社会開発調査部報告書

JAPAN INTERNATIONAL COOPERATION AGENCY

MINISTRY OF LANDS, MINERAL RESOURCES AND ENERGY
REPUBLIC OF FIJI

THE STUDY
ON
GROUNDWATER DEVELOPMENT IN NORTH VITI LEVU
IN THE REPUBLIC OF FIJI

VOLUME I

FINAL REPORT
EXECUTIVE SUMMARY

MAY 1995

NIPPON KOEI CO., LTD.
NIKKO EXPLORATION & DEVELOPMENT CO., LTD.

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PREFACE

In response to a request from the government of the Republic of Fiji, the Government of Japan decided to conduct a study on Groundwater Development in North Viti Levu in the Republic of Fiji and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Fiji a study team headed by Dr. Noboru Miyamoto Nippon Koei Co., Ltd. 5 times between June, 1993 and May, 1995.

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

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

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

May, 1995

Kimio Fujita
President
Japan International Cooperation Agency

May, 1995

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

LETTER OF TRANSMITTAL

Dear Sir,

We have the pleasure of submitting to you the Final Report of "The Study on Groundwater Development in North Viti Levu in the Republic of Fiji", in accordance with the Scope of Work agreed upon between the Ministry of Land and Mineral Resources and Japan International Cooperation Agency. The study was carried out for a total period of 24 months from June, 1993 to May, 1995, aiming to evaluate groundwater development potential and to formulate water supply plan in the northern area of Viti Levu.

This report consists of four volumes. The Executive Summary contains the summary of the study result. The Main Report presents the evaluation of groundwater resources and the formulation of water supply plan. The Supporting Report describes the analysis and discussion of hydrogeology, water use, population projection and water demand. The Data Book contains the basic data of the study.

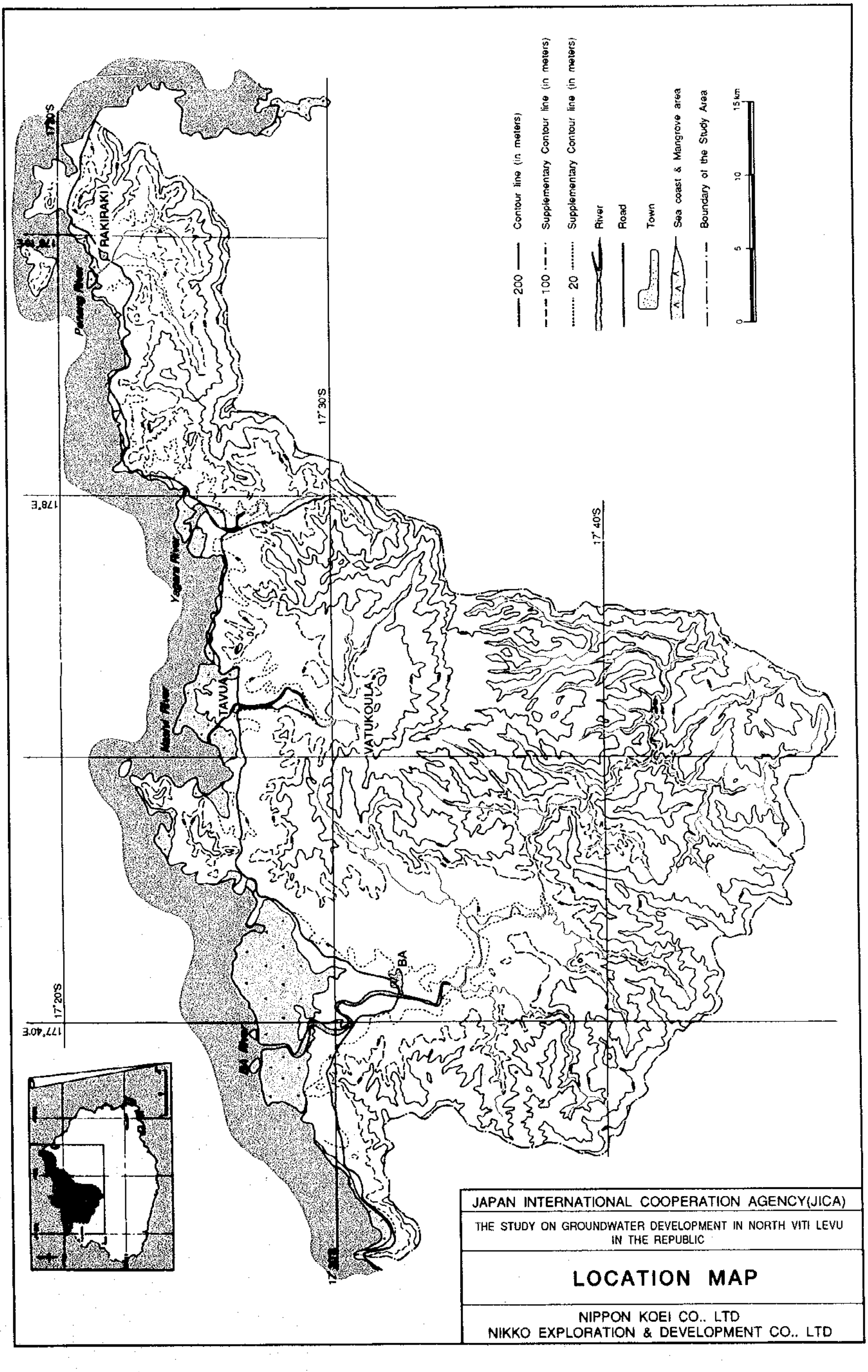
As the result of the scientific study on groundwater resources in the consolidated rock masses underlying the study area, groundwater development potential is locally available but not for the whole area. The water supply schemes were formulated in the limited areas with the groundwater development potential aiming enhancement of the living standard of inhabitants. The study team sincerely hopes that the study result would contribute to the future water supply plan in North Viti Levu.

We wish to express our deep appreciation and gratitude to the personnel concerned of your Agency and Office in Fiji, the Embassy of Japan in the Republic of Fiji, as well as officials concerned of the Government of Fiji.

Sincerely yours,

N. Miyamoto

Noboru Miyamoto
Team Leader
The Study on Groundwater Development
in North Viti Levu in the Republic of Fiji



JAPAN INTERNATIONAL COOPERATION AGENCY(JICA)

THE STUDY ON GROUNDWATER DEVELOPMENT IN NORTH VITI LEVU
IN THE REPUBLIC

LOCATION MAP

NIPPON KOEI CO., LTD
NIKKO EXPLORATION & DEVELOPMENT CO., LTD

THE STUDY ON GROUNDWATER DEVELOPMENT IN NORTH VITI LEVU IN THE REPUBLIC OF FIJI

Study period: June 1993 - May 1995

Counterpart agency: Ministry of Lands, Mineral Resources and Energy

SUMMARY

1. BACKGROUND

Since the urban areas in the Study Area depend mainly on rivers for their water supply, serious water shortage problems repeatedly occur in the dry season. Even in rural areas, by the end of the dry season, water is occasionally unobtainable from creeks and springs. Therefore, groundwater development is urgently required for the urban and rural areas where, at present, water supply facilities are in poor condition and surface water source capacities are inadequate and unreliable.

Even though water saturation of the volcanic sediments which overlie the northern part of the island is relatively high, groundwater seems to quickly drain off into the sea because the mountains are so close to the coastline with only narrow plains between them. Groundwater development in this area is not an easy task because of these topographic and geologic conditions. Therefore, groundwater development technical assistance from technically developed countries is eagerly desired.

2. OBJECTIVES

The objective of the Study is to evaluate groundwater resources potential and formulate the groundwater development plan for adequate, reliable and safe water supply in the north Viti Levu covering 1,567 km^2.

3. GROUNDWATER RESOURCES EVALUATION

Groundwater Resources Potential

The Study Area is divided into 13 groundwater regions as seen in Fig. 2, based on their hydrogeological characteristics. It is considered that one of the factors of groundwater development depends on the capacity of yield of a typical borehole. Therefore, the potential for groundwater development is essentially justified by the yield capacity of common boreholes such as test wells. Transmissivity and water quality are also taken into consideration. It is not feasible to develop areas with poor potential, but medium and excellent potential regions are possible to be developed. The areas are summarized below:

Groundwater region	Transmissivity (m^2/day)	Well yield (l/sec)	Conductivity (MS/cm)	Potential
1. Mountainous Area	<40	<3	115	poor, locally medium
2. Tavua-Raviravi Coastal Plain	1-285	0.1-5.4	180-1,793	poor, locally medium
3. Ba River Lower Plain	<20	<2	138	medium, locally poor
4. Moto Uplands	0.1-0.3	<0.7	30-740	poor
5. Koronubu Uplands	1-50	<2	500-1,400	poor, locally medium
6. Ba Uplands	5-140	0.3-4.8	30-650	medium
7. Vatia-Lousa Coastal Plain	1-96	0.2-8.0	240-920	poor, locally medium
8. Matalevu Uplands	1-122	0.1-3.0	200-500	medium
9. Tavua Basin	0.1-5	0.1-0.8	130-1,200	poor
10. Rabulu Coastal Plain	0.1-5	0.1-1.8	80-860	poor
11. Yaqara River Basin	800-2,600	<15	130-330	excellent
12. Wailevu-Narewa Coastal Plain	0.5-1	0.4-0.8	320-630	poor
13. Penang River Basin	0.1-7	0.2-1.2	150-530	poor

The Study Area is underlain by well consolidated basaltic and sedimentary rock masses of the Tertiary in which the fractured section form the essential aquifer. The transmissivity of the aquifer is generally low, therefore, a typical borehole such as the test well, yields 1 to 5 l/sec of water even in the medium and excellent potential regions. However, the groundwater development potential in this Study Area was judged to be limited due to the scarce groundwater resources identified from the results of the groundwater resources evaluation.

Water Balance Analysis

Among these groundwater potential regions, the Ba Uplands are selected for further analysis of water balance by groundwater model simulation, because of the size of the population and the high water demand. As a result, the optimization study indicated two possible pumping strategies as summarized below:

Unit: m^3/day

	Plan 1	Plan 2
TW004	70	70
TW005	102	77
GW035	115	115
Proposed well	-----	150
Total	287	412

4. WATER SUPPLY DEVELOPMENT PLAN

Principle of Development

1) The proposed communities to receive water supply from the groundwater development plan are selected from the areas with an inadequate water supply and identified groundwater development potential;

2) The scale of the proposed plan is determined by the possible pumping rate of the production wells without causing environmental impact, and

3) The production wells for the proposed schemes are selected in principle from the existing test wells drilled by Japan International Cooperation Agency (JICA) or the Mineral Resources Department (MRD) which had been confirmed to produce sufficient groundwater for the formulation of the proposed water supply plan.

Water Demand Projection

1) Present Water Consumption: In 1991 the water consumption for domestic use was estimated to be 6,510 m^3/day for 49,122 inhabitants in the three existing regional water supply systems (Ba, Tavua, and Rakiraki) of the Public Works Department (PWD). These regional systems supply water to about 50 % of the inhabitants in the Study Area. The present per capita consumption for domestic use in the areas with the water supply systems was inferred as 140 lpcd in Ba area and 120 lpcd in other areas.

2) Domestic Water Demand Projection: Referring to the existing design manual, 160 lpcd is utilized in areas with a regional water supply system

except the Ba urban area. 200 lpcd was adopted in the Ba urban area. In areas without a regional water supply system, 80 lpcd was adopted for domestic demand obtained by interview survey.

3) Water Demands in 1991 and 2011 in the Study Area are summarized below:

Unit: m^3/day

	1991	2011
Domestic use		
With regional water supply	6,510	10,170
Without regional water supply	3,990	6,290
Commercial use	1,740	2,720

Water Supply Development Plan of Priority Schemes

A summary of the principal features and construction costs of three priority schemes is shown below:

	Vutuni Creek Community Scheme	Vatuyaka Expansion Scheme	Rabulu Expansion Scheme
Service population in 2011	314	561	930
Projected water demand in 2011 (m^3/day)	50	90	149
Water source well (Test well No.)	TW001	GW025	GW254
Well yields (l/sec)	0.84	1.50	2.50
Pumping time (hour/day)	20	20	20
Diameter of transmission pipe (mm)	75	75	100
Volume of service reservoir (m^3)	75	135	230
Construction costs (F$)*	320,700	464,300	756,900

*: Without the construction of a water source well

5. PROJECT EVALUATION

The Economic Internal Rate of Return (EIRR) of the three priority schemes are listed below:

Name of Scheme	Vutuni Creek Community Scheme	Vatuyaka Expansion Scheme	Rabulu Expansion Scheme
EIRR (%)	2.61	1.25	13.83

The Vutuni Creek community scheme indicates a low EIRR of 2.62 %, which is economically not feasible. However, the annual benefit exceeds the annual O&M cost. This means that the operation and management of the water supply system by the community will be possible if the construction cost is excluded.

The Vatuyaka expansion scheme shows a low EIRR of 1.25 % and is financially negative. The Rabulu expansion scheme achieves a comparatively high EIRR of 13.83 %, which is economically feasibility, but this scheme indicates a negative Financial Internal Rate of Return (FIRR) , i.e. not financially viable. However, it is noted that both schemes will be promoted as an expansion of the existing regional water supply systems and that the operation of the project will be economically possible after its completion, because the annual economic benefit in both schemes exceeds the annual O&M cost.

6. RECOMMENDATIONS

1) The majority of households in the areas covered by the three priority schemes spend a lot of time fetching their daily domestic water, due to a serious continual water shortage problem. Therefore, realization of these schemes is expected to have a fair effect on social and environmental improvement, even though the economic effect is low. These schemes are not financially viable. However the operation of the water supply system is economically possible, because economic annual benefit exceeds the economic annual operation and maintenance cost. Consequently, it is recommended that the three proposed priority water supply development schemes be urgently implemented.

2) It is evident that the groundwater resources are unable to fulfill all of the future water demands in the whole Study Area. The results of the geological

survey and hydrological analyses conducted in the course of this Study indicate the possibility of development of surface water sources upstream of Toge in the Ba river. It is recommended that a water resource study on the Ba river basin be conducted for the Northwest Viti Levu area including the Ba area.

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ABBREVIATIONS

AES	Agricultural Experimental Station
APHA	American Public Health Association
AWWA	American Water Works Association
EPA	Environmental Protection Agency (United States)
FEA	Fiji Electricity Authority
FMS	Fiji Meteorological Service
FSC	Fiji Sugar Corporation
GDP	Gross Domestic Product
GNP	Gross National Product
GOF	Government of Fiji
GOJ	Government of Japan
JICA	Japan International Cooperation Agency
MFARD	Ministry of Fijian Affairs and Regional Development
MLMRE	Ministry of Lands, Mineral Resources and Energy
MOH	Ministry of Health
MRD	Mineral Resources Department
PWD	Public Works Department
WEF	Water Environment Federation (United States)
WHO	World Health Organization
EIRR	Economic Internal Rate of Return
FIRR	Financial Internal Rtae of Return
O&M	Operation and Maintenance
El	Elevation
HWL	High Water Level
LWL	Low Water Level
WL	Water Level

ABBREVIATIONS OF MEASUREMENT

Length

cm = Centimeter
m = Meter
km = Kilometer
ft = Foot
yd = Yard
mm = Milimeter
inch = Inch

Area

cm^2 = sq.cm = Square centimeter
m^2 = sq.m = Square meter
ha = Hectare
km^2 = sq.km = Square kilometer

Volume

cm^3 = cu.cm = Cubic centimeter
l = lit = liter
kl = Kiloliter
m^3 = cu.m = Cubic meter
gal. = Gallon
MCM = Million Cubic Meters

Weight

mg = Milligram
g = Gram
kg = Kilogram
ton = Metric ton
1b = Pound

Time

min = Minute
sec = Second
hr = Hour
d = Day
yr = Year

Electrical Measures

V = Volt
A = Ampere
Hz = Hertz (cycle)
W = Watt
kW = Kilowatt
MW = Megawatt

Other Measures

% = Percent
PS = Horsepower
° = Degree
' = Minute
" = Second
°C = Degree centigrade
10^3 = Thousand
10^6 = Million

Derived Measures

m^3/s = m^3/sec = Cubic meter per second
cusec = Cubic feet per second
mgd = Million gallon per day
kWh = Kilowatt hour
MWh = Megawatt hour
kVA = Kilovolt ampere
mg/l = Milligram per liter
meg/l = Milliequiralent per liter
MS/cm = Micro Siemens per centimeter
ppm = Part per million
NTU = Nephelometric turbidity unit
lpcd = Liter per capita per day

Money

F$ = Fijian Dollar
US$ = US dollar
J.Yen = Japanese Yen

1. INTRODUCTION

1.1 Background

This report describes the results of the study on groundwater development in North Viti Levu in the Republic of Fiji.

The Study Area is located in the northern coastal zone of Viti Levu covering an area of 1,567 km^2 with a population of about 98,000.

There are three regional water supply systems covering Ba, Tavua, and Rakiraki urban areas. These systems supply water to about 50% of the inhabitants in the Study Area. The remaining 50% depend on water from private wells and rain water collection tanks. Springs and creeks provide the water sources for people living in mountainous areas.

Since the urban areas in the Study Area depend mainly on rivers for their water supply, serious water shortage problems repeatedly occur in the dry season. Even in rural areas, by the end of the dry season, water is occasionally unobtainable from creeks and springs.

Therefore, groundwater development is urgently required for urban and rural areas where, at present, water supply facilities are in poor condition and surface water source capacities are inadequate and unreliable.

Groundwater is one of the resources for water supply, though its development in this area is not an easy task because of the topographic and geologic conditions. Therefore, technical assistance on groundwater development from technically developed countries is eagerly desired.

The Government of Fiji considers that an adequate, reliable, and safe water supply by solving the repeated water shortage problems is one of the most important targets of the National Development Plan (Policies and Strategies for the Second and Medium Term) before the year 2000.

Thus, since 1989, the Government of Fiji has requested that the Government of Japan provides technical assistance to groundwater development in the northern part of Viti Levu. In response to the official request from the Government of Fiji in June 1992, Japan International Cooperation Agency (JICA) dispatched a Preparatory Study Team to prepare a Scope of Works (S/W) for groundwater development in North Viti Levu.

The Scope of Works was signed between the Minister for Lands and Mineral Resources and the Leader of JICA's Preparatory Team on December 14, 1992.

1.2 The Scope of Works

The objective of the Study is to evaluate groundwater resources potential and formulate a groundwater development plan for adequate reliable and safe water supply in north Viti Levu.

The project period was selected as 24 months and was divided into three phases which will essentially cover the following items.

(1) Phase 1 (June 1993 - November 1993)

- Review and analysis of previous studies and existing data
- First field investigation concerning geology, geophysical prospecting, and environmental aspects, survey on conditions of water utilization and demand

(2) Phase 2 (November 1993 - August 1994)

- Second field investigation covering test well drilling, and hydrological analysis
- Study and analysis

(3) Phase 3 (September 1994 - May 1995)

- Groundwater development planning
- Water supply system planning
- Report

In order to perform the above works, JICA organized and dispatched to the project site a Study Team of 15 Japanese engineers of respective engineering fields. They have conducted their duties in cooperation with the counterpart team formed by engineers from the Mineral Resources Department (MRD) and the Public Works Department (PWD) of the Government of Fiji.

2. STUDY AREA

2.1 Location and Topography

The Study Area is located in the northern coastal zone of Viti Levu and is bounded by the southern watershed, the northern coast, the watershed of the Penang river on the west, and the eastern end of the Lautoka water supply system on the west, and covers an area of 1,567 km^2. The administration of the Study Area stretches over Ba and Ra provinces in the Western Division where Ba, Tavua and Rakiraki are the major towns.

The Study area consists of steep and moderately steep mountains in the south occupying 1,107 km^2, or 70.5% of the whole Study Area, low hills extending from the skirt of the mountains lower than 100 meters in elevation, and flat lands of terrace and alluvial plains along the lower reaches of the rivers and the coastal zone.

Plateaus occur locally in the higher area of the mountains. Talus slopes and inter mountainous basins are partly found at the foot of the mountainous slopes.

The majority of inhabitants live in the low hills and flat lands totaling 366 km^2, or 23.4% of the Study Area.

2.2 Climate

The Study Area is located in the dry zone of Viti Levu, with an average rainfall varying from 1,800 to 3,000 mm. Based on the monthly rainfall pattern, the rainy season occurs between December and April. The monthly rainfall, especially from January to March at the rainy season peak, reaches 300 to 500 mm. The total amount of rainfall which occurs over these three months is about 50% of the total annual rainfall. The dry season continues from May to October, and the monthly rainfall in this period decreases to less than 100 mm.

The seasonal variation of the average temperature ranges from 24 °C to 27 °C in the flat lands. The average daily maximum temperature is 32.4 °C, while the average daily minimum temperature is 17 °C.

2.3 Land Use

Land use depends on the land form. Forest and grassy areas occupy 1,051 km^2, or 67.1% of the Study Area, extending chiefly on the slopes of the steep and moderately steep mountains. Sugar cane fields and pastures are spread on low hills and flat lands, occupying 478 km^2, or 30.5% of the Study Area. The urban areas are also located on the flat lands with an area of 7.7 km^2, or 0.5% of the Study Area. The remaining area of 29 km^2, or 1.3% of the Study Area is unused because of rock outcrops and river beds.

2.4 Socio-economy

The population of Fiji was estimated at 749,481 in 1991 based on the 1986 census and the growth rates. Fiji's GDP at current prices amounted to F$ 1,995 million in 1991, an increase at an average annual rate of 8.1% from F$ 1,329 in 1987. The per capita GDP also grew at a high annual rate of 7.4% on average during the same period and amounted to F$ 2,365 in 1991.

Agriculture, including sugar cane, forestry and fishing is the major economic sector of Fiji.

The population of the Study Area was estimated to be 98,936 in 1991 under the assumption of a high variant of growth rate. 19,673 inhabitants live in the urban area and 79,263 in the rural area.

2.5 Present Water Use

PWD, the government agency responsible for water supply, has three piped water supply systems in the Study Area; Ba, Tavua / Vatukoula, and Rakiraki regional water supply systems, supplying water to 49,118 inhabitants, in urban areas and their vicinities.

The potable water for these systems is derived chiefly from surface water sources and a minor part of the Ba regional water supply system is supplied from four tube wells.

In addition to the regional water supply systems, some communities have established their own piped water supply systems, so called communal water supply systems, where water supply facilities including boreholes have been privately constructed.

Other than the regional and communal water supply systems, there are two piped water supply systems owned by Fiji Sugar Cooperation (FSC) in Ba and Rakiraki, and M.R. Dayal in Ba.

In non-service areas, dug wells, tube wells, rainwater storage tanks, and river/ creek water are the main sources of water supply.

In the dry season, many communities, even in the service area face water shortage problems and emergency water is often supplied.

A total of 521 existing wells are registered in the well inventory. 472 boreholes and 37 dug wells are privately built, 11 boreholes are owned by PWD, and 10 boreholes are drilled for test by MRD. However, 101 are in disuse because of poor production of water or insufficient maintenance of the pumps.

The standard private borehole usually runs for several hours per day with a discharge rate of 0.3 to 0.8 l/sec. The estimated amount of pumped groundwater reaches 340,000 m^3 per year in total. The annual abstraction amount of groundwater from PWD's four production boreholes was estimated to be 117,365 m^3, or less than 4% of the whole supply of the Ba regional water supply system. A total of 457,000 m^3 of groundwater is abstracted in a year.

3 HYDROGEOLOGY

3.1 General Geology and Structure

The mountainous areas and low undulating hills are underlain by consolidated pyroclastic rocks and lava formed in the Mio-Pliocene, partly intercalated with sedimentary rocks of sandstone, mudstone, and tuff beds. Alluvial deposits exist on the river beds and in the coastal area covering these volcanic rocks. The hydrogeological map of the Study Area is shown in Figure 1.

The pyroclastic rocks show a variety of products from volcanic activity during the Mio-Pliocene. These are basaltic and andesitic lavas and their breccia which are well consolidated.

Tuffaceous sandstone, mudstone and tuff beds occur widely at the middle reaches of the Ba river and partly in other areas. They are commonly composed of a series of a hard sandstone beds of 0.5 m in thickness with thin layers of siltstones and mudstones. The bedding planes of the rocks dip gently at around 10° in various directions. Cracks, of about 50 cm in size showing rectangular shape have developed in the weathered outcrops of sandstone.

Unconsolidated alluvial deposits occur chiefly on the river bed and in the coastal plain. Terrace and river bed deposits are mostly unconsolidated gravel, however, clayey materials are common in their matrix. The alluvial sediments along the coastal zone are formed by unconsolidated soft clay deposited in a shallow bay.

Lineaments were interpreted from aerial photographs even though existence of a great fault zone was not known. Their remarkable directions are E-W and NE-SW in the middle reaches of the Ba river, NW-SE and NE-SW in the upper reaches of the Ba river, NW-SE and NWW-SEE in the western part of Ba town, E-W, NE-SW, NWW-SEE and NEE-SWW in the area of Vatukoula, and NWW-SEE, NEE-SWW and NW-SE in the area of Rakiraki.

These lineaments are considered to lengthen due to faults, fractured zones, and/or intercalated soft beds.

Because the pyroclastic rocks and the intercalated beds of the Mio-Pliocene series are well consolidated, it is naturally considered that groundwater occurs in the open fractures chiefly controlled by these lineaments.

A caldera structure is also located in the upper reaches of the Nasivi river at Vatukoula where gold mining is being conducted.

The results of geophysical prospecting indicate the subsurface geological characters from their resistivities. Generally, well consolidated fresh pyroclastic rock masses show a high resistivity, and the weathered rocks, sedimentary rocks, and fractured zones show a low resistivity of less than 30 ohm-m. A very low resistivity of less than 10 ohm-m possibly indicates a high clay content and/or high groundwater salinity.

The surface of the rocks, especially in the areas of low hills and flat lands, is covered with highly weathered materials or clayey materials with low resistivities. Higher resistivities generally appear towards the deeper zone in profiles because of the occurrence of more fresh rock masses. However, in case a lower resistivity section is detected between these higher resistivity zones, it is assumed that the lower resistivity section probably suggests the occurrence of fractured zones in the hard rock masses. For the selection of the test well drilling sites, low resistivity zone's geologic conditions and the attitude of the local inhabitants were taken into consideration.

3.2 Test Well Drilling and Pumping Test

Eleven test well sites were selected for the evaluation of groundwater development potential as shown in Figure 2. Ten test wells were drilled to around 70 m in depth to detect fractured zones containing water and one test well was made to a depth of 36 meters to study the river bed deposits. These test wells were usually cased with a string of casing pipe and screen with a nominal diameter of 150 mm. The annular space was filled with sieved natural gravel with diameters raging from 3 to 10 mm.

Three test wells encountered Tertiary sedimentary rocks such as tuffaceous mudstone, and sandstone, and the other seven deep test wells penetrated basalt masses and their breccia. Since these rocks are well consolidated, only fractures in them contain groundwater. A shallow test well was placed into deposits of gravel and clay under the Ba river bed. These deposits are not consolidated but contain an abundance of clayey materials which lower their permeability.

Pumping tests were carried out on these test wells, however, the continuous pumping test was not successful on four test wells because of the poor production of water. In order to obtain the hydrogeologic constants as widely as possible, the pumping test was also carried out on two existing MRD boreholes in addition.

The specific yields of the test wells range from 0.05 to 0.44 l/sec/m. The existing borehole GW245 showed an excellent yield at the initial stage of the continuous pumping test, however, a rapid drawdown appeared 5 hours after the pumping had started. This was probably caused when the depression cone of the drawdown reached the surrounding barrier of common pyroclastic rock masses.

It was realized during the drilling operation that TW006 produced mineralized water with a electric conductivity of 1,400 MS/cm when the drilled hole exceeded 31 m in depth. Thus, the drilled hole was filled with sand, gravel, and cement to a depth of 18.8 m, after confirming the geologic log to a depth of 76 m. Therefore, the water was produced only from the upper aquifer when the pumping test was executed. The results of the test well drillings are shown below;

Well No	Depth (m)	Q'ty (l/sec)	S.W.L. (m)	D'down (m)	Pumping hours	W. Quality*
TW001	76	3.2	23.03	11.20	48	good
TW002	36	2.8	3.27	10.45	48	Fe, Mn
TW003	74	0.05	41.19	3.76	0.8	Fe, Mn, Al
TW004	75	2.9	8.12	10.25	48	good
TW005	72	2.4	9.81	13.64	48	turbidity, Fe, Mn, Al
TW006**	76	2.0	+0.26	4.81	48	turbidity
TW008	75	1.3	0.92	7.00	48	good
TW009	71	0.08	7.52	10.91	2	turbidity, Fe, Mn
TW010	70	0.05	1.07	13.04	2	good
TW011	75	0.23	6.79	8.15	2	Al
TW012	75	1.0	5.68	18.23	48	good
GW035	45	4.8	7.52	10.91	24	good
GW254***	38	15.1	7.9	0.79	24	good

* Constituents above WHO standards in concentration levels.

** Completed depth of well is 18.8m.

*** Rapid drawdown appeared 5 hours after pumping started.

3.3 Aquifer

The top part of the rock masses, especially on hills and flat lands, is covered with weathered materials or unconsolidated deposits. These soft materials form an unconfined aquifer where phreatic water is initially stored from infiltration of rainfall and/or surface stream. A number of dug wells tap this shallow aquifer.

Fresh rock masses of the Tertiary are located beneath the unconfined aquifer and form the aquitard base of the phreatic water because of their lower permeability.

It is known that fresh rock masses of both sedimentary and pyroclastic rocks are very thick and well consolidated. It is, therefore, considered that only their fractures allow groundwater to flow.

In the observation boreholes tapping the fractured section in the fresh rock, water level fluctuates seasonally corresponding to the amount of rainfall. The hydrographs obtained by automatic water level recorders at GW013, GW014, and GW042 located 0.3 to 2 km from the sea coast, show tidal fluctuations of 2 cm to 4 cm. These facts indicate that fractures in the consolidated rock masses are likely connected to a net structure in a wider area. Groundwater in these fractures is recharged from the upper aquifer and discharged to the sea under the confining condition. In the Study Area, it is, therefore considered that the fractured section in these consolidated rock masses below water level forms the confined aquifer.

The transmissivity of the confined aquifer obtained by the pumping test ranges from 830 to less than 20 m^2/day in which values between 200 and 20 m^2/day are common.

3.4 Meteorology and Hydrology

Meteorological data such as rainfall, temperature, relative humidity, evaporation, sunshine hours, and wind were collected to determine the climatorological condition and to analyse the water balance in the Study Area.

Runoff data were also collected from four gauging stations; Toge and Navala in the Ba river, Vatukoula in the Nasivi river, and Vatusekiyasawa in the Nakauvadora river. Because of the limited distribution of the gauging stations, supplementary discharge measurements were carried out at engaged river basins.

The Study Area, covering an area of 1,567 km^2, can be divided into 9 drainage basins. The maximum amount of basin mean rainfall is estimated to be 2,517 mm in the 957 km^2 Ba river catchment area, and the minimum is estimated to be 1,807 mm in the 32 km^2 catchment area of the Waisali river. The basin mean rainfall is greater in the upstream reaches.

In general, the mountains in the upstream basin of the rivers possess very steep slopes and are not densely forested. The middle and lower reaches are well cultivated for growing sugar cane. It seems that runoff concentration occurs within a short period due to the low retardation effects of the upstream basin.

Drought occasionally occurs in the dry season owing to the significant difference in rainfall between the dry and rainy seasons as well as the above mentioned characteristics of the basin.

The initial runoff analysis was carried out at the existing gauging stations using a Tank Model simulation which required runoff records and the basin mean rainfall for the upstream basin of each objective stream gauge. The basin wide runoff was obtained by a theoretical extension of the above.

The possible development yield of surface water is defined as the 95% dependable daily discharge which exceeds the river maintenance flow of the minimum daily discharge in the drought standard year of a return period in 10 years. The possible development yields of the nine basins were estimated, by conversion based on the above analysis, to be 27.04 MCM/year in total in the Study Area, in which the Ba river basin.

3.5 Groundwater Flow

Simultaneous water level observations were carried out in the dry and wet seasons on the selected 39 existing wells. The well water levels ranged from 0.25 to 13.17 m below ground surface, measured during the dry season in September 1993.

The configuration of the contour lines of the water level shows a concordant form to the regional topography. It is somewhat difficult to distinguish the piezometric surface from the unconfined phreatic water level by the water levels in the existing wells. Probably, the difference between the confined and the unconfined water levels is minor.

The difference of well water levels between the dry and wet seasons ranges from 0.19 to 4.89 m. The hydrographs of the boreholes observed by the automatic water level recorders shows two different types of fluctuation. One type of fluctuation indicates that the water level rises gradually, shortly later than the beginning of the rainy season, and it remains at an almost constant level until the beginning of the dry season, declining towards the end of the dry season. Another type of fluctuation shows that the water level rises rapidly corresponding to the precipitation at the beginning of the rainy season, and then declines gradually towards the end of the dry season. Annual fluctuations of water level are greater in the latter than in the former.

Tidal fluctuations in the range of 2 to 4 cm are observed from some of the hydrographs of the boreholes located 0.3 to 2 km from the sea coast. This suggests that the groundwater in these boreholes occurs in a confined aquifer of fractures which opens to the sea.

3.6 Water Quality

A water quality study was carried out to determine the suitability of surface and groundwater for a potable water supply and to analyse the circulation of groundwater based on geochemical characteristics. To justify the suitability of a potable water supply, the World Health Organization (WHO) and the Environmental Protection Agency USA (EPA) standards were applied.

61 water samples were collected in the dry season and 64 in the rainy season at sampling points selected in regard to the existing well's locations, hydrologic environments, and the progress of the test well drillings. In addition, 10 water samples were collected in both seasons for an agrochemical analysis.

The results found that the water except for a few samples is generally good for drinking purposes. Agrochemicals were not detected in the water samples collected in the dry and rainy seasons.

The fertilizers being used in sugar cane fields are ammonium sulfate, diammonium phosphate, and triple superphosphate. These are normally dissolved as nitrogen, phosphorus, and sulfur. The results of water quality analysis indicate that levels of these constituents such as nitrate (NO3) and sulfate, are less than WHO standards. This means that currently contamination by fertilizers does not occur in this area.

However, in some of the water samples, constituents such as Fe, Mn, Al, color, and turbidity slightly exceeded WHO standards for a potable water supply system. These constituents are often found in water as products from weathered rocks, especially in tropical regions.

Water with high electric conductivities of over 750 MS/cm occur in some limited sites, caused by contamination from mineralized water or sea water.

It was noticed that hazardous constituents of Cadmium, Arsenic, and Chromium, higher than WHO standards, were found in some of the water samples obtained from sites in Vatukoula. Surface water and groundwater around these sampling sites and along the lower reaches are to be carefully inspected if these waters are to be used for the potable water supply.

Geochemical characteristics of water are generally classified into 5 types in the tri-linear diagram, indicated by the ratio of cautions and anions of the dissolved constituents.

In conclusion, the majority of groundwater samples belong to the alkaline earth bicarbonate type or typical natural water. Regularity in concentration levels of constituents was not found in regional distribution and/or between waters of shallow and deep wells. This means that rainfall quickly infiltrates to groundwater and is discharged to surface water. In some limited sites, groundwater belongs to the alkaline earth non-carbonate type or the alkaline non-bicarbonate type. These types indicate the contamination with mineralized water from very deep sources or with sea water.

4. GROUNDWATER RESOURCES EVALUATION

4.1 General

The potential for groundwater development is usually considered as the amount of sustainable water which can be pumped without producing any environmental problems. It is difficult to practically evaluate the regional groundwater balance in the Study Area, because of the poor transmissivity of the aquifer and the complicated topographical features. The groundwater balance was studied in the limited area of the right bank of the lower reaches of the Ba river, where water demand is high.

However, it is considered that one of the factors of groundwater development depends on the capacity of yield of a typical borehole. Therefore, the potential for groundwater development is essentially justified by the yield capacity of common boreholes such as the test wells. Transmissivity and water quality are also taken into consideration.

4.2 Groundwater Resources Potential

The Study Area is divided into 13 groundwater regions as shown in Figure 2, based on the hydrogeological characteristics described in Table 1.

The Yaqara River Basin, where a MRD tube well yields more than 5 l/sec, has excellent potential for groundwater development.

The Ba River Lower Plain, the Ba Uplands, the Koronubu Uplands, the Vatia-Lousa Coastal Plain, and the Matalevu Uplands all have medium potential for groundwater development, producing water ranging from 1 to 5 l/sec.

In the mountainous region occupying about 70% of the Study Area, the groundwater level becomes deeper at the elevation becomes higher . As groundwater has been utilized in areas where the water level is located within the allowable depth for pumping, groundwater development is limited to the lower periphery of regions lower than around 100 m in altitude. Ground water development potential in the periphery of the Mountainous Area is medium, as indicated by the TW001 yield.

The Tavarau-Raviravi Coastal Plain has a number of boreholes commonly yielding water at a rate of 1- 5 l/sec. Groundwater development potential seems medium in this region. However, it was noted that water quality in several boreholes along the coastal area had deteriorated probably due to sea water intrusion. Therefore additional groundwater development is not possible, especially in the area along the sea coast.

The remaining five regions of the Moto Uplands, the Tavua Basin, the Rabulu Coastal Plain, the Wailevu-Narewa Coastal Plain, and the Penang River Basin have poor potential for development with a yield capacity of less than 1 l/sec by a common borehole, or heavy contamination.

4.3 Groundwater Simulation

Among the groundwater potential regions, the Ba Uplands, covering an area of 75 km^2, located at the right bank of the Ba river is selected for further analysis of groundwater balance, because of the size of its population and the high water demand.

As mentioned in the previous section, the aquifer system in this region consists of three layers; an unconfined aquifer, a confining layer, and a confined aquifer, in descending order.

It is inferred that unconfined groundwater is essentially recharged by infiltration of rainfall or surface stream, and is moved vertically through the underlying confining layer or the aquitard to the confined aquifer when the piezometric head in the confined aquifer is lower than the water table. The confined groundwater flows horizontally through the aquifer due to the hydraulic gradient.

The amount of recharge to the unconfined aquifer was calculated for the hydrological standard years of an average year (1991) and a drought year over a 10 year period (1992). The amounts using the Tank Model were 554 mm/year for 1991, and 296 mm/year for 1992.

Flow simulation was conducted on the confined groundwater using a Nodular Three Dimensional Finite Difference Groundwater Flow Model on 10 cases of the development plans in this region.

The results of the optimization study indicated two possible pumping strategies of pumping rates; 287 m^3/day with three boreholes and 412 m^3/day with four boreholes, without the constraints of interference to other existing wells and of sea water intrusion.

5. WATER DEMAND

5.1 Major National Policies

In Fiji's Ninth Development Plan, it was insisted that an adequate, reliables and safe water supply by solving the repeated water shortages, is one of the most important targets of the water supply sector.

PWD, as an executive agency of the Government for the water supply project, has prepared several manuals for design and planning of the water supply project in Fiji, in which the following unit consumption rates are recommended;

Rural Water Supply Design Manual

160 lpcd for house connection

115 lpcd for public standpipes used for washing, cooking, drinking, and bathing

45 lpcd for public standpipes used for drinking and bathing

Water Supply Design Manual (draft)

200 lpcd for cities i.e. Suva and Lautoka

150 lpcd for towns

5.2 Population Projection

The population projections were carried out at intervals of five years for the period 1991 to 2011, using the 1986 census population and the proper growth rate for the same period.

The annual growth rates were based on the 1976 and 1986 census. During this period, Ba and Ra Provinces, which take in a major part of the Study Area, had relatively low growth rates compared to other provinces. Taking this matter into account, the population projections in the Study Area are first based on urban and rural areas in the respective Tikinas. Next, the growth rates which are derived from the initial population projections are used to project the population of communities included in the urban and rural areas.

The results of the population projection in the Study Area are summarized as ,

Scenario (Year)	Population 1991	2011
High variant	98,936	138,852
Middle variant	96,838	104,248
Low variant	95,042	85,707

The population in the urban and rural areas for the high scenario are estimated as,

Area	1991	2011
Urban	19,673	21,161
Rural	79,263	117,691
Total	98,936	138,852

5.3 Present Water Consumption

The present water consumption for domestic use, from 1988 to 1993, was estimated in the existing regional water supply systems of PWD as,

	Quantity (m^3/day)	
Town	Minimum	Maximum
Ba	1,986	4,394
Tavua	1,220	1,311
Rakiraki	668	874

The amount of water supplied varied year by year. Thus, the per capita consumption was determined from the maximum year.

The present per capita consumption for domestic use in the areas with water supply systems are,

Ba : 140 lpcd (180 lpcd for urban area, 120 lpcd for rural)
Tavua : 120 lpcd
Rakiraki : 120 lpcd

5.4 Domestic Water Demand Projection

The domestic water demand was estimated by multiplying the population served with the per capita consumption. The per capita domestic consumption was referred to by the existing design criteria of PWD. According to the existing design manual, 160 lpcd is utilized for house connections in the rural area's water supply systems and 200 lpcd is proposed for the urban water supply which will be applied to the Ba regional water supply system in future. In areas without a regional water supply system, 80 lpcd was adopted for domestic demand which was obtained from the interview survey.

The water demand for the domestic use in the area with a water supply system was estimated to be about 10,170 m^3/day for a population of 60,181 in 2011, while the present water demand for domestic use is estimated as 6,510 m^3/day for a population of 49,122 in 1991.

The water demand in the area without a water supply system was estimated to be about 6,290 m^3/day for a population of 78,664 in 2011, while the present water demand was estimated about 3,990 m^3/day for a population of 49,814 in 1991.

5.5 Commercial Water Demand Projection

According to the present water consumption study, commercial water use ratios in the Study Area ranged from 20 to 30% of the effective amount. The ratio of commercial water use against domestic use are 20% in Ba, 25% in Tavua, and 43% in Rakiraki.

The commercial water demand is estimated to be 2,720 m^3/day in 2011, while the present commercial water demand was estimated at about 1,740 m^3/day.

6. OVERALL WATER SUPPLY DEVELOPMENT PLAN

6.1 Development Principle

The proposed communities selected for the water supply development plan are from areas with an inadequate water supply system. The scale of the proposed scheme is determined by the possible pumping rate of each production well without causing environmental impact. The production wells for the proposed schemes are selected in principle from the existing test wells drilled by JICA or MRD which had been confirmed to produce sufficient groundwater. The project target year determined in consultation with PWD is 2011.

The proposed schemes are divided into four types; "Single community system", Expansion for regional system", Supplemental water sources for regional system" and "Emergency water source system".

6.2 Development Schemes

For the overall water supply development plan, nine schemes with water supply systems were formulated in areas as shown in Figure 3, using groundwater sources of the existing test wells drilled by JICA team or MRD, and one new proposed well. The nine schemes are summarized below,

Scheme	Type of System	Service population (2011)	Source	Yield	Construction cost (F$)*3 ($m^3$/day)
Vutuni Creek	Single Community	314	TW001	60.0	384,567
Kukunirewa	Single Community	230	TW008	45.0	284,629
Vatuyaka	Expansion for regional system	561	GW035	108.0	489,162
Varadoli-Veisaru(1)	Supplemental source for regional system	*1	TW004 TW005	158.4	396,111
Varadoli-Veisaru(2)*2	Supplemental source for regional system	*1	New well TW004 TW005	273.6	579,236
Rabulu	Expansion for regional system	930	GW254	180.0	799,038
Vaileka	Emergency use	882	TW012	15.0	81,137
Yalalevu	Emergency use	1,141	TW002	20.0	86,643
Koronubu	Emergency use	1,115	TW006	20.0	128,308

Note:*1; Not planned, *2 Alternative of the above, 3*Including construction cost of production well

6.3 Cost Estimates

The water supply facilities for the proposed nine schemes were initially designed based on the existing topographic map with a scale of 1:50,000. The principal facilities of the water supply system for the nine schemes are shown in Table 2.

The project cost was based on the said brief design by the usual means of referring prices and foreign exchange rates in December 1994. For the main construction materials and equipment, the costs were estimated in local and foreign portions, respectively. Engineering services, value added tax, import duty, and price and physical contingencies are included in the project cost.

The construction cost for each scheme was estimated in two cases of with and without the construction cost of the existing wells. The construction cost tabled in section 6.2 includes the construction cost of the test well for the comparison of the project.

The annual operation and maintenance costs are also estimated for each schemes.

6.4 Socio-economic Evaluation

This evaluation aims to rate the nine overall schemes from a socio-economic point of view.

The economic benefit of the project is given as the difference between the water supply conditions before and after construction of the project. The benefit is estimated as the saving of time and/or expenses spent in retrieving water, the reduction of emergency water supply costs, and an increase in water volume to be supplied.

The result of the economic analysis shows that the Rabulu scheme achieves a high EIRR of 13.59 % which indicates economic feasibility as the opportunity cost of capital in Fiji is about 12%.

The Vutuni Creek scheme and the Vatuyaka scheme indicate low EIRRs of 2.51 % and 1.64 %, respectively due to the low time values resulting from the low average income per household, despite the poor condition of the existing water supply. It is, however, expected that these EIRRs will increase, provided the average household income in these communities also increases.

EIRR for the Kukunirewa scheme shows a negative percentage, however, the total economic benefit sufficiently exceeds the total economic operation and maintenance cost for the period of project life.

The other four schemes are not economically feasible and the operation and maintenance of the projects seem to be difficult because the O&M cost exceeds the benefit every year during the period of the project life.

6.5 Environmental Impact

The environmental impact of the groundwater development was studied in regard to land subsidence, sea water intrusion, influence to the existing wells, groundwater pollution, and health.

For the nine schemes planned, serious environmental impact was unforeseen for reasonable groundwater development. It is, however, noted that the water quality of the water sources for the Yalalevu scheme (TW002), Varadori-Veisaru scheme (TW005), and Koronubu scheme (TW006S) is not in compliance with WHO standards and that water treatment is needed for potable water.

7. WATER SUPPLY DEVELOPMENT PLAN FOR PRIORITY SCHEMES

7.1 Water Supply Plan

As mentioned in section 6.4, four schemes among the proposed nine schemes are judged to have a higher priority for water supply development.

In order to mitigate the present water shortage problems as much as possible, three schemes were finally selected as the priority schemes and their preliminary designs were commenced.

-Vutuni Creek Community Scheme
-Vatuyaka Expansion Scheme
- Rabulu Expansion scheme

7.2 Design Criteria

PWD design criteria was principally applied to the preliminary design.

The transmission and distribution pipes will be mainly UPVC pipes and installed underground in trenches. Galvanized steel pipes are used for the river/creek crossings. Pipes with diameters of 150 mm, 100 mm, 75 mm and 50 mm are applied in regard to the hydraulic calculations.

Air valves will be installed at each peak point along the pipelines and sluice valves will be placed on the pipelines downstream of connection/branching points.

A service reservoir with an effective depth of 3 m will be made by reinforced concrete. Chlorination facilities will be adjacent to the service reservoir.

7.3 Proposed Development Schemes

The layout of the three proposed schemes is presented in Figure 4. The brief description of each scheme is as follows;

-Vutuni Creek Community Scheme

Water is pumped up with a submersible motor pump from the existing test well (TW001) at a discharge rate of 0.84 l/sec for 20 hours a day. The pumped water is conveyed through a 75 mm diameter transmission pipe to a service reservoir with a storage capacity of 75 m^3 to be located on a hill 250 m west from the well.

The distribution pipes will be laid along the Vutuni road about 2 km to the west and 2.4 km to the east from the service reservoir, providing potable water for 314 inhabitants in 2011.

-Vatuyaka Expansion Scheme

Water is pumped up with a submersible motor pump from the existing MRD well (GW035) at a discharge rate of 1.5 l/sec for 20 hours a day. The pumped water is conveyed through a 75 mm diameter transmission pipe to a service reservoir with a storage capacity of 135 m^3 sited on a hill in the northeast of the community.

The distribution pipes will be laid on Daro, Sorokoba and Khaisa roads to cover the service area with a population of 561 in 2011.

-Rabulu Expansion Scheme

Water is pumped up with a submersible motor pump from the existing MRD well at a discharge rate of 2.5 l/sec for 20 hours a day. The pumped water is carried through a 100 mm diameter transmission pipe to a service reservoir with a storage capacity of 230 m^3 sited on a hill in the north eastern part of the community.

The size of the distribution pipes will be 150 mm, 100 mm, and 75 mm in diameter. On the pipeline route, east along the Kings Road, the distribution pipe will be installed parallel to the transmission pipe in the same trench. Potable water will be provided for 930 inhabitants in 2011.

7.4 Implementation Program.

The financial arrangement for the implementation of the selected three schemes will be made within 1995 following the completion of the Study in May 1995.

Land acquisition will be intermittently carried out in parallel with the financial arrangement and will be finished in January 1996. The topographic survey and detailed design are scheduled at the beginning of January 1996 and the construction will follow completion of the design.

All the construction works will be completed at the end of 1996 and the water supply will commence in late 1996 or early 1997.

7.5 Operation and Maintenance

The following periodical inspections and maintenance are recommended for the proper use of the facilities;

-Daily inspection

- -water level at the service reservoir
- -groundwater level in the well
- -pumping head and discharge
- -electric voltage and current of the submersible pumping equipment

-Weekly inspection and maintenance

- -setting bleaching powder in the chlorination facility
- -water quality

-Monthly inspection and maintenance

- -water leakage from the transmission and distribution pipes
- -insulation resistance value of the submersible pump equipment.

Other than the recommended inspection and maintenance, it is required to conduct an overhaul of the pump facilities at intervals of several years.

The Vutuni Creek scheme will be implemented by PWD with the cooperation of the community, including the provision of unskilled laborers. When the facilities are completed, PWD will maintain them for a period of 6 months, then, they will be handed over to the community. The proper operation, maintenance, and management will be done by the water supply union of the community, under the guidance of PWD. Water charges will be determined in consideration of the costs of electricity for pumping and purchasing of spare parts, and of the operations organization.

The Vatuyaka and the Rabulu schemes will be operated, maintained, and managed by PWD has been conducted up to the present.

7.6 Cost Estimates

The construction cost for these three priority schemes was estimated by the preliminary design formulated on the topographic survey results. The construction cost of the wells is not included because these schemes can use the existing deep wells. The estimated construction cost of each scheme is,

(Unit: F$)

Scheme	L/C	F/C	Total
Vutuni Creek	276,728	43,983	320,711
Vatuyaka	407,796	56,543	464,339
Rabulu	669,247	87,703	756,950
Total	1,353,771	188,139	1,541,910

The annual O&M costs in 1997 estimated on the operation, maintenance and management plan are,

(Unit: F$)

Scheme	L/C	F/C	Total
Vutuni Creek	2,137	588	2,725
Vatuyaka	5,636	612	6,248
Rabulu	4,866	732	5,598

8. PROJECT EVALUATION

8.1 Economic Evaluation

The economic cost for the selected three schemes was estimated from the construction cost of the facilities based on the preliminary design and the operation and maintenance cost.

The Vutuni Creek and the Vatuyaka schemes indicate low EIRR's of 2.61 % and 1.25 %, respectively, which are very difficult to realize economically. These low percentages of EIRR result chiefly from the low time value, which is due to the average low income per household. However, the annual economic benefits for these two schemes sufficiently exceed the annual economic O&M cost every year during the period of the project life.

Accordingly, although these schemes are not economically feasible, it will be possible to operate and maintain the project after completion of the facilities.

Of the three schemes, the Rabulu expansion scheme achieves a comparatively high EIRR of 13.83 %, which indicates economic feasibility. This is due mainly to a high time saving benefit.

8.2 Financial Analysis

This analysis was carried out for the Vatuyaka and the Rabulu expansion schemes, where domestic water will be supplied by the regional water supply system in the near future.

FIRR for the two schemes is estimated using the annual flows of cost and revenue. However the percentages are negative for both schemes, and the annual O&M cost also exceeds the annual revenue every year for the period of the projects lives.

8.3 Summary of Project Evaluation

The Vutuni Creek scheme covering 314 inhabitants is given a low EIRR. It is also noted that the annual economic benefit exceeds the annual O&M cost. This means that the operation of the project will be possible in case the construction is executed by PWD.

The Rabulu schemes are economically feasible but financially negative. The Vatuyaka scheme shows a low percentage of EIRR but is financially negative.

However, it is noted that these schemes will be promoted as an expansion of the existing regional water supply systems providing water for an additional 1,491 inhabitants in total and that the operation of the project will be economically possible after completion, because the annual economic benefit in both schemes exceeds the annual O&M cost.

9. ENVIRONMENTAL ASSESSMENT

In the Vutuni creek and the Vatuyaka schemes the main aquifer occurs in the consolidated volcanic rocks. Water quality of the source well is good. Neither land subsidence nor sea water intrusion is foreseen under reasonable groundwater development.

In the Rabulu schemes, environmental impact is unforeseen under reasonable groundwater development. It is, however, noted that the water level of the source well GW254 should be monitored because the water level recovery was abnormal during the pumping test.

10. CONCLUSIONS AND RECOMMENDATIONS

The Study Area is underlain by well consolidated basaltic and sedimentary rock masses of the Tertiary in which the fractured sections form the essential aquifer.

The Study Area is classified into 13 groundwater regions based on their hydrogeological characteristics. The transmissivity of the aquifer is generally low, therefore, a typical borehole such as the test well, yields 1 to 5 l/sec of water even in the medium and excellent potential regions.

Accordingly, for the master plan of overall groundwater development, nine schemes of a water supply system were formulated using the existing test wells on which the yield had been confirmed. Among these nine schemes, three priority schemes were selected for further study based on their economical analysis.

The three schemes, Vutuni Creek, Vatuyaka, and Rabulu, have positive EIRRs and their annual economic benefits exceed the annual O&M costs during the period of the project life, although their FIRRs are negative.

Notwithstanding the relatively low economic and financial returns, it is recognized that water supply development is one of the important basic needs for insuring subsistence in the Study Area, especially in the areas faced with water shortages. It has been confirmed that a safe and stable water supply will contribute to preserving public health and hygiene and promoting sustainable economic growth. It is recommended that the proposed priority water supply development scheme be implemented urgently, following the completion of the Study.

However, it is evident that the groundwater resources are unable to fulfill all of the future water demands in the whole Study Area. It is also recommended to develop surface water sources available in major rivers, in addition to the groundwater development.

There are three possible sites for constructing a dam/weir to take water upstream of Toge in the Ba river. A water resource study on the Ba river basin should be conducted for regional development in terms of water supply for domestic, industrial, tourism, and agricultural uses, and should cover the Northwest Viti Levu including the Ba area.

Proper groundwater management should be carried out to achieve sustainable use of the groundwater without serious over pumping or deterioration of its water quality.

TABLES

Table 1 GROUNDWATER RESOURCES POTENTIAL OF THE STUDY AREA

Region No.	Region	Geology	Stratigraphic division	Aquifer	Transmissivity m^2/day	Specific capacity (l/s/m)	Well yield (l/sec.)	Electric conductivity (MS/cm)	JICA & MRD well	Groundwater development potential*
1.	Mountainous Area	Basalt, andesite, andesitic breccia sandstone, and conglomerate	Ba series Koroimavua and Suva series	Weathered fractured rock	<40	<0.49	<3	115	TW001	Poor, locally medium
2.	Tavarau-Raviravi Coastal Plain	Augite and hornblende andesite	Ba series	Fractured rock	1-285	0.02-4.35	0.1-5.4	180-1,793	GW043 GW044	Poor, locally medium
3.	Ba River Lower Plain	Alluvial and terrace deposits	Quaternary	Sand and gravel deposits	<20	0.26-0.59	<2	138	TW002	Medium, locally poor
4.	Moto Uplands	Tuffaceous sandstone, mudstone, and tuff	Ba series	Fractured sandstone	0.1-0.3	0.01-0.03	<0.7	30-740	TW003	Poor
5.	Koronubu Uplands	Tuffaceous sandstone, mudstone, and tuff	Ba series	Fractured mudstone	1-50	0.05-0.63	<2	500-1,400	TW006	Poor, locally medium
6.	Ba Uplands	Basalt and basaltic breccia	Ba series	Fractured and weathered rock	5-140	0.11-0.44	0.3-4.8	30-650	TW004 TW005 GW035	Medium
7.	Vatia-Lousa Coastal Plain	Basalt, hornblende andesite lava	Ba series, Vatia series	Fractured rock and lava flow	1-96	0.67-2.25	0.2-8.0	240-920	GW042	Poor, locally medium
8.	Matalevu Uplands	Basalt and basaltic breccia	Ba series	Fractured rock and lava flow	1-122	0.16-3.0	0.1-3.0	200-500	TW008 GW030	Medium
9.	Tavua Basin	Basalt, biotite, and augite andesite, tuff	Ba series, Tavua series	Fractured rock	0.1-5	0.03-0.05	0.1-0.8	130-1,200	TW009	Poor
10.	Rabulu Coastal Plain	Basalt and basltic breccia	Ba series	Fractured rock	0.1-5	0.005-0.05	0.1-1.8	80-860	TW010	Poor
11.	Yaqara River Basin	Basalt, agglomerate	Ba series	Fissured rock and lava flow	800-2,600	<19	<15	130-330	GW013 GW014 GW254	Excellent
12.	Wailevu-Narewa Coastal Plain	Chloritized tracky basaltic volcanic rocks	Ba series	Fractured rock	0.5-1	0.03-0.05	0.4-0.8	320-630	-	Poor
13.	Penang River Basin	Basalt, chloritized tracky basaltic volcanic rocks	Ba series	Weathered and fractured rock	0.1-7	0.05-0.07	0.2-1.2	150-530	TW011 TW012	Poor

*Note: Excellent: Potential yield of boreholes is more than 5.0 l/s, Transmissivity is more than 200 m^2/day

Medium: Potential yield of boreholes is from 1.0 to 5.0 l/s, Transmissivity is from 20 to 200 m^2/day

Poor: Potential yield of boreholes is less than 1.0 l/s, Transmissivity is less than 20 m^2/day

Water quality is taken into consideration in the evaluation of the potential.

Table 2 PRINCIPLE FEATURES OF WATER SUPPLY FACILITIES FOR DEVELOPMENT SCHEMES

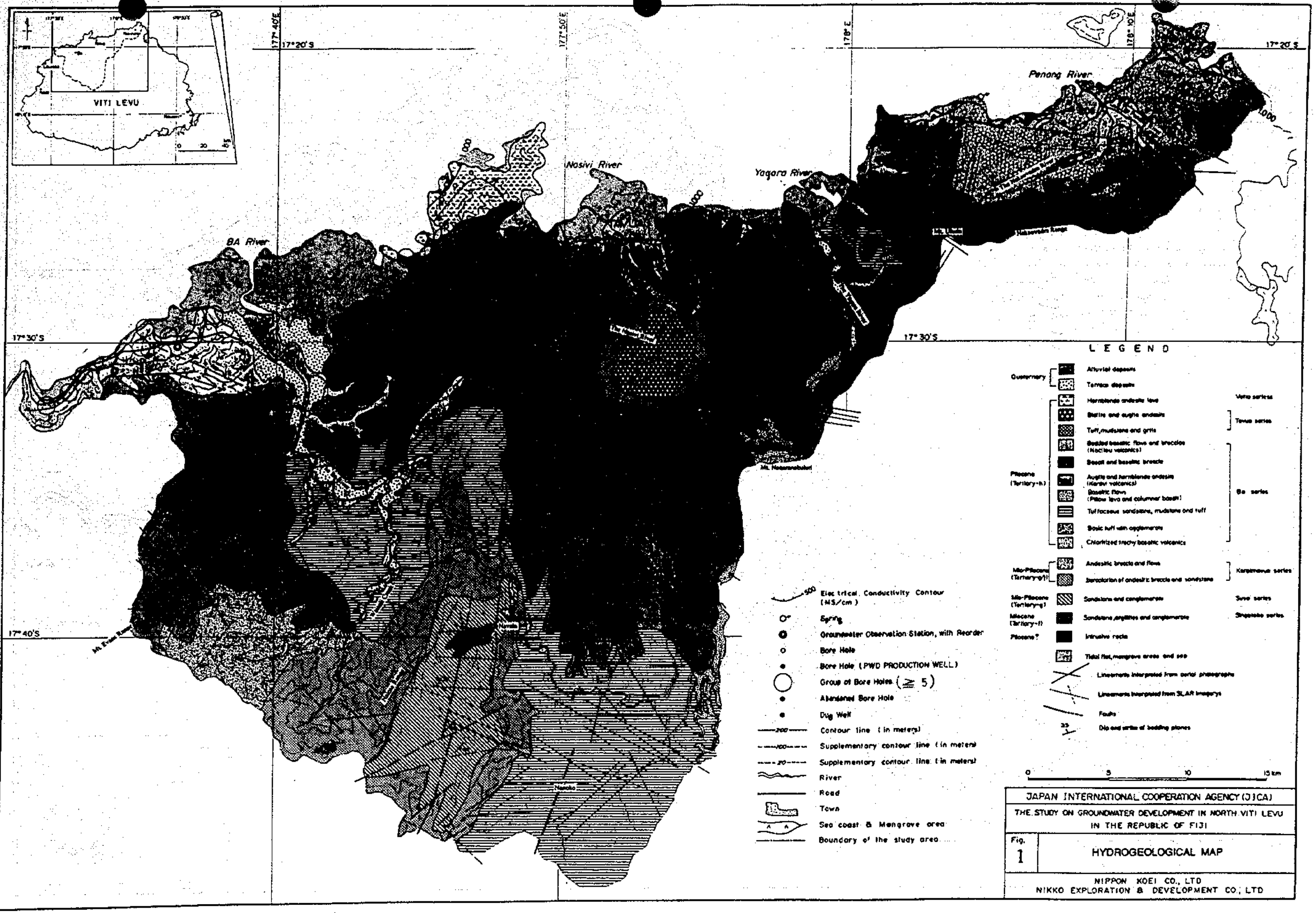
Item	Scheme No. / Scheme	1 Vutuni creek community	2 Kukunirewa community	3 Vatuyaka expansion	4 Varadoli-Veisaru supplemental (1)		5 Varadoli-Veisaru supplemental (2)			6 Rabulu expansion	7 Vaileka emergency	8 Yalalevu emergency	9 Koronubu emergency
Well	No.	TW001	TW008	GW035	TW004	TW005	TW004	TW005	TW000	GW254	TW012	TW002	TW006
	Elevation(m)	62.2	57.76	35.1	17.76	40.92	17.76	40.92	38	15	20	7.2	35
	Diameter(mm)	150	150	150	150	150	150	150	150	200	150	150	150
	Depth(m)	76	74.45	45	75.3	72	75.3	72	70	38.3	74.45	35	18.80
Submersible pump	Diameter (inch or mm)	1 1/4" or 32	1 1/2" or 40	1 1/2" or 40	1 1/4" or 32	1 1/2" or 40	1 1/4" or 32	1 1/4" or 32	2" or 50	2" or 50	1 1/4" or 32	2" or 50	2" or 50
	Pumping discharge (l/s)	0.84	1.3	1.5	0.8	1.4	0.8	1.0	2.0	2.5	1.0	2.0	2.0
	Pumping head (m)	102	129	111	74	70	74	68	70	104	50	40	20
	Pumping hours (hr)	20	9.62	20	20	20	20	20	20	20	4.2	2.8	2.8
	Electric capacity (kw)	1.5	3.7	3.7	1.1	1.5	1.1	1.5	2.2	5.5	1.1	1.5	1.1
Transmission pipe	Material	UPVC	UPVC	UPVC	UPVC		UPVC			UPVC			
	Diameter (mm)	75	75	75	75		100/75			100			
	Length (m)	400	1,100	3,950	6,100		5,500/1,200			6,800			
Service reservoir	Storage volume (cu.m)	75	60	135						230			
	HWL (m)	113	143	93						65			
	LWL (m)	110	140	90						62			
Distribution pipe	Material	UPVC	UPVC	UPVC						UPVC			
	Diameter (mm)	75	75/50	100/75/50						150/100/75			
	Length (m)	4,600	1,600/1,500	1,550/3,250/400						850/2,200/3,600			
Booster pump	Pumping discharge (l/s)				4.6		8.0						
	Pumping head (m)				22		22						
	Electric capacity (kw)				2.2		3.7						
Water Treatment Facility	Items of Water quality exceeded the drinking water standard				Fe, Mn, Al Color, Turbidity		Fe, Mn, Al Color, Turbidity					Fe, Mn	Turbidity
	Place to be treated	service reservoir	service reservoir	service reservoir	existing service reservoir		existing service reservoir			service reservoir	-	well	well
	Treatment method	chlorination	chlorination	chlorination	mixing with reserved water & chlorination		mixing with reserved water & chlorination			chlorination	-	chlorination	pre-chlorination & direct filtration

Remarks: TW000 : proposed to be newly constructed

(shaded) : existing system

(hatched) : to be distributed by truck

FIGURES



VITI LEVU
17°40'E
17°50'E
178°E
178°10'E
17°20'S
17°30'S
17°40'S
BA River
Nasivi River
Yagara River
Penang River
1,000
LEGEND
Quaternary
Alluvial deposits
Terrace deposits
Pliocene (Tertiary-h)
Hornblende andesite lava
Vatia series
Tavua series
Tuff, mudstone and grits
Basalt and basaltic breccia
Basaltic flows (Pillow lava and columnar basalt)
Tuffaceous sandstone, mudstone and tuff
Basic tuff with agglomerate
Chloritized trachy basaltic volcanics
Ba series
Andesitic breccia and flows
Koroimavua series
Sandstone and conglomerate
Savu series
Sandstone, argillites and conglomerate
Sigatoka series
Miocene (Tertiary-f)
Pliocene?
Intrusive rocks
Tidal flat, mangrove areas and sea
Lineaments interpreted from aerial photographs
Lineaments interpreted from SLAR imagery
Faults
Dip and strike of bedding planes
Electrical Conductivity Contour (μS/cm)
Spring
Groundwater Observation Station, with Recorder
Bore Hole
Bore Hole (PWD PRODUCTION WELL)
Group of Bore Holes (≧ 5)
Abandoned Bore Hole
Dug Well
Contour line (in meters)
Supplementary contour line (in meters)
Supplementary contour line (in meters)
River
Road
Town
Sea coast & Mangrove area
Boundary of the study area
0 5 10 15 km
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
THE STUDY ON GROUNDWATER DEVELOPMENT IN NORTH VITI LEVU IN THE REPUBLIC OF FIJI
Fig. 1
HYDROGEOLOGICAL MAP
NIPPON KOEI CO., LTD
NIKKO EXPLORATION & DEVELOPMENT CO., LTD

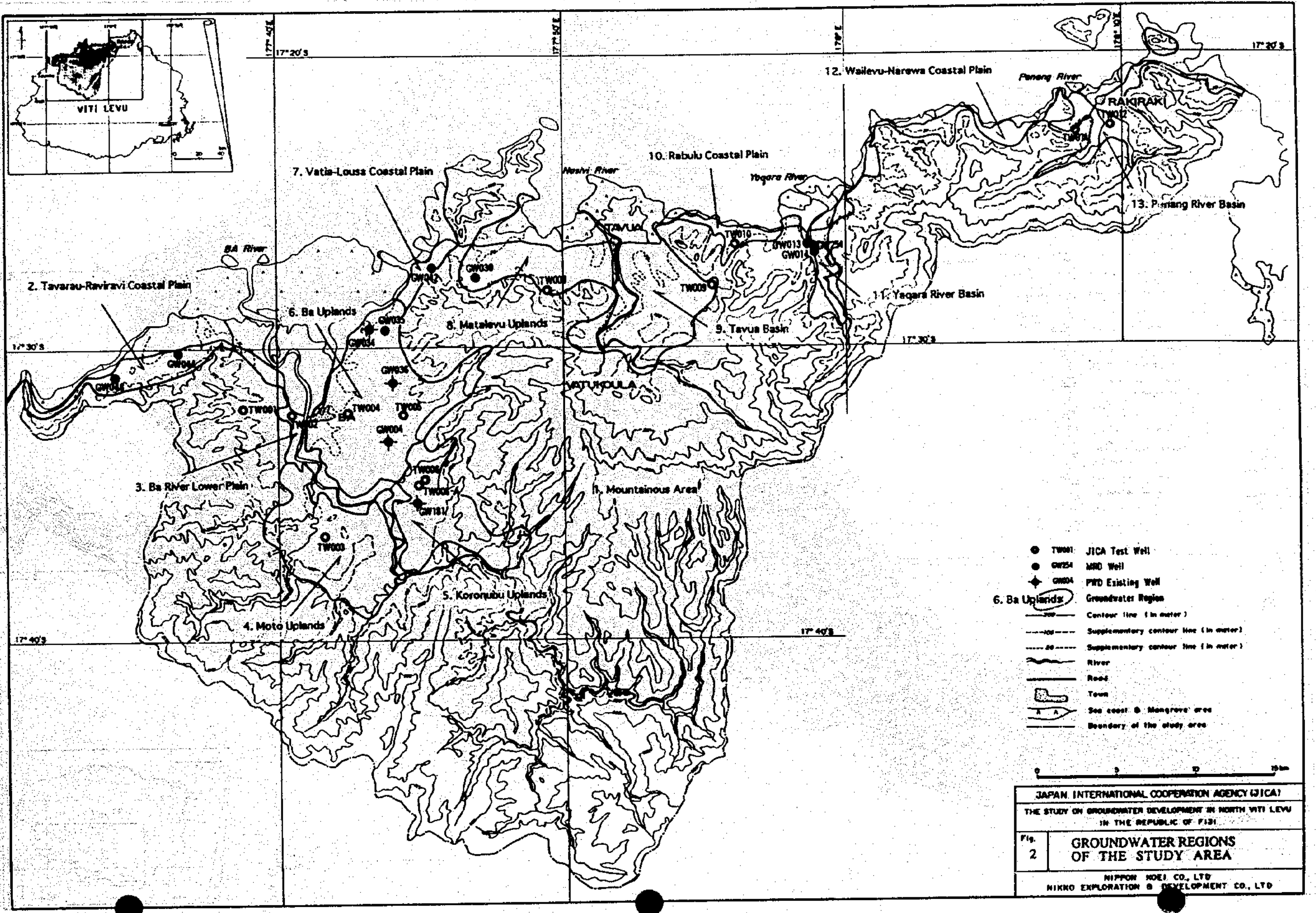
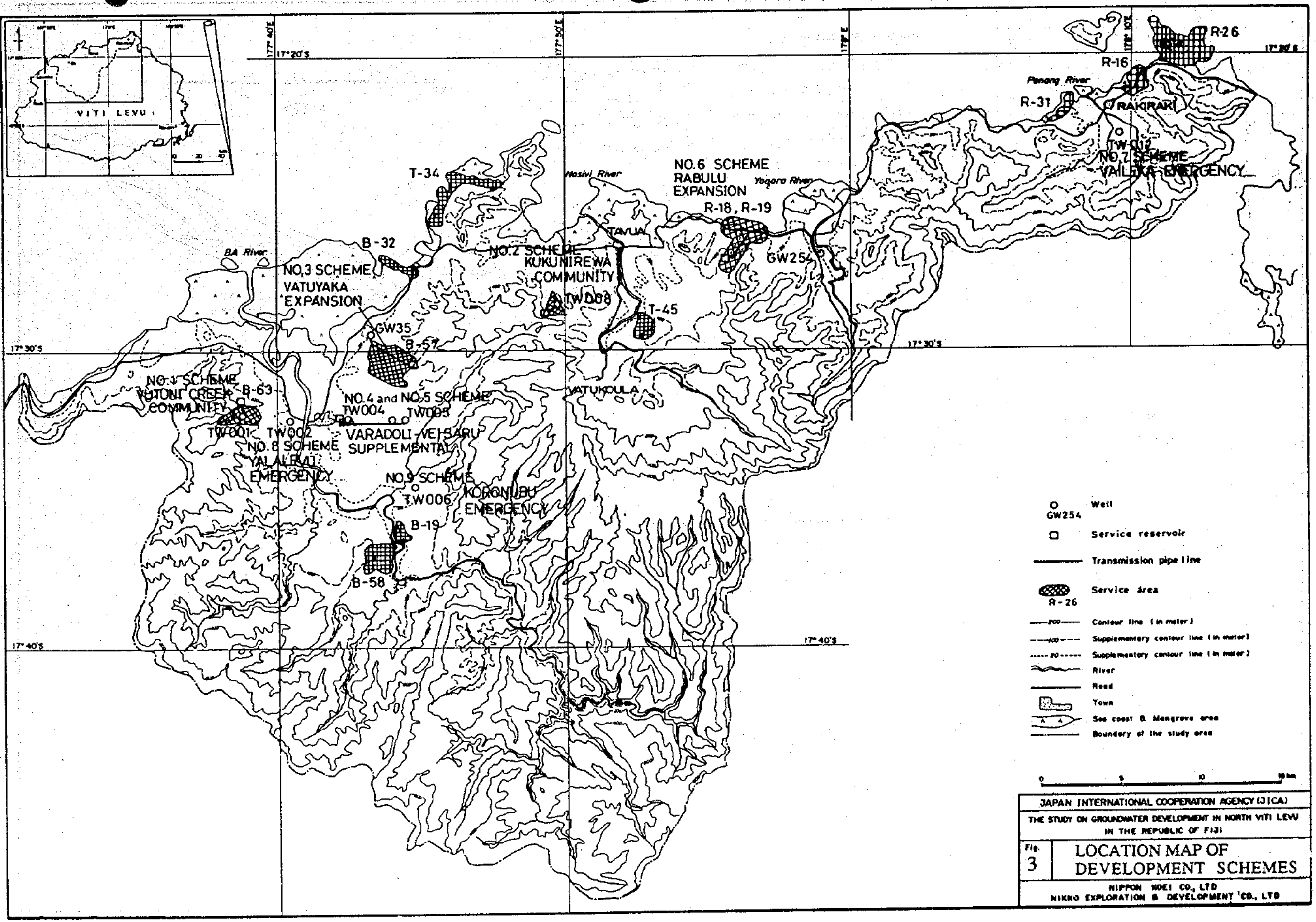
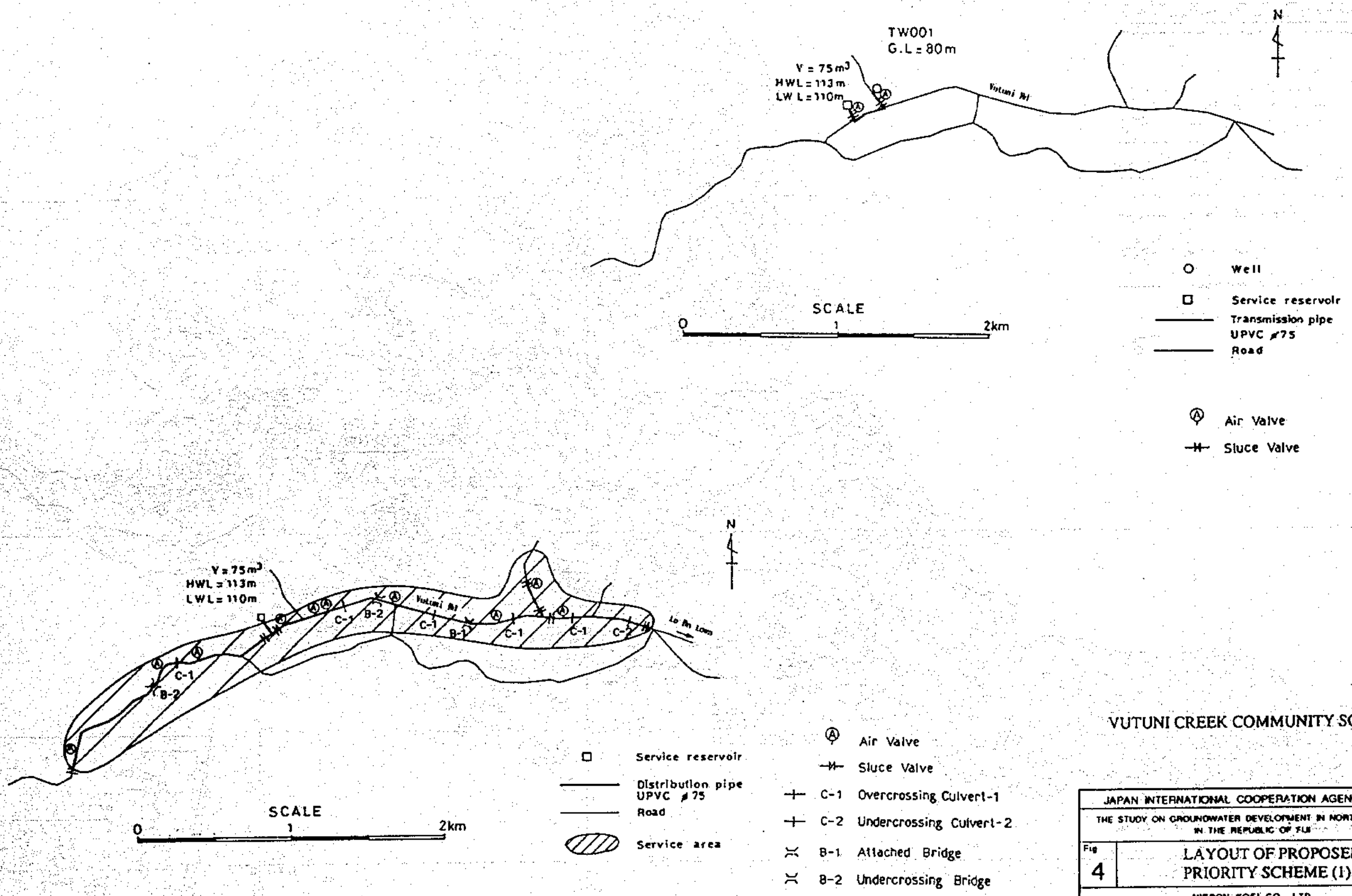


Fig. 2 GROUNDWATER REGIONS OF THE STUDY AREA



VITI LEVU
17°20'S
17°30'S
17°40'S
177°40'E
177°50'E
178°E
178°10'E
17°30'S
BA River
Nasivi River
Yaqara River
Penang River
T-34
B-32
NO.3 SCHEME
VATUYAKA
EXPANSION
GW35
B-57
NO.2 SCHEME
KUKUNIREWA
COMMUNITY
TW008
TAVUA
T-45
NO.6 SCHEME
RABULU
EXPANSION
R-18, R-19
GW254
R-31
R-16
R-26
RAKIRAKI
TW-012
NO.7 SCHEME
VAILEKA EMERGENCY
VATUKOULA
NO.1 SCHEME
VUTUNI CREEK
COMMUNITY
B-63
TW001
TW002
NO.8 SCHEME
YALALEVU
EMERGENCY
NO.4 and NO.5 SCHEME
TW004
TW003
VARADOLI-VEISARU
SUPPLEMENTAL
NO.9 SCHEME
TW006
KORONUBU
EMERGENCY
B-19
B-58
GW254 Well
Service reservoir
Transmission pipe line
R-26 Service area
Contour line (in meter)
Supplementary contour line (in meter)
Supplementary contour line (in meter)
River
Road
Town
Sea coast & Mangrove area
Boundary of the study area
0 5 10 15 km
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
THE STUDY ON GROUNDWATER DEVELOPMENT IN NORTH VITI LEVU IN THE REPUBLIC OF FIJI
Fig. 3
LOCATION MAP OF DEVELOPMENT SCHEMES
NIPPON KOEI CO., LTD
NIKKO EXPLORATION & DEVELOPMENT CO., LTD



VUTUNI CREEK COMMUNITY SCHEME

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THE STUDY ON GROUNDWATER DEVELOPMENT IN NORTH VITI LEVU IN THE REPUBLIC OF FIJI

Fig 4 LAYOUT OF PROPOSED PRIORITY SCHEME (1)

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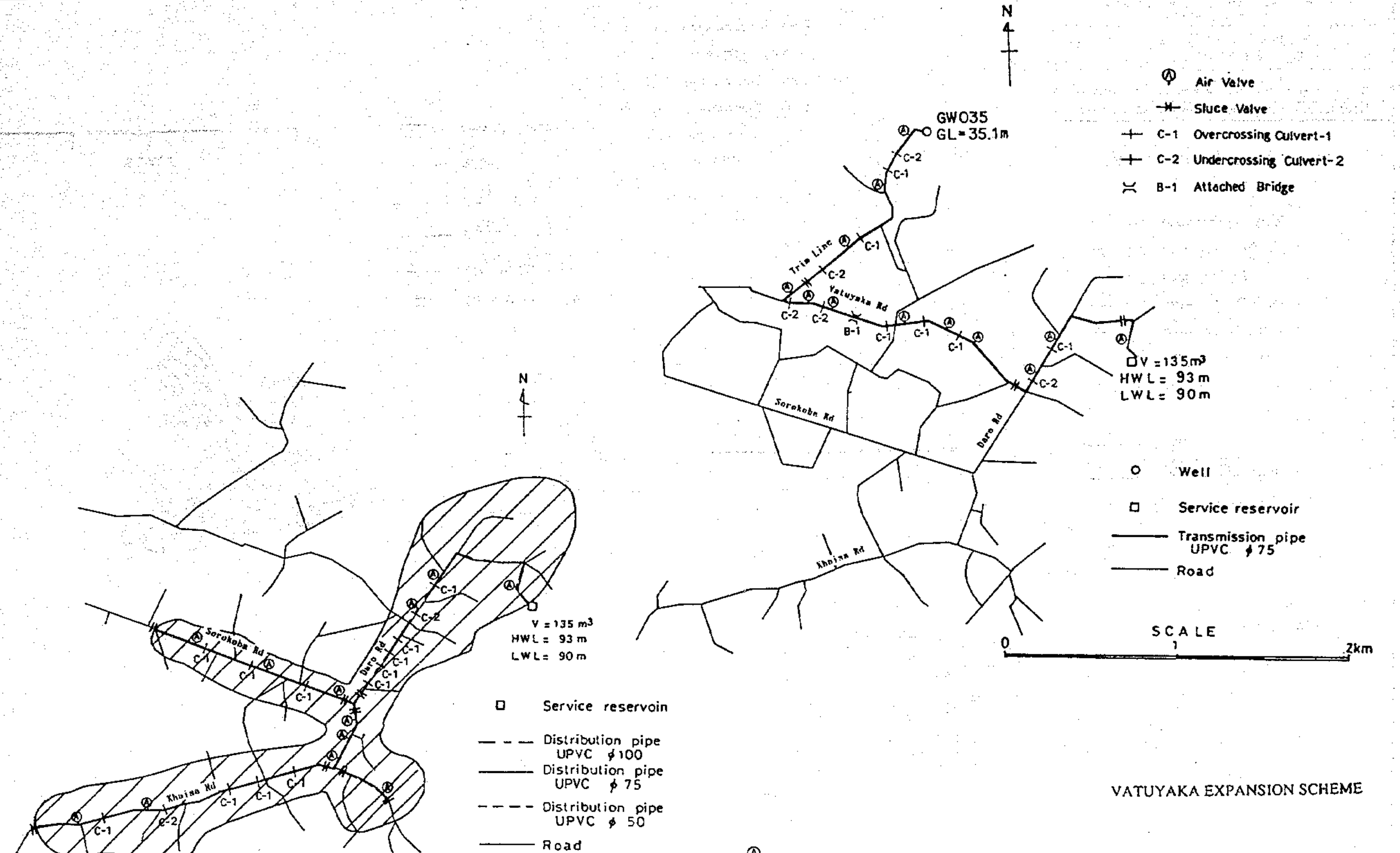
NIKKO EXPLORATION & DEVELOPMENT CO., LTD.

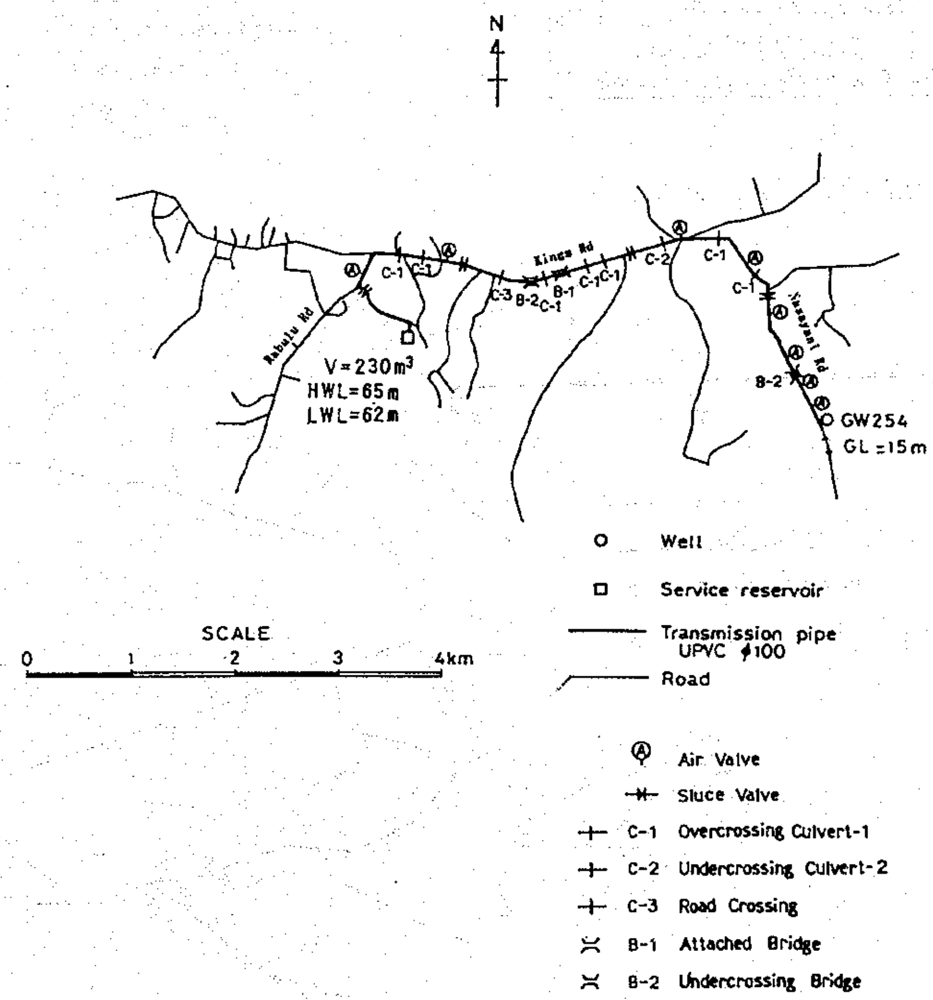


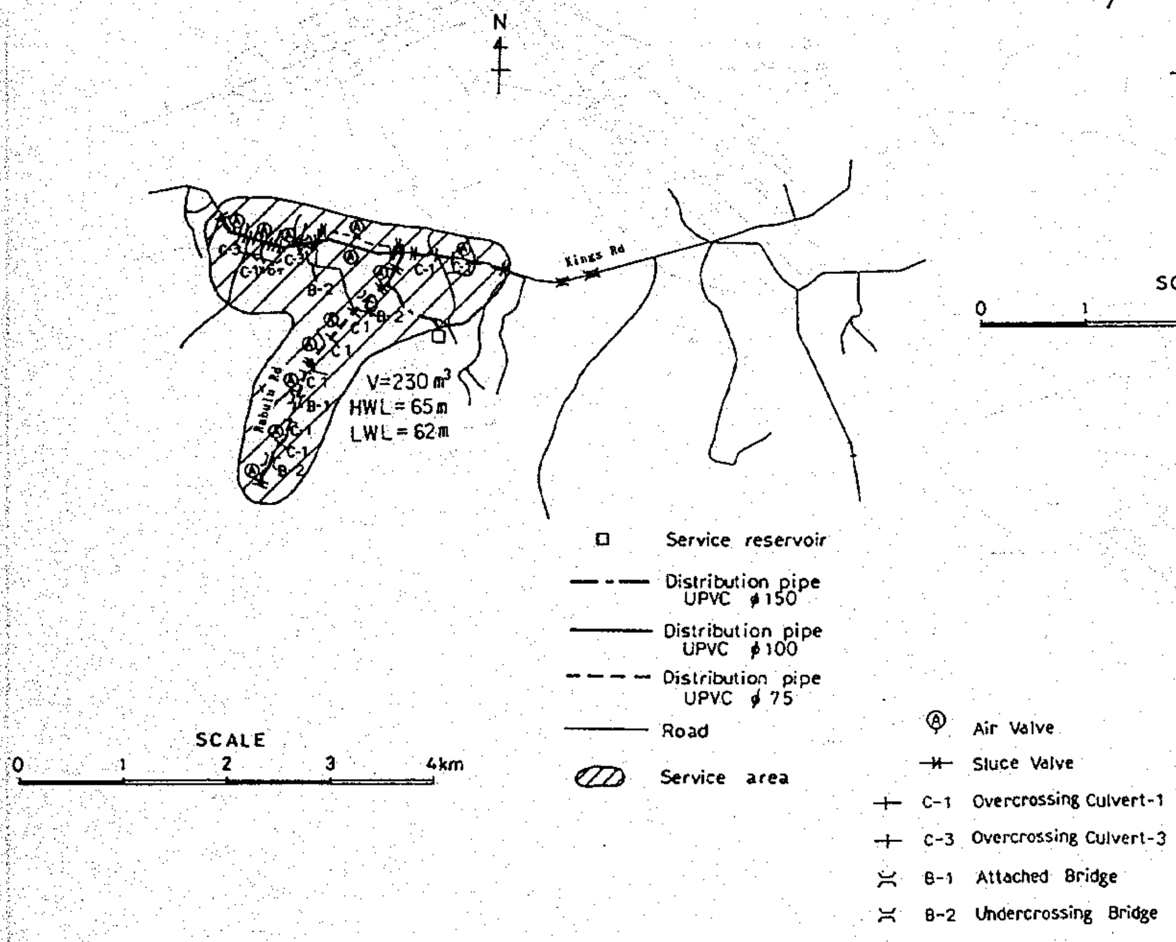
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

THE STUDY ON GROUNDWATER DEVELOPMENT IN NORTH VITI LEVU IN THE REPUBLIC OF FIJI

Fig. 4 LAYOUT OF PROPOSED PRIORITY SCHEME (2)

NIPPON KOEI CO., LTD
NIKKO EXPLORATION & DEVELOPMENT CO., LTD





RABULU EXPANSION SCHEME

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
THE STUDY ON GROUNDWATER DEVELOPMENT IN NORTH VITI LEVU IN THE REPUBLIC OF FIJI

Fig. 4 LAYOUT OF PROPOSED PRIORITY SCHEME (3)

NIPPON KOEI CO., LTD
NIKKO EXPLORATION & DEVELOPMENT CO., LTD