an experiment for erosion control effectiveness by planting sugarcanes along the contour line and practicing a cane trash mulch along interrows in an experiment farm in Drasa Estate with good result. The method and its result are shown below.

1) Sugarcane was planted along contour and the inter-rows were left without cane trash mulch as conventional cultivation.
2) Sugarcane was planted along contour and the inter-rows were mulched with cane trash.
3) Furrow was made along contour but no crop was planted (bare soil surface).
4) Furrow run uphill and downhill, and sugarcane was planted in a conventional way without trash conservation.
5) Furrow run uphill and downhill, and no crop was planted (bare soil surface).

As a result of the experiment, the method 2) was proved as most effective as shown in Figure-H2.5. Most soil loss occurred by heavy rain storm in the rainy season.



Source: Fiji Sugar Corporation (1994)

Figure-H2.5 Relation between Accumulated Rainfall and Cumulative Soil Erosion in 1993/94 Crop Season at Drasa Estate

At present, *vetiver* grasses is not applied in sugarcane fields and no contour cultivation method or cane trash mulch are taken for the reason that farmers are not educated enough for the awareness of importance of soil conservation, and FSC considers that farmers are only contractors to supply sugarcane and soil conservation should be taken by each farmer.

Sugarcane fields tend to move to steeper slopes for the reason of urbanization, increase of sugar consumption and increase of the number of farmers engaged, which causes the hindrance of soil erosion measures.

The soil loss in sugarcane farm is also estimated by an empirical method using the Universal Soil Loss Equation. Morrison (1981) estimated at 112.0 ton/ha/year of soil loss for the typical sugarcane cultivation in low land hills in the Ba (Table-H2.2 (1/2)).

2.2.4 Grassland (include Grazing Area) and Burning

Grassland results from various factors such as cultivation, grazing, hunting, intentional or unintentional fires, and widely extends in "Dry zone" with hard condition of forest recovery. As further soil erosion advances, all fertile top soil is flow out, resulting in bared stone and parent material.

According to Peter Drysdale, the Land Conservation Board, sugarcane fields with a steep slope leased to a farmer turn into a grassland with the following process.

- First year of farming : Reeds and bushes extends in large part of uncultivated lands covering top soil except for some ridges.
- After 10 years : Sugarcanes are planted except for part of the valley where bushes are still growing.

- After 20 years : Cultivation is impossible because of soil loss on steep slopes. Sugarcane cultivation can be continued in the valley where soil eroded from the slopes is deposited.
- After 40 years : Soil loss area is bigger and the area possible for sugarcane cultivation is smaller.

Leone (1992) studied the factors of degradation in Toge-Naqerelevu grazing area in the Ba watershed qualitatively. He concluded that the high rate stock of goat and cattle, and reiterated burning resulted in degradation of Toge-Naqerelevu area. He also pointed out that the grazing practiced there should not be agriculturally sustainable and not economically feasible.

Weathering of soil and parent material is accelerated by burning and the soil erosion takes place successively. Jai S. Gawander (1993) described that burning is an old practice referring the record dated 1840 regarding the burning in the dry zone. The reason of burning is to burn the cane trash, cultivation for subsistence, to grow a new graze, hunting or sometimes pleasure. And no plan is made before burning, which causes unnecessary burning of plants or trees. Young trees in the boundary of grassland and forests are so weak at fires that forest area is gradually smaller and smaller at every fire, while grassland become bigger. The problems of repeated burning at the same site are not only soil loss but also slope instability. Cochrane (1969) gave an example of a regularly burned area of 243 ha at Tubenasolo in the western Viti Levu where 20 landslides occurred a few weeks after burning.

Actual conditions of land use and erosion of grassland are almost unknown. No quantitative experiment or observation of soil loss in grassland has been carried out and there is only assumption by the Universal Soil Loss Equation. Nelson (1987) presumed the soil loss from several types of land in the Ba watershed where most part is grassland. As shown in Table-H2.2 (2/2), its soil loss from Ridge Lands (U1), Basin Floor (U2) and Ridge and Basin land (U4) is 54.0, 57.7 and 146.5 ton/ha/year, respectively.

To promote the land conservation measures in grassland, education and extension to landowners or people holding the rights to use lands are necessary, and an administrative organization by the government to formulate and manage a land use plan is indispensable.

2.3 River Bank Erosion

River bank erosion is caused by a torrent during flood. According to the Department of Environment, the recent flood in Nadi river causes river bank erosion. In Fiji, application of river bank protection is limited to the small area; however, since the residential area expands close to a river, its damage will be increased without countermeasure.

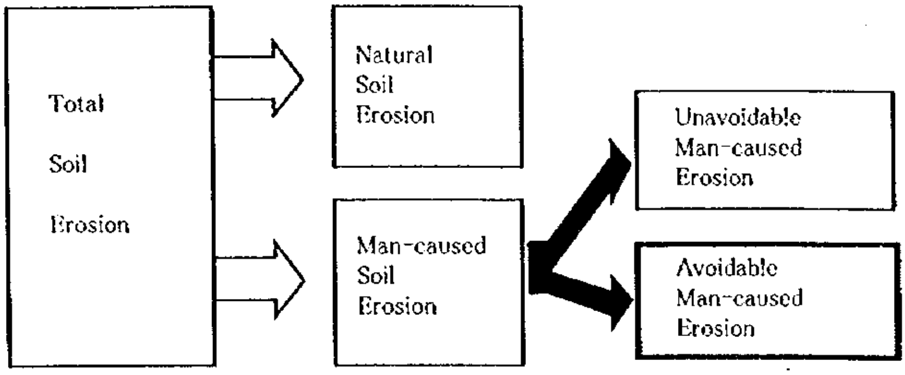
2.4 Factors of Sedimentation Studied for Planning

2.4.1 Landslide

Damages by landslides are classified into the direct human and physical damage near the site and the sedimentation to the downstream river channel. In this Study, sedimentation supplied to the lower reach was considered; however, the measures to landslide itself are not discussed here.

2.4.2 Soil Erosion

Figure-H2.6 (Nelson, 1987) shows a conceptual breakdown of total soil erosion to isolate the erosion which would be reduced by improved land use practices.



Notice: Figure is for illustrative purpose and is not intended to suggest quantitative relationships.
Source: Nelson (1987)

Figure-H2.6 Conceptual Breakdown of Total Soil Erosion

Sedimentation by "Total Soil Erosion" was considered in flood control plan and watershed management plan. "Avoidable Man-caused Erosion" was studied to propose the measures to control soil erosion as a part of the watershed management plan.

Factors inducing avoidable man-caused erosion are identified as follows. Although the factors of erosion include road construction and urbanization, the former does not contribute to increase in the total erosion because it is too small in area compared to the whole watershed, and the latter is not separately mentioned here because it causes reduction of forests and expansion of farming lands. Therefore, road construction and urbanization are excluded from the factors.

1) Cultivation, farming and grazing
2) Deforestation
3) Burning surface vegetation for grazing, farming, hunting, etc.

The problems caused by soil erosion and its runoff are shown below. "1)" includes river bank erosion and soil runoff caused by landslide.

1) Aggradation of river bed and frequent flood caused by soil sedimentation in a river course in the lower reach
2) Frequent flood caused by increase of maximum flow due to reduction of soil water retention capacity of watershed
3) Reduction of land productivity and soil fertility

2.4.3 River bank erosion

To reduce river bank erosion in a small or medium scale flood, making the green belt along the river (nonstructural measure) is effective, but for the target flood in this Study (20 year return period flood), structural measures, such as revetment works, are necessary.

Since sedimentation due to river bank erosion is considered relatively small compared to sedimentation induced by soil erosion and landslide, quantitative study of river bank erosion was excluded from the Study.

CHAPTER 3 ESTIMATE OF SOIL EROSION AND SEDIMENTATION

3.1 Estimate of Soil Erosion

Soil erosion from each watershed was estimated based on the soil loss study by Nelson (1987) which estimated the soil loss from each land unit in the Rewa and Ba watersheds (Table-H2.2). Nelson's study on soil loss was adopted by the following reasons.

- The experiments on soil erosion or loss in research sites have limitation and are not suitable for application to such a wide area of whole watershed. Sheet erosion and rill erosion are measured in the experiment but large scale gully erosion and soil loss by landslide are not measured. The experiment has been carried out in a limited farm or site of sugarcane, dalo, cassava and ginger, and has not covered the erosion from the wide areas of forests, plantation, grazing and grasslands.
- In this Study, it is most important to use a uniform standard to all watersheds in the estimate of soil erosion. Nelson's study is the one applying the same criteria to both the Rewa watershed (wet zone) and the Ba watershed (dry zone), setting units by topography and land use.
- The precise accuracy should not be required to this estimate, but the magnitude is important to compare the soil loss from each watershed.

Regarding soil erosion in the Rewa and Ba watersheds, Nelson's study results were directly adopted to estimate the average soil loss from the watershed. Average soil loss from the Sigatoka and Nadi watersheds was estimated based on the Nelson's data of the Ba watershed, as the topographical, climatic and land use characteristics of these watershed are similar. The distinctive land use (agriculture, grassland & grazing land and forest) was selected from the unit in Table-H2.2 (2/2), and the average soil loss was calculated (Table-H3.1).

There is a large discrepancy in the soil loss of "grassland" and "forest" in Table-H3.1. For example, the soil loss of U1 unit (= grassland) is 54.0 ton/ha/year, while the soil loss of U4 unit (= grassland) is 146.5 ton/ha/year. And the soil loss of U3 unit (= forest) was particularly large. Since pine plantation occupying large area in the U3 unit are too young to prevent the soil loss, the average soil loss of "forest" was relatively large.

Since the number of samples is limited, to take the average soil loss of grassland and forest, and to compare them is meaningless.

Table-H3.1 Soil Loss by Land Use in Ba Watershed

Unit	Land Use	Area (ha)	Soil Loss (ton/ha/year)	Area x Soil Loss (ton/year)	Average of Soil Loss (ton/ha/year)
L11	Agriculture	10,732	112.0	1,201,984	
L13		4,716	84.5	398,502	
Total		15,448		1,600,486	103.60
U1	Grassland and Grazing	48,542	54.0	2,621,268	
U2		2,855	57.7	164,734	
U4		2,879	146.5	421,774	
Total		54,276		3,207,775	59.10
U5	Forest	4,806	50.9	244,625	
U3		12,920	100.1	1,293,292	
Total		17,726		1,537,917	86.76

Source : Nelson (1987)

Table-H3.2 Estimated Average Soil Loss of Sigatoka and Nadi Watershed

Land Use	Soil Loss (ton/ha/year)	Sigatoka		Nadi	
		Area (ha)	Area x Soil Loss (ton/year)	Area (ha)	Area x Soil Loss (ton/year)
Forest	86.76	71,900	6,238,044	24,800	2,151,648
Agriculture	103.60	13,900	1,440,040	13,200	1,367,520
Grassland	59.10	59,200	3,498,720	11,500	679,650
Urban	0.00	300	0	2,100	0
Total		145,300		51,600	
Average			76.92		81.37

The estimated soil loss of the four watershed is summarized in Table-H3.3.

Table-H3.3 Soil Loss of Four Watersheds

Watershed	Soil Loss (ton/ha/year)	Soil Loss (mm/year)	Total Soil Loss (ton/year)
Rewa	32.3	2.2	9.3×10^6
Ba	69.0	4.6	6.4×10^6
Sigatoka	76.9	5.1	1.1×10^7
Nadi	81.4	5.4	4.2×10^6

1) Rewa, Ba : Nelson (1987), Sigatoka, Nadi : estimated by JICA Study Team
2) The areas for the calculation of total soil loss were referred from Table-H2.2 and Table-H3.2.
3) The specific gravity of soil is 1.5. (That of sand is usually 1.4~1.7)

3.2 Sedimentation

Characteristics of sediment transport of each target river were evaluated comparing with the characteristics of river bed material based on the result of the analysis of river bed material and measurement of sediment conducted by the Study Team through subcontract with a local consultant. Besides, quantity of siltation in structures, such as dams, was studied.

3.2.1 Definitions

According to the International Standard Organization and the American Society of Civil Engineers, sediment is defined in terms of origin and transport as follows.

Sediment Transport : The movement of solids transported in any way by a flowing liquid. From the point of transport, the sum of the suspended load transported and bed load transported. From the point of origin, the sum of the bed material load and the wash load.

Total Load : From the point of transport of sediment, the "total load" comprises "bed load" and "suspended load", the latter including "wash load". From the point of origin of the sediment, the "total load" comprises the "bed material load" (including the suspended portion) and the "wash load".

Bed Load : The sediment in almost continuous contact with the bed, carried forward by rolling, sliding or hopping.

Suspended Load : The part of the total sediment transported which is maintained in suspension by turbulence in the flowing water for considerable period of time without contact with the stream bed. It moves with practically the same velocity as that of the flowing water. It is generally expressed in mass or volume per unit time.

Bed Material Load : The part of the total sediment transport which consists of the bed material and whose rate of movement is governed by the transporting capacity of the channel.

Wash Load : The part of the suspended load which is composed of particle sizes smaller than those found in appreciable quantities in the bed material. It is in near permanent suspension and, therefore, is transported through the stream without deposition. The discharge of the wash load through a reach depends only on the rate with which these particles become available in the watershed and not on the transportability of flow. It is generally expressed in mass or volume per unit of time.

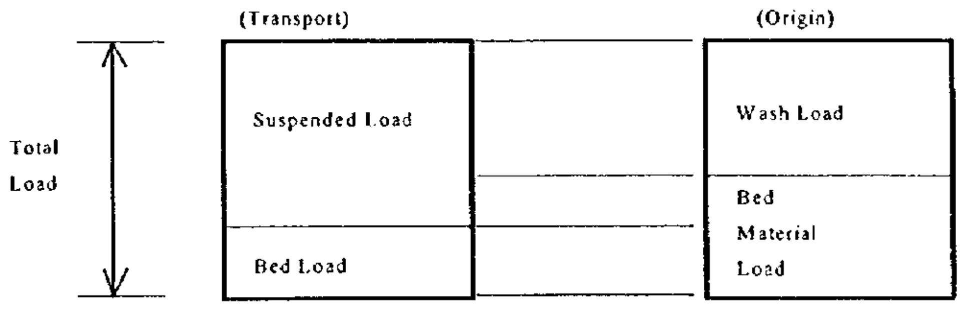


Figure-H3.1 Definition of Sediment

3.2.2 Analysis of River Bed Material and Measurement of Sediment

Analysis of river bed material and measurement of sediment were conducted at the same site by a local consultant. The number of sites for the analysis is ten and their locations are shown in Figure-H3.2.

The works consisted of:

1) Analysis of River Bed Material
   - Sampling
   - Analysis of particle size
   - Analysis of specific gravity

2) Measurement of Sediment
   - Cross section survey
   - Sampling suspended sediment and bed load
   - Measurement of flow velocity
   - Analysis of dry weight, specific gravity and particle size for bed load
   - Analysis of concentration and particle size for suspended sediment

3.2.3 Characteristics of River Bed Material

The sampling was carried out at three places in cross section indicated in Figure-H3.3.

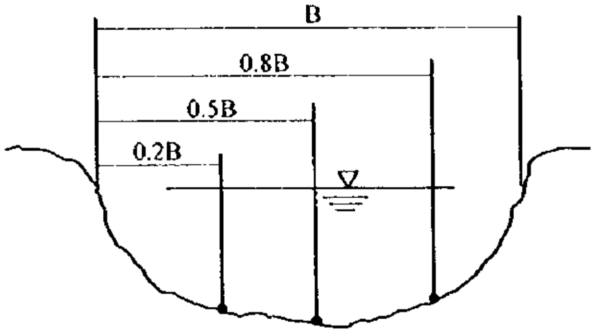


Figure-H3.3 Sampling Places of River Bed Material

Results of river bed material analysis are shown in Table-H3.4. Gravel is dominant at the sites of Nadi, Rewa-2, Sigatoka-2 and Ba-3, while sand forms 70 ~ 90 % of the river bed material in the other sites.

Table-H3.4 Results of River Bed Material Analysis

(Unit: %)

Site	Rewa			Sigatoka		Nadi		Ba		
	1	2	3	1	2	1	2	1	2	3
Gravel	12.6	73.2	13.3	19.6	75.9	57.8	77.2	25.1	13.2	61.1
Sand	86.5	26.6	86.4	80.1	24.0	41.6	22.2	74.1	86.6	38.8
Silt & Cray	0.9	0.2	0.3	0.4	0.1	0.6	0.6	0.8	0.2	0.1

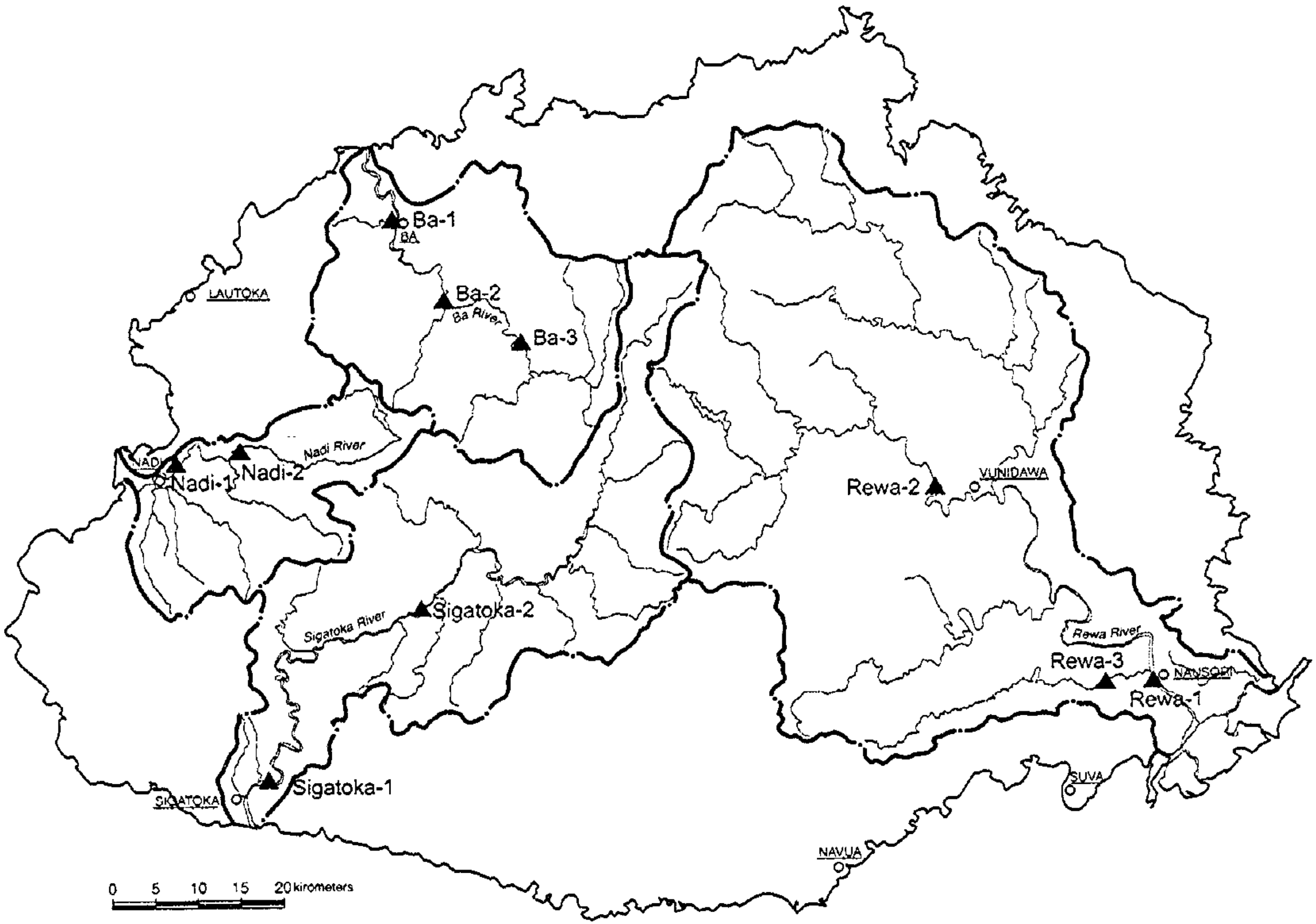


Figure-H3.2 Location Map of Sampling Site

Particle size distribution of river bed material at each sampling site is shown in Figure-3.4 by watershed. The figure of each site was represented by the intermediate one among three samples

River beds at the both sites of Nadi-1 and Nadi-2 were covered with gravel sediment and they are placed as "sedimentation zone", where sediment provided to the zone surpass sediment carried away from the zone. Among the sampling sites near river mouth, only Nadi-1 was gravel rich, which indicates that the sediment carrying capacity is considered higher than the other 3 rivers.

Ratio of fine particles at Ba-2 was more than that at Ba-1. The reasons are considered influence of the dredging at the river mouth and supply of fine particles from the land around Ba-2.

Sigatoka-1 is classified as "sedimentation zone", and Sigatoka-2 as "transportation zone", where sediment provided to the zone and carried away from the zone is balanced. Similarly Rewa-1 and Rewa-3 are classified as "sedimentation zone" and Rewa-2 as "transportation zone".

The relation between bed slope and average size of bed material (D_{50}) is shown in Figure-H3.5. The right-upper corner (bed slope: steep, grain size: large), such as Ba-3, shows the characteristics of the rivers in mountainous areas. The left-lower corner (bed slope: flat, grain size: fine), such as Rewa-1 and Rewa-3, shows the characteristics of rivers on an alluvial plain. This figure also shows that the bed material of Nadi-1 and Nadi-2 is placed between the bed material of the river on a plain in a valley, such as Sigatoka-2, and the bed material of the river on an alluvial plain, such as Rewa-1 and Rewa-3.

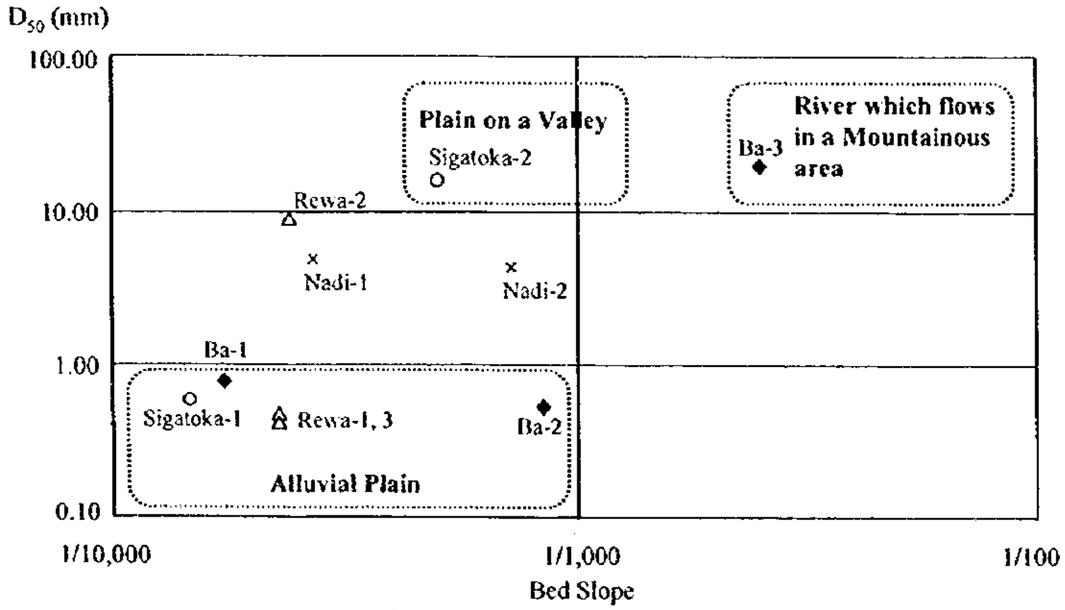


Figure-H3.5 Relation between Bed Slope and Average Size of Bed Material (D_{50})

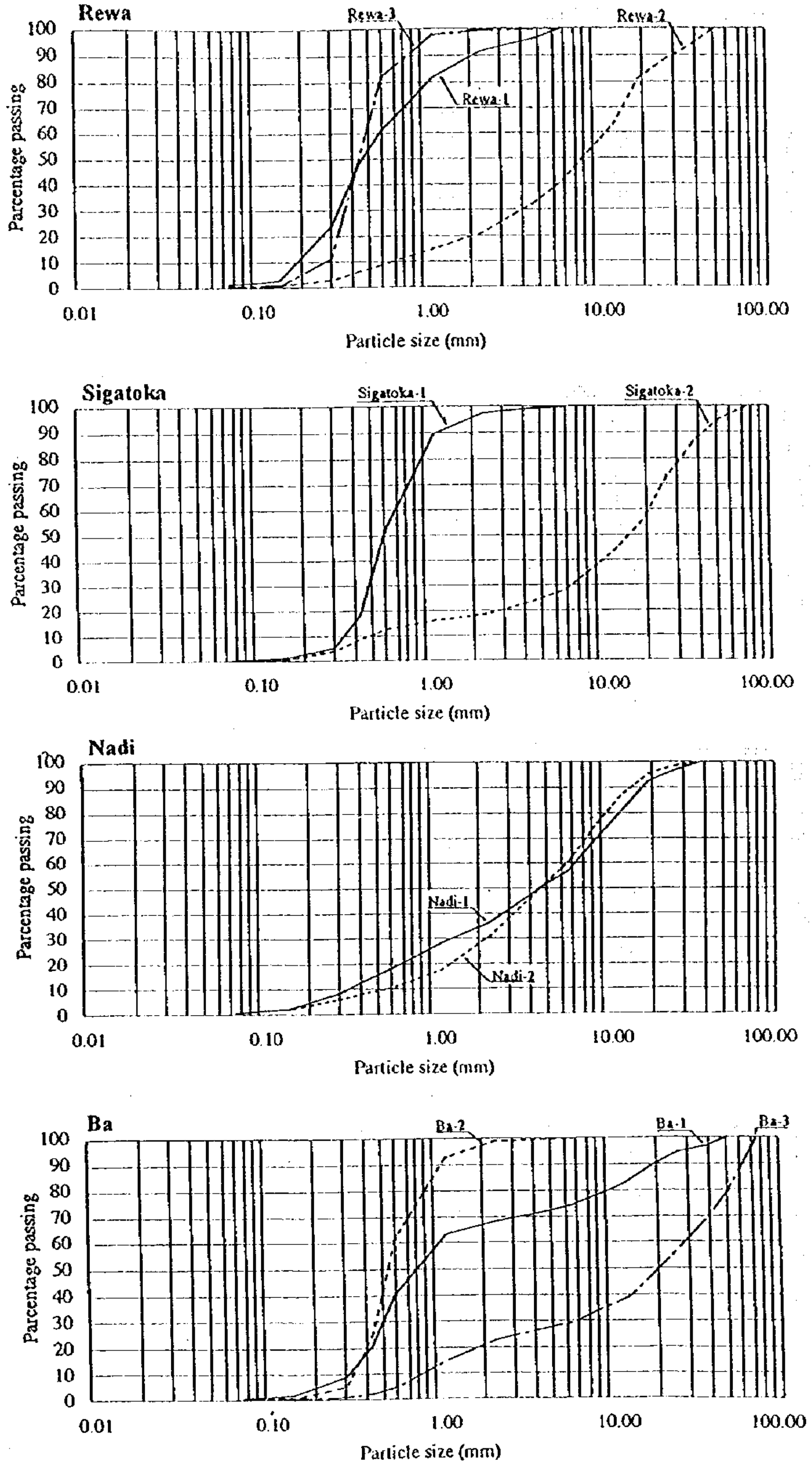


Figure-H3.4 Particle Size Distribution

3.2.4 Results of Suspended Load and Bed Load Analysis

Discharge, suspended load, bed load and total load were calculated as shown in Table-H3.5 based on the analysis results of suspended load/bed load survey. The survey was carried out in a day when the discharge was small, except Rewa-1 of 29/10/96, as the survey period was fixed during September to October. As a result, total loads (suspended load + bed load) were very small in the most of time, while there was a sharp tendency at Rewa-1 that the total load increased as the discharge increased.

Table-H3.5 Results of Suspended Load and Bed Load Analysis

Date	Site		Discharge (m^3/sec)	Suspended Load (g/sec)	Bed Load (g/sec)	Total Load (g/sec)	B.L./S.L. (%)
19/09/92	Nadi	1	2.1	31.37	NA	31.37	NA
15/10/92	Nadi	1	0.82	13.23	0.0032	13.23	0.024
19/09/92	Nadi	2	0.38	14.21	NA	14.21	NA
15/10/92	Nadi	2	0.36	1.57	0.0015	1.57	0.095
16/10/92	Sigatoka	1	23.66	165.38	0.1811	165.56	0.109
23/09/92	Sigatoka	1	22.87	59.27	NA	59.27	NA
24/09/92	Sigatoka	2	15.27	603.94	0.2593	604.20	0.043
16/10/92	Sigatoka	2	4.08	66.38	0.0509	66.43	0.077
26/09/92	Ba	1	24.2	251.85	0.0437	251.89	0.017
17/10/92	Ba	1	31.8	226.67	0.0220	226.69	0.010
30/09/92	Ba	2	4.26	23.87	0.0040	23.87	0.017
18/10/92	Ba	2	5.65	18.33	0.0051	18.34	0.028
27/09/92	Ba	3	3.15	12.34	0.0118	12.35	0.096
17/10/92	Ba	3	2.61	23.45	0.0036	23.45	0.015
10/10/92	Rewa	1	185.08	189.55	0.1165	189.67	0.061
29/10/92	Rewa	1	288.53	29092.3	11.4343	29103.72	0.039
03/10/92	Rewa	2	11.92	53.65	0.0048	53.65	0.009
30/10/92	Rewa	2	13.93	718.67	0.2482	718.92	0.035
30/10/92	Rewa	3	8.9	19.96	0.0646	20.02	0.324

NA: not available, BL: Bed Load, S.L: Suspended Load

3.2.5 Estimate of Sedimentation

It was planed that sedimentation with different discharge was measured. However, samples with large amount of total load during a heavy rain could not be obtained. Therefore, sedimentation was estimated from annual soil loss so as to avoid its underestimate.

It is assumed that all soil loss (shown in Table-H3.3) is transported into a river and flows as total load. Total load consists of bed material load and wash load. Since their ratios are not available in Fiji, they were determined by the following assumptions based on the data in Japan because of similar topographic features, neglecting the difference of rainfall. The result is shown in Figure-H3.6.

1) According to the observations in Japan, about 80 % of wash load transported in a dam reservoir is deposited. Although sedimentation in a dam reservoir depends on the scale of dam, function of dam, current sedimentation ratio and so on, its ratio is expected to be high even in Fiji if a dam has a water supply function. Therefore, sedimentation ratio of wash load is assumed to be 80 %.
2) According to 40 estimates in Japanese main dams, deposit volume of wash load is approximately 4 times greater than one of bed material load. This ratio was applied.

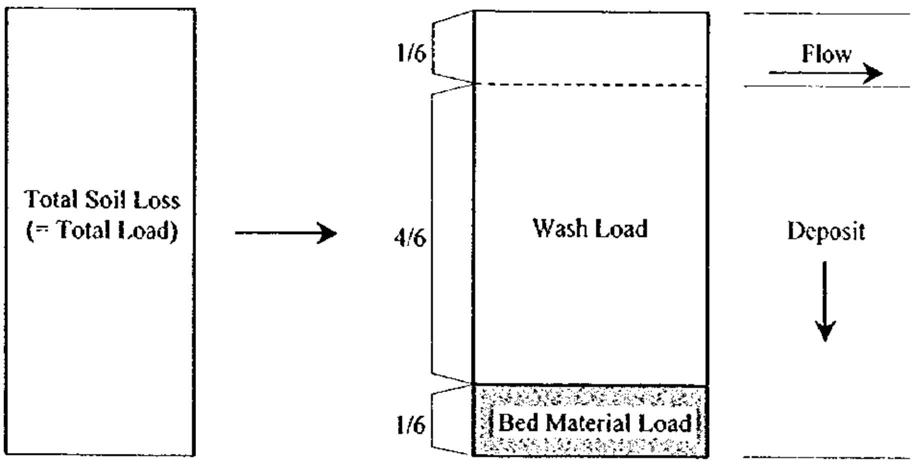


Figure-H3.6 Ratio and Behavior of Bed Material Load and Wash Load

Based on the sedimentation ratios in Figure-H3.6, only bed material load, 1/6 of total load, is deposited in a normal river, while bed material load and 80 % of wash load are deposited where the flow velocity is extremely small, such as a reservoir.

Deposit volume was estimated with the above assumptions. Table-H3.6 shows the result of sedimentation estimate in a normal river comparing with the volume of dredging currently conducted. The annual volume of dredging at river mouth is about 850,000 m^3 for Rewa and 480,000 m^3 for Ba. Since they are 82 % and 68 % of the estimated deposit volume, the estimate is considered as reasonable.

Table-H3.7 shows the result of sedimentation estimate in a reservoir where the flow velocity is extremely slow.

As mentioned before, the sedimentation ratio for reservoir varies with location, scale and function of dam, the ratio needs to be adjusted when the details of dam are determined.

Table-H3.6 Deposit Volume per Unit Area for River Planning

Watershed	Area	Soil Loss (=Total Load)		Volume of Deposit		Volume of Dredging	
	(ha)	(ton/ha/year)	(m^3/ha/year)	(m^3/ha/year)	(m^3/year)	(m^3/year)	(%)
Rewa	288,925	32.3	21.5	3.59	1,036,920	848,981	82 %
Sigatoka	145,300	76.9	51.3	8.54	1,241,508	0	0 %
Nadi	51,600	81.4	54.3	9.04	466,693	0	0 %
Ba	92,665	69.0	46.0	7.67	710,432	479,852	68 %

Notice : Density of sand is assumed 1.5 by M. R. Hasan (1986).
Source : Volume of Dredging: D/I Briefing Paper (1996).

Table-H3.7 Deposit Volume per Unit Area for Reservoir Planning

Watershed	Area	Soil Loss (=Total Load)		Volume of Deposit	
	(ha)	(ton/ha/year)	(m^3/ha/year)	(m^3/ha/year)	(m^3/year)
Rewa	288,925	32.3	21.5	17.94	5,184,599
Sigatoka	145,300	76.9	51.3	42.72	6,207,539
Nadi	51,600	81.4	54.3	45.22	2,333,467
Ba	92,665	69.0	46.0	38.33	3,552,158

Notice : Density of sand is assumed 1.5 by M. R. Hasan (1986).

CHAPTER 4 COUNTERMEASURES FOR SOIL EROSION

4.1 Objectives

The objectives of countermeasures for soil erosion is as follows;

- To control soil erosion and reduce sedimentation in lower reach of river channels
- To maintain and improve soil fertility and land productivity

The countermeasures by type of land are described in this section, and institutional and organizational measures are described in Supporting Report, Part K (Institution).

4.2 Fire Prevention in Forest, Grassland and Agricultural Land

Burning in agriculture land will accelerate soil erosion and will reduce land productivity. Fire in grassland and marginal area of forest will cause loss of forest and prevent from forming of soil which retains much water. This is one of the causes for frequent flooding. Therefore, it is necessary to conduct effective education and enlightenment activities to prevent unnecessary burning and forest fire.

4.3 Countermeasures for Commercial Crop Area

For sugarcane, contour planting and cane trash mulching should be implemented at first, and then *vetiver* grass hedgerow planting should be promoted step by step as the progress of farmers' awareness that the countermeasure contribute to improvement of productivity, considering the past practice that once the *vetiver* grass hedge had not been accepted by the sugarcane farmers because it became obstacle to introduction of machinery, such as tractors and trucks. For the cultivation of dalo, cassava and ginger etc. which mechanization in cultivation is not expected, hedgerow planting of *vetiver* grass or pineapple etc. should be promoted.

For steep slopes where sustainable cultivation is difficult, conversion to orchard or forest which require less plow shall be implemented. For farms on slopes, soil sedimentation pits or ditches should be prepared on the foot of cultivated slopes in order to trap or promote sedimentation of eroded soil. The deposited soil will be returned to the cultivated slopes later by farmers.

For river bank, forest belts should be made along the rivers to prevent river bank erosion by flooding as well as to control inflow of eroded soil from the agricultural land to the river.

4.4 Countermeasures for Small Farming (Teitei)

Agroforestry should be promoted. Practice of agroforestry will be effective in order to utilize the limited land around villages in a sustainable, intensive and diversified way.

4.5 Countermeasures for Logged-out Area, Grassland and Grazing Area

It is discussed in the Chapter 6.

CHAPTER 5 PRESENT CONDITIONS OF FOREST

5.1 Outline

Most of the forests in Viti Levu island are located in the wet zone, the south east of Viti Levu, while scattered forests and grass land are located in the dry zone. The scattered forest in the dry zone might be classified into the forest distributed in the plateau, pine plantation, the forest in high altitude near the border of the wet zone and the forest in valleys on soil sediment.

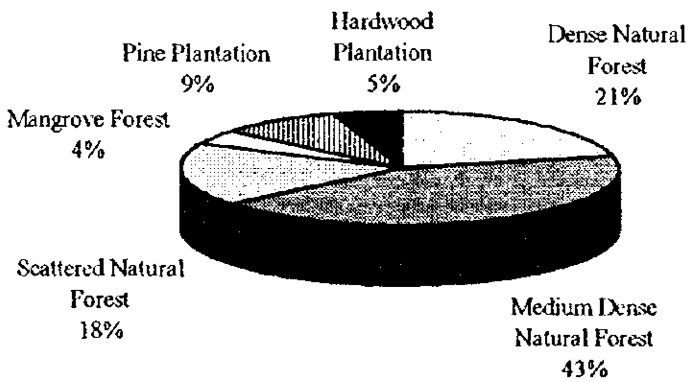
Table-H5.1 and Figure-H5.1 show the area of forest by type. And Table-H5.2 and Figure-H5.2 also show those area by watershed. "Non Forest" includes grassland, cultivation area, town area and grazing etc. The information has been processed from the GIS data by the Management Services Division (Department of Forestry).

The forest cover is 6,135 km^2 or 59 % of Viti Levu island. Natural forest consists of 48 % or 5,031 km^2, hardwood plantation 3 % (296 km^2), pine plantation 5 % (568 km^2) and mangrove forest 2 % (239 km^2).

Table-H5.1 Forest Cover in Viti Levu as of December, 1995

Forest Type	Watershed Total (ha)	Viti Levu Total (ha)	% to Forest Cover	% to Total Land
Natural Forest	310,293	503,147	83 %	48 %
Dense Natural Forest	78,694	127,338	21 %	12 %
Medium Dense Natural Forest	170,435	268,432	44 %	26 %
Scattered Natural Forest	61,164	107,377	18 %	10 %
Mangrove Forest	4,948	23,927	4 %	2 %
Hardwood Plantation	22,209	29,641	5 %	3 %
Pine Plantation	15,505	56,828	9 %	5 %
Total	352,955	613,543	100 %	59 %
Non Forest	246,845	425,257	-	41 %
Study Area Total	599,800	1,038,800	-	100 %

Source: Management Services Division (Department of Forestry)



Source: Management Services Division (Department of Forestry)

Figure-H5.1 Forest Cover in Viti Levu Island

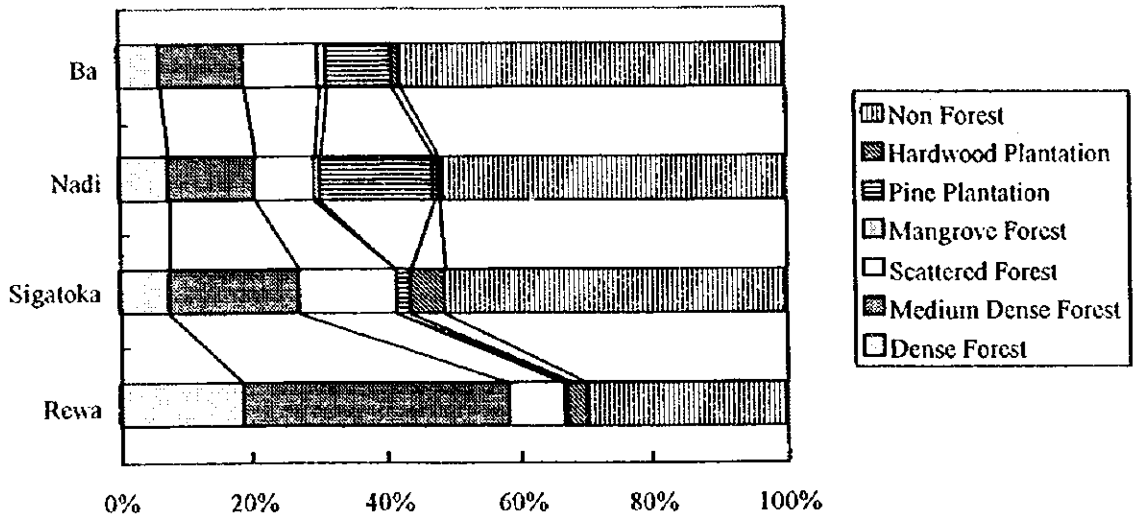
In the Rewa watershed, the forest cover is as much as 2,164 km^2 (70 %) and percentage of dense and medium dense forest is high (Table-H5.2). Mangrove forests are widely extended along the coast of the delta. The forests of the Sigatoka, Nadi and Ba watersheds form less than half of the watersheds area. There is large pine plantation in the Nadi and Ba watersheds and hardwood plantation is located in the upstream of the Sigatoka watershed. Around river mouths of the Nadi and Ba watersheds, there is the mangrove forest.

Table-H5.2 Forest Area by Watershed

unit: ha

Forest Type	Rewa		Sigatoka		Nadi		Ba	
Dense Natural Forest	58,263	19 %	10,743	7 %	3,943	8 %	5,745	6 %
Medium Dense Natural Forest	122,077	40 %	29,477	20 %	6,853	13 %	12,028	13 %
Scattered Natural Forest	24,767	8 %	20,883	14 %	4,602	9 %	10,912	12 %
Mangrove Forest	3,598	1 %	13	0 %	407	1 %	930	1 %
Pine Plantation	1,294	0 %	3,074	2 %	8,679	17 %	9,162	10 %
Hardwood Plantation	6,368	2 %	7,667	5 %	309	1 %	1,161	1 %
Total	216,367	70 %	71,857	49 %	24,793	48 %	39,938	43 %
Study Area Total	309,200	100 %	145,300	100 %	51,600	100 %	93,700	100 %

Source : Management Services Division (Department of Forestry, MAFFA)



Notice: Coconut Plantation is omitted in the table as the area is very small.
Source: Management Services Division (Department of Forestry)

Figure-H5.2 Ratio by Forest Type

For the management purpose, forests are classified as follows.

- Production Forest
  - Indigenous Production Forest
  - Plantation Forest
    - Softwood (Pine)
    - Hardwood
    - Coconut
- Protection Forest (Indigenous)
- Non-commercial Forest (Indigenous)
- Mangrove Forest

Among them, present conditions of production forest, protection forest and non-commercial forest are described in the following section. And the mangrove forest in the delta around river mouth is described in Supporting Report, Part J (Environment).

5.2 Production Forest

Production forest has a stock of commercial species from 30 to 100 m^3/ha, and are considered suitable for commercial exploitation. 33 commercial species of 35 cm diameter of trunk are permitted to be felled for sale (Department of Forestry, 1993).

5.2.1 Logging

No statistics about volume and area of logging in the production forest is available even in the Department of Forestry. Available data is only the logged area of production forest estimated based on GIS data. Ratio of the logging area to the watershed area is approximately 9 % in the Rewa and Ba watersheds, while approximately 14 % in the Sigatoka and Nadi watersheds.

Haulage road construction and logging are currently conducted based upon National Code of Logging Practice which includes the preventive technique against land degradation. Reforestation techniques for the logged area are now under study.

Table-H5.3 Logging Area of Production Forest

Watershed		Logged Area (ha)						b)/a)
	a) Area (ha)	before 1992	1992	1993	1994	1995	b) Total	(%)
Rewa	309,200	25,145	567	623	395	1,154	27,884	9.0
Sigatoka	145,300	17,450	795	435	932	284	19,896	13.7
Nadi	51,600	4,632	405	815	1,306	0	7,158	13.9
Ba	93,700	4,182	1,767	446	1,301	689	8,384	8.9

Source: Management Services Division (Department of Forestry)

5.2.2 Hardwood Plantation

The Department of Forestry has been undertaking hardwood plantation mainly with Mahogany replanting in logged areas in production forest. Because of the frequent damage by *Ambrosia beetles* to Mahogany (boring small holes in the trunk to degrade the quality) in 1970's, such species as Cadamba (*Anthocephalus Cadamba*), Deglupta (*Eucalyptus* *deglupta*), Maesopsis (*Maesopsis eminii*), Cordia (*Cordia alliodora*), Kauvula (*Endospeemum macrophyllum*) had been planted besides Mahogany after 1972. They are introduced species, except Kauvula. However, seeds of those, particularly Maesopsis, were scattered away out of plantation area resulting in invasion to indigenous species and cyclones breaked trunks of the trees. As a result, plantation of those species except Mahogany are not carried out at present.

Impact on the environment caused by the use of intensely poisonous Arsenic Pentoxide for the healthy growth of Mahogany until 1995 had been pointed out, but since 1996 it has been replaced by Tordon which has smaller impact on the environment, resulting in the improvement of the situation. There is no logged plantation area because hardwood planted has not grown enough for logging.

Hardwood plantation area is shown in Figure-H5.3. And undergoing change of the plantation area based upon "Forestry Department 1995 Annual Report" is shown in Table-H5.4. Plantation area has been increasing except for 5 years from 1971 to 1975. The considered cause of temporary decrease of the said 5 years is the frequent damage by *Ambrosia beetles*.

Table-H5.4 Hardwood Plantation Area

Unit: ha

Division	Station	Hardwood Plantation Areas								
		1950-60	1961-65	1966-70	1971-75	1976-80	1981-85	1986-90	1991-95	Total
Southern	Nukurua		1,369	2,639	807	1,143	821			6,779
	Galoa		573	872	266	280	560	2,947	1,168	6,666
	Naboutini		459	520	48	47	1,321	351	1,770	4,516
	Colo-i-Suva	297	91						11	399
	Sawakawa						750	1,002	1,397	3,149
	Total Southern	297	2,492	4,031	1,121	1,470	3,452	4,300	4,346	21,509
Western	Nausori-Highlands						826	494	244	1,564
	Nadarivatu	169	5	11		110	1,902	2,061	776	5,034
	Baravi							500	1,038	1,538
	Total Western	169	5	11	0	110	2,728	3,055	2,058	8,136

Source: Forestry Department 1995 Annual Report

5.2.3 Pine Plantation

Afforestation or extension of planting in the western area has been carried out with mostly pine. Afforestation program from 1960 until 1990 had been carried out by the Department of Forestry, and since 1990 by Fiji Pine Limited. Fiji Pine Limited is contributing to increase of the forest cover especially in the dry zone as well as timber and pulpwood/chip production. Establishment of the pine plantations has had, in balance, overwhelmingly positive environmental impacts.

Table-H5.5 shows an undergoing change of the plantation area in the whole of Fiji after the establishment of Fiji Pine Limited (1991 to 1995). More than 8,600 ha of pine plantation was increased during 1991 to 1995 in total. Pine stations in Viti Levu island are four, Lololo, Nabou, Nadi and Ra (Figure-H5.3), and the total plantation area of these stations in

1995 is shown in the right column of Table-H5.5. In Viti Levu, pine plantation of 358 ha was expanded in 1995.

Table-H5.5 Pine Plantation by Fiji Pine Limited

	Whole Fiji						Viti Levu
	1991	1992	1993	1994	1995	Total	(1995)
Addition (ha)							
Newly Planted	794	1,492	1,274	857	1,024	5,441	891
Restocked after logging	1,891	1,437	704	2,746	2,260	9,038	1,750
Reinstated					3,105	3,105	25
Reduction (ha)							
Logging	-1,471	-1,282	-1,474	-1,310	-2,071	-7,608	-2,042
Witten-off			-85	-1,111	-317	-1,513	-266
Balance (Total Addition)	1,214	1,647	419	1,182	4,001		358
Stocked Area (ha)	35,632	37,566	37,291	38,519	42,583		28,854
Estate Area (ha)	73,459	73,726	75,515	75,643	75,041		NA
Wood Supply (ton)	328,004	314,836	353,616	330,378	419,351	1,746,185	NA
Yield (ton/ha)	223	246	240	252	202	230	NA

Source: Fiji Pine Limited Annual Report 1995

Fiji Pine Limited has the timber supply plan until 2015 as shown in Table-H5.6. In this plan, the timber supply by four pine stations in Viti Levu shows no marked increase.

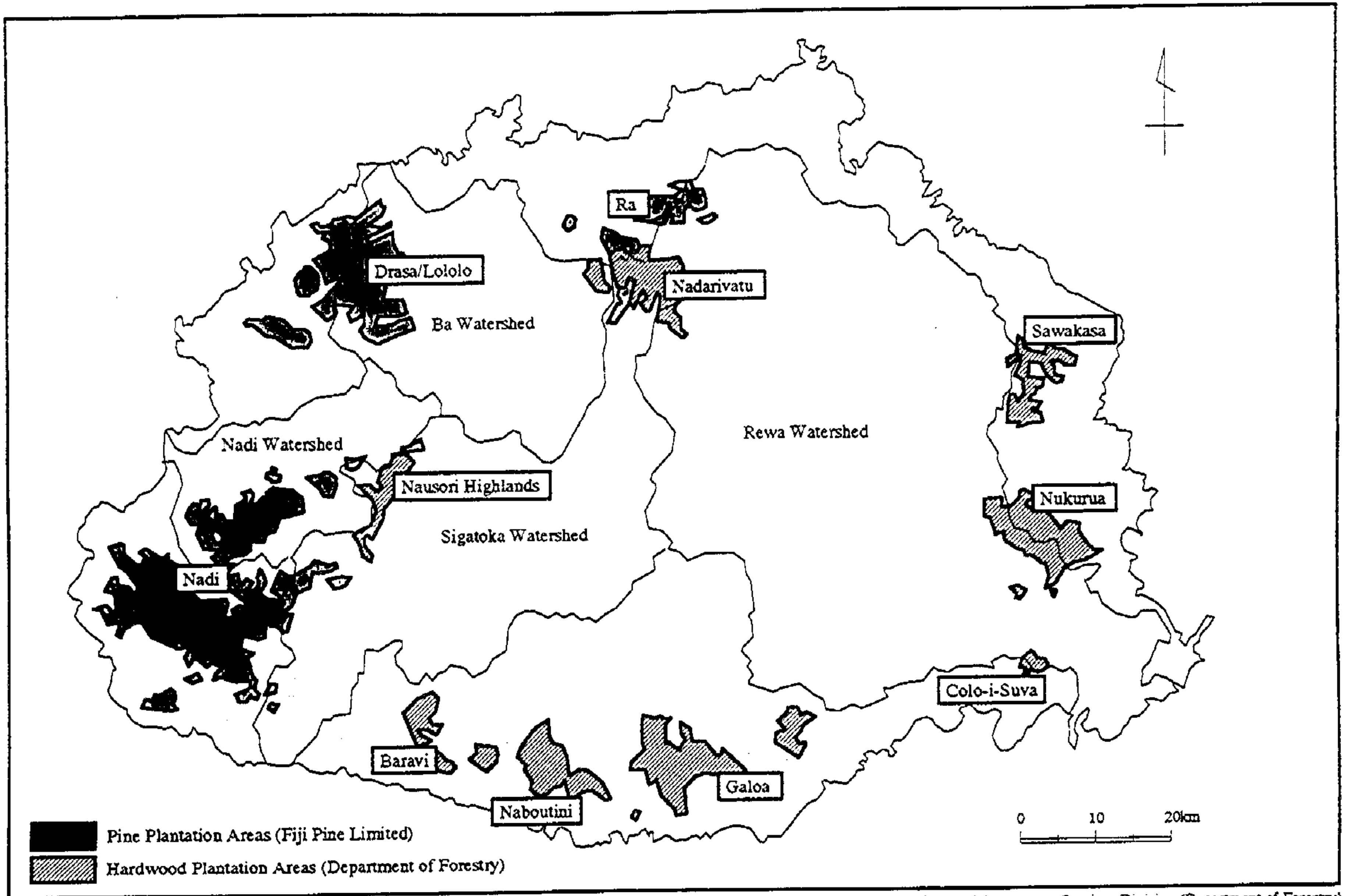
Table-H5.6 Planed Wood Supply from Standing Trees

unit: ton

Period	Viti Levu	Vanua Levu	Total
1991-1995	NA	NA	1,746,185
1996-2000	1,515,600	456,000	1,971,600
2001-2005	1,531,600	1,187,000	2,718,600
2006-2010	1,877,100	1,187,500	3,064,600
2011-2015	1,390,400	1,066,700	2,457,100

Source: Fiji Pine Limited Annual Report 1995
Notice: The figures 1991-1995 are actual ones.

Pines are logged in 18 years on the average. In this case, logging volume to the stock is proper and even in future timber production is possible as planned, as long as no serious damages as ever for some reasons happen. Since the plantation area is in the dry zone, it has been often damaged by fires mainly caused by unintentional and intentional burning in sugarcane field and grassland. However, Fiji Pine Limited considers the damage by fires is not so much serious as to influence the production plan. And no damage has been found by harmful insects until now. According to Fiji Pine Limited, estate area at present is enough and no plan to increase is necessary.



Source: Management Services Division (Department of Forestry)

Figure-H5.3 Location Map of Plantation Areas

5.3 Protection Forest and Protected Areas

5.3.1 Protection Forest

Protection forest has slopes in excess of 30° (usually 40° to 60°), with shallow and unstable soil. Normally, there is a risk of land slides, and ground often covered with large boulders. Although the protection forest is classified for management purposes, it is not declared by law (Department of Forestry, 1993). In protection forest, logging is not permitted, but actually logging for firewood and cultivation in a small scale for subsistence has been carried out in some areas; however, its situation is not well known.

5.3.2 Protected Areas

Under the Forest Act, the following three protected areas are stipulated and in protected areas, logging is not permitted. Though the objectives for designation of each area are different, they contribute to mitigation of soil erosion as a result.

– **Forest Act : 1953 (Cap 150)**	
Outline of Provision :	Minister may declare Nature Reserves and sylviculture areas in reserved forests and declare native land to be Protected Forest

(1) Nature Reserve

Cutting plants and hunting are prohibited in Nature Reserve unless approved in writing. Out of 7 Nature Reserves of the country, 3 Nature Reserves are in Viti Levu island (in Ba Province), with the area of 1,695 ha in total.

One area in Naitasiri (Wabu) is to be declared as a Nature Reserve. The due process is in progress.

(2) Forest Reserve

Commercial activities are prohibited in Forest Reserve unless approved in writing by the Conservator of Forest. Among 19 Reserves, 17 Forest Reserves are in Viti Levu island with the area of 19,075 ha in total.

Five plantation forests of hardwood and softwood (24,498 ha) are proposed as Forest Reserve. In these areas, natural forests have not existed any more; however, they should be protected to conserve the planting.

A forest in the catchment of Monasavu dam in Naitasiri and Nadoroga provinces, a forest in Korobasabasaga area in Namosi province and forests in Nakauvadra and Nakorotubu areas in Ra province are proposed as Forest Reserves.

(3) Protected Forest

A Protected Forest is declared by the Minister. There is one Protected Forest in Serua with the area of 15,750 ha.

The parks officially designated such as National Park or Forest Park are shown in Table-H5.7. The purpose of designation varies with the result of contribution to control soil erosion.

(4) National Park

The Sigatoka Sand Dunes is the first National Park of Fiji declared in 1989 in the Gazette. The Sigatoka Sand Dunes has been opened for visitation since January 1997 and has a complement of full time personnel managing the area.

(5) Proposed National Park

Sovi Basin National Park is proposed by NLTB, and Garrick National Park is also proposed by National Trust for Fiji. Sovi Basin has a large area of 192 km^2 and located in the center of the Rewa watershed and considered important.

(6) Other Parks in Viti Levu

The location and area of the other national parks are shown in Table-H5.7.

Table-H5.7 Protected Areas

Status	Area	Division	Province	Established	Area (ha)
Nature Reserve	Draunibota Island	Central	Rewa	1959	1.9
	Lobiko Island	Central	Rewa	1959	0.3
	Vuo Island	Central	Rewa	1960	1.2
	Nadarivatu	Western	Ba	1956	93
	Naqaranibuluti	Western	Ba	1958	279
	Tomaniivi	Western	Ba	1958	1,323
	Sub-total of Viti Levu Island				1,699
	Ravilevu	Northern	Cakaudrove	1959	4,019
	Vunimoli	Northern	Cakaudrove	1968	20
Proposed Nature Reserve	Wabu	Central	Naitasiri		1,120
Forest Reserve	Colo-i-Suva	Central	Naitasiri	1963	369
	Maranisaqa	Central	Naitasiri	1955	77
	Naitasiri	Central	Naitasiri	1955	30
	Savura	Central	Naitasiri	1963	448
	Vago	Central	Naitasiri	1959	25
	Navoro	Central	Rewa	1969	19
	Qoya	Central	Rewa	1955	67
	Suva and Namuka	Central	Rewa	1913	foreshore
	Yarawa	Central	Serua	1962	162
	Buretolu	Western	Ba	1926	1,198
	Lololo	Western	Ba	1968	8
	Nadarivatu	Western	Ba	1954	7,397
	Saru Creek	Western	Ba	1973	3
	Tavua	Western	Ba	1958	0.2
	Sub-total of Viti Levu Island				9,804
	Korotari	Northern	Cakaudrove	1961	1,047
	Taveuni	Northern	Cakaudrove	1914	11,291
Proposed Forest Reserve (Plantation)	Nukurua	Central	Naitasiri		2,610
	Sawakasa	Central	Naitasiri		8,481
	Galoa	Central	Nuku		3,127
	Naboutini	Central	Nuku		3,364
	Yarawa	Central	Nuku		162
	Nausori Highland	Western	Navosa		6,916
	Sub-total of Viti Levu Island				24,660
Proposed Forest Reserve	Monasavu Dam	Central Western	Naitasiri Nadroga		11,720
	Korobasabasaga	Central	Namosi		1,250
	Nakauvadra Range	Western	Ra		3,700
	Nakorotuvu	Central	Ra		2,880
Protected Forest	Batiwai	Central	Serua	1956	15,750
Proposed National Park	Sovi Basin National Park	Central	Naitasiri		19,160
	Garrick National Park	Central	Namosi		1,760
Other Parks in Viti Levu	Waikatakata Archeological	West	Nadronga	1988	70
	Nalowela Forest Park	West	Ba	1992	35
	Lololo Forest Park	West	Ba	1968	1
	Sigatoka Sand Dune National	West	Nadroga	1989	240
	J.H.Garrick Memorial Park	Central	Namosi	1986	429
	Nukulau Island Park	Central	Rewa		8
	Naqalimare Limestone	West	Nadroga		204

A provisional table. (Source : Department of Forestry, Environmental Division)

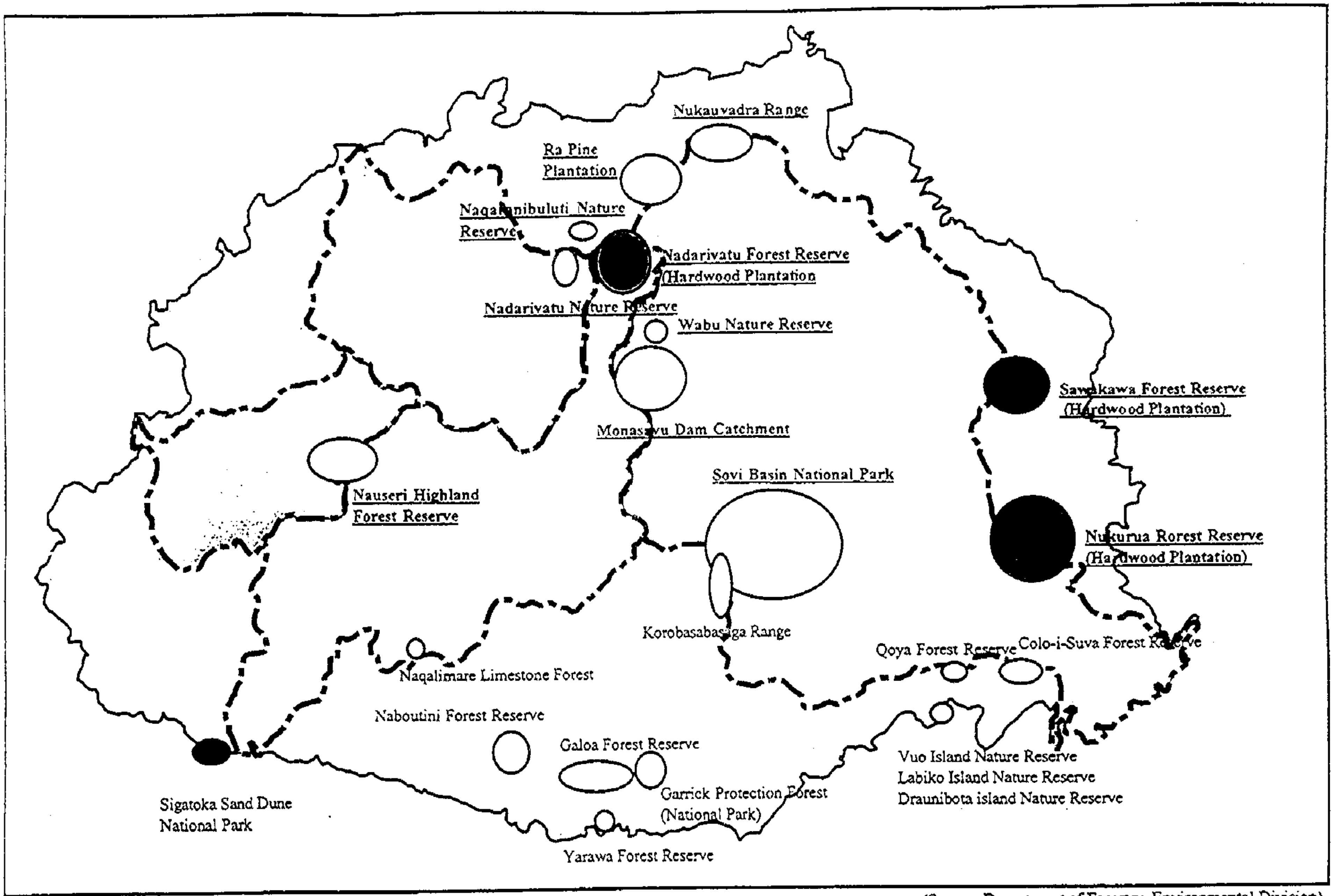


Figure-H5.4 Location Map of Protected Areas

(Source: Department of Forestry, Environmental Division)

5.4 Non-commercial Forest

Non-commercial forest has a stock of commercial species less than 30 m^3/ha of trees of 35 cm diameter of trunk. Stock rates are too low for commercial exploitation (Department of Forestry, 1993). Therefore commercial logging for timber production is not carried out, but logging for firewood and cultivation in a small scale for subsistence is practiced; however, the situation is not known.

5.5 Present Situation of Deforestation

Deforestation for firewood and cultivation in a small scale for subsistence is found everywhere in forests. But deforestation of this kind is considered spotted shaped like remnant patches that the situation is not statistically known. The only document available about deforestation is the one by Daniel van R Claasen Consultant (1991). In this report covering four areas as shown by dotted line in Figure-H5.5, the deforested areas and its ratio to the forests were calculated by comparison between new aerial photographs or satellite image and the old ones, and the comments of logging situation at that stage were added on it. But deforested areas include production forests where logging is carried out, so it is impossible to know only the deforestation caused by subsistence in volume.

Table-H5.8 shows loss of forest cover in each catchment area and present situation of logging based upon this document. The number in catchment corresponds to the number shown in Figure-H5.5. Forest areas are decreasing in all of the forests belonged to the watersheds of Rewa, Sigatoka, Nadi and Ba, but the decrease is particularly conspicuous in the Ba-Sigatoka divide forest (No.10) by 40 % during 7 years from 1982 to 89. And also, loss of forest cover in the other catchment (No. 4, 6 and 7) belonging to the Sigatoka watershed is relatively high by 7 ~ 10 %. Some cases reported are that even protection forests with no logging have been destroyed by fires. Reasons of deforestation was considered as follows:

- Large scale development
- Conventional farming and subsistence farming in small scale
- Unintentional and intentional burning
- Settlements, urbanization and other infrastructure development

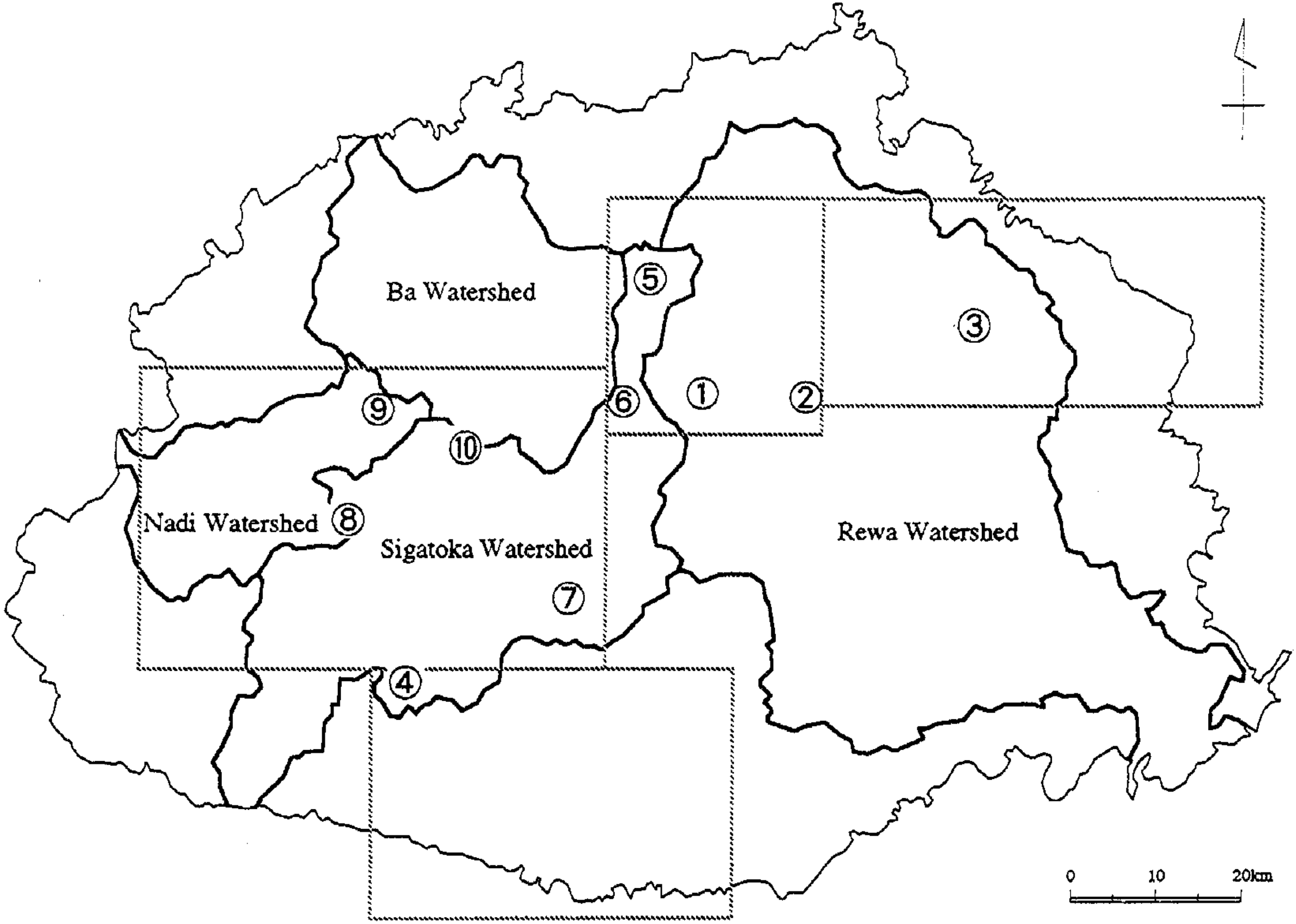


Figure-H5.5 Location of Study Area on Deforestation by Daniel van R Claasen Consultant (1991)

Table-H5.8 Loss of Forest Cover by Catchment

No.	Catchment	Loss of Forest Cover (Period, %)	Type of Land Use	Notes
1.	Nanuku	1969 - 1986 2.9 %	- Agriculture - Scrub-reed-grass/secondary forest - Settlement/infrastructure (dams. roads are not included) - Forestry - Other	1. Logging in Protection Forest?: No 2. Logging outside of concession area (s)?: No 3. Impoundment area of Monasavu Dam is over 816 ha. Loss of forest cover area includes this area. 4. Immediate catchment of Monasavu is logged forest - was part of a logging concession. 5. Lomaiviti (Mt Victoria) Nature Reserve - located on SE slopes of mountain and ridges (4,341 ft).
2.	Wainimala	1969 - 1986 <1.0%	- Agriculture (Subsistence) - Scrub-reed-grass/secondary forest - Settlement/infrastructure (roads, dams) - Forestry - Other	1. Logging in Protection Forest?: No appreciable logging activity. 2. Logging outside of concession area(s)?: Not applicable. 3. There are no logging concessions in this area. 4. Forests are used only to subsistence mixed farming activity and some minor roads.
3.	Wainibuka	1969 - 1986 3.3 %	- Agriculture (Mixed and extensive farming) - Scrub-reed-grass/secondary forest - Settlement/infrastructure (roads) - Forestry - Other	1. Logging in Protection Forest?: No logging in protection forest, but some loss of forests caused by scrub clearing and fire etc. was found. 2. Logging outside of concession area(s)?: Not evident, logging is a minor activity in this area. 3. Total of logging concessions are approximately 1000 ha.
4.	Wainamoli	1969 - 1986 9.9 %	- Agriculture - Scrub-reed-grass/secondary forests - Settlement/infrastructure (roads) - Forestry - Other	1. Logging in Protection Forest?: Logging concession centred on Yalavou Creek headwaters is 50% of Protection Forest. 2. Logging outside of concession area(s)?: There are signs of logging outside of concession area(s). The area centred on Busanga Ck (NNE of Sheet - mid Sigatoka Valley) is logged out and extensive reduction of forest cover can be seen. 3. Non commercial forest "islands" in valley in 1969 LRD maps have been cut out for agricultural/subsistence farming and other purposes, leaving only agricultural/scrub/grasslands. 4. Forests on the edges of the Sigatoka grass/scrublands are gradually being nibbled away by fire, non-commercial forest cutting, some forest activity and subsistence clearing. 5. Wainamoli area is relatively untouched except for old settlement are near confluence of Wainamo Ck/Rana Ck/Wainimai Ck (South of Matokana Village). Clear area was some 63 ha in 1969. Open canopy extends a further 80 ha but this is probably due to open nature of canopy and does not reflect new clearing (no signs of such activity).
5.	Nadarivatu	1969 - 1986/87 2.3%	- Agriculture (mixed farming) - Scrub-reed-grass/secondary forest - Settlement/infrastructure (roads, dams) - Forestry - Forests station and plantation area are approximately 9100 ha. - Logging Concessions are approximately 3,000 ha - Other	1. Logging in Protection Forests?: Concessions extend over protection forest areas and logging activity and access roads may be seen in the air photos. This is particularly the case near Vanua Levu village. 2. Logging outside of concession area(s)?: Yes, minor signs evident. 3. The approximately 11,000 ha of forest cover includes the 9,000 ha of the Forestry station and plantation managed area.
6.	Solikana	1969 - 1986/87 10.0 %	- Agriculture - Scrub-reed-grass/secondary forest formed by fire - Settlement/infrastructure (roads) - Forestry - Other	1. Logging in Protection Forests?: No, but losses of Protection Forest occurs in steep terrain - probably due fires and small garden activity. 2. Logging outside of concession area(s)?: No concession areas. 3. Most forest cover lost is on Non-commercial forest .
7.	Lotoloto Creek	1969 - 1986/87 7.2%	- Agriculture - Scrub-reed-grass/secondary forest formed by fire - Settlement / infrastructure (roads, dams) - Forestry - Other	1. Logging in Protection Forests?: No, but scattered forest on steep terrain near by grassland is particularly vulnerable to fire etc. 2. Logging outside of concession area(s)?: No concessions. This area adjacent to Sigatoka Valley. 3. Small amount of production forest lost near Nareba Falls. The vulnerability of the forest fringe is a pattern which continues to the South (Wainimori Creek Catchment) and loss of steep land forest is noticeable. 4. This pattern is representative of forests fringing grass/reed/scrublands.
8.	Nausori Highlands - SW group	1969 - 1989 6%	- Agriculture - Scrub-reed-grass/secondary forest formed by fire - Settlement/infrastructure (roads) - Forestry - Other	1. Forests are logged for subsistence and other agricultural purposes by small-holders. 2. Re/afforestation is proceeding using Caribbean pine species although this is principally carried out in the grassland areas.
9.	Nausori Highlands - N group (Vaturu Dam)	1969 - 1989 8%	- Agriculture - Scrub-reed-grass/secondary forest formed by fire - Settlement/infrastructure (roads, dams) - Forestry - Other	1. Forests are logged for subsistence and other agricultural purposes by small-holders. 2. Forests are remaining at the highland area centred on Vaturu Dam.
10.	Sigatoka - Ba Highlands	1982 - 1989 40%	- Agriculture - Scrub-reed-grass/secondary forest formed by fire - Settlement/infrastructure (roads) - Forestry - Other	1. Forests are logged for subsistence and other agricultural purposes by small-holders. 2. Logging activity is intensive. The Ba - Sigatoka divide forest is estimated to have decreased in size by over 600 ha (40%) over a seven year period (1982-1989), mainly as a result of logging followed by subsistence and small-hold commercial farming.

Notice: Number in 1st column refers to the number in the "Figure-H5.5".
Source: Daniel van R Claasen Consultant (1991)

CHAPTER 6 FOREST PRESERVATION AND AFFORESTATION

6.1 Effect of Forest on Watershed Management

Forests have effect on mitigation of flood (effect of decreasing peak flood discharge) as well as effect on prevention of soil erosion and development of water resources, as the forests have the function of temporary retention of rain water on the crown and the function to increase the water retention capability of soil.

Countermeasures for forest preservation and afforestation (forest preservation, sustainable forestry production, and forest rehabilitation and afforestation), and the flood mitigation effect of forests is described in the following sections.

6.2 Countermeasures for Forest Preservation

6.2.1 Target

Target of countermeasures is forests which consists of the protection forests and the protected area.

6.2.2 Countermeasures

Countermeasures for forest preservation are as follows;

- Strengthening control and supervision of the protection forests from illegal logging and fire
- Formulation and intention of a regulation to control subsistence logging in the protection forests
- Designation of new protected areas or forests for mitigation of flood, development of water resources and soil erosion control

The protected areas to be designated in this countermeasure should be coordinated with the national land use plan to be prepared.

For the watershed where a large part of forest had been deforested, such as the Sigatoka, Nadi, Ba and Wainibuka watersheds, afforestation should be promoted based on the countermeasure for forest rehabilitation and afforestation as described later in the section 6.4, and then the formed forest should be designated as the protected areas.

6.3 Countermeasures for Sustainable Forestry Production

6.3.1 Target

Target of countermeasures is the production forest, excluding small scale coconut forest whose purpose is production of coconuts.

6.3.2 Countermeasures

Countermeasures for sustainable forest production are as follows;

- Management and control of national timber or wood production

- Regulation of compulsory planting to logged out areas by loggers
- Revision or improvement of "Fiji National Code of Logging Practice"

For the Master Plan or policy for the forestry development by 2015, "Strategy for Forestry Sector Development, A. Leslie (1988)" should be referred to.

The hardwood plantation to the logged out areas which has been carried out by the Department of Forestry by now should be implemented by the loggers instead. The Department of Forestry should do administration and promotion of afforestation activities, in order to stop the decrease of forest areas in Viti Levu island and implement the forest rehabilitation and afforestation effectively.

Researches to reduce the negative effect of logging or soil and natural environment should be strengthened. Moreover, the existing "Fiji National Code of Logging Practice" should be revised and updated properly. From the view point of control of soil erosion, the unit area of logging should be smaller (patchwork logging, no carpet logging), and the plantation after logging should be done as sooner as possible.

6.4 Countermeasures for Forest Rehabilitation and Afforestation

6.4.1 Target

Target of countermeasure is the non-commercial forest, devastated protection forest, grassland and grazing land.

6.4.2 Countermeasures

Countermeasures for forest rehabilitation and afforestation are as follows;

- The whole grassland of which land utilization is low, and the steep area of pasture (15 % of the total grazing area) where sustainable grazing is difficult should be afforested by 2015 with plantation and fire protection, for prevention of flood and soil erosion.
- The non-commercial forest and devastated protection forest should be rehabilitated to improve the condition and function of forest.
- The afforested forest should be basically protected for prevention of flood, water resources development and soil erosion control.

The species of tree to be planted shall be strong enough to dry weather and intensive sunshine. Native forests which form various ecosystem give much more benefit rather than forests formed by one variety, such as pine forests. However, recovery of native forests on the land whose fertility was lost by soil erosion requires a large investment for a long term. Therefore, pine should be planted at first and then native trees should be introduced or added step by step in order to shift from the pine forest to more natural forest, gradually. Pine is the one which fits to dry condition and there are a lot of successful records in Fiji.

6.4.3 Target Afforestation Area

The area of the steep grazing land where sustainable grazing is difficult was estimated from the area ratio of slope classes prepared by the Management Services Division (Department of Forests). The area ratio of each slope in objective 4 watersheds is shown in Table-H6.1. The distribution of slope classes in grazing area is assumed to be same as Table-H6.1 which includes all land use.

Table-H6.1 Slope Classes

Categories	Slope Ranging (degree)	Area (%)
Low	0 ~ 16	83.3
Moderate	17 ~ 27	14.3
Steep	28 ~ 31	1.1
Extreme	32 ~	1.2
Total		100.0

Source : Management Service Division (Department of Forestry, MAFFA)

The ratio of the area where sustainable grazing is difficult is considered about 15 %, taking the slope ranging more than 20 degree. The target of afforestation area by 2015 is set based on the above countermeasures, as shown in Table-H6.2.

Table-H6.2 Proposed Land Use in 2015

Land Use	Rewa		Sigatoka		Nadi		Ba	
	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
Forest	2,573	83.2	952	65.5	295	57.2	554	59.1
(Conservation)	(2,164)	(70.0)	(719)	(49.5)	(248)	(48.1)	(399)	(42.6)
(Afforestation)	(409)	(13.2)	(233)	(16.0)	(47)	(9.1)	(155)	(16.5)
Agriculture	196	6.3	170	11.7	132	25.6	233	24.9
Grazing	296	9.6	327	22.5	69	13.4	136	14.5
Urban	27	0.9	4	0.3	20	3.9	14	1.5
Total	3,092	100.0	1,453	100.0	516	100.0	937	100.0

Notice: Land use plan without afforestation is described in the Part G.

6.4.4 Cost of Afforestation

Cost of afforestation was estimated on condition that all plantation adopts pine. The cost of afforestation by watershed was calculated as shown in Table-H6.3, based on the afforestation area by watershed and the unit afforestation cost (F$ 94,000/km^2) obtained from the average of the plantation expenditure divided by the plantation area in 5 years (Table-H6.4). The plantation expenditure includes silviculture and nursery costs, station overhead, lease and rental costs, head office overheads, interest and depreciation. The method of planting is by hand or aerial seeding.

Table-H6.3 Cost of Afforestation by Watershed

Watershed	Area to be afforested (km^2)	Cost of Afforestation (F$ 1,000)
Rewa	409	38,446
Sigatoka	233	21,902
Nadi	47	4,418
Ba	155	14,570
Total	844	79,336

Table-H6.4 Cost of Afforestation per 1km²

	1991	1992	1993	1994	1995	Average
Plantation Expenditure (F$)	1,950,000	2,187,000	2,719,000	3,889,000	4,776,000	
Plantation Area (ha)	2,685	2,929	1,978	3,603	6,389	
(F$/$km^2$)	72,626	74,667	137,462	107,938	74,753	93,489

Source : Fiji Pine Limited Annual Report 1995

6.4.5 Afforestation Priority and Schedule

Priority of afforestation as the countermeasure for control of flood and soil erosion is set as follows considering the existing vegetation, erodibility, degree of forest decrease, and the recent actual plantation;

First) the area around the divide of the Sigatoka - Ba watersheds
Second) grassland and grazing area in the Sigatoka and Ba watersheds
Third) grassland and grazing area in the Nadi watershed
Fourth) grassland and grazing area in the Rewa watershed

The implementation schedule of the afforestation by 2015 is shown in Table-H6.5. The first priority is placed on the Sigatoka watershed rather than other watersheds because in the Sigatoka watershed no large scale structural measure for flood control will be implemented (refer to Supporting Report, Part E). Since there is little area suitable for afforestation in the Nadi watershed due to the pine plantation developed, it is placed at third priority. The afforestation area in the Rewa watersheds is large; however, since the forest cover in the Rewa is relatively high, 70 % of watershed at present, afforestation is not urgently required.

The schedule is planned with the preconditions that the afforestation in the Sigatoka is managed to finish by 2015, and successively the afforestation in the Ba, Nadi and Rewa watersheds is conducted in order by 2063, considering the priorities discussed above and financial capacity of the government. Table-H6.6 shows the annual capital expenditure of Department of Forestry during 1989 ~ 1993 and its average is approximately F$ 2,439,000/year. Assuming that the same amount to the half of the average annual capital expenditure can be newly allocated to afforestation, F$ 1,222,000, the implementation schedule of afforestation was formulated. The result is shown in Table-H6.5 and the annual plantation area would be approximately 13 km^2/year. The schedule of afforestation can be shortened by increasing the budgetary allocation of the Government.

Table-H6.5 Cost and Implementation Schedule of Afforestation

Watershed	Plantation Area (km²)	Cost (F$ 1,000)	2000 99	04	09	2015 14	19	24	29	34	39	44	49	54	59
Rewa	409	38,446													
Sigatoka	233	21,902													
Nadi	47	4,418													
Ba	155	14,570													
Total	844	79,336													
5 Year Progress Rate (%)			7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.6%
Average Plantation Area (km²/year)			13												13
Average Cost of Plantation (F$1,000/year)			1,222												1,203

Notice: The thickness of lines conceptually indicates the weight of distribution of the annual budget (average 13 km²/year), and does not show the actual amount.

Table-H6.6 Annual Capital Expenditure of Department of Forestry

Unit: F$

	1989	1990	1991	1992	1993	Average
Capital Expenditure	2,737,300	2,089,700	2,646,700	2,617,100	2,104,900	2,439,140

Source: Ministry of Finance and Economic Development

Literature Cited

A. Leslie (1988). "Forestry Sector Development Study Fiji, Strategy for Forestry Sector Development," FAO of The United Nations.

American Society of Civil Engineer (ASCE) (1977). "Sedimentation Engineering.", ASCE Manual, No. 54, New York.

Bakker, M.L., & Walsh, A.C. (1976). "Urban Fiji". University of the South Pacific.

Bureau of Statistics (1996). "Current Economic Statistics 1996".

Daniel van R. Claasen Consultant (1991). "Consultancy Report on Deforestation.", Fiji National Environmental Management Project, TA No. 1206-Fiji.

Department of Forestry (1993). "Forestry Information 1993."

Department of Forestry (1995). "Forestry Department 1995 Annual Report."

Devon Nelson (1987). "Land Conservation in the Rewa and Ba Watersheds.", Watershed Management Study, Ministry of Primary Industries Fiji.

Drainage and Irrigation Division (1996). "Drainage and Irrigation Division Briefing Paper June 1996".

FAO (1989). "Forest Sector Development Study, Fiji", Vol. 2. United Nations.

Fiji Pine Limited (1995). "Fiji Pine Limited Annual Report 1995."

Glatthaar, D. (1988). "The Sediment load of the Waimanu River (Southeastern Viti Levu, Fiji).", Report about two research projects in the Republic of Fiji, sponsored by the German Research Foundation (Deutsche Forschungsgemeinschaft, Bonn, Federal Republic of Germany), Geographical Institute, Ruhr-University Bochum, Bochum., pp.52-75.

Government of Fiji and IUCN (1992). "Environment: Fiji The National State of The Environment Report."

International Standards Organization (1977). "Methods for Measurement of Suspended Sediment.", ISO 4363.

Jai S. Gawander (1993). "Sugarcane and Erosion", Network Document No.7, The Management of Sloping Lands in the South Pacific Islands (IBSRAM/PACIFICLAND), pp.25-31.

Land Use Section (1979). "Land Use Capability Classification and Land Inventory System". Ministry of Agriculture, fisheries, Forest and ALTA.

Leone S. Limalevu (1992). "Land Degradation Toge - Naqerelevu Grazing Area Ba Catchment.", Report to the Land Conservation Board (Technical report No.1 (Draft)).

M. R. Hasan (1986). "Watershed Management of Study, Hydrology of Rewa and Ba Watersheds.", Ministry of Primary Industries, Fiji.

MAFFA (1991), "Fiji National Agricultural Census 1991". Ministry of Agriculture, Fishers, Forest and ALTA.

MAFFA (1995), "Annual Report 1995". Ministry of Agriculture, Fisheries, Forest and ALTA.

MAFFA (1996), "Agricultural Statistics 1996". Ministry of Agriculture, Fisheries, Forest and ALTA.

MUDHE (1996). "Fiji's Draft Sustainable Development Bill, Integrated and Consolidated Environmental and Resource Management Legislation". Ministry of Urban Development, Housing and Environment.

PWD (1984). "Suva Water Supply Master Plan Study". Public Works Department.

PWD (1995). "Ba Regional Water Supply Master Plan". Public Works Department.

PWD (1996[1)]). "Nadi-Sigatoka Regional Water Supply Final Master Plan". Public Works Department.

PWD (1996[2)]). "Nadi-Lautoka Regional Water Supply Master Scheme". Public Works Department.

Patrick D. Nunn (1990). "Recent Environmental Changes in Pacific Island.", The Geographical Journal, Vol.156, Part.2.

R. J. Morrison (1981). "Factors Determining The Extent of Soil Erosion in Fiji.", INR Environmental Studies Report No.7, Institute of Natural Resources (University of The South Pacific).

Sugarcane Research Centre (1995). "Soil Conservation.", 1994 Annual Report, Sugar Technical Advisory Mission of The Republic of China to Fiji.

T. Lawson (1993). "MRD Note BP59/2 South-east Viti Levu Landslide Project Preliminary Study.", Mineral Resources Department.

Tabua, S. (1995) "Land Tenure System in Fiji". Native Land Trust Board.

Water Resources Environment Technology Center (1989). "Symposium for Sedimentation in Dam Reservoir Text V.", pp.4-6, Japan.

SUPPORTING REPORT

PART I

COASTAL INVESTIGATION

THE STUDY ON WATERSHED MANAGEMENT AND FLOOD CONTROL FOR THE FOUR MAJOR VITI LEVU RIVERS IN THE REPUBLIC OF FIJI ISLANDS

SUPPORTING REPORT
PART I, COASTAL INVESTIGATION

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

B/C	: Benefit Cost Ratio
BOD	: Biological Oxygen Demand
COD	: Chemical Oxygen Demand
D&I	: Drainage and Irrigation Division, MAFF
DO	: Dissolved Oxygen
DOE	: Department of Environment, MUDHE
DOF	: Department of Forest, MAFF
EIA	: Environmental Impact Assessment
EIRR	: Economic Internal Rate of Return
FAO	: Food and Agriculture Organization of the United Nations
FEA	: Fiji Electricity Authority
FMS	: Fiji Meteorological Service, MTCA
FSC	: Fiji Sugar Corporation
GDP	: Gross Domestic Product
GIS	: Geographical Information System
IEE	: Initial Environmental Examination
INR	: Institute of Natural Resources
JICA	: Japan International Cooperation Agency
MAFFA	: Ministry of Agriculture, Fisheries, Forests and ALTA
MAFF	: Ministry of Agriculture, Fisheries, and Forests
MPWIT	: Ministry of Public Works, Infrastructure and Transport
MRD	: Mineral Resources Department
MTCA	: Ministry of Tourism and Civil Aviation
MUDHE	: Ministry of Urban Development, Housing and Environment
NLTB	: Native Land Trust Board
NPV	: Net Present Value
PWD	: Public Works Department, MPWIT
SOPAC	: South Pacific Applied Geoscience Commission
SPC	: South Pacific Commission
SS	: Suspended Solids
TH	: Total Hardness
TN	: Total Nitrogen
TOR	: Terms of Reference
TP	: Total Phosphorus
UNDP	: United Nation Development Programme
USP	: University of the South Pacific
WHO	: World Health Organization

CHAPTER 1 PRESENT CONDITIONS OF COASTAL AREA

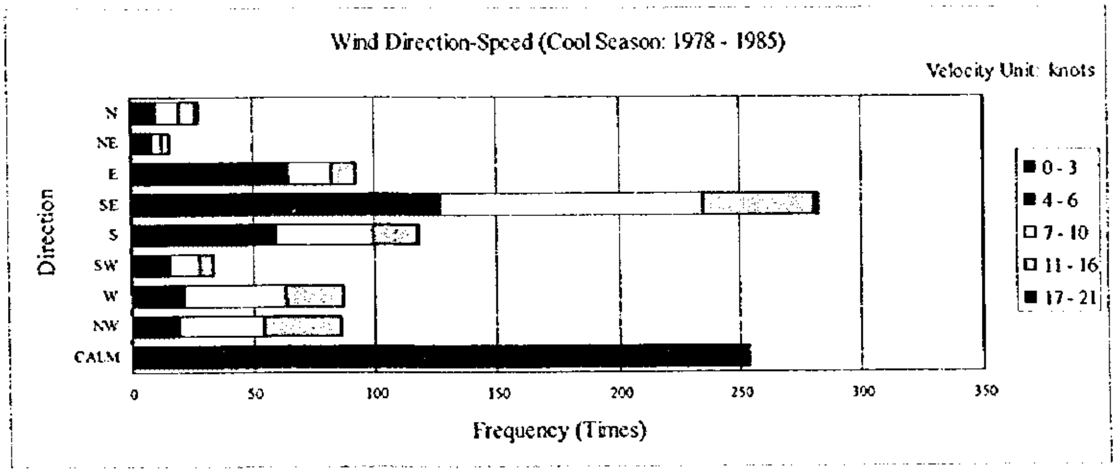
1.1 Wind

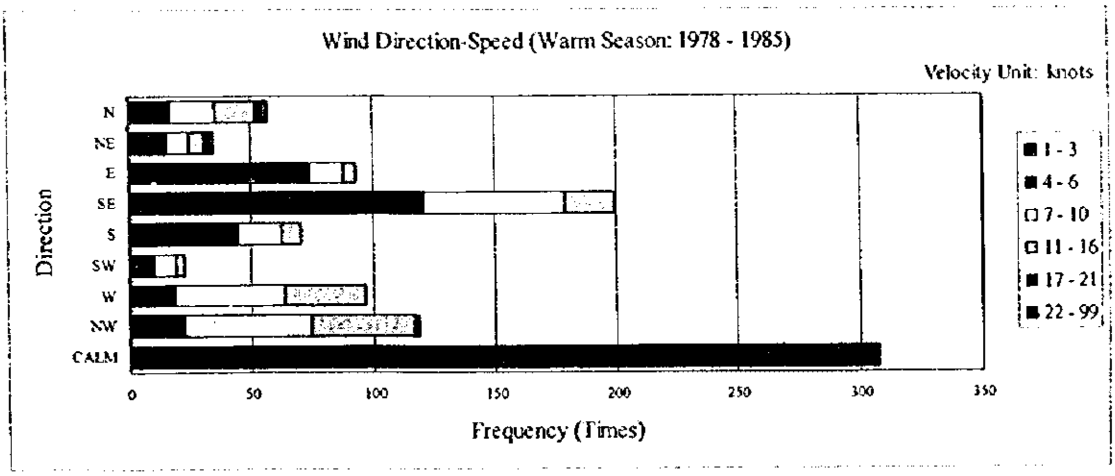
Regarding wind in the Nadi bay area, data is collected at the Nadi international airport adjacent to the bay. Based on eight year record of hourly surface wind speed over the period, 1978 ~1985 (inclusive of cyclone), the following statistics were identified.

In the cool season (from May to October), the predominant directions are East, Southeast and South (approximately 50 %) and the velocity does not exceed 21 knots.

In the warm season (from November to April) when cyclones occur frequently, the frequency of predominant winds during the cool season decreases to about 26 %, while the frequency of wind with directions of West, Northwest and North increases to about 27 %. Wind velocity during the warm season sometime exceeds 22 knots.

Calm conditions are counted approximately 25 % in the cool season, while it exceeds 30 % in the warm season (refer to Figure-II.1).





Data Source: Fiji Meteorological Service

Figure-II.1 Wind Direction - Speed (1978 -1985)

1.2 Tide Levels

Based on tide data at Vuda Point, where is the nearest tidal station to Nadi and located in the northern part of Nadi bay, the relations of the tide levels between in Nadi bay and at Standard Port (Suva harbour) are shown as follows.

Table-II.1 Tide Levels

Description	Vuda Point	Standard Port (Suva Harbour)
Mean High Water Springs	1.70 m	1.60 m
Mean High Water Neaps	1.50 m	1.40 m
Mean Sea Level	0.97 m	0.96 m
Mean Low Water Neaps	0.40 m	0.50 m
Mean Low Water Springs	0.20 m	0.30 m
Chart Datum (CD) and Lowest Astronomical Tide (LAT)	0.00 m	0.00 m
Spring Tidal Range	1.50 m	1.30 m
Neap Tidal Range	1.10 m	0.90 m

Source: Marine Department, 1998

The elevations of land survey on this study are based on the mean sea level at Standard Port in Fiji (Suva Harbour).

1.3 Deepwater Waves

Nadi Bay opens to the west, where sheltered by numerous off-shore islands against waves from the open sea. As waves inside the bay has not been measured, the deepwater wave heights were estimated using the SMB (Sverdrup-Munk-Bretschneider) method. The SMB relations allow the height and period of wind generated waves in deepwaters to be estimated as functions of wind speed, fetch and duration. Average wind speed over 1960 – 1984 is available at Nadi airport, as shown in Table-II.2.

(1) Ordinary sea conditions

The wind velocity in ordinary sea conditions reaches a maximum of 11.4 knots (5.9 m/sec), causing deepwater waves with a height of 40 cm and a period of roughly 2.4 seconds (wind velocity: 5.9 m/sec, fetch: 17 km).

(2) Storms

The report on the extension of the Nadi Airport (Civil Aviation Authority of Fiji, 1994) estimated waves during storm as shown in Table-II.3. Since the method of estimate could not be obtained , figures in the table were not examined by the Study Team.

Table-11.2 Average Wind Speed at NADI Airport (1960 – 1984)

unit: knots

HOUR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	MEAN
0	2.7	2.9	2.9	3.0	3.3	3.2	4.1	4.0	4.1	4.4	3.8	3.3	3.5
1	2.7	2.9	2.7	3.1	3.3	3.2	4.1	4.0	3.9	4.2	3.7	3.3	3.4
2	2.7	2.8	2.6	3.0	3.3	3.2	4.1	4.0	4.0	4.0	3.6	3.1	3.4
3	2.7	2.9	2.6	3.0	3.2	3.1	3.9	3.8	4.0	3.8	3.3	3.1	3.3
4	2.6	2.9	2.6	3.1	3.3	3.2	4.0	3.7	4.0	3.8	3.4	2.9	3.3
5	2.6	2.9	2.8	3.1	3.2	3.1	3.9	3.7	4.1	4.0	3.4	2.9	3.3
6	2.6	2.9	3.1	3.1	3.3	3.4	4.0	3.9	3.9	4.0	3.3	3.2	3.4
7	3.0	3.2	3.1	3.2	3.4	3.3	4.1	3.9	4.1	4.7	4.0	3.9	3.6
8	3.5	3.4	3.4	3.5	3.7	3.4	4.2	4.2	5.0	5.7	4.6	4.4	4.1
9	3.9	3.5	3.3	3.8	4.3	4.1	5.6	5.2	5.6	6.1	5.2	4.9	4.6
10	5.9	5.1	4.1	4.4	4.7	4.7	6.2	6.0	6.9	7.9	6.9	6.8	5.8
11	7.8	7.2	6.3	6.1	6.0	6.5	7.6	7.8	8.7	9.4	9.0	8.8	7.6
12	9.2	8.6	8.2	7.5	7.4	7.9	8.5	9.4	10.2	10.6	10.0	10.0	9.0
13	10.1	9.9	9.1	8.6	8.3	8.8	9.8	10.6	11.2	11.3	11.1	10.8	10.0
14	10.2	10.1	9.2	8.7	8.6	9.0	10.4	10.9	11.4	11.3	11.1	10.9	10.2
15	9.7	9.8	9.0	8.5	8.5	9.0	10.2	10.7	11.2	11.0	10.5	10.4	9.9
16	8.7	8.6	7.6	7.6	7.8	8.3	9.8	9.8	10.3	10.1	9.7	9.7	9.0
17	7.7	7.4	6.7	6.4	6.3	6.8	8.5	8.7	9.2	9.0	8.5	8.7	7.8
18	6.4	6.3	5.3	4.6	4.3	4.6	6.4	6.9	7.3	7.3	7.0	7.1	6.1
19	4.8	4.7	4.1	3.9	3.6	3.8	5.2	5.1	5.2	5.7	5.0	5.3	4.7
20	4.2	4.0	3.5	3.6	3.6	3.6	4.8	4.7	4.6	5.3	4.4	4.4	4.7
21	3.5	3.5	3.3	3.3	3.6	3.6	4.5	4.6	4.5	5.1	4.3	4.3	4.0
22	3.3	3.2	3.2	3.1	3.5	3.5	4.4	4.3	4.3	4.9	4.2	3.9	3.8
23	3.0	3.0	2.9	3.0	3.5	3.2	4.3	4.2	4.1	4.7	4.0	3.5	3.6
Mean	5.1	5.1	4.6	4.6	4.7	4.9	5.9	6.0	6.3	6.6	6.0	5.8	5.5

Source: Fiji Meteorological Service

Table-11.3 Deepwater Wave Conditions

Direction	Return Period (years)	Wind Speed (m/sec)	Wave Height (m)	Wave Period (sec)
W & NW	2	35	2.7	5.7
	5	47	4.4	7.0
	10	56	5.8	8.0
	20	64	7.1	8.8

Source: Civil Aviation Authority of Fiji (1994)

1.4 Storm Surge

Storm surge is defined as the temporary rise in sea level beyond the astronomical tide level during a severe storm, and is composed of pressure or atmospheric set-up, wind set-up and wave set-up.

According to the report on the extension of Nadi airport (Civil Aviation Authority of Fiji, 1994), estimated storm surge is as follows. Since the method of estimate could not be obtained, figures in Table-II.4 were not examined by the Study Team. However, the duplicated application of return period of central pressure and sustained wind speed may cause the large storm surge.

Table-II.4 Storm Surge

Return Period (years)	Central Pressure (Pa)	Sustained Wind Speed (m/sec)	Storm Surge (m)
2	999	35	0.9
5	961	47	1.8
10	946	56	2.4
20	932	64	3.0

Source: Civil Aviation Authority of Fiji (1994)

1.5 Tidal Current

According to the report on the extension of Nadi airport (Civil Aviation Authority of Fiji, 1994), the mean and maximum velocities of tidal currents at the mouth of the Sabeto river and Nadi bay are 4.17 cm/sec and 15.31 cm/sec, respectively. Since those data were collected only at the proposed site for airport extension, the Study Team conducted the tidal current survey in the Nadi bay through subcontract with a local consultant. Its result is discussed in the following chapter. Locations of tidal current survey by the Study Team and by Civil Aviation Authority of Fiji are shown in Figure-II.2.

1.6 Materials of Shore

Properties of beach sand and seabed are available in Civil Aviation Authority of Fiji (1994). Those data were adopted to study the materials of shore.

(1) Grain Size Distribution of Beach Sand

The grain size distribution and materials of the beach sand around the proposed location for the outlet of diversion channel are shown in Table-II.5.

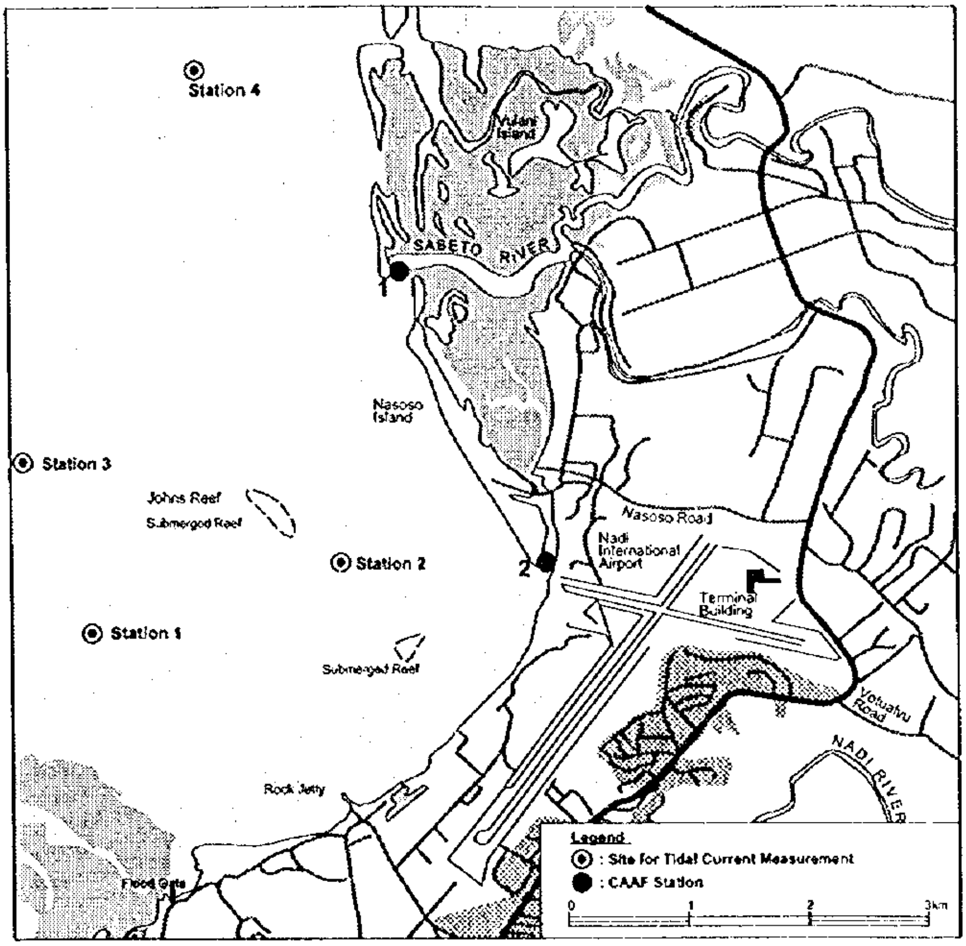


Figure-II.2 Locations of Current Observation by Civil Aviation Authority and Study Team

Table-II.5 Grain Size Distribution

unit: %

Particle Size (mm)	Below mean sea level	At mean sea level	seaward
37.500	100	100	100
26.500	100	100	100
19.000	99	100	100
13.200	99	100	100
9.500	99	100	100
6.700	99	100	100
4.750	98	99	100
2.360	98	99	99
1.180	97	99	99
0.600	95	98	99
0.425	94	95	99
0.300	87	77	97
0.150	25	14	18
0.075	2	3	1

Source: Civil Aviation Authority of Fiji (1994)

(2) Material of Seabed

The materials of seabed vary from clays to gravel but the majority of samples are sandy silts with minor clay and gravel content. The gravel content in the deltaic sediments is an alluvial gravel, while in the marine sediments it is shell and coral debris. There is no indication of variation in grain size with depth.

1.7 Shore Erosion

Since the western shore of the Denarau Island, located in the south of Nadi bay, has been reported to be considerably eroded, the Study Team conducted the field reconnaissance and analysis of aerial photos to assess the effect of the diversion channel and short cut channel on the seashore erosion.

As a result of comparison of aerial photos taken in 1967, 1986 and 1994 at the mouth of Nadi river, there is no significant change in the last 30 years. Besides, the study based on aerial photos and field reconnaissance disagrees with the idea that the littoral drift from the mouth of Nadi river has sent sand to form the western beach of Denarau Island.

Based on the above examination, reduction in sediment transport of Nadi river by the diversion channel is considered not to have significant effect on the shore erosion in the western Denarau Island. The Land and Water Resource Management Division (LWRMD) has planned to conduct a research on the shore erosion at river mouth of Nadi river. It is recommendable to conduct the further study on effect of the diversion channel on the shore erosion based on the research result by LWRMD at the detailed design stage.

Literature Cited

Civil Aviation Authority of Fiji (1994). "Feasibility Study on the Proposed Extension of Runway 09-27 at Nadi International Airport", Fiji.

Marine Department (1998). "Fiji Nautical Almanac 1998", Hydrographic Office, Suva, Fiji.

CHAPTER 2 TIDAL CURRENT SURVEY

To assess the movement of sediment drained from the diversion channel under the sea, the tidal current survey was conducted through subcontract with a local consultant. The method and result are discussed below.

2.1 General Description

The tidal current survey was undertaken in December, 1997 to measure the tidal flow in the Toba ko Nadi (Nadi bay). The current measurement commenced on 30 December,1997 and covered a total period of 25 hours. The two current meters (CM-2 model) were used for the measurement .

Four buoys each rigged with a red flag, a light bulb and a battery were anchored in positions on 29 December, as shown in Figure-I1.2. Coordinates of the 4 buoys were measured by Global Positioning System (GPS).

2.2 Current Measurement

The current measurement commenced at 6 o'clock on 30 December and ended at about 8 o'clock on 31 December 1997, when the tide is the high water springs. The total period of measurement is 25 hours. Flow velocity (once) and direction (three times) were taken at 2 m depth at every one hour interval.

2.3 Tide Level Observation

Tide level observation during the tidal current measurement was also conducted in order to relate the tidal currents with the stage of the tide. Tide level readings were taken from a tide pole installed at the jetty near the airport. The tide pole was leveled to a Bench Mark close by and Lowest Astronomical Tide (LAT) was adopted as the datum.

2.4 Measurement Results

(1) Tide Level

Observed tide levels are shown in Figure-I2.1. Observed high water times were 0640 hours and 1840 hours on 30 December and 0720 hours on 31 December. Heights were 1.83 m, 2.12 m and 1.89 m, respectively.

Observed low water times were 1240 hours on 30 December and 0100 hours on 31 December. The heights were 0.55 m and 0.20 m respectively.

The predicted tide levels based on the tide data at Vuda Point, are also plotted in Figure-I2.1. Times predicted for high and low water can be affected by changes in the force and direction of the wind and by changes in the barometric pressure. In general, the heights are increased with on-shore and decreased with off-shore winds. Sea level rises as barometer falls, and vice versa, approximately 1 cm for each millibar.

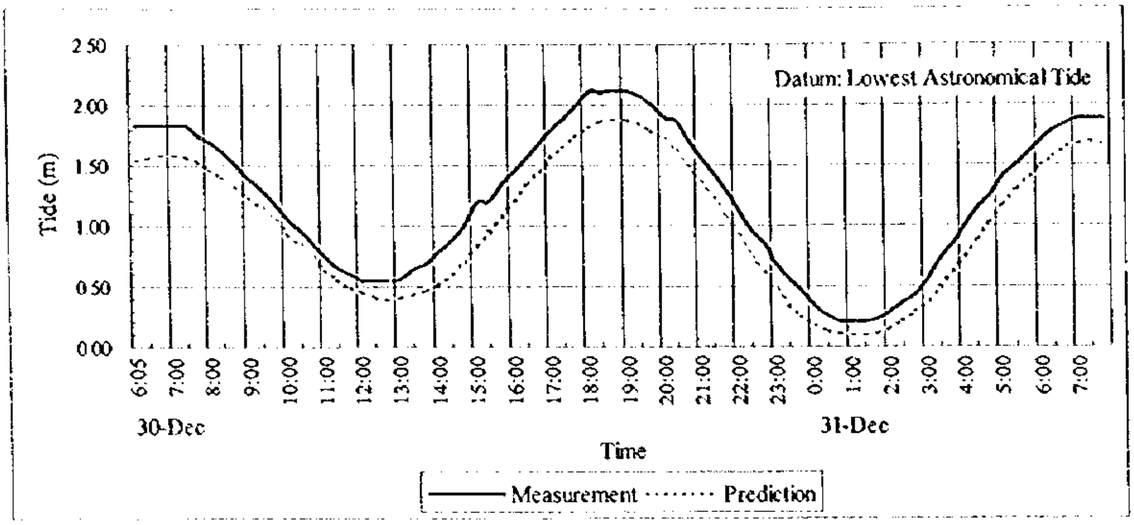


Figure-I2.1 Tidal Observations in Nadi Bay

(2) Current Data

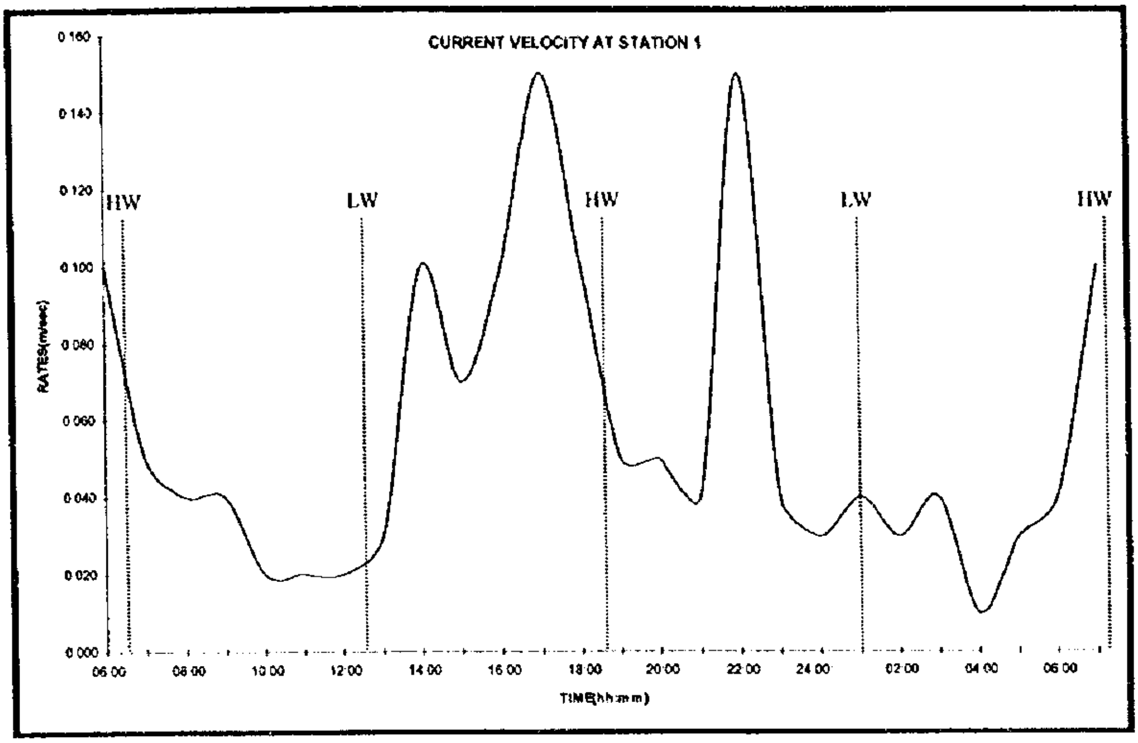
Current velocities of each location are shown in Figure-I2.2. As shown in the Figure, there is no typical relation between current velocities and tide levels.

The mean current velocities over the observed period at each station are summarized in Table-I2.1. The average and maximum velocities at Station 1 and 2 where the sea depth is about 5 m are 0.04 ~ 0.06 m/sec and 0.15 m/sec, respectively. The figures are close to those obtained near the Nadi International Airport (Civil Aviation Authority of Fiji, 1994). On the other hand, those at Station 3 and 4 where the sea depth is about 10 m are 0.11 m/sec and 0.25 m/sec, respectively.

The flow direction was measured together with velocity and the results are shown in Figure-I2.3. The directions are random and have no typical tendency.

Table-I2.1 Current Velocity in Nadi Bay

Item		Station 1	Station 2	Station 3	Station 4
Coordinates		177°23'57.70"E 17°45'24.95"S	177°25'05.66"E 17°44'59.97"S	177°23'19.83"E 17°44'34.5"S	177°24'29.17"E 17°42'54.9"S
Velocity	Average	0.06 m/sec (216 m/hr)	0.04 m/sec (144 m/hr)	0.11 m/sec (383 m/hr)	0.11 m/sec (383 m/hr)
	Maximum	0.15 m/sec (540 m/hr)	0.15 m/sec (540 m/hr)	0.25 m/sec (900 m/hr)	0.25 m/sec (900 m/hr)
	Minimum	0.01 m/sec (36 m/hr)	0.01 m/sec (36 m/hr)	0.04 m/sec (144 m/hr)	0



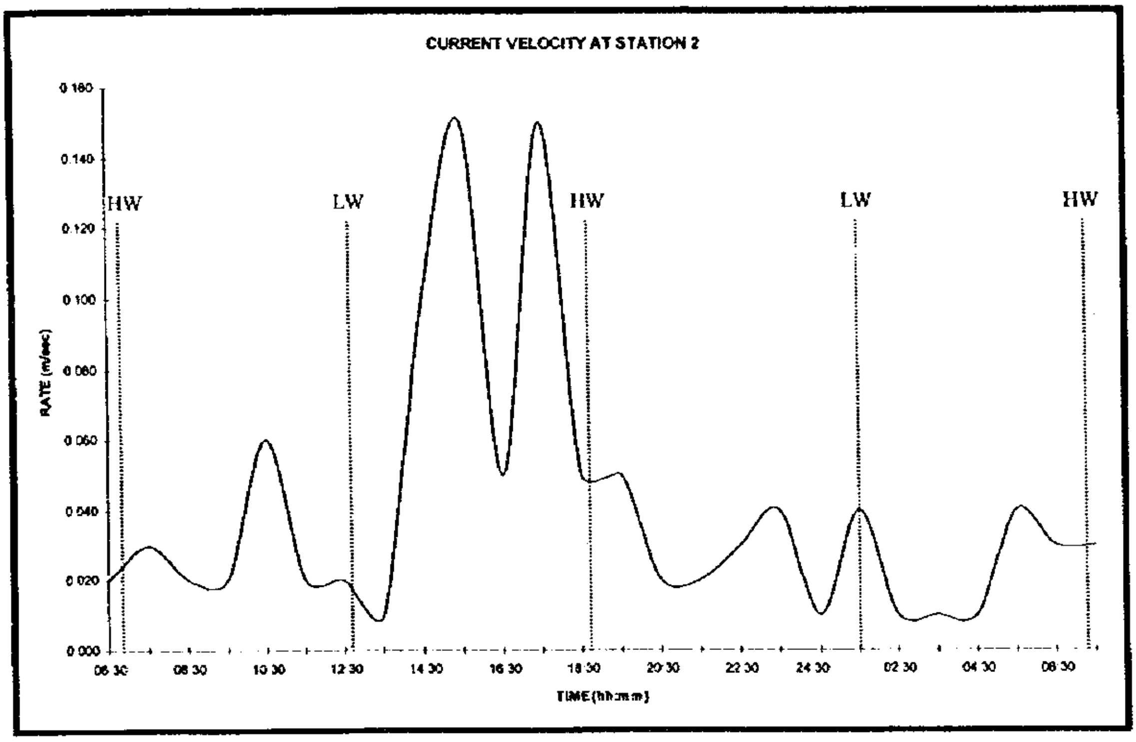
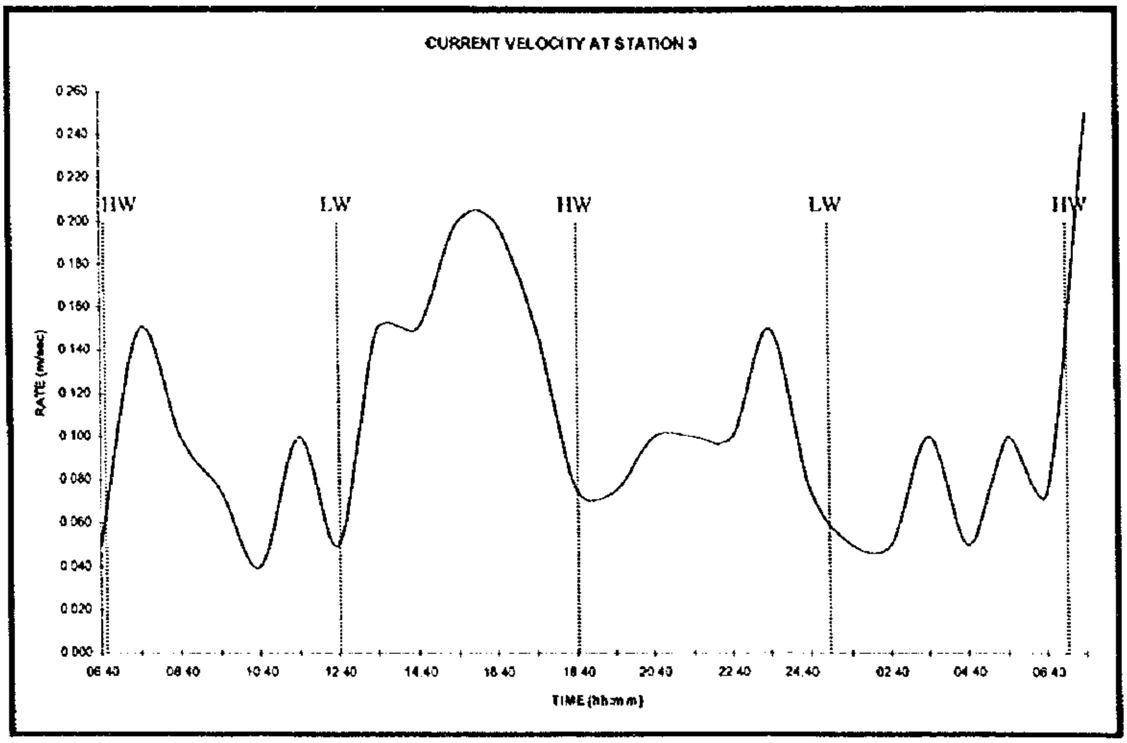


Figure-I2.2 (1/2) Current Velocities at the 4 Stations (Station 1 ,Station2)



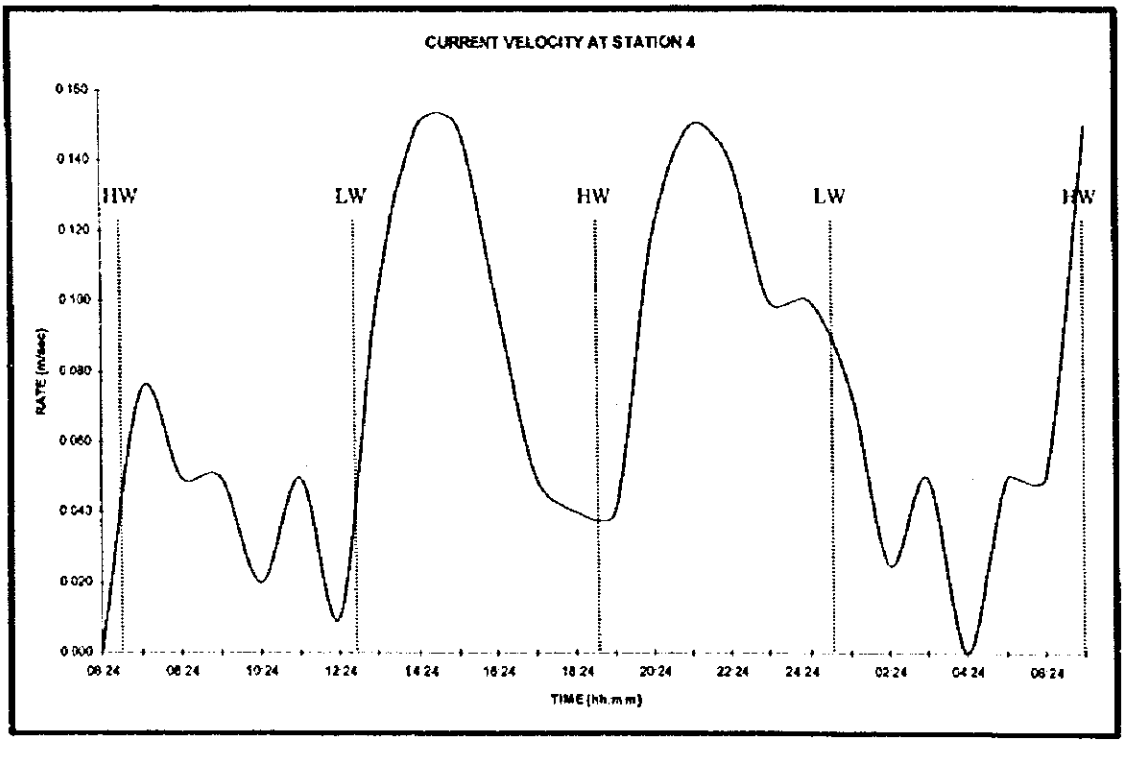
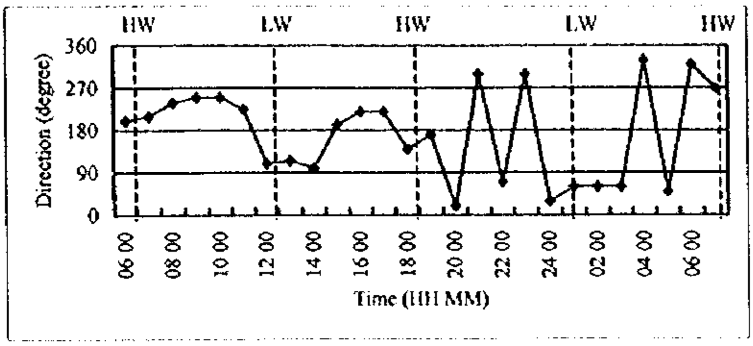
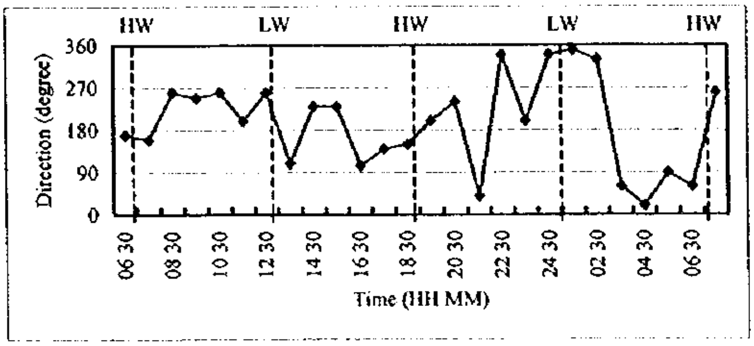


Figure-12.2 (2/2) Current Velocities at the 4 Stations (Station 3 ,Station4)

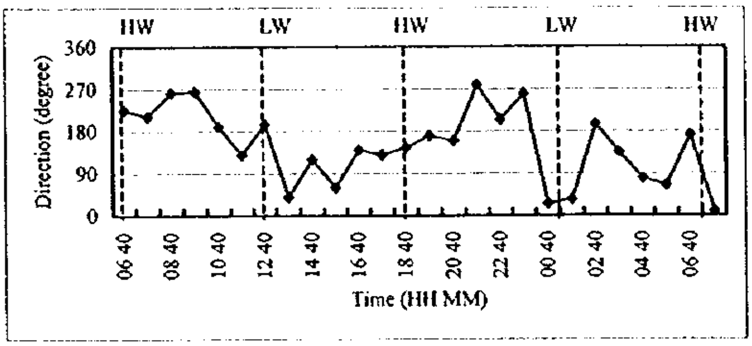
Station 1



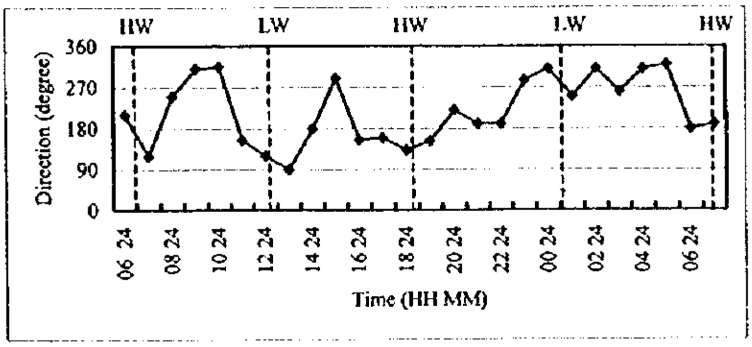
Station 2



Station 3



Station 4



Direction (degree)	0 (360)	from North to South
	90	from East to West
	180	from South to North
	270	from West to East

Figure-12.3 Tidal Directions at the 4 Stations