SUPPORTING REPORT

PART C

METEOROLOGY AND HYDROLOGY

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

SUPPORTING REPORT
PART C, METEOROLOGY AND HYDROLOGY

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 OBJECTIVES OF METEOROLOGICAL AND HYDROLOGICAL ANALYSIS

Since the Study focuses on watershed management and flood control for 4 major Viti Levu rivers, Rewa, Sigatoka, Nadi and Ba rivers, objectives of meteorological and hydrological analysis associated with the Study are;

1) to identify general characteristics of meteorology in Viti Levu
2) to estimate potential evapotranspiration to examine surface water potential
3) to identify characteristics of rainfall distribution in Viti Levu
4) to conduct stochastic analysis of rainfall for flood analysis
5) to identify characteristics of discharge from 4 major Viti Levu rivers for water resource development
6) to process discharge data for flood analysis
7) to rehabilitate raingauge and gauging (water level) stations to supplement the lack of hydrological data

The flowchart of the meteorological and hydrological analysis is shown in Figure-C1.1. Analysis of high water (flood), is a part of hydrological analysis; however, it is discussed in Supporting Report D (Runoff Analysis).

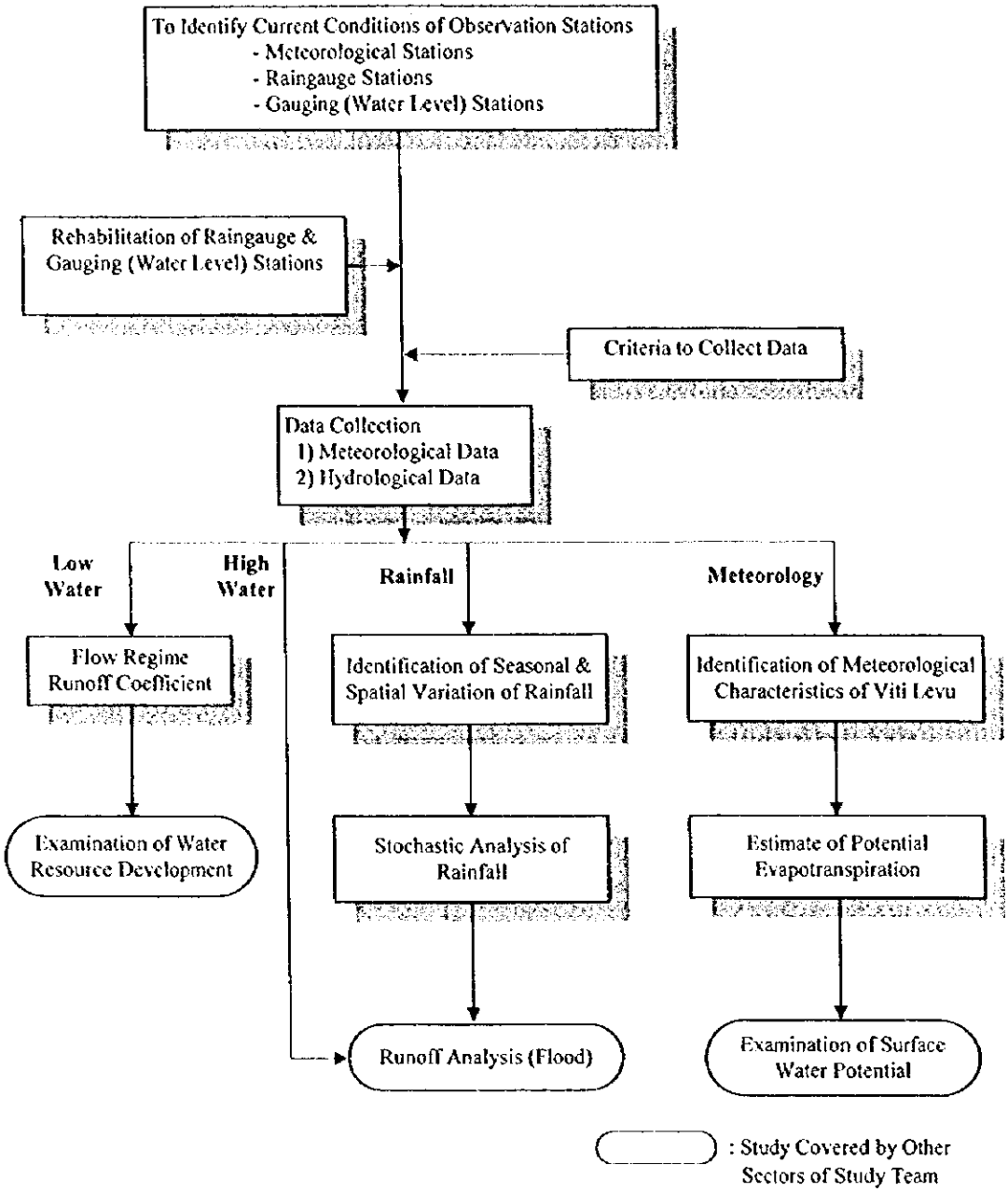


Figure-C1.1 Flowchart of Meteorological and Hydrological Analysis

CHAPTER 2 OBSERVATION STATIONS

2.1 Existing Meteorological Stations

In Viti Levu, there are 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.

Items of meteorological observation vary depending on station. Considering the Study objectives, the data availability of 7 items (temperature, rainfall, evaporation, relative humidity, sunshine hours, surface wind and solar radiation) was checked as shown in Table-C2.1. Observation of evaporation, sunshine hours and solar radiation is limited to 6 ~ 11 stations, while other 4 items have been observed at almost all stations.

Although FMS has been trying to process the raw data into database systematically, there are still lots of data in the form of chart or sheet, except rainfall. As long as the data are on chart or sheet, it is difficult to use them. Since the meteorological data are very valuable for the development of Fiji, the data processing by FMS should be promoted.

2.2 Existing Raingauge Stations

In Viti Levu, there are 112 raingauge stations (77 automatic recording and 35 manual stations) operated as of August 1996 as shown in Table-C2.2. The 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.

Hydrological section, PWD, maintains the above raingauge stations and is in charge of collection, review and processing of rainfall data. Since raingauge stations have been installed for particular projects but not for hydrological analysis of the whole Viti Levu, the hydrological section has faced difficulty to maintain the raingauge stations due to the lack of budget after an individual project was terminated. As a result, there are lots of data gaps despite of efforts of the hydrological section.

Any study related to watershed management and water resource development requires the hydrological analysis based on rainfall data. Therefore, it is necessary to improve the network of raingauge stations, and data collection and processing.

2.3 Existing 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 as shown in Table-C2.3. 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. It is necessary to improve the gauging stations.

Table-C2.1 Availability of Meteorological Data

as of August, '96

No.	Station Name	Observing Authority	Location		Observation Items Checked															
			Latitude	Longitude	Temperature		Rainfall			Evaporation		Relative Humidity		Sunshine Hours		Surface Wind		Solar Radiation	
					D(M)	Ob	D(M)	D(D)	Ob	D(M)	Ob	D(M)	Ob	D(M)	Ob	D(M)	Ob	D(M)	OB
V77554	Lololo Pine	FPC	17° 34' S	177° 35' E	72-93	72 -	72-93	78-92	72 -	No Data		72-93	72 -	No Data		No	72 -	No Data	
V77581	Vatukoula	MM	17° 30' S	177° 51' E	84-93	84 -	36-93	36-92	36 -	No Data		84-93	84 -	No Data		No	84 -	No Data	
V77648	Lautoka AES	FSC	17° 37' S	177° 27' E	30-94	30 -	10-96	79-92	10 -	No*	58 -	58-94	58 -	57-94	57 -	No	72 -	No Data	
V77744	Nadi Airport	FMS	17° 45' S	177° 27' E	42-95	42 -	42-96	42-95	42 -	No*	72 -	42-95	42 -	47-95	47 -	No	72 -	72-96	64 -
V77747	Legalega	AD	17° 45' S	177° 28' E	No	86 -	77-93	77-92	77 -	No*	86 -	No	87 -	No Data		No	86 -	No Data	
V77765	Vaturu Dam	PWD	17° 45' S	177° 40' E	No	82 -	82-94	82-96	82 -	No*	82 -	No	82 -	82-94	82 -	No	82 -	No*	84 -
V77861	Nausori Highland	FD	17° 49' S	177° 37' E	66-95	66 -	60-95	79-92	59 -	No Data		66-95	66 -	No Data		No	72 -	No Data	
V77931	Nawaicoba	AD	17° 56' S	177° 22' E	71-93	71 -	66-93	79-92	66 -	No Data		71-93	71 -	No Data		No Data		No Data	
V77932	Nabou Pine	FPC	17° 58' S	177° 19' E	74-95	74 -	73-95	79-92	73 -	No Data		74-95	74 -	No*	74 -	No	74 -	No Data	
V78311	Penang Mill	FSC	17° 22' S	178° 10' E	80-94	30-	10-94	80-96	10 -	No	71 -	No	71 -	No Data		No	72 -	No Data	
V78401	Drauniivi Pine	FPC	17° 25' S	178° 00' E	78-93	78 -	78-93	79-92	78 -	No Data		81-93	78 -	No Data		No	78 -	No Data	
V78521	Dobuilevu	AD	17° 34' S	178° 15' E	80-94	64 -	37-96	78-96	37 -	No Data		No	65 -	71-94	71 -	No Data		No Data	
V78708	Monasavu	PWD	17° 45' S	178° 03' E	No	80 -	80-96	80-95	80 -	No*	80 -	No	80 -	80-94	80 -	No	80 -	No*	80 -
V88053	Koronivia	AD	18° 03' S	178° 32' E	65-93	65 -	50-93	79-92	50 -	No*	83 -	65-93	65 -	71-93	71 -	No	72 -	No*	87 -
V88054	Nausori Airport	FMS	18° 03' S	178° 34' E	No	56 -	56-96	79-92	56 -	No Data		No	57 -	No Data		No	57 -	No Data	
V88143	Suva Laucala Bay	FMS	18° 09' S	178° 27' E	42-94	41 -	42-94	42-95	42 -	No*	68 -	43-94	43 -	41-94	41 -	No	42 -	83-96	83 -
V88212	Navua Tamanoa	PWD	18° 13' S	178° 10' E	No	71 -	31-94	35-92	31 -	No Data		No	71 -	71-93	71 -	No	71 -	No Data	
V88214	Tokotoko	MAFFA	18° 12' S	178° 10' E	No	92 -	No	92	92 -	No*	92 -	No	92 -	No*	92 -	No	92 -	No Data	
V87152	Nacocolevu	AD/PWD	18° 06' S	177° 32' E	38-95	38 -	30-96	55-95	26 -	No*	84 -	38-95	38 -	54-95	54 -	No	72 -	87-95	87 -
V77873	Keiyasi PA090	PWD	17° 53' S	177° 46' E	No	84 -	73-94	76-92	73 -	No Data		No	84 -	No Data		No	84 -	No Data	
V78931	Nabukaluka	AD	17° 59' S	178° 20' E	No	68 -	67-84	No	67 -	No Data		No	68 -	No Data		No	72 -	No Data	

Note: "Observation Items Checked" does not cover all observation items. It means that only items necessary for the Study were checked.
Unit: Figures show year. For example, "72-93" means that the database is available for 1972 - 1993, and "72 -" means that observation was started in 1972 and is still continued.
D(M): computer database for monthly data, D(D): computer database for daily data, Ob: observation
No*: Database for monthly data is not available but one for daily data is available., No Data: no observation
FPC: Fiji Pine Commission, MM: Mines Manager, FSC: Fiji Sugar Corporation, FMS: Fiji Meteorological Service, AD: Agriculture Department,
PWD: Public Works Department, FD: Forestry Department, MAFFA: Ministry of Agriculture Fisheries Forests and ALTA
The case that D(M) is "No" but Ob is "86 -" means that observation has been conducted since 1986 but the data is still in the form of chart or sheet.

Source: Fiji Meteorological Service

Table-C2.2 (1/2) List of Raingauge Stations Operated

as of August 1996

No.	Station Name	Basin	Latitude	Longitude	Height (m)	Open Date	Closed Date	Daily Data	Hourly Data
P 004	NADURUILOUILAU	NAUSORI	17°58'20"	178°31'05"	18	Jun-61		available	
P 028	MAVUA	SIGATOKA	18°01'04"	177°32'52"	18	May-66		available	
P 036	NAGATAGATA	TAVUA	17°40'57"	177°55'53"	756	Aug-67		available	
P 038	KORO	BA	17°42'21"	177°54'35"	180	Aug-67		available	
P 040	NADRAU VILLAG	TAVUA	17°42'30"	177°56'59"	643	Nov-55		available	
P 052	VOTUALEVU/P	NADI	17°46'13"	177°30'07"	15	1970		available	
P 062	NASAUVERE	NAUSORI	17°52'35:	178°05'00"	305	Jan-71		available	
P 064	WAIBASAGA	NAUSORI	17°48'15"	178°06'45"	146	Jan-71		available	
P 065	NASAYANI	TAVUA	17°29'40"	178°00'22"	61	Jan-71		available	
P 066	NARARA	RAKIRAKI	17°24'58"	178°09'02"	82	Jan-71		available	
P 067	NAKORO	SIGATOKA	17°57'05"	177°54'18"	235	Feb-71		available	
P 069	LEWA	TAVUA	17°32'27"	177°56'03"		Aug-01		available	
P 070	VANUALEVU	TAVUA	17°44'14"	177°57'27"	731	Jan-68		available	
P 073	DAKUIVUNA	TAILEVU	17°46'35"	178°26'05"	168	Oct-71		available	
P 074	KOROVOU	TAILEVU	17°48'05"	178°32'25"	18	Oct-71		available	
P 076	NAVILAWA	NADI	17°41'18"	177°35'20"	275	Feb-71		available	
P 077	WAIBAU	NAUSORI	18°00'00"	178°24'50"	43	Mar-72		available	
P 082	NARAVIRAVI	RAKIRAKI	17°31'29"	178°06'30"	82	Mar-72		available	
P 099	NAMARAI	RAKIRAKI	17°31'24"	178°22'05"	9	Feb-75		available	
P 101	KOROLEVU	SIGATOKA	17°52'11"	177°53'27"	100	Feb-75		available	
P 106	SOA	KOROVOU	17°39'10"	178°22'20"	46	Nov-76		available	
P 135	SAVUNABA	TAVUA	17°45'08"	177°39'46"	600	Sep-77		available	
P 141	NAIVICULA	KOROVOU	17°45'15"	178°29'45"	30	Oct-78		available	
P 143	NUBUMAKITA	RAKIRAKI	17°38'50"	178°09'10"	274	Jan-78		available	
P 148	WAILUTU	TAVUA	17°50'13"	178°00'55"	939	Jan-79		available	
P 156	NAOSQO/NAVAI	TAVUA	17°38'15"	178°01'13"	975	Jan-80		available	
P 163	WAINIKASOU	TAVUA	17°49'15"	178°02'01"	817	Sep-79		available	
P 164	NABILABILA	TAVUA	17°48'29"	178°02'39"	823	Dec-79		available	
P 170	KOROVISILIOU	NAVUA	18°14'30"	177°52'50'	30	Sep-80		available	
P 181	SALIADRAU	NAVUA	18°01'24"	178°04'40"	137	Sep-81		available	
P 188	WAIKUBUKUBU	TAVUA	17°32'43"	177°56'36"	189	Jan-76		available	
P 197	NADRUGU	NADI	17°42'30"	177°45'00"	335	Feb-83		available	
P 199	NANOKO	BA	17°45'11"	177°51'10"	602	Feb-83		available	
P 205	VATUMA	NADI	17°53'09	177°27'58"	259	Sep-83		available	
P 206	MASI	BA	17°53'45"	177°27'17"	805	Sep-83		available	
PA002	BA F/HOUSE	BA	17°34'33"	177°40'42"	98	Jan-65		available	available
PA005	SAVURA H/W	SUVA	18°02'55"	178°26'30"	163	Jan-61		available	available
PA008	NABOUTNI	NADI	17°43'15"	177°32'10"	36	Dec-62		available	available
PA011	NAMOSI MISSION	NAVUA	18°02'15"	178°08'25"	107	Mar-61		available	available
PA012	SARU -F/HOUSE	LAUTOKA	17°38'47"	177°27'19"	104	Jan-64		available	available
PA017	WAINIKAVIKA	NAVUA	18°09'45"	178°08'20"	76	Nov-64		available	available
PA019	TAMAVUA W/S	SUVA	18°05'35"	178°26'35"	125	Mar-65		available	available
PA020	NAVOLAU	NAUSORI	17°52'00"	178°23'00"	90	Dec-65		available	available
PA022	WAILOKU	SUVA	18°04'30"	178°25'40"	131	1965		available	available
PA024	SIGATOKA-H/W	SIGATOKA	17°07'17"	177°29'53"	61	Dec-65		available	available
PA026	NAIRUKURUKU	VUNIDAW	17°45'00"	178°17'00"	55	Mar-66		available	available
PA027	NALEBALEBA	SIGATOKA	17°57'21"	177°40'34"	46	May-66		available	available
PA033	NAMUAMUA	NAVUA	18°05'30"	178°03'35"	27	May-67		available	available
PA034	NABUKELEVU	NAVUA	18°07'30"	177°52'10"	155	Jun-67		available	available
PA039	NABUKALUKA	NAUSORI	17°58'30"	178°19'30"	55	Sep-67		available	available
PA054	TAVUA-F/HOUSE	TAVUA	17°26'47"	177°52'03"	61	Jul-71		available	
PA056	VAILEKA-DEPO	RAKIRAKI	17°22'59"	178°09'57"	46	Jul-71		available	
PA058	DRAVO	NAUSORI	18°01'05"	178°36'50"	5	Jul-70		available	available
PA059	LASELEVU	NAUSORI	17°45'05"	178°08'10"	91	Nov-77		available	available
PA063	NAROKOROKOYAWA	NAUSORI	17°50'55"	178°06'35"	195	Jan-71		available	available
PA072	NABUKAVESI	NAVUA	18°09'35"	178°14'30"	24	Sep-71		available	available
PA078	NAITAUVOLI	VUNIDAWA	17°49'15"	178°13'40"	91	Mar-72		available	available

Table-C2.2 (2/2) List of Raingauge Stations Operated

No.	Station Name	Basin	Latitude	Longitude	Height (m)	Open Date	Closed Date	Daily Data	Hourly Data
PA079	NASEUVOU	NAVUA	18°00'15"	178°12'55"	52	Mar-72		available	available
PA081	VUNAMOLI	NADI	17°56'43"	177°29'36"	174	Mar-72		available	
PA083	DEUBA T/P	NAVUA	18°15'20"	178°03'20"	9	May-72		available	available
PA084	NAYAVU	KOROVOU	17°41'20"	178°22'05"	60	Jan-78		available	available
PA085	VUNIDAWA	VUNIDAWA	17°49'25"	178°19'30"	27	Feb-72		available	available
PA087	REWASAU	TAVUA	17°42'42"	178°04'18"	366	Jan-71		available	available
PA089	SAKISA	NAVUA	18°06'30"	178°11'05"	259	Jan-77		available	available
PA090	KEIYASI	SIGATOKA	17°52'50"	177°45'36"	70	Jan-71		available	available
PA092	BUKUYA	BA	17°46'31"	177°45'41"	480	Jul-73		available	available
PA096	DELAKADO	KOROVOU	17°37'30"	178°29'20"	24	May-74		available	available
PA113	MOLIVEITALA	NADI	17°44'57"	177°33'45"	90	Sep-76		available	available
PA114	VATURU-CLIMA	NADI	17°44'42"	177°40'12"	500	Sep-76		available	available
PA115	MAGODRO	NADI	17°43'00"	177°38'53"	640	Dec-76		available	available
PA117	WENA	REWA	17°43'00"	178°01'43"	868	Mar-77		available	available
PA118	WAINISAVULEV	REWA	17°50'34"	178°01'38"	915	Feb-77		available	available
PA120	QALINASAVU	REWA	17°40'27"	177°59'08"	777	Apr-77		available	available
PA121	TUBENASOLO	NADI	17°51'41"	177°31'06"	710	Nov-76		available	available
PA122	SALOVI	NADI	17°50'52"	177°31'06"	198	Sep-76		available	available
PA124	NAVAI	TAVUA	17°36'57"	177°59'30"	710	Apr-77		available	available
PA125	LUMUDA	TAVUA	17°44'55"	177°59'24"	975	Apr-77		available	available
PA127	WAILEBULEBU	TAVUA	17°48'35"	178°01'01"	1173	May-78		available	available
PA129	WANIKAVOU	NAVUA	18°11'05"	178°01'35"	249	Nov-77		available	available
PA130	MONAVATU	TAVUA	17°51'35"	178°00'25"	1067	May-78		available	available
PA131	TOKARAVUTIA	TAVUA	17°45'35"	178°00'32"	1128	Nov-77		available	available
PA132	WAINABUA	TAVUA	17°45'35"	178°02'24"	670	Apr-78		available	available
PA133	WAINAKA	TAVUA	17°46'45"	178°02'24"	990	Mar-78		available	available
PA134	NASIGA	TAVUA	17°50'19"	177°59'46"	945	Dec-77		available	available
PA136	WAIDAMU	TAVUA	17°44'43"	177°35'52"	850	Dec-77		available	available
PA137	WAINABORO	SUVA	18°06'55"	178°15'50"	223	Oct-78		available	available
PA147	WAINIMAKUTU	NAVUA	17°57'50'	178°05'25"	256	May-79		available	available
PA154	NASOQO	TAVUA	17°40'19"	178°05'02"	244	Dec-79		available	available
PA155	WAILOA	TAVUA	17°43'03"	178°05'51"	152	Dec-79		available	available
PA158	MONASAVU-CLIMATE	TAVUA	17°44'31"	178°03'24"	808	Feb-80		available	available
PA159	WANITAKOTO	NAVUA	18°00'45"	178°08'15"	335	Oct-78		available	available
PA160	WAINITOTOEUE	NAVUA	17°59'20"	178°08'15"	686	Sep-78		available	available
PA167	DELAIVOLOSA	NAVUA	18°10'40"	177°51'25"	533	Aug-80		available	available
PA169	NACAU	VUNIDAW	17°50'00"	178°14'30"	274	Aug-80		available	available
PA171	CABE	SIGATOKA	18°07'09"	177°42'59"	426	Sep-80		available	available
PA172	NAVALA	BA	17°39'28"	177°48'59"	61	Nov-80		available	available
PA178	WAINIURA	SUVA	18°04'10"	178°20'20"	350	Sep-81		available	available
PA187	REWARANI	SIGATOKA	18°07'13"	177°46'37"	518	Oct-81		available	available
PA190	NAITITI	KOROVOU	17°42'47"	178°30'54"	343	Dec-81		available	
PA191	NUKULAU	RAKIRAKI	17°38'57"	178°07'30"	335	Dec-81		available	
PA194	TAUNABE	TAVUA	17°36'42"	177°56'30"	563	Feb-82		available	available
PA198	NAGADO	BA	17°44'13"	177°33'03"	152	Feb-82		available	available
PA207	VATUKACEVACEVA	NAKAUVA	17°05'08"	178°05'03"	113	Oct-83		available	available
PA208	NARAVIRAVI	WANIBUKA	17°31'38"	178°07'22"	85	Nov-83		available	available
PA209	ABACA	LAUTOKA	17°39'52"	177°32'22"	390	Oct-83		available	available
PA218	VARACIVA	LAUTOKA	17°35'49"	177°36'36"	123	Jan-84		available	available
PA219	KALELI	MONASAVU	17°43'28"	178°01'14"	750	Aug-84		available	available
PA220	MATAMATA	MONASAVU	17°43'03"	178°01'25"	811	Aug-84		available	available
PA221	QALINAOLO	MONASAVU	17°42'30"	177°58'57	792	Aug-84		available	available
PA222	WAINABACA	MONASAVU	17°43'56"	178°00'55"	762	Aug-84		available	available
PA223	MASIVOU	NADI	17°54'11"	177°27'42"	352	Oct-84		available	available
PA235	WAIMANU	NAUSORI	18°02'05"	178°27'10"		Sep-89			available

Note: "available" does not guarantee that data is available for the period specified. There are lots of data gaps.
Source: PWD, Hydrological Section

Table-C2.3 List of Gauging (Water Level) Stations Operated

No.	Ref. No.	Station Name	River	Basin	Latitude	Longitude	Start Date	Rating Curve	Daily Data	Hourly Data	Remark
1	H 016	VARAQE H/W	VARAQE	LAUTOKA	17° 39'58"	177° 29'54"	Aug-69	available	available	N.A.	
2	H 017	BUABUA	BUABUA	LAUTOKA	17° 38'27"	177° 32'27"	Jun-75	available	available	N.A.	
3	H 058	NAVAI	QALIWANA	SIGATOKA	17° 37'25"	177° 59'20"	Jun-72	available	available	N.A.	
4	H 064	VARACIVA/H/W	VARACIVA	BA	17° 35'41"	177° 38'48"	Jun-72	available	available	N.A.	
5	H 076	WAINABORO	WAINABORO	NAVUA	18° 08'00"	178° 17'40"	Apr-73	available	available	N.A.	
6	H 111	SOA	WAILOU	REWA	17° 39'00"	178° 22'20"	Nov-76	available	available	N.A.	
7	H 132	WAINIKAVOU	WAINIKAVOU	NAVUA	18° 06'30"	178° 03'05"	Jul-77	available	available	N.A.	
8	HA003	NAKAVU	NAVUA	NAVUA	18° 11'25"	178° 06'15"	Apr-69	available	available	available	
9	HA006	NABUKALUKA	WAIDINA	REWA	17° 58'55"	178° 19'20"	May-70	available	available	available	telemetry
10	HA008	NAIRUKURUKU	WAINIMALA	REWA	17° 48'30"	178° 16'35"	Jul-70	available	available	available	telemetry
11	HA009	NAVOLAU	REWA	REWA	17° 52'25"	178° 23'30"	Mar-63	available	available	available	telemetry
12	HA010	WAIMANU	WAIMANU	REWA	18° 02'05"	178° 27'10"	Jun-71	available	available	available	telemetry
13	HA012	NABUKAVESI	NABUKAVESI	NABUKAV	18° 09'25"	178° 14'20"	Nov-71	available	available	available	
14	HA019	DRASA-Rd	TEIDAMU	LAUTOKA	17° 35'00"	177° 33'30"	Jul-78	available	available	available	
15	HA021	YAVUNA	NAMOSI	NADI	17° 43'40"	177° 33'10"	Sep-76	available	available	available	
16	HA034	VATUSEKI	NAKAUVADRA	RAKIRAKI	17° 23'36"	178° 08'30"	Mar-72	available	available	available	
17	HA065	TEIDAMU	TEIDAMU	LAUTOKA	17° 34'04"	177° 32'48"	Mar-69	available	available	available	
18	HA067	VITOGO	VITOGO	LAUTOKA	17° 36'14"	177° 31'47"	Jul-78	available	available	available	
19	HA093	TOGE	BA	BA	17° 37'30"	177° 44'11"	Nov-72	available	available	available	
20	HA100	NATUACERE	NATUACERE	NADI	17° 50'14"	177° 28'18"	May-76	available	available	available	
21	HA139	WAINAKA	WAINAKA	REWA	17° 46'45"	178° 02'24"	Feb-78	available	available	available	
22	HA143	NAYAVU	WAINIBUKA	REWA	17° 41'02"	178° 21'45"	Jun-78	available	available	available	telemetry
23	HA148	SAILOMA	NABUKAVESI	NABUKAVES	18° 08'10"	178° 12'35"	Dec-79	available	available	available	
24	HA151	WAISOI-WES	WAISOI	REWA	18° 00'45"	178° 08'45"	Sep-78	available	available	available	
25	HA154	WAINITOTOEO	WAINITOTOEU	REWA	18° 00'00"	178° 08'50"	Nov-78	available	available	available	
26	HA155	DOBUILEVU	WAINIBUKA	REWA	17° 33'38"	178° 14'56"	Dec-83	available	available	available	
27	HA160	LEWA	NUIKUNUKU	SIGATOKA	17° 39'40"	177° 54'48"	Aug-81	available	available	available	
28	HA165	VARACIVA	VARACIVA	BA	17° 36'00"	177° 37'27"	Oct-82	available	available	available	
29	HA173	MONASAVU	NANUKU	REWA	17° 45'17"	178° 03'15"	Mar-83	available	available	available	
30	LA001	NADI-BRIDGE	NADI	NADI	17° 47'50"	177° 25'08"	Apr-81	available	available	available	tidal
31	LA002	DREINAKELO	REWA	REWA	17° 58'41"	178° 31'33"	Feb-70	N.A.	available	available	tidal
32	LA023	NAUSRI-CRT	REWA	REWA	18° 01'47"	178° 32'10"	Jan-85	available	available	available	tidal\telemetry
33	LA032	NAMOSAU-Br	BA	BA	17° 32'27"	177° 40'52"	Sep-81	available	available	available	tidal
34	LA033	DRAVO	DRAVO	NAUSORI	18° 01'07"	178° 36'56"	Jul-90	N.A.	available	available	tidal

Note: H: staff gauge station, HA: gauging station with an automatic recorder, LA: gauging station with an automatic recorder under tidal influence
N.A.: not available
"available" does not guarantee that data is available since "Start Date". There are lots of data gaps.

Source: PWD, Hydrological Section

2.4 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-C2.4 and Figure-C2.1.

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-C2.4 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

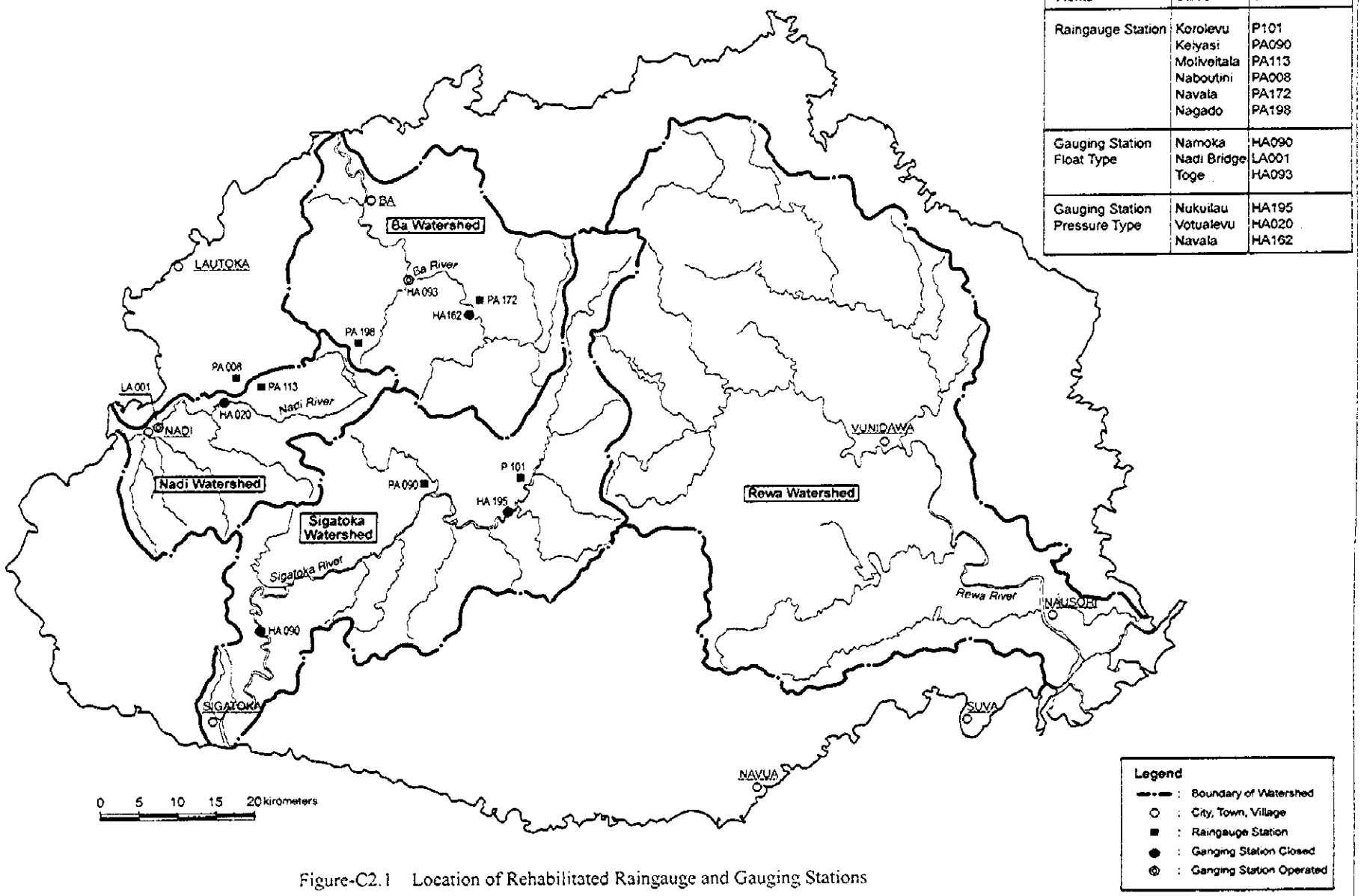


Figure-C2.1 Location of Rehabilitated Raingauge and Gauging Stations

CHAPTER 3 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 by information from Hydrological Section (Public Works Department, PWD) and Fiji Meteorological Service. The number of stations selected varies depending on analysis. For example, 13 meteorological stations out of 21 stations were selected for the meteorological analysis, while 28 raingauge stations out of 112 stations and 13 meteorological stations were initially selected for the rainfall analysis. Data from 14 gauging (water level) stations out of 27 stations were used for the runoff analysis (low water). The details of data collection, such as location of selected stations, period of data extracted and so on, are described in the following chapters.

As mentioned in Chapter 2, raingauge stations have been installed for particular projects but not in terms of hydrological analysis of whole Viti Levu. As a result, the network of raingauge stations is not appropriate and available data are limited for the hydrological analysis of Viti Levu. Therefore, only limited number of stations are applicable for the analysis.

CHAPTER 4 METEOROLOGICAL ANALYSIS

4.1 Selected Stations and Items of Analysis

Considering the availability of data and study objectives, 13 meteorological stations out of 21 stations operated were selected. Collected data and location of stations are shown in Table-C4.1 and Figure-C4.1, 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.

There are some data gaps even in the specified period. However, since those data gaps are minor in terms of quantity, the following meteorological analysis was conducted neglecting the data gaps.

Items analyzed to identify meteorological characteristics of Viti Levu are temperature, relative humidity, surface wind velocity, potential evapotranspiration and rainfall. Rainfall is discussed in Chapter 5, while others are discussed in this chapter.

In Table-C4.1, there are 14 meteorological stations, inclusive of Nausori Airport (V88054). Only the average value of surface wind was extracted from Nausori Airport station to estimate the potential evapotranspiration.

Hourly rainfall in Table-C4.1 was collected for the runoff analysis (Flood). It is discussed in Supporting Report D (Runoff Analysis).

4.2 Temperature

Monthly maximum, mean and minimum temperatures at each meteorological station were averaged over 1976 ~ 1995 and the results are summarized in Table-C4.2 and Figure-C4.2. Although some stations do not have the complete data for 1976 ~ 1995, the average values were analyzed as figures for 1976 ~ 1995 assuming that there is no significant change of meteorology in the last twenty years. In fact, the difference between monthly mean daily temperature for the last twenty years and one for the last ten years is in the order of one decimal (less than 0.1 in most of cases).

As shown in Figure-C4.2, 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.

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.

Table-C4.1 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	Drauniivi	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

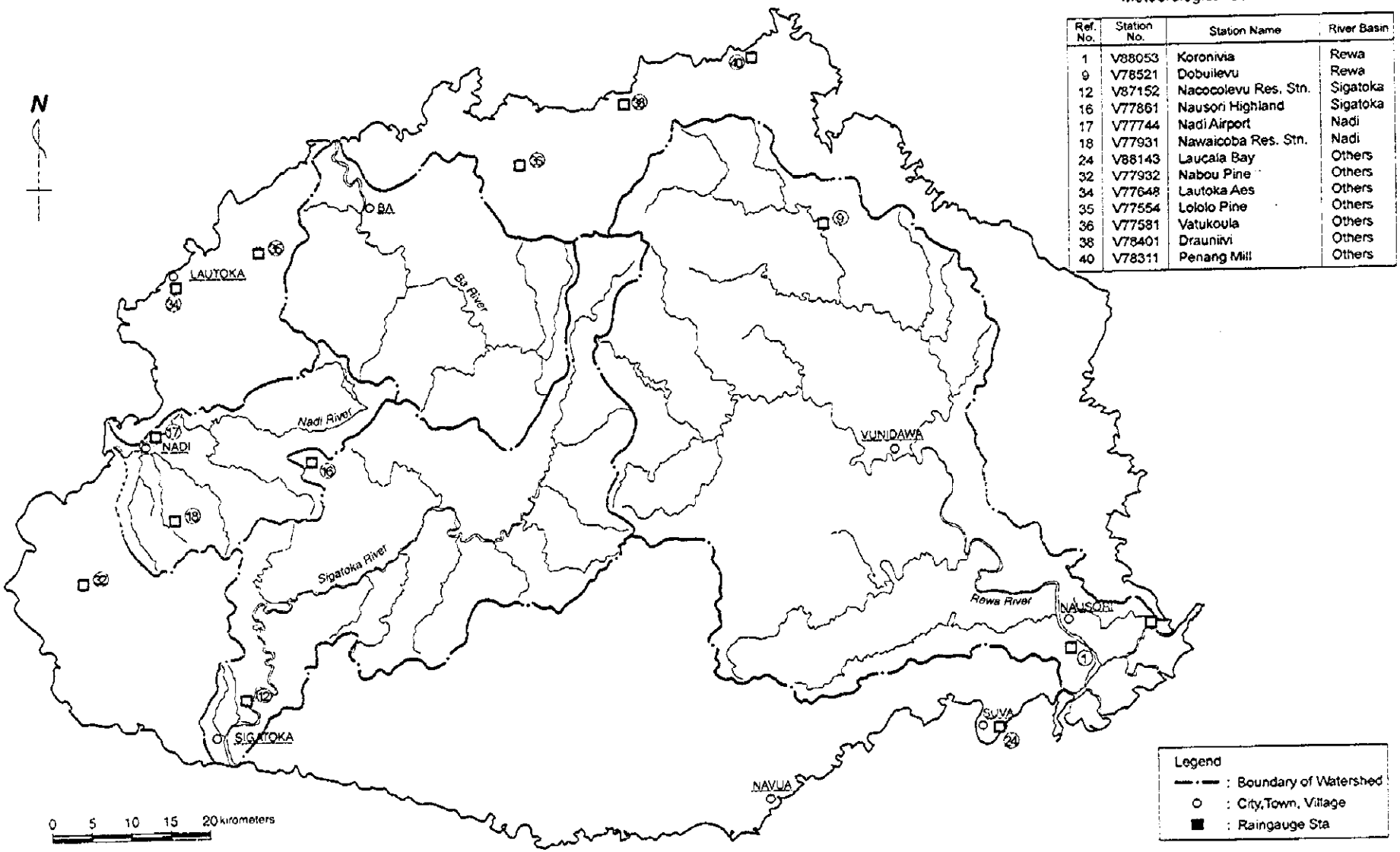


Figure-C4.1 Meteorological Stations Selected

Table-C4.2 Mean Temperature (1976 ~ 1995)

Ref. No.	Station No.	Station Name	River Basin	Latitude	Longitude	EL (m)	Open Date	Level	Monthly Mean Daily Temperature (°C) Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean Temperature (°C)	Availability (Year)
1	V88053	Koronivia	Rewa	18° 03'S	178° 32'E	15	Jan-54	Max	30.4	30.9	30.4	29.4	28.0	27.3	26.3	26.1	26.7	27.6	28.7	29.6	28.5	76-93
								Min	22.7	23.2	23.0	22.4	21.0	20.3	19.3	19.2	19.4	20.5	21.6	22.0	21.2	76-93
								Mean	26.6	27.1	26.7	25.9	24.5	23.9	22.8	22.7	23.1	23.8	25.0	25.9	24.8	76-93
9	V78521	Dobuilevu	Rewa	17° 34'S	178° 15'E	58	Jul-68	Max	30.9	31.2	30.9	29.7	28.5	27.8	26.8	27.1	28.1	28.9	29.9	30.6	29.2	76-95
								Min	22.1	22.4	22.3	21.4	20.1	19.1	18.0	18.2	18.9	19.5	20.9	21.7	20.4	76-95
								Mean	26.5	26.8	26.6	25.6	24.3	23.5	22.4	22.6	23.3	24.2	25.4	26.1	24.8	76-95
12	V87152	Nacocolevu Res. Stn.	Sigatoka	18° 06'S	177° 32'E	11	Jan-59	Max	31.4	31.5	31.1	30.2	28.6	28.3	27.3	27.3	27.6	28.9	30.4	30.9	29.5	76-95
								Min	22.0	22.6	22.5	21.4	19.5	18.4	17.5	17.7	18.0	19.3	20.6	21.3	20.1	76-95
								Mean	26.7	27.1	26.8	25.8	24.0	23.4	22.4	22.5	22.8	24.1	25.5	26.1	24.8	76-95
16	V77861	Nausori Highland	Sigatoka	17° 49'S	177° 37'E	453	Jan-83	Max	28.2	28.4	28.2	27.7	26.7	25.8	25.6	25.8	26.4	26.9	27.8	28.1	27.1	76-95
								Min	19.4	19.2	19.6	19.2	17.8	16.5	15.7	16.2	16.0	16.7	18.4	18.7	17.8	76-95
								Mean	23.8	23.8	23.9	23.5	22.2	21.1	20.7	21.1	21.2	21.8	23.2	23.3	22.5	76-95
17	V77744	Nadi Airport	Nadi	17° 45'S	177° 27'E	16	Jan-46	Max	31.7	31.7	31.3	30.8	29.7	29.0	28.5	28.7	29.1	30.2	31.3	31.7	30.3	76-95
								Min	22.6	23.0	22.8	21.8	20.1	19.0	18.0	18.4	18.9	20.2	21.5	22.3	20.7	76-95
								Mean	27.2	27.4	27.1	26.3	24.9	24.1	23.3	23.6	24.0	25.2	26.4	27.0	25.5	76-95
18	V77931	Nawaicoba Res. Stn.	Nadi	17° 56'S	177° 22'E	91	Jan-83	Max	30.8	30.6	30.4	29.7	28.9	28.6	27.7	27.6	28.3	29.5	30.3	30.5	29.4	76-93
								Min	22.6	22.6	22.6	21.7	20.0	19.1	18.0	18.0	18.3	19.7	20.6	21.4	20.4	76-93
								Mean	26.4	26.7	26.5	25.7	24.5	23.9	22.8	22.8	23.4	24.6	25.5	26.0	24.9	76-93
24	V88143	Laucala Bay	Others	18° 09'S	178° 27'E	6	Jan-46	Max	30.8	31.2	30.8	29.9	28.4	27.6	26.5	26.4	26.9	27.9	29.1	30.1	28.8	76-94
								Min	23.9	24.1	23.9	23.3	22.2	21.3	20.5	20.6	20.7	21.7	22.7	23.5	22.4	76-94
								Mean	27.3	27.6	27.4	26.6	25.3	24.5	23.5	23.5	23.8	24.9	25.9	26.8	25.6	76-94
32	V77932	Nabou Pine	Others	17° 58'S	177° 19'E	91	Jan-83	Max	31.6	31.4	31.2	30.5	29.2	28.3	27.6	27.8	28.4	29.5	30.8	31.2	29.8	76-95
								Min	21.8	22.3	22.0	20.9	19.1	17.7	16.9	17.4	17.9	18.7	20.1	21.0	19.7	76-95
								Mean	26.7	26.8	26.6	25.7	24.2	23.1	22.2	22.5	23.0	24.2	25.4	26.2	24.7	76-95
34	V77648	Lautoka Aes	Others	17° 37'S	177° 27'E	19	Dec-68	Max	31.0	31.2	31.0	30.5	29.4	28.6	28.1	28.2	28.4	29.4	30.6	31.1	29.8	76-94
								Min	23.7	24.1	23.8	22.9	21.4	20.6	19.6	19.8	20.3	21.4	22.5	23.2	21.9	76-94
								Mean	27.4	27.6	27.4	26.7	25.5	24.8	23.9	24.0	24.4	25.4	26.6	27.2	25.9	76-94
35	V77554	Lololo Pine	Others	17° 34'S	177° 35'E	91	Jan-82	Max	31.2	31.1	31.1	30.7	29.7	29.2	28.5	28.6	29.1	30.0	30.9	31.3	30.1	76-93
								Min	21.6	21.9	21.7	20.9	19.3	18.6	17.5	17.7	17.9	19.1	20.4	20.9	19.8	76-93
								Mean	26.4	26.5	26.5	25.8	24.5	23.9	23.0	23.2	23.5	24.5	25.7	26.2	25.0	76-93
36	V77581	Vatukoula	Others	17° 30'S	177° 51'E	61	Jan-40	Max	32.0	31.7	31.4	31.0	30.1	29.5	28.8	29.1	29.8	31.0	31.7	31.8	30.7	84-93
								Min	21.5	22.5	22.0	20.8	19.0	18.1	16.6	17.4	17.8	18.9	20.4	21.4	19.7	84-93
								Mean	26.7	27.1	26.7	25.9	24.6	23.8	22.7	23.1	23.7	25.0	26.1	26.6	25.2	84-93
38	V78401	Draunitvi	Others	17° 25'S	178° 00'E	35	Jan-83	Max	31.6	31.5	31.4	30.7	29.8	29.3	28.4	28.6	29.6	30.7	31.5	31.9	30.4	78-93
								Min	23.8	23.8	23.5	23.5	22.5	21.7	20.2	20.1	20.6	21.9	22.9	23.4	22.3	78-93
								Mean	27.7	27.7	27.5	27.1	26.1	25.5	24.2	24.3	25.2	26.3	27.3	27.3	26.4	78-93
40	V78311	Penang Mill	Others	17° 22'S	178° 10'E	3	Jan-34	Max	30.3	30.5	30.4	29.5	28.5	27.6	27.1	27.2	27.9	28.8	29.5	30.2	29.0	76-94
								Min	24.1	24.0	23.7	23.3	22.1	21.2	20.2	20.5	20.7	21.9	22.9	23.5	22.3	76-94
								Mean	27.3	27.1	27.0	26.3	25.3	24.4	23.6	23.9	24.3	25.4	26.2	26.8	25.6	76-94

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	Draunivi	Others
40	V78311	Penang Mill	Others

V: Meteorological Station

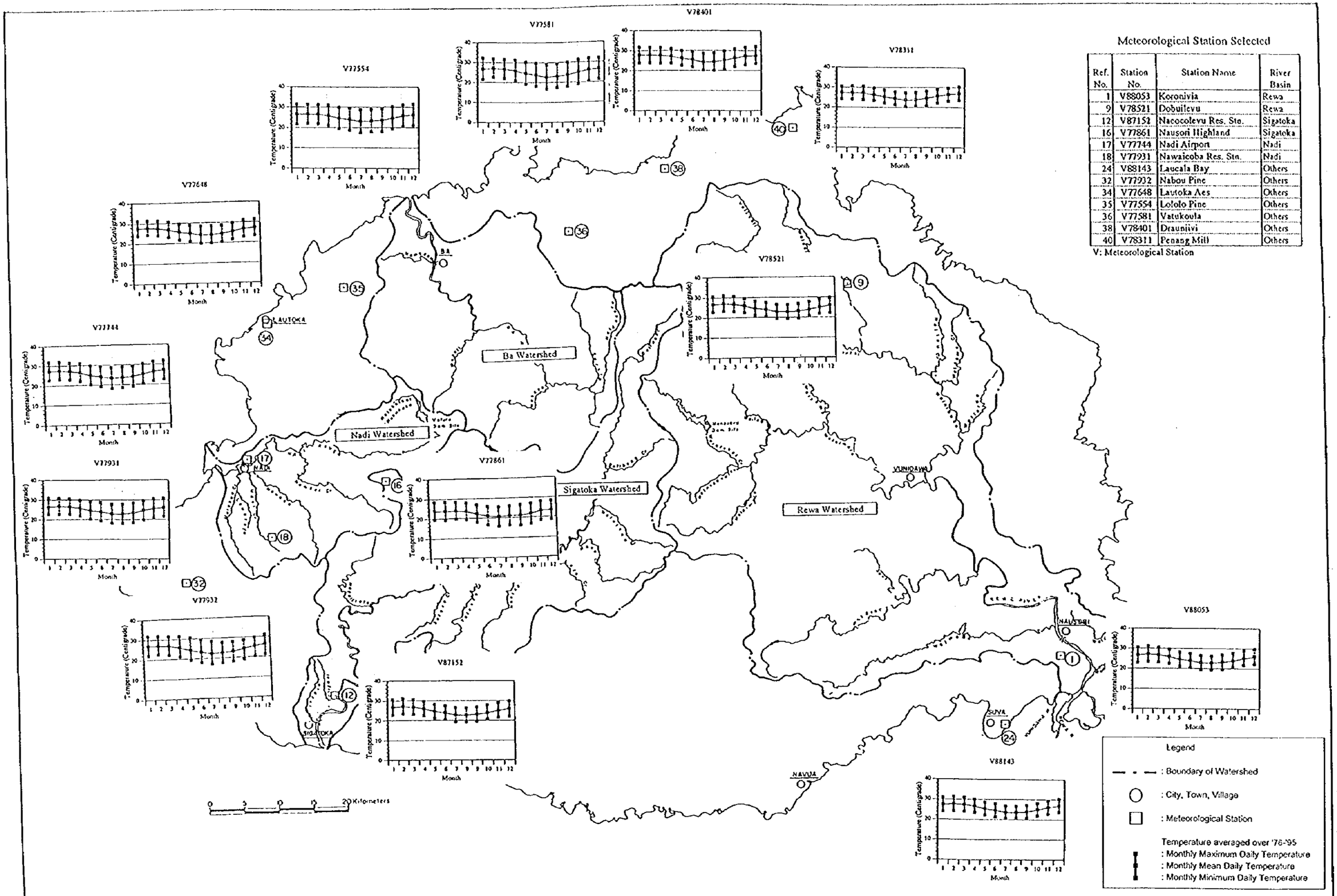


Figure-C4.2 Variation of Temperature in Viti Levu

Spatial variation of monthly mean daily temperature is not significant as shown in Table-C4.2 and Figure-C4.2. Nausori Highland station (V77861) shows the lowest temperature compared to other stations; however, this is due to the altitude, 453 m. The relations between mean temperature averaged over the last twenty years and altitude are plotted in Figure-C4.3. Although the number of data is limited, it shows the general tendency that the higher the altitude is, the lower the temperature is.

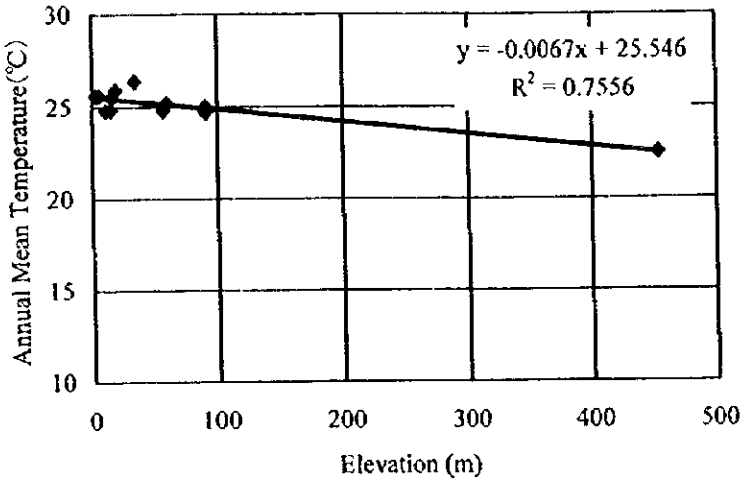


Figure-C4.3 Relation between Temperature and Elevation

4.3 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. The results are summarized in Table-C4.3 and Figure-C4.4. Although some stations do not have the complete data for 1976 ~ 1995, the average values were analyzed as figures for 1976 ~ 1995 assuming that there is no significant change of meteorology in the last twenty years.

As shown in Figure-C4.4, 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 %.

Table-C4.3 Monthly Mean Daily Relative Humidity

Ref. No.	Station No.	Station Name	River Basin	Latitude	Longitude	EL (m)	Open Date	Monthly Mean Daily Relative Humidity (%)												Annual Average RH (%)	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-54	78.3	83.2	84.1	83.5	83.3	85.0	82.3	82.2	77.9	78.6	78.3	77.7	81.2	76-93
9	V78521	Dobuilevu	Rewa	17° 34'S	178° 15'E	58	Jul-68														
12	V87152	Nacocolevu Res. Stn.	Sigatoka	18° 06'S	177° 32'E	11	Jan-59	77.7	80.5	81.1	80.4	80.2	82.8	80.7	79.0	75.1	71.7	72.8	74.6	78.1	76-95
16	V77861	Nausori Highland	Sigatoka	17° 49'S	177° 37'E	453	Jan-83	76.4	85.9	85.5	85.1	85.5	83.3	83.7	82.5	82.5	81.1	79.9	80.8	82.7	76-95
17	V77744	Nadi Airport	Nadi	17° 45'S	177° 27'E	16	Jan-46	70.5	75.8	76.4	74.3	73.1	75.3	71.6	68.0	64.8	61.6	62.4	64.3	69.8	76-95
18	V77931	Nawaicoba Res. Stn.	Nadi	17° 56'S	177° 22'E	91	Jan-83	76.9	79.7	78.9	78.4	78.5	78.5	76.0	77.2	72.6	70.7	71.6	73.6	76.1	76-93
24	V88143	Laucala Bay	Others	18° 09'S	178° 27'E	6	Jan-46	80.5	81.8	83.0	82.4	81.4	82.3	79.4	80.0	78.1	78.0	78.3	78.5	80.3	76-94
32	V77932	Nabou Pine	Others	17° 58'S	177° 19'E	91	Jan-83	72.7	75.7	78.1	75.3	75.3	77.3	74.9	72.0	68.8	65.8	68.0	68.0	72.7	76-95
34	V77648	Lautoka Aes	Others	17° 37'S	177° 27'E	19	Dec-68	74.4	77.4	77.2	74.7	73.8	75.1	71.5	70.0	69.0	70.2	68.7	70.1	72.7	76-94
35	V77554	Lololo Pine	Others	17° 34'S	177° 35'E	91	Jan-82	71.4	74.3	75.0	72.9	71.9	73.3	69.9	68.2	64.0	60.6	63.2	65.7	69.2	76-93
36	V77581	Vatukoula	Others	17° 30'S	177° 51'E	61	Jan-40	68.6	77.0	75.3	73.4	71.0	72.5	67.5	66.6	62.8	60.0	63.3	64.1	68.5	84-93
38	V78401	Drauniivi	Others	17° 25'S	178° 00'E	35	Jan-83	73.3	75.3	75.3	73.8	71.9	71.6	67.3	69.8	66.5	66.4	66.5	68.9	70.6	81-93
40	V78311	Penang Mill	Others	17° 22'S	178° 10'E	3	Jan-34														

RH: Relative Humidity, Remarks: Available Year in the last twenty years and period which monthly mean daily relative humidity was obtained

: not available

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	Drauniivi	Others
40	V78311	Penang Mill	Others

V: Meteorological Station

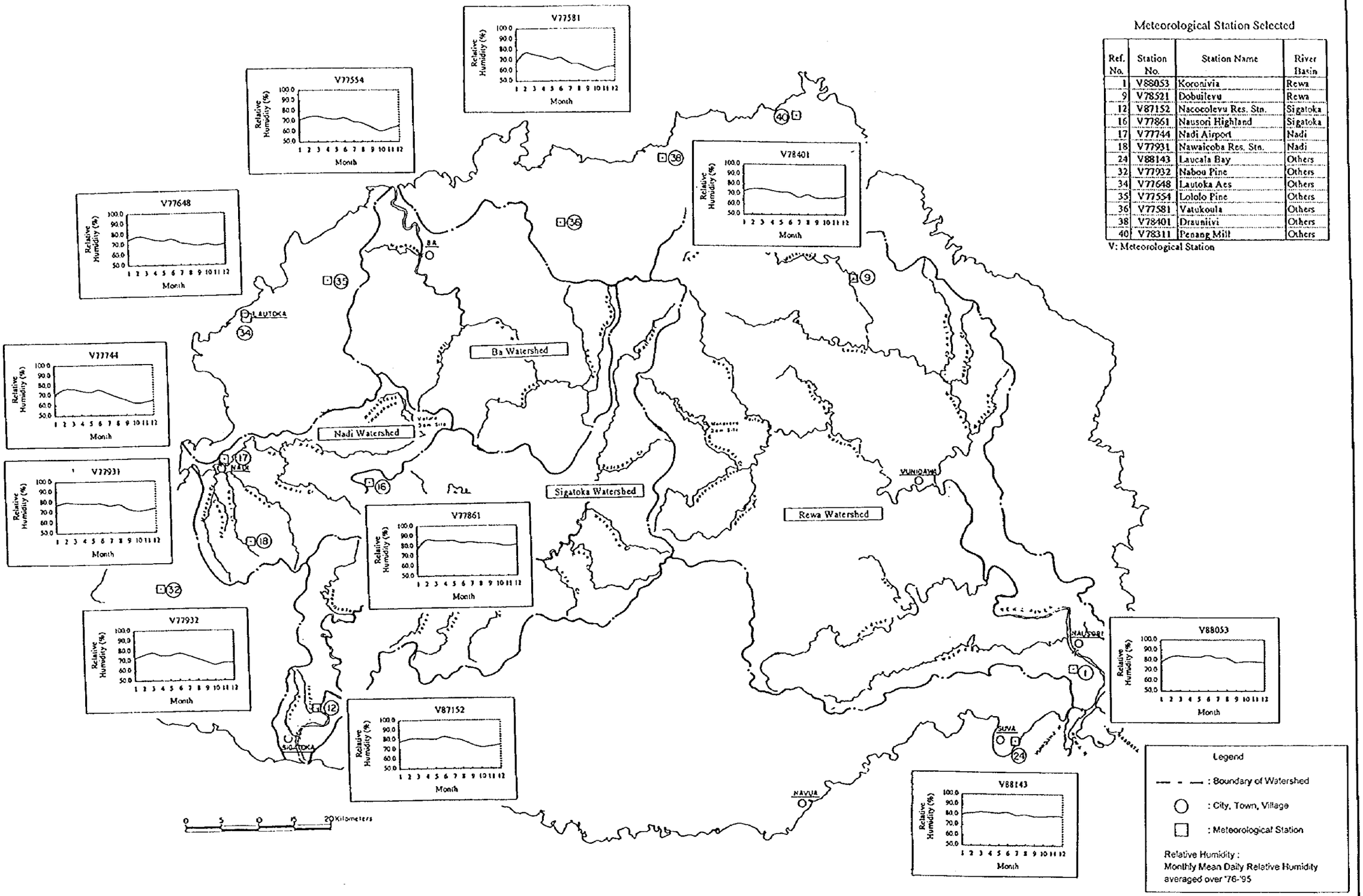


Figure-C4.4 Variation of Relative Humidity

4.4 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-C4.4, 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.

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: Wind is felt on face and leaves start to rustle.
Wind of 5.0 m/sec: 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.

Table-C4.4 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

4.5 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. The basic formulae of the modified Penman method are as follows.

$$ET_p = \frac{\Delta R_n + \gamma E_a}{\Delta + \gamma}$$

$$\Delta = \frac{4098 e_{sa}}{(T_a + 237.3)^2}$$

$$e_{sa} = \exp\left(\frac{19.08 T_a + 429.4}{T_a + 237.3}\right)$$

$$\gamma = \frac{1615 P_a}{2.49(10)^6 - 2.13(10)^3 T_a}$$

$$P_a = 1013 - 0.1152h + 5.44(10)^{-6} h^2$$

$$E_a = (0.27 + 0.2333u)(e_{sa} - e_a)$$

$$R_n = 0.75 R_s - 2.00(10)^{-9} (T_a + 273.16)^4 \left(0.34 - 0.044\sqrt{e_a}\right)\left(-0.35 + 1.8\frac{R_s}{R_a}\right)$$

Where ET_p: reference crop evapotranspiration or potential evapotranspiration (mm/day)

Δ : slope of saturation vapor pressure vs. temperature curve at air temperature T_a (mbar/°C)

R_n: net radiation (mm/day), equation by Doorenbos and Pruitt (1977)

γ : psychrometric constant (mbar/°C)

E_a: wind function (mm/day), equation by Doorenbos and Pruitt (1977)

e_{sa}: saturation vapor pressure at air temperature T_a (mbar)

e_a: actual vapor pressure of the air (mbar)

P_a: air pressure (mbar)

h: elevation above mean sea level (m)

R_a: extraterrestrial solar radiation expressed in equivalent evaporation (mm/day), obtainable by dividing extraterrestrial solar radiation by latent heat

R_s: observed solar radiation expressed in equivalent evaporation (mm/day), obtainable by dividing observed solar radiation by latent heat

Latent Heat: heat added per unit mass of phase change (liquid to vapor)

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-C4.5. 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-C4.5, 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-C4.5, 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.

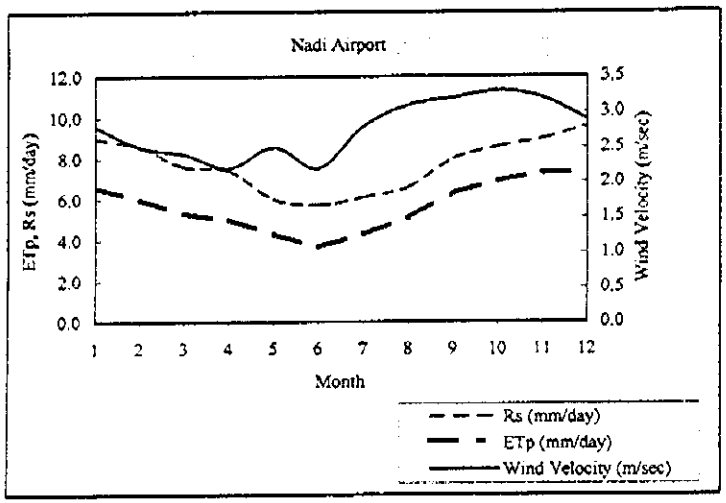
Spatial variation of ET_p is obvious in Table-C4.5. ET_p at Nadi located in the western Viti Levu is higher than that at Nausori located in eastern Viti Levu. Observed solar radiation at Nausori is lower than that at Nadi despite the fact that extraterrestrial radiation is same. Since the amount of extraterrestrial 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.

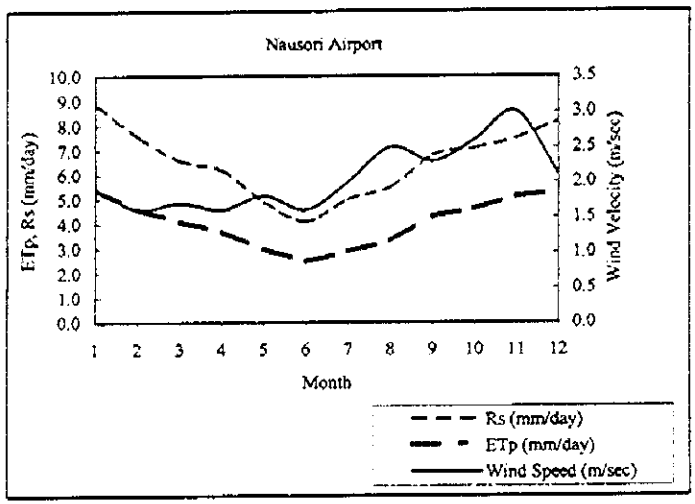
Based on ET_p, evaporation from open water surfaces can be approximated by multiplying by a factor of 1.1 (Doorenbos and Pruitt, 1977). Therefore, annual evaporation from the open water surfaces could be estimated as 2,280 mm at Nadi, and 1,630 mm at Nausori. The multiplier, 1.1, expresses the variation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

Table-C4.5 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





CHAPTER 5 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-C5.1.

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.

5.1 Rainfall Characteristics of Viti Levu

34 stations (12 meteorological stations and 22 raingauge stations) were selected for this analysis due to the data availability. Their locations are shown in Figure-C5.1. 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-C5.1, Figure-C5.2 and Figure-C5.3.

5.1.1 Annual Rainfall

Since there are still some gaps in the data of the 34 stations, mean annual rainfall of the station whose data is insufficient for 1976 ~ 1995 was expanded because the period of average should be same to compare mean annual rainfall with that at other stations. Therefore, the rainfall data was modified in the following manner, assuming that the tendencies of annual rainfall at two nearby stations are the same.

For example, rainfall data is only available from 1982 to 1993 at Tokaravutia station (reference No. 7) and its mean annual rainfall is 4,546 mm. The nearest station to Tokaravutia which has data from 1976 to 1995 is Laselevu station (reference No. 6).

According to the assumption;

$$\frac{R7(82-93)}{R7(76-95)} = \frac{R6(82-93)}{R6(76-95)}$$

Therefore, the mean annual rainfall of Tokaravutia for 1976 ~ 1995 is;

$$\begin{aligned} R7(76-95) &= R7(82-93) \times R6(76-95) / R6(82-93) \\ &= 4546 \times 3323 / 3443 \\ &= 4388 mm \end{aligned}$$

where R7(82-93): mean annual rainfall of Tokaravutia for '82 ~ '93, 4546 mm
R7(76-95): modified mean annual rainfall of Tokaravutia

R6(82-93): mean annual rainfall of Laselevu for '82 ~ '93, 3443 mm
R6(76-95): mean annual rainfall of Laselevu for '76 ~ '95, 3323 mm

As shown in Table-C5.1 and Figure-C5.2, 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-C5.2. 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.

5.1.2 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-C5.3. 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	Naval	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	V83143	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	Nabuketevu	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	Valukoula	Others
37	PA054	Tavua F/House	Others
#38	V78401	Draunivi	Others
#39	PA055	Vaileka Depo	Others
40	V78311	Penang Mill	Others
#41	PA190	Nariti	Others

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

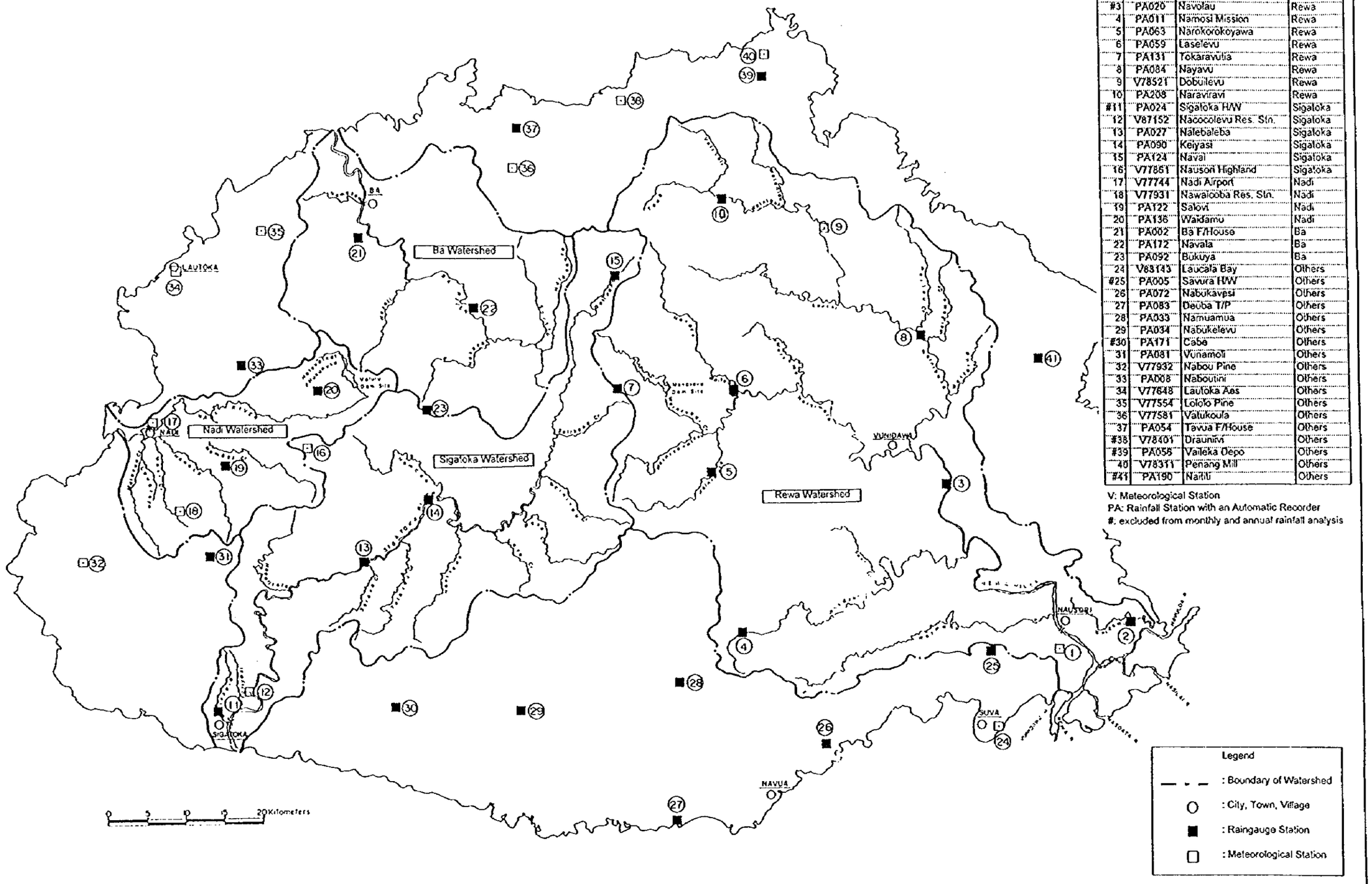


Figure-C5.1 Location of Raingauge and Meteorological Stations Selected

Table-C5.1 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	Narokorokovawa	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	Tokaravutta	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)	82-95
8	PA034	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	Naravitravi	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	Keiyasi	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	252	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	Nabouttni	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	Vanukoula	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	Draunitvi	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	Naitiri	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.

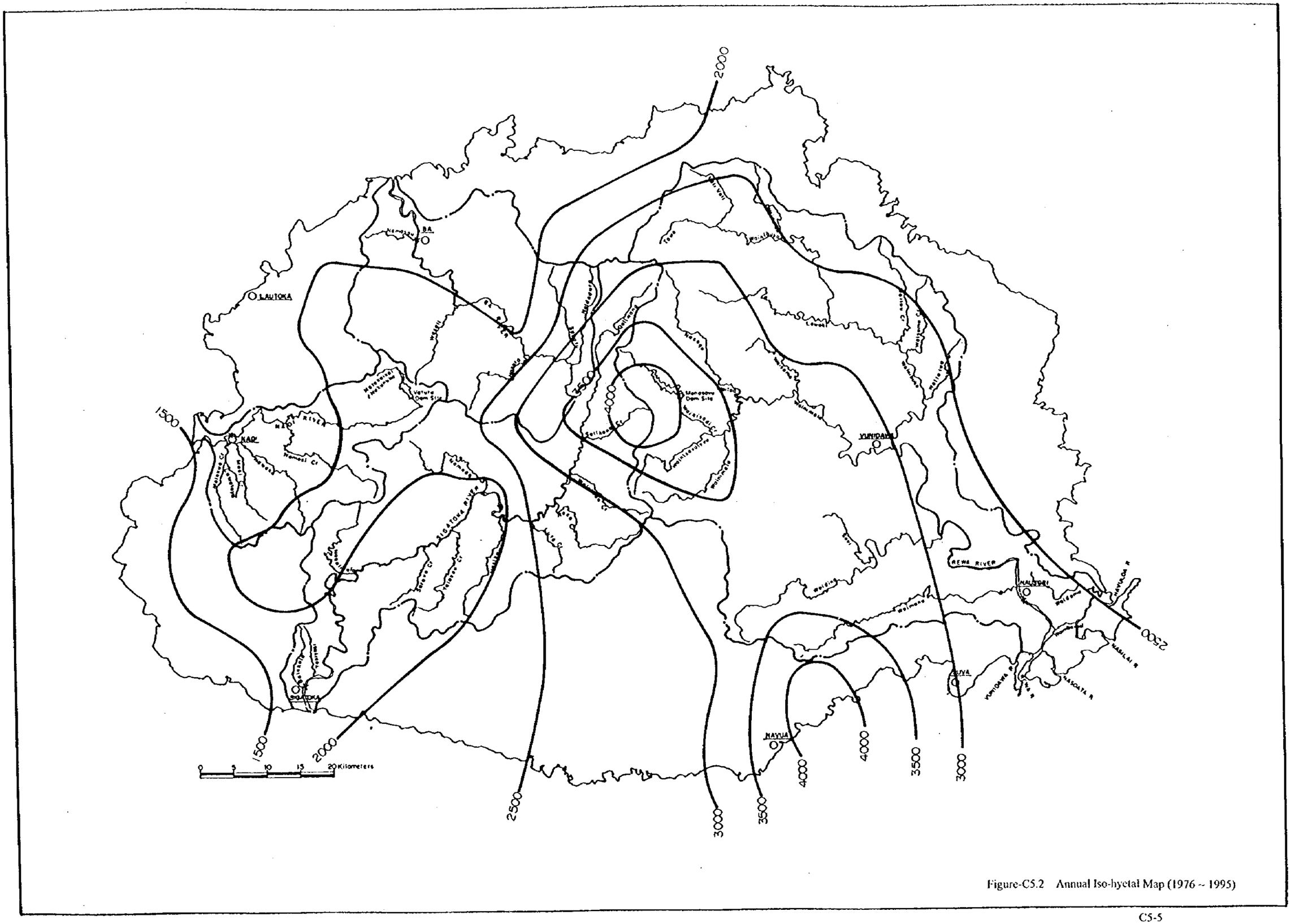


Figure-C5.2 Annual Iso-hyetal Map (1976 ~ 1995)

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 HW	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 HW	Others
26	PA072	Nabukavesi	Others
27	PA083	Deuba T/P	Others
28	PA033	Namuamua	Others
29	PA034	Nabukelevu	Others
#30	PA171	Caba	Others
31	PA081	Vunanoli	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	Draunitvi	Others
#39	PA056	Vaileka 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

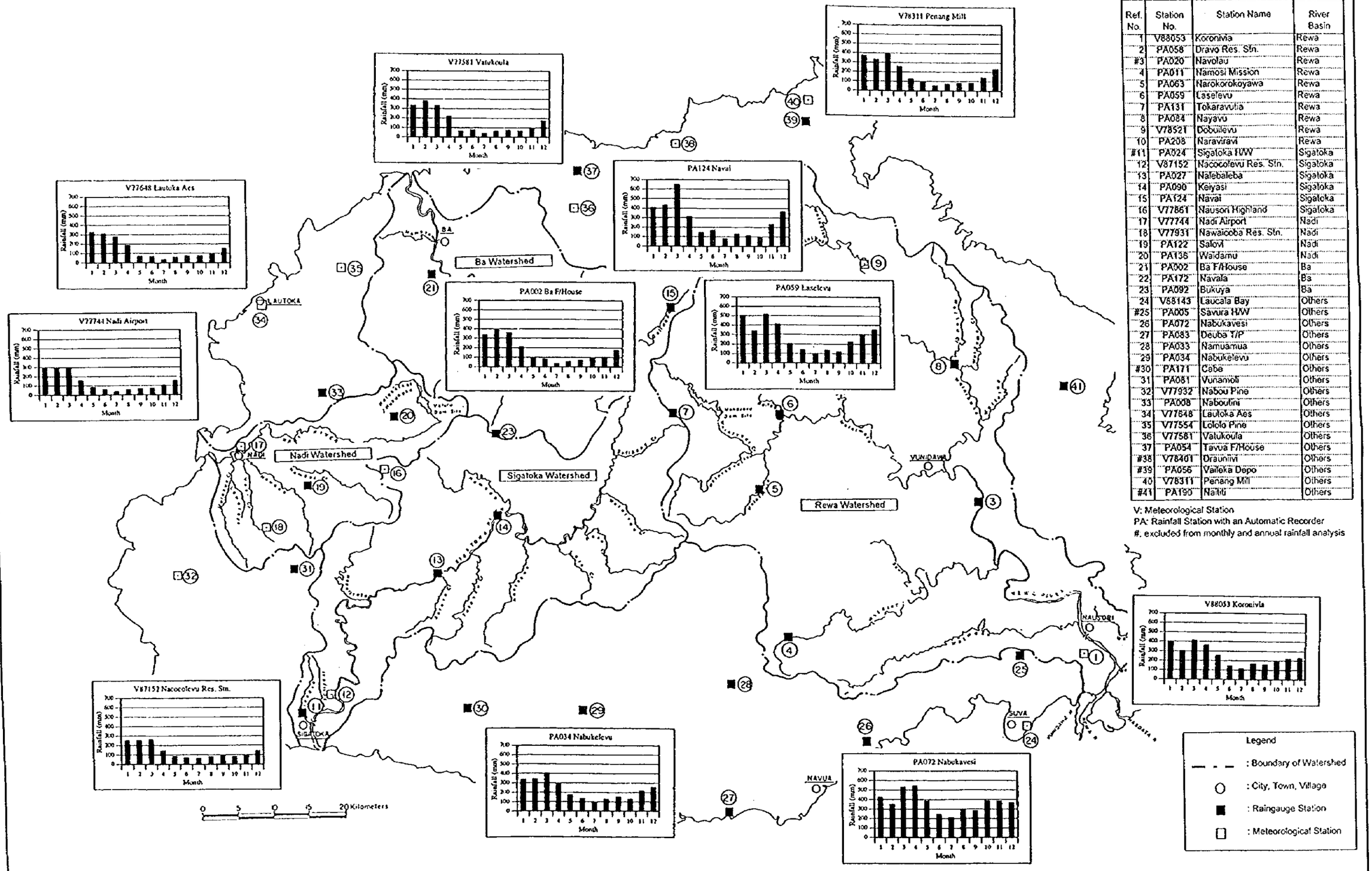


Figure-C5.3 Seasonal and Spatial Variation of Rainfall

5.2 Rainfall Probability

5.2.1 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-C5.4. 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-C5.4. The mean rainfall of watershed is the weighted average of Thiessen's polygons in the watershed.

Table-C5.2 Thiessen Ratio

Watershed	Thiessen Ratio											
Rewa	Station No.	V88053	PA059	PA084	V78521	PA208	PA124	V88143	PA072	V78401	V78311	
	Ref. No.	1	6	8	9	10	15	24	26	38	40	
	Ratio	0.169	0.273	0.184	0.086	0.089	0.058	0.016	0.116	0.006	0.003	
Sigatoka	Station No.	PA059	V87152	PA027	PA090	PA124	V77861	PA122	PA092	PA034	PA171	PA081
	Ref. No.	6	12	13	14	15	16	19	23	29	30	31
	Ratio	0.035	0.11	0.185	0.296	0.099	0.052	0.005	0.103	0.028	0.031	0.056
Nadi	Station No.	V77861	V77744	V77931	PA122	PA136	PA092	PA081	PA008			
	Ref. No.	16	17	18	19	20	23	31	33			
	Ratio	0.131	0.148	0.191	0.212	0.196	0.016	0.033	0.070			
Ba	Station No.	PA124	PA136	PA002	PA092	PA008	V77554	V77581				
	Ref. No.	15	20	21	23	33	35	36				
	Ratio	0.125	0.043	0.383	0.261	0.004	0.036	0.148				

As mentioned in section 5.1, 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.

Table-C5.3 Annual Maximum Daily Rainfall of Watershed

Unit: mm/day

Hydrological Year	Rewa	Sigatoka	Nadi	Ba
1971	68.2	35.8	41.6	55.3
1972	275.4	174.5	239.0	185.9
1973	123.5	214.5	260.8	206.7
1974	75.9	85.4	111.6	125.0
1975	83.2	151.8	192.4	183.0
1976	93.6	85.1	128.2	164.9
1977	99.3	43.9	35.5	48.1
1978	137.8	122.5	152.3	158.8
1979	225.5	89.6	70.1	129.4
1980	120.8	113.7	134.1	113.9
1981	107.5	185.4	114.1	261.9
1982	191.8	182.0	296.0	167.7
1983	160.6	120.8	195.1	231.0
1984	150.7	205.0	165.9	233.7
1985	220.0	169.8	152.3	236.6
1986	152.8	66.5	56.1	61.7
1987	54.5	44.2	55.3	56.8
1988	96.9	131.1	130.5	298.3
1989	237.8	176.2	194.1	211.6
1990	99.2	122.4	160.5	151.0
1991	53.7	55.1	71.8	111.4
1992	404.0	314.0	316.9	309.3
1993	75.2	77.8	104.5	153.3
1994	69.6	90.9	163.1	135.9

Hydrological Year: July 1 to June 30 of the following year

Raingauge Station Selected for Stochastic Analysis

Ref. No.	Station No.	Station Name	River Basin
1	V88053	Koronivia	Rewa
6	PA059	Laselevu	Rewa
8	PA084	Nayavu	Rewa
9	V78521	Dobuilevu	Rewa
10	PA208	Naraviravi	Rewa
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	Nawakoba Res. Stn.	Nadi
19	PA122	Salovi	Nadi
20	PA136	Waidamu	Nadi
21	PA002	Ba F/House	Ba
23	PA092	Bukuya	Ba
24	V88143	Laucala Bay	Others
26	PA072	Nabukavesi	Others
29	PA034	Nabukelevu	Others
30	PA171	Cabe	Others
31	PA081	Vunamoli	Others
33	PA008	Naboutini	Others
34	V77648	Lautoka Aes	Others
35	V77554	Lololo Pine	Others
36	V77581	Vatukoula	Others
38	V78401	Draunilvi	Others
40	V78311	Penang Mill	Others

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

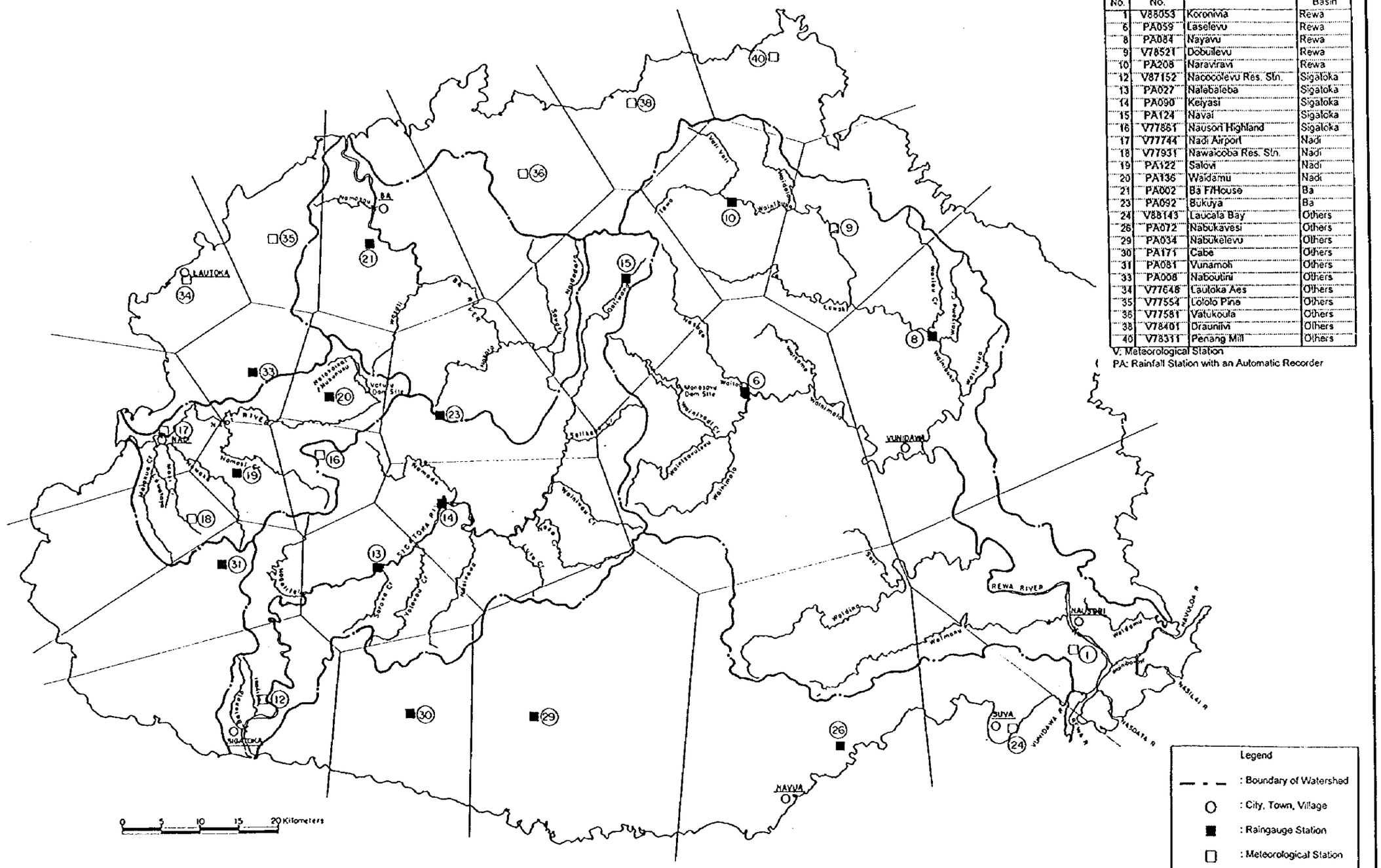


Figure-C5.4 Thiessen Polygons

5.2.2 Stochastic Analysis

Logarithmic normal distribution and extreme value distribution (Gumbel) were applied to stochastic analysis of annual maximum daily rainfall.

1) Logarithmic Normal Distribution

Logarithmic normal distribution is popular to describe the frequency distribution of the hydrological quantities because of its wide variety of analysis methods. The basic formulae of the logarithmic normal distribution are as follows.

$$P(x) = \frac{1}{\sqrt{2\pi}} \int_u^\infty e^{-u^2/2} du$$

$$u = a' \times \log \frac{x+b}{x_0+b}$$

$$\log(x+b) = \log(x_0+b) + \frac{1}{a'} \cdot u$$

$$a' > 0, \quad x_0 > -b, \quad -b < x < \infty$$

where, x: probable hydrological quantity

u: value converted from x, standard normal variable

P(x): probability of excess

x_0, a', b: constant

There are several methods to obtain the constant, x_0, a' and b. For this study, least squares method and moment method were applied. The least squares method computes a regression line to fit the plotted data. The moment method (Ishihara and Takase's method) uses the following formulae to determine the constants; however, there are tables and figures to simplify the computation.

$$\frac{1}{a'} = \frac{\log e}{\sqrt{2}} \cdot \frac{1}{k}$$

$$b = \frac{1}{\sqrt{\lambda^2 - 1}} \sigma_x - m_x$$

$$x_0 = m_x - \frac{\lambda - 1}{\lambda \sqrt{\lambda^2 - 1}} \sigma_x$$

$$\lambda = \exp\left(\frac{1}{4k^2}\right)$$

$$m_x \equiv \bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i, \quad \sigma_x \equiv \sqrt{V_x} = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (x_i - \bar{x})^2}$$

where k: constant obtained from skew coefficient

N: number of samples

x_i: ith hydrological value from the maximum

To determine the plotting position of samples, two methods, Hazen plot and Thomas plot (Weibull plot), were applied. Probability of excess is obtained by the following formulae.

Thomas Plot

$$P(x_j) = \frac{j}{N+1}$$

Hazen Plot

$$P(x_j) = \frac{2j-1}{2N}$$

where $P(x_j)$: probability of excess of x_j

j: order of x_j from the maximum

N: number of samples

2) Gumbel Extreme Value Distribution

This method is popular in Fiji, as well as in the USA. The basic formulae are as follows.

$$P(x) = 1 - \exp(-e^{-y})$$

$$y = a(x - x_0) \quad or \quad x = x_0 + \frac{1}{a}y$$

$$a, \quad x_0 > 0, \quad -\infty < x < \infty$$

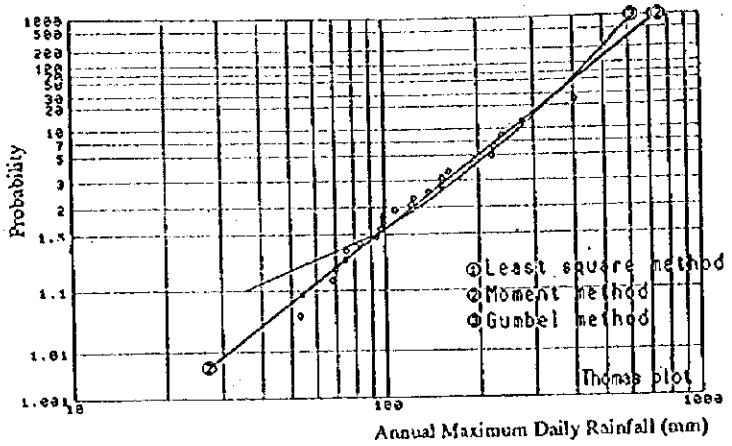
where x: probable hydrological value

P(x): probability of excess

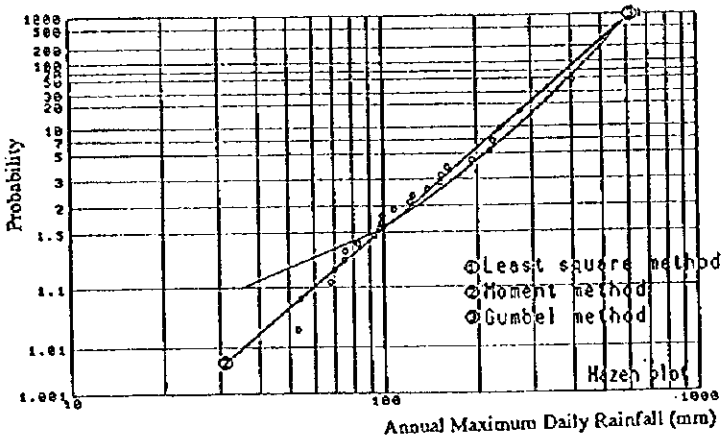
x_0, a: constant

(3) Result of Stochastic Analysis

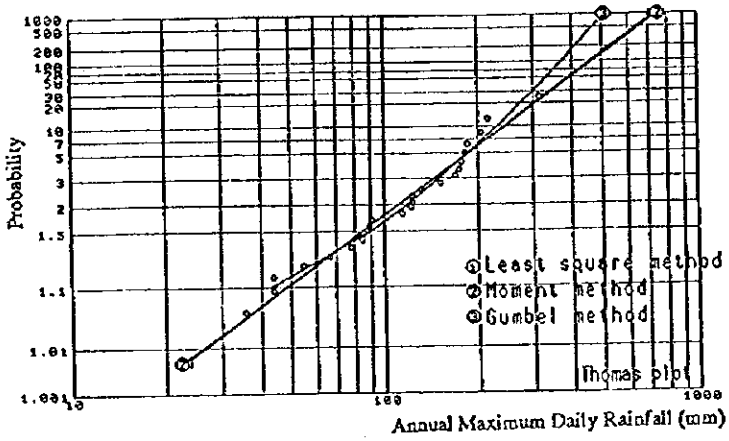
Thomas plot and Hazen plot of each watershed are shown in Figure-C5.5. The result of stochastic analysis is shown in Table-C5.4 as the deviation of the above analysis methods from the annual maximum daily rainfall. For Rewa watershed, either least squares or moment method describes the data well, while the Gumbel method is the most suitable for the other watersheds.



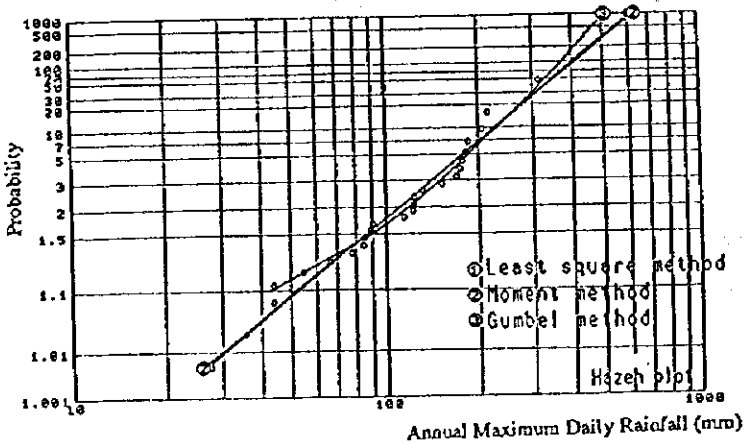
Log Normal Curve Paper for Rewa



Log Normal Curve Paper for Rewa

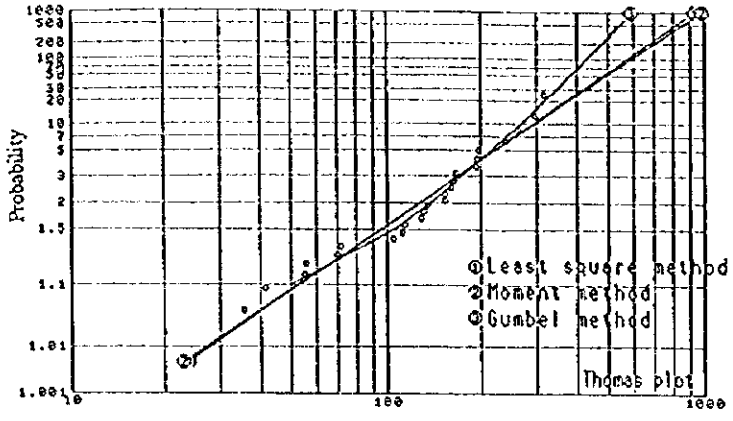


Log Normal Curve Paper for Sigatoka

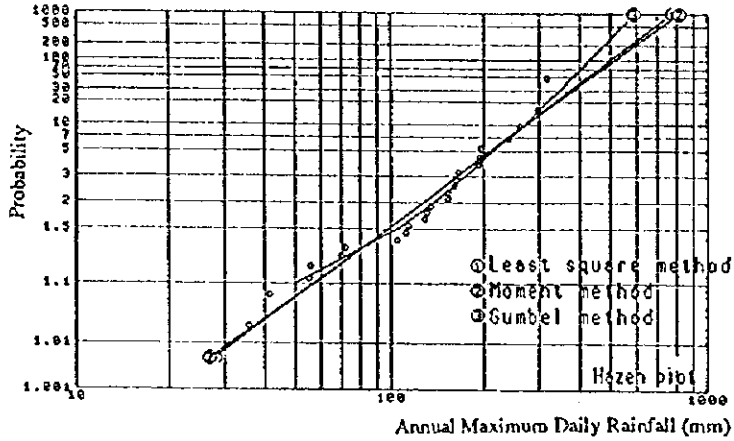


Log Normal Curve Paper for Sigatoka i

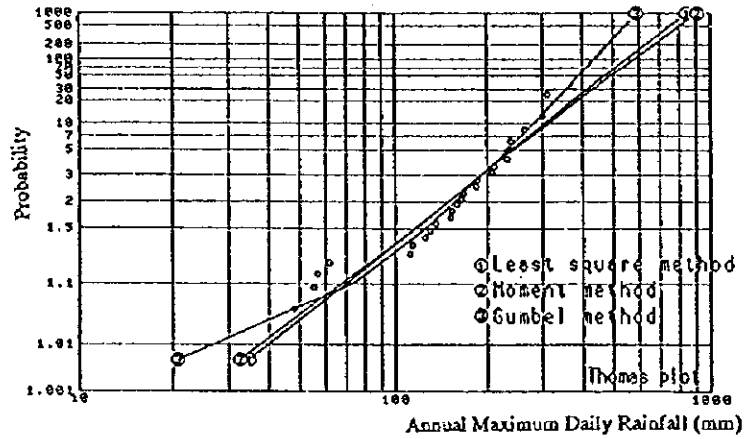
Figure-C5.5 (1/2) Thomas and Hazen Plot of Annual Maximum Daily Rainfall



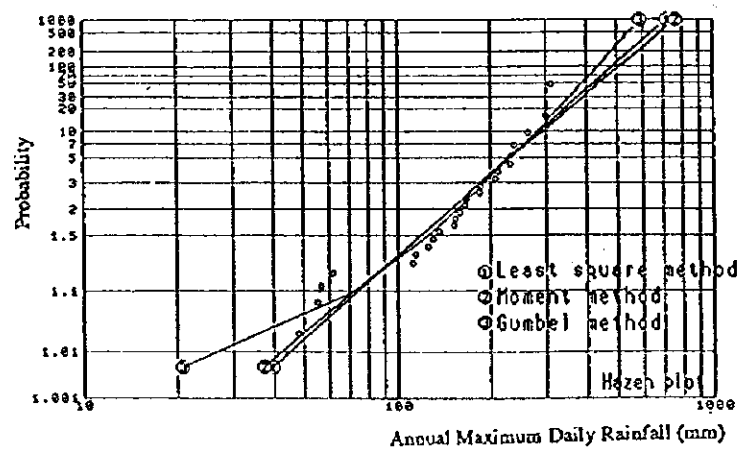
Log Normal Curve Paper for Nadi



Log Normal Curve Paper for Nadi



Log Normal Curve Paper for Ba



Log Normal Curve Paper for Ba

Figure-C5.5 (2/2) Thomas and Hazen Plot of Annual Maximum Daily Rainfall

Table-C5.4 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

The above table shows the deviation of each method from the data. However, the main concern of this study is higher values of rainfall. As shown in Figure-C5.5, least squares and moment methods by the Hazen plot fit the higher rainfall better than those by Thomas plot for Rewa and Sigatoka watershed, while those by Thomas plot are preferable for Nadi and Ba watershed.

The Gumbel method is the most suitable method to describe the annual maximum daily rainfall in Viti Levu. Although the deviation throughout all data is not satisfactory in the Rewa watershed compared to other methods, it is the best fitting method for the higher values. For the other watersheds, the Gumbel method fits throughout the data, inclusive of the higher values.

Applying the Gumbel method, the relation between return period and amount of rainfall was determined. Equations to calculate expected values of rainfall and frequency factors with return periods are shown in Table-C5.5 based on the above stochastic analysis. The results are shown in Table-C5.6.

Table-C.5.5 Frequency Factors & Equations of Gumbel Method

Return Period	Frequency Factor, U	Equation for Rewa	Equation for Sigatoka	Equation for Nadi	Equation for Ba
100	4.600	X=100.9+75.1786U	X=95.6+60.0202U	X=110.8+69.4485U	X=131.2+66.2841U
50	3.902				
30	3.384				
20	2.970				
10	2.250				
5	1.500				
2	0.367				

The probable rainfalls are almost same with the exception of Sigatoka where the probable rainfalls are less than the other watersheds. This is probably due to tracks of cyclones and topographical features. Regarding the tracks of cyclones which hit Viti Levu, there are two tracks, one passing from the north to east side of Viti Levu and the other passing western Viti Levu (Nadi). Since the Sigatoka watershed is bounded on the west by Nausori highland with an altitude of 500 ~ 900 m and on the east by Nadrau Plateau with an altitude of 900 ~ 1,200 m, cyclones which hit Viti Levu with either track will be depressed by these mountain chains. Since the other three watersheds are open to the tracks of cyclones, their probable rainfalls are greater than those in Sigatoka watershed.

Table-C5.6 Return Period of Rainfall by Gumbel Method

Return Period (years)	Rainfall in Rewa Watershed (mm/day)	Rainfall in Sigatoka Watershed (mm/day)	Rainfall in Nadi Watershed (mm/day)	Rainfall in Ba Watershed (mm/day)
100	450	375	430	440
50	395	330	385	390
30	355	300	350	360
20	325	275	320	330
10	270	235	270	280
5	215	190	215	235
2	130	120	140	160

CHAPTER 6 RUNOFF ANALYSIS

6.1 Selected Gauging Stations

In Viti Levu Island, there are 8 staff gauge stations and 27 gauging stations with automatic recorders operated as of August, 1996. Of the 27 gauging stations, 5 stations are located where there is tidal influence. All gauging stations are operated and maintained by Hydrological Section, Public Works Department (PWD).

Considering the availability of data, 20 gauging stations were initially selected, 13 stations still operated and 7 stations now closed. After analyzing the data, 14 stations out of 20 stations were re-selected as shown in Figure-C6.1 because of the limitation of data and tidal influence. Runoff analysis of Low Water was conducted using the data from these 14 stations; however, stations selected for runoff analysis of High Water vary depending on the objective floods.

6.2 Low Water

Mean daily discharge was used for this analysis. Since there are still lots of data gaps even after the re-selection of gauging stations, the period of analysis could not be fixed. As many data as possible were used.

6.2.1 Flow Regime

Flow regime of each station was analyzed based on the above data to determine the discharge characteristics. Analysis was conducted for years having at least 200 days' data available. Based on the discharge histogram, flow regime was obtained. Flow regimes of years with data gaps were extended to 365 days. For example, 26 % of the 200 day discharge histogram was adopted as High Discharge assuming that even 200 days' data describes the annual flow characteristics. The result is summarized in Table-C6.1 showing the duration curve of the typical year. Since observation days of discharge for a year vary annually due to data gaps, the duration curve of mean flow regime is not obtainable. Therefore, the duration curve of a year whose flow regime is close to average value was drawn as a typical duration curve.

Based on the duration curve, the following discharges are defined for the utilization of water resources, such as water development and hydro-power, etc.

1) High Discharge: 95th daily discharge from the maximum, discharge exceeding this volume for 95 days in a year (26 % of a year)
2) Normal Discharge: 185th daily discharge from the maximum, discharge exceeding this volume for 185 days in a year (50 % of a year)
3) Low Discharge: 275th daily discharge from the maximum, discharge exceeding this volume for 275 days in a year (75 % of a year)
4) Drought Discharge: 355th daily discharge from the maximum, discharge exceeding this volume for 355 days in a year (97 % of a year)

Ref. No.	Selected Station for Analysis	No.	Station Name	Watershed	Catchment Area (km2)	Latitude	Longitude
1		LA023	NAUSORI-CRT	REWA	2903	18°01'S	178°32'E
2		LA002	DREINAKELO	REWA	2677	17°58'S	178°31'E
3	Y	HA010	WAIMANU	REWA	165	18°02'S	178°27'E
4	Y	HA006	NABUKALUKA	REWA	253	17°58'S	178°19'E
5	Y	HA149	NATUBA	REWA	146	17°54'S	178°16'E
6	Y	HA009	NAVOLAU	REWA	1961	17°52'S	178°23'E
7	Y	HA008	NAIRUKURUKU	REWA	790	17°48'S	178°16'E
8	Y	HA143	NAYAVU	REWA	706	17°41'S	178°21'E
9	Y	HA155	DOBUILEVU	REWA	316	17°33'S	178°14'E
10	Y	HA090	NAMOKA	SIGATOKA	1333	18°02'S	177°38'E
11		HA024	NALEBALEBA	SIGATOKA	1120	18°57'S	177°40'E
12		HA195	NUKUILAU	SIGATOKA	443	17°53'S	177°51'E
13		LA001	NADI-BRIDGE	NADI	333	17°47'S	177°25'E
14	Y	HA100	NATUACERE	NADI	70	17°50'S	177°28'E
15	Y	HA021	YAVUNA	NADI	62	17°43'S	177°33'E
16	Y	HA020	VOTUALEVU	NADI	164	17°46'S	177°30'E
17		LA032	NAMOSAU-Br	BA	940	17°32'S	177°40'E
18	Y	HA093	TOGE	BA	579	17°37'S	177°44'E
19	Y	HA162	NAVALA	BA	323	17°39'S	177°48'E
20	Y	HA062	KORO	BA	62	17°42'S	177°54'E

Y: finally selected station for analysis
HA: station with no tidal influence
LA: station with tidal influence

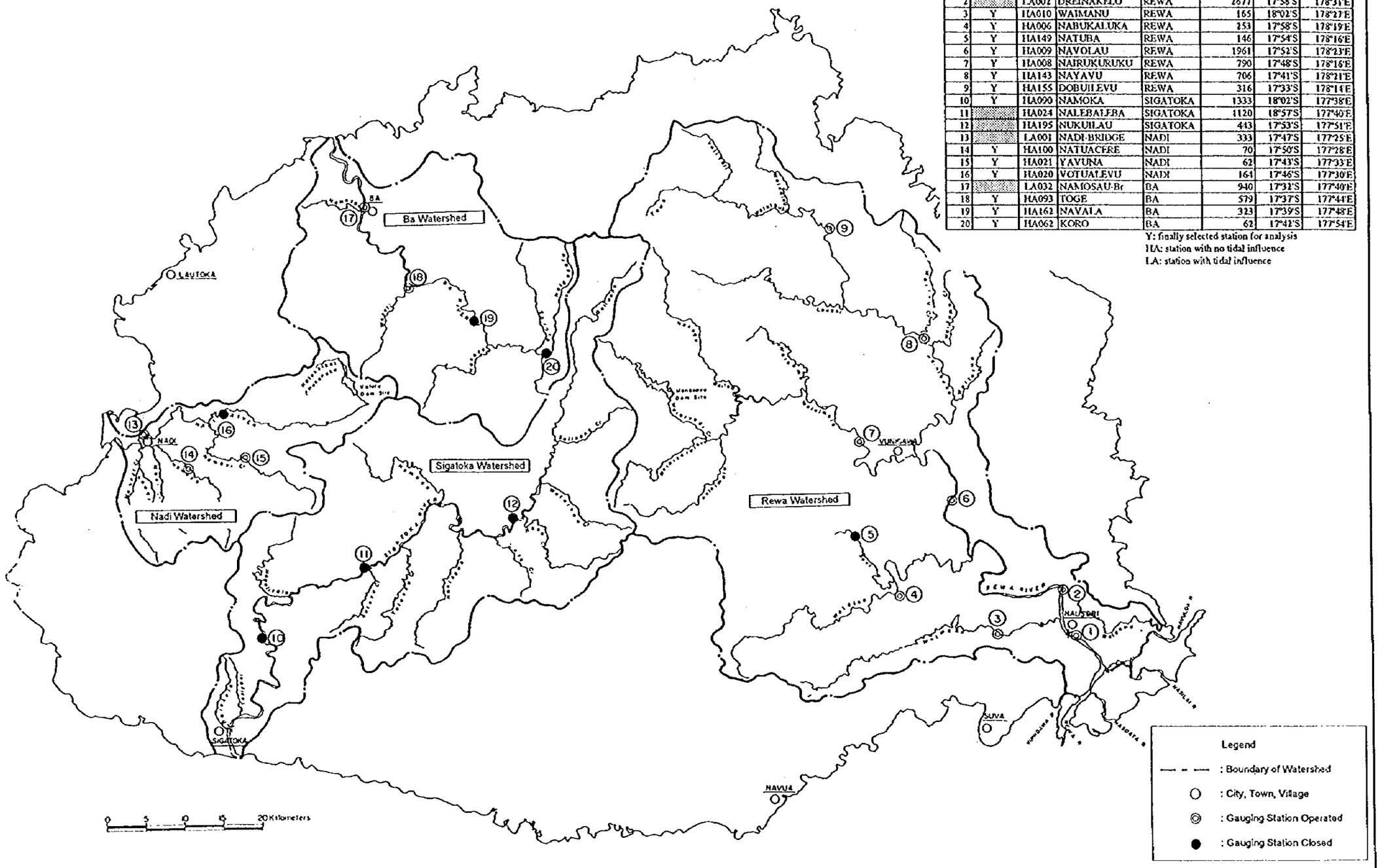
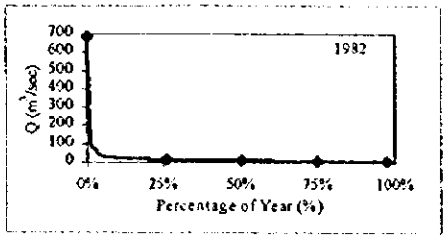


Figure-C6.1 Location of Selected Gauging Stations for Runoff Analysis

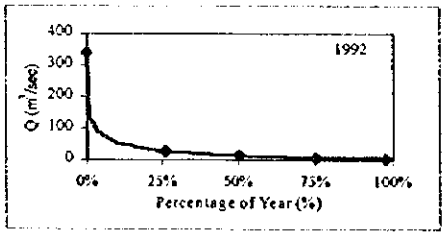
Table-C6.1 (1/3) Flow Regime of Selected Gauging Stations

Rewa Tributary — Waimanu (HA010)
Ref. No.: 3
Catchment Area: 165 km²



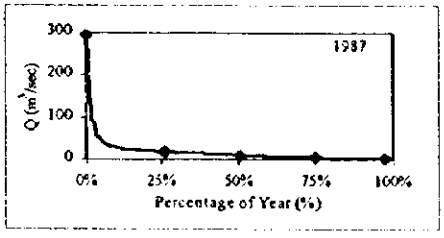
Year	Max	Q26%	Q50%	Q75%	Q97%	Min
1972	994.0	18.0	11.0	9.0	5.0	5.0
1973	291.0	10.0	8.0	6.0	1.0	1.0
1977	394.0	12.0	7.0	4.0	3.0	2.0
1978	247.0	14.0	8.0	5.0	3.0	2.0
1979	1771.0	15.0	9.0	5.0	3.0	3.0
1980	4044.0	13.0	8.0	5.0	3.0	2.0
1981	128.0	12.0	9.0	6.0	4.0	4.0
1982	***689.0***	***15.0***	***11.0***	***9.0***	***7.0***	***7.0***
1983	309.0	14.0	10.0	8.0	6.0	5.0
1984	527.0	18.0	15.0	14.0	10.0	9.0
1985	540.0	12.0	7.0	4.0	1.0	1.0
1987	2334.0	11.0	7.0	4.0	3.0	3.0
1988	192.0	18.0	10.0	7.0	5.0	4.0
1989	154.0	12.0	9.0	7.0	5.0	3.0
1990	515.0	16.0	8.0	6.0	4.0	3.0
1991	398.0	14.0	7.0	5.0	3.0	3.0
1992	443.0	14.0	6.0	4.0	1.0	1.0
1993	2755.0	21.0	13.0	7.0	4.0	4.0
1994	181.0	17.0	8.0	5.0	4.0	3.0
1995	237.0	19.0	11.0	7.0	5.0	5.0
Average	857.0	15.0	9.0	6.0	4.0	4.0

Rewa Tributary — Nabukaluka (HA006)
Station No.: 4
Catchment Area: 253 km²



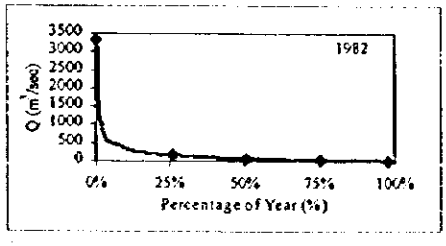
Year	Max	Q26%	Q50%	Q75%	Q97%	Min
1970	234.0	25.0	8.0	4.0	3.0	2.0
1971	373.0	20.0	9.0	5.0	3.0	3.0
1972	583.0	35.0	16.0	7.0	3.0	2.0
1973	293.0	42.0	25.0	14.0	5.0	4.0
1974	224.0	29.0	16.0	7.0	3.0	3.0
1975	298.0	26.0	11.0	4.0	2.0	1.0
1976	134.0	34.0	20.0	13.0	8.0	6.0
1977	406.0	27.0	8.0	2.0	1.0	1.0
1978	296.0	28.0	16.0	9.0	3.0	2.0
1979	283.0	23.0	13.0	8.0	3.0	3.0
1980	895.0	28.0	18.0	10.0	7.0	6.0
1981	120.0	20.0	10.0	6.0	4.0	2.0
1982	353.0	24.0	13.0	10.0	7.0	4.0
1983	196.0	15.0	9.0	6.0	4.0	4.0
1984	126.0	20.0	13.0	7.0	4.0	4.0
1985	240.0	22.0	14.0	9.0	5.0	4.0
1986	536.0	23.0	10.0	5.0	2.0	2.0
1989	102.0	24.0	17.0	11.0	3.0	2.0
1991	209.0	28.0	11.0	5.0	2.0	1.0
1992	***339.0***	***28.0***	***15.0***	***9.0***	***7.0***	***5.0***
1994	255.0	50.0	36.0	26.0	19.0	18.0
1995	250.0	59.0	45.0	36.0	28.0	26.0
Average	307.0	29.0	16.0	10.0	6.0	5.0

Rewa Tributary — Natuva (HA149)
Station No.: 5
Catchment Area: 146 km²



Year	Max	Q26%	Q50%	Q75%	Q97%	Min
1980	1255.0	20.0	12.0	6.0	3.0	2.0
1981	281.0	17.0	10.0	5.0	3.0	3.0
1982	292.0	17.0	10.0	7.0	5.0	5.0
1983	366.0	16.0	9.0	5.0	3.0	3.0
1984	392.0	20.0	13.0	7.0	3.0	3.0
1985	301.0	17.0	9.0	5.0	3.0	2.0
1986	647.0	15.0	7.0	4.0	3.0	3.0
1987	***294.0***	***18.0***	***10.0***	***5.0***	***3.0***	***2.0***
1988	97.0	26.0	17.0	12.0	8.0	7.0
1989	182.0	19.0	13.0	7.0	3.0	3.0
1991	50.0	17.0	9.0	5.0	3.0	3.0
1992	154.0	24.0	15.0	9.0	5.0	4.0
Average	359.0	19.0	11.0	6.0	4.0	3.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

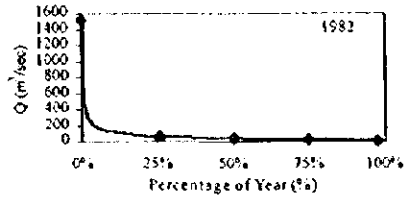
Rewa Main — Navofau (HA009)
Station No.: 6
Catchment Area: 1961 km²



Year	Max	Q26%	Q50%	Q75%	Q97%	Min
1971	1345.0	169.0	73.0	34.0	18.0	15.0
1972	6711.0	199.0	122.0	71.0	33.0	29.0
1977	655.0	57.0	26.0	17.0	10.0	9.0
1978	2057.0	165.0	53.0	24.0	8.0	6.0
1979	2259.0	124.0	68.0	40.0	23.0	22.0
1980	4218.0	152.0	77.0	39.0	20.0	16.0
1981	1362.0	116.0	48.0	15.0	2.0	1.0
1982	***3311.0***	***163.0***	***73.0***	***38.0***	***17.0***	***17.0***
1984	2703.0	171.0	97.0	68.0	32.0	31.0
1985	3960.0	128.0	81.0	60.0	48.0	45.0
1988	2054.0	230.0	130.0	90.0	73.0	68.0
1991	2221.0	132.0	49.0	24.0	16.0	13.0
1993	6925.0	132.0	65.0	46.0	32.0	28.0
1994	1112.0	158.0	69.0	49.0	34.0	34.0
1995	1305.0	159.0	88.0	51.0	29.0	20.0
Average	2813.0	150.0	74.0	44.0	26.0	24.0

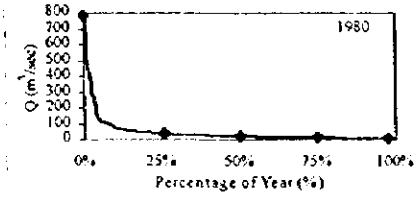
Table-C6.1 (2/3) Flow Regime of Selected Gauging Stations

Rewa — Naitukuruku (HA008)
Tributary
Station No.: 7
Catchment Area: 790 km²



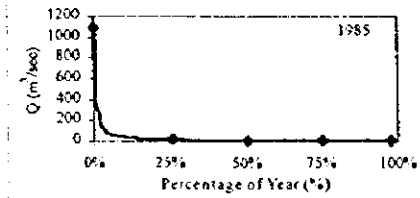
Year	Max	Q26%	Q50%	Q75%	Q97%	Min
1978	833.0	52.0	33.0	26.0	19.0	18.0
1979	877.0	45.0	30.0	21.0	13.0	11.0
1980	2161.0	65.0	40.0	22.0	10.0	9.0
1981	535.0	50.0	25.0	16.0	8.0	6.0
1982	***1526.0***	***68.0***	***42.0***	***30.0***	***18.0***	***15.0***
1983	2132.0	50.0	25.0	14.0	11.0	10.0
1984	1320.0	62.0	38.0	23.0	15.0	13.0
1985	2628.0	55.0	34.0	26.0	21.0	19.0
1986	832.0	49.0	31.0	23.0	19.0	15.0
1987	1027.0	53.0	29.0	21.0	18.0	17.0
1988	478.0	67.0	38.0	31.0	26.0	25.0
1989	383.0	58.0	36.0	28.0	22.0	21.0
1990	2769.0	78.0	55.0	46.0	32.0	28.0
1991	779.0	65.0	40.0	29.0	24.0	22.0
1992	2085.0	60.0	45.0	36.0	27.0	22.0
1994	589.0	63.0	51.0	46.0	37.0	35.0
1995	751.0	133.0	91.0	66.0	46.0	42.0
Average	1277.0	63.0	40.0	30.0	22.0	19.0

Rewa — Nayavu (HA143)
Tributary
Station No.: 8
Catchment Area: 706 km²



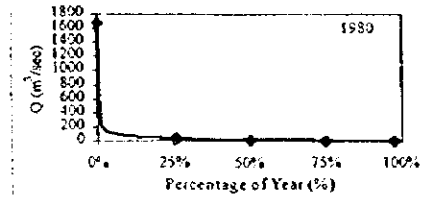
Year	Max	Q26%	Q50%	Q75%	Q97%	Min
1979	608.0	30.0	18.0	13.0	9.0	8.0
1980	***782.0***	***39.0***	***23.0***	***14.0***	***9.0***	***7.0***
1981	878.0	33.0	20.0	13.0	11.0	10.0
1982	533.0	40.0	23.0	16.0	12.0	11.0
1983	458.0	21.0	13.0	10.0	7.0	6.0
1984	1458.0	39.0	24.0	13.0	9.0	9.0
1985	779.0	35.0	23.0	16.0	11.0	10.0
1986	1556.0	32.0	19.0	10.0	8.0	7.0
1987	673.0	34.0	18.0	11.0	6.0	5.0
1988	537.0	56.0	35.0	22.0	9.0	9.0
1989	641.0	42.0	22.0	15.0	10.0	9.0
1990	1885.0	38.0	26.0	19.0	10.0	8.0
1991	225.0	39.0	26.0	20.0	8.0	2.0
1992	255.0	21.0	13.0	9.0	4.0	3.0
1993	569.0	32.0	19.0	13.0	9.0	8.0
1994	548.0	31.0	14.0	9.0	7.0	7.0
1995	908.0	39.0	26.0	17.0	10.0	8.0
Average	784.0	35.0	21.0	14.0	9.0	7.0

Rewa — Dovuilevu (HA155)
Tributary
Station No.: 9
Catchment Area: 316 km²



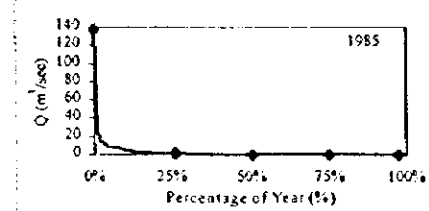
Year	Max	Q26%	Q50%	Q75%	Q97%	Min
1984	964.0	20.0	14.0	11.0	9.0	8.0
1985	***1088.0***	***20.0***	***13.0***	***11.0***	***8.0***	***8.0***
1987	293.0	17.0	11.0	7.0	7.0	6.0
1988	252.0	25.0	13.0	9.0	7.0	6.0
1989	631.0	25.0	14.0	9.0	8.0	8.0
1992	1160.0	18.0	7.0	3.0	1.0	1.0
1993	2012.0	21.0	8.0	6.0	4.0	2.0
1994	602.0	15.0	8.0	6.0	5.0	4.0
1995	266.0	19.0	10.0	6.0	5.0	4.0
Average	808.0	20.0	11.0	8.0	6.0	5.0

Sigatoka — Nameka (HA090)
Main
Station No.: 10
Catchment Area: 1333 km²



Year	Max	Q26%	Q50%	Q75%	Q97%	Min
1979	204.4	23.1	11.9	7.6	3.8	2.9
1980	***1676.0***	***39.0***	***13.0***	***9.0***	***7.0***	***4.0***
1981	889.6	22.6	11.8	6.3	3.9	3.3
1982	2141.0	61.0	14.0	8.0	5.0	4.0
1983	1005.0	40.0	26.0	22.0	9.0	5.0
Average	1183.0	37.0	15.0	11.0	6.0	4.0

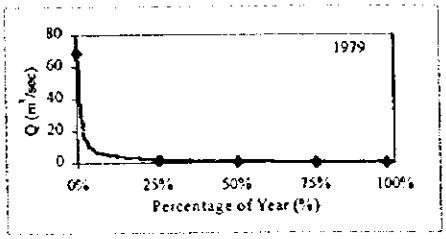
Nadi — Nawaka (HA100)
Tributary
Station No.: 14
Catchment Area: 70 km²



Year	Max	Q26%	Q50%	Q75%	Q97%	Min
1977	2.2	0.3	0.2	0.1	0.1	0.1
1978	14.2	0.5	0.3	0.2	0.1	0.1
1979	137.1	2.1	0.5	0.3	0.2	0.2
1980	53.3	2.7	0.6	0.3	0.2	0.2
1981	129.2	1.7	0.8	0.3	0.1	0.1
1982	35.3	1.9	0.7	0.3	0.1	0.1
1983	563.6	2.2	1.5	0.5	0.2	0.1
1984	167.0	0.9	0.2	0.1	0.1	0.1
1985	***137.3***	***0.9***	***0.3***	***0.2***	***0.1***	***0.1***
1987	17.2	0.4	0.2	0.1	0.1	0.1
1988	14.9	1.0	0.4	0.2	0.2	0.1
1989	370.9	2.9	0.6	0.3	0.1	0.1
1990	72.0	0.7	0.4	0.2	0.1	0.1
1991	31.6	1.8	0.4	0.1	0.1	0.1
1992	1.6	0.2	0.1	0.1	0.1	0.1
1993	26.9	1.1	0.3	0.1	0.1	0.1
1994	164.9	2.7	0.1	0.1	0.0	0.0
Average	114.1	1.4	0.4	0.2	0.1	0.1

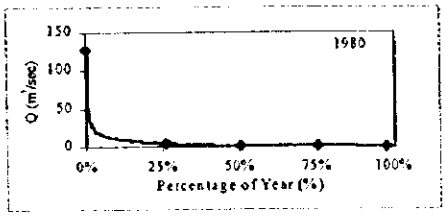
Table-C6.1 (3/3) Flow Regime of Selected Gauging Stations

Nadi — Tributary — Yavuna (HA021)
Station No.: 15
Catchment Area: 62 km²



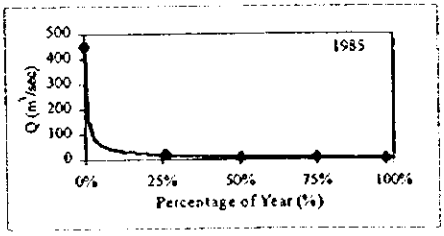
Year	Max	Q26%	Q50%	Q75%	Q97%	Min
1977	31.4	0.9	0.4	0.2	0.1	0.1
1978	6.1	0.4	0.2	0.1	0.1	0.1
1979	***65.8***	***1.8***	***0.6***	***0.3***	***0.2***	***0.1***
1980	32.4	0.9	0.3	0.2	0.1	0.1
1981	66.1	0.9	0.4	0.3	0.2	0.1
1982	48.9	1.9	0.6	0.3	0.1	0.1
1983	19.1	1.7	1.2	0.7	0.2	0.1
1984	92.7	2.0	0.4	0.2	0.1	0.1
1985	119.3	2.0	0.9	0.5	0.3	0.3
1986	117.8	1.5	0.3	0.1	0.1	0.1
1987	8.6	0.6	0.3	0.1	0.1	0.1
1988	3.6	1.5	0.3	0.2	0.1	0.1
1989	23.6	2.9	0.5	0.2	0.1	0.1
1990	80.7	0.5	0.2	0.1	0.1	0.1
1991	7.2	0.3	0.1	0.1	0.1	0.1
1992	1.9	0.2	0.1	0.1	0.1	0.1
1995	17.2	0.7	0.4	0.2	0.1	0.1
Average	43.8	1.2	0.4	0.2	0.1	0.1

Nadi — Main — Votualevu (HA020)
Station No.: 16
Catchment Area: 164 km²



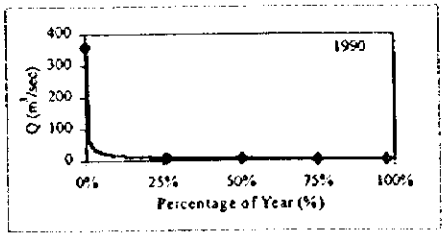
Year	Max	Q26%	Q50%	Q75%	Q97%	Min
1980	***127.0***	***4.5***	***1.8***	***1.1***	***0.5***	***0.5***
1981	127.3	4.3	2.7	1.3	0.7	0.6
1982	415.0	5.9	1.9	0.7	0.2	0.1
1984	87.6	9.5	6.9	5.7	2.6	2.3
1986	378.0	6.6	5.3	4.5	4.2	4.2
1988	84.0	7.7	4.5	3.2	2.3	2.2
Average	203.2	6.4	3.9	2.8	1.8	1.7

Ba — Main — Toge (HA093)
Station No.: 18
Catchment Area: 579 km²



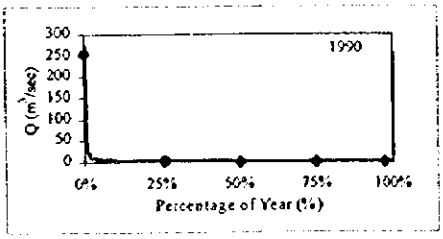
Year	Max	Q26%	Q50%	Q75%	Q97%	Min
1980	185.5	17.7	6.8	5.4	2.4	1.8
1981	276.9	12.2	7.9	5.3	3.7	3.4
1982	1879.0	18.0	8.0	6.0	4.0	4.0
1983	1119.0	10.0	5.0	4.0	3.0	3.0
1984	1379.0	20.0	10.0	5.0	3.0	3.0
1985	***451.9***	***17.9***	***10.3***	***7.6***	***5.0***	***4.8***
1986	1574.0	13.0	6.0	3.0	3.0	3.0
1987	159.2	6.2	3.3	2.6	2.1	2.1
1988	120.3	9.4	6.2	4.4	3.2	2.8
1990	96.1	11.4	7.9	6.1	5.4	5.4
1991	186.0	13.8	6.2	5.4	4.6	4.2
1992	162.7	6.8	5.0	3.9	3.0	3.0
1995	276.3	10.6	5.1	3.5	3.1	3.1
Average	605.0	13.0	7.0	5.0	4.0	3.0

Ba — Main — Navala (HA162)
Station No.: 19
Catchment Area: 323 km²



Year	Max	Q26%	Q50%	Q75%	Q97%	Min
1983	604.3	7.8	4.3	3.4	2.7	2.7
1984	590.2	15.8	8.0	4.0	2.7	2.5
1985	986.8	13.1	6.2	4.3	3.3	2.8
1986	231.0	7.9	4.6	3.3	2.6	2.6
1987	117.2	5.1	2.9	2.2	1.8	1.8
1988	299.6	8.1	4.5	3.0	2.5	2.5
1989	344.9	21.8	7.6	4.9	3.6	3.4
1990	***358.3***	***8.8***	***6.2***	***5.2***	***4.3***	***4.1***
1991	508.0	9.6	4.2	3.3	2.7	2.6
1992	101.4	4.8	2.8	2.4	1.8	1.8
Average	414.0	10.0	5.0	4.0	3.0	3.0

Ba — Main — Koro (HA062)
Station No.: 20
Catchment Area: 62 km²



Year	Max	Q26%	Q50%	Q75%	Q97%	Min
1990	***256.3***	***2.2***	***1.5***	***1.2***	***1.0***	***0.9***
1991	861.3	4.9	2.5	2.0	1.2	1.1
1992	45.2	1.3	1.0	0.8	0.6	0.6
Average	387.6	2.8	1.7	1.3	0.9	0.9

The main characteristic of flow regime in Viti Levu is a sharp decline after the maximum. It implies that the sub-surface runoff, recharge of groundwater and water storage of the watersheds are small.

6.2.2 Runoff Coefficients

The relation between annual discharge and annual rainfall was analyzed to determine runoff coefficients. The sum of mean daily discharge in a year was divided by the area of watershed in order to compare with annual rainfall. Least squares method was employed to correlate discharge and rainfall. The results are shown in Figure-C6.2.

The runoff coefficient was determined to estimate roughly the long term hydrological water balance. If there was no rainfall at all for a long enough period, there would be no base flow. Therefore, the regression line of the discharge and rainfall correlation has to pass through the origin.

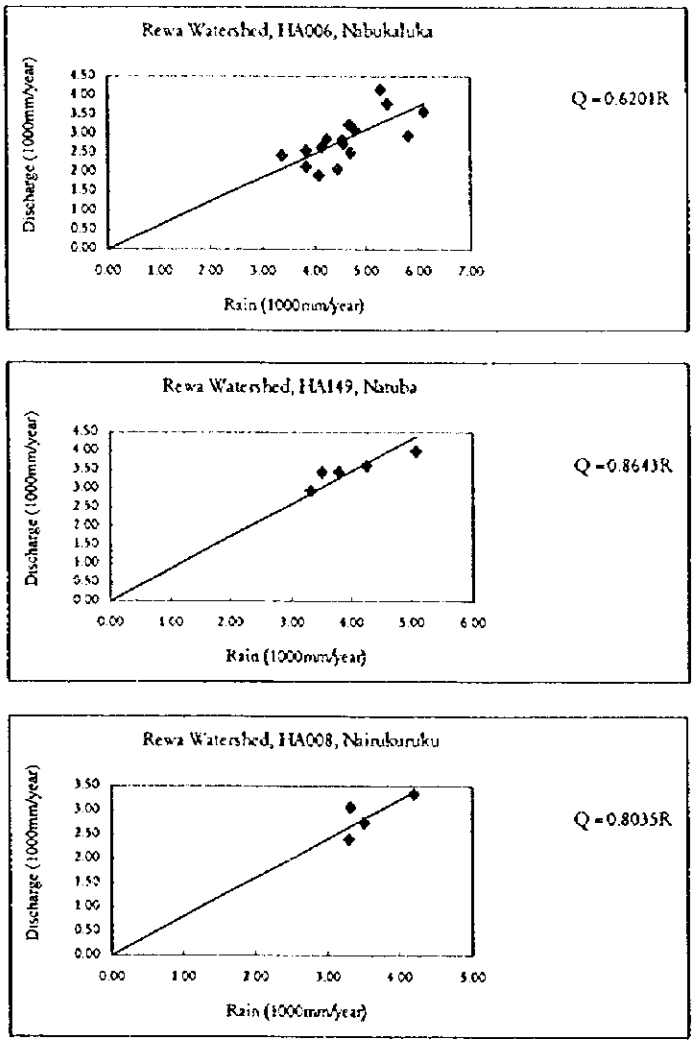
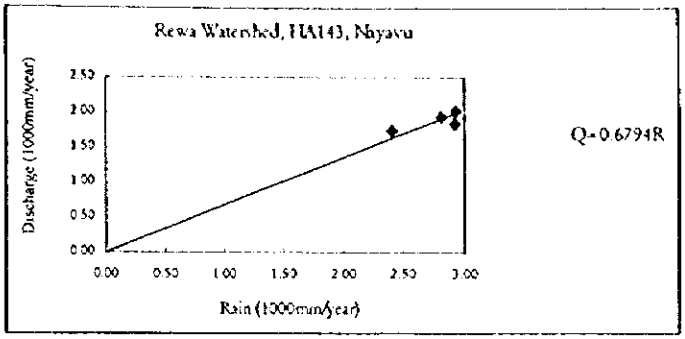
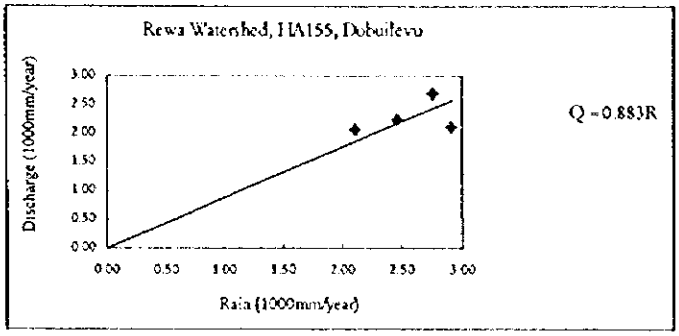
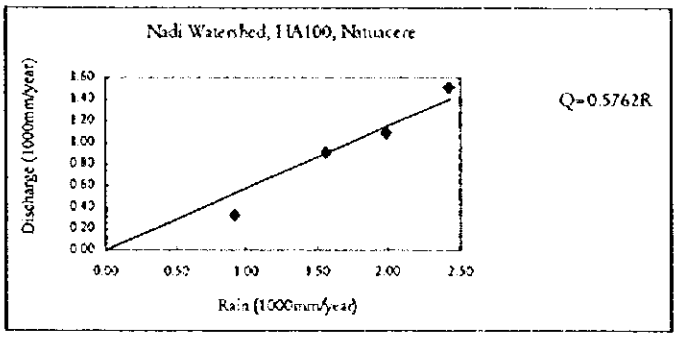
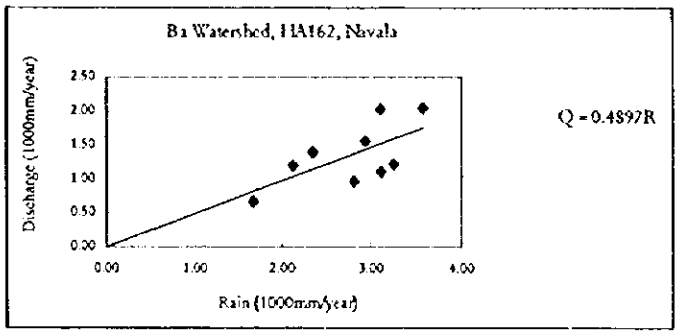


Figure-C6.2 (1/2) Total Runoff Coefficient









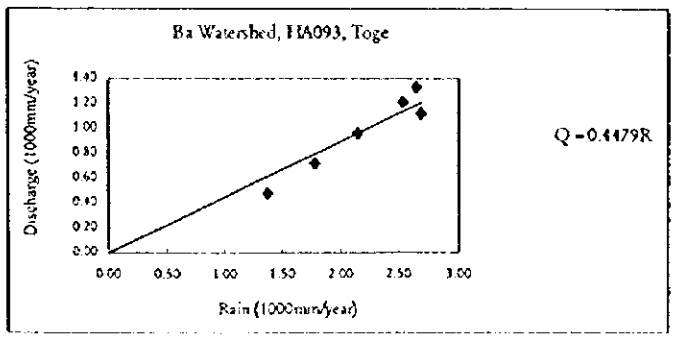


Figure-C6.2 (2/2) Total Runoff Coefficient

Total runoff coefficient for a year varies between 0.45 and 0.88 depending on location. In general, runoff coefficient is a function of topography, vegetation and rainfall intensity. Therefore, it depends on the individual flood. However, the total runoff coefficient for a year is the average value of all these factors. In addition, the total runoff coefficients presented here are approximations due to the limited data.

Annual ET_p (reference crop evapotranspiration or potential evapotranspiration) in the western side of Viti Levu is approximately 2,000 mm, while one in the eastern side is 1,500 mm. Since ET_p is the maximum evapotranspiration, the actual value is lower than ET_p. Annual rainfalls in the western and eastern side are about 2,000 and 3,000 mm, respectively. If actual value of evapotranspiration was assumed 50 % of Et_p and recharge to groundwater was small enough to be ignored, the total runoff coefficient computed would be reasonable.

6.2.3 Flow Capacity of 4 Major Viti Levu Rivers

Flow capacity of river channel was examined by computation of non uniform flow. The sections examined are those at which the river profile and cross section survey was conducted.

Rewa River	50 km from river mouth with 500 m interval
Sigatoka River	50 km from river mouth with 500 m interval
Nadi River	25 km from river mouth with 500 m interval
Ba River	35 km from river mouth with 500 m interval

Explanation of the model and discussion of the results are described in Supporting Report Part D, Runoff analysis.

6.3 High Water

Hydrograph analysis using the storage function was employed to analyze the High Water. The details of the model and discussion of the results are described in Supporting Report Part D, Runoff Analysis.

Literature Cited

Doorenbos, J., and Pruitt, W.O. (1977). Guidelines of Predicting Crop Water Requirements. FAO Irrigation and Drainage Paper 24. Food and Agriculture Organization of the United Nations. Rome.

SUPPORTING REPORT

PART D

RUNOFF ANALYSIS

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

SUPPORTING REPORT
PART D, METEOROLOGY AND HYDROLOGY

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 5

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 OBJECTIVES OF RUNOFF ANALYSIS

Main objective of runoff analysis is to understand flood characteristics of 4 major Viti Levu rivers (Rewa, Sigatoka, Nadi and Ba) in order to formulate flood control master plans. Items included in runoff analysis are;

1) To examine flow capacity of river channel
2) To simulate floods with different return periods of rainfall

Runoff analysis was conducted in accordance with the following flowchart, Figure-D1.1.

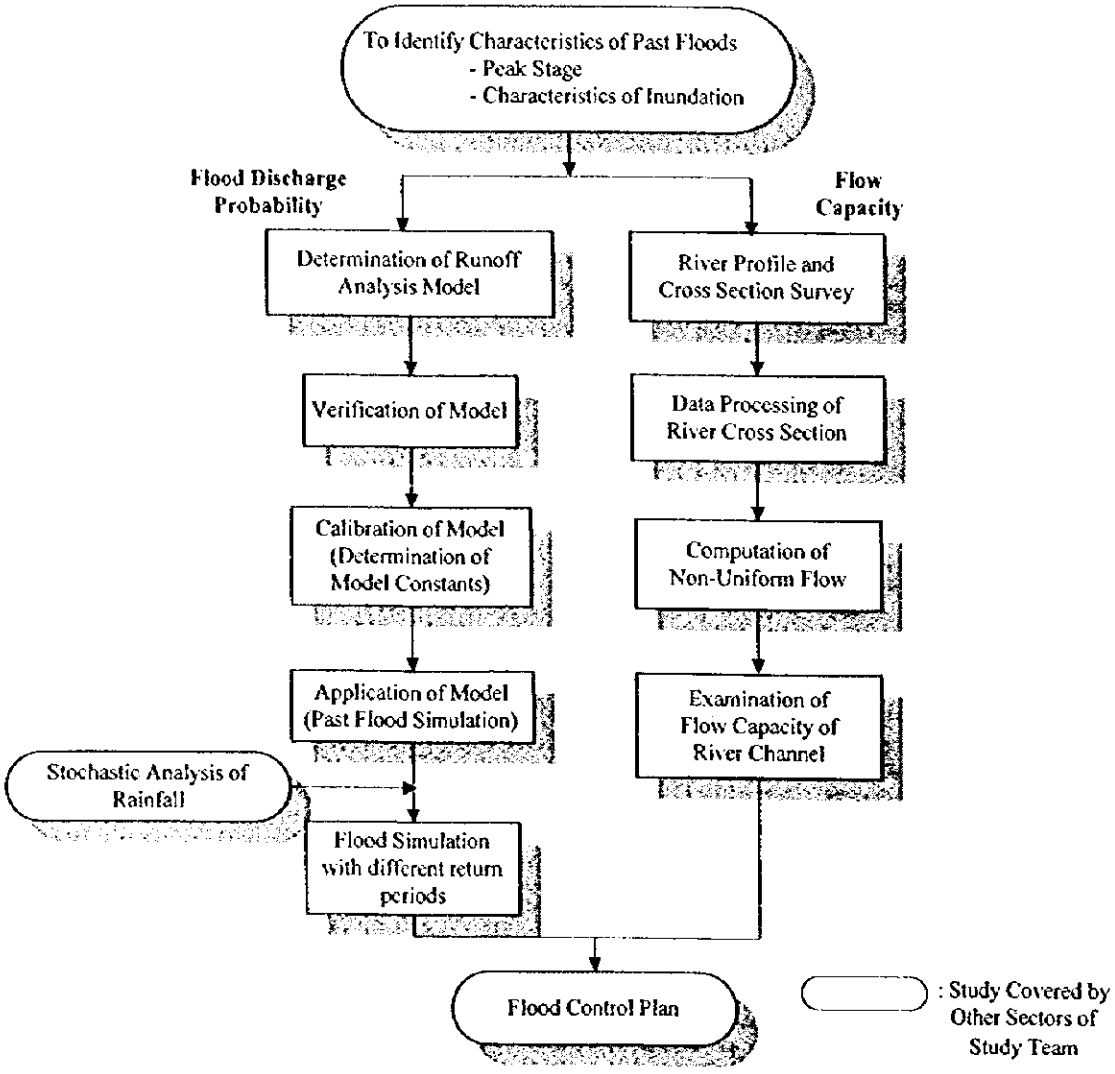


Figure-D1.1 Flowchart of Runoff Analysis

CHAPTER 2 FIELD INVESTIGATION

The Study Team conducted the river profile and cross section survey to understand physical characteristics of the target 4 rivers during the first work period in Fiji, from August 1996 to December 1996. The survey was carried out through subcontract with a local consultant.

Areas covered by the river profile and cross section survey are described in Table-D2.1 and their locations are shown in Figure-D2.1.

Table-D2.1 Site for River Profile and Cross Section Survey

Watershed	River	Survey Area
Rewa	Rewa	from river mouth to 50 km upstream
Sigatoka	Sigatoka	from the river mouth to 50 km upstream
Nadi	Nadi	from river mouth to 25 km upstream
	Malakua	from confluence with Nadi river to 3km upstream
	Nawaka	from confluence with Nadi river to 7 km upstream
Ba	Ba	from river mouth to 35 km upstream

The survey works consisted of;

1) Mobilization
2) Route clearing
3) Control point survey
4) Installation of distance markers and bench marks
5) Traverse survey
6) River profile survey
7) Cross section survey
8) Report inclusive of plans

The cross section survey was conducted every 500 m as shown in Figure-D2.2 ~ Figure-D2.5 and the total lengths of the river profile survey are shown in Table-D2.1. Regarding datum for leveling, mean sea level (normal datum in river engineering) was adopted.

In compliance with the request from the counterpart agency, Land and Water Resource Management Division (former Drainage and Irrigation), the results of the cross section survey were drawn looking upstream of river. However, definition of left or right bank of river in the Study follows that in river engineering (always looking downstream). Therefore, banks are defined by looking downstream throughout all reports, inclusive of figures and plans, unless specified.

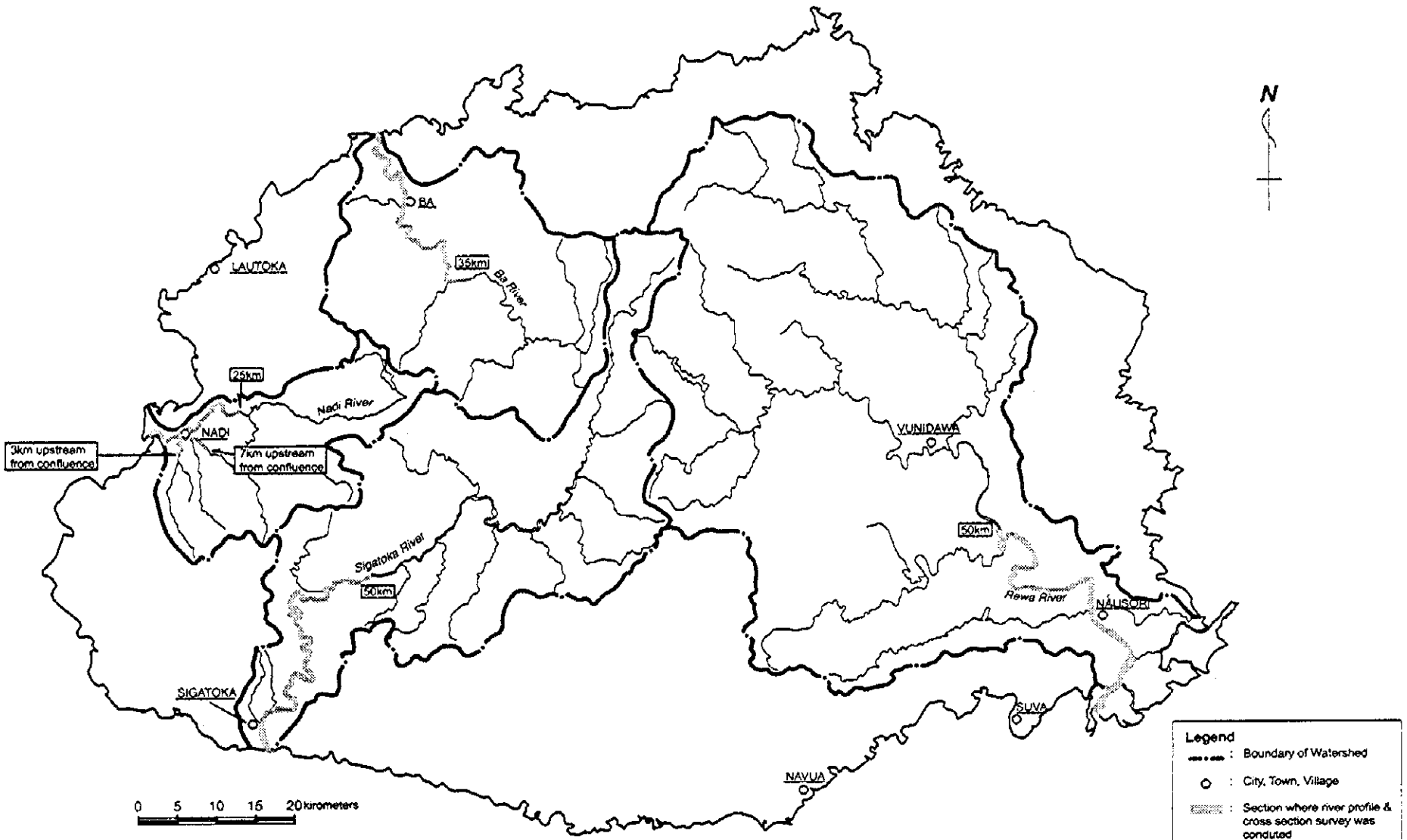


Figure-D2.1 Sites for River Profile and Cross Section Survey

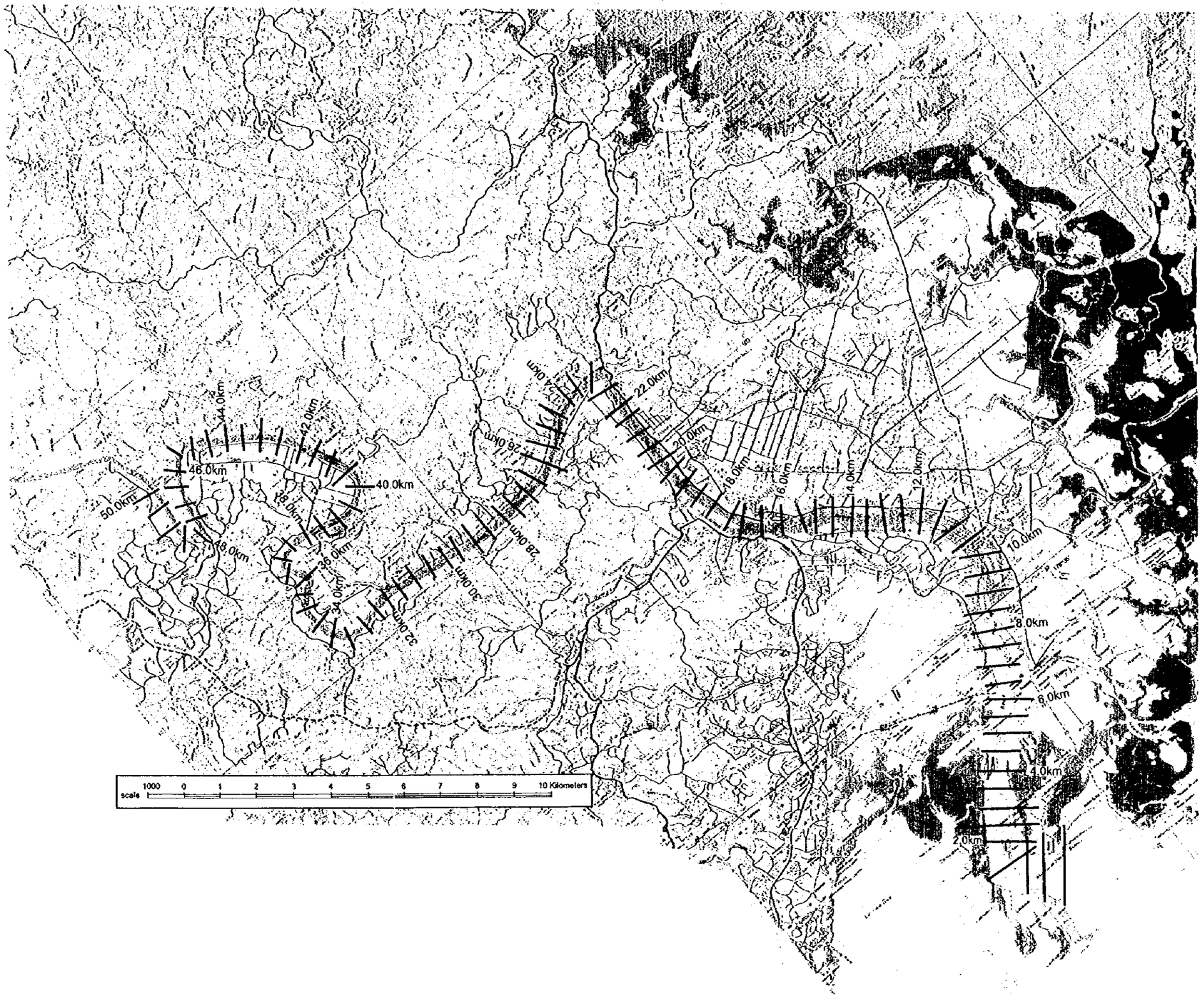


Figure-D2.2 Cross Section Locations (Rewa)

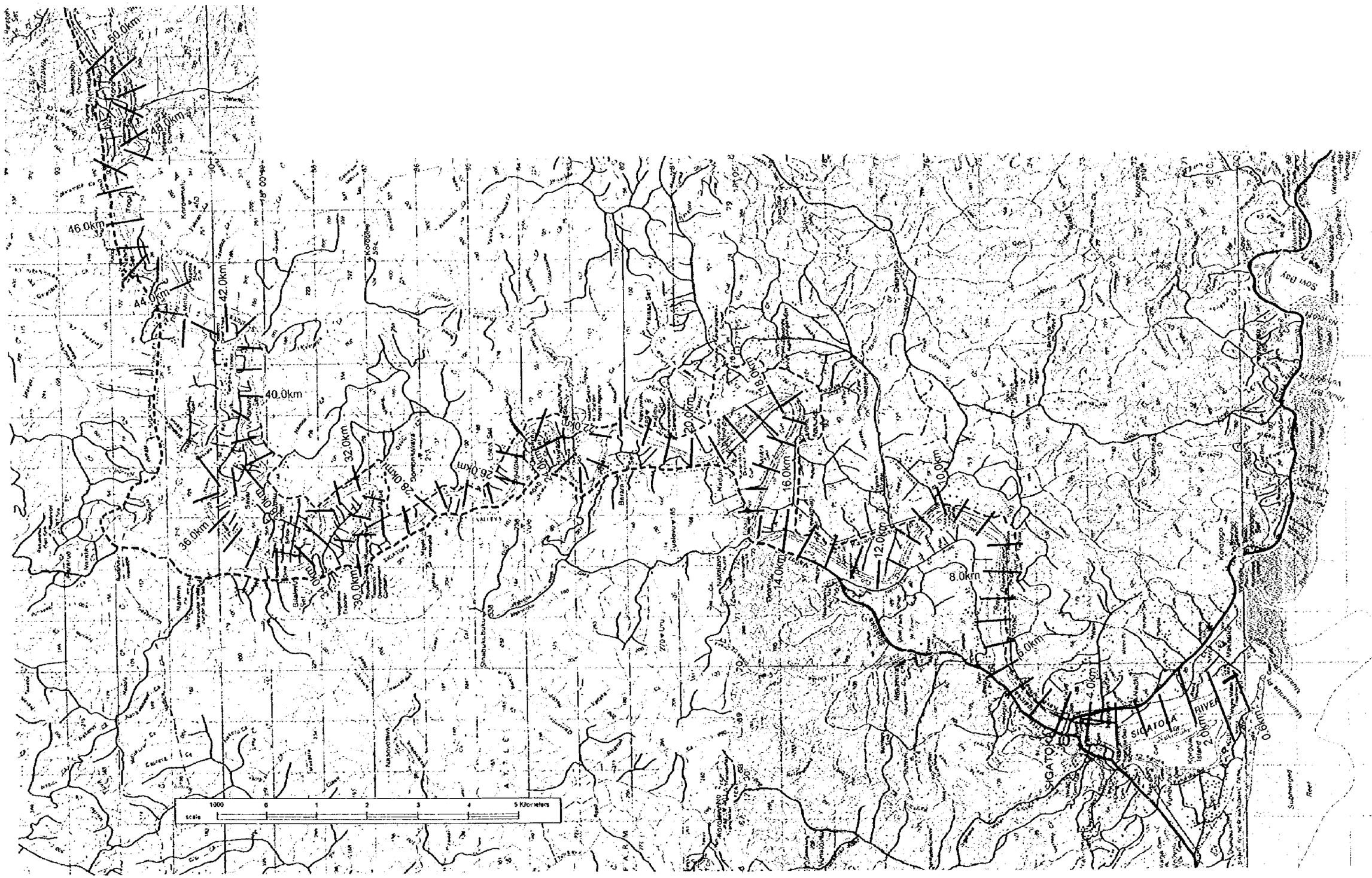


Figure-D2.3 Cross Section Locations (Sigatoka)

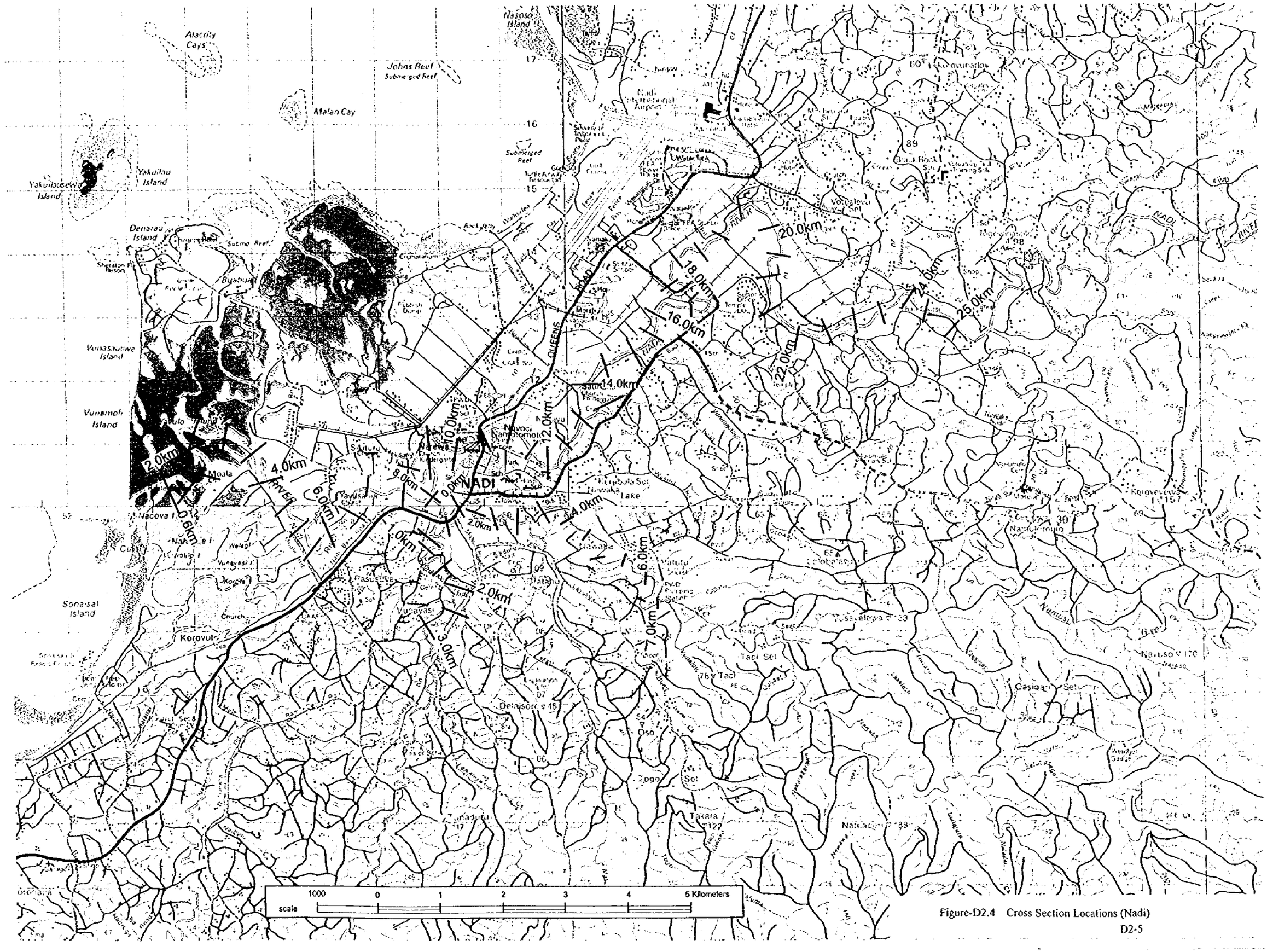


Figure-D2.4 Cross Section Locations (Nadi)

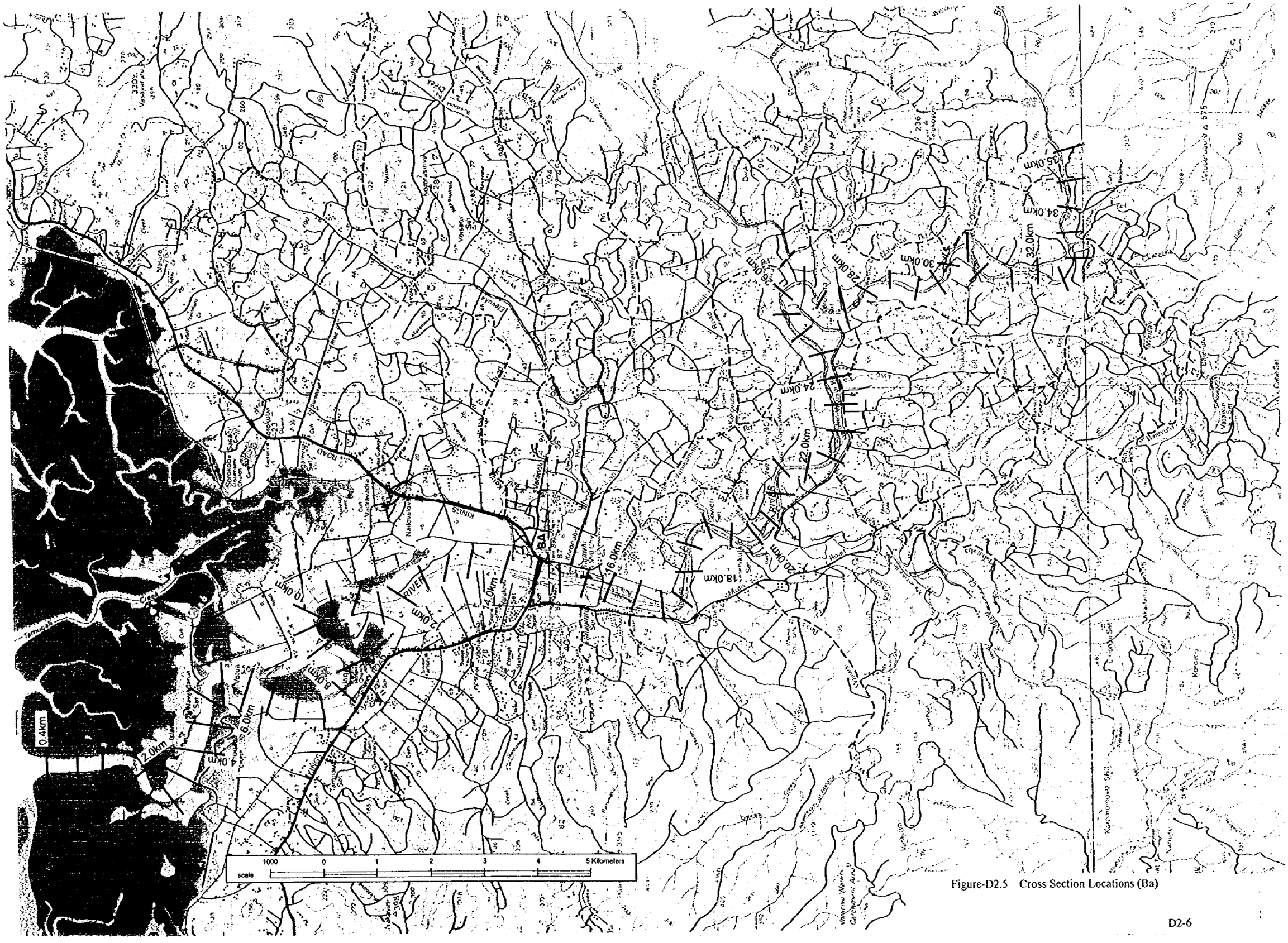


Figure-D2.5 Cross Section Locations (Ba)