JAPAN INTERNATIONAL COOPERATION AGENCY

MINISTRY OF AGRICULTURE, FISHERIES AND FORESTS,

THE REPUBLIC OF FIJI ISLANDS

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

FINAL REPORT

MAIN REPORT

October, 1998

Yachiyo Engineering Co., Ltd.

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Exchange Rate

1US$ = ¥115.80 = 1.408F$
(as of July 1, 1997)

PREFACE

In response to the request from the Government of the Republic of Fiji Islands, the Government of Japan decided to conduct the study on Watershed Management and Flood Control for the Four Major Viti Levu Rivers and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Fiji a study team headed by Mr. Yoshio Nakagawa of Yachiyo Engineering Co., Ltd., several times between August 1996 to October 1998.

The team held discussions with the officials concerned of the Government of Fiji, and conducted field surveys at the study area. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Republic of Fiji Islands for their close cooperation extended to the team.

October, 1998

Kimio Fujita
President
Japan International Cooperation Agency

October, 1998

Mr. Kimio Fujita
President
Japan International Cooperation Agency
Tokyo, Japan

Letter of Transmittal

Dear Mr. Fujita

We are pleased to submit to you the study report on Watershed Management and Flood Control for the Four Major Viti Levu Rivers in the Republic of Fiji Islands. The report contains the advice and suggestions of the authorities concerned of the Government of Japan and your Agency as well as the comments made by the Ministry of Agriculture, Fisheries and Forests of the Government of Fiji during technical discussions which were held in Suva, Fiji, in the course of the study.

The report proposes the Master Plan for the watershed management and flood control of the Rewa, Sigatoka, Nadi and Ba watersheds in the Viti Levu island aiming at the target year of 2015. The report also presents the results of the Feasibility Study on the priority project, the diversion and shortcut channel project in Nadi river, which was selected among the projects proposed in the Master Plan.

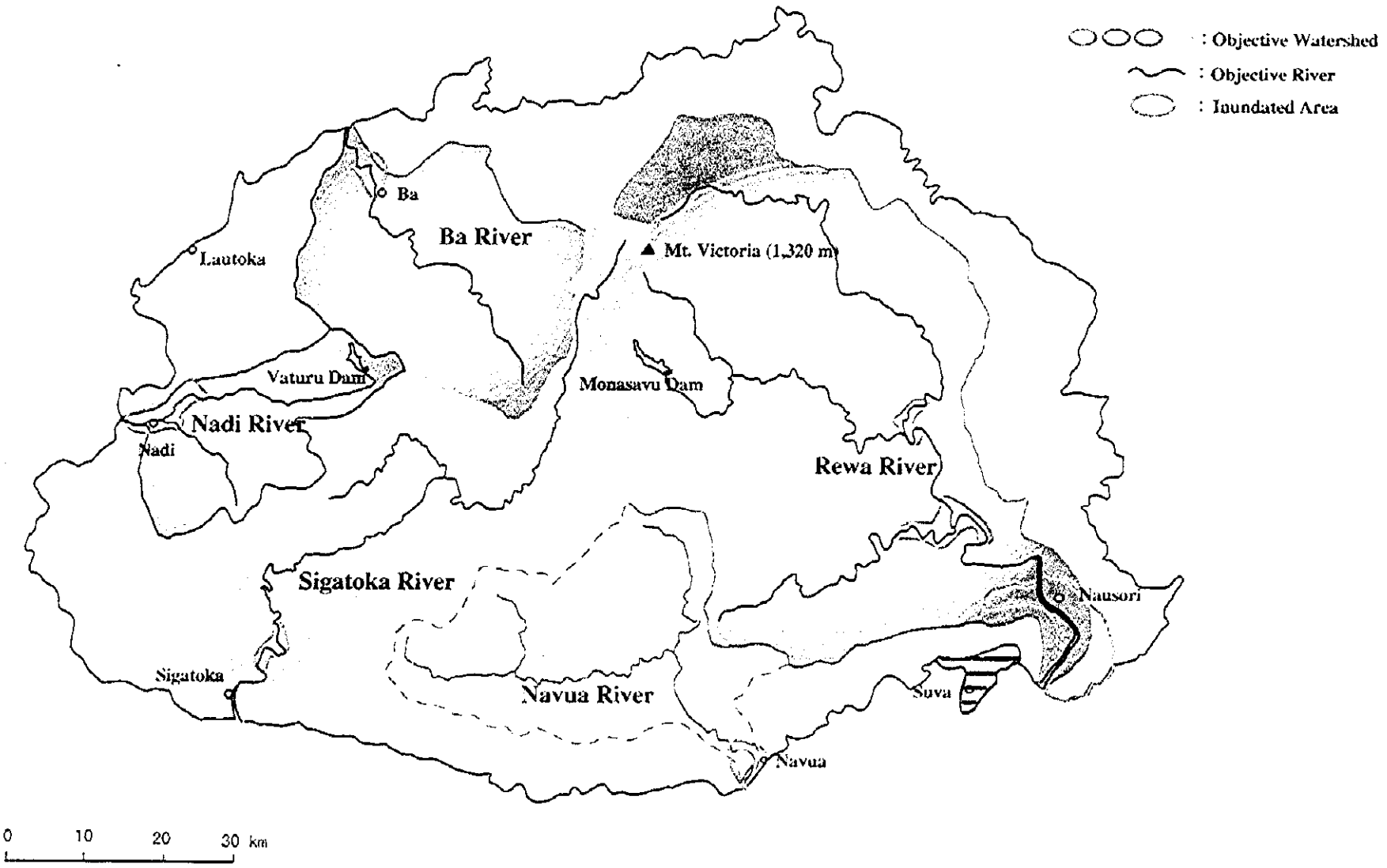
In view of the urgency of flood control and of the need for the socio-economic development in Fiji, we recommend the Government of Fiji to implement the priority project and the Master Plan as soon as possible. It would be a great honor for us that the results of the study would contribute to socio-economic development and public welfare and to closer friendship between Japan and the Republic of Fiji Islands.

We wish to take this opportunity to express our sincere gratitude to your Agency, the Ministry of Foreign Affairs, the Ministry of Construction and the Embassy of Japan in Fiji. We also wish to express our deepest gratitude to the Ministry of Agriculture, Fisheries and Forests and other authorities concerned of the Government of Fiji for the close cooperation and assistance extended to us.

Very truly yours,

Y. Nakagawa

Yoshio Nakagawa
Team Leader
The Study on Watershed Management
and Flood Control for the Four Major
Viti Levu Rivers in the Republic of Fiji


: Objective Watershed
: Objective River
: Inundated Area
Ba
Ba River
Lautoka
Mt. Victoria (1,320 m)
Vaturu Dam
Monasavu Dam
Nadi River
Nadi
Rewa River
Sigatoka River
Nausori
Sigatoka
Navua River
Suva
Navua
0
10
20
30 km

COMPOSITION OF FINAL REPORT

1. SUMMARY

2. MAIN REPORT
   - Part I Master Plan for Four Major Viti Levu Rivers
   - Part II Feasibility Study for Nadi Diversion Channel

3. SUPPORTING REPORT

   Volume-1
   - A. Socio-Economy
   - B. Topography and Geology
   - C. Meteorology and Hydrology
   - D. Runoff Analysis
   - E. Flood Control Plan

   Volume-2
   - F. Surface Water Quality
   - G. Land Use and Regional Development
   - H. Forest and Soil Erosion
   - I. Coastal Investigation
   - J. Environment
   - K. Institution

4. DATA BOOK

SYNOPSIS

The Study on Watershed Management and Flood Control for the Four Major Viti Levu Rivers in the Republic of Fiji Islands

Study Period: August, 1996 – October, 1998
Counterpart Agency: Ministry of Agriculture, Fisheries and Forests

1. Background

Fiji is comprised of more than 300 islands, and has a total area of approximately 18,300 km^2 and a population of about 773,000 (1996 estimate). The largest island is Viti Levu island (10,389 km^2) which covers 57 % of the total area. Viti Levu island is the center of politics and economy of Fiji comprising Suva (the capital), Nadi (the center of tourism) and farming land for sugarcane as the major crop.

In the rainy season from November to April, cyclones with strong wind and heavy rain often hit Fiji causing not only direct damage to residents, houses, crops, social infrastructures but also indirect damage to economic activities, tourism industry and public welfare. Major cities and towns are located near mouths of rivers and the population there has been increasing. With this situation as a background, the Government of Fiji decided to mitigate the flood damages and requested the technical cooperation to the Government of Japan.

2. Objectives of the Study

The objectives of the Study are as follows:

1) formulate a Master Plan for the watershed management and flood control of Rewa, Sigatoka, Nadi and Ba rivers in the Viti Levu island aiming at the target year of 2015
2) implement the Feasibility Study of a priority project selected during the Master Plan Study
3) to promote the technology transfer to the Fijian counterparts during the Study

3. Study Area

The Study Area covers the Rewa, Sigatoka, Nadi and Ba watersheds with total area of around 6,000 km^2 and total population of about 210,000. The area is 58 % of the total area of Viti Levu island, and the population shares 27 % of the total population of Fiji.

4. Master Plan for Watershed Management and Flood Control

(1) Contents and Schedule of the Master Plan

Contents and Schedule of the Master Plan is shown in Table-1. Results of an economic analysis show that structural measures (diversion channel and dike construction) in the Rewa watershed with a design flood of 1/20 probability have low economic viability. Out of the measures, dike construction (total length of 4.5 km) only on the left bank of the Rewa river (design flood of 1/11 probability) is proposed in the Master Plan as the first step of step wise implementation. The dike construction project was found economically feasible.

Dredging in Sigatoka river was not adopted in the Master Plan because of its low economic viability. Although economic return of the afforestation in the upstream of the Sigatoka watershed was also estimated low in the analysis, the afforestation is recommended in the Master Plan because of its economically uncountable benefits, such as prevention of soil erosion, mitigation of sedimentation, conservation of water resources, preservation of water quality, etc.

Table-1 Contents and Schedule of Master Plan

Contents of Master Plan	Cost	Implementation Schedule			
	F$ 1,000	~ 2000	2001 ~ 2005	2006 ~ 2010	2011 ~ 2015
I. Structural Measures					
(1) Rewa River					
Dike (L= 4.5 km), (Step I)	7,350				
(2) Nadi River					
Diversion (L=3.0 km) and Short Cut (L= 0.25 km)	50,950				
(3) Ba River					
Dike (L=13 km)	13,170				
Sub total	71,470				
II. Non-Structural Measures					
(1) Improvement of Land Use Regulation	N.A				
- Zoning and restriction of residence					
- Preservation of land for water retention and retarding					
- Flood proofing					
(2) Flood Forecasting, Alarming and Evacuation					
- Rewa River	1,800				
- Sigatoka River	800				
- Nadi River	300				
- Ba River	500				
Sub total	3,400				
(3) Soil Erosion Control	N.A.				
- Fire prevention					
- Improvement of commercial crop area					
- Agroforestry for small farming					
- Forest belt along river					
(4) Afforestation					
- Sigatoka River (232 km^2)	21,900				
- Nadi, Ba, Rewa River (611 km^2)*	-	(to be implemented after 2015)			
(5) Institutional Improvement	N.A				
- Defining watershed management entities					
- Defining administrative units and establishment of water management committees					
- Reorganization/strengthening of the hydrological section					
- Establishment/strengthening organizations for structural flood control measures					
- Enhancement of preparedness in disaster management (facilitating post damage evaluation)					
- Institutional strengthening for extension of land conservation practices					
- Strengthening the forest and forestry management					
Annual Average Cost (per year)	5,690	8,860		2,910	4,050
Total Cost	96,770	62,010 (64 %)		14,530 (15 %)	20,230 (21 %)

* It may be implemented much earlier than 2015 if alternative finance is available.

(2) Evaluation of Master Plan

1) Economic Evaluation

a) Magnitude of Investment

The average capital expenditure, grant aid and overseas loan of the Central Government are shown in Table-2.

Table-2 Average Capital Expenditure and Foreign Aid

Unit: F$ 1,000/year

	Average Amount (1991-1995)
Government Total	98,000
Infrastructure	40,900
MAFFA	10,700
Grant Aid	5,900
Overseas Loan	19,400

Note: The above figures exclude VAT.
Infrastructure; Ministry of Infrastructure and Public Works (inclusive Marine Dept. and Road Transport Dept.), Dept. of Civil Aviation, and Dept. of Meteorological Service
MAFFA; Ministry of Agriculture, Fisheries, Forests and ALTA inclusive Dept. of Forests

The total capital cost required for implementation of the Master Plan is estimated F$ 96.9 million with the annual average cost of F$ 5.7 million and the maximum annual average cost of F$ 8.9 million to 2005. The annual average cost over the whole implementation period is 6 % of the total capital expenditure of the Government, 14 % of total capital expenditure for infrastructure construction and 29 % of the overseas loan. The magnitude of budget allocation to the implementation of the Master Plan is quite reasonable and possible.

b) Economic Evaluation

The results of economic evaluation for proposed structural flood control measures are shown in the Table-3.

Table-3 Economic Evaluation of Flood Control Measure

Watershed		Rewa	Nadi	Ba
Project		Dike (4.5 km) (Step I)	Diversion (3.0 km) & Short Cut Channel (0.25 km)	Dike (13.0 km)
Economic Benefit	(F$ 1,000/year)	798	8,278	1,446
Project Cost	(F$ 1,000)	6,039	43,794	11,358
Maintenance Cost	(F$ 1,000/year)	2	31	8
EIRR	(%)	13.2	15.1	10.7
B/C	(ratio)	1.31	1.61	1.08
NPV	(F$ 1,000)	1,685	21,143	737

Note: EIRR (Economic Internal Rate of Return), B/C (Benefit and Cost Ratio), NPV (Net Present Value)
Discount Rate: 10 %

The opportunity cost of capital (OCC) in Fiji, a criterion with which EIRR can be compared, is 10 %. Therefore, the proposed three projects are economically feasible and recommendable.

2) Social and Natural Environment Evaluation

The structural and non-structural measures proposed in the Master Plan have much greater positive impact rather than negative impact on environment. Since this Study is at the master plan level, detailed examination of the negative impacts would be difficult. According to the Initial Environmental Examination (IEE), the following negative issues should be examined in detail in feasibility studies.

a) Significant Impacts

- Lands acquisition, compensation and resettlement
- Effect on traffic and living facilities
- Solid waste during earth work
- Sedimentation and ecology in coastal area
- Water pollution

b) Possible Impacts

- Economic activity
- Water right and right of common
- Topography and geography
- Groundwater
- Landscape
- Noise and vibration during construction stage

(3) Recommendations

Recommendations as the result of the Master Plan Study are as follows:

- Step-by-step implementation of the Master Plan
- Review of the Master Plan in every five years corresponding to the socio-economic development of watersheds
- Hydro-power development as a supplement to the Monasavu Power Station, which cannot meet the demand after 2015, and as risk diversification
- Conservation of water quality in rivers
- Enhancement of hydrological observation and analysis
- Accumulation of data on flood damages
- Accumulation of data for watershed management
- Review of land tenure

(4) Selection of Priority Project

Among the projects proposed in the Master Plan, the structural measures were adopted for selection of Priority Project because of their clear and drastic effect on flood damage mitigation compared with the non-structural measures. Factors considered for the selection

are; current flow capacity of river channel, population in beneficial area, total project cost, average annual damage reduction, economic effect, land acquisition and compensation, and impact on social and natural environment. Significance of those factors in each flood control measure was evaluated and classified into four classes from A to D. As a result of an integrated assessment, the construction of Nadi diversion channel and short cut channel was selected as the Priority Project.

5. Feasibility Study on Priority Project.

(1) Contents of the Project

Outline of components and their scales of the Nadi diversion and short cut channel are as follows:

- Diversion Channel: Total length = 3.3 km, Channel width = 100 m
  Earth works = 2.3 million m^3
- Short Cut Channel: Total length = 0.25 km, Channel width = 60 m
- Queens Road Bridge: 10.9 m Width x 120 m Length
- Tramline Bridge: 4.5 m Width x 111 m Length
- Pedestrian Bridge: 2.8 m Width x 93 m Length
- Access Roads: 8.0 m Width x 2.0 km Length x 2 Roads
  (left and right banks of the diversion channel)

(2) Implementation Schedule

Implementation schedule of the Priority Project is shown in Table-4

Table-4 Implementation Schedule of the Priority Project

Item	1st year	2nd year	3rd year	4th year	5th year
Fund Raising					
Consulting Contract					
Detail Design					
Construction Contract					
Construction					
Operation/Maintenance					

(3) Project Evaluation

1) Economic Evaluation

Construction of the Nadi diversion channel and short cut channel will require the project cost of F$ 62.9 million, and bear the annual economic benefit of F$ 8.3 million. The economic internal rate of return (EIRR) of the project was estimated at 14.5 %, the benefit-cost ratio (B/C) is 1.46, and the net present value (NPV) is F$ 21.4 million. The economic feasibility is high, comparing the opportunity cost of capital 10 % in Fiji. The EIRR would be 11.9 % in an unfavorable condition, 10 % decrease in the economic benefit and 10 % increase in the cost. The economic viability holds even in the condition.

Land development of 49 ha for a hotel and high-grade residential lots reclaimed with surplus soil of the diversion channel construction can be combined with the diversion channel. The combined project would accrue a total cost of F$ 71.3 million and enable sales of F$ 22.4 million, resulting in reduction of financial requirement to F$ 48.9 million. The EIRR, B/C, and NPV of the combination project was estimated at 17.2 %, 1.58 and F$ 30.2 million, respectively. The combination would enhance the economic viability of the project.

2) Financial Evaluation

Because of the large scale of the project cost, a large portion of the costs should be funded with overseas loans. When overseas loans with interest rate of 1.7 %, repayments in 25 years including grace period of 7 years are assumed, the total repayment, maximum and average annual repayment would be F$ 67.1 million, F$ 3.8 million and F$ 2.7 million, respectively. The maximum annual repayment and average annual repayment corresponds to 12 %, and 8 % of the average overseas loan repayment (F$ 32.8 million) in the mid-term projection of the government overseas loan repayments (1996-2000).

In parallel with the repayment of the overseas loan, 15% of the project cost, F$ 9.4 million, should be allocated with the government budget. The average cost of F$ 4.7 million over construction period of 2 years accounts for 5 % of average capital expenditure (1991-1995) by the whole Government, and 11% of average expenditure for infrastructure development by the Government (refer to Table-2). The average annual repayment is 3 % of the former and 7 % of the latter. The allocation of this portion can be considered possible. If the land development at soil disposal site is combined, the profit of the land development would be F$ 14.1 million (F$ 22.4 million of sales of developed land minus F$ 8.3 million of cost of the land development). The profits might be enough to cover the cost of F$ 9.4 million.

3) Environmental Impact Assessment

Construction of the diversion channel and short cut channel will largely reduce areas and duration of inundation caused by floods and mitigate direct and indirect flood damage drastically, contributing to socio-economic development and improvement of social welfare in the area. The positive effects would be huge.

Adverse effects on social and natural environment by the project, coupled with the countermeasures against the effects, are discussed in Chapter 18. Recommended countermeasures would adequately cope with the effects. Among them, significant effects would be as follows.

- Resettlement: Before the construction, 36 household would possibly be involved in resettlement. Sufficient negotiation with residents on conditions for the land acquisition and compensation is necessary.
- Topographical and scenic change: The appearance of the diversion channel would cause substantial changes in topographical conditions and the landscape. Land development for parks, a hotel and high-grade residences with sufficient landscape design would better be combined.
- Coastal areas: No particular impacts would be caused by sediment from the diversion channel. No serious impacts are anticipated on flora and fauna.

- Deterioration in water quality: No sensible change in water quality would be resulted in the mainstream. Regular monitoring on intrusion of saline water should be conducted.

(4) Recommendations

Recommendations regarding the project implementation are as follows:

- Immediate implementation of the Priority Project
- Forming consensus for the implementation in the Government and with the residents
- Starting preparation for application of overseas loan
- Starting negotiation for land acquisition and compensation
- Hydraulic model experiment and environmental monitoring
- Promotion of land development combined with diversion construction

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FOR THE FOUR MAJOR VITI LEVU RIVERS
IN THE REPUBLIC OF FIJI ISLANDS

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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 INTRODUCTION

1.1 Background of the Study

Fiji is comprised of more than 300 islands, and has a total area of approximately 18,300 km^2 and a population of about 773,000 (1996 estimate). The largest island is Viti Levu island (10,389 km^2) which covers 57 % of the total area. Viti Levu island is the center of politics and economy of Fiji comprising Suva (the capital), Nadi (the center of the tourism area) and farming land for sugarcane as the major crop.

The annual rainfall varies from 2,500 mm ~ 4,000 mm in the east side and from 1,500 mm ~ 3,000 mm in the west side divided by mountains in the middle of the island. The rainy season from November to April has relatively higher rainfall than the dry season from May to October. In the rainy season, cyclones with strong wind and heavy rain often hit Fiji causing not only direct damage to residents, houses, crops, social infrastructures but also indirect damage to economic activities, tourism industry and public welfare.

The government of Fiji has been implementing a dredging project at the river mouth of Rewa river as the flood mitigation project in accordance with the UNDP study. However, a long term solution has not been achieved yet. Major cities are located on river mouths, and the population of these cities has been increasing. In addition, the Government intends to increase agricultural production and expand the tourism industry. Therefore, countermeasures against flood are urgently required.

With this situation as a background, the Government of Fiji requested the technical cooperation related to the Study on Watershed Management and Flood Control for the Four Major Viti Levu Rivers in the Republic of Fiji (hereinafter referred to as the "Study") from the Government of Japan in December 1994. In compliance with the request, Japan International Cooperation Agency (hereinafter referred to as "JICA") dispatched a Preparatory Study Team headed by Mr. Shin Tsuboka in February 1996, and the Scope of Work and Minutes of Meeting were agreed between the Permanent Secretary of Ministry of Agriculture, Fisheries, Forests and ALTA, and the Leader of the Preparatory Study Team.

With these agreements, a study team headed by Mr. Yoshio NAKAGAWA (Study Team) commenced the Study at the beginning of August 1996.

1.2 Implementation of the Study

Objectives of the Study are as follows:

1) To formulate a Master Plan for the watershed management and flood control of Rewa, Sigatoka, Nadi and Ba rivers in Viti Levu island aiming at the target year of 2015
2) To implement the Feasibility Study of a priority project selected among the Master Plan Study
3) To promote the technology transfer to the Fijian counterparts during the Study

The area covered by the Study is the whole Viti Levu island; however, the Master Plan Study focuses on only the following four watersheds (refer to the figure at frontispiece), Rewa, Sigatoka, Nadi and Ba watersheds, and the study in areas other than the four watersheds is limited to data collection and field reconnaissance.

The Study has been implemented in accordance with the flowchart of Study which is shown in the Appendix-1, for about 27 months from August 1996 to October 1998 by the Study Team under the close cooperation with the Fijian counterparts. The members and the assignment schedule of the Study Team are shown in the Appendix-2. The Government of Fiji organized the Steering Committee and the Technical Committee for the purpose of over seeing the execution of the Study and providing technical guidance to the Study Team, respectively. In the same manner, JICA set up the Advisory Committee to manage the Study effectively. The members of the above committees are also shown in the Appendix-3.

Technology transfer was achieved by joint working of the Study Team and the Fijian counterparts in the course of the Study, by the first and second technical seminars held jointly by the Japanese side and Fijian side, and by participation of three Fijian counterparts in JICA training course in Japan.

The output of the Study was submitted as the Final Report to the counterpart agency, the Ministry of Agriculture, Fisheries and Forests. The Final Report comprise the Executive Summary, Main Report, two volumes of Supporting Reports and one Data Book.

1.3 Acknowledgment

Throughout the Study, the Study Team has been ably supported by the Steering Committee, the Technical Committee and the JICA Advisory Committee which have contributed to the Study by a great deal of helpful assistance and advice. The Team wishes to express sincere gratitude to all members of the Committees in both Fiji and Japan. The Team wishes to thank the Fijian counterparts who worked closely with the Team to ensure that collection of data, field survey and study works were successful, and also the local consultants who undertook surveys and investigation on behalf of the Study Team. Finally, the Team wishes to acknowledge the cooperation and assistance of all who contributed to the Study in terms of data collection or provision of information. Such contributors are too numerous to list, but include many of the Government agencies, semi-governmental agencies and many other individuals and organizations. The Team sincerely thanks all the above officials and individuals who helped to achieved the successful completion of the Study on Watershed Management and Flood Control for the Four Major Viti Levu Rivers in the Republic of Fiji Islands.

CHAPTER 2 TOPOGRAPHY AND GEOLOGY

2.1 Topography

2.1.1 Topographic Features of Viti Levu

Viti Levu is the largest island in the archipelago of the Fiji islands with an area of 10,389 km^2 having an oval shape of length 146 km and breadth 106 km. On Viti Levu, the central mountain range named Nandrau plateau forms a north-south backbone dividing Viti Levu into the western and eastern areas as shown in Figure-2.1.

The Nandrau plateau contains many peaks of over 900 m above sea level, with the highest, Mt. Victoria reaching 1,323 m above sea level. The Nandrau plateau shows highly rugged mountain shape with perpendicular cliffs and pointed peaks.

Highlands which show well rounded hills at elevations of 300 m to 600 m widely spread on both side of the Nandrau plateau. The east highland is covered with dense tropical rain forest. The west highland, on the contrary, is in a dry zone known as talasiga (sun-burnt or barren lands) mainly covered with grass and reed.

Alluvial plains including the coastal plains on Viti Levu are fairly narrow and they quickly merge into low hills. In the delta areas of the main rivers, populations are dense and cultivation such as sugarcane and vegetables is intensive because of the fertility of soils. These areas, however, are flood prone and have suffered from much flood damage.

2.1.2 River System of Viti Levu

The drainage system of Viti Levu consists of five major rivers, namely Rewa, Sigatoka, Nadi, Ba and Navua, and the former four rivers constitute the Study Area as shown in Figure-2.1.

There are two noticeable characteristics found on the river systems in Viti Levu. One of them is that the southern drainage areas occupy the greater part of the island and only small parts are remained for the northern drainage areas.

Another noticeable characteristic is that the gradient of the riverbeds is very gentle from the mouth to the middle reach and abruptly gets very steep in the upper reach as shown in Figure-2.2. The average riverbed gradient of main four rivers is shown in Table-2.1.

Such forms of the riverbeds are normally caused by rapid uplifting of the hills located in the upstream area or sudden regression of sea level. In fact, it is reported that doming and lifting of the island took place in recent geological age (Early Pliocene, 5.0 to 4.5 million years ago) according to Rodda (1984).

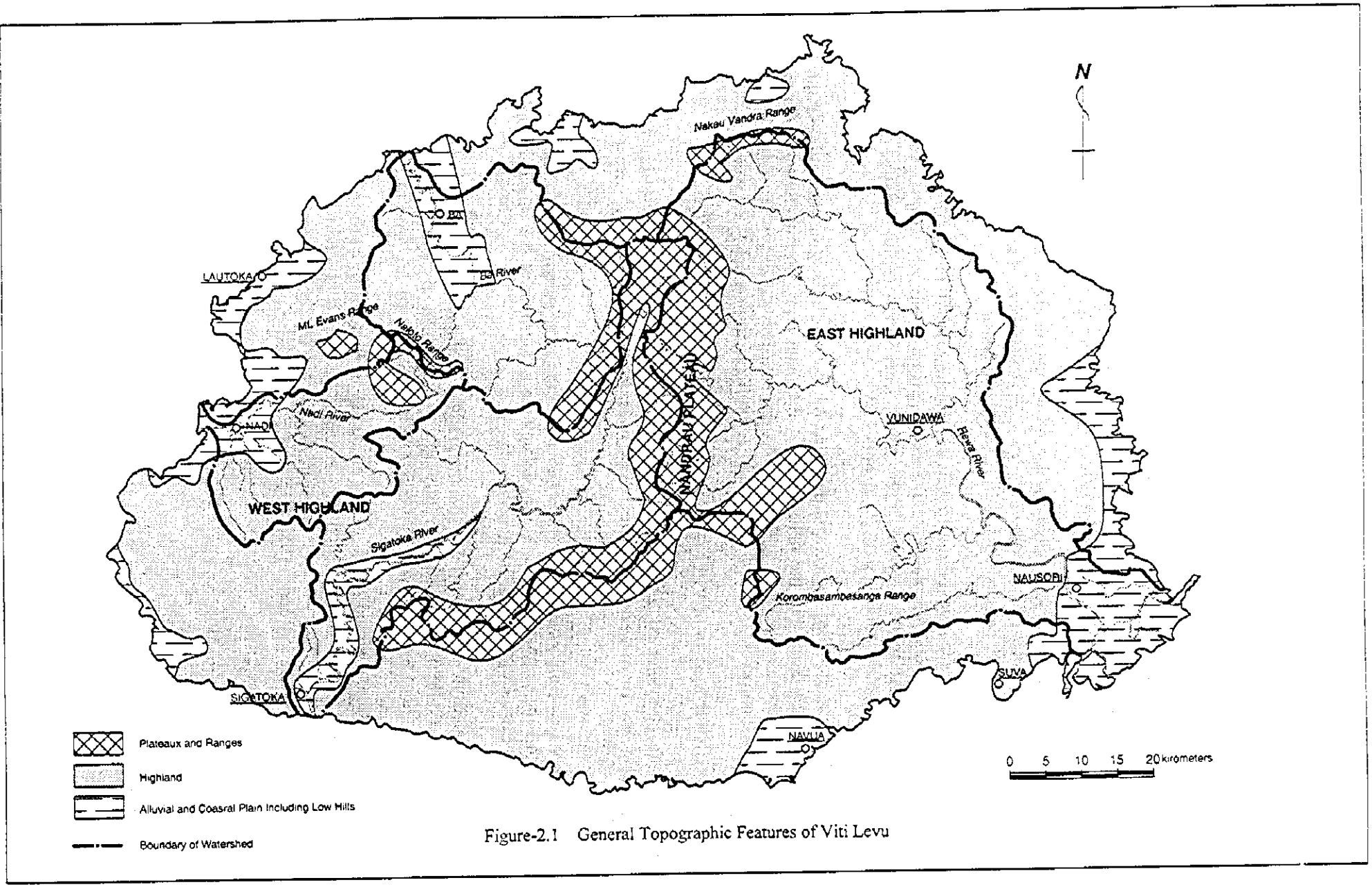
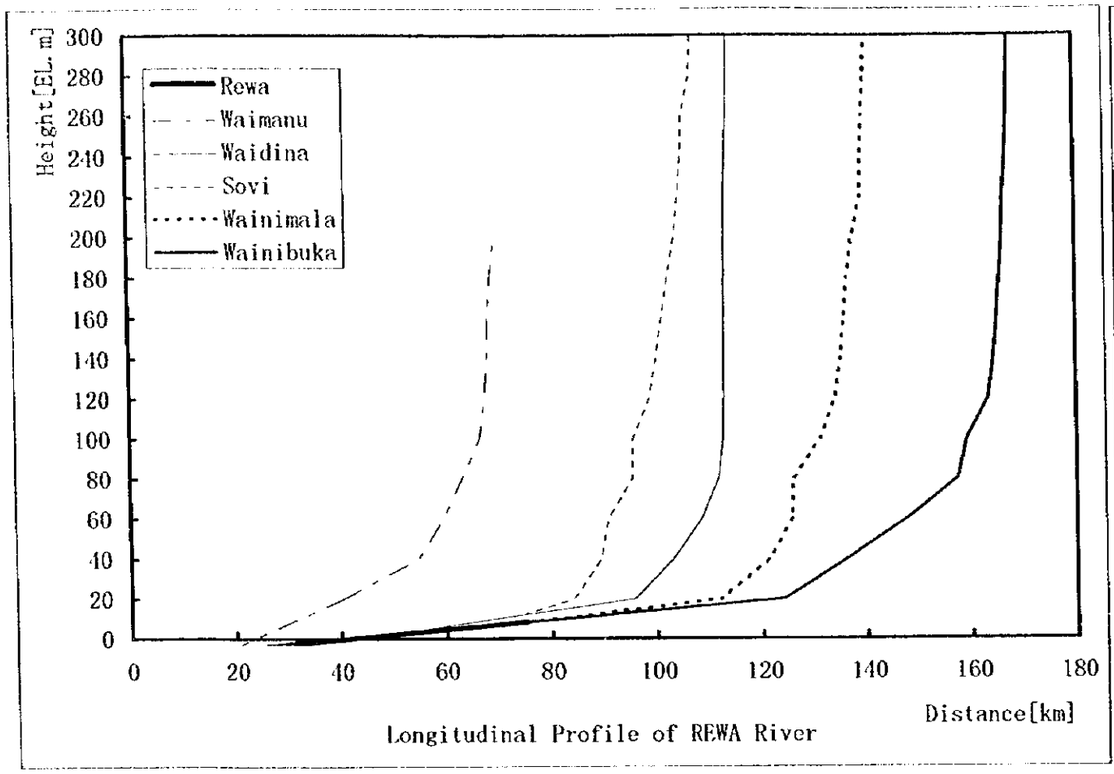
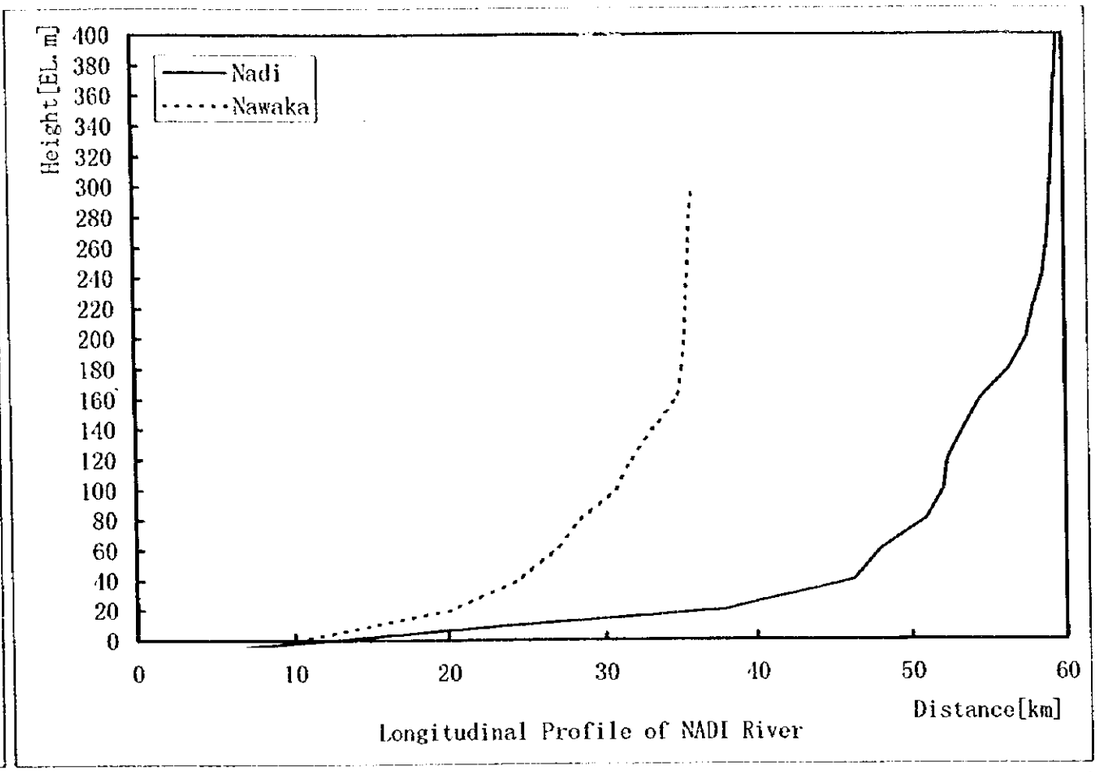
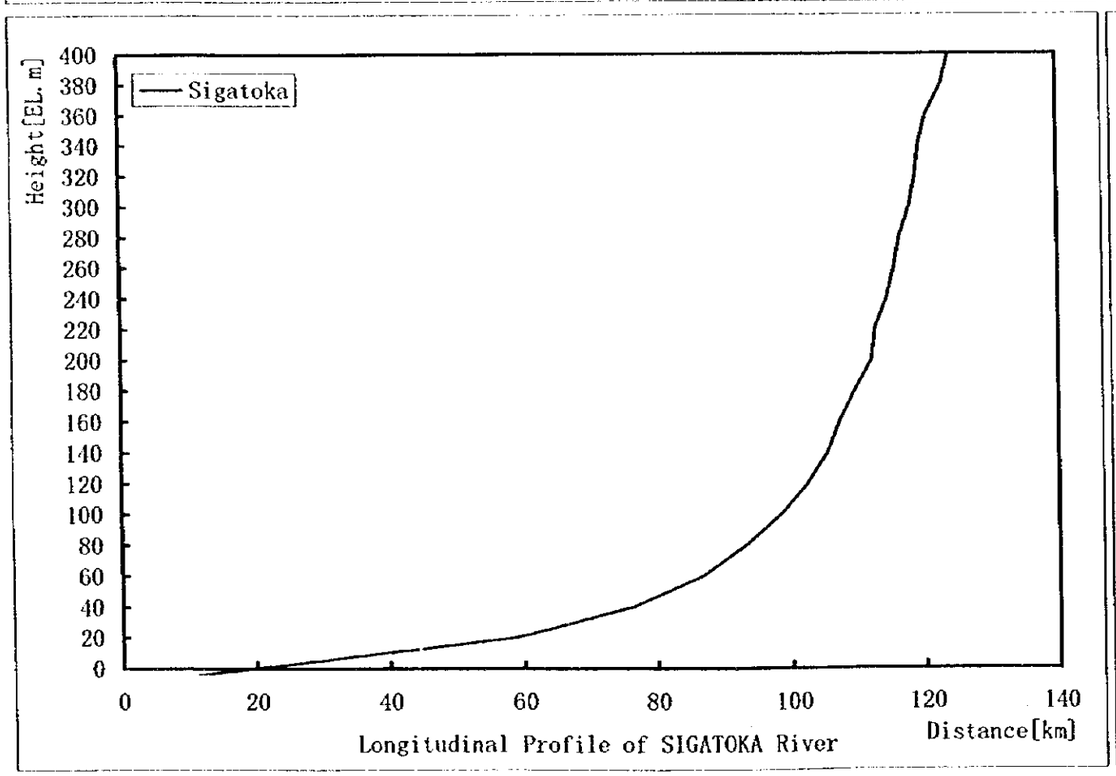


Figure-2.1 General Topographic Features of Viti Levu







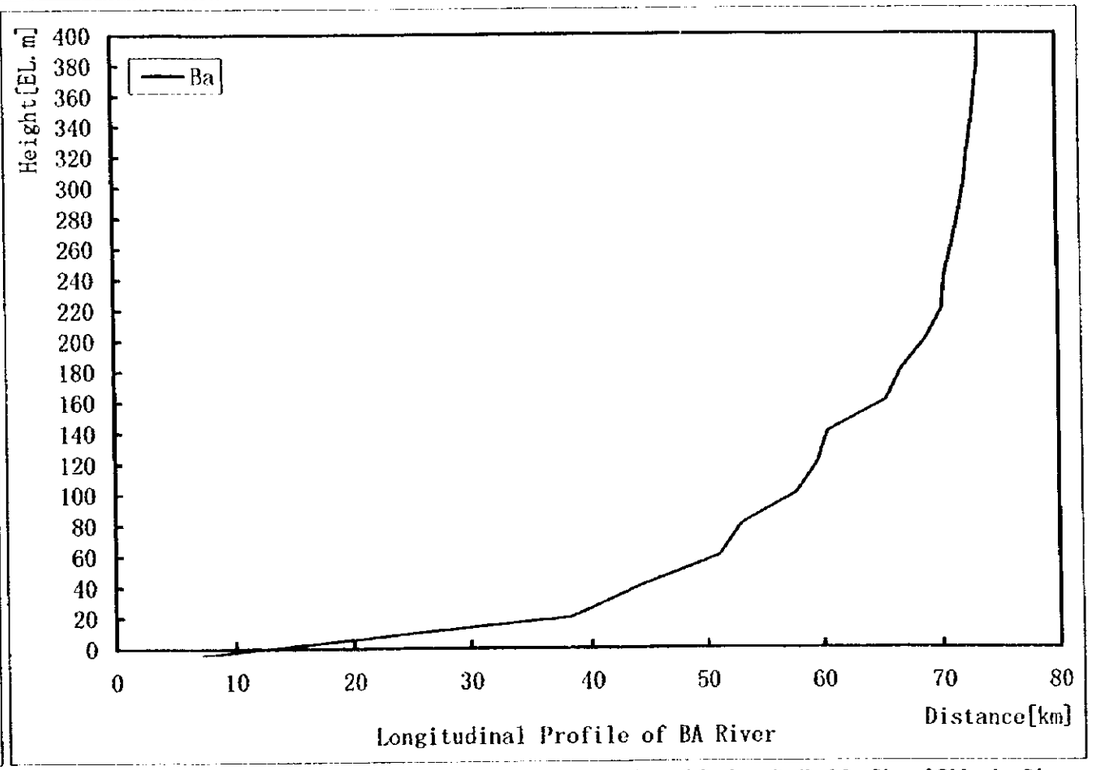


Figure-2.2 Longitudinal Profiles of Objective Rivers

Table-2.1 Average Riverbed Gradient of Four Main Rivers

River	Average Riverbed Gradient		
	Lower Reach[a]	Middle Reach[a]	Upper Reach[a]
Rewa[c]	1/4,400 (0 - 120 km)[b]	1/550 (120 - 160 km)	1/30 (160 - 174 km)
Sigatoka	1/2,000 (0 - 60 km)	1/300 (60 - 110 km)	1/60 (110 - 149 km)
Nadi	1/1,200 (0 - 40 km)	1/120 (40 - 55 km)	1/20 (55 - 69 km)
Ba	1/1,300 (0 - 40 km)	1/200 (40 - 70 km)	1/20 (70 - 83 km)

a : classified based on the longitudinal profile of river
b : Bracketed figures show the distance from the river mouth.
c : Rewa here includes the Rewa mainstream and Wainibuka river.

2.2 Geology

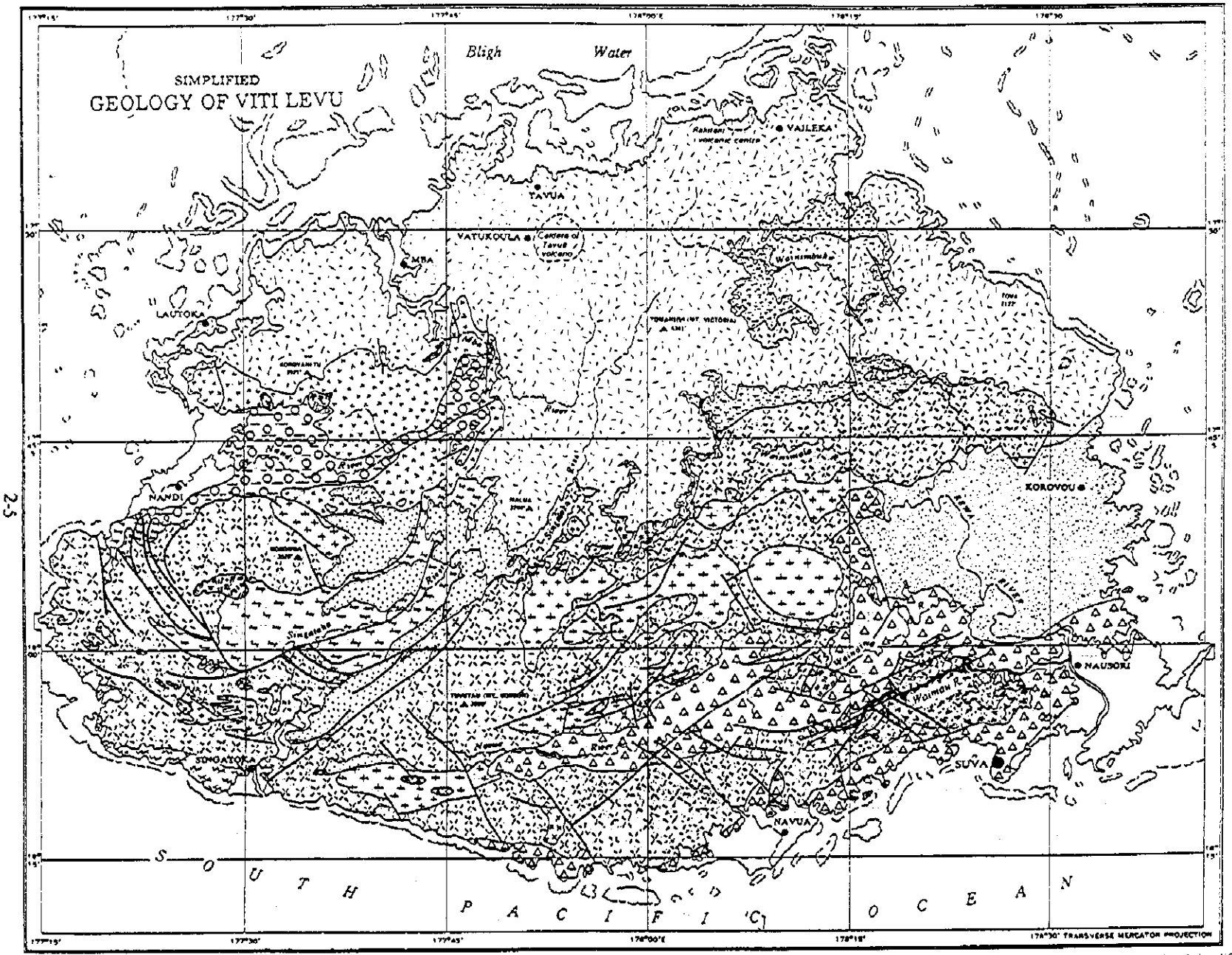
2.2.1 Lithostratigraphy

Fiji archipelago is composed of a complex arc of volcanic rocks, volcanic originated sediments and reef deposits. Viti Levu is the largest island among the Fiji archipelago and also mainly composed of various type of igneous rocks and sedimentary rocks delivered from volcanic rocks dating from the Early Cenozoic (40 to 50 million years ago) to present as shown in Figure-2.3.

Lithostratigraphic units of Viti Levu are briefly summarized below based on the existing geological maps and bulletins (see Literature Cited).

(1) Eocene-Miocene Series

- Wainimala Group : It comprises largely basaltic, andesitic flows and coarse volcaniclastic rocks. It outcrops widely in the southwestern part of Viti Levu.
- Sigatoka Sedimentary Group : It is composed of sandstone, mudstone, various volcanic rocks and massive limestone. Its distribution area is restricted to the middle and upper reaches of the Sigatoka watershed and to the south of Nadi town.
- Savura Volcanic Group : It is composed of andesite lava, rhyolite lava, basalt lava and associated pyroclastic rocks. It is mainly distributed on the right bank of the Waimanu river.
- Ra Sedimentary Group : It is composed of conglomerate, sandstone, mudstone and minor limestone. It is distributed in the upstream of the Rewa watershed.



Note : Compiled and simplified based on 1/250,000 Geological Map, 1966

Figure-2.3 Geological Map of Viti Levu

(2) Miocene-Pliocene Series

- Mendrausuthu Andesitic Group : It is composed of andesite lava, mudstone, sandstone, andesitic volcanic conglomerate, marl and limestone. Its distribution is restricted in southwest of the island showing narrow bands.
- Nadi Sedimentary Group : It is composed of conglomerate, marl and andesitic pyroclastic rocks. It is distributed along Nadi river.
- Navosa Sedimentary Group : It is composed of conglomerate, sandstone, marl and limestone. It is distributed in the upper reaches of the Sigatoka watershed.
- Koroimavua Andesitic Group : It is composed of andesite lava, andesitic pyroclastic rocks and sandstone. It is distributed in the Nadi watershed.

(3) Pliocene-Pleistocene Series

- Ba Basaltic Group : It is composed of basalt lava, basaltic breccia, basaltic conglomerate, sandstone, andesite lava and minor limestone. Its distribution area occupies almost the northern half of the island.
- Verta Sedimentary Group : It is composed of weakly consolidated conglomerate and soft sandstone. It is distributed in the middle course of the Rewa watershed.
- Thuvu Sedimentary Group : It is composed of marl, limestone and conglomerate. Its outcrop area is narrow and restricted to the southeast corner of the island.

(4) Holocene Series (Alluvium)

Alluvium is composed of recent unconsolidated sand, gravel, silt and clay. It forms deltas in the mouth of the main rivers and narrow strips of the coastal plains along the shorelines.

(5) Intrusive Rocks

Intrusive rocks vary from basic to intermediate plutonic rock ranging from gabbro to diorite and tonalite. They are mainly distributed in the southern half of the island.

2.2.2 Geological Structure

As shown in the geological map, the southern part of the island is highly faulted. No major faults, however, can be detected in the northern part of the island.

Faults in NE-SW and NW-SE direction are prominent. It is thought that this fault system was formed by an orogenic phase called "Colo Orogeny" which took place in Middle to Late Miocene (inferred around 12 to 7 million years ago).

After the Colo Orogeny, doming of the island occurred in the Early Pliocene (inferred about 5.0 to 4.5 million years ago). Among the effects of the doming, the present Nandrau plateau was formed and there may have been overall tilting and uplifting of the island reactivating the existing fault system (Rodda, 1984).

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CHAPTER 3 METEOROLOGY AND HYDROLOGY

3.1 Rehabilitation of Raingauge and Gauging Stations

3.1.1 Current Conditions of Raingauge Stations

In Viti Levu, there are 112 raingauge stations (77 automatic recording and 35 manual stations) and 21 meteorological stations operated as of August 1996. Meteorological stations belong to several government authorities, such as FMS (Fiji Meteorological Service), PWD (Public Works Department), Fiji Sugar Corporation and so on. FMS is the agency in charge of collection, review and processing of meteorological data, while raingauge stations mostly belong to PWD.

Observation of rainfall is conducted at both raingauge and meteorological stations. If the total number of these observation stations was compared to the area of Viti Levu (10,389 km^2), the number of stations would be sufficient. However, since the raingauges have been installed for individual purposes, they are located densely in some parts of Viti Levu but sparsely elsewhere. For example, there are more than 30 raingauge stations operated within a radius of 15 km from the Monasavu dam, while the network of raingauge station in western Viti Levu is sparse.

It is essential to have a proper network of raingauges to conduct hydrological analysis. To supplement the lack of raingauge stations, the Study Team has rehabilitated existing stations.

3.1.2 Current Conditions of Gauging (Water Level) Stations

In Viti Levu, there are 7 staff gauge stations and 27 gauging stations with automatic recorders operated as of August 1996. Of the 27 gauging stations, 5 stations (three in the Rewa, one in the Nadi and one in the Ba watershed) are located where there is tidal influence. All gauging stations are operated and maintained by the hydrological section, PWD.

In the Rewa watershed, there are 13 gauging stations (with automatic recorders) operated, while there are only 1 station in the Sigatoka, 3 stations in the Nadi and 3 stations in the Ba watershed. Compared to the Rewa, the gauging stations in western Viti Levu are sparse. Besides, the data availability of these stations is limited due to clogging of observation wells, problems with data loggers and so on.

Discharge data is essential for hydrological analysis. To supplement the lack of data, the Study Team has rehabilitated gauging stations in the target watersheds.

3.1.3 Rehabilitation of Raingauge and Gauging Stations

To supplement the lack of raingauge and gauging stations, the Study Team rehabilitated existing stations through subcontract with a local consultant in the 1st work period in Fiji. Stations for the rehabilitation were determined through the counterpart meeting (2nd Technical Committee Meeting on September 17, 1996). Since PWD stations in western Viti Levu suffer from inadequate or lack of facilities compared to ones of other government authorities or PWD stations in the eastern side, all stations for the rehabilitation works were

selected from the PWD stations in the western side. The location of chosen raingauge and gauging (water level) stations are shown in Table-3.1 and Figure-3.1.

For the rehabilitation of raingauge stations, six stations were selected. The works in general consisted of 1) preparation of site, 2) removal of old facilities, 3) construction of foundation for raingauge, 4) installation and calibration of raingauge and 5) construction of fence.

There are two types of gauging (water level) stations for the rehabilitation. One is the pressure type and the other is the float type. For each type, three stations were selected. The works varied depending on the type of station and location. In general, the works consisted of;

Float type:
- preparation of site
- temporary works (scaffolding)
- removal of old facilities
- repair of observation well, such as de-rusting, painting, desilting, etc.
- repair of recorder shelter
- installation and calibration of water level recorder
- fabrication and installation of staff gauge

Pressure type:
- preparation of site
- installation of pipes for pressure transducer
- construction of recorder shelter
- installation and calibration of water level recorder
- fabrication and installation of staff gauge

Table-3.1 Site for Rehabilitation Works

Works	Station	Station Number	Watershed
Raingauge Station	Korolevu	P101	Sigatoka
	Keiyasi	PA090	Sigatoka
	Moliveitala	PA113	Nadi
	Naboutini	PA008	Others
	Navala	PA172	Ba
	Nagado	PA198	Ba
Gauging Station Float Type	Namoka	HA090	Sigatoka
	Nadi Bridge	LA001	Nadi
	Toge	HA093	Ba
Gauging Station Pressure Type	Nukuilau	HA195	Sigatoka
	Votualevu	HA020	Nadi
	Navala	HA162	Ba

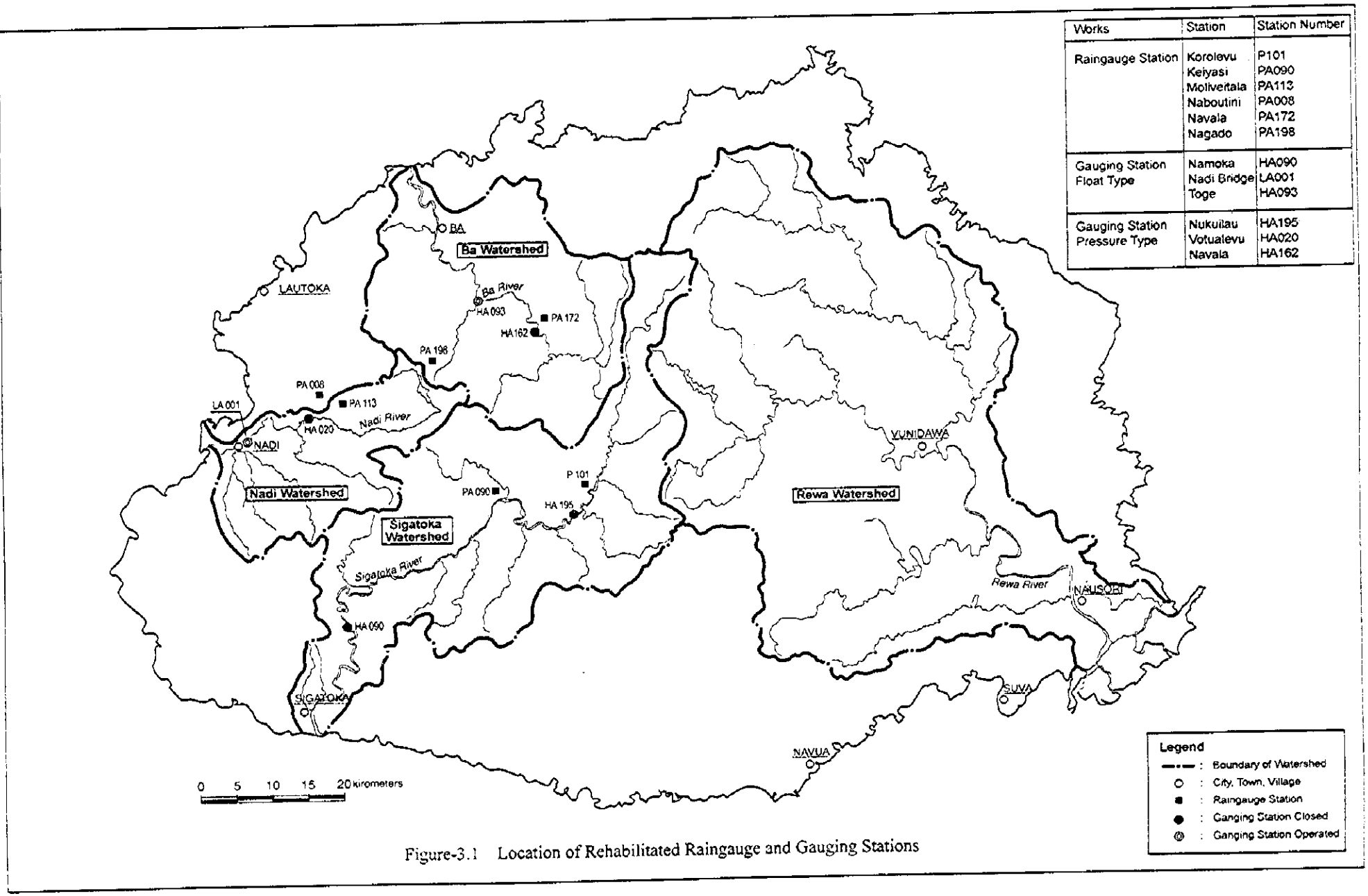


Figure-3.1 Location of Rehabilitated Raingauge and Gauging Stations

3.2 Criteria to Collect Data

Since one of the study objectives is flood control, it is ideal to have meteorological and hydrological data for 50 or 100 years with a dense network of observation stations. However, as discussed in the previous chapter, the availability of these data in Viti Levu is limited. Therefore, as much data as possible were used for the meteorological and hydrological analysis. Criteria to select stations for the collection of data are as follows.

1) The data is available for a long period (at least 20 years).
2) The data is in database. Since the Study does not include formulation of database and data processing takes quite a long time, the data in chart or sheet format is considered as not available.
3) Where stations are located close to others, the station which has the data for the longest period is selected. In Viti Levu, stations are located very densely in some areas for particular projects.
4) The distance between two stations is not far, 20 km at maximum; however it could not be achieved in some parts of Viti Levu due to the limited number of available stations meeting the criteria.
5) The data is available for the same period throughout stations selected inclusive of the year of 1993 when the cyclone Kina occurred.

Using the above criteria, stations were selected for data collection. The number of stations selected varies depending on analysis. For example, 13 meteorological stations were selected for the meteorological analysis, while 28 raingauge stations and 13 meteorological stations were initially selected for the rainfall analysis. Data from 14 gauging (water level) stations were used for the runoff analysis (low water).

3.3 Meteorological Analysis

Considering the availability of data and study objectives, 13 meteorological stations out of the 21 stations operated were selected. Collected data and location of stations are shown in Table-3.2 and Figure-3.2, respectively. All meteorological data was obtained from Fiji Meteorological Service and the data in the last twenty years, 1976 ~ 1995, was analyzed. However, the data availability of each station varies depending on item of meteorological data. Period of available data is specified in the following sections.

3.3.1 Temperature

Monthly maximum, mean and minimum temperatures at each meteorological station were averaged over 1976 ~ 1995. As shown in Figure-3.2, monthly mean daily temperature fluctuates seasonally, the lowest in July (around 22 °C) and highest in February (around 27 °C). However, the fluctuation is small and temperatures range between 20 °C and 30 °C throughout the year.

Table-3.2 Collected Data from Meteorological Stations

Figures show year.

Reference No.	No.	Station Name	River Basin	Observing Authority	Monthly Data				Daily Data	Hourly Data	
					Temp.	Rainfall Total	RH mean	Solar Radiation	Evap.	Rainfall	Surface Wind
35	V77554	Lololo Pine	Other	FPC	72-93	72-93	72-93				
36	V77581	Vatukoula	Other	MM	84-93	36-93	84-93				
34	V77648	Lautoka AES	Other	FSC	30-94	10-96	58-94		79-92		
17	V77744	Nadi Airport	Nadi	FMS	42-95	42-96	42-95	72-96	70-95	during Cyclone	78-85 Ave.
16	V77861	Nausori Highland	Sigatoka	FD	66-95	60-95	66-95				
18	V77931	Nawaicoba Res. Stn.	Nadi	AD	71-93	66-93	71-93				
32	V77932	Nabou Pine	Other	FPC	74-95	73-95	74-95				
40	V78311	Penang Mill	Other	FSC	80-94	10-94			84-92		
38	V78401	Draunlivi	Other	FPC	78-93	78-93	81-93				
9	V78521	Dobuilevu	Rewa	AD	80-94	37-96	No			during Cyclone	
1	V88053	Koronivia	Rewa	AD	65-93	50-93	65-93		79-92	during Cyclone	
24	V88143	Laucala Bay	Other	FMS	42-94	42-94	43-94	83-96	83-95	during Cyclone	
12	V87152	Nacocolevu Res. Stn.	Sigatoka	AD/PWD	38-95	30-96	38-95	87-95	72-95	during Cyclone	
-	V88054	Nausori Airport	Rewa	FMS						during Cyclone	78-85 Ave.

FPC: Fiji Pine Commission, MM: Mines Manager, FSC: Fiji Sugar Corporation, FMS: Fiji Meteorological Service, AD: Agriculture Department, FD: Forestry Department,
MAFFA: Ministry of Agriculture Fisheries Forests and ALTA
Other: river basin in Viti Levu island other than Rewa, Sigatoka, Nadi and Ba
Temp.: maximum, minimum and average daily temperature
Hourly Rainfall during Cyclone: 12/26/92-1/5/93, 12/6/92-12/13/92, 11/24/90-11/30/90, 3/10/85-3/18/85, 1/14/85-1/21/85, 1/14/85-1/19/85, 2/24/83-3/2/83, 1/13/81-1/15/81, 3/24/79-3/28/79
Surface Wind: average
Solar Radiation: global shortwave radiation
Evap.: pan evaporation

Source: Fiji Meteorological Service

Meteorological Station Selected

Ref. No.	Station No.	Station Name	River Basin
1	V88053	Koronivia	Rewa
9	V78521	Dobuilevu	Rewa
12	V87152	Nacocolevu Res. Stn.	Sigatoka
16	V77851	Nausori Highland	Sigatoka
17	V77744	Nadi Airport	Nadi
18	V77931	Nawaicoba Res. Stn.	Nadi
24	V88143	Laucala Bay	Others
32	V77932	Nabou Pine	Others
34	V77648	Lautoka Aes	Others
35	V77554	Lololo Pine	Others
36	V77581	Vatukoula	Others
38	V78401	Drauniivi	Others
40	V78311	Penang Mill	Others

V: Meteorological Station

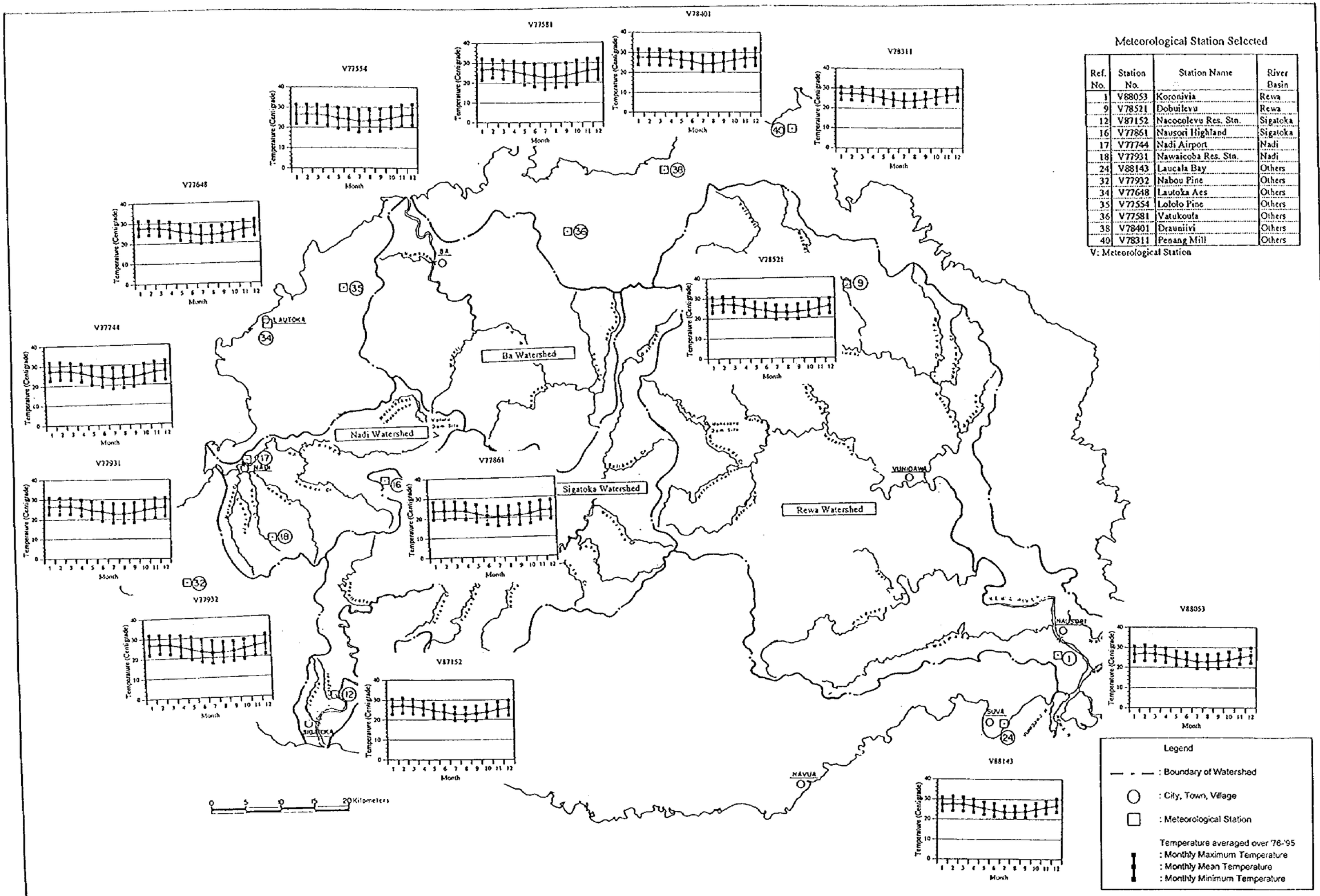


Figure-3.2 Variation of Temperature in Viti Levu

Monthly maximum daily temperature ranges from 26 °C in July at Nausori Highland station to 32 °C in February at Vatukoula station (V77581), while monthly minimum daily temperature ranges from 16 °C in July at Nausori Highland station to 24 °C in February at Penang Mill station (V78311). The difference between maximum and minimum daily temperature is approximately 10 °C throughout the year, indicating that the daily fluctuation is small.

Spatial variation of monthly mean daily temperature is not significant. Nausori Highland station (V77861) shows the lowest temperature compared to other stations; however, this is due to the altitude, 453 m. In general, the higher the altitude is, the lower the temperature is.

3.3.2 Relative Humidity

Mean daily relative humidity for the month is available at 11 meteorological stations out of 13 stations and were averaged over 1976 ~ 1995. As shown in Figure-3.3, relative humidity (monthly mean daily relative humidity averaged over 1976 ~ 1995) in the eastern side of Viti Levu is higher than the western side. Values in the eastern side range between 75 and 85 %, while those in the western side range between 60 and 80 %. This is due to the rainfall distribution, higher in the eastern side and lower in the western side. Although the Sigatoka watershed belongs to the western side, its relative humidity shows a similar tendency to the eastern side.

Seasonal variation of relative humidity is distinct in the western side. It is lower in September to November, while other season is relatively high. For example, relative humidity at Nadi airport (V77744) is more than 70 % from January to July and starts to decline in August. In October, it is the lowest, 62 %.

Relative humidity in the eastern side, especially in the coastal area (Suva and Nausori), does not vary seasonally. It is almost constant at a high relative humidity of around 80 %.

3.3.3 Wind Velocity

Surface wind velocity data is not available in the FMS's database despite the fact that its observation has been conducted. However, the monthly mean velocity of surface wind at Nausori airport (V88054) and Nadi airport (V77744) from 1978 to 1985 is available at FMS. Therefore, this mean value was adopted instead of the raw data.

As shown in Table-3.3, mean surface wind velocity at Nadi airport ranging from 2.2 m/sec to 3.3 m/sec is higher than that at Nausori airport ranging from 1.6 m/sec to 3.0 m/sec. This difference is probably due to the location of the stations. Nadi airport faces the sea, while Nausori airport is located inland. Both stations show higher wind velocity from August to November.

Meteorological Station Selected

Ref. No.	Station No.	Station Name	River Basin
1	V88053	Koronivia	Rewa
9	V78521	Dobuilevu	Rewa
12	V87152	Nacocolevu Res. Stn.	Sigatoka
16	V77861	Nausori Highland	Sigatoka
17	V77744	Nadi Airport	Nadi
18	V77931	Nawaicoba Res. Stn.	Nadi
24	V88143	Laucala Bay	Others
32	V77932	Nabou Pine	Others
34	V77648	Lautoka Aes	Others
35	V77554	Lololo Pine	Others
36	V77581	Vatukoula	Others
38	V78401	Draunitivi	Others
40	V78311	Penang Mill	Others

V: Meteorological Station

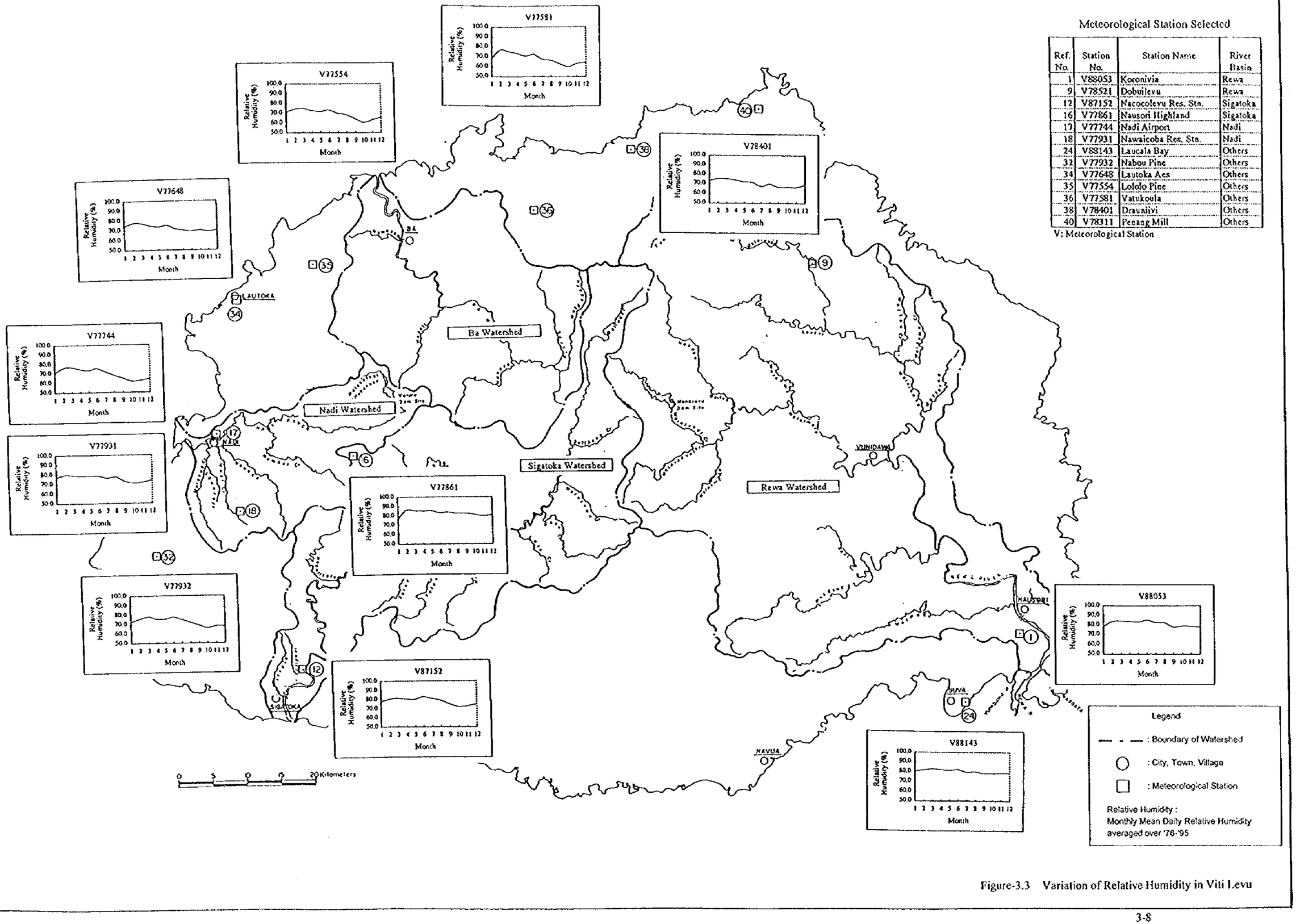


Figure-3.3 Variation of Relative Humidity in Viti Levu

Table-3.3 Mean Surface Wind Velocity, 1978 - 1985

Unit: m/sec

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nadi Airport	2.8	2.5	2.4	2.2	2.5	2.2	2.8	3.1	3.2	3.3	3.2	2.9
Nausori Airport	1.9	1.6	1.7	1.6	1.8	1.6	2.0	2.5	2.3	2.6	3.0	2.1

Source: Fiji Meteorological Service

Surface wind velocity less than 2.0 m/sec is defined as light, and that between 2.0 m/sec and 5.0 m/sec is defined as moderate. Doorenbos and Pruitt (1977) describes wind velocity as follows.

Wind of 2.0 m/sec (light) : Wind is felt on face and leaves start to rustle.
Wind of 5.0 m/sec (moderate) : Twigs move, paper blows away and flags fly.

According to this definition, wind velocity of both stations is categorized as light to moderate throughout the year.

3.3.4 Potential Evapotranspiration

Potential evapotranspiration is generally thought as the maximum rate of evapotranspiration from a large area covered completely and uniformly by an actively growing vegetation with adequate moisture at all times. This definition is ambiguous because potential evapotranspiration can vary with different kinds of crop and with growth stage of the crop. Doorenbos and Pruitt (1977) define reference crop evapotranspiration as evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water. Since reference crop evapotranspiration (ET_p) is preferable, this terminology is used instead of potential evapotranspiration.

As long as temperature, humidity, surface wind and solar radiation data are available, the Penman method provides the most satisfactory results of ET_p computation, based on its wide application all over the world. Therefore, applying the modified Penman method, ET_p was computed as potential evapotranspiration.

As mentioned before, surface wind velocity is available only at two stations, Nadi and Nausori Airports. Therefore, ET_p was estimated for those two stations. Since mean surface wind velocity is available only from 1978 to 1985, other necessary data, such as air temperature, relative humidity and observed solar radiation, were averaged for the same period. Available data at Nausori airport is only mean surface wind velocity. Assuming that the data of stations near the airport does not vary from that at the airport, air temperature and relative humidity were obtained from Koronivia station (V88053) which is about 5 km far from the airport and observed solar radiation was obtained from Laucala bay station (V88143) which is about 15 km far from the airport. However, solar radiation data at Laucala Bay is available only from 1983. Therefore, it was assumed that average values over 1983 ~ 1985 are equivalent to those from 1978 to 1985.

The availability of data limits the validity of estimate. Although this estimate of ET_p is rough due to the lack of data, it is considered good enough to figure out the general characteristics of ET_p in Viti Levu. The results of ET_p estimate are summarized in Table-3.4. Since Nausori airport and Nadi airport are located in eastern and western

Viti Levu respectively, they are good representative to distinguish characteristics of ET_p in Viti Levu.

As shown in Table-3.4, reference crop evapotranspiration (ET_p) is lower from May to July with a range of 3.7 ~ 4.3 mm/day at Nadi and 2.5 ~ 3.0 mm/day at Nausori. Highest values at Nadi are 7.3 mm/day in November and December, while that at Nausori is 5.4 mm/day in January. Annual ET_p is therefore estimated approximately as 2,070 mm at Nadi and 1,480 mm at Nausori.

Dominant factors controlling evapotranspiration are generally energy to evaporate water (net radiation) and drying power of the air (wind function and slope of saturation vapor pressure, in other words relative humidity). Since relative humidity does not vary much and surface wind velocity is light to moderate throughout the year, the governing factor to fluctuate evapotranspiration seasonally is solar radiation. As shown in Table-3.4, ET_p has a similar tendency to observed solar radiation. The fluctuation of observed solar radiation is explained by extraterrestrial radiation in the southern hemisphere which is higher from October to March and lower from April to September.

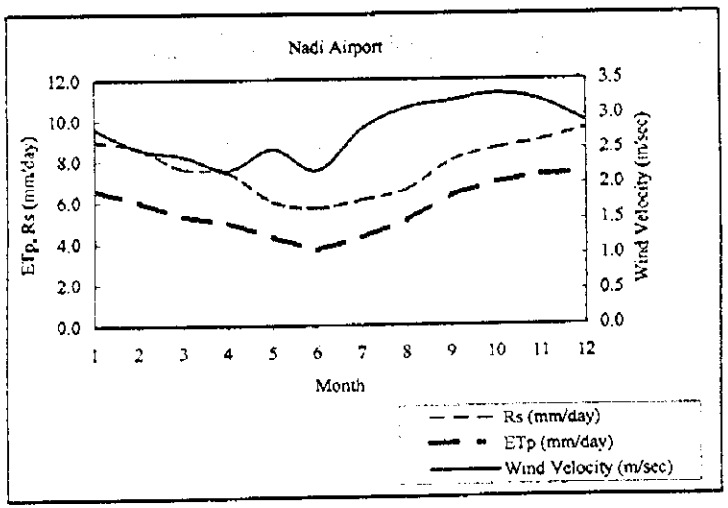
Spatial variation of ET_p is obvious in Table-3.4. ET_p at Nadi located in the western Viti Levu is higher than that at Nausori located in eastern Viti Levu. Observed solar radiation at Nausori is lower than that at Nadi despite the fact that extraterrestrial radiation is same. Since the amount of extraterrestrial radiation depends only on latitude, the difference in observed radiation is due to cloud cover. This corresponds well to the observed rainfall distribution of Viti Levu.

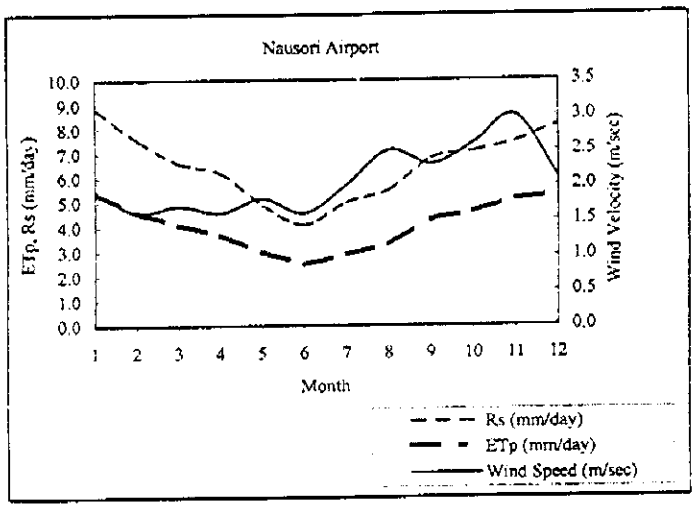
Based on ET_p, evaporation from open water surfaces can be approximated by multiplying by a factor of 1.1 (Doorenbos and Pruitt, 1977). Therefore, annual evaporation from the open water surfaces could be estimated as 2,280 mm at Nadi, and 1,630 mm at Nausori. The multiplier, 1.1, expresses the variation in the reflection of solar radiation.

Table-3.4 Computation of Reference Crop Evapotranspiration by Penman Method

Ref. No.	Station No.	Station Name	Latitude	EL (m)	Meteorological Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Remarks
17	V77744	Nadi Airport	17° 45'S	16	Wind Velocity (m/sec)	2.8	2.5	2.4	2.2	2.5	2.2	2.8	3.1	3.2	3.3	3.2	2.9	78-85
					Ra (mm/day)	17.1	16.5	15.1	13.2	11.4	10.4	10.8	12.3	14.1	15.8	16.8	17.1	
					Ta (°C)	27.3	27.6	27.1	26.5	25.0	24.2	23.3	23.5	24.1	25.3	26.5	26.8	78-85
					RH (%)	71.0	75.1	76.5	74.5	73.5	76.5	72.8	69.4	63.1	64.1	63.1	63.4	78-85
					Rs (MJ/m2)	22.0	21.0	18.7	18.1	14.7	13.9	14.9	16.2	19.7	21.2	22.0	23.6	78-85
					Rs (mm/day)	9.0	8.6	7.6	7.4	6.0	5.7	6.1	6.6	8.0	8.6	9.0	9.6	
					ETp (mm/day)	6.6	6.0	5.3	5.0	4.3	3.7	4.3	5.1	6.3	6.9	7.3	7.3	
-	-	Nausori Airport	-	-	Wind Velocity (m/sec)	1.9	1.6	1.7	1.6	1.8	1.6	2.0	2.5	2.3	2.6	3.0	2.1	78-85
1	V88053	Koronivia	18° 03'S	15	Ra (mm/day)	17.1	16.5	15.1	13.2	11.4	10.4	10.8	12.3	14.1	15.8	16.8	17.1	
1	V88053	Koronivia	18° 03'S	15	Ta (°C)	26.6	27.2	26.9	26.1	24.6	23.9	22.9	22.6	23.3	24.0	25.1	25.8	78-85
1	V88053	Koronivia	18° 03'S	15	RH (%)	81.3	84.1	84.6	84.4	84.0	86.4	84.0	84.8	79.8	80.4	80.4	78.0	78-85
24	V88143	Laucala Bay	18° 09'S	6	Rs (MJ/m2)	21.8	18.7	16.1	15.2	11.9	10.1	12.3	13.5	16.8	17.3	18.3	20.0	83-85
					Rs (mm/day)	8.9	7.6	6.6	6.2	4.9	4.1	5.0	5.5	6.8	7.1	7.5	8.2	
					ETp (mm/day)	5.4	4.6	4.1	3.7	3.0	2.5	2.9	3.3	4.3	4.6	5.1	5.3	

Wind Velocity: surface wind velocity, Ra: extraterrestrial solar radiation, Ta: air temperature, RH: relative humidity, Rs: observed solar radiation,
ETp: reference crop evapotranspiration or potential evapotranspiration, Remarks: years for data extraction
Since Koronivia (V88053) and Laucala Bay (V88143) are close to Nausori airport, it was assumed that the data from these stations is applicable to Nausori airport.
Source: Fiji Meteorological Service for wind velocity, air temperature, relative humidity and observed solar radiation
Doorenbos & Pruitt (1977) for extraterrestrial solar radiation





3.4 Rainfall Analysis

In Viti Levu Island, rainfall is observed at 112 raingauge stations and 21 meteorological stations. Meteorological stations belong to several government authorities, while raingauge stations mostly belong to Hydrological Section, PWD. Considering study objectives and criteria to collect data, 28 raingauge stations and 13 meteorological stations were initially selected as shown in Figure-3.4.

Daily rainfall was extracted for the rainfall analysis and hourly rainfall was extracted for the flood analysis from the stations selected. Since there are gaps in the data from most of the stations, the above 41 stations were re-selected depending on the analysis.

3.4.1 Rainfall Characteristics of Viti Levu

34 stations (12 meteorological stations and 22 raingauge stations) were selected for this analysis due to the data availability. The daily rainfall data in the last twenty years, from 1976 to 1995, was analyzed to understand seasonal and spatial variation of rainfall.

Average monthly and annual rainfall over the last 20 years was computed and annual iso-hyetal map was determined. The results are shown in Table-3.5, Figure-3.5 and Figure-3.6.

(1) Annual Rainfall

As shown in Table-3.5 and Figure-3.5, average annual rainfall over the last 20 years varies from 1,500 mm/year to 4,300 mm/year depending on the location. Spatial variation of annual rainfall is illustrated in Figure-3.5. Rainfall is higher in the eastern side and lower in the western side divided by the central mountain chain.

Rainfall in the Rewa watershed ranges from 2,500 mm/year to more than 4,000 mm/year, while rainfall in the Nadi watersheds ranges from 1,500 mm/year to less than 2,500 mm/year. Since the Sigatoka and Ba watersheds adjoin the central mountain chain, the annual rainfall is distributed higher (4,000 mm/year) in the upstream and lower (1,500 mm/year) in the downstream.

(2) Monthly Rainfall

One of the main characteristics of rainfall distribution in Viti Levu is that rainfall from November to April is relatively high compared to the rest of the year as shown in Figure-3.6. This characteristic is applicable regardless of location; however, this tendency is more distinct in western Viti Levu. Since cyclones generally hit Viti Levu from January to March, monthly rainfall in this season is particularly high.

Monthly rainfall is the lowest in July; however, it still ranges from 30 to 200 mm depending on the location. The eastern side of Viti Levu shows higher rainfall than the western side even during the low rainfall season.

Seasonal variation of rainfall in Viti Levu can be defined that November to April in the following year is the rainy season and May to October is the dry season.

Raingauge Station Selected for Rainfall Analysis

Ref. No.	Station No.	Station Name	River Basin
1	V88053	Koronivia	Rewa
2	PA058	Dravo Res. Stn.	Rewa
#3	PA020	Navolau	Rewa
4	PA011	Namosi Mission	Rewa
5	PA063	Narokorokoyawa	Rewa
6	PA059	Laselevu	Rewa
7	PA131	Tokaravutia	Rewa
8	PA084	Nayavu	Rewa
9	V78521	Dobuilevu	Rewa
10	PA208	Naraviravi	Rewa
#11	PA024	Sigatoka H/W	Sigatoka
12	V87152	Nacocolevu Res. Stn.	Sigatoka
13	PA027	Nalebaleba	Sigatoka
14	PA090	Keiyasi	Sigatoka
15	PA124	Navai	Sigatoka
16	V77861	Nausori Highland	Sigatoka
17	V77744	Nadi Airport	Nadi
18	V77931	Nawaicoba Res. Stn.	Nadi
19	PA122	Salovi	Nadi
20	PA136	Waidamu	Nadi
21	PA002	Ba F/House	Ba
22	PA172	Navala	Ba
23	PA092	Bukuya	Ba
24	V88143	Laucala Bay	Others
#25	PA005	Savura H/W	Others
26	PA072	Nabukavesi	Others
27	PA083	Dauba T/P	Others
28	PA033	Namuamua	Others
29	PA034	Nabukelevu	Others
#30	PA171	Cabe	Others
31	PA081	Vunamoli	Others
32	V77932	Nabou Pine	Others
33	PA008	Naboutini	Others
34	V77848	Lautoka Aes	Others
35	V77554	Lololo Pine	Others
36	V77581	Vatukoula	Others
37	PA054	Tavua F/House	Others
#38	V78401	Draunlvi	Others
#39	PA056	Valeka Depo	Others
40	V78311	Penang Mill	Others
#41	PA190	Naititi	Others

V: Meteorological Station
PA: Rainfall Station with an Automatic Recorder
#: excluded from monthly and annual rainfall analysis

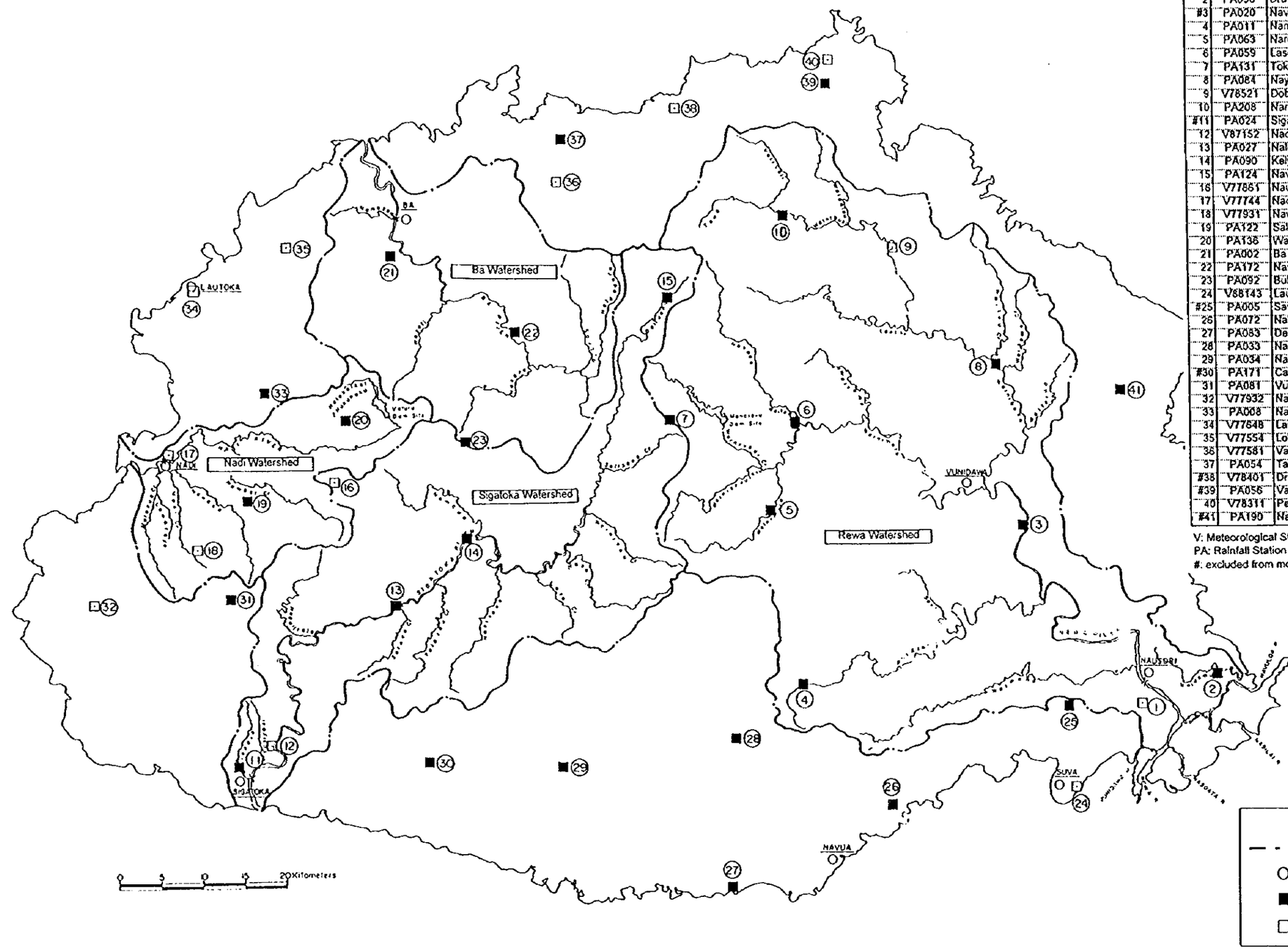


Figure-3.4 Location of Raingauge and Meteorological Stations Selected

Table-3.5 Mean Monthly and Annual Rainfall

Ref. No.	Station No.	Station Name	River Basin	Latitude	Longitude	EL. (m)	Open Date	Mean Monthly Rainfall (mm)												Mean Annual Rainfall (mm)	Modified Mean Annual Rainfall (mm)	Remarks
								Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
1	V88053	Koronivia	Rewa	18°03'S	178°32'E	15	Jan-50	392	302	411	361	254	143	114	166	158	199	219	228	2947		76-95
2	PA058	Dravo Res. Stn.	Rewa	18°01'S	178°36'E	5	Jul-70	327	282	380	319	198	114	79	163	130	147	226	201	2566		76-95
3	PA020	Navolau	Rewa	17°52'S	178°23'E	90	Dec-65															not useful
4	PA011	Namosi Mission	Rewa	18°02'S	178°08'E	107	Mar-67	439	331	410	325	212	164	99	191	125	221	314	307	3138		78-95
5	PA063	Narokorokoyawa	Rewa	17°50'S	178°06'E	195	Jan-71	510	369	611	423	202	150	112	141	159	218	306	392	3593		76-95
6	PA059	Laselevu	Rewa	17°45'S	178°08'E	91	Jan-71	499	337	514	407	201	137	98	135	117	222	301	355	3323		76-95
7	PA131	Tokaravutia	Rewa	17°45'S	178°00'E	1128	Nov-77	451	585	633	500	285	263	213	233	162	236	419	566	4546	4388 (Ref. No. 6)	82-93
8	PA084	Nayavu	Rewa	17°41'S	178°22'E	60	Jan-65	369	291	400	451	201	175	75	130	170	200	260	217	2939	2825 (Ref. No. 9)	76-86
9	V78521	Dobuilevu	Rewa	17°34'S	178°15'E	58	Jul-64	389	330	432	278	120	106	45	87	107	126	179	249	2448		76-95
10	PA208	Naraviravi	Rewa	17°31'S	178°07'E	85	May-80	421	397	482	324	153	126	71	64	75	143	218	284	2758	2717 (Ref. No. 9)	80-95
11	PA024	Sigatoka H/W	Sigatoka	17°07'S	177°29'E	61	Dec-65															not useful
12	V87152	Nacocolevu Res. Stn.	Sigatoka	18°06'S	177°32'E	11	Jan-55	251	251	262	142	82	69	63	79	90	79	99	141	1608		76-95
13	PA027	Nalebaleba	Sigatoka	17°57'S	177°40'E	46	May-66	285	236	254	146	72	55	36	50	65	80	122	180	1581	1532 (Ref. No. 14)	80-95
14	PA090	Keivasi	Sigatoka	17°52'S	177°45'E	70	Jan-71	303	299	323	207	73	64	32	71	78	96	161	185	1892		76-95
15	PA124	Navai	Sigatoka	17°36'S	177°59'E	710	Apr-77	405	431	651	308	147	169	81	129	109	90	229	364	3113	3216 (Ref. No. 36)	82-95
16	V77861	Nausori Highland	Sigatoka	17°49'S	177°37'E	453	Jan-79	363	377	342	204	79	58	39	51	90	80	129	223	2035		76-95
17	V77744	Nadi Airport	Nadi	17°45'S	177°27'E	16	Jan-42	295	300	302	158	83	59	35	55	66	70	103	153	1679		76-95
18	V77931	Nawaicoba Res. Stn.	Nadi	17°56'S	177°22'E	91	Jan-79	304	295	303	186	88	61	59	61	87	88	110	162	1804		76-95
19	PA122	Salovi	Nadi	17°50'S	177°31'E	198	Sep-76	298	369	249	152	88	58	30	52	60	67	121	197	1741	1708 (Ref. No. 17)	81-95
20	PA136	Waidamu	Nadi	17°44'S	177°35'E	850	Dec-77	394	433	481	203	128	93	60	70	72	118	170	269	2491		78-95
21	PA002	Ba F/House	Ba	17°34'S	177°40'E	98	Mar-60	335	385	360	209	89	80	32	57	70	88	101	176	1982		76-95
22	PA172	Navala	Ba	17°39'S	177°48'E	61	Nov-80	287	374	387	136	95	79	31	62	68	71	138	242	1970	1938 (Ref. No. 21)	81-95
23	PA092	Bukuya	Ba	17°46'S	177°45'E	480	Jul-73	380	491	401	252	104	83	49	89	61	81	191	354	2536	2487 (Ref. No. 16)	81-95
24	V88143	Laucala Bay	Others	18°09'S	178°27'E	6	Jan-42	362	278	393	373	251	156	120	170	170	181	225	232	2911		76-95
25	PA005	Savura H/W	Others	18°02'S	178°26'E	163	Jan-61															not useful
26	PA072	Nabukavesi	Others	18°09'S	178°14'E	24	Sep-71	423	351	529	541	383	243	209	290	278	384	383	368	4382		76-95
27	PA083	Deuba T/P	Others	18°15'S	178°03'E	9	Jan-72	316	278	416	327	276	147	168	130	130	196	275	215	2874		76-95
28	PA033	Namuamua	Others	18°05'S	178°03'E	27	May-67	299	408	423	379	215	129	118	145	138	160	286	246	2946		76-95
29	PA034	Nabukelevu	Others	18°07'S	177°52'E	155	Jun-67	334	341	401	287	176	134	97	130	154	131	219	256	2660		76-95
30	PA171	Cabe	Others	18°07'S	177°42'E	426	Sep-80															not useful
31	PA081	Vunamoli	Others	17°56'S	177°29'E	174	Mar-72	401	460	427	240	98	66	44	69	59	92	152	314	2422	2450 (Ref. No. 32)	81-95
32	V77932	Nabou Pine	Others	17°58'S	177°19'E	91	Jan-79	264	301	262	135	82	61	52	59	79	74	78	135	1582		76-95
33	PA008	Naboutini	Others	17°43'S	177°32'E	36	Nov-62	342	358	345	165	79	52	30	49	65	82	116	211	1894		76-95
34	V77648	Lautoka Aes	Others	17°37'S	177°27'E	19	Dec-64	325	309	277	183	68	65	34	58	71	74	92	150	1706		76-95
35	V77554	Lololo Pine	Others	17°34'S	177°35'E	91	Jan-78	335	355	392	207	104	74	34	50	95	80	98	185	2009		76-95
36	V77581	Vatukoula	Others	17°30'S	177°51'E	61	Jan-36	331	380	332	220	64	78	39	65	74	65	93	172	1913		76-95
37	PA054	Tavua F/House	Others	17°26'S	177°52'E	61	Jan-71	251	307	287	181	61	71	37	62	61	69	73	126	1586		76-92
38	V78401	Draunivi	Others	17°25'S	178°00'E	35	Jan-79															not useful
39	PA056	Vaileka Depo	Others	17°22'S	178°09'E	46	Jul-71															not useful
40	V78311	Penang Mill	Others	17°22'S	178°10'E	3	Jan-30	369	329	400	256	127	91	50	69	77	77	138	230	2213		76-95
41	PA190	Natutu	Others	17°42'S	178°30'E	343	Dec-81															not useful

V: Meteorological Station PA: Rainfall Station with an Automatic Recorder

Source: Public Works Department for PA Stations & Fiji Meteorological Service for V Stations

Remarks: This is a period which data was analyzed. There are the data gaps even in this period.
Mean annual rainfall was the average over the specific years.

Modified mean annual rainfall: Mean annual rainfall for the station whose data is insufficient for '76 - '95 was enlarged for '76 - '95. A station used for modification is shown in parenthesis.

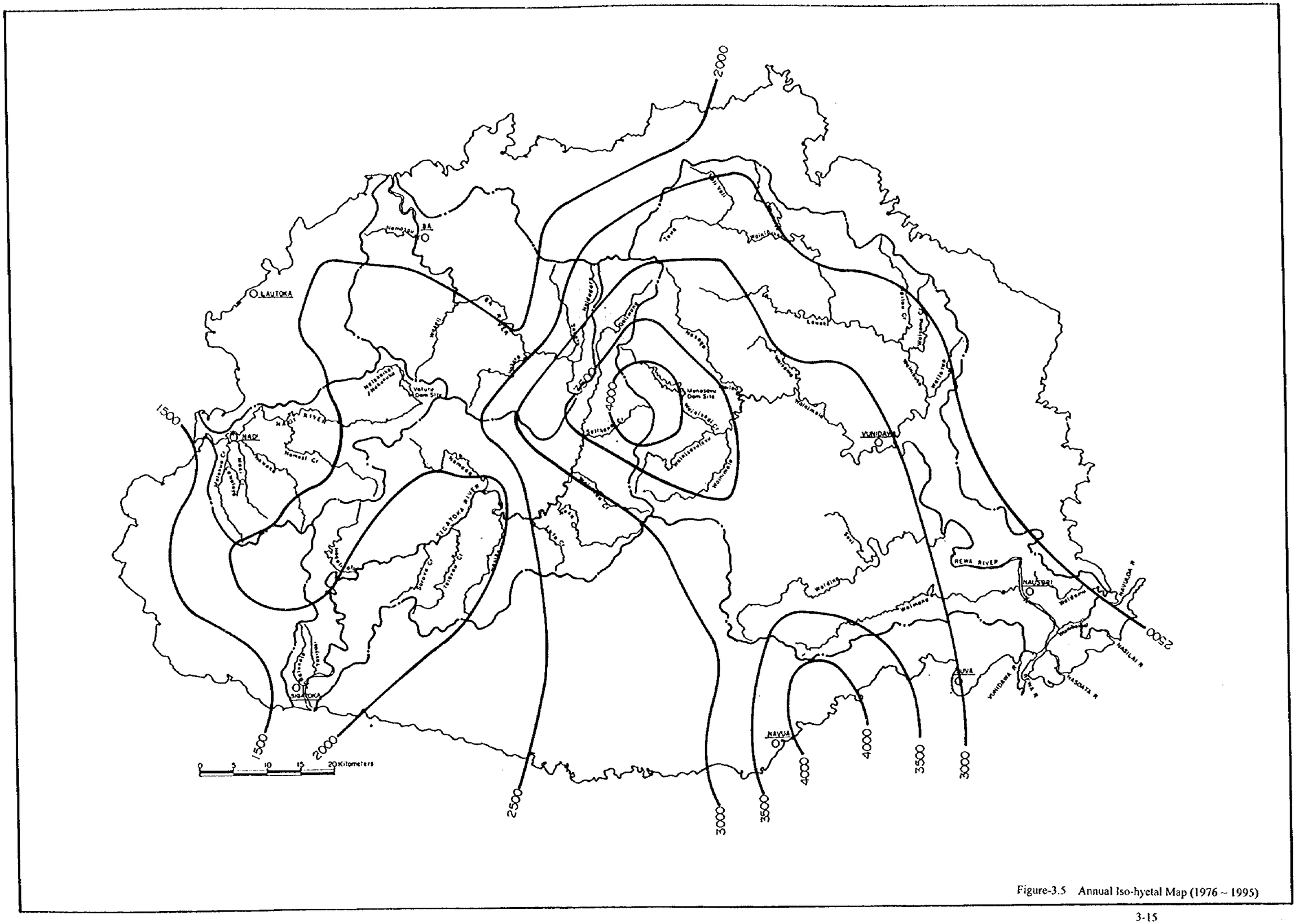


Figure-3.5 Annual Iso-hyetal Map (1976 ~ 1995)

Raingauge Station Selected for Rainfall Analysis

Ref. No.	Station No.	Station Name	River Basin
1	V88053	Koronivia	Rewa
2	PA058	Dravo Res. Stn.	Rewa
#3	PA020	Navolau	Rewa
4	PA011	Namosi Mission	Rewa
5	PA063	Narokorokoyawa	Rewa
6	PA059	Laselevu	Rewa
7	PA131	Tokaravutia	Rewa
8	PA084	Nayavu	Rewa
9	V78521	Dobuilevu	Rewa
10	PA208	Naraviravi	Rewa
#11	PA024	Sigatoka H/W	Sigatoka
12	V87152	Nacocolevu Res. Stn.	Sigatoka
13	PA027	Nalebaleba	Sigatoka
14	PA090	Keiyasi	Sigatoka
15	PA124	Navai	Sigatoka
16	V77861	Nausori Highland	Sigatoka
17	V77744	Nadi Airport	Nadi
18	V77931	Nawaicoba Res. Stn.	Nadi
19	PA122	Salovi	Nadi
20	PA136	Waidamu	Nadi
21	PA002	Ba F/House	Ba
22	PA172	Navala	Ba
23	PA092	Bukuya	Ba
24	V88143	Laucala Bay	Others
#25	PA005	Savura H/W	Others
26	PA072	Nabukavesi	Others
27	PA083	Deuba T/P	Others
28	PA033	Namuamua	Others
29	PA034	Nabukelevu	Others
#30	PA171	Cabe	Others
31	PA081	Vunamoli	Others
32	V77932	Nabou Pine	Others
33	PA008	Naboutini	Others
34	V77648	Lautoka Aes	Others
35	V77554	Lololo Pine	Others
36	V77581	Vatukoula	Others
37	PA054	Tavua F/House	Others
#38	V78401	Draunivi	Others
#39	PA056	Valieka Depo	Others
40	V78311	Penang Mill	Others
#41	PA190	Naibe	Others

V: Meteorological Station
PA: Rainfall Station with an Automatic Recorder
#: excluded from monthly and annual rainfall analysis

Legend
: Boundary of Watershed
: City, Town, Village
: Raingauge Station
: Meteorological Station

Figure-3.6 Seasonal and Spatial Variation of Rainfall

3.4.2 Rainfall Probability

(1) Preparation of Data

Analysis of rainfall probability uses daily rainfall. Since most of stations suffer from gaps in the data, correlation was applied to the daily data in order to fill the gaps.

After filling gaps by correlation, 27 stations (15 raingauge stations and 12 meteorological stations) out of 41 stations were re-selected for the stochastic analysis based on the data availability. The location of these stations are shown in Figure-3.7. Since the longest period of the data covered by all 27 stations is from 1971 to 1994, the analysis was conducted over this period of 24 years.

Thiessen method was applied to determine the mean rainfall of each watershed. The result is shown in Figure-3.7. The mean rainfall of the watershed is the weighted average of Thiessen's polygons in the watershed.

As mentioned in section 3.4.1, seasonal variation of rainfall is distinct, higher from November to April and lower from May to November. Since the successive rainy periods should be considered for the stochastic analysis, the hydrological year was determined as July 1 to June 30 of the following year. For example, 1971 for this analysis means the year July 1, 1971 to June 30, 1972.

The period of the analysis is from 1971 to 1994. It means from July 1, 1971 to June 30, 1995. Since the Study focuses on flood, the annual maximum daily rainfall of each station in the Thiessen polygons was extracted and the weighted values of annual maximum daily rainfall were computed for each watershed. These data were used for the stochastic analysis.

(2) Stochastic Analysis

Logarithmic normal distribution and extreme value distribution (Gumbel) were applied to stochastic analysis of annual maximum daily rainfall. Thomas plot and Hazen plot of each watershed are shown in Figure-3.8.

The result of stochastic analysis is shown in Table-3.6 as the deviation of the above analysis methods from the annual maximum daily rainfall. For the Rewa watershed, either least squares or moment method describes the data well, while the Gumbel method is the most suitable for the other watersheds.

Table-3.6 Mean Deviation from Data

unit: mm

Watershed	Thomas Plot		Hazen Plot		Gumbel
	Least Square	Moment	Least Square	Moment	
Rewa	8.5	8.5	12.1	11.6	15.5
Sigatoka	9.9	10.3	9.9	9.7	8.5
Nadi	14.1	15.1	12.5	12.1	8.3
Ba	18.1	19.5	15.6	16.5	10.3