5.3 Water Resources

5.3.1 Introduction

The future demand of water resources development shall be estimated considering the population growth and improvement of life standard for domestic water, irrigation plans for agricultural water and large scale industrial and commercial development plans for industrial and hydro-power water.

The main cities in Fiji are located in the coastal area and most population is concentrated in the urban areas. The tertiary industry including tourism and services is developed in the urban area and the reliable water supply is considered as the most important issue. In particular, tourism contributes to the international balance of payment earning foreign currency and it is being developed. The security of water supply will be a basis for the tourism development.

The major source of domestic water in the urban areas is the Vaturu dam in the western division and Rewa river in the central division. No serious shortage of domestic water has not occurred by now.

Although the main industry in Fiji is agriculture, the agricultural sector does not consume the large volume of water because the major crop is sugarcane which does not require irrigation. The extension of its area is not expected due to the influence of the international market on Fiji's sugar price.

The major industries in the mining and manufacturing are gold mining, sugar production and food processing etc. among which only sugar production consumes a lot of water. However, the large increase in sugar production is not expected considering its price in the international market.

Fuel is a major import item as well as manufactured goods, machinery and food, and it is used for power generation. Power demand is expected to increase in the future. If the shortage of electricity will be supplied by thermal generation, the growth of fuel import may give financial straits.

Thus, the secured supply of domestic water to the urban areas and hydro-power development are considered as main factors of water resources development in Fiji.

5.3.2 Existing Water Supply Scheme

(1) Domestic Water

1) Existing Water Treatment Plant and Intake

The existing facilities of water supply are described in Table-5.14 and the locations of main water treatment plants are shown in Figure-5.11.

Table-5.14 Facility of Water Supply

Watershed	Area of Watershed (km^2)	Water Treatment Plant	Site of Intake	Supplying Area
Rewa River	3,092	Tamavua	Waimanu River	Suva
		Waila	Waimanu River	Nausori
		Nausori	Rewa River	Nausori
Sigatoka River	1,453	Matovo	Sigatoka River	Sigatoka
		Lawaqa*	Balekelo Creek	Sigatoka
		Korotogo*	2 boreholes	Korotogo
Nadi River	516	Nagando	Vaturu Dam	Nadi & Saru
		Saru	Nagando	Lautoka
Ba River	937	Waiwai	Nawetavuni Creek Varaciva	Ba

*: plant not operated

Source: Regional Master Plan, Public Works Department

2) Water Supply

Annual volume of water supply from each treatment plant is shown in Table-5.15. Water supply tends to increase with growth rate of more than 10 % except the Rewa area where the growth rate is relatively small. The rate in the Sigatoka area tends to decrease year by year, while one in the Ba area rapidly increased in 1995. The rate in the Nadi area decreased in 1994.

Table-5.15 Quantity of Water Supply

Watershed	Treatment Plant	Supply quantity (10^3m^3/year)				
		1991	1992	1993	1994	1995
Rewa	Tamavua	10,609	14,105	15,914	18,355	20,505
	Waila	–	18,920	19,209	19,428	19,228
	Nausori	N.A.	N.A.	N.A.	N.A.	N.A.
	growth rate			1.06	1.08	1.05
Sigatoka	Matovo	1,158	1,470	1,738	1,996	2,013
	growth rate		1.27	1.18	1.15	1.09
Nadi	Nagado	8,245	9,211	10,325	10,559	defect
	growth rate		1.12	1.12	1.02	
Ba	Waiwai	–	–	1,848	2,062	2,451
	growth rate				1.12	1.67

N.A.: not available

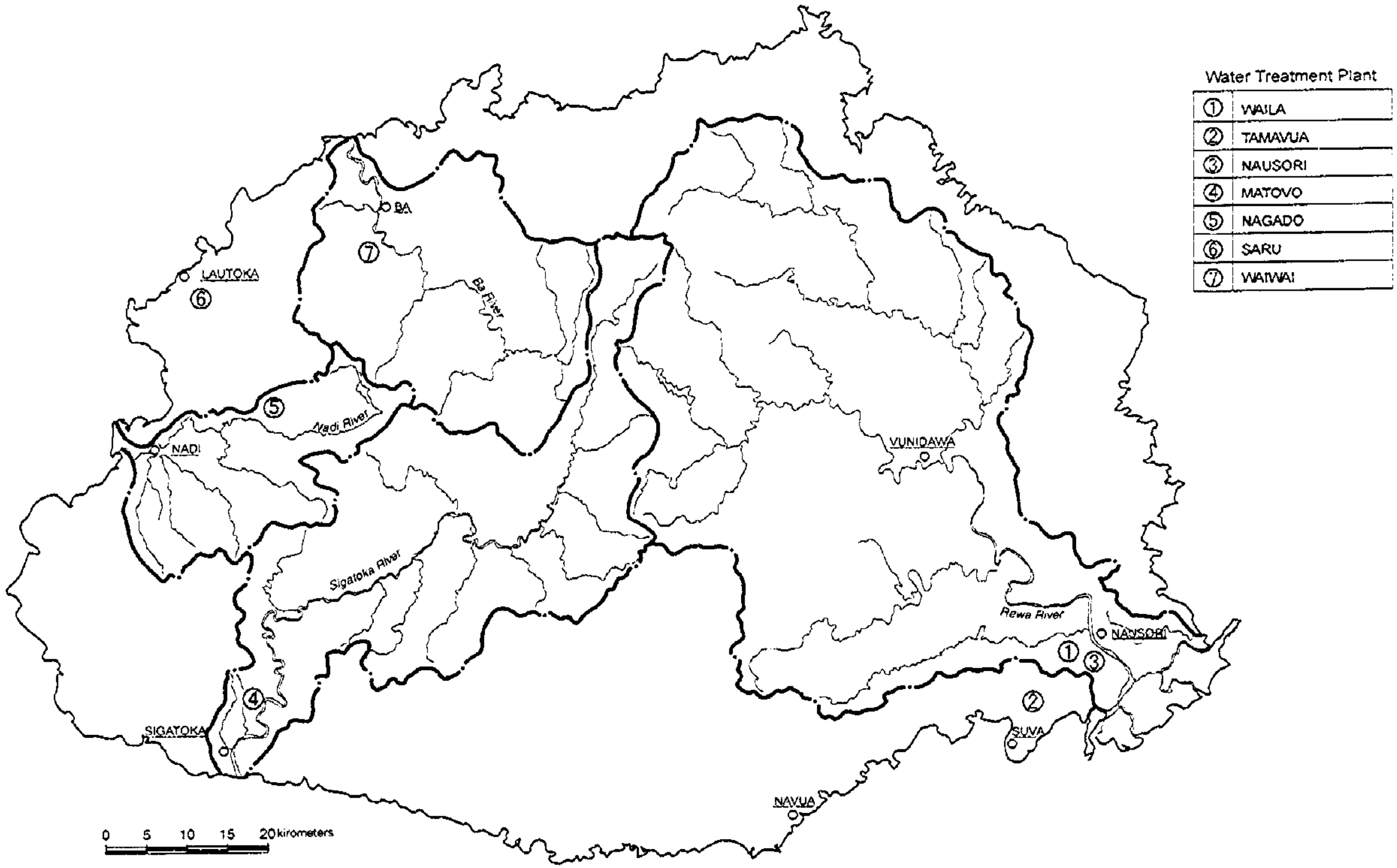


Figure-5.11 Location of Water Treatment Plant

3) Water Consumption

The data regarding the water consumption in the Rewa area including Suva City, is not available from the Public Works Department, PWD, while the data is available for the western division. Table-5.16 shows the present water consumption in the Sigatoka, Nadi and Ba areas.

Table-5.16 Water Consumption in Western Division

Unit: m³ where not specified

	Year	Period (month/day)				Total (m^3/year)	Average (m^3/day)	Growth Rate
		1/1 ~ 3/31	4/1 ~ 6/30	7/1 ~ 9/30	10/1 ~ 12/31			
Sigatoka	1993	104,375	327,056	286,577	236,345	954,353	2,615	
	1994	246,314	*299,835	278,227	310,400	1,134,776	3,109	1.19
	1995	285,732	272,614	308,507	523,639	1,390,492	3,810	1.23
Nadi	1993	1,048,098	9,34,817	922,981	926,935	3,832,831	10,500	
	1994	947,336	992,998	920,482	1,044,845	3,905,661	10,700	1.02
	1995	1,068,765	1,262,499	1,023,,634	1,182,314	4,537,212	12,430	1.16
Ba	1993	328,852	427,726	368,729	431,388	1,556,695	4,265	
	1994	444,912	406,463	384,227	470,208	1,705,810	4,673	1.10
	1995	368,960	421,097	506,049	523,639	1,819,745	4,986	1.07

*: 299,835 = (327,056 + 272,614)/2

Source: PWD in Lautoka

The rates of water use (water consumption / water supply x 100 %) in 1993 and 1994 are estimated approximately 80 %, while that in 1995 is calculated approximately 50 %. Since the rate of water use is too low, the figures of water supply in 1995 seems to be incorrect.

4) Findings and Problems in Domestic Water

Water supply system in Fiji is operated and maintained by PWD. As a result of the study, the followings findings and problems were found with respect to water supply.

- Statistical data on the domestic water is collected and analyzed by each Division of PWD.
- Treatment of water is reasonable.
- Water pressure gets sometimes lower than adequate level in residential area.
- Number of meters in every residence and office is confirmed, but population for water supply is not.

(2) Agricultural Water

Agricultural water in Viti Levu island mainly consists of irrigation and livestock use.

1) Irrigation Scheme

The main irrigation scheme in Viti Levu is the Sigatoka Valley Rural Development Project (SVRDP). There is no such scheme in the Rewa, Nadi and Ba watersheds because sugarcane is a main crop in these areas.

Sprinkler irrigation has been adopted under SVDRP for vegetable cultivation. Although the project is still under going, 250 ha land has been covered with irrigation facilities. The final goal of the project is to irrigate 300 ha. The specifications of the project is summarized below.

a) total area of irrigation : 300 ha

b) crops to be irrigated : vegetable, fruit, coconuts, ginger

c) irrigation period : May ~ September

d) intake facility : pump

- capacity : 18 horse power
- discharge rate : 9 liter/sec
- number of pumps: 34

e) irrigation system : sprinkler

- outlet : 11 liter/sec

2) Livestock

According to the Animal Health and Production Division (Ministry of Agriculture, Fisheries, Forest and ALTA), annual consumption of water by particular livestock is as shown in Table-5.17.

Table-5.17 Water Consumption by Livestock (1995)

m^3/year

Item		River Basin			
		Ba	Nadi	Sigatoka	Rewa
Poultry	Broilers	1,014	50	30	6,000
	Ducks	8	20	20	300
	Breeder	70	NA	NA	NA
	Egg Layers	150	40	15	240
Pigs	Commercial Farms	2,550	NA	NA	13,870
	Non-Commercial	NA	NA	NA	7,000
	Institutional	NA	NA	2,550	20,000
Daily Cattle	Large Farms	NA	NA	NA	46,630
	Medium to Small	NA	NA	NA	18,620
	Adult Cows	NA	NA	NA	89,430
	Growing Animals	NA	NA	NA	18,250
	Young Calves	NA	NA	NA	5,480
Goats		39,410	23,646	15,880	683
Sheep		122	337	68	NA
Total in 1995		43,324	24,093	18,563	226,503

NA: not available

Source: Animal Health & Production Division of MAFFA

3) Findings and Problems in Agricultural Water

The findings and problems associated with the agricultural water are as follows.

a) Irrigation

- Irrigation was first introduced to the paddy field in late 1960's and early 1970's by FAO as Nausori Irrigation Project.
- The major irrigation projects implemented between 1969 ~ 1978 were Nausori Irrigation and Navua West Irrigation in the central division.
- Nausori Irrigation Project ceased its operation in 1995.
- Irrigation Project operated now is only SVRDP in the Sigatoka watershed.

b) Livestock

Consumption of water by livestock is not significant compared to other water utilization.

(3) Industrial Water

The main consumers of the industrial water in Viti Levu island are the Fiji Sugar Corporation (FSC) and Emperor Gold Mines (EGM). Water consumption of other industries is rather small due to their limited scale.

FSC does not rely on the public water supply system but has its own water supply system for the industrial and domestic water. The volume of water supplied and its water resources are summarized in Table-5.18.

Talbe-5.18 FSC Water Supply (1995)

Name of Mill	Water Supply (m^3/year)		Water Resources	
	Factory	Domestic	Surface	Boreholes
Ba	736,000	426,000	1 (Tavo Pond)	-
Lautoka	635,690	86,488	1 (Tavakuvu Creek)	3

Source: FSC

(4) Hydro-Power Water

1) Existing Water Supply Scheme

Regarding the hydro-power water, there are the Monasavu dam, the largest facility, and mini hydro facilities for the electric supply to villages in Viti Levu island. Production of electric power generation with the above facilities is shown in Table-5.19.

Table-5.19 Production of Power Generation in Viti Levu Island

Facility	Installed Capacity (MW)	Production (MWh)				
		1991	1992	1993	1994	1995
Monasavu	83.2	382,960	377,027	376,786	386,965	382,828
Mini Hydro	0.8	–	1,602	1,902	1,631	1,653
Diesel	81.4	31,405	34,617	32,437	33,267	44,083

Source: FEA

2) Findings and Problems

Findings and problems regarding hydro-power are as follows.

a) Future Plan of Hydro-power

The following projects are being studied by FEA, Fiji Electric Authority.

- Wanisavuleve Weir

  To increase diversion capacity of the existing weir to the Monasavu dam expecting 21 MWh of additional firm energy.

- Wainikasau Power Station

  To develop a power station with 6 KWh expecting 18 MWh of the firm energy

- Vaturu Hydro Power Scheme

  It is a development of a power station at the Vaturu dam. A hydrological study will be carried out in the near future to determine its full potential.

b) Future Demand

- In addition to the above schemes, there will be further requirement for hydro-power plants to supplement the production of the Monasavu dam. Although a few projects have been identified, only desk studies have been carried out. A proper feasibility study is required.
- According to FEA, the electric demand in 1997 for Viti Levu island is estimated at 442,000 MWh and it is expected to increase to 1,187,000 MWh by the year of 2015. Similarly, the total electric demand in 1997 for Fiji including Vanua Levu and Ovalau is estimated at 478,000 MWh and it will be 1,310,000 MWh by the year of 2015.

5.3.3 Future Demand

(1) Domestic Water

1) Rewa Watershed

Future water demand was projected taking into consideration the "Suva Water Supply Master Plan Study (PWD, 1984)", herein after referred to as SWSMP, which has formulated a plan for domestic water supply to Suva city and the urban areas in the Rewa watershed.

a) Population for Water Supply

At present, water sources for domestic water supply in those areas are Rewa river and its tributaries (Waimanu river and Savura creek). According to SWSMP, future expansion of water supply shall mainly depend on Rewa river. Therefore, in this Study, Rewa river is considered as the main water resources.

The population of water supply has been estimated as 378,000 for the year of 2006 in SWSMP; however, according to the population projection based on the provisional result of 1996 census, the total population for the year of 2015 in Fiji will be 1.21 times more than that in 1996 as shown in Table-5.20. The water supply population in 1996 is shown in Table-5.21. If the future population is projected applying 1.21 times to the figures in Table-5.21, the total population in the water supply areas for the year of 2015 will be 293,000 (242, 000 x 1.21), which is much lower than SWSMP projection. This discrepancy is due to the decline in population growth rate during 1986 ~ 1996, which SWSMP did not take account of.

It is considered that the population projection based on the 1996 census is suitable to be applied for the water demand projection. Therefore, the population of water supply in 2015 is set as 300,000.

Table-5.20 National Population Projection

Year	Total Population	Ratio
1996 (Base Year)	773,000	1.00
2001	816,000	1.06
2006	857,000	1.11
2011	904,000	1.17
2015	936,000	1.21

Table-5.21 Population in Water Supply Area (1996)

Province & Tikina		Population
Naitasiri	Naitasiri	111,624
Rewa	Noco	2,488
	Rewa	5,802
	Suva	22,024
	Suva City	69,640
Taileve	Bau	22,621
	Nakelo	8,114
Total		242,313

b) Water Demand

There are no existing data available about the unit water consumption in this area. However, SWSMP estimated the unit water consumption in 1983 as 160 *l*/day per capita in the urban area and 50 *l*/day per capita in its vicinity, and that in 2006 was projected as 200 *l*/day per capita and 100 *l*/day per capita for the urban and its vicinity, respectively. If the water consumption increases at the same rate after 2006, the unit water consumption will be 220 *l*/day per capita for the urban area and 120 *l*/day per capita for its vicinity.

Based on the 1996 census, the water supply population in 1996 is approximately 242,000 and the present total supply at Tamavua plant and Waila plant is estimated as 110,000 m^3/day (40 million m^3/year). Applying the same loss rate as SWSMP, 33 %, the present demand and unit consumption are calculated as 74,000 m^3/day and 306 *l*/day per capita. These figures include not only domestic water but also industrial and commercial water in the urban area.

Assuming that the loss rate does not vary even in future, the necessary volume of water supply in 2015 is calculated as 140,000 m^3/day (51.1 million m^3/year), which is 30 % more than the present water supply at Tamavua and Waila plants, 39.7 million m^3/year.

2) Sigatoka Watershed

Water demand was projected for the Sigatoka area taking into consideration the "Nadi-Sigatoka Regional Water Supply Final Master Plan (PWD, 1996[1])", herein after referred to as NSRWSFP.

a) Population for Water Supply

In the Sigatoka area, sources for water supply are currently Matovo (a well field and sump intake), Lawaqa (Balekelo creek) and Kolotogo (2 wells).

According to NSRWSFP, the population in the water supply area was 47,000 for the year of 1995 and would be 73,000 for the year of 2015 based on the 1986 census. However, in this Study, it was estimated that the population in the Sigatoka area would increase from 26,000 in 1996 (provisional result of 1996 census) to 32,000 in 2015. Since the 1996 census is the latest information available, 32,000 is set as the future population in the Sigatoka area.

b) Water Demand

According to the 1996 census, the population in the Sigatoka area was 26,000. If 90 % of the population had water supply, the water supply population would be 23,400 and the unit water consumption would be 170 *l*/day per capita assuming the daily water consumption of 4,000 m^3/day (Table-5.16).

Since the main industry in the Sigatoka area is agriculture, the unit water consumption will not increase like the urban area even if there is a slight increase by improvement of life standard. Therefore, the unit water consumption in 2015 was determined as 200 *l*/day per capita. As a result, the water demand will be 7,000 m^3/day (0.08 m^3/sec) for the projected population, 32,000. Applying the same loss rate in 1995, 30 %, the volume of water supply in 2015 will be 10,000 m^3/day (0.12 m^3/sec).

3) Nadi Watershed

Future water demand was projected for the Nadi area taking into consideration the "Nadi-Lautoka Regional Water Supply Master Scheme (PWD, 1996[2])", herein after referred to as NLRWSMS.

a) Population for Water Supply

At present, water supply in this area depends on the Vaturu dam at the upstream of Nadi river. Its catchment area is approximately 40 km^2 and the storage capacity is 29 million m^3.

According to NLRWSMS, the water supply population in 2015 shall be about 86,000 consisting of 75,500 in Nadi tikina and 10,400 in Nawaka (converted figures of original projection for the year of 2016). The figures in NLRWSMS are more than 70 % greater than the total population predicted by the Study Team, 50,000, on the basis of the 1996 census. This discrepancy is due to the decline in population growth rate during 1986 ~ 1996, which NLRWSMS did not take account of. Therefore, the water supply population in 2015 is set as 50,000.

On the other hand, Nadi is famous in tourist industry and has many large hotels and resorts. It is predicted that the total number of tourists shall amount to 711,000 in 2015. The figures are equivalent to 2,000 tourists per day on average. Since the water supply to tourists should be included for the estimate of future water demand, the total population of water supply in the Nadi area shall become 52,000 in 2015.

b) Water Demand

According to the provisional result of 1996 census, the population in Nadi and Nawaka was 40,000 and the number of tourists was 700 on average in 1996. The daily consumption in 1996 is estimated as 13,600 m^3/day with the same rate during 1993 ~ 1995. As s result, the unit water consumption in 1996 is estimated as 330 *l*/day per capita. On the other hand, NLRWSMS estimated the future unit consumption as 300 *l*/day per capita, which is almost same as the estimate for 1996.

For this Study, the unit consumption of 330 *l*/day per capita in 1996 is adopted because the figures are already high level. The water demand in 2015 will be 17,200 m^3/day (52,000 x 330 *l*/day per capita) or 0.20 m^3/sec . Applying the same loss rate in 1995, 12 %, the volume of water supply will be 20,000 m^3/day (0.23 m^3/sec).

4) Ba Watershed

The future water demand was projected taking into consideration the "Ba Regional Water Supply Master Plan (PWD, 1995)", herein after referred to as BRWSMP.

a) Population for Water Supply

At present, water sources in this area are Nawetavuni creek, Varaciva creek and 4 wells.

According to BRWSMP, the water supply population in 2015 shall be 40,500 consisting of 13,500 in the urban area and 27,000 in its vicinity. However, the population projection by the Study Team based on the provisional result of 1996 census shows 57,000 in 2015. Therefore, 57,000 is adopted as the water supply population in 2015.

b) Water Demand

The water supply population in 1995 is estimated as 33,000 assuming that 70 % of population in 1996 (46,800) has water supply. Consequently, the current unit water consumption is calculated as 150 *l*/day per capita. According to BRWSMP, the unit consumption in 2015 shall be 240 *l*/day per capita. Comparing the current unit consumption with the future unit consumption projected, 200 *l*/day per capita is set as the unit consumption in 2015 with an assumption that the unit consumption in the Ba area is similar to the Sigatoka area.

The water demand in 2015 will be 12,000 m^3/day (57,000 x 200 *l*/day per capita) or 0.14 m^3/sec. Applying the same loss rate in 1995, 50 %, the volume of water supply will be 24,000 m^3/day.

(2) Agricultural Water

Agricultural water demand includes those for irrigation and livestock.

1) Irrigation Demand

In Viti Levu island, irrigation is mainly used in the Sigatoka watershed for vegetables cultivation. According to Sigatoka Valley Rural Development (SVDRP), irrigation facilities have covered 250 ha at present, and are planed to cover 300 ha in the future. It is predicted that in 2015, 34 pumps each with a discharge rate of 9 liter/sec shall be put into use. Assuming that each pump is operated 2 hours per day, the water demand shall be 2,200 m^3/day.

2) Livestock Demand

Table-5.17 shows the water consumption for livestock in 1995. Assuming that livestock production shall grow at a rate of 3.5 % per year (similar to the GDP growth rate in Fiji), and water consumption shall increase proportionally, the water demand for livestock is estimated to be two times as much as that in 1995.

Table-5.22 Future Projection of Agricultural Water

Item		River Basin			
		Ba	Nadi	Sigatoka	Rewa
Total in 1995 (m^3/year)		43,324	24,093	18,563	226,503
Projection for 2015	m^3/year	86,648	49,806	37,126	453,006
	m^3/day	249	140	100	1,240
	Grand Total (m^3/day)	1,720			

Source: Animal Health & Production Division of MAFFA for 1995 data

(3) Industrial Water

The Main consumers of the industrial water in Viti Levu island are Fiji Sugar Corporation (FSC) located in the Ba watershed and Emperor Gold Mining (EGM) located outside the study area (Lautoka). Both of them have there own water supply systems. The water consumption of the Ba mill in 1995 and demand projection for 2015 are shown in Table-5.23. The water demand was estimated assuming that it increases in proportion to the industrial production which is supposed to increase at the same rate as the GDP growth

(3.5 % per year) in Fiji. Therefore, the water demand in 2015 is two times more than the water consumption in 1995.

Table-5.23 Industrial Water Demand in FSC

Unit: m^3/year

Location	Water Supply in 1995 (m^3/year)			Water demand in 2015 (m^3/year)		
	Industry	Domestic	Total	Industry	Domestic	Total
Ba	736,000	426,00	1,162,000	1,472,000	852,000	2,324,000

(4) Hydro-Power Water

There are three kinds of power generation in Viti Levu island: Monasavu hydro-power plant, mini hydropower plans and diesel-power plants. Their productions are shown in Table-5.19. As shown in the table, Monasave hydro-power plant takes about 90 % of the total power production in Viti Levu island. The power projection was conducted applying the same rate as the GDP growth (3.5 % per year), and consequently it will be 860 GWh in 2015, which is approximately two times more than the power production in 1995.

The water demand for hydro-power plants has different characteristic to the other water demand such as domestic water, agricultural water and industrial water. The water used for hydropower plants only passes through water turbine for generation and is not consumed. Therefore, the water demand for hydro-power plants dose not affect significantly downstream water consumption.

As the transmission line covers almost all area of the Viti Levu island, the generated hydro-power at any location in any watershed can be transferred to any place where the electricity is required.

5.3.4 Evaluation of Water Balance

(1) Water Demand

Table-5.24 summarizes the water demand in the four watersheds in 2015. By comparing the water demand per km^2 of each watershed, it can be seen that water demand in the Nadi watershed is relatively high due to the high demand for domestic water in the small watershed area.

Table-5.24 Water Demand in 2015

Watershed	Watershed Area (km²)	Domestic Water (m^3/day)		Agricultural Water (m^3/day)	Industrial Water (m^3/day)	Total (m^3/day) ( ) m^3/sec	Water Demand per Watershed Area (m^3/day/km²)
		Demand	Supply				
Rewa	3,092	93,000	140,000	1,240		141,240 (1.63)	48.0
Sigatoka	1,453	7,000	10,000	2,300		12,300 (0.14)	8.5
Nadi	516	18,000	20,000	140		20,140 (0.23)	41.1
Ba	937	12,000	24,000	240	6,400	24,240 (0.28)	26.1
Total	5,998	130,000	194,000	3,920	6,400	197,920 (2.29)	123.7

(2) Surface Water Potential

The surface water potential was estimated on the assumption that water is developed by direct intake from river. In order to take water safely, drought discharge, once ten years, is considered as the potential water based on the experience in Japan.

Due to the limitation of runoff observation data, drought year, once in ten years, was estimated by average annual rainfall of observation stations in each watershed. The year in which the average rainfall is the second lowest among 19 years from 1976 to 1994 was identified as the drought year, once in ten years. The drought discharge, once in ten years is extracted from flow regime of the same year. The surface water potential which is defined equal to the drought discharge, once in ten years, at river mouth is shown in Table-5.25 comparing with the total water demand in each watershed.

Table-5.25 Surface Water Potential and Water Demand

Watershed	Watershed Area (km²)	Observation Station		Drought Discharge		Surface Water Potential (m^3/sec)	Water Demand (m^3/sec)
		Name	Catchment Area (km²)	Year	Unit Discharge (m^3/sec/100 km²)		
Rewa	3,092	Navolau	1,961	1991	0.82	25.4	1.63
Sigatoka	1,453	Namoka	1,333	1983	0.68	9.9	0.14
Nadi	516	Natuacere	70	1992	0.14	0.7	0.23
Ba	937	Toge	579	1987	0.36	3.4	0.28
Total	5,998					27.9	2.29

In total balance, the surface water potential is far more than water demand in three watersheds, Rewa, Sigatoka and Ba. Therefore, the surface water can be developed simply by direct intake method. In the Nadi watershed, the difference between the surface water potential and the water demand is not so much. Depending on the location, water demand may exceed surface water potential. In this case, regulating river flow by dam or transfer of water adjacent watershed by pipeline etc., may be required. Further detailed study will be necessary on the Nadi watershed.

In conclusion, it is understood that except for the Nadi watershed, the surface water potentials are sufficient to meet the water demands in 2015.

(3) Hydro-Power Potential

The hydro-power potential in the four watersheds was roughly estimated based on the following assumptions.

1) The hydropower potential upstream of the following gauging stations which are located in the middle reach of each watershed is estimated.

   Rewa River : Navolau (catchment area = 1,961 km^2)

   Sigatoka River : Namoka (catchment area = 1,333 km^2)

   Nadi River : Votualeve (catchment area = 164 km^2)

   Ba River : Toge (catchment area = 579 km^2)

2) The type of power station is direct intake type.

3) The discharge effective for hydro-power generation is less than low discharge at the gauging station.

4) The head difference effective for hydro-power generation is difference between the elevation where the gauging station is located and the intermediate elevation from the station to the top elevation of the river course.

5) The following formula are used for estimate of hydropower production.

$$PKH = 24 \times \Sigma Q\ell \times Ha \times g \times \alpha$$

$$Pa = PKH \div 365 days \div 24 hours$$

where;

PKH : Annual Hydropower Production Potential (kwh)

$\Sigma Q\ell$: Annual Average of Total Daily Discharge less than Low Discharge (m^3/sec)

H_a : Effective Head Difference (m)

g : Acceleration of Gravity (9.8 m/sec^2)

α : Efficiency (assumed 0.5)

P_a : Average Hydropower Yield (kw)

The calculation result of the hydropower production potential is shown in Table-5.26.

Table-5.26 Hydropower Production Potential

	$\Sigma Q\ell$ (m^3/sec)	H_a (m)	PKH (Mwh)	P_a (Mw)
Rewa	15,300	500	900,000	103
Sigatoka	3,600	300	127,000	14
Nadi	1,000	300	35,000	4
Ba	1,400	300	49,000	6
Total			1,111,000	127

The total hydropower production potential in the four watersheds is approximately 1,100 Gwh which is more than the demand of 860 Gwh in 2015. The potential in the Rewa watershed is remarkable among four watersheds.

(4) Maintenance Discharge

In addition to water utilization, the maintenance discharge should be kept in river channel for keeping picturesque scenery, preservation of ecosystem, securing cleanliness of river flow, inland navigation, fishing etc. The maintenance discharge should be more than the average drought discharge during 10 years based on the experience in Japan.

The average drought discharge in each watershed was estimated as shown in Table-5.27. It is understood that except for the Nadi watershed, the average drought discharges are far more than the water demands. Therefore, even if same amount of water to meet the demand was developed, the development would not much affect the maintenance flow.

Table-5.27 Average Drought Discharge during 10 Years

Watershed	Watershed Area (km^2)	Average Drought Discharge		Water Demand (m^3/sec)
		Unit discharge ($m^3/sec/100\ km^2$)	Discharge at River Mouth (m^3/sec)	
Rewa	3,092	1.73	53.5	1.63
Sigatoka	1,453	1.43	20.8	0.14
Nadi	516	0.14	0.7	0.23
Ba	937	0.52	4.9	0.28
Total				2.29

5.3.5 Rough Case Study of Water Resources Development

(1) Re-development of Vaturu Dam

1) Domestic Water

Total run-off volume at the dam site is estimated as follows.

$$QT = R \times CA \times \alpha$$

where,

QT	:	Total runoff volume	(m^3/year)
R	:	Annual rainfall	(assumed 2,300 mm)
CA	:	Catchment area	(38.6 km^2)
α	:	Runoff coefficient	(assumed 0.7)

$$QT = 2{,}300\ mm \times 38.6\ km^2 \times 0.7$$
$$= 62.1 \times 10^6\ m^3/year$$

Considering regulating function of effective reservoir capacity of 27 x 10^6 m^3, the effective coefficient (β) may be assumed at least 0.5. Therefore, the potential volume of water development could (PQT) be estimated as follows:

$PQT = \beta \times QT = 0.5 \times 62.1 \times 10^6 = 31.1 \times 10^6\ m^3/year$

$= 85{,}000\ m^3/day$

The potential developed water volume of 85,000 m^3/day is far more than the present supply volume about 20,000 m^3/day.

2) Hydropower Generation

The potential hydropower generation is estimated by the following formula.

$P = \alpha\, g\, QH$

$PH = P \times 24\ hours \times 365\ days$

where,

P	:	Hydropower yield	(kw)
α	:	Effective coefficient	(0.85)
g	:	Acceleration of Gravity	(9.8 m/sec^2)
Q	:	Discharge	(m^3/sec)

$Q = PQT\ (m^3/day) \div 86{,}400\ sec = 85{,}000 \div 86{,}400 = 0.98\ m^3/sec$

Ha : Effective Head Difference (m)

Ha = (Average Water Level at Reservoir - River Bed Elevation) x 0.9

$$= \left\{\frac{1}{2}(527.0+510.0) - EL.300\right\} \times 0.9 = 197\ m$$

$P = 0.85 \times 9.8 \times 0.98 \times 197 = 1{,}600\ kw$

$PH = 1{,}600 \times 24 \times 365 = 14{,}000\ kwh/year$

The hydro-power production obtained by re-development of the Vaturu dam is not much.

(2) Water Resources Development by Dam/Reservoir

In this section, the required reservoir capacity for water development was estimated at the dam site (N-3) in the middle reach of Nadi River, based on the following assumption.

1) Development water volume is 20,000 m^3/day (0.23 m^3/sec).
2) Flow regime at the dam site is obtained by converting that of the Votualevu gauging station (HA 020) in proportion to the ratio of the catchment area (dam site 109 km^2 ÷ station 164 km^2 = 0.664). The flow regime at the dam site is shown in Table-5.28.
3) Maintenance discharge equal to the average of drought discharge (Q_{355} = 1.16 m^3/sec) is kept all the year round.
4) Objective design year is 1980 which is the lowest among the observed data, except for 1982 in which water discharge is extremely low.
5) Required reservoir capacity for regulating discharge variation could be estimated as shown in Figure-5.12.

The required capacity of reservoir estimated is approximately 10 million m^3 (= [1.06 x 10 + 1/2 (1.06 + 0.66) x 80 + 1/2 (0.66 + 0.19) x 90 +1/2 x 0.19 x 9.5] x 86400). The economic evaluation was made as a multi-purpose dam including flood control in the section 6.8.

Table-5.28 Flow Regime at Dam Site

Unit: m^3/sec

Year	Q_{95}	Q_{185}	Q_{275}	Q_{355}	Q_{365}
1980	3.00	1.20	0.73	0.33	0.33
1981	2.86	1.79	0.86	0.46	0.40
1982	3.92	1.26	0.46	0.13	0.07
1983	–	–	–	–	–
1984	6.31	4.58	3.78	1.73	1.53
1985	–	–	–	–	–
1986	4.38	3.52	2.99	2.79	2.79
1987	–	–	–	–	–
1988	5.11	2.99	2.12	1.53	1.46
Average	4.26	2.56	1.82	1.16	1.10

Catchment Area = 109 km^2

Q_{95}: discharge exceeding this volume for 95 days in a year

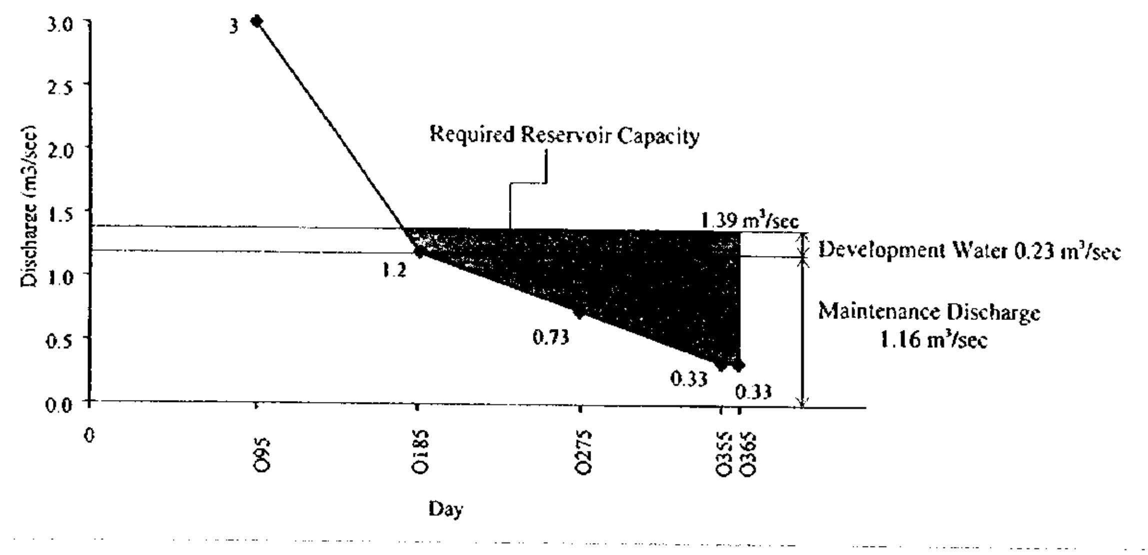


Figure-5.12 Schematic Diagram for Reservoir Capacity (1980)

5.3.6 Strategic Policy for Water Resources Development

Generally speaking, Viti Levu island is blessed with plenty of rainfall resulting in enough amount of water resources in comparison with its population size, and the characteristics and scale of its industry.

The followings are the basic strategic policy for the water resources development.

1) The demand for domestic water in the Nadi and Lautoka areas will increase due to expansion of tourism and population concentration in the urban areas. The re-development of the Vaturu dam located in the upstream of Nadi river could cope with the future demand because the developed water at present is less than 20,000 m^3/day and there is a possibility of more than 60,000 m^3/day of development in future.

2) In the other three watersheds, Rewa, Sigatoka and Ba, the domestic water can be developed easily by direct intake from main stream or tributaries because the developed water is not so much compared with surface water potential.

3) The demand for agricultural water will not increase except extraordinary drought year because main agricultural products is sugarcane and irrigated crops such as paddy rice ceased to be cultivated due to its loss in international competition. The required water for vegetable can be developed by direct intake from main streams or tributaries.

4) The demand for industrial water, which is used mainly by sugar mill will not increase. The demand for food factory and other light industries can be supplied together with domestic water through present water supply system.

5) The demand for hydro-power generation will increase almost twice by 2015. The capacity of Monasavu Dam Power Station (83,000 kw) can not cope with the demand. In order to save the import of fuel for diesel electric power generation, the large scale hydro-power station should be developed along Rewa river which has rich potential of hydro-power.

5.4 Surface Water Quality

5.4.1 Water Quality Survey

Water quality survey was conducted twice in early October and later November 1996 for an investigation of surface water quality in the dry and rainy seasons, respectively. At each time, 26 samples were collected from selected locations at the upper, middle and down stream parts of Ba, Sigatoka, Nadi and Rewa rivers, and also the estuaries adjacent to the river mouths. The locations of these sampling points are shown in Figure-5.13.

The first water quality survey in the dry season was conducted by the Study Team under the cooperation of D & I and PWD counterparts. The second survey in the rainy season was mainly conducted by the counterparts. The National Water Quality Laboratory, PWD, provided a full technical support to the survey.

A total of 14 water quality items were analyzed by using a portable water quality analyzer (DREL/2000-05) provided by the Study Team and also the equipment in the National Water Quality Laboratory. The results are shown in Table-5.29.

(1) Temperature

Water temperature is mainly affected by the air temperature. It ranges from 24 to 31 °C in the dry season and 26 to 28 °C in the rainy season and does not show any abnormality if the difference of weather in the two seasons are considered.

(2) pH

At most of the water sampling sites, water shows a neutral pH from 6.0 to 8.0. Only at the middle stream of Ba river (site No. 3 and 4), a lower pH of 5.5 was detected in the dry season. This might have been affected by the wastewater effluent from the sugarcane mill as will be mentioned below for some other water quality items.

(3) Electric Conductivity, Salinity and Total Dissolved Solids

Electric conductivity (EC), salinity or total dissolved solids (TDS) of the river water are affected by sea water intrusion or tidal flow. At the river mouth, EC is similar to or slightly lower than that of the sea water. At the middle stream locations, EC is more or less affected by the tidal flow. Most of the upstream samples show very low EC values. However, due to limited sampling locations and frequency, it is difficult to evaluate the extent of sea water intrusion and salinity fluctuation in these rivers.

(4) Suspended Solids

Suspended solids (SS) in most of the water samples range from 10 to 200 mg/L. SS is higher in samples from the sea or the river mouth. No appreciable difference is noticed between the dry and rainy seasons.

Table-5.29 Water Quality Analysis Results

(1) Ba River — Site No. & Location

Item	Unit	1 Open Sea		2 River Mouth		3 Down-stream the Bridge		4 Down-stream Sugar-cane Mill		5 Under the Bridge		6 Nabou-tolu Crossing	
Season		Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
Water Tem.	°C	29.5	28.1	30.8	27.9	30.2	27.3	30.8	27.2	27.9	-	27.4	26.9
pH	-	6.8	7.52	6.8	7.61	5.54	6.02	5.52	6.15	7.34	-	8.48	7.88
EC	uS/cm	44,800	50,000	26,000	26,000	1018	260	293	350	2,410	-	189	150
Salinity	‰	28.8	-	19.9	-	-	-	-	-	-	-	-	-
TDS	mg/L	-	-	-	-	579	-	144	-	1,200	-	89	-
SS	mg/L	125	180	85.7	74	18.4	23	19	48	11	-	4	12
NH_4-N	mg/L (as N)	0.08	0.1	0.09	0.26	0.09	0.24	0.1	0.27	0.33	-	0.11	0.18
NO_3-N	mg/L (as N)	3.5	0.57	3.1	1.3	7.4	0.59	7.3	0.47	9.7	-	3.3	0.66
NO_2-N	mg/L (as N)	0.41	0.46	0.47	0.03	0.17	0.15	0.09	0.17	0.09	-	0.1	0.22
TN	mg/L	1.6	1.26	1.5	1.85	3.2	1.35	2.4	2.25	-	-	2.3	1.83
DO	mg/L	6.15	7.21	6.45	6.61	1.25	3.25	0.66	2.15	1.12	-	6.8	7.92
TH	mg/L	400	2,250	2,370	980	228	150	88	142	305	-	92	132
TP	mg/L (as PO_4)	0.6	0.11	0.7	0.11	1.3	0.27	0.9	0.35	-	-	0.8	0.07
COD	mg/L	210	245	202	220	15	28	11	21	-	-	1	2
Remark		Seawater		Half-seawater		Fresh-water		Fresh-water		High-tide time		Fresh-water	

(2) Nadi River — Site No. & Location

Item	Unit	1 Vaturu Dam		2 Upper Stream		3 Middle Stream		4 Up-stream Nadi Bridge		5 Down-stream Nadi Town		6 River Mouth		7 Open Sea	
Season		Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
Water Tem.	°C	23.8	26.3	27.2	26.5	26.7	26.8	29.1	27.3	29.1	27.4	28.9	27.8	27.9	27.7
pH	-	7.66	7.21	8.14	7.38	7.9	7.42	7.88	7.41	8.08	7.55	7.97	7.62	8.13	7.83
EC	uS/cm	62.6	680	162	160	195	570	345	470	1,440	1,800	40,550	50,000	47,000	50,000
Salinity	‰	-	-	-	-	-	-	-	-	-	-	26.0	-	30.8	-
TDS	mg/L	30	-	78	-	92	-	162	-	668	-	-	-	-	-
SS	mg/L	13	55	99	65	54	13	25	38	15	15	191	208	131	145
NH_4-N	mg/L (as N)	0.23	0.15	0.09	0.14	0.12	0.14	0.22	0.31	0.53	6.4	0.12	0.04	0.09	0.06
NO_3-N	mg/L (as N)	0.36	0.66	0.34	0.47	0.31	0.64	0.43	0.97	0.21	0.6	0.33	0.62	0.31	0.61
NO_2-N	mg/L (as N)	0.03	0.07	0.09	0.15	0.14	0.2	0.18	0.35	0.35	0.6	0.49	0.4	0.46	0.45
TN	mg/L	3.1	1.92	1.9	2.25	3.0	3.11	2.6	2.62	2.6	2.73	1.6	2.15	1.5	2.07
DO	mg/L	6.8	7.45	7.6	7.72	7.4	7.64	8.2	8.25	9.8	8.3	6.75	7.21	6.0	7.18
TH	mg/L	31	68	84	95	124	155	132	180	85	145	5210	2550	5810	4975
TP	mg/L (as PO_4)	0.8	0.28	0.7	2	0.7	2.22	0.8	0.12	1.02	0.13	0.7	0.25	0.6	0.11
COD	mg/L	2.9	4.2	8.3	8.3	13.3	15.1	9.6	18.4	19.6	22.1	225	174	210	152
Remark		Fresh-water		Fresh-water		Fresh-water		Fresh-water		Fresh-water		Seawater		Seawater	

(3) Sigatoka River — Site No. & Location

Item	Unit	1 Open Sea		2 River Mouth		3 Lawaqa Con-fluence		4 Naroro		5 Tonga Village Crossing		6 Keyasi	
Season		Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
Water Tem.	°C	26.6	26.8	27.5	26.3	28.2	26.4	28.21	26.2	29.8	26.3	29.5	26.1
pH	-	8.79	795	8.82	7.83	7.8	7.81	7.44	7.28	6.99	7.01	6.60	6.97
EC	uS/cm	38,900	50,000	22,400	24,000	12,740	4,500	1,040	240	235	210	203	230
Salinity	‰	24.8	-	13.5	-	7.2	-	-	-	-	-	-	-
TDS	mg/L	-	-	-	-	-	-	489	-	110	-	96	-
SS	mg/L	149	33	49	39	40	29	23	26	15	27	25	31
NH_4-N	mg/L (as N)	0.08	0.03	0.07	0.05	0.05	0.08	0.07	0.07	0.08	0.09	0.09	0.06
NO_3-N	mg/L (as N)	0.33	0.45	0.62	0.47	0.65	0.5	0.73	0.65	0.4	0.97	0.72	0.82
NO_2-N	mg/L (as N)	0.41	0.05	0.41	0.05	0.34	0.07	0.43	0.06	0.35	0.04	0.21	0.05
TN	mg/L	1.13	0.97	1.56	1.02	1.23	1.13	1.87	1.74	2.15	1.83	2.55	1.96
DO	mg/L	7.3	7.53	6.4	6.61	6.5	6.82	7.6	7.71	9.1	7.95	8.4	8.22
TH	mg/L	2,620	3,000	1,340	1,520	1,160	680	121	138	86	70	94	88
TP	mg/L (as PO_4)	0.7	0.63	0.6	0.64	0.6	0.68	0.8	0.89	0.7	0.81	0.9	0.35
COD	mg/L	232	188	70	84	29	33	19	21	5	11	22	15
Remark		Seawater		Half-seawater		High-tide time		Fresh-water		Fresh-water		Fresh-water	

(4) Rewa River — Site No. & Location

Item	Unit	1 Nau-thala Bay		2 Open Sea		3 River Mouth		4 Down Stream		5 Up-stream the Bridge		6 Middle Stream		7 Upper Stream	
Season		Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
Water Tem.	°C	25.5	27.4	26.6	27.6	27.7	27.1	26.7	26.9	27	26.8	26.4	26.6	27	26.2
pH	-	7.13	7.6	7.12	7.64	6.85	7.45	6.21	7.23	6.02	7.21	7.2	7.19	6.09	7.07
EC	uS/cm	41,200	42,500	37,000	40,800	10,680	8,500	180	220	111.5	150	117	140	94	320
Salinity	‰	26.5	-	23.2	-	6.0	-	-	-	-	-	-	-	-	-
TDS	mg/L	-	-	-	-	-	-	85	-	52	-	54	-	42	-
SS	mg/L	30	-	40	-	40	-	40	-	10	-	40	-	40	-
NH_4-N	mg/L (as N)	6.15	0.69	3.85	0.66	1.41	0.31	0.22	0.32	0.25	0.36	0.28	0.29	0.19	0.27
NO_3-N	mg/L (as N)	0.79	0.47	0.35	0.28	0.5	0.26	0.3	0.25	0.24	0.21	0.28	0.19	0.28	0.07
NO_2-N	mg/L (as N)	0.56	0.53	0.47	0.55	0.61	0.68	0.12	0.29	0.05	0.22	0.04	0.13	0.04	0.07
TN	mg/L	2.7	2.15	1.8	1.78	1.75	1.35	0.75	0.68	0.68	0.75	0.62	0.78	0.55	0.63
DO	mg/L	6.9	7.72	6.2	7.75	7.0	7.63	7.8	7.89	7.25	8.18	8.2	8.42	9.1	8.69
TH	mg/L	5,790	3,010	4,550	2,50	1,225	780	57	166	44	78	47	35	35	76
TP	mg/L (as PO_4)	0.2	1.25	0.7	1.46	0.8	1.11	0.4	0.63	0.3	0.61	0.3	0.58	0.2	0.41
COD	mg/L	180	-	175	-	36	-	5	-	2	-	10	-	9	-
Remark		Sea-water		Sea-water		Half-seawater		Fresh-water		Fresh-water		Fresh-water		Fresh-water	

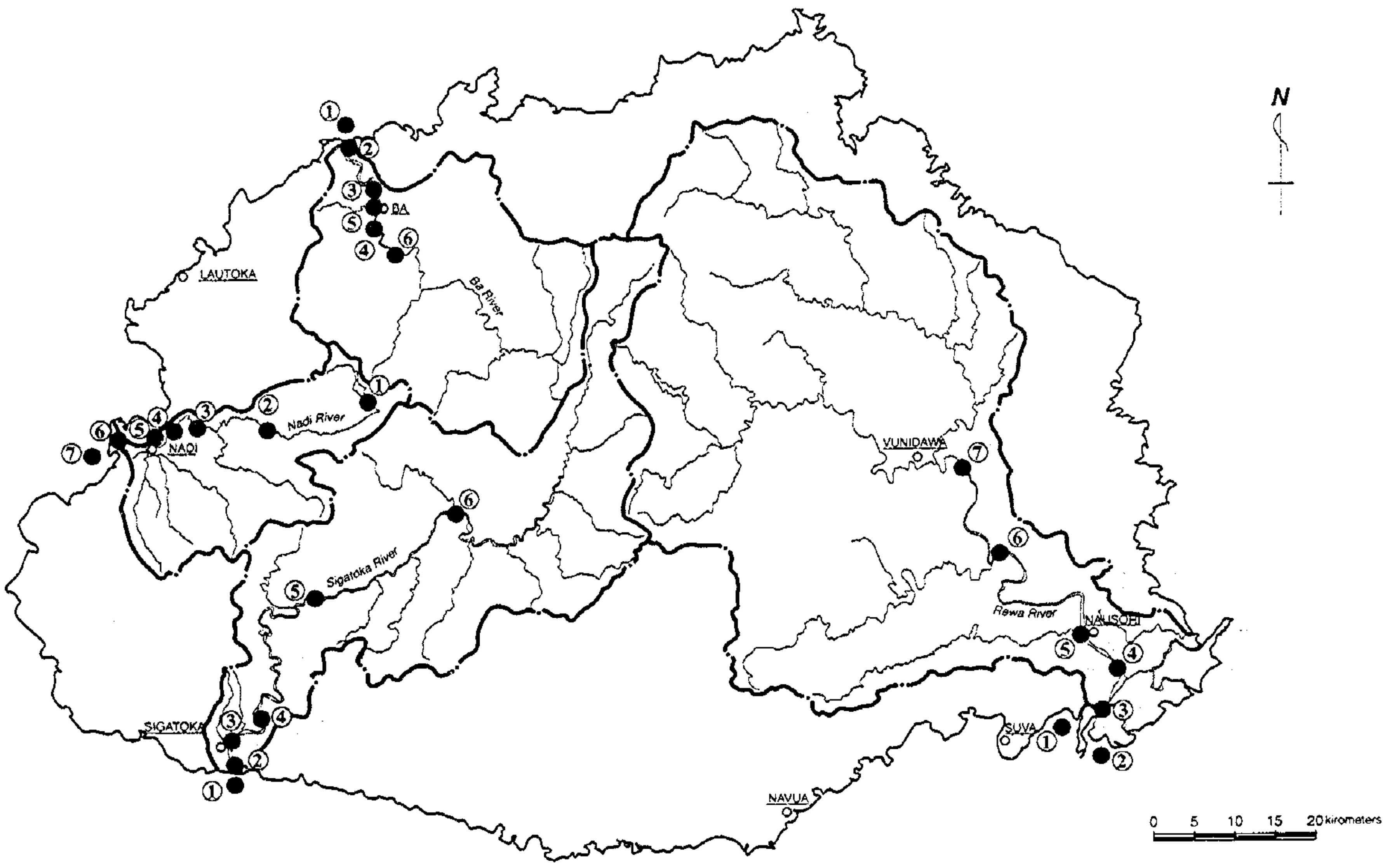


Figure-5.13 Locations of Water Sampling Sites

(5) Ammonia, Nitrate, Nitride and Total Nitrogen

Regarding nitrogen, three kinds of inorganic nitrogen: ammonia (NH-N), nitrate (NO3-N) and nitride (NO2-N), and total nitrogen (TN) were analyzed. For Ba, Nadi and Sigatoka rivers, the TN ranges from 1.0 to 3.2 mg/L. Rewa river shows a TN lower than 1.0 along the whole river course except at the river mouth and in the adjacent coastal area. Among the three kinds of inorganic nitrogen, NO3-N shows higher concentration especially in Ba river at the dry season.

(6) Dissolved Oxygen

Dissolved oxygen (DO) is an important indicator of water pollution. For Nadi, Sigatoka and Rewa rivers, DO ranges from 6.0 to 9.0 and shows a favorable biological condition. However, in the middle stream of Ba river (site No. 3, 4 and 5) DO is as low as 0.66-1.25 in the dry season and 2.15-3.25 in the rainy season. Similar results have also been reported by some previous studies for Ba river (Anderson, 1995; D & I, 1996). Considering that these sampling locations are within 2 km downstream of a wastewater outlet from the sugarcane mill, it is questionable that high concentration organic pollutant may be discharged into the river due to insufficient industrial wastewater treatment.

(7) Total Hardness

The total hardness (TH) in most of the river water samples is at very low level. The higher TH value at the river mouth is due to the high salinity but not the real hardness substance.

(8) Total Phosphorous

Most of the water samples show a total phosphorus (TP) of 0.5-1.2 mg/L as PO4 which is equivalent to a TP of 0.2-0.4 mg/L as P. There is no apparent difference between the dry and rainy seasons.

(9) Chemical Oxygen Demand

It should be pointed out that by using the reactor digestion method for chemical oxygen demand (COD) analysis in this study, it is difficult to get rid of the interference from a high concentration of chloride (Cl). Therefore, the measured COD values for saline water samples (those from open sea and river mouth) may not be accurate and only the results for fresh water samples are suitable for comparison. Generally speaking, at the upstream side of these rivers, COD is lower than 10 mg/L. Most of the samples from the middle and down stream parts show a COD of 10-20 mg/L.

The above mentioned characteristics of water quality can be schematically presented in Figure-5.14, where 4 main water quality items, DO, COD, TN and TP, are cited. It is apparent that water quality does not change much along these rivers and in their estuaries. The only exception is Ba river where there is a sharp drop in DO at its middle stream section. However, the other parameters do not differ much from the other rivers.

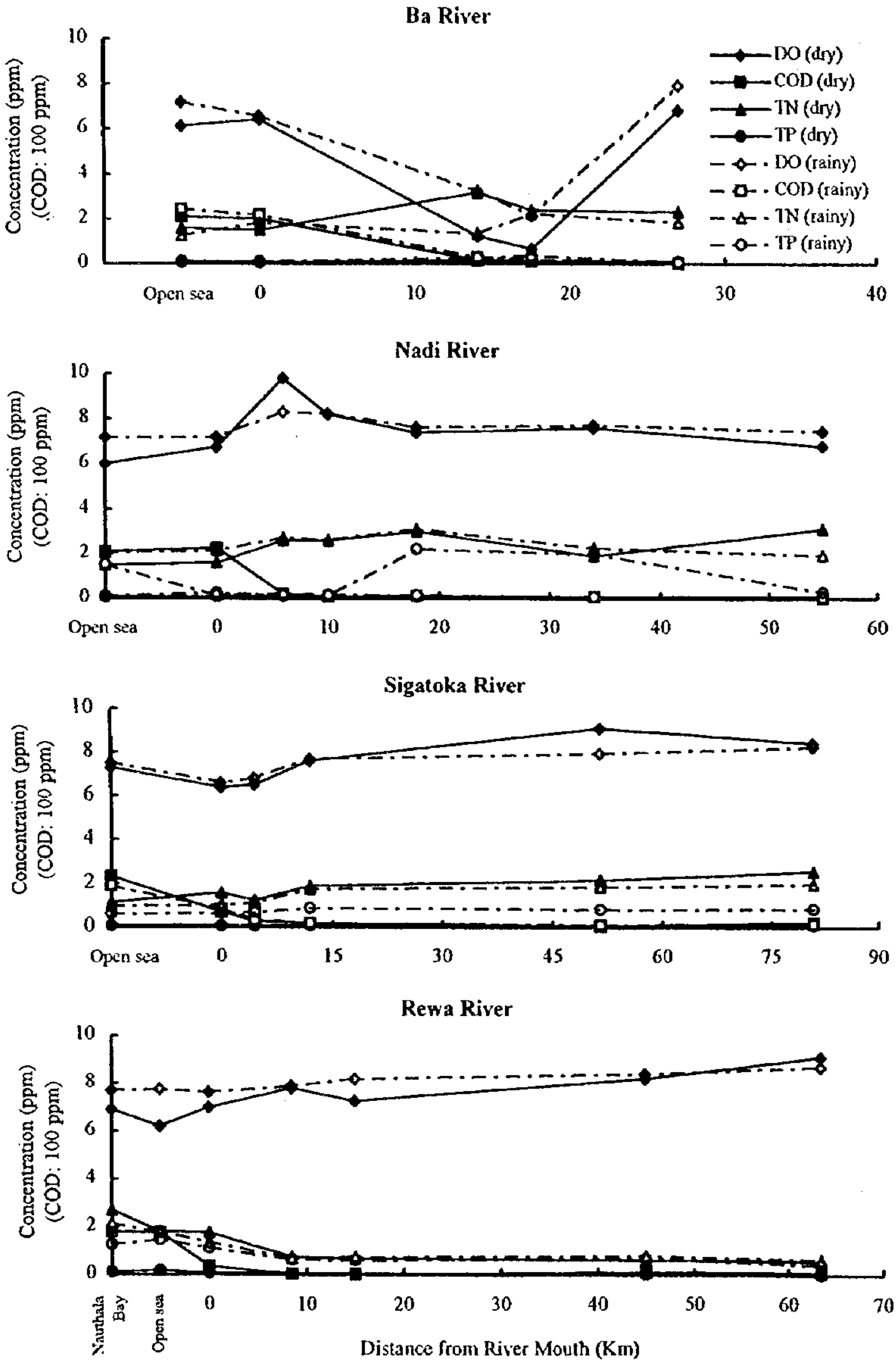


Figure-5.14 Water Quality of Four Rivers and Their Estuary

5.4.2 Evaluation of Present Water Quality

Since the objectives of the water quality survey are to understand the present condition of river water quality and to study the suitability of water resource development for the purpose of drinking water supply, it is necessary to conduct an evaluation by comparing the water quality analysis results with the water quality criteria currently applied in Fiji.

Table-5.30 summarizes the water quality criteria specified in the newly published Fiji's "Draft Sustainable Development Bill". Coastal waters and fresh waters have been categorized respectively into three classes according to the purpose of water usage. The water quality items include coliform bacteria, pH, TP, TN, DO and turbidity and other inorganic and organic substances (not listed in Table-5.30). For a reference, COD and BOD specified in Japan's water environmental criteria for coastal and fresh waters are cited at the bottom of the table.

Table-5.30 Water Quality Criteria

Item	Coastal Waters			Fresh Waters		
	Class AA	Class A	Class B	Class 1	Class 2	Class 3
Faecal Coliform (a)*	< 70	< 200		< 70	< 200	
(Count/100 mL) (b)**	< 230	< 400		< 230	< 400	
Enterococci (a)***	< 33		-	-	-	-
(Count/100 mL) (b)**	< 60		-	-	-	-
pH	7.7 - 8.5			6.5 - 8.5		6.5 - 9.0
TP (mg/L as P)	< 0.025		< 0.500	< 0.200		
TN (mg/L as N)	< 0.400		< 0.800	< 0.750	< 1.500	
TN/TP Ratio	11.1 - 27.1		6.1 - 18.1	-	-	-
DO (mg/L)	> 6.0	> 5.0	> 4.5	> 6.0	> 5.0	> 4.5
Turbidity (NTU)	< 5.0		-	< 5.0		-
COD or BOD (mg/L) ****	< 8 (COD)			< 8 (COD for lakes) < 10 (BOD for rivers)		

Note: 1) Water classification:

Coastal Waters

- Class AA: oceanographic research, marine life conservation
- Class A: recreational, aesthetic enjoyment
- Class B: ports and harbors

Fresh Waters

- Class 1: drinking water supply
- Class 2: swimming
- Class 3: industrial activities

2) * for 10 consecutive samples

** for single sample

*** for any 5 samples in a given 30 day period

****Japan's criteria for reference

3) Criteria for radioactive materials and toxic substances have not been listed in this table.

4) Groundwater has not been listed in this table.

Source: MUDHE, 1996

The results of evaluation on river water quality are shown in Table-5.31. For each river, both the river course and estuary area are considered, and the criteria for coastal and fresh waters are applied.

(1) Water Quality in the Estuaries

Regarding water quality in the estuaries, the evaluation results can be summarized as below:

- pH is within an acceptable range although it is slightly lower than the criteria value of 7.7-8.5 at some locations;
- DO meets Class AA for all the waters;
- TN and TP do not meet Class AA nor Class A for all the waters.

Therefore, high concentration of nutrient substances is considered to be the main problem for the estuary areas of the four rivers. By a rough estimation of the TN/TP ratio which shows the condition of a nutrient balance, it is noticed that total phosphorus seems to be over-weighted in the Sigatoka and Rewa estuaries. Since a high nutrient level may result in algae growth and deteriorate the biological condition of the coastal area, it is recommendable that comprehensive studies should be conducted for identifying the nutrient sources and working out countermeasures for coastal environment protection.

Due to lack of accuracy of COD data for sea water as mentioned above, COD is not considered in the evaluation.

(2) Water Quality in the Rivers

Regarding water quality in the rivers, the evaluation results can be summarized as below:

- there is almost no problem with pH;
- DO meets Class 1 for Nadi, Sigatoka and Rewa rivers, but is worse than Class 3 for Ba river at its middle stream section;
- water in Rewa river and in the upper stream part of Ba and Nadi rivers meets Japan's river water quality criteria for COD, but Sigatoka river shows higher COD concentration;
- similar to the water in the estuaries, TN and TP exceed the criteria values for these rivers except Rewa river.

Although there are certain problems with the water quality in these rivers when comparing with the water quality criteria, using these rivers as the water resource for drinking water supply is considered to be possible if location is carefully selected and suitable treatment processes are applied, since Fiji has already had much experience in river water utilization. However, it is considered to be urgent to take action for river water quality protection and conservation. Restriction on sewage and industrial wastewater discharge is in every sense the most important measure to be taken. For a river itself, eutrophication may not be a significant problem, but if water is stored in a reservoir, high concentration of nutrient substances may become the reason of micro-organism and algae growth, which should be fully taken into account in planning water resources development in a tropical climate region. On the other hand, river water quality protection is also very important to coastal environment conservation, since the river is one of the carriage ways of pollutants to the sea.

Table-5.31 Water Quality Evaluation

River	Region	Parameter	Measurement*	Evaluation**
Ba	Estuary	pH	6.8-7.5	slightly low
		TN	1.26-1.6	worse than Class B
		TP***	0.04-0.2	Class B
		TN/TP Ratio	about 12	Class AA or A
		DO	6.15-7.21	Class AA
		COD	-	
	River	pH	5.5-7.9	slightly low
		TN	1.35-3.2	Classes 2, 3 or worse
		TP	0.02-0.43	Classes 1, 2, 3 or worse
		DO	0.66-7.92	middle stream section - Class 3 or worse
		COD	1-28	meet Japan's criteria at upper stream side
Nadi	Estuary	pH	7.8-8.1	Class AA
		TN	1.5-2.07	worse than Class B
		TP	0.04-0.2	Class B or worse
		TN/TP Ratio	about 15	Class AA
		DO	6-7.2	Class AA
		COD	-	
	River	pH	7.2-8.1	Class 1
		TN	1.9-3.1	worse than Class 3
		TP	0.04-0.74	Classes 1, 2, 3 or worse
		DO	6.8-9.8	Class 1
		COD	2.9-22.1	meet Japan's criteria at upper stream side
Sigatoka	Estuary	pH	8-8.8	Class AA
		TN	0.97-1.56	worse than Class B
		TP	0.2-0.23	Class B
		TN/TP Ratio	about 6	Class B or worse
		DO	7.3-7.5	Class AA
		COD	-	
	River	pH	7-7.8	Class 1
		TN	1.13-2.55	Classes 2, 3 or worse
		TP	0.12-0.3	Classes 1, 2, 3 or worse
		DO	6.5-9.1	Class 1
		COD	5-22	only 1 sample meets Japan's criteria
Rewa	Estuary	pH	7.1-7.6	slightly low
		TN	1.8-2.7	worse than Class B
		TP	0.23-0.49	Class B
		TN/TP Ratio	about 7	Class B
		DO	6.2-7.8	Class AA
		COD	-	
	River	pH	6.1-7.5	almost Classes 1, 2
		TN	0.55-0.78	Class 1 or Class 2
		TP	0.07-0.21	almost Class 1
		DO	7.2-9.1	Class 1
		COD	2-10	meet Japan's criteria

Note: * based on water quality analysis results shown in Table-5.29
unit as mg/L except for pH and TN/TP ratio
** based on water quality criteria shown in Table-5.30
*** TP is calculated as P

5.4.3 Requirement of Water Quality Management

Water quality management is one of the tasks for watershed management. Due to a high annual rainfall rate, surface water is rich and becomes the main water resource in Fiji. Although water quality analysis results have not indicate serious water pollution, certain problems do arise at some locations and water quality improvement is necessary in order to meet the requirement for various purposes of water utilization. The followings are recommendations.

(1) Water Area Classification

In order to make clear the goals of water quality conservation and improvement, it is necessary to classify the major rivers and coastal waters at national level. For example, a river or a section of river should be designated as Class 1 if it is used as source water for water supply, and an estuary area should be designated as Class AA if it is important for oceanographic research or marine life conservation. In this way, the water quality criteria to be enacted with the environmental legislation can easily be applied for a critical judgment of the water quality in a specific area.

(2) Water Quality Monitoring

A long term water quality monitoring program is needed to be implemented for the major rivers and important coastal areas. All the important water quality parameters such as BOD, DO, TP, TN etc. should be monitored regularly and a data base should be built. In this way, the condition of water pollution can be checked and all problems can be solved immediately.

(3) Restriction on Industrial Wastewater

The water quality analysis results have shown the present condition of industrial pollution on the river at some location. It is necessary to restrict the discharge of industrial wastewater to any of the rivers or coastal areas. All industrial wastewater should be treated before it is discharged to a water body.

(4) Reduction of Pollutants from Domestic Discharge

In Fiji, large cities and towns have already been served by sewerage systems. However, there are still many sources of untreated domestic sewage which is discharged directly to a water and results in water quality deterioration at some locations especially at the dry season. In addition to expansion of existing sewage treatment plants, installation of small scale treatment facilities and improvement of septic tanks shall also be considered.

(5) Sanitary Education

For an effective water quality management, sanitary education is indispensable for raising public awareness of the importance of water quality improvement. Although not so common in Fiji, dumping of garbage or other wastes to a water is thought to be one of the reasons for water pollution. This needs a sanitary education to call people of all ages to take actions for keeping a comfortable and beautiful water environment.

5.5 Forest and Soil Erosion

67 % of Viti Levu island is steep lands (slopes greater than 18°). Therefore, much of the surface runoff after heavy rain over steep slopes increase eroding effect remarkably. Steep slopes also lead to frequent landslides after heavy rain. Besides, soil erosion on steep lands is accelerated by cultivation and grazing on that lands, deforestation, etc.

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

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

5.5.1 Estimate of Soil Erosion and Sedimentation

(1) Estimate of Soil Erosion

Soil erosion from each watershed (Rewa, Sigatoka, Nadi and Ba) was estimated based on the soil loss study by Nelson (1987) which estimated the soil loss from each land unit in the Rewa and Ba watershed (Table-5.32). Nelson's study on soil loss was adopted by the following reasons.

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

Regarding soil erosion in the Rewa and Ba watersheds, Nelson's study results were directly adopted to estimate the average soil loss from the watershed. Average soil loss from the Sigatoka and Nadi watersheds was estimated based on the Nelson's data of the Ba watershed, as the topographical, climatic and land use characteristics of these watershed are similar. The distinctive land use (agriculture, grassland & grazing land and forest) was selected from the unit in Table-5.32 (2/2), and the average soil loss was calculated (Table-5.33).

Table-5.32 (1/2) Characteristics of Land Units

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

Source: Nelson (1987)

Table-5.32 (2/2) Characteristics of Land Units

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

Source: Nelson (1987)

There is a large discrepancy in the soil loss of "grassland" and "forest" in Table-5.33. For example, the soil loss of U1 unit (= grassland) is 54.0 ton/ha/year, while the soil loss of U4 unit (= grassland) is 146.5 ton/ha/year. And the soil loss of U3 unit (= forest) was particularly large. Since pine plantation occupying large area in the U3 unit are too young to prevent the soil loss, the average soil loss of "forest" was relatively large.

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

Table-5.33 Soil Loss by Land Use in Ba Watershed

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

Source : Nelson (1987)

The average soil loss from the Sigatoka and Nadi watersheds was estimated based on soil loss by land use in the Ba watershed (Table-5.34).

Table-5.34 Estimated Average Soil Loss of Sigatoka and Nadi Watershed

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

The estimated soil loss of the four watershed is summarized in Table-5.35.

Table-5.35 Soil Loss of Four Watersheds

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

1) Rewa, Ba : Nelson (1987), Sigatoka, Nadi : estimated by JICA Study Team
2) The areas for the calculation of total soil loss were referred from Table-5.32 and Table-5.34.
3) The specific gravity of soil is 1.5. (That of sand is usually 1.4~1.7)

(2) Estimate of Sedimentation

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

1) Definitions

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

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

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

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

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

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

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

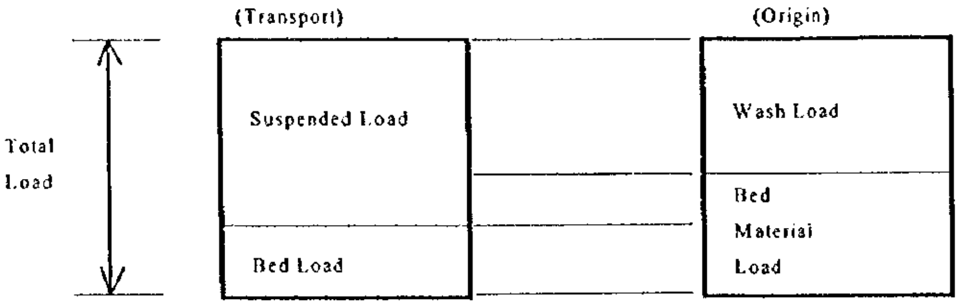


Figure-5.15 Definition of Sediment

2) Analysis of river bed material and measurement of sediment

Analysis of river bed material and measurement of sediment were conducted at the same site by a local consultant. The number of sites for the analysis is ten and their locations are shown in Figure-5.16.

The works consisted of:

a) Analysis of River Bed Material

- Sampling
- Analysis of particle size
- Analysis of specific gravity

b) Measurement of Sediment

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

3) Characteristics of river bed material

The sampling was carried out at three places in cross section indicated in Figure-5.17.

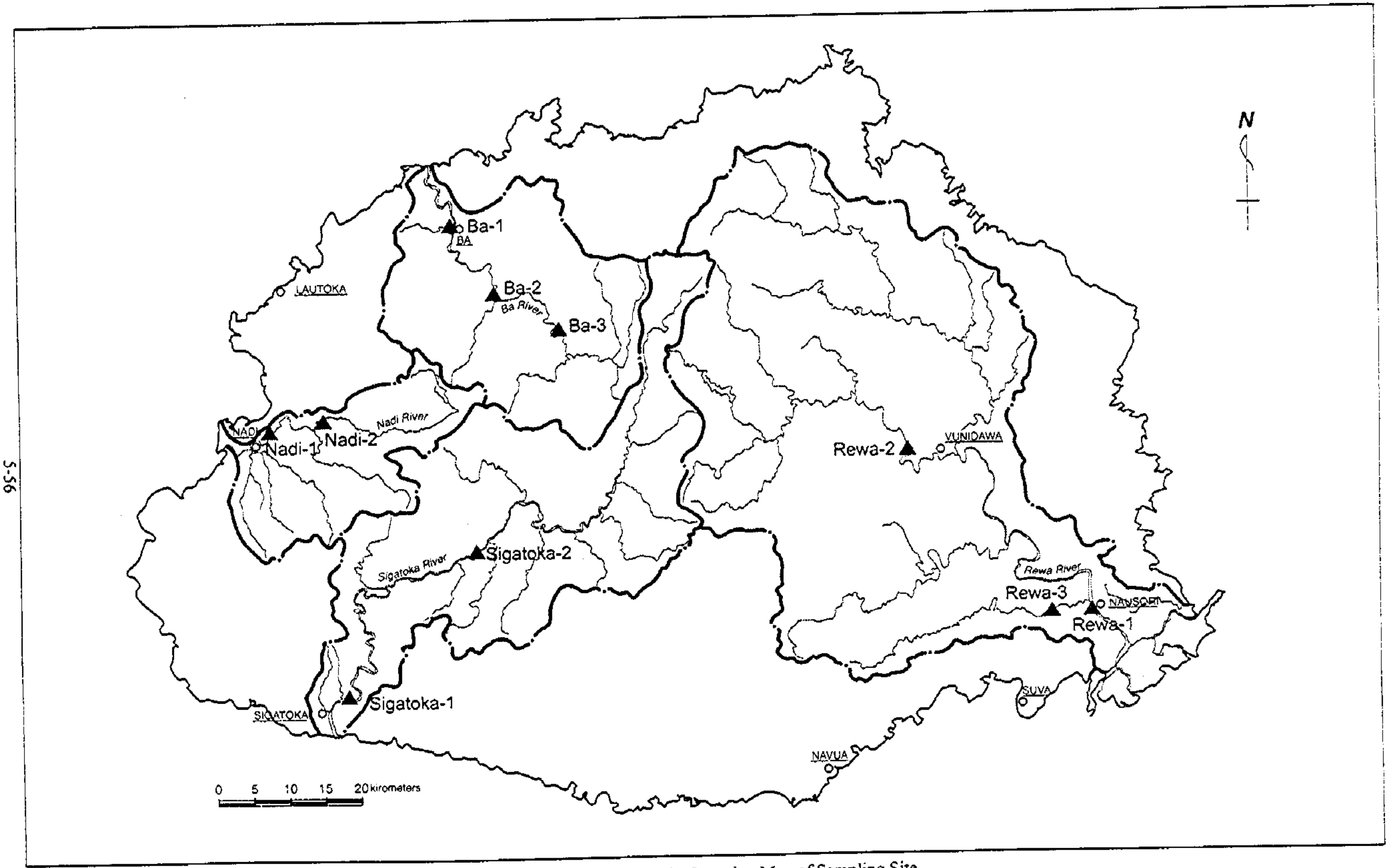


Figure-5.16 Location Map of Sampling Site

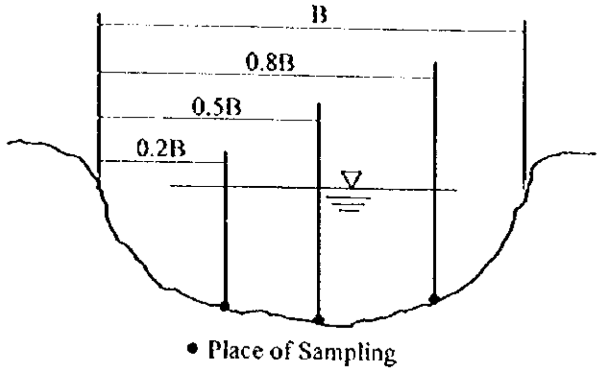


Figure-5.17 Sampling Places of River Bed Material

Results of river bed material analysis are shown in Table-5.36. Gravel is dominant at the sites of Nadi, Rewa-2, Sigatoka-2 and Ba-3, while sand forms 70 ~ 90 % of the river bed material in the other sites.

Table-5.36 Results of River Bed Material Analysis

(Unit: %)

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

Particle size distribution of river bed material at each sampling site is shown in Figure-5.18 by watershed. The figure of each site was represented by the intermediate one among three samples

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

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

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

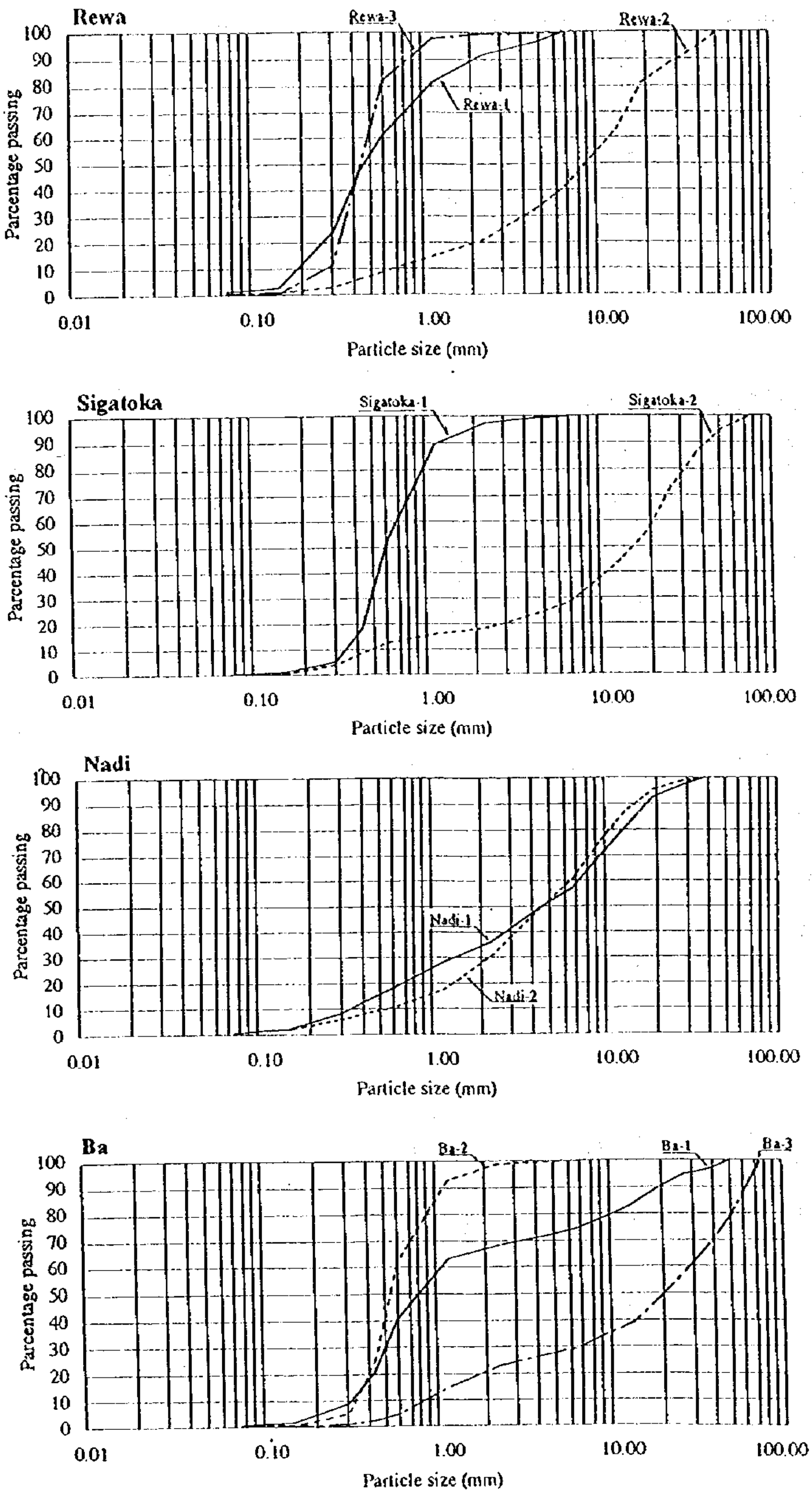


Figure-5.18 Particle Size Distribution

The relation between bed slope and average size of bed material (D_{50}) is shown in Figure-5.19. The right-upper corner (bed slope: steep, grain size: large), such as Ba-3, shows the characteristics of rivers in mountainous areas. The left-lower corner (bed slope: flat, grain size: fine), such as Rewa-1 and Rewa-3, shows the characteristics of rivers on an alluvial plain. This figure also shows that the bed material of Nadi-1 and Nadi-2 is placed between the bed material of the river on a plain in a valley, such as Sigatoka-2, and the bed material of the river on an alluvial plain, such as Rewa-1 and Rewa-3.

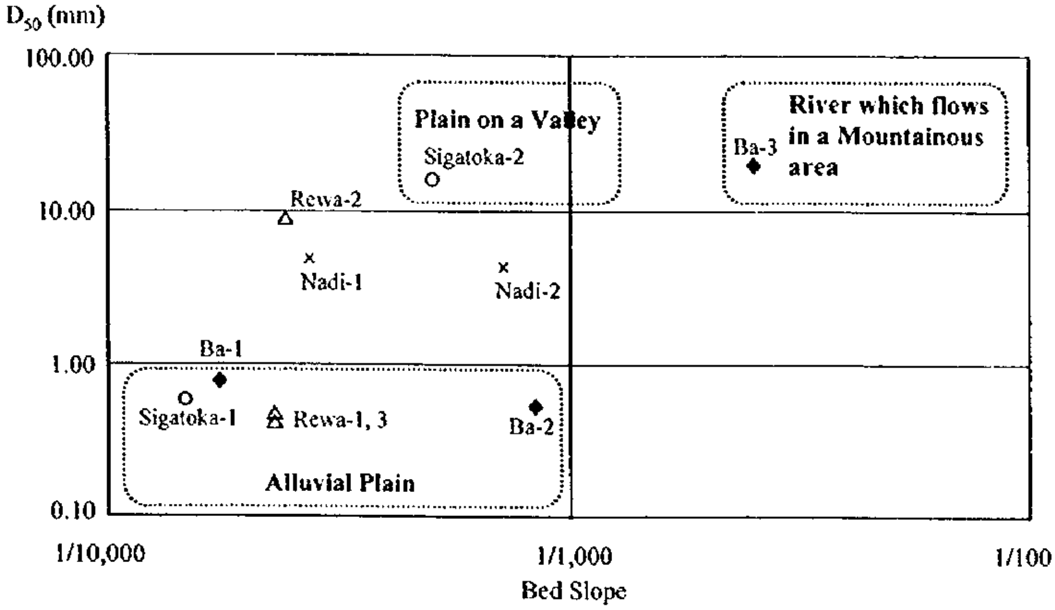


Figure-5.19 Relation between Bed Slope and Average Size of Bed Material (D_{50})

4) Results of suspended load and bed load analysis

Discharge, suspended load, bed load and total load were calculated as shown in Table-5.37 based on the analysis results of suspended load/bed load survey. The survey was carried out in a day when the discharge was small, except Rewa-1 of 29/10/96, as the survey period was fixed during September to October. As a result, total loads (suspended load + bed load) were very small in the most of time, while there was a sharp tendency at Rewa-1 that the total load increased as the discharge increased.

Table-5.37 Results of Suspended Load and Bed Load Analysis

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

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

5) Estimate of Sedimentation

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

It is assumed that all soil loss (shown in Table-5.35) is transported into a river and flows as total load. Total load consists of bed material load and wash load. Since their ratios are not available in Fiji, they were determined by the following assumptions based on the data in Japan because of similar topographic features, neglecting the difference of rainfall. The result is shown in Figure-5.20.

a) According to the observations in Japan, about 80 % of wash load transported in a dam reservoir is deposited. Although sedimentation in a dam reservoir depends on the scale of dam, function of dam, current sedimentation ratio and so on, its ratio is expected to be high even in Fiji if a dam has a water supply function. Therefore, sedimentation ratio of wash load is assumed to be 80 %.

b) According to 40 estimates in Japanese main dams, deposit volume of wash load is approximately 4 times greater than one of bed material load. This ratio was applied.

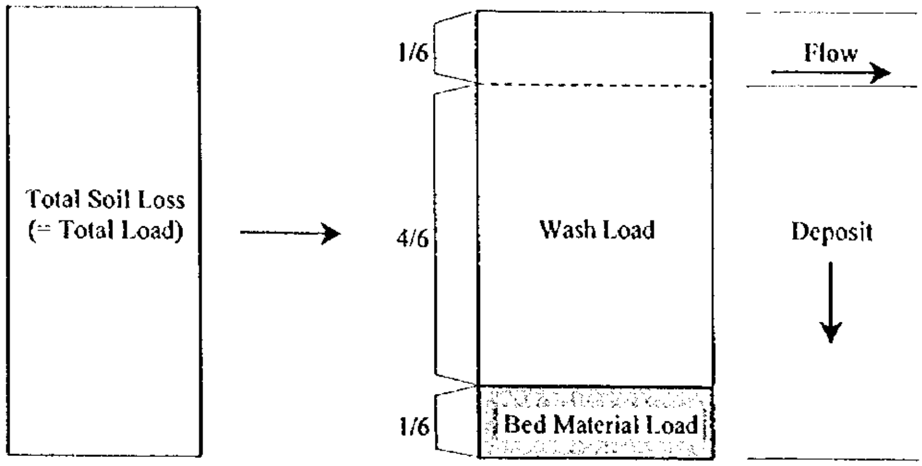


Figure-5.20 Ratio and Behavior of Bed Material Load and Wash Load

Based on the sedimentation ratios in Figure-5.20, only bed material load, 1/6 of total load, is deposited in a normal river, while bed material load and 80 % of wash load are deposited where the flow velocity is extremely small, such as a reservoir.

Deposit volume was estimated with the above assumptions. Table-5.38 shows the result of sedimentation estimate in a normal river comparing with the volume of dredging currently conducted. The annual volume of dredging at river mouth is about 850,000 m^3 for Rewa and 480,000 m^3 for Ba. Since they are 82 % and 68 % of the estimated deposit volume, the estimate is considered as reasonable.

Table-5.39 shows the result of sedimentation estimate in a reservoir where the flow velocity is extremely slow.

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

Table-5.38 Deposit Volume per Unit Area for River Planning

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

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

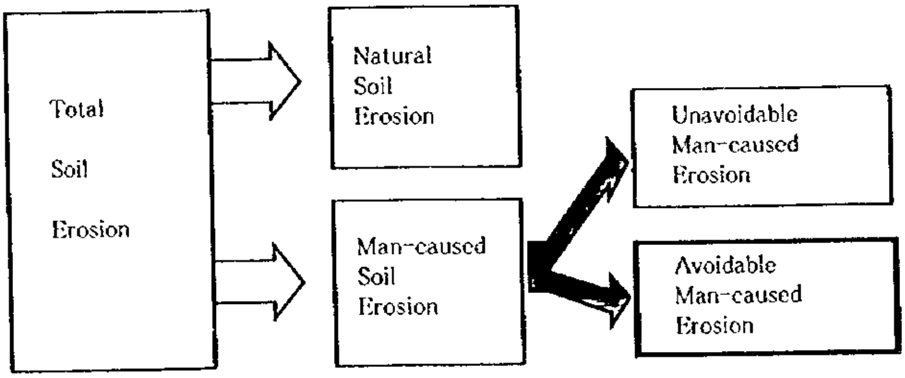
Table-5.39 Deposit Volume per Unit Area for Reservoir Planning

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

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

5.5.2 Countermeasures for Soil Erosion

Figure-5.21 (Nelson, 1987) shows a conceptual breakdown of total soil erosion to isolate the erosion which would be reduced by improved land use practices.



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

Figure-5.21 Conceptual Breakdown of Total Soil Erosion

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

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

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

(1) Objectives

Objectives of countermeasures for soil erosion is as follows;

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

The countermeasures by type of land are described in this section, and institutional and organizational measures are described in Chapter 8.

(2) Fire Prevention in Forest, Grassland and Agricultural Land

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

(3) Countermeasures for Commercial Crop Area

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

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

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

(4) Countermeasures for Small Farming (Teitei)

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

(5) Countermeasures for Logged-out Area, Grassland and Grazing Area

Forest rehabilitation and afforestation should be promoted. Details are described in the following section.

5.5.3 Forest Preservation and Afforestation

(1) Effect of Forest on Watershed Management

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

(2) Present Conditions of Forest

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

Table-5.40 shows the area of forest by type. And Table-5.41 also shows those area by watershed. "Non Forest" includes grassland, cultivation area, town area and grazing etc. The information has been processed from the GIS data by the Management Services Division (Department of Forestry).

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

Table-5.40 Forest Cover in Viti Levu as of December, 1995

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

Source: Management Services Division (Department of Forestry)

In the Rewa watershed, the forest cover is as much as 2,164 km^2 (70 %) and percentage of dense and medium dense forest is high (Table-5.41). The forests of the Sigatoka, Nadi and Ba watersheds form less than half of the watershed area. There is large pine plantation in the Nadi and Ba watersheds and hardwood plantation is located in the upstream of the Sigatoka watershed.

Table-5.41 Forest Area by Watershed

unit: ha

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

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

For the management purpose the forests are classified as follows. The present conditions of each forest is described in Supporting Report Part II.

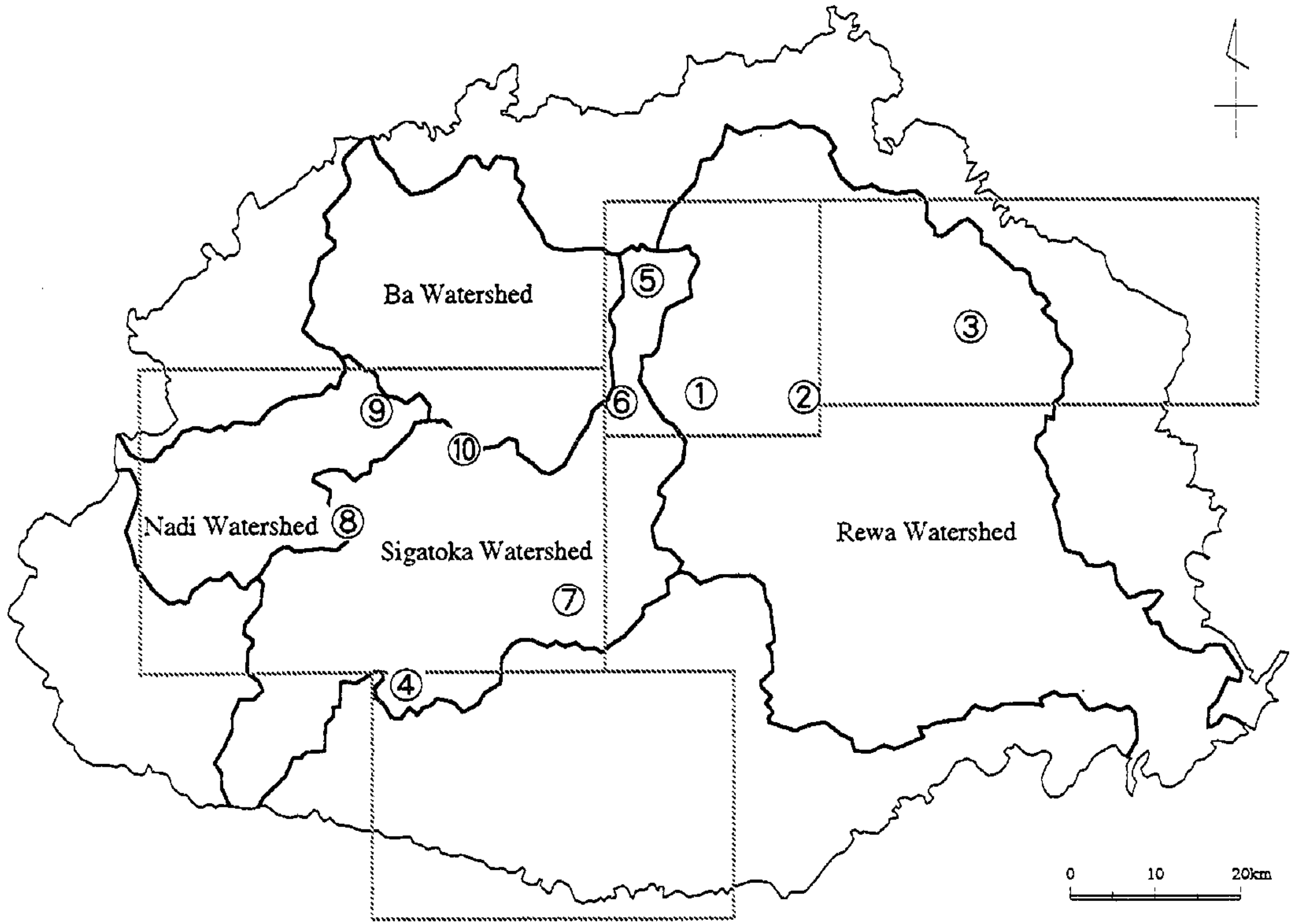
- Production Forest
  - Indigenous Production Forest
  - Plantation Forest
    - Softwood (Pine)
    - Hardwood
    - Coconut
- Protection Forest (Indigenous)
- Non-commercial Forest (Indigenous)
- Mangrove Forest

(3) Present Situation of Deforestation

Deforestation for firewood and cultivation in a small scale for subsistence is found everywhere in forests. But deforestation of this kind is considered spotted shaped like remnant patches that the situation is not statistically known. The only document available about deforestation is the one by Daniel van R Claasen Consultant (1991). In this report, covering four areas as shown by dotted line in Figure-5.22, the deforested areas and its ratio to the forests were calculated by comparison between new aerial photographs or satellite image and the old ones, and the comments of logging situation at that stage were added on it. But deforested areas include production forests where logging is carried out, so it is impossible to know only the deforestation caused by subsistence in volume.

Table-5.42 shows loss of forest cover in each catchment area and present situation of logging based upon this document. The number in catchment corresponds to the number shown in Figure-5.22. The forest areas are decreasing in all of the forests belonged to the watershed of Rewa, Sigatoka, Nadi and Ba, but the decrease is particularly conspicuous in the Ba-Sigatoka divide forest (No. 10) by 40 % during 7 years from 1982 to 89. And also, loss of forest cover in the other catchment (No. 4, 6 and 7) belonging to the Sigatoka watershed is relatively high by 7 ~ 10 %. Some cases reported are that even protection forests with no logging have been destroyed by fires. Reasons of deforestation was considered as follows:

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



Notice: Number refers to the number on the "Table-5.48".

Figure-5.22 Location of Study Area on Deforestation by Daniel van R Claasen Consultant (1991)

Table-5.42 Loss of Forest Cover by Catchment

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

Notice: Number in 1st column refers to the number in the "Figure-5.22".
Source: Daniel van R Claasen Consultant (1991)

(4) Countermeasures for Forest Preservation

1) Target

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

2) Countermeasures

Countermeasures for forest preservation are as follows;

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

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

For the watershed where a large part of forest had been deforested, such as Sigatoka, Nadi, Ba and Wainibuka watersheds, afforestation should be promoted based on the countermeasure for forest rehabilitation and afforestation as described later in (6), and then the formed forest should be designated as the protected areas.

(5) Countermeasures for Sustainable Forestry Production

1) Target

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

2) Countermeasures

Countermeasures for sustainable forest production are as follows;

- Management and control of national timber or wood production
- Regulation of compulsory planting to logged out areas by loggers
- Revision or improvement of "Fiji National Code of Logging Practice"

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

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

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

(6) Countermeasures for Forest Rehabilitation and Afforestation

1) Target

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

2) Countermeasures

Countermeasures for forest rehabilitation and afforestation are as follows;

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

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

3) Target Afforestation Area

The area of the steep grazing land where sustainable grazing is difficult was estimated from the area ratio of slope classes prepared by the Management Services Division (Department of Forests). The area ratio of each slope in objective 4 watersheds is shown in Table-5.43. The distribution of slope classes in grazing area is assumed to be same as Table-5.43 which includes all land use.

Table-5.43 Slope Classes

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

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

The ratio of the area where sustainable grazing is difficult is considered about 15 %, taking the slope ranging more than 20 degree. The target of afforestation area by 2015 is set based on the above countermeasures, as shown in Table-5.44.

Table-5.44 Proposed Land Use in 2015

Land Use	Rewa		Sigatoka		Nadi		Ba	
	(km²)	(%)	(km²)	(%)	(km²)	(%)	(km²)	(%)
Forest	2,573	83.2	952	65.5	295	57.2	554	59.1
(Conservation)	(2,164)	(70.0)	(719)	(49.5)	(248)	(48.1)	(399)	(42.6)
(Afforestation)	(409)	(13.2)	(233)	(16.0)	(47)	(9.1)	(155)	(16.5)
Agriculture	196	6.3	170	11.7	132	25.6	233	24.9
Grazing	296	9.6	327	22.5	69	13.4	136	14.5
Urban	27	0.9	4	0.3	20	3.9	14	1.5
Total	3,092	100.0	1,453	100.0	516	100.0	937	100.0

Notice: Land use plan without afforestation is described in the Chapter 5.2.

4) Cost of Afforestation

Cost of afforestation was estimated on condition that all plantation adopts pine. The cost of afforestation by watershed was calculated as shown in Table-5.45, based on the afforestation area by watershed and the unit afforestation cost (F$ 94,000/km²) obtained from the average of the plantation expenditure divided by the plantation area in 5 years (Table-5.46). The plantation expenditure includes silviculture and nursery costs, station overhead, lease and rental costs, head office overheads, interest and depreciation. The method of planting is by hand or aerial seeding.

Table-5.45 Cost of Afforestation by Watershed

Watershed	Area to be afforested (km²)	Cost of Afforestation (F$ 1,000)
Rewa	409	38,446
Sigatoka	233	21,902
Nadi	47	4,418
Ba	155	14,570
Total	844	79,336

Table-5.46 Cost of Afforestation per 1 km²

	1991	1992	1993	1994	1995	Average
Plantation Expenditure (F$)	1,950,000	2,187,000	2,719,000	3,889,000	4,776,000	
Plantation Area (ha)	2,685	2,929	1,978	3,603	6,389	
(F$/km²)	72,626	74,667	137,462	107,938	74,753	93,489

Source : Fiji Pine Limited Annual Report 1995

5) Afforestation Priority and Schedule

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

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

The implementation schedule of the afforestation by 2015 is shown in Table-5.47. The first priority is placed on the Sigatoka watershed rather than other watersheds because in the Sigatoka watershed no large scale structural measure for flood control will be implemented (refer to Chapter 6). Since there is little area suitable for afforestation in the Nadi watershed due to the pine plantation developed, it is placed at third priority. The afforestation area in the Rewa watershed is large; however, since the forest cover in the Rewa is relatively high, 70 % of watershed at present, afforestation is not urgently required.

The schedule is planned with the preconditions that the afforestation in the Sigatoka is managed to finish by 2015, and successively the afforestation in the Ba, Nadi and Rewa watersheds is conducted in order by 2063, considering the priorities discussed above and financial capacity of the government. Table-5.48 shows the annual capital expenditure of Department of Forestry during 1989 ~ 1993 and its average is approximately F$ 2,439,000/year. Assuming that the same amount to the half of the average annual capital expenditure can be newly allocated to afforestation, F$ 1,222,000, the implementation schedule of afforestation was formulated. The result is shown in Table-5.47 and the annual plantation area would be approximately 13 km^2/year. The schedule of afforestation can be shortened by the effort of increasing the budgetary allocation of the Government.

Table-5.47 Cost and Implementation Schedule of Afforestation

Watershed	Plantation Area (km^2)	Cost (F$ 1,000)	2000 99	04	09	2015 14	19	24	29	34	39	44	49	54	59
Rewa	409	38,446													
Sigatoka	233	21,902													
Nadi	47	4,418													
Ba	155	14,570													
Total	844	79,336													
5 Year Progress Rate (%)			7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%	7.6%
Average Plantation Area (km^2/year)			13												13
Average Cost of Plantation (F$1,000/year)			1,222												1,203

Notice: The thickness of lines conceptually indicates the weight of distribution of the annual budget (average 13 km^2/year), and does not show the actual amount.

Table-5.48 Annual Capital Expenditure of Department of Forestry

unit: F$

	1989	1990	19914	1992	1993	Average
Capital Expenditure	2,737,300	2,089,700	2,646,700	2,617,100	2,104,900	2,439,140

Source: Ministry of Finance and Economic Development

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CHAPTER 6 FLOOD CONTROL PLAN

6.1 Field Investigation

Regarding the flood control, the Study Team conducted the river profile and cross section survey and the study of flood damage through subcontract with a local consultant during the first work period in Fiji, from August 1996 to December 1996. The former is to figure out the physical characteristics of the target 4 watershed, and the latter is to assess the flood damage of past floods in the target 4 watersheds, especially the cyclone Kina, for the economic evaluation of proposed plans.

6.1.1 River Profile and Cross Section Survey

Areas covered by the river profile and cross section survey are described in Table-6.1 and their locations are shown in Figure-6.1.

Table-6.1 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 mobilization, route clearing, control point survey, installation of distance markers and bench marks, traverse survey, river profile survey, cross section survey, and report inclusive of plans. The cross section survey was conducted every 500 m and the lengths of the river profile survey are shown in Table-6.1. 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.

6.1.2 Study of Flood Damage

The study of flood damage was conducted in 7 sites in Viti Levu through subcontract with a local consultant. Sites for flood damage study are shown in Talbe-6.2 and Figure-6.2. The works consisted of interview to 50 sufferers in each site with a questionnaire formulated by the Study Team, leveling survey to determine the elevation of flood marks, collection of flood information from local government authorities and reporting.

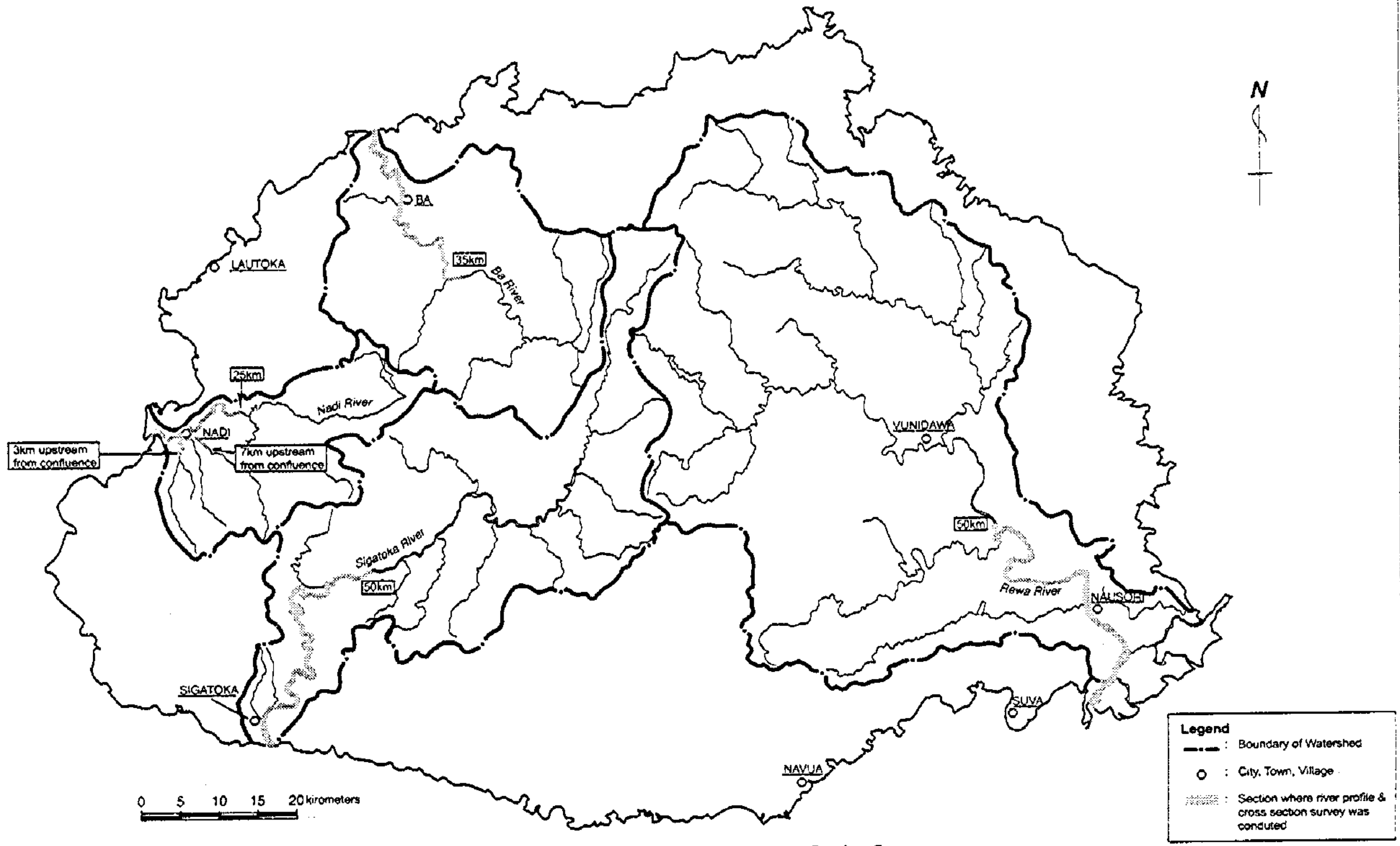


Figure-6.1 Sites for River Profile and Cross Section Survey

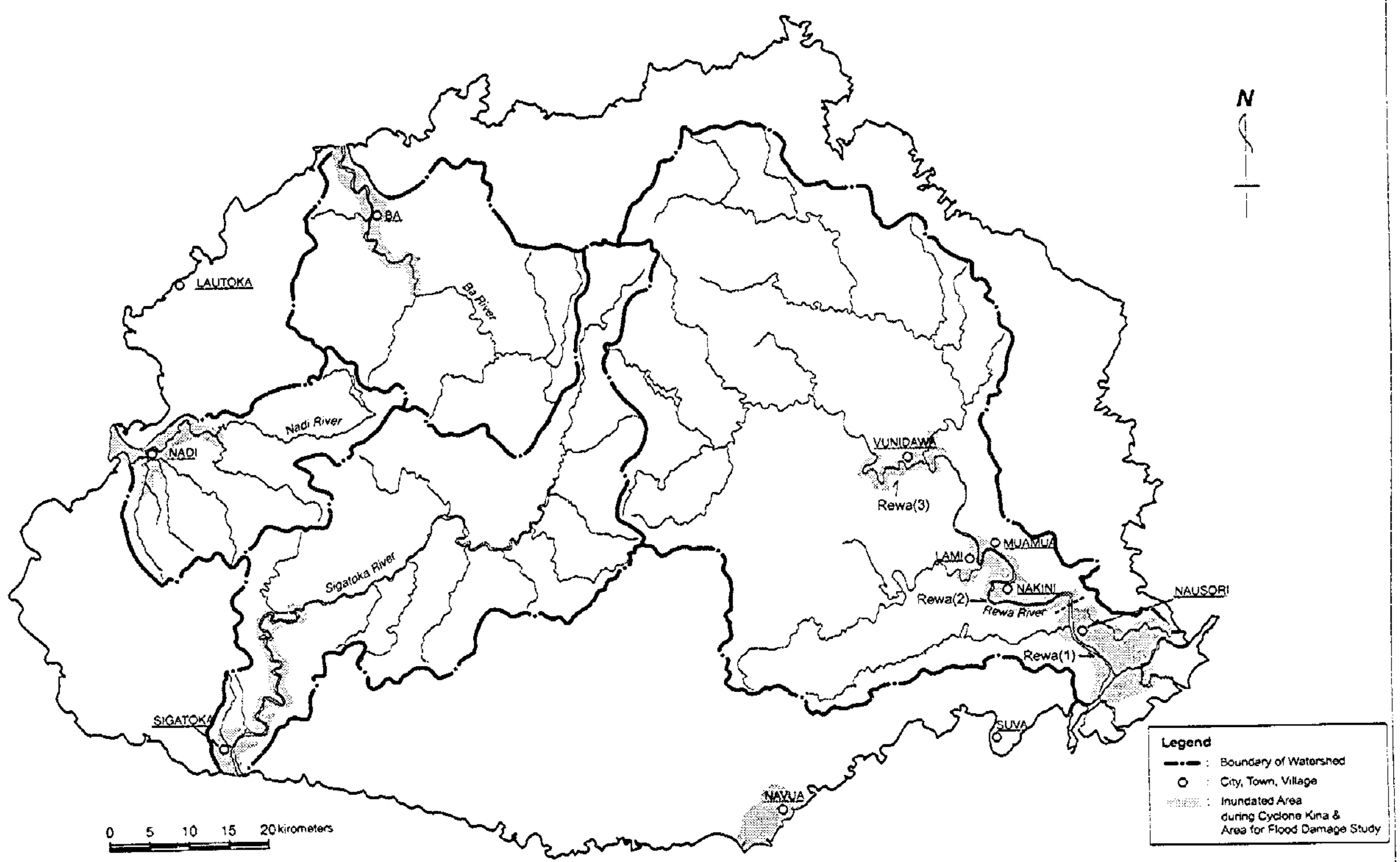


Figure-6.2 Site for Study of Flood Damage

Main items in the questionnaire are household information, flood damage to housing and properties, flood damage to agriculture and business, flood marks and so on. The interview was conducted for the past major floods; however, since most of residents remember only the cyclone Kina, the results could be used to estimate the flood damage by only the cyclone Kina.

Table-6.2 Sites for Study of Flood Damage

Watershed	Rewa (1)	Rewa (2)	Rewa (3)	Navua	Sigatoka	Nadi	Ba
Adjacent Town or Village	Nausori	Nakini, Muamua & Lami	Vunindawa	Navua	Sigatoka	Nadi	Ba

6.2 Flow Capacity of River Channel

Flow capacity of river channel was examined by non-uniform flow computation based on the results of the river profile and cross section survey. The details and results of the examination are discussed in the following section.

6.2.1 Section Examined

Sections examined are shown below and correspond to sites where the river profile and cross section survey was conducted, excluding Nadi tributaries (refer to Figure-6.1).

Rewa river: from river mouth to 50 km upstream with an interval of 500 m
Sigatoka river: from river mouth to 50 km upstream with an interval of 500 m
Nadi river: from river mouth to 25 km upstream with an interval of 500 m
Ba river: from river mouth to 35 km upstream with an interval of 500 m

Each section is denoted by accumulated distance from river mouth throughout the report.

6.2.2 Cross Sections of River Examined

Cross sections of river examined were within current banks or revetments. Based on the results of the river profile and cross section survey, cross sections for the non-uniform flow computation were determined comparing with aerial photos (1/50,000 scale) in 1994.

6.2.3 Method of Analysis

Flow capacity of river was examined with the following procedure.

1) to compute stage (water level) of each cross section by non-uniform flow computation varying discharge
2) to understand the relation between stage (H) and discharge (Q)
3) to obtain discharge at the stage equivalent to the height of bank or revetment from the above H ~ Q relation
4) to examine flow capacity of river channel longitudinally based on 3)

Cross sections of river vary with location and there are several confluences within the objective sections. Besides, there is a backwater by tidal influence due to the very gentle slope of river bed. Therefore, non-uniform flow model was employed to assess H and Q relation. The mean high water of tide in Viti Levu, EL=1.0 m (above mean sea level), was adopted as the boundary condition and Manning roughness coefficient was assumed to be 0.03.

6.2.4 Current Flow Capacity of River Channel

Current flow capacities of 4 rivers are shown longitudinally in Figure-6.3 and Figure-6.4. Although current flow capacities were examined with an interval of 500 m, results are shown every 5 km and at critical points as summary.

Flow capacities of 4 rivers tend to be the smallest at river mouth compared to other sections. Since mangrove extends over the large swampy area in the vicinities of river mouth, the flood disperses through the mangrove. Besides, there are tributaries in the vicinities of river mouth to drain flood from the main stream. Therefore, the figures computed for these areas are considered as underestimate and not useful for the examination of current flow capacity. Therefore, current flow capacities of river were examined for the upstream of these areas. The result is discussed in the followings.

1) Rewa River

As shown is Figure-6.4, flow capacities expressed in specific discharge (discharge divided by watershed area) downstream from 16.5 km (Nausori bridge) are relatively small compared to other sections. Those figures are considered as underestimate because non-uniform flow computation was applied to only Rewa main stream not considering drainage through tributaries located downstream from 16.5 km, such as Wainibokasi, Nasoata and Toga river. Therefore, those flow capacities were excluded from examination of current flow capacity of Rewa river.

Flow capacities (specific discharge) are almost constant at 2.0 $m^3/sec/km^2$ between 16.5 km and 25 km point. Sections with the smallest flow capacity are located from 30 km to 35 km point and the flow capacity at 35 km point is the lowest, 1.54 $m^3/sec/km^2$. In the sections upstream from 35 km, flow capacities increase because the river flows the mountainous area.

If the lowest flow capacity in terms of specific discharge (1.54 $m^3/sec/km^2$ at 35 km point) was converted to the discharge at the downstream end (river mouth), it would be approximately 4,800 m^3/sec. This discharge is considered as current flow capacity of Rewa river.

2) Sigatoka River

Since Sigatoka river flows the mountainous area, flow capacities of some sections tend to be large. However, in the sections between river mouth and 50 km point, most of flow capacities range at 1.85 ~ 3.00 $m^3/sec/km^2$.

If the lowest value in terms of specific discharge at 10 km point, 1.78 $m^3/sec/km^2$, was converted to discharge, it would be about 2,600 m^3/sec at river mouth. This discharge is considered as current flow capacity of Sigatoka river.

3) Nadi River

At the downstream nearby the confluence with Nawaka creek (7.5 km point), Nadi river shows the lowest flow capacity, 0.59 $m^3/sec/km^2$. In the upstream of this point, the flow capacities increase; however, they are approximately 1.5 $m^3/sec/km^2$ until 15 km. Those values are relatively small compared to other 3 rivers.

If the lowest flow capacity in terms of specific discharge (0.59 $m^3/sec/km^2$ at 7.5 km point) was converted to discharge at river mouth, it would be 300 m^3/sec. This discharge is considered as current flow capacity of Nadi river.

4) Ba River

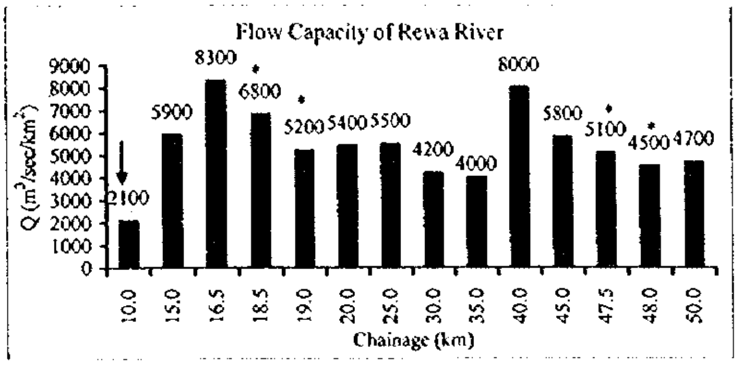
As the river flows downstream, the flow capacities decrease and one near Ba bridge (15 km from river mouth) is the lowest, 2.13 $m^3/sec/km^2$, excluding the downstream of Ba town (13.5 km point) where very few properties are located. However, the sections where the flow capacities are relatively low are located in a short distance, about 20 km from river mouth. In the upstream from 20 km point, the flow capacities are more than 3.00 $m^3/sec/km^2$ and those figures show the higher capacity compared to other rivers.

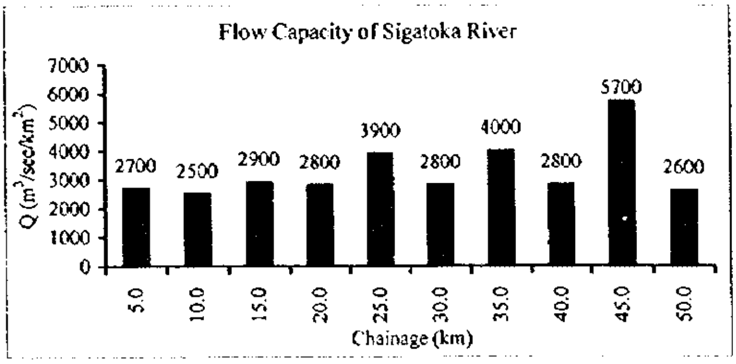
If the lowest flow capacity in terms of specific discharge (2.13 $m^3/sec/km^2$ at 15 km point) was converted to discharge at river mouth, it would be about 2,000 m^3/sec. This discharge is considered as current flow capacity.

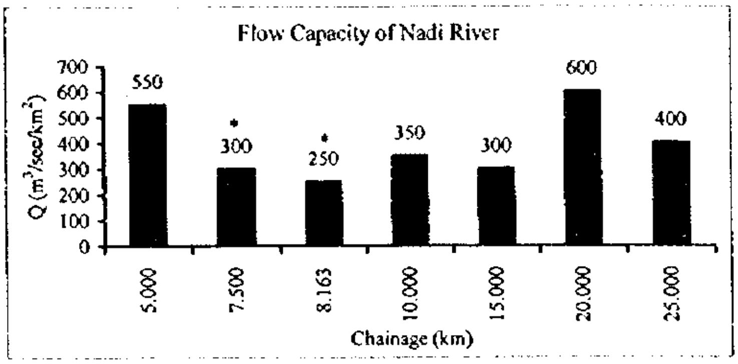
Flow capacities of 4 rivers tend to be larger in the upstream. This is a reason that most inundated areas are located in the downstream. The flow capacities of 4 rivers are summarized in Table-6.3. Comparing the flow capacity of each river in terms of specific discharge, Nadi river has the lowest capacity, one order lower. After Nadi river, Rewa river and Sigatoka river are the second and third lowest. Ba river has the highest capacity.

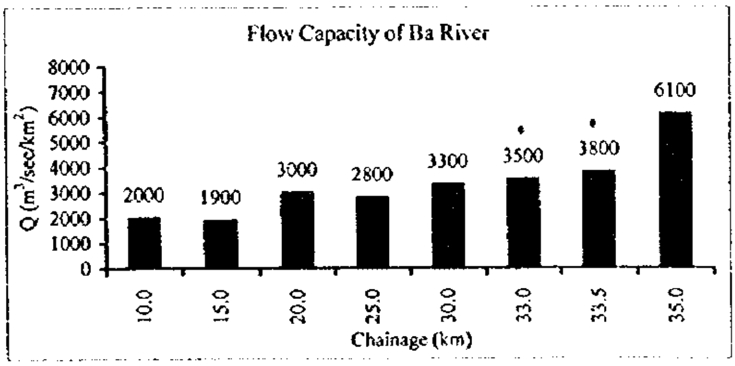
Table-6.3 Current Flow Capacity of Target Rivers

River	Critical Point (km, distance from river mouth)	Flow Capacity (m^3/sec)	Catchment Area (km^2)	Specific Discharge ($m^3/sec/km^2$)	Discharge at River Mouth (m^3/sec)
Rewa	35.0	4,000	2,594	1.54	4,800
Sigatoka	10.0	2,500	1,405	1.78	2,600
Nadi	7.5 (downstream of confluence)	300	506	0.59	300
	8.2 (upstream of confluence)	250	317	0.79	400
Ba	15.0	1,900	891	2.13	2,000





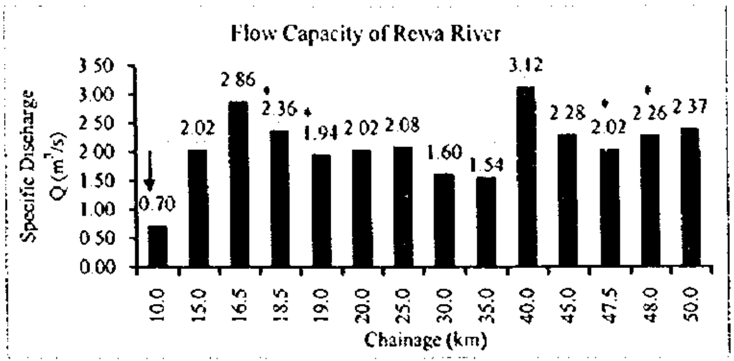


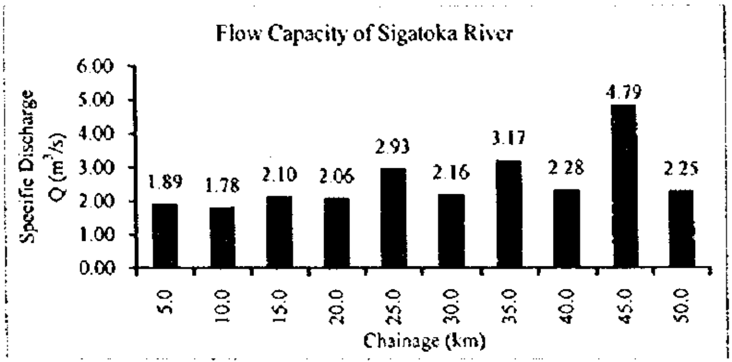


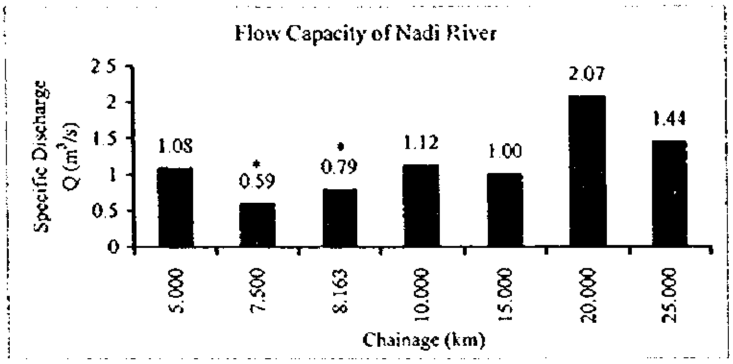
↓ : under estimate due to the mangrove area

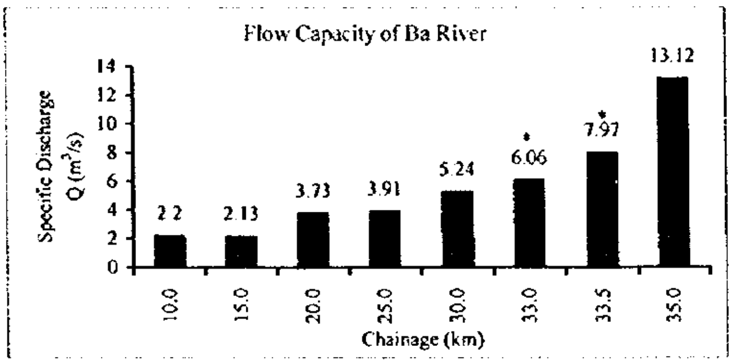
* : point before or after the major confluence

Figure-6.3 Longitudinal Flow Capacity (Discharge)









↓ : under estimate due to the mangrove area

* : point before or after the major confluence

Figure-6.4 Longitudinal Flow Capacity (Specific Discharge)

6.3 Runoff Analysis

If hydrological data in Viti Levu is considered, rainfall data is much more available than discharge data. Therefore, flood discharges with different return periods should be estimated based on stochastic analysis of rainfall. In this section, a runoff model to simulate floods using the results of stochastic analysis of rainfall was determined and floods with different return periods were simulated.

6.3.1 Model Employed

The storage function model (Kimura, 1962) was employed in order to transform rainfall to runoff because of the following reasons.

1) Topographical features of Viti Levu are similar to Japan.
2) The storage function model can take account of characteristics of watershed and river channel even though there is few gauging stations to calibrate the model. For example, some constants are obtainable from the topographic map and the lag time is generally a function of length of river.

The method has an advantage to consider the storage of water in watershed and river channel. On the other hand, the limitation of the model is that the accuracy of its application to small areas, less than 10 km^2, is not as high as the application to large areas. The basic formulae of this method consist of the dynamic equation and continuity equation as shown below.

The relation between the storage of water in watershed or river channel (S_l) and runoff (Q_l) is expressed by the following equation as the solution of the dynamic equation.

$$S_l = kQ_l^{p}$$

where k, p: constant for watershed, K and P for river channel

The continuity equation for watershed is;

$$\frac{dS_l}{dt} = \frac{1}{3.6} f \cdot r_{ave} A - Q_l$$

where f: runoff coefficient

r_{ave}: average rainfall in watershed (mm/h)

A: area of watershed (km^2)

S_l: apparent volume of storage in watershed (m^3/sec·h)

Q_l: volume of runoff considering the time lag (excluding the base flow, m^3/sec)

The continuity equation for river channel is;

$$\frac{dS_l}{dt} = I - Q_l$$

where I: inflow from watershed, tributary or upstream end to river channel considered (m^3/sec)

S_l: apparent volume of storage in river channel (m^3/sec·h)

Q_l: volume of runoff considering the time lag (excluding the base flow, m^3/sec)

6.3.2 Partition of Watershed

Considering the confluences and tributaries, 4 watersheds (Rewa, Sigatoka, Nadi and Ba) were divided in blocks for the runoff analysis. Partition of watershed is shown in Figure-6.5.

6.3.3 Average Rainfall of Watershed

Average rainfall of watershed was computed by applying Thiessen method to raingauge stations where hourly data is available. The location and number of the stations available vary depending on flood. Therefore, the different Thiessen polygons were determined. The following cyclones were initially selected for the runoff analysis.

1) Cyclone Arthur: January, 1981
2) Cyclone Oscar: February, 1983
3) Cyclone Nigel: January, 1985
4) Cyclone Joni: December, 1992
5) Cyclone Kina: January, 1993

6.3.4 Verification of Model

For the verification of the model (to check the applicability of the storage function model to the runoff analysis in Viti Levu), both hyetograph and hydrograph during floods are essential. After checking hyetograph and hydrograph of the above floods in each watershed, it was found that the availability of both data is very limited. Although distribution and number of raingauge stations are not enough to take account of spatial variation of rainfall, both data are available for only the Rewa watershed. Therefore, verification of the model was conducted for the Rewa watershed. After confirming the applicability of the model, the model constants were determined for other 3 watersheds by the same method applied to the Rewa.

For the verification, the model was calibrated by repetition of model application until the discharge simulated satisfies the following items compared to the discharge observed.

- peak discharge during flood
- time of peak discharge
- pattern of hydrograph

Figure-6.5 Partition of Watershed

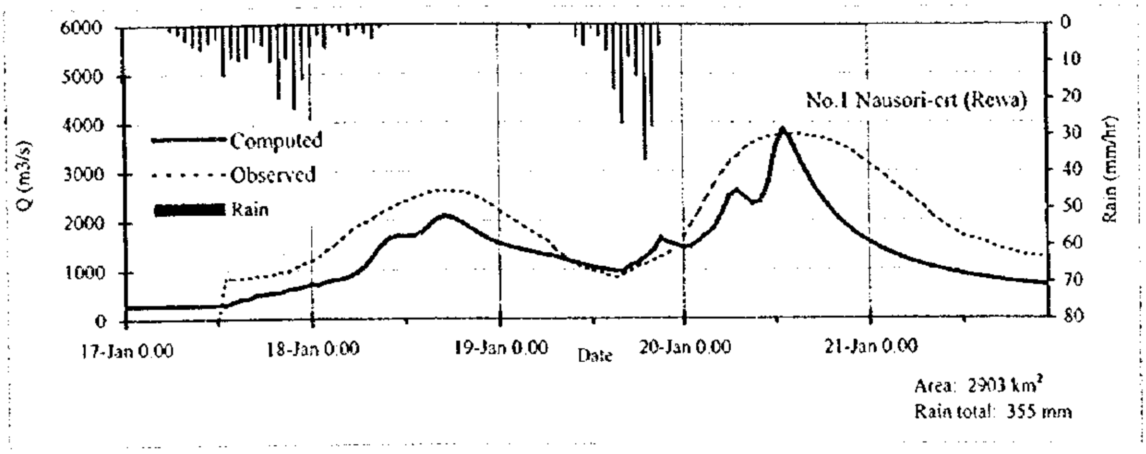
Results of model application in the Rewa main stream are shown in Figure-6.6 (cyclone Nigel) and Figure-6.7 (cyclone Kina). Simulated hydrograph, observed hydrograph and weighted average rainfall used for the simulation at each gauging station are shown in Figures.

Since the cyclone Kina caused large inundation, its observed hydrograph in the Rewa delta is considered as not accurate enough due to overflow from the river channel. Therefore, Nausori station was excluded from the comparison for the cyclone Kina flood.

There are some differences between the observed and simulated hydrographs, especially, time of peak and pattern of hydrograph. Any discrepancy between them is considered mainly due to the lack of data. Hourly rainfall is available only at 6 raingauge stations for the cyclone Nigel and 5 raingauge stations for the cyclone Kina. Compared to the watershed area of Rewa, 3,092 km^2, the available data is insufficient to take account of spatial variation of rainfall. To improve the accuracy of the model, the adequate network of raingauge stations and continuous observation are required.

During the recession stage, hydrograph is generally the exponential curve; however, the observed hydrographs show the straight recession lines. The reason is probably that water from the inundated area (inland) was drained gradually to the river channel.

As far as the peak discharge is concerned, the storage function model meets the observed data well. Since the main objective of flood control is to drain the peak discharge of target flood without inundation, the model satisfies the Study objective.



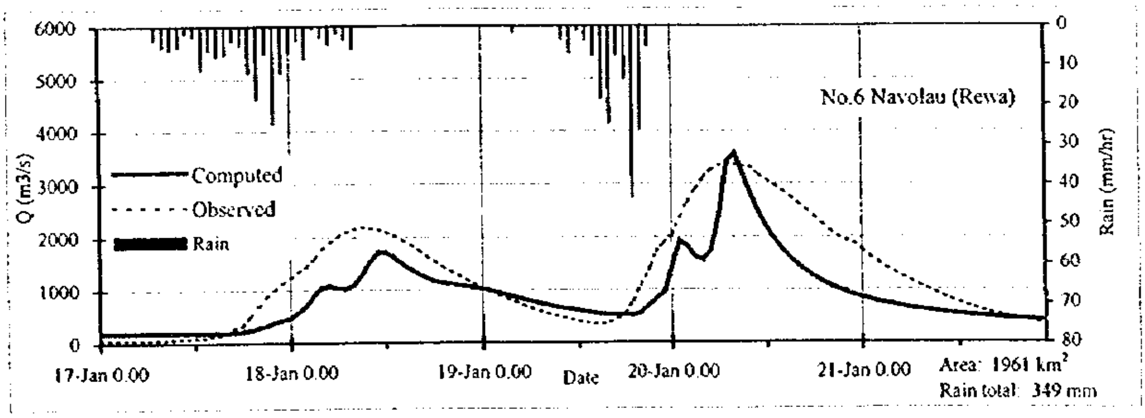


Figure-6.6 Hydrograph Observed and Simulated (Cyclone Nigel: Rewa Watershed)

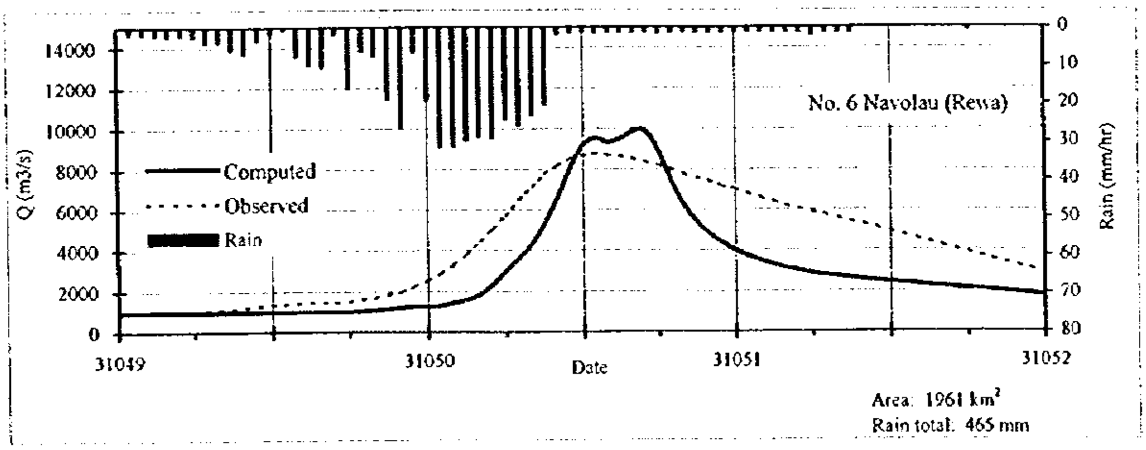


Figure-6.7 Hydrograph Observed and Simulated (Cyclone Kina: Rewa Watershed)

6.3.5 Constants of Runoff Model

Constants of the model were determined for each watershed after the calibration and verification of the model in the Rewa watershed. The model constants were determined by the same methods finally applied to the Rewa. The results are summarized in Table-D4.1 ~ D4.4.

Table-6.4 Constants of Storage Function Model (Rewa River)

Item	Name	Catchment Area (km^2)	k or K	p or P	T_l	C
Watershed	Wainibuka Watershed I	247.0	62.9	0.333	2.05	-
	Wainibuka Watershed II	143.1	45.8	0.333	1.26	-
	Lawaki Watershed	169.4	65.4	0.333	2.49	-
	Wainibuka Watershed III	344.3	58.5	0.333	1.61	-
	Wainimala Watershed I	305.7	51.9	0.333	1.72	-
	Wailoa Watershed	187.5	54.6	0.333	1.98	-
	Wainimala Watershed II	82.6	21.6	0.333	1.00	-
	Waisomo Watershed	129.8	63.8	0.333	2.04	-
	Wainimala Watershed III	261.5	35.6	0.333	1.17	-
	Rewa Watershed I	121.1	65.9	0.333	1.07	-
	Waidina Watershed	536.6	94.3	0.333	3.79	-
	Rewa Watershed II	147.5	55.4	0.333	1.00	-
	Waimanu Watershed	203.8	98.8	0.333	3.02	-
	Rewa Watershed III	212.3	54.7	0.333	1.00	-
River	River I	-	32.6	0.600	2.13	0.57
	River II	-	113.7	0.600	5.69	2.35
	River III	-	22.8	0.600	1.64	0.32
	River IV	-	67.4	0.600	3.30	1.15
	River V	-	68.8	0.600	3.56	1.28
	River VI	-	108.9	0.600	4.60	1.80
	River VII	-	66.6	0.600	2.33	0.67

f_1=0.5, R_{sa}=250 mm, q_{base}=0.1 $m^3/sec/km^2$

Table-6.5 Constants of Storage Function Model (Sigatoka River)

Item	Name	Catchment Area (km^2)	k or K	p or P	T_l	C
Watershed	Sigatoka Watershed I	310.1	71.9	0.333	2.71	-
	Sigatoka Watershed II	349.9	47.5	0.333	1.54	-
	Namada Watershed	249.4	77.2	0.333	2.34	-
	Sigatoka Watershed III	543.4	68.7	0.333	1.07	-
River	River I	-	26.7	0.600	1.89	0.45
	River II	-	173.4	0.600	6.64	2.28

f_1=0.5, R_{sa}=250 mm, q_{base}=0.1 $m^3/sec/km^2$

Table-6.6 Constants of Storage Function Model (Nadi River)

Item	Name	Catchment Area (km^2)	k or K	p or P	T_l	C
Watershed	Nadi Watershed I	39.4	31.8	0.333	1.00	-
	Nadi Watershed II	144.5	30.8	0.333	1.08	-
	Namosi Watershed	90.7	67.0	0.333	2.08	-
	Nadi Watershed III	52.7	40.4	0.333	1.00	-
	Nawaka Watershed	98.8	59.3	0.333	1.87	-
	Malakua Watershed	89.8	77.4	0.333	1.46	-
River	River I	-	13.6	0.600	1.47	0.24
	River II	-	25.4	0.600	2.05	0.53

f_1=0.5, R_{sa}=250 mm, q_{base}=0.1 $m^3/sec/km^2$

Table-6.7 Constants of Storage Function Model (Ba River)

Item	Name	Catchment Area (km^2)	k or K	p or P	T_l	C
Watershed	Ba Watershed I	153.1	57.0	0.333	1.89	-
	Nakara Watershed	153.6	48.2	0.333	1.51	-
	Ba Watershed II	170.2	32.3	0.333	1.06	-
	Waisali Watershed	101.2	44.9	0.333	1.37	-
	Ba Watershed III	359.3	44.7	0.333	1.59	-
River	River I	-	15.7	0.600	1.61	0.31
	River II	-	63.0	0.600	3.06	1.03

f_1=0.5, R_{sa}=250 mm, q_{base}=0.1 $m^3/sec/km^2$

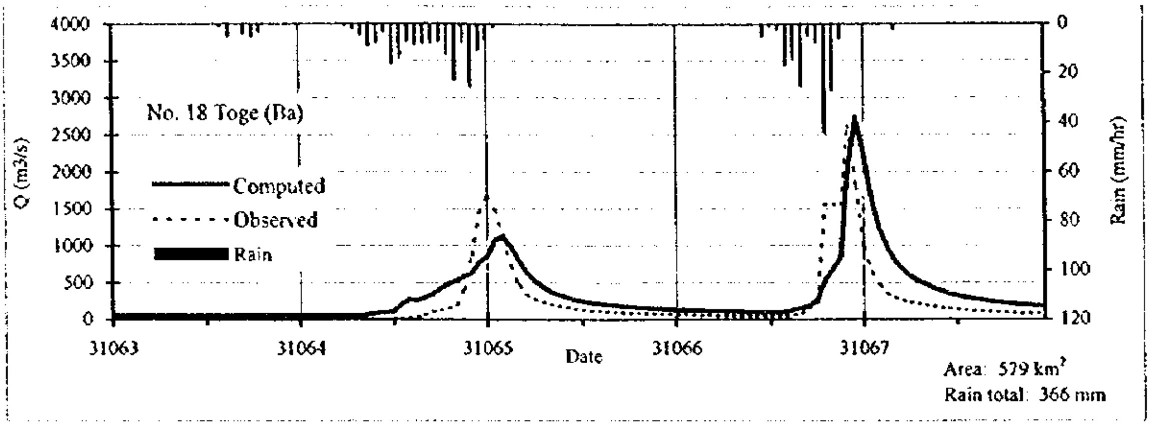
6.3.6 Application of Model

(1) Floods Simulated

After determining the model constants, the model was applied to the past floods to reconfirm the accuracy of the model. According to the data availability, the model is applicable to two cyclones in three watersheds as shown in Table-6.8. Since raingauge and gauging stations in the Nadi watershed were rehabilitated by the Study Team in 1996, the data availability was improved so that the flood of the cyclone Gavin in the Nadi watershed could be simulated by the model. Results are shown in Figure-6.8 and Figure-6.9.

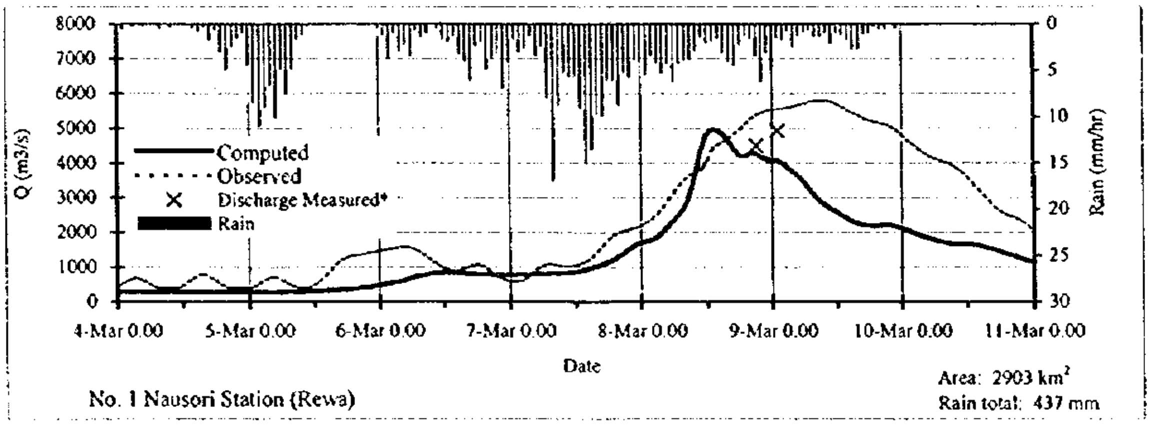
Table-6.8 Floods Simulated

Cyclone	Watershed	Simulated Period
Nigel	Ba	January 16 - 21, 1985
Gavin	Rewa	March 4 - 11, 1997
Gavin	Nadi	March 6 - 10, 1997

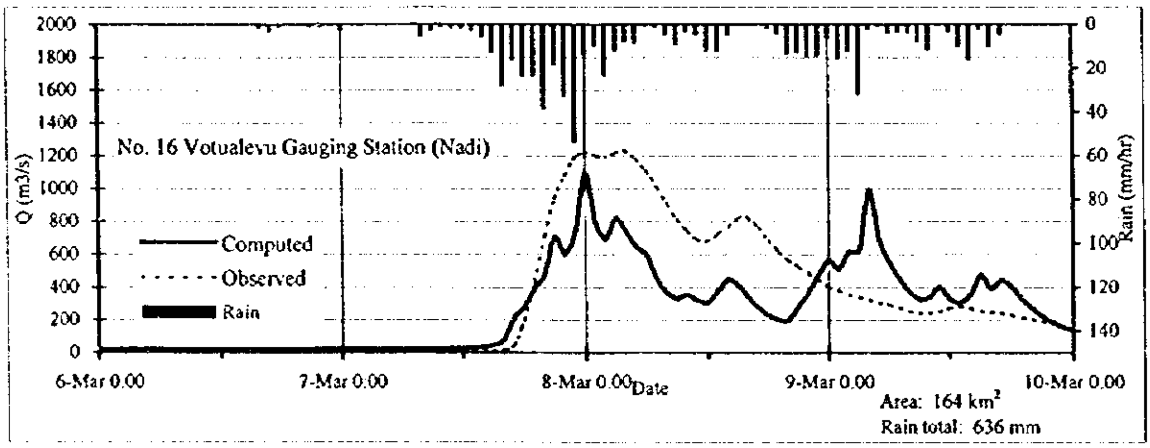


Hydrograph Observed and Simulated (Cyclone Nigel: Ba Watershed)

Figure-6.8 Application of Storage Function Model (Cyclone Nigel)



Hydrograph Observed and Simulated (Cyclone Gavin: Rewa Watershed)



Hydrograph Observed and Simulated (Cyclone Gavin: Nadi Watershed)

Figure-6.9 Application of Storage Function Model (Cyclone Gavin)

(2) Cyclone Nigel in Ba Watershed

The simulation result of the cyclone Nigel in the Ba watershed meets the observed data well. The result satisfies the peak discharge, time of peak and pattern of hydrograph. Although only two raingauge stations located far from the watershed are available, the data from these stations seems to describe well the rainfall characteristics in the Ba.

(3) Cyclone Gavin in Rewa Watershed

At the Nausori gauging station, the peak discharge observed is 5,802 m^3/sec, while one simulated is 4,963 m^3/sec. PWD hydrological section conducted the discharge measurement by current meter during the cyclone June (May 6, 1997) and the results are shown in Table-6.9. Even if the difficulty in measuring discharge during flood is considered, the flood discharge by the rating curve seems to deviate from the actual figures. According to the gauging data, the highest stage during the cyclone Gavin is 4.515 m and only 8.2 cm higher than the stage when the discharge measurement was conducted. Taking account of overestimate by the rating curve, the simulated discharge (4,963 m^3/sec) is considered as the reasonable figures.

Table-6.9 Discharge Measurement by Current Meter

Date	Stage (m)	Discharge Measured by Current Meter (m^3/sec)	Discharge by Rating Curve (m^3/sec)
May 6, 1997	4.433	4,933	5,548
May 6, 1997	4.370	4,503	5,378

The time of the peak discharge simulated deviates from the observed one. Although rainfall data from 14 raingauge stations are available for the cyclone Gavin in the Rewa watershed, the number of stations may be not enough to take account of the delay of floods from the tributaries resulting from the spatial variation of rainfall. Another reason maybe that drainage of river channel was hindered by storm surge.

(4) Cyclone Gavin in Nadi Watershed

Rating curve of Votualevu station has not been determined yet because the station was rehabilitated by the Study Team and reopened in January 1997 after a long cease of observation. Therefore, uniform flow computation was applied to relate the stage with discharge based on the cross section surveyed by PWD and average bed slope obtainable from the results of the river profile and cross section survey. Observed discharge in Figure-6.9 is the result of uniform flow computation.

The model agrees with the observed hydrograph as long as the time of peak and peak discharge are concerned. During the recession, the simulated hydrograph deviates from the observed one. Since the peak discharge is the main concern for the Study, the result of model application is satisfactory.

6.3.7 Flood by Probability

(1) Procedures of Simulation

Floods with different return periods were simulated with the following procedures.

1) to select target floods considering the availability of hourly rainfall and the scale of total rainfall
2) to sum weighted average of hourly rainfall over watershed computed by Thiessen method so as to obtain daily rainfall of the target flood
3) to compute the ratio to transform the above daily rainfall (based on observation) to the probable daily rainfall, dividing the probable daily rainfall by maximum observed daily rainfall computed in 2)
4) to select a flood which the above ratio of transformation is less than 2.0 because too large ratio overestimates the rainfall in a short period and successively flood
5) to determine the hyetograph of probable rainfall by transforming the hyetograph of observed rainfall with the above ratio
6) to apply the storage function model to simulate the runoff for a particular probable rainfall

(2) Objective Flood

5 floods (Arthur, Oscar, Nigel, Joni and Kina) were initially selected to calculate ratios between observed daily rainfall and probable daily rainfall. As a result, only ratios of the cyclone Kina do not exceed 2.0. Therefore, the hyetograph of the cyclone Kina was selected for the flood simulation with different return periods. Ratios to transform the Kina's hyetograph to probable rainfall are shown in Table-6.10.

Table-6.10 Ratios of Transformation for Cyclone Kina

Watershed	Maximum Observed Daily Rainfall (mm/day)	Return Period	1/100	1/50	1/30	1/20	1/10	1/5	1/2
Rewa	389	Probable Rainfall (mm/day)	450	390	360	320	270	210	130
		Ratio	1.16	1.00	0.93	0.82	0.69	0.54	0.33
Sigatoka	294	Probable Rainfall (mm/day)	375	330	300	275	235	190	120
		Ratio	1.28	1.12	1.02	0.94	0.80	0.65	0.41
Nadi	189	Probable Rainfall (mm/day)	430	385	350	320	270	215	140
		Ratio	2.28	2.04	1.85	1.69	1.43	1.14	0.74
Ba	321	Probable Rainfall (mm/day)	440	390	360	330	280	235	160
		Ratio	1.37	1.21	1.12	1.03	0.87	0.73	0.50

Observed daily rainfall is obtained from the sum of weighted average of hourly rainfall over watershed.

(3) Flood Simulation with different Return Periods

Floods with different return periods in each watershed were computed by the storage function model with application of probable rainfall based on Kina's hyetograph and the results are shown in Table-6.11 ~ Table-6.14. Based on Tables, probable discharges of each river are plotted as shown in Figure-6.10.

Table-6.11 Floods with Different Return Periods (Rewa River)

unit: m^3/sec

No.	Point	Catchment Area (km^2)	Flood Discharge by Return Period						
			1/100	1/50	1/30	1/20	1/10	1/5	1/2
R1	Wainibuka	904	6,100	4,700	3,700	3,100	2,200	1,600	620
R2	Wainimala	967	6,800	5,500	4,600	4,000	2,600	1,800	790
R3	before Waidina	1,992	12,300	9,700	7,600	6,500	4,600	3,200	1,400
R4	Waidina	537	4,000	3,000	2,400	2,000	1,300	850	300
R5	before Waimanu	2,676	14,700	11,200	9,000	7,600	5,400	3,700	1,600
R6	Waimanu	204	530	410	330	280	190	120	50
R7	River Mouth	3,092	14,800	11,500	9,200	7,800	5,500	3,800	1,700

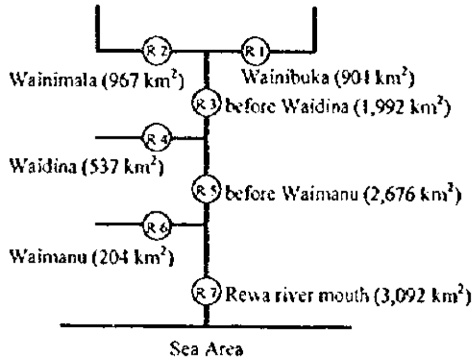


Table-6.12 Floods with Different Return Periods (Sigatoka River)

unit: m^3/sec

No.	Point	Catchment Area (km^2)	Flood Discharge by Return Period						
			1/100	1/50	1/30	1/20	1/10	1/5	1/2
S1	before Namada	660	3,400	2,500	2,100	1,800	1,400	960	480
S2	Namada	249	1,200	880	740	640	470	330	150
S3	after Namada	909	4,400	3,300	2,700	2,300	1,800	1,300	620
S4	River Mouth	1,453	5,600	4,200	3,500	2,900	2,200	1,500	680

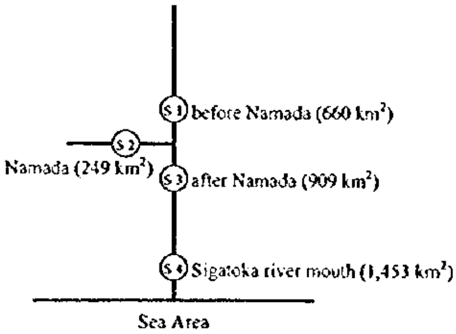


Table-6.13 Floods with Different Return Periods (Nadi River)

unit: m³/sec

No.	Point	Catchment Area (km²)	Flood Discharge by Return Period						
			1/100	1/50	1/30	1/20	1/10	1/5	1/2
N1	before Namosi	184	3,000	2,300	1,900	1,500	950	720	410
N2	Namosi	91	360	290	240	210	170	120	60
N3	before Nawaka	327	3,200	2,700	2,200	1,800	1,200	810	460
N4	Nawaka	99	260	230	200	180	140	100	50
N5	Nalakua	90	210	180	150	130	100	70	30
N6	River Mouth	516	3,700	3,100	2,500	2,100	1,400	960	530

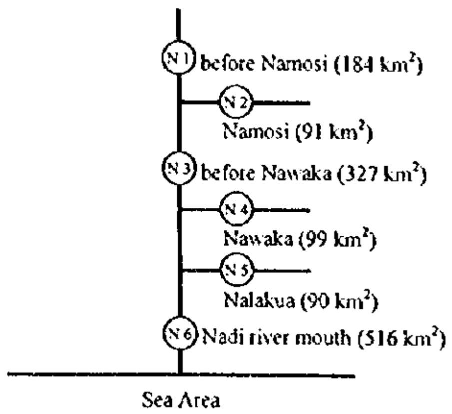
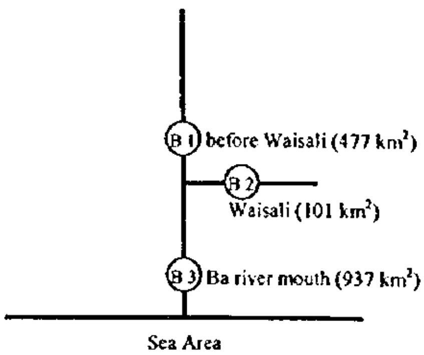
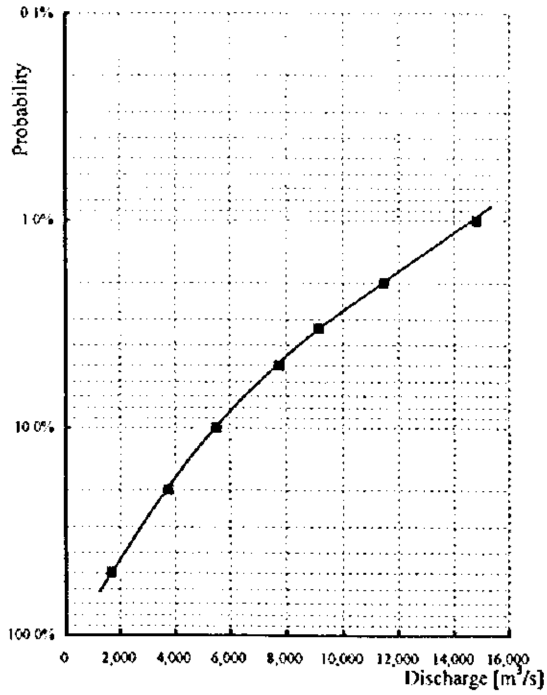


Table-6.14 Floods with Different Return Periods (Ba River)

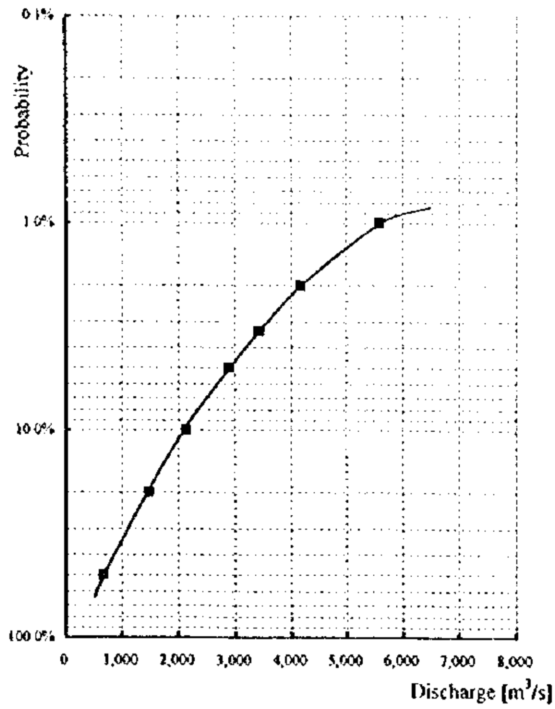
unit: m³/sec

No.	Point	Catchment Area (km²)	Flood Discharge by Return Period						
			1/100	1/50	1/30	1/20	1/10	1/5	1/2
B1	before Wasali	477	4,000	3,000	2,600	2,300	1,800	1,400	730
B2	Wasali	101	820	640	570	510	400	300	170
B3	River Mouth	937	7,000	5,200	4,500	3,900	3,000	2,300	1,300

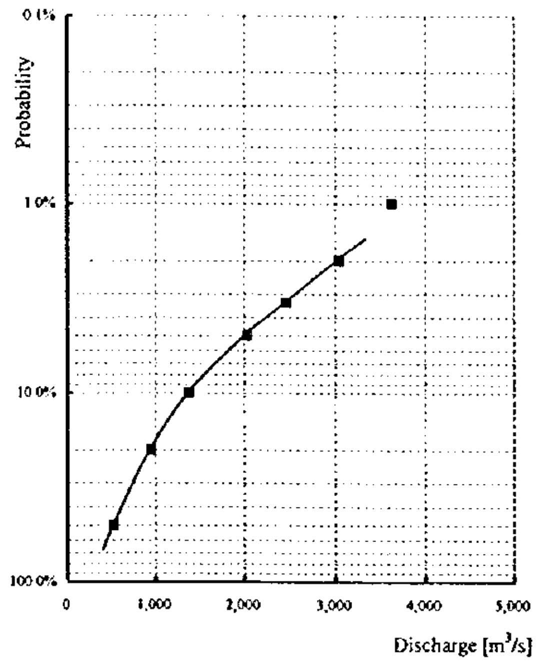




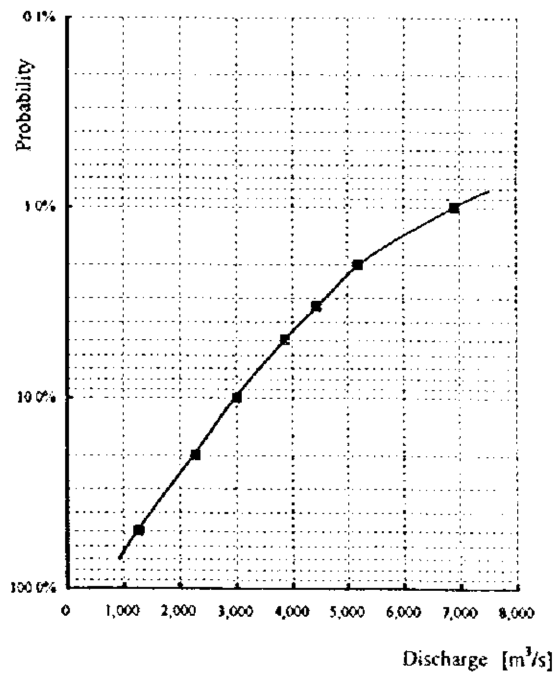
at River Mouth of Rewa



at River Mouth of Sigatoka



at River Mouth of Nadi



at River Mouth of Ba

Figure-6.10 Probable Discharge Curve

(4) Flood Discharge of Cyclone Kina

Flood discharge with a certain return period of rainfall can be read from Figure-6.10. According to the stochastic analysis of rainfall, return period of the cyclone Kina's scale rainfall in the Rewa watershed is 1/50. Therefore, flood discharge of the cyclone Kina is estimated as 11,500 m^3/sec from Figure-6.10. Flood discharge of the cyclone Kina in the 4 watersheds were estimated based on Figre-6.10 as shown in Table-6.15.

Table-6.15 Flood Discharge of Cyclone Kina

Watershed	Maximum Daily Rainfall (mm/day)	Return Period of Rainfall	Flood Discharge (m^3/sec)
Rewa	389	1/50	11,100
Sigatoka	294	1/30	3,500
Nadi	189	1/5	960
Ba	321	1/20	3,900

6.4 Flood Damage Analysis

6.4.1 Flood Damage by Cyclone Kina

The study of flood damage was conducted by the JICA Study Team through the contract with a local consultant as described in the section 6.1.2. Based on the study results, the flood damage estimate of the cyclone Kina was carried out as shown below.

(1) Objects of Flood Damage Estimate

The major economic benefit of the flood control project can be presented as expected reduction in flood damage by implementing the project. The major flood damage to be reduced is composed of the damage to assets and damage to economic activities.

In this study, the assets are presented by buildings, household effects, agricultural field crops and public facilities. The building and household effects are called "general assets" herein. Components of each asset are described as follows.

1) The general assets are represented by residences, factories, commercial units and institutions. And each household in rural residence is assumed to keep some livestock as household effects.

2) The public facilities contains facilities of transport, agriculture, electricity, water supply, drainage, etc.

3) Agricultural field crops are limited to major crops represented by sugarcane, rice, root crops, vegetables and grazing.

4) Economic activities are represented by household income and profits of business activity, such as of factories, shops, restaurants, etc.

(2) Method of Flood Damage Estimate

The flood damages to general assets were estimated by multiplication of 1) number of assets inundated, 2) appraisal value of assets, and 3) damage rate of assets inundated.

Meanwhile, the damages to agricultural crops were estimated by multiplication of 1) crop areas inundated, 2) price amount of product per unit area, and 3) damage rate of agricultural crops inundated.

Damage to public facilities in each inundated area could not be obtained during the flood damage study, while Department of Regional Development (1993) estimated damage to public facilities in the whole Fiji caused by the cyclone Kina. Therefore, the flood damage to public facilities was assumed to be 40 % of flood damage to general assets on the basis of the figures in Department of Regional Development (1993).

(3) Estimate of Flood Damage by Cyclone Kina

The population and number of household suffered from the cyclone Kina were estimated by each inundated area and are totally 44,149 and 7,970, respectively. And the inundated area of scattered forest, agriculture and town were also estimated and the total area is 3,530 ha, 17,820 ha and 320 ha, respectively as shown in Table-6.16.

The number of the assets and the area of respective agricultural field crops in each inundation area were estimated based on Table-6.16, landuse map and information collected from relative government authorities and district offices.

Table-6.16 Population and Areas Suffered from Cyclone Kina

	Urban		Rural		Total		Area (ha)			
	Population	Household	Population	Household	Population	Household	Scattered Forest	Agriculture	Town	Total
Rewa (1)	5,542	942	5,268	806	10,810	1,748	2,730	6,910	60	9,700
Rewa (2)	0	0	2,110	386	2,110	386	220	2,080	0	2,300
Rewa (3)	0	0	2,173	381	2,173	381	580	1,420	0	2,000
Sigatoka	2,217	416	5,191	902	7,408	1,318	0	2,640	60	2,700
Nadi	8,151	1,707	2,912	491	11,063	2,198	0	2,930	120	3,050
Ba	6,889	1,314	3,696	625	10,585	1,939	0	1,840	80	1,920
Total	22,799	4,379	21,350	3,591	44,149	7,970	3,530	17,820	320	21,670

The economic losses of business activities are caused by suspensions of business activities. Those losses were assumed to be 6 days based on the result of flood damage study. Therefore, the annual household income, annual sales profit of factory and annual commercial profit were multiplied by 0.016 (= 6 days/365 days) to assess the flood damage to economic activities.

The flood damage caused by the cyclone Kina was estimated based on the method and conditions described above. The results are shown in Table-6.17.

Table-6.17 Flood Damage by Cyclone Kina

Unit: F$ 1,000

Asset	Rewa (1)	Rewa (2)	Rewa (3)	Sigatoka	Nadi	Ba	Total
General Assets	28,536	2,891	2,351	6,560	16,602	16,720	73,660
Agricultural Crops	26,167	8,731	5,960	8,580	1,727	2,983	54,148
Business activities	413	37	36	105	300	260	1,151
Public Facilities	11,414	1,156	940	2,624	6,641	6,688	29,464
Total	66,530	12,815	9,287	17,869	25,270	26,651	158,423

6.4.2 Annual Average Damage Reduction

Annual average damage reduction by the implementation of flood control plans was estimated in accordance with the flow chart shown in Figure-6.11.

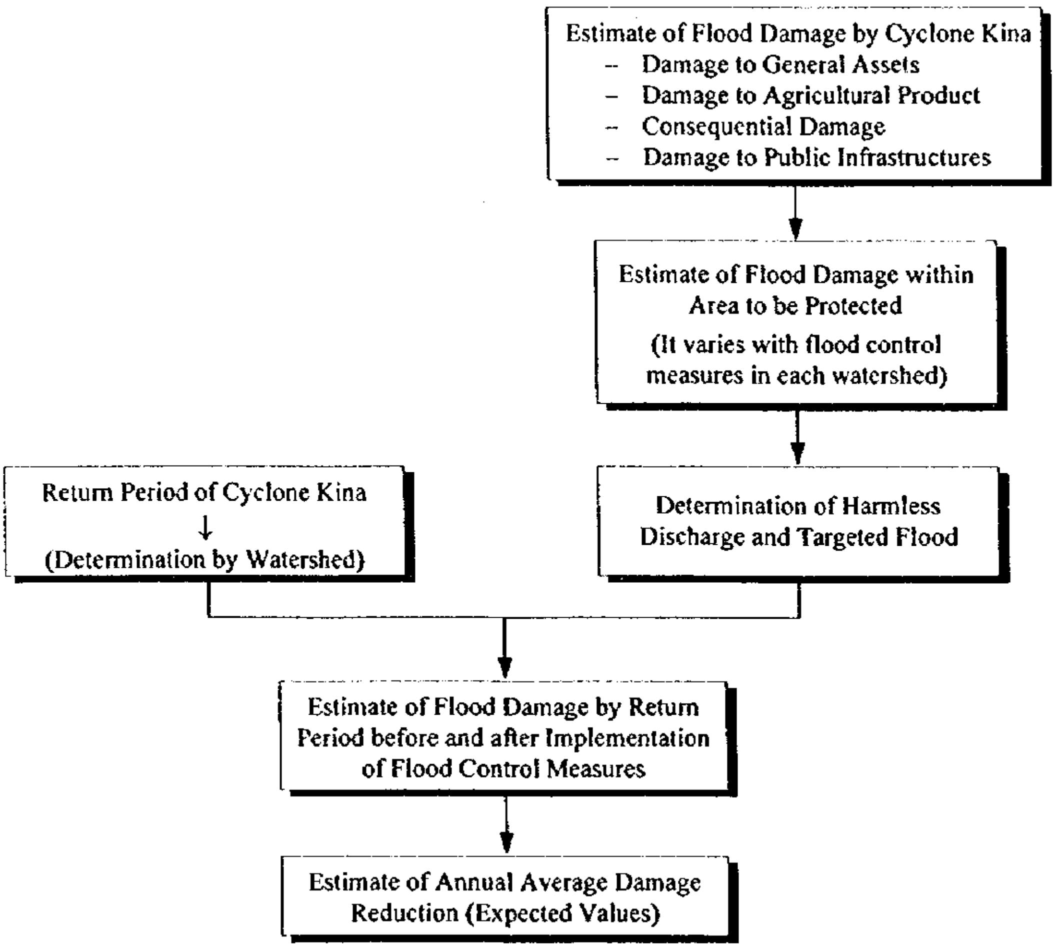


Figure-6.11 Flow Chart to Estimate Annual Average Damage Reduction

(1) Flood Damage within Area to be Protected

Based on the flood damage by the cyclone Kina, its damage within the area to be protected by flood control measures proposed in the section 6.6 was estimated. For the estimate of damage associated with building, household effects, livestock and agriculture, the ratio between the inundated area during the cyclone Kina and area to be protected was simply applied. Since factory, institution and commercial area are located in the target area of flood control, all their damage was included in the damage within the area to be protected.

1) Rewa Watershed

The flood control measures are effective to only Rewa (1) but not Rewa (2) and (3). Therefore, the flood damage in the area to be protected is equal to the damage in Rewa (1), F$ 66,530,000. The locations of Rewa (1), (2) and (3) are shown in Figure-6.2.

2) Sigatoka Watershed

The effect of flood control measures covers the area from the river mouth to 30 km upstream of Sigatoka river. The area ratio is 0.718 (= 24.2 km^2/33.7 km^2) and the flood damage within the area to be protected is F$ 12,829,000.

3) Nadi Watershed

The effect of flood control measures covers the area from the river mouth to 18 km upstream of Nadi river. The area ratio is 0.819 (= 23.5 km^2/28.7 km^2) and the flood damage within the area to be protected is F$ 20,696,000.

4) Ba Watershed

The effect of flood control measures covers the area from the river mouth to 20 km upstream of Ba river. The area ratio is 0.732 (= 18.0 km^2/24.6 km^2) and the flood damage within the area to be protected is F$ 19,509,000.

(2) Estimate of Annual Average Damage Reduction

The annual average damage reduction was estimated with the following assumptions and conditions.

1) Return Period of Cyclone Kina

The flood damage within area to be protected was estimated based on the analysis of flood damage by the cyclone Kina. The damage within the aforesaid area is assumed to occur with the same return period of the cyclone Kina. The return period of the cyclone Kina in each watershed is shown in Table-6.18.

2) Harmless Discharge

The harmless discharge, discharge which dose not cause any flood damage, is assumed to be the flow capacity of river in the town or its vicinity. The harmless discharge of each watershed is shown in Table-6.18.

3) Effect of Flood Control Measures

The effect of flood control measures is the improved flow capacity of river after implementation of the measures for 20 year return period flood. The effects of flood control measures discussed in the section 6.6 are examined below. Discharges discussed underneath are discharges at river mouth.

Rewa: The flood discharge of 7,800 m³/sec (20 year return period flood) would be reduced to 5,900 m³/sec by implementation of diversion channel. Besides, the currently inundated area with a flood of 3,800 m³/sec would be protected against a flood of 5,900 m³/sec by dike construction. Therefore, the effect is;

$$7{,}800 - 3{,}800 = 4{,}000 \text{ m}^3\text{/sec}$$

Sigatoka: The currently inundated area with a flood of 2,300 m³/sec would be protected against a flood of 2,900 m³/sec (20 year return period flood) by dredging. Therefore, the effect is;

$$2{,}900 - 2{,}300 = 600 \text{ m}^3\text{/sec}$$

Nadi: Out of 2,100 m³/sec (20 year return period flood), 1,500 m³/sec would be drained by diversion channel and the discharge of the Nadi river would be reduced to 600 m³/sec. Beside, its flow capacity of 50 m³/sec would be improved by a short cut channel. Therefore, the effect is;

$$2{,}100 - (600 - 50) = 1{,}550 \text{ m}^3\text{/sec}$$

Ba: The inundated area with a flood of 2,000 m³/sec would be protected against a flood of 3,900 m³/sec (20 year return period flood). Therefore, the effect is;

$$3{,}900 - 2{,}000 = 1{,}900 \text{ m}^3\text{/sec}$$

Table-6.18 Estimate Conditions of Annual Flood Damage Reduction

Item		Rewa River	Sigatoka River	Nadi River	Ba River
Whole Watershed Area (km²)		3,092	1,453	516	937
Harmless Discharge	Point from River Mouth (km)	11.5	3.0	11.0	15.5
	Watershed Area (km²)	2,930	1,439	330	890
	Water Level (EL.m)	4.44	2.40	5.20	5.00
	Discharge at Point (m³/sec)	3,600	1,300	350	1,900
	Converted Discharge at River Mouth (m³/sec)	3,800	1,310	550	2,000
	Return period	1/5.0	1/4.0	1/2.5	1/4.5
Cyclone Kina	Discharge (m³/sec)	11,500	3,500	960	3,900
	Return Period	1/50	1/30	1/5	1/20
	Flood Damage (thousand F$)	66,530	12,829	20,696	19,509

The annual average damage reduction was estimated with the following procedures.

- To determine the relation between discharge and flood damage based on the flood damage estimated (cyclone Kina) and harmless discharge (damage = 0)
- To estimate the flood damage before and after the implementation of flood control measures based on the above relation
- To estimate the annual average damage reduction based on the flood damage reduction at a certain return period

The relation between discharge and flood damage varies depending on the watershed characteristics. Since there is no general relation, as many data as possible should be plotted to determine the relation; however, in Viti Levu this relation is available only for the cyclone Kina. Therefore, the straight line was assumed to express the relation as shown in Figure-6.12.

Flood damage at a certain return period was read by from those figures. The maximum return period to estimate the flood damage corresponds with the Step 1 target (20 year return period flood) proposed in the section 6.5.

Annual average flood damage reduction for each watershed was estimated based on Figure-6.12. The result of estimate is shown in Table-6.19. With the structure measures proposed in the section 6.6, the annual average damage reduction of each watershed is F$ 1,966,000 for Rewa, F$ 381,000 for Sigatoka, F$ 8,278,000 for Nadi and F$ 1,446,000 for Ba.

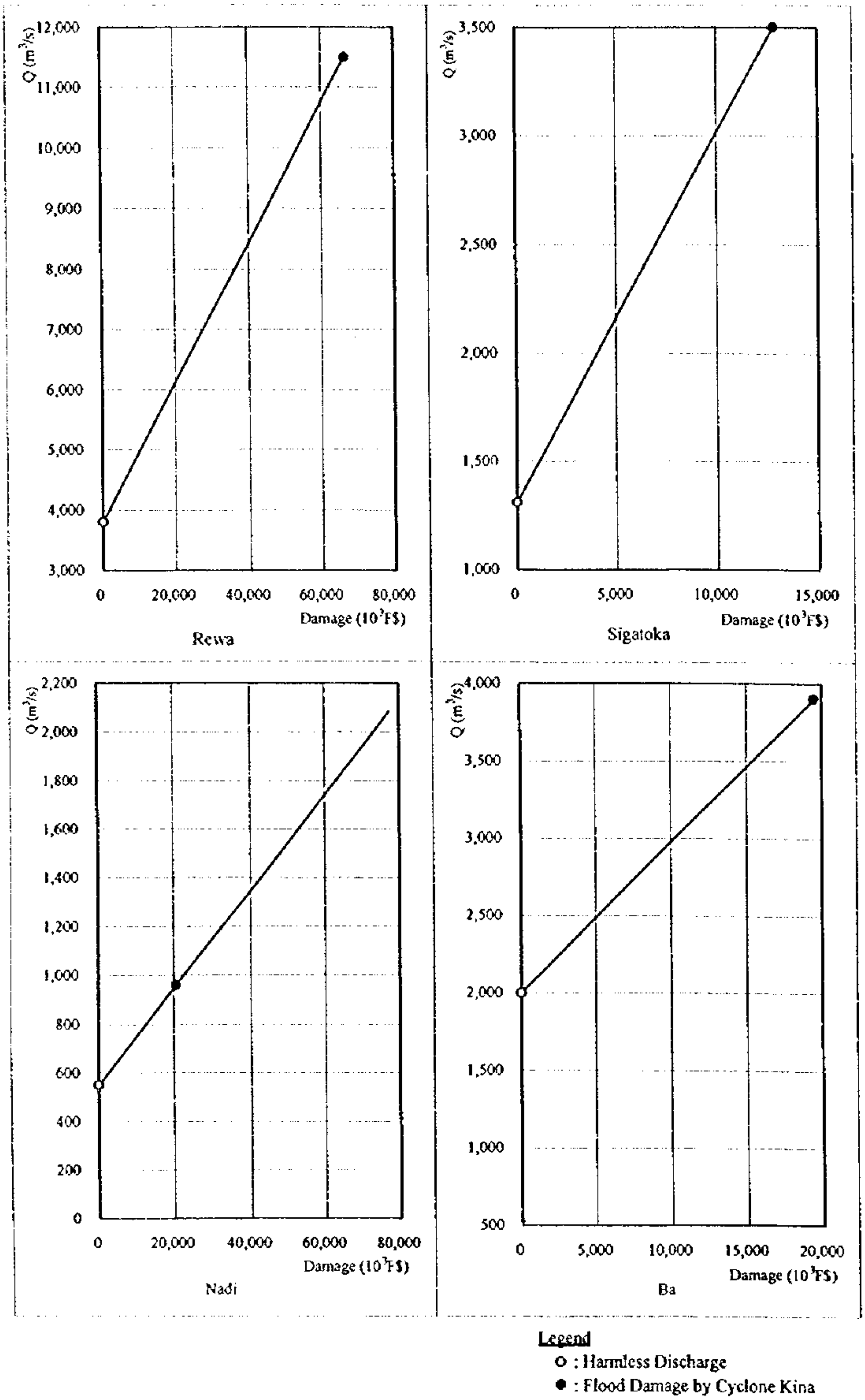


Figure-6.12 Relation between Discharge and Flood Damage

Table-6.19 Estimate Result of Annual Average Damage Reduction

River	Return Period		Annual Average Return Periods	Discharge			Flood Damage		Flood Damage Reduction	Average Flood Damage Reduction	Annual Average Flood Damage Reduction
				Current	After Imple-mentation	Effect	Current	After Imple-mentation			
			①	②	③	④=②-③	⑤	⑥	⑦=⑤-⑥	⑧=(⑦n+⑦n-1)/2⑦	⑨=①x⑧
				m³/sec	m³/sec	m³/sec	10³F$	10³F$	10³F$	10³F$	10³F$
Rewa	1/20	0.050	-	7,800	3,800	4,000	34,561	0	34,561	-	-
	1/10	0.100	0.050	5,500	2,680	2,820	14,688	0	14,688	24,625	1,231
	1/5	0.200	0.100	3,800	1,850	1,950	0	0	0	7,344	734
Total											1,966
Sigatoka	1/20	0.050	-	2,900	2,300	600	9,314	5,799	3,515	-	-
	1/10	0.100	0.050	2,200	1,740	460	5,214	2,519	2,695	3,105	155
	1/6	0.167	0.067	1,650	1,310	340	1,992	0	1,992	2,343	156
	1/5	0.200	0.033	1,460	1,160	300	879	0	879	1,435	48
	1/4	0.250	0.050	1,310	1,040	270	0	0	0	439	22
Total											381
Nadi	1/20	0.050	-	2,100	550	1,550	78,241	0	78,241	-	-
	1/10	0.100	0.050	1,400	370	1,030	42,906	0	42,906	60,574	3,029
	1/5	0.200	0.100	960	250	710	20,696	0	20,696	31,801	3,180
	1/2.5	0.400	0.200	550	140	410	0	0	0	10,348	2,070
Total											8,278
Ba	1/20	0.050	-	3,900	2,000	1,900	19,509	0	19,509	-	-
	1/10	0.100	0.050	3,000	1,540	1,460	10,268	0	10,268	14,888	744
	1/5	0.200	0.100	2,300	1,180	1,120	3,080	0	3,080	6,674	667
	1/4.5	0.222	0.022	2,000	1,030	970	0	0	0	1,540	34
Total											1,446

6.5 Determination of Design Flood

The scale of design flood is determined by safety degree against flood which each inundated area requires. Safety degree against flood varies depending on the social and economic importance of a particular area. High safety degree has to be allocated in the urban area and its vicinity where social and economic infrastructures are located densely.

An objective river is examined by watershed indices, such as area of watershed, population and properties in inundated area, in order to assess the necessary safety degree against flood. In Japan, there is a following relation between watershed index and design flood as shown in Table-6.20.

Table-6.20 Relation between Watershed Index and Design Flood in Japan

Return Period of Design Flood		1/30	1/50	1/70	1/100
Catchment Area (km²)		less than 50	50 ~ 300	300 ~ 600	more than 600
Area of Inundation (ha)		less than 1,000	1,000 ~ 3,000	3,000 ~ 5,000	more than 5,000
Inundated Area	Residential Area (ha)	less than 100	100 ~ 800	800 ~ 2,000	more than 2,000
	Population (1,000 persons)	less than 30	30 ~ 100	100 ~ 200	more than 200
	*Property (10⁷)	less than 12	12 ~ 120	120 ~ 400	more than 400
	*Industrial Product (10⁷)	less than 4	4 ~ 40	40 ~ 80	more than 80

*Value divided by GDP per Capita

Based on Table-6.20, the objective 4 rivers were examined by watershed indices and the result is shown in Table-6.21. Design flood of 4 watersheds in terms of areas of watershed and inundation ranges at 1/50 ~ 1/100, while design flood in terms of conditions of inundated area ranges at 1/30 ~ 1/50. Therefore, the flood of 50 year return period is considered appropriate as the design flood of 4 watersheds.

Table-6.21 Design Flood of 4 Watersheds by Watershed Index

Water Index		Rewa		Sigatoka		Nadi		Ba	
		Index Value	Return Period	Index Value	Return Period	Index Value	Return Period	Index Value	Return Period
Catchment Area (km^2)		3,092	1/100	1,450	1/100	515	1/70	936	1/100
Area of Inundation (ha)		14,000	1/100	2,700	1/50	3,050	1/70	1,920	1/50
Inundated Area	Residential Area (ha)	60	1/30	60	1/30	120	1/50	80	1/30
	Population (1,000 persons)	15.1	1/30	7.4	1/30	11.1	1/30	10.6	1/30
	*Property (10^3)	50	1/50	12	1/50	59	1/50	30	1/50
	*Industrial Product (10^3)	4.0	1/50	0.3	1/30	3.5	1/30	9.3	1/50
Design Flood Determined		1/50		1/50		1/50		1/50	

*Value divided by GDP per capita

Design flood discharge (50 year return period flood) and current flow capacity at river mouth were compared as shown in Table-6.22.

As discussed in the section 6.2, flow capacity of Rewa river is the lowest at 35 km from river mouth and its converted discharge at river mouth is 4,800 m^3/sec. This lowest flow capacity at 35 km is concluded as current flow capacity of Rewa based on runoff analysis. However, for flood control plan, capacity of Rewa river around Nausori town was adopted as current flow capacity, because areas where population and properties are located densely is main concern for flood control rather than remote areas. Therefore, current flow capacity of 5,900 m^3/sec (converted discharge at river mouth) is used to formulate a flood control master plan.

Table-6.22 Flood Discharge of 50 Year Return Period and Current Flow Capacity

River		Rewa	Sigatoka	Nadi	Ba
① Flood Discharge of 50 year return period (m^3/sec)		11,500	4,200	3,100	5,200
② Current Flow Capacity	Discharge (m^3/sec) at river mouth	5,900	2,600	300	2,000
	Return Period	1/7	1/16	1/1	1/5
③ Insufficient Capacity	①-② (m^3/sec)	5,600	1,600	2,800	3,200
	①/②	1.9	1.6	10.3	2.6

As shown in Table-6.22, the flow capacity of Rewa, Sigatoka and Ba rivers has to be improved approximately twice as much as the current capacity, while one of Nadi has to be improved 10 times more. When the difference between the current flow capacity and design flood discharge is very large, the flood control plans may encounter the difficulty of implementation due to the large investment and works to be required. Under the circumstances, the stepwise plans are recommended and are effective to flood control.

The first step is to improve the current flow capacity by 50 % of insufficient capacity above and at the second step the river is improved to drain the design flood discharge (50 year return period flood). After implementation of the first step, the flow capacity of river would be improved as follows.

- Rewa: 8,700 m^3/sec (1/25 probability)
- Sigatoka: 3,400 m^3/sec (1/30 probability)
- Nadi: 1,700 m^3/sec (1/14 probability)
- Ba: 3,600 m^3/sec (1/16 probability)

Flood probability varies with watershed. If the different scales of design flood were determined for each watershed, the safety degree against flood would be different depending on watershed. The different safety degrees are not preferable from an administrative point of view. After improvement of 50 % of insufficient flow capacity, each river would be able to flow almost 1/20 probability flood. Therefore, the flood of 20 year return period was set as a goal of the first step.

In this Study, the Master Plan of flood control was formulated for the Step 1 (1/20 probability). Design flood discharge at river mouth and distribution of design flood discharge in watershed are shown in Table-6.23 and Figure-6.13, respectively.

Table-6.23 Design Flood Discharge at River Mouth

River	Step 1 1/20 Probability (m^3/sec)	Step 2 1/50 Probability (m^3/sec)	Current Flow Capacity (m^3/sec)
Rewa	7,800	11,500	5,900
Sigatoka	2,900	4,200	2,600
Nadi	2,100	3,100	300
Ba	3,900	5,200	2,000

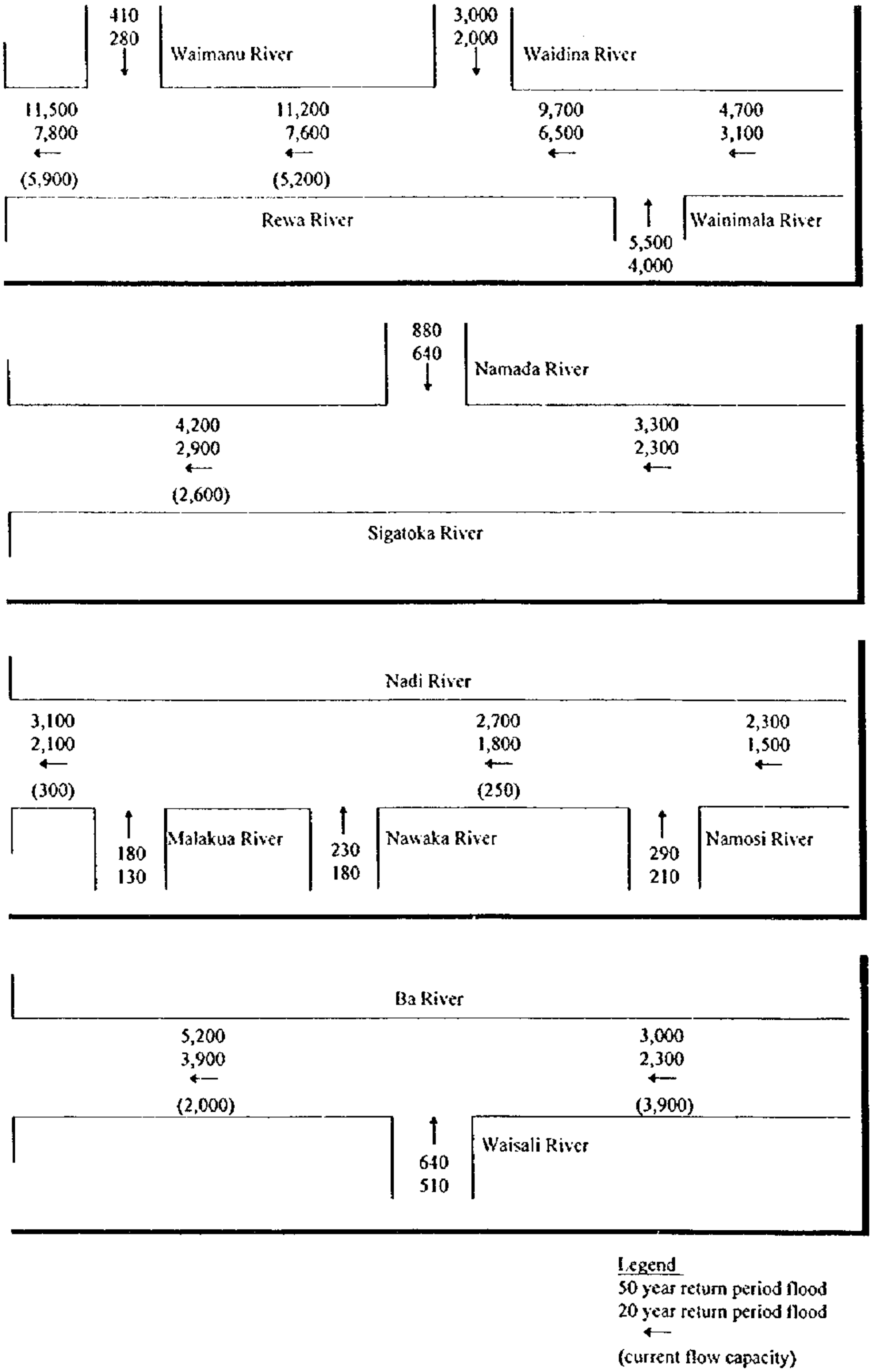


Figure-6.13 Distribution of Design Flood Discharge