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JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

THE SOCIALIST REPUBLIC OF VIET NAM
MINISTRY OF AGRICULTURE AND RURAL DEVELOPMENT

THE MASTER PLAN STUDY
ON
DONG NAI RIVER AND SURROUNDING BASINS
WATER RESOURCES DEVELOPMENT

FINAL REPORT

VOLUME IV

APPENDIX II TOPOGRAPHY AND GEOLOGY
APPENDIX III METEOROLOGY AND HYDROLOGY

AUGUST 1996

NIPPON KOEI CO., LTD., TOKYO JAPAN

This Report consists of

Volume I	Executive Summary	
Volume II	Main Report	
Volume III	Appendix I	Socio-economy and Institution
Volume IV	Appendix II	Topography and Geology
	Appendix III	Meteorology and Hydrology
Volume V	Appendix IV	Natural Environment
Volume VI	Appendix V	Hydropower Generation
Volume VII	Appendix VI	Agricultural Development and Irrigation
Volume VIII	Appendix VII	Domestic and Industrial Water Supply
Volume IX	Appendix VIII	Flood Mitigation and Urban Drainage
	Appendix IX	Salinity Intrusion
Volume X	Appendix X	Formulation of Master Plan
Volume XI	Data Book	

The cost estimate was based on the December 1995 price level and expressed in US$ according to the exchange rate of US$ 1.00 = Vietnamese Dong 11,014 = Japanese Yen 101.53 as of December 15, 1995.

LIST OF ABBREVIATIONS

AFS	Agriculture and Forestry Service (PC)
CEMMA	Committee for Ethnic Minorities and Mountainous Areas
DCWSSS	Design Company for Water Supply and Sanitation System (HCMC-PC)
EA	Environment Assessment (Multi-lateral Lending Agencies)
ECSP	Evaluation Commission for State Projects
EIA	Environmental Impact Assessment
ENCO	Ho Chi Minh City Environmental Committee
EVN	*General Company of Electricity of Viet Nam (Abolished and renamed in November 1995 as Vietnamese Power Corporation)*
FIPI	Forest Inventory and Planning Institute (MOARD)
GCOP	Governmental Committee on Organization and Personnel
GDLA	General Department of Land Administration
GDMH	General Department of Meteorology & Hydrology
GOV	Government of Viet Nam
GSO	General Statistical Office
HCMC	Ho Chi Minh City
HEC	Ho Chi Minh Environment Committee (HCMC)
HIDC	Hydraulic Investigation and Design Company (MOARD)
HPC	Ho Chi Minh People's Committee (HCMC)
HSDC (or SDC)	Ho Chi Minh Sewerage and Drainage Company (HCMC)
HWSC (or WSC)	Ho Chi Minh Water Sypply Company (HCMC)
IDD	Irrigation and Drainage Department (MOARD)
IEE	Initial Environmental Examination
IER	Institute for Economic Research (HCMC-PC)
IHPH	Institute of Hygiene and Public Health (MOPH)
IM	Institute of Mines (MOID)
INVESCo	Investment Company for the Development of Water Sector (HCMC-PC/TUPWS)
IOE	Institute of Energy (MOID)
IURP	Institute of Urban and Rural Planning (HCMC-PC/Construction Service)
IWRE	Institute of Water Resources Economics (MOARD)
IWRP	Institute of Water Resources Planning (MOARD)
IWRR	Institute of Water Resources Research (MOARD)
JICA	Japan International Cooperation Agency (Japan)

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IWRE	Institute of Water Resources Economics (MOARD)
IWRP	Institute of Water Resources Planning (MOARD)
IWRR	Institute of Water Resources Research (MOARD)
JICA	Japan International Cooperation Agency (Japan)

MOAFI	*Ministry of Agriculture and Food Industry (Abolished and integrated into the new MOARD)*
MOAP	Ministry of Aquatic Products
MOARD (New)	Ministry of Agriculture and Rural Development (Created in October 1995 by the merger of the former Ministry of Water Resources, Ministry of Agriculture and Food Industry and Ministry of Forestry)
MOC	Ministry of Construction
MOCI	Ministry of Culture and Information
MOD	Ministry of Defence
MOE	*Ministry of Energy (Abolished and integrated into the new MOID)*
MOET	Ministry of Education and Training
MOFI	Ministry of Finance
MOFO	*Ministry of Forestry (Abolished and integrated into the new MOARD)*
MOFA	Ministry of Foreign Affairs
MOHI	*Ministry of Heavy Industry (Abolished and integrated into the new MOID)*
MOID(New)	Ministry of Industry (Created in November 1995 by the merger of the former Ministries of Heavy Industry, Light Industry and Energy)
MOJ	Ministry of Justice
MOIT	Ministry of Interior
MOLI	*Ministry of Light Industry (Abolished and integrated into the new MOID)*
MOLWISA	Ministry of Labour, War Invalids and Social Affairs
MOPH	Ministry of Public Health
MOPI (New)	Ministy of Planning and Investment (Formed from a merger of the former SPC amd SCCI)
MOSTE	Ministry of Science, Technology and Environment
MOTC	Ministry of Transport and Communications
MOT	Ministry of Trade
MOWR	*Ministry of Water Resources (Abolished and integrated into the new MOARD)*
MPAC	Ministrial Project Appraisal Committee
NEA	National Environment Agency
NGO	Non-Governmental Organization
NIAPP	National Institute for Agricultural Planning and Projection
NPAC	National Project Appraisal Committee
OECC	Overseas Environmental Cooperation Centre
OECF	Overseas Economic Cooperation Fund (Japan)
PC	People's Committee (executive arm of the People's Council)

PCC	Power Construction Company (VPC)
PIDC	Power Investigation and Design Company (VPC)
PPC	Provincial People's Committee (City People's Committee = CPC)
SBV	State Bank of Viet Nam
SCCI	*State Committee for Cooperation and Investment (Abolished and integrated into the new MOPI)*
SFEZ (or SFEA)	Southern Focal Economic Zone (or Southern Focal Economic Area)
SIWRP	Sub-Institute of Water Resources Planning (MOARD-IWRP)
SIWRR	Southern Institute of Water Resources Research (MOARD)
SPC	*State Planning Committee (Abolished and integrated into the new MOPI)*
SRV	Socialist Republic of Viet Nam
UNDP	United Nations Development Programme
UNICEF	United Nations International Children's Education Fund
UNIDO	United Nations Industrial Development Agency
VPC (New)	Vietnam Power Corporation (the former General Company of Electricity of Viet Nam = EVN)
WASECO	Water and Sewerage Construction Company (MOC)
WB	World Bank
WHO	World Health Organization
WPMI (IWRPM)	Water Planning and Management Institute (MOARD)
WRD(or WRS)	Water Resources Department or Water Resouce Service (PC)
WSC	Water Supply Company (under Construction Services of the PC)

Note : Abbreviations in *Italics* are no more existent (already abolished and integrated in November 1995).

Measurements

Length

mm	=	millimeter
cm	=	centimeter
m	=	meter
km	=	kilometer
ft	=	foot
yd	=	yard

Area

cm^2	=	square centimeter
m^2	=	square meter
ha	=	hectare
km^2	=	square kilometer

Volume

cm^3	=	cubic centimeter
l	=	litre
kl	=	kilolitre
m^3	=	cubic meter

Weight

g	=	gram
kg	=	kilogram
ton	=	metric ton

Time

s	=	second
min	=	minute
h	=	hour
d	=	day
y	=	year

Electric Measurements

V	=	Volt
A	=	Ampere
Hz	=	Hertz (cycle)
W	=	Watt
kW	=	kilowatt
MW	=	Megawatt
GW	=	Gigawatt

Other Measures

%	=	percent
PS	=	horsepower
°	=	degree
10^3	=	thousand
10^6	=	million
10^9	=	billion

Derived Measures

m^3/s	=	cubic meter per second
kWh	=	Kilowatt hour
MWh	=	Megawatt hour
GWh	=	Gigawatt hour
kVA	=	kilovolt ampere

Currencies

US$	=	US Dollar
VND	=	Vietnamese Dong

Volume IV

Appendix II

TOPOGRAPHY AND GEOLOGY

APPENDIX II
Topography and Geology

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1. TOPOGRAPHY

1.1 Topographic Condition in the Study Area

The main stem of the Dong Nai River originates from the high hills (El. 1,000 to 2,000 m) lying in the northern end of Lam Dong province, initially taking the southwestward direction in its flow course. After the join of the Da Dung River from east, the Dong Nai River turns its flow direction to west, making the border line between Lam Dong and Dac Lac provinces.

After passing counter-clockwisely along the border lines between Dac Lac and Lam Dong provinces and between Lam Dong and Song Be provinces, the Dong Nai River heads its flow direction to south-east. After the join of the Da Te River from north-east, the Dong Nai River changes its flow direction to south-west, and crosses Dong Nai province. Meandering east of Ho Chi Minh City, the Dong Nai River finally debouches in the South China Sea with a catchment area of 40,683 km^2 at the estuary including the tributaries.

There are two main tributaries, the La Nga and Be rivers, in the Dong Nai River besides the Saigon River meeting into it about 30 km upstream of the estuary and the Vam Co River merging into it almost at the estuary. The La Nga River originating from the south-west flank of Mt. Pantar (El. 1,654 m) in Lam Dong province lies in the south of the basin consisting of the main stem of Dong Nai River. Meandering westwardly, the La Nga River merges into the Dong Nai River at Thanh Son.

The origin of the Be River lies in the Tuy Duc mountain area (El. 950 to 1,000 m) standing on the international border between Viet Nam and Cambodia in Dac Lac province, and its main tributary called the Dac Hoyt River runs south-westwardly by forming the international boundary between the two countries. The Be River meets the Dong Nai main stem downstream of the Tri An damsite after passing the wide valley extending in the centre of the Song Be province.

The Saigon River, which originates from the southern flank of the hill (El. 100 to 200 m) bordering with Cambodia in Tay Ninh province, has characteristics of gentle slope and meandering. Five km upstream of the confluence with the Dong Nai, there is the Saigon inland port, which is the pivot of navigation to support the economic activities in Ho Chi Minh City and the Mekong Delta.

In the west of the Saigon River, there is the Vam Co River, which has two main tributaries; the East Vam Co River and the West Vam Co River. Both of them originate in the low hill area lying in Cambodia and gently flow down south-eastwardly through the wide plain extending in the Long An province, finally merging into the Dong Nai River near the estuary.

In the coastal zone of the Study Area, south of the La Nga River basin, there are several rivers such as Cai, Luy, Phan, Dinh and Rai, which directly debouch in the South China Sea. Due to small catchment area, i.e. 1,000 to 2,000 km^2, and dry climate, these rivers are a less reliable source in terms of water resources development.

Catchment area of the rivers in the Study Area totals to 48,471 km^2 and is summarized as follows:

River	Point to measure the catchment area	Catchment area, km^2
Dong Nai	Confluence at the Be River including the La Nga River basin	14,979
Dong Nai	From the confluence at the Be River to the estuary	4,093
Be	Confluence at the Dong Nai	7,201
Saigon	Confluence at the Dong Nai	4,316
West Vam Co	Confluence at the East Vam Co excluding the west bank area	921
East Vam Co	Including the estuary	5,005
	Total of the Dong Nai River basin	36,515
Coastal Rivers	Estuaries with north-east bound of Khanh Hoa/Ninh Thuan province	11,956
	Total of the Study Area	48,471

The Be River, the Saigon River and the East Vam Co River include a catchment area of 4,168 km^2 in the territory of Cambodia, and thus the total catchment area of the Dong Nai River becomes 40,683 km^2.

1.2 Topographic Maps Available in the Study Area

Topographic maps with a scale of 1 to 250,000, 1 to 100,000, 1 to 50,000 and 1 to 10,000 are available in the Study Area. Maps with a scale of 1 to 250,000 were prepared in the year 1972 for the entirety of the Study Area, whilst topographic maps with a scale of 1 to 100,000 were reproduced by reducing the scale of 1 to 50,000 scale topographic maps, which were prepared in the year 1965 and reprinted in the year 1975. Both of 1 to 100,000 and 1 to 50,000 scale topographic maps are available for the whole of the Study Area.

Topographic maps with a large scale of 1 to 10,000 are available in and around the Ho Chi Minh City area. Furthermore, the same scale maps were prepared especially for planning the

projects of Dai Ninh, Dong Nai No. 3, Dong Nai No. 4, Dong Nai No. 5, Dong Nai No. 8, Can Don, Phuoc Hoa and Da Den by the Ministry of Industry (then Ministry of Energy) and the Ministry of Agriculture and Rural Development (then Ministry of Water Resources).

1.3 Topographic Surveys

Topographic surveys to prepare river cross sections and profiles have been carried out by the Study Team in the lower reaches of the Dong Nai River, the Saigon River, the East Vam Co River and the West Vam Co River for the salinity intrusion survey over a period of December 1994 to March 1995. The survey area is depicted in Figure 1.1, and the work quantity is summarized below:

Name of Rivers	Extent of Survey (Longitudinal profile)	Number of Cross Sections
Dong Nai River	From river mouth to 85 km upstream	18 sections
Saigon River	From river mouth to 60 km upstream	17 sections
East Vam Co River	From river mouth to 120 km upstream	23 sections
West Vam Co River	From river mouth to 120 km upstream	22 sections
Total	385 km	80 sections

It is noted one section in the tributary of the Dong Nai River, four sections in the tributaries of the Saigon River and one section in the tributary of the East Vam Co River are included in the above work quantity.

The other topographic survey to prepare river cross sections was carried out through the field work of Phase III for three dam projects, Dong Nai No. 3, Fu Mieng and Luy which are among the selected master plan projects, to supply more reliable topographic data for the design of those three projects. Work quantity of the cross section survey is summarized below:

Project	Number of Cross Sections	Total Surveyed Length, m
Dong Nai No. 3	3	1,600
Fu Mieng	2	3,800
Luy	3	4,400

It is noted that it was intended in Phase I to prepare 1 to 10,000 scale topographic maps by applying photogrammetry for promising dam projects, but was cancelled due to availability of such a scale topographic map for those promising dam projects.

2. GEOLOGY

2.1 General

Central to southern part of Viet Nam is situated on the Indosinian Platform, the central core of so-called Indosinian Continent that was built up by Mesozoic orogenesis and has been established up to the present time. Basement rock of this region is metamorphic rocks of Late Pre-Cambrian or Early Paleozoic, which are covered by folded sedimentary rocks of Paleozoic to Mesozoic eras. Also widely distributed are intensive granites and volcanic rocks, including andesites and basalts, formed in the course of the orogenic movement. While Tertiary sediments are very limited in distribution, Quaternary deposits are located at many places along rivers. Especially in the southernmost part of the country thick Quaternary deposits are formed in an extensive plain of 100 km in width developing from the Mekong Delta north-west toward Cambodia.

2.2 Regional Geology

From the geological point of view, the Study Area can be divided into three regions, i.e. the Dong Nai River basin including the La Nga River basin, the Be River and Vam Co River basins and the coastal zone. The geological conditions of the Study Area are illustrated in Figure 2.1 and stratigraphy is presented in the Table below:

Sedimentary Deposit/Rocks

Cenozoic	Quaternary		Deposit not cemented, clay, silt, sand and gravel
	Neogene		Siltstone and mudstone
		Di Linh	Sandstone with cobble and siltstone, mudstone containing coal and organic matters
Mesozoic	Cretaceous	Dong Duong	Rhyolite, dacite, tuff and sandstone
		Bao Loc	Andesite, dacite, tuff and sandstone
	Jurassic		
		Ban Don	Mainly siltstone, sandstone and clayey schist
Paleozoic	Permian	Ta Thiet	Sandstone, conglomerate, clayey schist and limestone

Igneous Rocks

Geological	Time	Formation	Geological Description
Cenozoic	Quaternary		Olivin basalt
			Dolerite basalt and olivine basalt
	Neogene		
Mesozoic	Cretaceous		Granite and diorite

The upper reaches of the Dong Nai River and La Nga River basins are mainly composed of Mesozoic sediments, intrusive rocks and basaltic rocks of Tertiary to Quaternary volcanic activities. Out of Mesozoic sediments, Ban Don formation of the Jurassic period is widely distributed. Bao Loc formation of Jurassic to Cretaceous and Dong Duong formation of Cretaceous mainly predominate on the central and eastern parts of the basin. These sedimentary rocks are strongly folded due to the tectonic stress, and their folding axes and bedding plane indicate the north-easterly and north-westerly direction. Most of faults and fractured zones also show the similar trends. Diorite and granite, intruded into sedimentary beds, occur at many places while Neogen sediment rock, Di Linh formation, can be recognised at the limited area along the Dong Nai River and La Nga River basins, and the Be River basin, which is characterized by plains and low hills, is mainly composed of basalts and uncemented deposits of Quaternary. Basalts covering Mesozoic sediments and Neogen-Quaternary basalts are distributed between the left bank of the Dong Nai River and the coastal line. Quaternary deposits that consist of sand, silt and clayey soil with occasional organic matters are wide-spread on the south to south-west of the basin.

The Saigon River and Vam Co River basins are basically composed of Quaternary and Neogene-Quaternary deposits which make expanded plains. Actually, the plain is completely flat and merges the Mekong Delta in the west. Neogene-Quaternary deposits, composed of siltstone and mudstone, are distributed along the Saigon River between the middle part of the basin and the confluence with the Dong Nai River. Quaternary deposits consisting of transported alluvial materials ranging from clay to gravel are wide-spread on the greater part of the basin. While, Paleozoic sedimentary rocks, the oldest formation in the Study Area, appear at the limited small places near the Cambodian border.

The coastal zone in which several rivers are flowing into the South China Sea is characterized by mountain zone of Mesozoic sedimentary and intrusive rocks, and plains of Quaternary deposits. Mesozoic sedimentary rocks, Ban Don, Bao Loc and Dong Duong formations, are distributed along the mountain ranging from the north-east to the south-west. Granite and diolite chiefly occur not only at the mountain but also at the east coast area. Besides, many small-scale independent mounts of Mesozoic sedimentary and intrusive rocks can be found at the many places in the plain. Quaternary deposits can be distinguished into alluvial and marine deposits. Alluvial deposits, mainly composed of sand and clayey soil, are well-spread in the

plain. Marine deposits, mainly sand, form continuous sand dune with its width of 5 to 20 km along the coastal line.

2.3 Geological Conditions at the Potential Damsites

Geological field reconnaissance was carried out for six out of 17 proposed damsites during 22 to 29 November 1994 in collaboration with SIWRP. On the basis of collected data, field reconnaissance results and topographic and geological maps, geological conditions at the proposed damsites, the location of which is referred to Figure 2.2, are summarized in Table 2.1 and discussed as below:

(1) Dong Nai River Basin

Dai Ninh Damsite

The damsite is located 700 m upstream of the Dai Ninh Bridge. Sandstone of Dong Duong formation interbedded with siltstone exposes at the riverbed and the top of both banks. The weathered layer is approximately 10 to 20 m thick. A rockfill type is suitable for dam construction.

Dong Nai No. 1 Damsite

Geology at the damsite is characterized by Neogene-Quaternary and Neogene formation. Both abutments are gentle with a gradient of 10 to 15 degree. Soft rock of Neogene is distributed on the riverbed. Geological points to be considered when the dam is constructed are extensive wethering developed at both the banks. Basement rocks on the riverbed with small bearing strength and high permeability and older river deposits under basalt lava have a high possibility of leakage.

Dong Nai No. 2 Damsite

Both abutments at the damsite are steep with a gradient of around 30 degree. Fresh rocks mainly consisting of granite in Cretaceous and Dong Duong formation expose on the riverbed and the abutments. This fact suggests that the concrete type will also be included as one of dam type alternatives for construction.

Dong Nai No. 3 Damsite

Slope gradients fall in a range of 15 to 20 degree at the right bank of damsite and around 20 degree at its left bank. Judging from the topographic conditions and gentle slope, it is assumed that strong weathering acts on both abutments, of which basement rock is Ban Don formation. A rockfill type is thus recommended for dam construction.

Dong Nai No. 4 Damsite

Ban Don formation and Neogene-Quaternary basalt are distributed around the damsite. Both abutments are steep with their gradients of 40 degree at the right bank and 35 degree at the left bank. The riverbed is 120 m wide. Basalt covers Ban Don formation around the elevation of 500 to 600 m on both banks. Three faults have been found at the damsite. Due to the strong weathering, rockfill type dam will be suitable to adopt. It is noted that geological investigation as part of its feasibility study was carried out by the then Ministry of Energy.

Dong Nai No. 5 Damsite

Geological condition, identified as Ban Don formation and Neogene-Quaternary basalt, is supposed almost similar to that of Dong Nai No. 4. The slope gradients are 35 degree at the right bank and 30 degree at the left bank. The riverbed is 100 to 150 m wide. In case of exposure of fresh rocks on the riverbed and the abutments, concrete gravity dam will also be included as a dam type to be selected for construction.

Dong Nai No. 6 Damsite

Ban Don formation is distributed at the damsite. The slope gradient is 25 degree at the left bank, and the slope at the right bank changes place by place, but is generally gentle. Due to 500 to 600 m wide riverbed, deep soft foundation on the riverbed and extensive weathering at both the abutments, the rockfill type will be appropriate for the construction of Dong Nai No. 6 dam.

Dong Nai No. 8 Damsite

The damsite predominant with the gentle hill is composed of Quaternary basalt and Ban Don formation. It was confirmed through field reconnaissance that basalt occurs at and around the damsite because hard boulders of basalt are widely scattered on the surface of the left bank. Sandstone interbedded with mudstone appears on the riverbed 400 m downstream of the damsite. Due to extensive weathering at both abutments, existence of old river deposits under basalt and permeability of the porus basalt, leakage is expected to cause from the reservoir. A rockfill type will be appropriate for the construction of Dong Nai No. 8 dam.

(2) La Nga River Basin

Ta Pao (La Nga No. 3) Damsite

The riverbed at the damsite is about 2 km wide. Fine sandstone interbedded with mudstone of Ban Don formation is distributed about 500 m downstream of the right bank. Granite occurs at the left bank but its accurate border with sedimentary rocks is not clear. No fresh rock can be found at the damsite. Rockfill type dam is suitable because of thick and soft river deposit and intensive weathering at both abutments.

Bao Loc Damsite

The damsite is located at the narrow valley with a slope gradient of around 30 degree at both banks. Granite of Cretaceous is predicted to be distributed. If fresh rocks can be found near the surface without extensively weathered layers, the concrete type besides the rockfill type will also be discussed as an alternative of the dam to be constructed.

(3) Be River Basin

Can Don Damsite

The damsite is situated in the undulating hill with their maximum height of 30 to 40 m above the riverbed, and Ban Don formation can be found at the site. Clayey schist occurs on the right edge of the riverbed. The strike and dip of foliation are N10E – N25E and 60 – 80° SW, respectively. Due to the topographic condition and the strongly developed weathering at the left bank, earthfill type dam or rockfill type dam is conceivable. Outcrops of basalt excluding its boulder are hardly found around the damsite.

Fu Mieng (Con Don) Damsite

The damsite lying in the gentle hill consists of Ban Don formation. From a geological point of view, weathered layers such as residual soil and decomposed rocks are expected to be thick, so earthfill type dam or rockfill type dam is acceptable.

Phuoc Hoa Damsite

The damsite lies in the plain composed of siltstone and mudstone of Neogene-Quaternary deposit overlain by coarse sand with gravel. Judging from topography and geological conditions at the site, the dam height is strictly limited.

(4) River Basin in the Coastal Zone

Ca Giay Damsite

The damsite lies in the undulating hill, and Dong Duong formation is distributed around the damsite. On both sides of the river, terrace widely developed is easily recognized. Hard rhyolite with joints occurs at the riverbed. Judging from the result of field reconnaissance, the weathered zone can be expected thick at both banks. Thus, rockfill dm is acceptable as a dam type.

Song Luy Damsite

The riverbed is about 3.5 km wide at the damsite. According to the geological map, granite of Cretaceous presents on the right bank, whilst Quaternary basalt on the left bank. Judging from topographic condition, rockfill type dam is adequate at the proposed damsite. Taking into

consideration the bearing strength of Quaternary deposits covering basement rock in the riverbed and permeability of basalt and older river deposits overlain by basalt, special attention should be paid to the leakage from the reservoir in the further study.

Song Ray Damsite

The riverbed is around 60 to 70 m wide at the damsite. Sandstone interbedded with mudstone of Dong Duong formation and intrusive granite of Cretaceous can be found 100 to 300 m upstream of the damsite. Both banks at the damsite are covered with Quaternary basalt because many hard basalt boulders are scattered on the left bank widely. In spite of fresh rock exposure on the riverbed, rockfill type dam can be acceptable due to extensive weathering of both banks.

Da Den Damsite

The damsite is located at the edge of undulating hill. In spite of fresh rock exposure on the riverbed, Neogene-Quaternary deposit is distributed. According to the geological map, siltstone may be distributed at and around the damsite. From a topographic point of view, rockfill type dam is suitable as a dam type, even if its height is strictly limited.

2.4 Dam Geology for the Master Plan Projects

2.4.1 Introduction

Master plan projects in this study were selected as follows:

a) Projects for the enhancement of living standard in the rural area

- Implementation of 1,207 rural water supply projects, and
- Improvement and rehabilitation of 164 existing small scale irrigation projects as well as the implementation of 65 new small scale irrigation projects, and

b) Projects for sustainable economic development

- Implementation of two hydropower projects (420 MW in total) with a reservoir, Dong Nai No. 3 (180 MW) and Dong Nai No. 4 (240 MW),
- Implementation of Fu Mieng (55 MW) multipurpose and Song Luy irrigation reservoirs,
- Implementation of ten irrigation projects (242,560 ha in total), Phuoc Hoa (45,680 ha), Dau Tieng Extension (48,390 ha), Phan Ri (29,700 ha), Phan Thiet

(10,000 ha), Ta Pao (19,000 ha), Vo Dat (12,620 ha), Long An Delta (31,170 ha) and HCMC Delta (46,000 ha), and

- Water supply project along National Highway No. 51 (a development demand of 1.7 million m^3/day).

Geological discussions for the master plan projects are mainly devoted for the dam projects such as Dong Nai No. 3, Dong Nai No. 4, Fu Mieng and Song Luy as well as La Buong, Song Ca and Phuoc Thai which are the projects considered as one of water sources for the water supply project along National Highway No. 51. It is noted that geological maps at a scale of 1 to 10,000 were prepared for the Dong Nai No. 3, Fu Mieng and Song Luy damsites to supplement geological investigation. Following are the mapped areas for those projects:

Project	Mapped Area, km^2
Dong Nai No. 3	2.6
Fu Mieng	18.0
Luy	10.0

Following is the geological discussion for the selected master plan projects.

2.4.2 Dong Nai No. 3

Two damsites (Alternative-1 and Alternative-2) shown in Figure 2.3 have been under consideration as alternative damsites. The geological conditions of both damsites can be clarified as discussed below.

(1) Alternative-1 (Upstream)

The riverbed is 150 m wide and the gradient of both abutments is around 30°. The basement rocks as shown in Figure 2.3 consist mainly of dark-gray shale interbedded by fine to medium grained sandstone of Ban Don formation in the Middle Jurassic. Fresh basement rocks are exposed at the riverbed of the damsite and the bedding planes, in a direction at an angle of 20° to the dam axis, strike N45-60E and dip 50-60S. While, joints are well-developed with their strikes of N40-45W and vertical dips, and each joint shows its interval of 5 cm to 100 cm. In general, the part of chiefly fresh sandstone is hard and massive, but shale is hard but fissile. Basaltic rocks, identified as lava flows in the Neogene-Quaternary, are in unconformity with the basement rocks underlying and form the flat-topped mountain of the right bank, higher than 650 m in elevation. Colluvium deposits including residual soil are distributed at the foot and

on the gentle slopes of both banks, and small terrace deposits present at the brink of riverbed sporadically.

The thickness of the weathered layers, not certain because of no drilling data, can be estimated at 10 to 20 m but partially more than 20 m at both banks. No major fault can be observed except for a few small-scale shear zones parallel to the direction of bedding planes and joints at and around the damsite.

Judging from engineering geology, it is considered that fresh rocks free from weathering have sufficient strength for an around 100 m high concrete type dam as well as low impermeability because of well-contacted bedding planes in-place and no large fractured zones. However, some weathered zones having open cracks can be evaluated to be permeable.

In regard with core materials, extensively weathered layers of the basaltic rocks and sedimentary rocks as well as colluviam deposits distributed within 3 km of the damsite can be used. In addition, excavated materials of fresh basaltic rocks and massive sandstones produced during the period of construction may also be available. As filter and concrete aggregates, crushed basalt and sandstone should be proposed due to the reason that only small amounts of sand and gravel can be found at and along the edge of river course locally.

(2) Alternative-2 (Downstream)

The riverbed is 120 m wide and the gradient of the right bank is nearly 45°, whilst around 40° for the left bank. Geological conditions at the damsite are almost the same as that of Alternative-1. The basement rocks as shown in Figure 2.3 consist mainly of fine to medium grained sandstones with their alternating beds of shale, dark gray, of Ban Don formation in the Middle Jurassic. Fresh basement rocks, hard and massive, are exposed widely at and around the damsite and form 2 m high rapids across the riverbed. The bedding planes, parallel to the dam axis, strike N45-60E and dip 65-75S. Joints are well-developed with their strikes of N35W and vertical dips. Interval of each joint and bedding planes is 5 cm to 100 cm. While, basaltic rocks in the Neogene-Quaternary are in unconformity with the basement rocks and form the flat-topped mountain of the right bank, higher than 650 m in elevation. In general, colluvium deposits are considered to be thin due to direct existence of the weathered rocks on the surface of both banks. The thickness of the weathered layers, less extensively, can be estimated at 10 to 20 m at both banks. No major fault can be found except for a few small-scale shear zones parallel to the direction of bedding planes and joints at and around the damsite. A large-scale landslide, 700 m long and 650 m wide, is recognized 500 m upstream of the right bank of the damsite.

Foundation conditions as well as the availability of construction materials are the same as those of Alternative-1.

Judging from the topographic conditions with a rather wide valley as well as rather thick weathered zones on both abutments, a rockfill type dam can be recommended for Alternative-1 damsite, even if foundation condition allows the construction of concrete gravity type dam. Meanwhile, a concrete gravity type dam is adequate for Alternative-2 damsite because of narrow riverbed, steep stable abutments, wide exposure of fresh hard rocks and slight weathering. Prior to the selection of damsite from among both alternative damsites, stability analysis on large scale landsliding expected to cause after impounding warter in Alternative-2 reservoir is required.

2.4.3 Dong Nai No. 4

Feasibility study including field geological investigations was carried out for Dong Nai No. 4 by PIDC-1 in the year 1987. Geological conditions for Dong Nai No. 4 are summarized on the basis of the geological investigation through the feasibility study as well as geological data collected by the Study Team. The basement rocks as shown in Figure 2.4 consist mainly of fine to medium grained sandstones of Ban Don formation in the Middle Jurassic, interbedded by fissile shales, and their intervals are in a range of 5 to 100 cm. Fresh rocks, hard and massive, are exposed at the damsite, and the bedding planes, at a right angle to the dam axis, strike N45E and dip 60-70S. Joints are well-developed with their strikes of N35W and dip of 80S, and an interval of each joint falls in a range of 10 to 30 cm. While, basaltic rocks in the Neogene-Quaternary are in unconformity with the underlying basement rocks, forming the flat-topped mountain higher than 500 to 600 m in elevation. Colluvium deposits are distributed at the foot and on the gentle slopes of both banks. According to the drilling data, the thickness of colluvium deposits is in a range of 10 to 20 m at the right bank and 5 to 6 m at the left bank. Weathering is extensively proceeding and its thickness is 20 m, partially 40 m at both banks of the damsite. Three faults, which are parallel to the bedding plane and joints, are reported to exist at the damsite according to the PIDC-1 feasibility study report, but fractured zones are small like shear zones.

It is considered that the fresh rocks free from weathering have sufficient strength for the foundation of around 100 m high concrete gravity type dam. Fresh rocks indicate impermeability because of well-contacted bedding and joints in-place, and no large fractured zones. However, weathered zones having open cracks may be considered to be permeable. It is evaluated that three faults reported at the damsite may not be a serious problem to the dam construction because of their small scale.

According to the investigation result on embankment materials and rock materials carried out by PIDC-1, it is concluded that construction materials except for concrete aggregates are easy to obtain and that their quantity and quality are of no problem. On the other hand, according to

the field investigation result by the Study Team, extensive weathered layers of the basaltic rocks and sedimentary rocks as well as colluviam deposits distributed within a few kilometers of the damsite can be used as core materials. The soil mechanics analysis shown in Tables 2.2 and 2.3 indicates that optimum water content of the materials is 2 to 7 % wetter than natural water content. In addition, excavated materials produced during the period of construction can also be available for core materials. On the other hand, fresh basaltic rocks and massive sandstones can be regarded as rock materials. As filter and concrete aggregates, crushed basalt and sandstone should be proposed to use due to the reason that only small amounts of sand and gravel can be found at and along the edge of river course locally.

Judging from topographic and geological conditions, a rockfill type can be recommended for the construction of Dong Nai No. 4.

2.4.4 Fu Mieng

The damsite is located in the gentle and undulating hill. As shown in Figure 2.5, basement rocks distributed at and around the damsite consist of mainly fissile shales and sandstones of Ban Don formation in the Mesozoic-Jurassic. Small sporadical outcrops, slightly weathered, are recognized on the brink of the present river course around 500 m upstream of the damsite and at the bottom of small creek crossing the left bank. The bedding planes strike N20-30E and dip nearly vertical with downstream-ward tendency, and are in a direction at right angle to the river course. Flat strips along the river are identified as stream terrace, covered with thin layers of alluvial deposits. Basaltic rocks of the Neogene-Quaternary lie on the top of both banks, spreding in the area higher than 70 to 80 m in elevation. No fault except for a large scale fractured zone can be found at the damsite.

The foundation conditions of the damsite are not adequate for a concrete gravity type dam because of thick alluvium and colluvium unconsolidated deposits as well as extensively weathered layers more than 20 m in thickness. Fresh rocks may be impermeable, but the weathered layers have a tendancy to show high permeability due to open cracks. Thus, possibility of the leakage from the reservoir flowing through the basaltic rocks is conceivable. According to the geological map prepared by the Study Team, the possibility of leakage can be considered small because the distribution boundary between basaltic rocks and basement rocks is identified in the area higher than Full Supply Level of 77 m.

Embankment earthfill materials, such as colluvial deposits and weathered layers of both sedimentary rocks and basaltic rocks, can be obtained from the nearby area of the damsite. No appropriate rock materials and concrete aggregates cannot be found around the damsite. Judging from topographic and geological conditions, an earthfill type dam is recommended for

the construction of Fu Mieng dam. On the other hand, further detailed investigation is required for the possibility of leakage from the basaltic rocks.

2.4.5 Song Luy

The damsite is characterized by spacious riverbed around 4 km long and moderately steep abutments with their slop gradient of 30° at both banks. Intrusive granite in the Cretaceous, hard and blocky, occurs at the right bank of the damsite as shown in Figure 2.6. Shale in the Middle Jurassic has a well developed bedding plane and strikes N80 E and dips 70S. Rhyolite of Don Duong formation in the upper Cretaceous and aplite in the Paleogene present at the left bank. Basaltic rocks identified as lava flow in the Quaternary cover the entire riverbed and form a small scale gorge along the present river course. Colluvial deposits containing boulders and blocks lie over the foots of both banks. No remarkable fractured zone like a large scale fault is found.

The rocks at the damsite show sufficient bearing strength because of slight weathering and no strongly fractured zone. A major geological problem is the possibility of leakage from the reservoir to the downstream side through the basaltic rocks and the old river deposits under the basaltic rocks, because the basaltic rocks have horizontally continuous open cracks and old river deposits consist of unconsolidated permeable sand and gravel. Their accurate distribution cannot be defined through this study.

Construction materials for the Song Luy dam are considered to be obtained easily except for core materials. Granite which exists around the damsite can be designated as rock materials and concrete aggregates. Alluvial deposits lying upstream of the damsite as well as colluvial deposits and strongly weathered layers around the damsite can be used for embankment materials of the transition zone. Since any core material has not been found around the damsite, investigation to look for core materials is needed at and around the damsite.

Judging from topographic and geological conditions, a rockfill type is recommended for the Song Luy dam. The further extensive investigations on the leakage possibility from basaltic rocks and old river deposits are required. Depending upon the investigation result, a place located about 2 km upstream of the damsite would be proposed as an alternative damsite, at which alluvial deposits composed mainly of fine sand are prevailing in the riverbed.

2.4.6 Damsites for the Water Supply Project along National Highway No. 51

Geological conditions of three damsites, i.e. La Buong, Song Ca and Phuoc Thai, for urban water supply to Bien Hoa-Vung Tau industry zone were reviewed based on the geological maps at the scale of 1 to 50,000 prepared by Geological Survey of Viet Nam. For the other two promising damsites, Da Den and Song Ray, geological interpretation is referred to preceding Section 2.3.

(1) La Buong

The damsite is located in the undulating gentle hill about 20 km east-south-east of Bien Hoa. The riverbed, 1 km long, is covered with alluvial deposits of silt, sand and gravel. Besides, both banks of the damsite are composed of fluvial deposits in Pleistocene. Quaternary basaltic rocks are distributed at the right bank 2 km upstream of the damsite, and its upper layer becomes reddish clay due to highly weathering. The major geological problem is leakage from the reservoir to the downstream side through the foundation of sand and gravel.

Judging from topographic and geological conditions, the damsite is not suitable for high dam construction because of no stable abutment at both banks, insufficient bearing strength and high permeability of the foundation. Therefore, only an earthfill type dam could be proposed and the dam height must be strictly limited.

In view of hydrogeology, the foundation is evaluated to be a water bearing layer and also a good aquifer. Thus, extensive study to develop groundwater is recommended, instead.

(2) Song Ca

The damsite is located in the undulating hilly mountain about 30 km southeast of Bien Hoa. Two potential sites, i.e. Song Ca-1 and 2, are under consideration for dam construction. Quaternary basaltic rocks cover entire both damsites widely. In particular, fresh basaltic rock is exposed over the riverbed of the damsite and forms small rapids. A major geological problem is the possibility of leakage from the reservoir to the downstream side through the basaltic rocks and the old river deposit under the basaltic rocks because the basaltic rocks have horizontally continuous open cracks and old river deposits consist of unconsolidated permeable sand and gravel. Accurate distribution of permeable layers has to yet be revealed.

Judging from topographic and geological conditions, an earthfill type dam is recommended. The further extensive investigations on the leakage possibility through the basaltic rocks and old river deposits are required for further detailed study.

(3) Phuoc Thai

The damsite is located in the undulating gentle hill about 30 km north of Vung Tau. The riverbed, 500 m long, is covered with alluvial deposits mainly composed of sand with layers of clay or gravel. Besides, both banks of the damsite are composed of fluvial deposits in Quaternary, which are almost the same as alluvial deposits in terms of material composition. A major geological problem is the leakage from the reservoir to the downstream side through the Quaternary foundation of sand and gravel.

Judging from topographic and geological conditions, the proposed site is not suitable for high dam construction because of insufficient bearing strength and high permeability of the foundation. Therefore, only an earthfill type dam could be proposed and the dam height must be strictly limited. As same as the La Buong site, the foundation is evaluated to be a water bearing layer and also a good aquifer. Thus, an investigation to develop groundwater is recommended at the proposed damsite area.

3. HYDROGEOLOGY

3.1 Hydrogeological Conditions in the Study Area

3.1.1 Hydrogeological Area

Discussions on hydrogeological conditions in the Study Area are based on the hydrogeological map with a scale of 1: 500,000 and its explanation reference obtained from Hydro-Geology Division No. 8 and information on wells collected from the water supply companies of each province. Based on the assessment of hydrogeological conditions, the Study Area can be divided into five areas, lower plain area, central plateau area, granite-diorite area, coastal area and mountainous area as shown in Figure 3.1. Following is the summary of hydrogeological characteristics in each area.

(1) Lower plain area

The area, situated on the eastern margin of the Mekong Delta covering Tay Ninh, Long An, Ho Chi Minh City and some parts of Song Be and Dong Nai provinces, is characterized by flat terrain and is overlain by unconsolidated sedimentary deposits of Neogene-Quaternary ages. Among the sedimentary deposits, five layers, composed of mainly sand and gravel, are judged to have ample aquifers and are shown in the ascending order of geological ages as listed below:

Symbol	Age
Q_{IV}	Holocene aquifer complex
Q_{II-III}	Upper - middle Pleistocene aquifer
Q_I	Lower Pleistocene aquifer
N2	Pliocene aquifer
N1	Miocene aquifer

Main recharge sources to the aquifers are infiltration of rain and stream water along with seepage from unlined irrigation canals. It is furthermore inferred that the unconsolidated sedimentary deposits have a thickness of 300 m in Ho Chi Minh City and 400 to 500 m in Tan An, provincial town of Long An province.

(2) Central plateau area

The area, characterized by gentle hill and formed by basalt lavas erupted in Neogen-Quaternary ages, covers the upstream reaches of the Be River and some parts of Dac Lac, Dong Nai, Lam

Dong and Ba Ria-Vung Tau provinces. The basalts are 20 to 100 m thick and can be divided into two types according to the difference of eruption time as listed below:

Symbol	Age
$B(Q_I - Q_{IV})$	Middle Pleistocene-Holocene Basalt
$B(N2 - Q_I)$	Pliocene -Lower Pleistocene Basalt

Layers bearing groundwater are identified as fissure and porous zones horizontally extending in the basalts. Besides, there are old river deposits, overlain by basalts and recharged by rainfall. It is expected in the areas with these old river deposits that movement of groundwater is active, resulting in high possibility with good aquifers in quantity, even if possibility changes by place.

(3) Granite - diorite area

The areas, sporadically situated on the eastern part of the Study Area and composed of granite and diorite, cover some parts of Lam Dong, Ninh Thuan and Binh Thuan provinces. Only fractured zones formed by fault activities and cooling joints are identified as aquifer and are recharged with rain water, so large scale development of groundwater in the area is not recommendable due to the limited areas of aquifer.

(4) Coastal area

The area, overlain by Quaternary fluvial deposit such as clay, sand and gravel and also sand dune along the 10 to 20 km wide seashore, covers south of Ninh Thuan and Binh Thuan provinces. The Quaternary deposits with 20 to 40 m in thickness are judged to be a small scale aquifer in terms of thickness. Furthermore, annual rainfall of more or less 1,000 mm makes hard the large scale development of groundwater, but limited use for local people. In addition, salinity intrusion from the sea to the wells is also reported in Phan Rang.

(5) Mountainous area

The area is characterized by the mountain range formed by Cretaceous-Permian sedimentary rocks. Aquifer can scarcely be found in the area except for fissure zone and riverbed deposit, resulting in less possibility of large scale development of groundwater.

It may be concluded from the above discussions that Neogene - Quaternary sedimentary deposits in Lower plain area and basalts in Central plateau area form significant and possible aquifers for future groundwater development in the Study Area.

3.1.2 Hydrogeological Structure of the Lower Plain Area

From a hydrogeological viewpoint, the Lower plain area can be divided into three regions, i.e. Q_{IV}, Q_{II-III} and Q as illustrated in Figure 3.2. Hydrogeological structures of the regions are explained by region as follows.

(1) Q_{IV} region

The region, 1 to 2 m in elevation, is overlain by Holocene (Q_{IV}) deposit composed mainly of clayey soil with thin layers of sand and gravel. Swamps with organic matters can be found in many places, especially nearby areas of river course. Q_{IV} is 10 to 30 m thick on an average in the region and has a tendency to increase its thickness toward the Mekong Delta.

Groundwater of Q_{IV} is inadequate for drinking, because of intensive acid and high content of SO_4^{2-}. Aquifers, presented beneath Q_{IV}, i.e. Pleistocene aquifer (Q_{I-III}), Lower Pleistocene aquifer (Q_I), Pliocene aquifer (N_2) and Miocene aquifer (N_1), are suitable for drinking.

The schematic cross section given in Figure 3.2 (Cross Section II-II') indicates that depth from ground surface to the top of N_2 gradually increases south-westward and is estimated at approximately 120 m at the centre of Tan An.

(2) Q_{I-III} region

The region, stretching north-westward in the centre of Lower plain area, is dominated by Q_{I-III} deposits widely. The hydrogeological cross section shown in Figure 3.2 (Cross Section I-I') indicates that thickness of Q_{I-III} is 10 to 20 m in Tay Ninh, 40 m in Hoc Mon and 50 to 60 m in Ho Chi Minh City. According to the investigation report on groundwater development in Hoc Mon prepared by Japanese Government in the year 1973, five layers, which are Q_{III}, Q_{I-II} and three of five layers in N_2, are confirmed to exist as available aquifer. Table 3.1 summarizes the characteristics of those five aquifers.

(3) Q region

The region is located on the upstream reaches of the Saigon River and the Be River with an elevation of 18 to 250 m and is characterized by gentle hill with valleys formed by small rivers. It can be estimated that sand and gravel of fluvial deposits of Quaternary age may be available aquifers, even if their thickness varies place by place. Due to scarcely available hydrogeological data, the development of these aquifers has not so far been made in a large scale.

3.2 Well Distribution and Present Groundwater Use

Well distribution and present groundwater use are clarified on the basis of the collected data and hearing results from water supply companies in each province, SIWRP, UNICEF and local inhabitants.

3.2.1 Well Type and Past Performance

Two types of wells, i.e. dug well and tube well, are widely used for domestic and industrial use in the Study Area. The dug well, around 1 m in diameter on an average, can be found very easily in the whole Study Area as private wells used in each family except for the mountain region. Depth of the well is 5 to 10 m in general, but more than 20 m in the Central plateau and Coastal area.

Tube wells can be divided into two groups basically; one is for water supply to urban area and industrial zones with 250 mm in diameter, 50 to 300 m in depth and a capacity of 15 to 50 m^3/ hour. The other, for domestic use, is 40 to 80 mm in diameter and 30 to 40 m in depth in general.

Table 3.2 shows a list of 4,425 tube wells in total drilled in Ho Chi Minh City, Ninh Thuan and Binh Thuan provinces by the end of the year 1992 with assistance of UNICEF (Programme of Drinking Water and Hygiene in Rural Area), indicating that there exist aquifers with high development potential in the Study Area. In particular, $Q_{I\text{-}III}$ would be most promising for development taking into consideration quantity, quality and construction cost for drilling.

3.2.2 Present Groundwater Use

There is difference between urban and rural areas in groundwater use; that is, urban areas, where water sources are sought to groundwater for domestic supply, drill deep wells to strike confined aquifers. In terms of quality, groundwater in the Lower plain area shows considerable acidity and higher content of Fe for drinking, but that of the Central plateau area is suitable for drinking. On the other hand, groundwater drawn from shallow aquifers is a major source of domestic use in the rural area.

Shallow aquifers in the Lower plain area have low pH and SO_4^{2-}, resulting in low suitability as potable water. Groundwater in the Coastal area is recognized to be contaminated by domestic waste water, and salinity intrusion is reported in the wells in the Phan Rang area. On the other

hand, in Q_I v region of the Lower plain area and some parts of the Central plateau area, local people cannot afford to construct wells by themselves due to the existence of hard rock of basalts.

Table 3.3 shows a list of deep wells in operation for domestic and industrial use in the Study Area, whilst Table 3.4 summarizes the result of water quality tests obtained from water supply companies. Present use of groundwater by province is discussed below.

(1) Tay Ninh province

In urban area, groundwater exploited from N_2 is used for urban water supply of three district capitals; that is, Trang Bang, Go Dau and Hoa Thanh. Depth of wells falls in a range of 50 to 80 m, and groundwater highly contains Fe^{2+} of around 1.2 mg/l with pH of 5.5 to 6.5.

In rural area, dug wells, 10 m deep, are widely used. Static water depth from the ground surface ranges in 5 to 10 m, and Q_I is the main aquifer to be drawn. Groundwater is comparatively acid and sulfated, resulting in less suitability for drinking. Recently, some local people have constructed deep wells of 30 to 50 m deep by themselves mainly for drinking.

(2) Song Be province

From a viewpoint of groundwater use, the province can be divided into two areas; Lower plain and Central plateau area. In the Lower plain area, groundwater from N_2 is used for urban water supply in Thu Dau Mot, Thuan An, Ben Cat and Binh Long. Wells are 50 to 90 m deep, and water quality is comparatively good because content of Fe^{2+} is less than 0.14 mg/l. On the other hand, in rural area dug wells are generally used, and the main aquifer struck is Q_I. A few local people in the area have installed deep wells for drinking as well as those of Tay Ninh province.

In the Central plateau area, water supply systems to use aquifer $B(N_2\text{-}Q_I)$ have been constructed in Loc Ninh, Bu Dang and Dong Phu, and depth of wells falls in a range of 80 to 85 m.

(3) Dac Lac province

No available data relating to present groundwater use were collected. In taking geological and hydrogeological information into account, it is inferred in the region that water sources for use are sought to surface water except for deep wells drilled for local agriculture water use.

(4) Lam Dong province

Groundwater from $B(N_2\text{-}Q_I)$ is a principal source for water supply in Bao Lam (Bao Loc), Di Linh and Duc Trong excluding Da Lat. Depth of wells ranges from 40 to 80 m, and

production capacity of a well is more than 15 m^3/hour. According to the water quality analysis for the groundwater of Di Linh as shown in Table 3.4, groundwater is adequate for drinking.

In the rural area, dug wells are distributed widely with a water depth of more than 20 m from ground surface. Shortage of water occurs in dry seasons occasionally due to further drawn-down of water table in dug wells.

(5) Ninh Thuan province

Shortage of drinking water in dry seasons is a serious problem in the province, mainly resulting from an average rainfall of less than 1,000 mm/year. Intrusion of sea water in the Phan Rang area and contamination of waste water released by local residents can be found in the wells sporadically.

(6) Binh Thuan province

Shortage of drinking water in dry seasons occurs in the area as reported in Ninh Thuan province. Groundwater exploited by deep wells is only used for water supply in Tuy Phong, but dug wells are popular at most of urban area and the whole of rural area. In sand dune along the seashore, groundwater exploitation with a small scale would be possible.

(7) Ba Ria - Vung Tau province

Groundwater from N_2 is used for urban water supply in Ba Ria, Vung Tau and Tan Thanh. Depth of deep wells falls in a range of 40 to 50 m, and water quality is adequate for drinking.

(8) Dong Nai province

From a viewpoint of groundwater use, the province can be divided into two areas; Lower plain and Central plateau area.

In the Lower plain area, groundwater from N_2 is used for urban water supply in Bien Hoa, where surface water is a major source, and Long Thanh. Deep wells are 50 to 70 m deep and groundwater is adequate for drinking with a Fe^{2+} content of 1 to 1.5 mg/l and pH of 6.5. In the rural area, dug wells, 10 m deep on an average , are used generally.

In the Central plateau area, groundwater from $B(Q_{II} - Q_{IV})$ is a principal source for urban water supply in Long Khanh, Tan Phu and Dinh Quan. Depth of wells is 30 to 70 m, and production capacity of a well is 15 m^3/hour as estimated in Lam Dong province. Even with no availability of data on water quality, groundwater in the area may be suitable for drinking. In rural area, dug wells are popular with their depth of 15 to 20 m, and shortage of water occurs sometimes in dry seasons.

(9) Ho Chi Minh City

A total volume of drinking water consumed in Ho Chi Minh City is said at some 800,000 m^3/day at present. Of it, 130,000 m^3/day, about 16.5 %, is relied on groundwater drawn from the pumping stations in Ho Chi Minh City, Hoc Mon and Cu Chi. In Ho Chi Minh City, a total of 25 wells as listed in Table 3.5 are in operation at present with their depth ranging from 11 to 118.6 m. Q_{II-III} and Q_I are main aquifers to draw groundwater, and their water quality is adequate for drinking. In the suburb and outskirts of Ho Chi Minh City, tube wells with a depth of 20 to 40 m have considerably been constructed by local people for their domestic use.

In Hoc Mon, a total of twelve deep wells are in operation at present with a total discharge of 32,000 m^3/day. Depth of wells falls in a range of 124 to 200 m, and the major aquifer to draw is N_2. Since groundwater contains Fe^{2+} of 10 to 20 mg/l, Mn^{2+} of 0.2 to 1.0 mg/l and pH of 5.2 to 5.5, some treatment has been performed. In Cu Chi, three deep wells are used for urban water supply.

(10) Long An province

Groundwater is a principal source for urban water supply in Tan An, Tan Tru, Can Giuoc, Ben Luc, Duc Hoa, Duc Hue and Thu Thua. Depth of deep wells is 170 to 300 m and N_2 is the major aquifer. Quality of groundwater is good, but Fe^{2+} falls in a range of 1 to 3 mg/l. In the rural area, local residents use stored rainfall water in rainy seasons and buy drinking water during the dry season from February to April as done in Mekong Delta. In general, groundwater from shallow aquifers highly contains SO_4^{2-} and acid, so it is less suitable for drinking. A few local people in the province have pumping wells with a depth of 150 to 300 m. These wells are constructed on their own or at the collaborated expense.

3.2.3 Present Groundwater Use in Quantity

According to the data prepared by Hydro-division No. 8 and Geology Sub-Division No. 806 in the year 1993, groundwater with an amount of about 300,000 m^3/day is lifted for domestic and industrial uses in the Study Area as shown in Table 3.6. In addition, groundwater used in the rural area is estimated at 340,000 m^3/day in the year 1993 as calculated below on condition that water use per capita is 50 l/day, so groundwater with an amount of 640,000 m^3/day is inferred to be consumed in the Study Area:

Province	Population in the rural area	Groundwater use (m^3/day)		
	(1993)	Urban	Rural	Total
Tay Ninh	770,700	14,032	38,535	52,567
Song Be	1,031,100	57,380	51,555	108,935
Dac Lac	189,169	0	9,458	9,458
Lam Dong	362,674	12,364	18,134	30,498
Ninh Thuan	371,200	1,200	18,560	19,760
Binh Thuan	656,300	1,490	32,815	34,305
Ba Ria-Vung Tau	436,800	16,000	21,840	37,840
Dong Nai	1,322,400	46,010	66,120	112,130
Ho Chi Minh City	1,123,800	151,808	56,190	207,998
Long An	548,910	3,544	27,446	30,990
Total	6,813,053	303,828	340,653	644,481

3.3 Problems in Groundwater Development

Intrusion of saline water, showing its total dissolved solids (TDS) in excess of 1g/l, appears in Q_{II-III} and N_2 extending in the downstream reaches of the Dong Nai, Saigon and East Vam Co rivers as shown in Figure 3.3. It is normally said that water is not suitable when TDS is 1g/l or more.

The groundwater with a high concentration value of TDS is considered to have become brackish due to intrusion of sea water. In Q_{II-III}, the areas with a high concentration value of TDS thrust up to Hiep Hoa and Cu Chi, whilst the uppermost intrusion area for N_2 is east of Ho Chi Minh City. Furthermore, the areas with a high concentration value of TDS sporadically exist along the West Vam Co River and west of Cu Chi. These are judged to be fossil groundwater caused by the intrusion of sea water when sediments of Neogene-Quaternary ages deposited.

It is reported in the Ho Chi Minh City area that salinity intrusion to Q_{II-III} was a serious problem by the middle of 1960s. However, such intrusion as well as any subsidence is not observed at present.

3.4 Development Potential and Possible Yield of Groundwater

Development potential of groundwater, equal to annual recharge of groundwater, is evaluated on the assumption that no groundwater flows into the Study Area from the outside areas. Annual recharge of groundwater based on water balance is expressed by the following equation:

$$Pw = Rr - Ro - E$$

where; Pw : Development potential of groundwater
Rr : Precipitation
Ro : Runoff
E : Evapotranspiration.

A time duration of recharge to evaluate the development potential of groundwater in the dry season, Pw, is assumed at six months of the rainy season due to the reason that rainfall in the dry season rarely infiltrates into the ground because of dry antecedent condition of soils. Ro and Rr are given from hydrological data collected in this study, whilst evapotranspiration, E, is assumed at 3 mm a day. Since 60 % and 35 % of the shallow aquifer in terms of ground surface area is brackish in Ho Chi Minh City and Long An province respectively, rainfall dropped in these areas is expected to become brackish, resulting in the exclusion from development potential of groundwater. Based on the assumptions and conditions mentioned above, development potential of groundwater in the Study Area is estimated by province as summarized in Table 3.7, totalling 61.6 million m^3/day.

Possible yield of groundwater is estimated at 0.6 times of development potential of groundwater by taking into account the losses through exploitation. Possible yield of groundwater in the Study Area is estimated based on this assumption by province as follows:

Unit: m^3/day

Province	Development potential of groundwater	Possible yield of groundwater	Present use of groundwater	Present use rate
Tay Ninh	6,287,807	3,772,684	52,567	0.014
Song Be	5,078,042	3,045,625	108,935	0.036
Dac Lac	6,895,097	4,137,058	9,458	0.002
Lam Dong	7,391,228	4,434,737	30,498	0.007
Ninh Thuan	306,828	184,106	19,760	0.107
Binh Thuan	7,934,293	4,780,576	34,305	0.007
Ba Ria-Vung Tau	3,260,289	1,956,161	21,840	0.011
Dong Nai	9,312,207	5,567,324	112,120	0.020
Ho Chi Minh City 1)	3,523,881	845,731	207,998	0.246
Long An 2)	2,772,358	1,081,220	27,446	0.025
	61,591,928	29,805,222	644,471	0.022

Note: possible yield of groundwater = Pw * 0.6

1) possible yield of groundwater = Pw * 0.6 * (1 - 0.60)

2) possible yield of groundwater = Pw * 0.6 * (1 - 0.35)

Possible yield of groundwater is estimated at some 29.8 million m^3/day in the whole of the Study Area, whilst present use of groundwater is inferred at some 0.6 million m^3/day. As a result, groundwater use in the Study Area stays at a low rate of 2.2 % on an average, even though Ho Chi Minh City and Ninh Thuan province show a high rate of 24.6 % and 10.7 % respectively.

Hydro-Geology Division No. 8 also estimated the development potential of groundwater through the dry season in the Study Area as well as monthly groundwater flowing through the provinces in the Study Area as summarized in Tables 3.8 and 3.9 respectively. Since the theoretical background of these derivation is not clear, these information is shown as reference.

3.5 Future Development of Groundwater in the Study Area

There is large room to develop groundwater in the Study Area, since a present groundwater use of 640,000 m^3/day is only 2.2 % of total possible yield estimated at 29,800,000 m^3/day. In proposing concrete development projects of groundwater, detailed assessment on aquifer, recharge and water quality is however necessary at the site where groundwater is actually exploited.

Figure 3.4, showing the development potential of groundwater in the Study Area, is prepared based on the data and information obtained by the Study Team, indicating that the Lower plain and Central plateau areas, where basalt extends, are promising for development of groundwater. In developing groundwater from aquifers of N2 and N1 in the Lower plain area, an intensive study on optimum yield, changes in groundwater movement and influence to surrounding environment such as salinity intrusion and ground subsidence shall be carried out prior to development by applying computer simulation model, since the aquifer with several layers interacts to each other.

The districts, where the development of groundwater is recommended for their water supply projects, in the Study Area are picked up on basis of its development potential and their demands as given in Table 3.10. It is however noted that the districts not shown in Table 3.10 do not necessarily imply to exclude the development of groundwater for their water supply projects. There is another note that static groundwater table of shallow aquifers lying downstream of the Dau Tieng reservoir has been raised after its completion because of ample recharge by leakage from the reservoir and irrigation canals. Positive use of these groundwater will ease the burden to surface water on which agricultural development relies.

TABLES

Table 2.1 Geological Conditions at the Proposed Damsites (1/2)

River Basin	Proposed Damsite	Basement Rocks	Geological Conditions and Comments
Dong Nai	Dai Ninh	Dong Duong formation (sandstone interbedded with siltstone)	Sandstone interbedded with siltstone is exposed at the riverbed and the top of both banks. The weathered layer is 10 to 20 m thick. Rockfill dam is suitable. Feasibility study for the project was carried out by the Ministry of Energy.
	Dong Nai No. 1	Neogene-Quaternary basalt Dong Duong formation Neogene sediment	Both abutments are gentle with a gradient of 10 to 15°. Soft rock of Neogene is distributed on the riverbed. Geological points to be considered are extensive weathering at both banks. Bearing strength and permeability of basement rocks on the riverbed, and older river deposits under basalt lava have possibilities of leakage.
	Dong Nai No. 2	Granite in Cretaceous Dong Duong formation	Both abutments are steep with a gradient of around 30°. On condition that fresh rocks occur on the riverbed and the abutments, concrete dam will be also included as a dam type alternative for construction.
	Dong Nai No. 3	Ban Don formation	Two sites, Alternative-1 and Alternative-2, are proposed as alternative damsites. Geological conditions at both the sites are almost the same by showing fresh and hard rocks mainly composed of shale are exposed around the riverbed. Judging from the topographic condition, a rockfill type dam is recommended for Alternative-1, whilst a concrete gravity type dam for Alternative-2.
	Dong Nai No. 4	Ban Don formation Neogene-Quaternary basalt	Both abutments are steep with their gradients of 40° at the right bank and 35° at the left bank. The riverbed is 120 m wide. Basalt covers Ban Don formation around El. 500 to 600 m at both banks. Three faults have been found at the damsite. Due to the strong weathering, rockfill dam is adopted. Geological investigation was carried out as part of feasibility study by the Ministry of Energy.
	Dong Nai No. 5	Ban Don formation Neogene-Quaternary basalt	Geological condition is supposed similar to Dong Nai No. 4. The slope gradients are 35° at the right bank and 30° at the left bank. The riverbed is 100 to 150 m wide. In case of exposure of fresh rocks on the riverbed and the abutments, concrete dam will be also included as a dam type for construction.
	Dong Nai No. 6	Ban Don formation	The slope gradient is 25° at the left bank and undulating gentle slope ranges at the right bank. Rockfill dam is conceivable because of 500 to 600 m wide riverbed, deep soft foundation on the riverbed and extensive weathering at the both abutments.
	Dong Nai No. 8	Quaternary basalt Ban Don formation	The damsite is located at gentle hill. Judging from field reconnaissance, basalt occurs at and around the damsite because hard boulders of basalt are widely scattered on the surface of the left bank. Sandstone interbedded with mudstone appears on the riverbed 400 m downstream of damsite. Due to extensive weathering at both abutments, existence of old river deposits under basalt and permeability of the porus basalt, a possibility of leakage is high. Rockfill dam is acceptable.
La Nga	Ta Pao (La Nga No. 3)	Ban Don formation (Sandstone interbedded with mudstone) Granite of Cretaceous	The riverbed is about 2 km wide. Fine sandstone interbedded with mudstone is distributed about 500 m downstream of the right bank. Granite occurs at the left bank but its accurate border with sedimentary rocks is not clear. No fresh rock can be found at damsite. Rockfill dam is suitable because of thick river deposit and intensive weathering at both abutments.
	Bao Lam	Granite of cretaceous	The damsite is located at the narrow valley with a slope gradient of around 30° at both banks. Granite of Cretaceous is predicted to be distributed. If fresh rocks can be found near the surface without extensive weathered layers, concrete dam will be also discussed as an alternative of rockfill dam.

Table 2.1 Geological Conditions at the Proposed Damsites (2/2)

River Basin	Proposed Damsite	Basement Rocks	Geological Conditions and Comments
Be	Can Don	Ban Don formation (Clayey Schist) Neogene-Quaternary basalt	The damsite is in undulating hill with their maximum height of 30 to 40 m above the river bed. Clayey schist occurs on the right edge of the riverbed. The strike and dip of foliation are N10E - N25E, 60 to 80 SW, respectively. Due to the topographic condition and strong weathering of the left bank, earth dam or rockfill dam is conceivable. Outcrop of basalt excluding its boulder cannot be found around the damsite.
	Fu Mieng (Con Don 3)	Ban Don formation	The damsite is in gentle hill. From a geological point of view, weathered layers such as residual soil and decomposed rocks may be thick. An earthfill type dam is acceptable.
	Phuoc Hoa	Neogene-Quaternary deposit	The damsite is in plain composed of siltstone and mudstone overlain by coarse sand with gravel. From a view point of topography and geological conditions the dam height is strictly limited.
Coastal Zone	Ca Giay	Dong Duong formation	The damsite is in undulating hill. On both sides of the river, terrace develops widely. Hard rhyolite with joints occurs at the riverbed. Field reconnaissance tells that the weathered zone can be expected very thick at both banks. Rockfill dam is acceptable.
	Song Luy	Granite of Cretaceous Quaternary basalt	The riverbed is about 4.0 km wide. According to the geological map, granite presents on the right bank, shale, rhyolite and aplite on the left bank and Quaternary basalt on the riverbed. From topographic condition, rockfill dam is adequate due to Quaternary deposits covering basement rock in the riverbed and permeability of basalt and older river deposits overlain by basalt.
	Song Ray	Dong Duong formation Granite of Cretaceous Quaternary basalt	The riverbed is around 60 to 70 m wide. Sandstone interbedded with mudstone and intrusive granite can be found 100 to 300 m upstream of the damsite. Both banks at the damsite are covered with basalt because many hard basalt boulders are scattered on the left bank widely. In spite of fresh rock exposure on the riverbed, rockfill dam can be acceptable due to extensive weathering of both banks.
	Da Den	Neogene-Quaternary deposit	The damsite is located at the edge of undulating hill. According to the geological map, basalt may be distributed at and around the damsite. From a topographic point of view, the dam height is strictly limited.

Table 2.2 Condition of Quarry Site for Dong Nai No. 4

Site No.	Location	Materials	Overburden		Rock Material Volume (m^3)		Properties		
			Thickness (m)	Volume (m^3)	Potential	Available	rc (g/cm^3)	porosity (%)	R_{BH} (kgf/cm^2)
No. 1	16 to 20 km from damsite	Basaltic rock	15 to 18	7.3×10^6	17.6×10^6	2.1×10^6 (40 m thick)	2.68	5.5	727
No. 2	-ditto-	-ditto-	1.5	0.1×10^6		14.4×10^6	2.61		1,021
No. 3	-ditto-	-ditto-	5	2.5×10^6		14.4×10^6	2.73		800

* Site No. 2 is most recommendable.

Table 2.3 Condition of Borrow Area for Dong Nai No. 4

Site No.	Location	Materials	Thickness (m)	Volume (m^3)	Properties					
					Wn (%)	Wopt (%)	C (kgf/cm^2)	Ø (°)	γc (g/cm^3)	K (cm/sec)
No. 1	Right bank (Within 1 km of damsite)	Basaltic soil	4.5	4.8×10^6		35	0.22	15	1.29	6.6×10^6
No. 2	Left bank (Within 1 km of damsite)	sedimentary (deluvial/eluvial)								
		Layer No. 2	2.0	6.1×10^6	19	26	0.22	16	1.41	4.5×10^6
		Layer No. 3	2.3		19	23	0.21	19	1.50	5.6×10^6
No. 3	Right bank (Within 1 km of damsite)	-ditto-								
		Layer No. 2	2.0	2.0×10^6	20	24.8	0.26	17	1.56	2.1×10^6
		Layer No. 3	0.46		22	23.6	0.36	17	1.57	

* Vegetation covering is 0.1 ~ 0.4 m thick on an average.

Table 3.1 Aquifers Exploitable in the Hoc Mon Area

Aquifer No.	Type of Aquifer	Geological Note Condition	Depth (m)	Thickness (m)	Properties		Note
					K(cm/sec)	S	
A - I	Unconfined (QIII)	Fine sand, clay and laterite	0 - 20	15 - 25			Many shallow wells
A - II	Confined (QI - QII)	Sand and gravel thin impermeable layer between A - I and A - II	20 - 40	10-15			Occasionally Correspond with A-I
A - III	-ditto- (N2)	Sand with fine gravel	50 - 90	10 - 45	9.4x10-2	9.7x10-4	Excellent Aquifer
A - IV	-ditto- (N2)	-ditto-	100 - 120	15 - 20			-ditto-
A - V	-ditto- (N2)	Sand with clay	140 - 200	more than 60			Possibility of highly mineral content

Note: K : Permeability coefficient
S : Storage coefficient
A - I and A - II are mainly used for local residence

Table 3.2 Number of UNICEF's Wells Completed by the End of the Year 1992

Province	District	Number of Wells	Remarks
Ho Chi Minh City	Thu Duc	713	
	Hoc Mon	658	
	Binh Chanh	610	
	Cu Chi	433	
	Nha Be	12	
	Tan Binh	216	
		2,854	
Ninh Thuan	Phan Rang	295	
	Ninh Phuoc	158	
	Ninh Hai	3	
		456	
Binh Thuan	Ham Thuan	245	
	Ham Tan	78	
	Phan Thiet	217	
	Bac Binh	280	
	Ham Thuan	128	
	Tuy Phong	94	
	Tanh Linh	77	
		1,114	
Total		4,425	

Source: Hydro - Geology No. 8 - Geology Sub - division No. 806 (1993)

Table 3.3 List of Deep Wells for Domestic and Industrial Use in the Study Area (1/2)

Province	District	Number of wells	Depth of well (m)	Discharge (m^3/day)	Type of Aquifer	Remarks
Tay Ninh	Tay Ninh	8	65-70	0	Sand (N2)	No operation, surface water supply
	Trang Bang	2	54-80	900	ditto-	
	Go Dau	2	54-80	1,000	ditto-	
	Hoa Thanh	2	54-80	650	ditto-	
Song Be	Thu Dau Mot	14	50-90	5000	-ditto-	
	Thuan An	4	60-90	4000	-ditto-	
	Ben Cat	1	50-60	500	-ditto-	
	Binh Long	2	60-65	500	-ditto-	
	Loc Ninh	2	80	500	Basalt (ßN2 - Q1)	One well is destroyed.
	Bu Dang	4	85	120	-ditto-	
	Dong Phu	4	85	120	-ditto-	
Dac Lac						
Lam Dong	Bao Loc	11	37-78	8,828	Basalt (ßN2 - Q1)	Water level is 12-28m. Two wells are destroyed.
	Di Linh	4	71-81	2,496		Water level is 22-28 m.
	Duc Trong	3	65-72	1,040		Water level is 3-13 m.
Ninh Thuan						
Binh Thuan	Tuy Phong	13				

Table 3.3 List of Deep Wells for Domestic and Industrial Use in the Study Area (2/2)

Province	District	Number of wells	Depth of well (m)	Discharge (m3/day)	Type of Aquifer	Remarks
Ba Ria-Vung Tau	Ba Ria town	19	30-40	1,100	Sand (QIV-QII)	
	Vung Tau		40-45	13,000	Sand (N2)	
	Tan Thanh	-	40-50	3,000		
Dong Nai	Bien Hoa	2	50	480	Sand (N2)	Fe^{TM}+ (1-1.5 ml./l)
	Long Thanh	20	60	720	-ditto-	
	Xuan Loc	4	70	192	Schist (J1-2)	Small discharge of each well
	Long Khanh	7	50-70	720	Basalt (ßQI-IV)	Good water quality, large potential
	Tan Phu	5	60	480	-ditto-	Excellent Aquifer
	Dinh Quan	6	30	360	-ditto-	Ecellent Aquifer
Ho Chi Minh City	Ho Chi Minh City	25	111-118.6	34,000	Sand (QIII-N2)	Treatment in operation
	Hoc Mon	12	124-200	32,000	Sand (N2)	
	Cu Chi	3		2,880	-ditto-	
Long An	Tan An	6	250-280	3,000	-ditto-	
	Tan Tru	3	200-220	240	-ditto-	
	Can Giuoc	9	170-300	120	-ditto-	
	Ben Luc	1	250	No operation	-ditto-	Destroyed
	Duc Hoa		100-170	24	-ditto-	
	Duc Hue	1	200	40	-ditto-	
	Thu Thua	1	220-240	120	-ditto-	

Table 3.4 Result of Water Quality Tests

Province	Sampling Place	Sampling Depth	Sampling Date	Aquifer Type	pH	HCO_3^-	CO_3^{2-}	Cl^-	SO_4^{2-}	SiO_3^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	Na^{1+}	Fe^{2+}	Al^{3+}	Mn^{2+}	NH^{4+}	Total Hard-ness	Con-duc-tivity	Note
Ho Chi	Hoc Mon	Swamp	28-Feb-73		3.4	0	0	27.4	192	5.1	-	9.2	1.5	61	1.5	5.2	0.25	1	2.9	508	
Minh	-ditto-	5.3		Sand(QIII)	5.7	-	-	121	-	15	-	-	-	-	0.18	-	-	-			S*
	-ditto-	95	19-Mar-73	Sand(N2)	5.8	15.3	0	-	-	63.5	0.1	2.4	0.7	35	0.56	1.7	0	0	0.9	43.5	D**
	-ditto-	200	Jun, 95	Sand(N2)	5.2	-	-	40mg	-	-	-	-	-	-	10-20		0.2	-	-	-	-ditto-
	Ho Chi Minh	48	Jan, 95	Sand(QI-N2)	5.5	-		45	-	-	-	-	-	-	0.05	-	1	-	-	-	-ditto-
Lam Dong	Di Linh	42.4	Dec, 91	Basalt (N2-Q1)	7.42 -	122.1		0.3	0.1		0.1	18.4			1.2		13.6	11.1			-ditto-
Song Be	Thu Dau Mot		Sep, 76	Sand(N2)		0	-	2	10	-	0	2	4	-	0.14		-	-	6	22	-ditto-
Tay Ninh	Tay Ninh	77	3-Mar-82	Sand(N2)	6.4	81.6	-	5	-	-	0.01	88	12	-	1.2		-	-	100	220	-ditto-

Table 3.5 List of Deep Wells in Operation in Ho Chi Minh City (excluding Hoc Mon field)

Ref No.	Name	Location (Number, Street)	Year of Building	Well Depth (m)	Pump Depth (m)	Flow (m^3/h)	Manometric Head (m)	Working Hours	Comments
1	CAPTAGE GO VAP	SAN GOLF, P9 GO VAP	1925	14-17		340	30	24	16 GIENG CAN THU NUOC
2	G.PHAM DANG HUNG	32 MAI THI LUU, P.DA KAO, Q1	1932	33.96	22	90	34	8	2 BOM TRUC NGANG 75 Hp
3	G.HUYNH TINH CUA	6 HUYNH TINH CUA, P13, Q3	1932	39.26	21.4	7	28	8	
4	G.HOC MON	2/10 TRIEU AU, HOC MON	1942	11	6.2	53	22	8	GIENG CAN THU NUOC MACH NONG
5	G.HONG THAP TU	18 NG.THI MINH KHAI, P.DA KAO	1949	44.8	22	100	30	16	
6	G.BA HUYEN THANH QUAN	89 BA HUYEN THANH QUAN	1949	48.8	24	69	25	8	AP LUC GHI TRONG BANG NAY
7	G.PHU THO II	KHUON VIEN XNCX LU GIA, Q11	1951	36.4	23	150	30	8	LA AP LUC BIEU KIEN CUA AP KE
8	G.LE VAN DUYET	GOC CMT8-DIEN BIEN PHU Q3	1953	41.1	21.3	100	30	10	GAN TREN ONG DAY CUA BOM
9	G.NGUYEN DU	CV VAN HOA TP, P11,Q1	1953	42.7	21.8	110	28	16	TAI TRAM
10	G.LY THAI TO	159 LY THUONG KIET, P7,Q11	1955	37.5	21.3	100	30	8	
11	G.TRAN QUOC TOAN 2	2 DUONG 3-2, P14,Q10	1958	39.9	25.2	116	25	16	
12	G.TRAN QUOC TOAN 3	385 DUONG 3-2,P10, Q10	1958	41.2	24.4	135	28	8	
13	G. TRAN QUOC TOAN	16F DUONG 3-2, P14, Q10	1961	37.5	21.6	133	23	8	
14	G.NGUYEN AN THOAI 1	90D, LY THUONG KIET, P14, Q10	1961	35.4	21.3	163	22	16	
15	G.TRUONG DUA 2 BIS	2B LY THUONG KIET, P15,Q11	1962	37.3	22.1	126	27	8	
16	G2.TAN SON NHAT	S.B TAN SON NHAT, P4, TAN BINH	1964	36.5	21.6	76	26	8	
17	G.TRUONG MINH KY	281 LE VAN SY, P1, TAN BINH	1964	35.6	21.6	140	28	8	
18	G.BA CHIEU	2 BIS NO TRANG LONG, BINH THANH	1964	34.5	18.3	120	24	8	
19	G.TAO DAN 2 FER	CV VAN HOA TP, P11, Q1	1966	45	21.6	135	32	16	
20	G.THUY DAI N GO VAP	198/10 NGUYEN THAI SON-GV	1971	38.1	24.4	120	30	16	
21	G.PHU THO HOA	112/23, P18, Q.TAN BINH	1971	43	21.6	156	25	10	
22	G.P9, Q.TAN BINH	HEM 140, LAC LONG QUAN, TB	1988	118	21.6	50	20	8	
23	G.P1, Q.11	192/36/30 HUNG VUONG, Q11	1989	104	27.2	60	25	8	
24	G.LE MINH XUAN	KHV5, THI TRAN AN LAC, BINH CHANH	1989	103	28.5	70	25	10	
25	G..P18, Q.TAN BINH	HUONG LO 14, Q. TAN BINH	1990	78.6	21.7	65	15	8	

Table 3.6 Present Amount of Groundwater Discharge of Class I*1 and II*2 in the Study Area

(unit: m^3/day)

Province	Types of water bearing strata								Total Discharge	Remarks
	Q	QIV	QII-III	Q1	N_2*3	N_1*3	(N2-QIV)*3	Others		
Tay Ninh				11482	2550				14032	
Song Be			133	31286	10000		3155	12806	57380	
Dac Lac									0	
Lam Dong							12364		12364	
Ninh Thuan		1200							1200	
Binh Thuan		800	200	270				220	1490	
Ba Ria-Vung Tau					16000				16000	
Dong Nai				19231	8403		3207	15169	46010	
Ho Chi Minh city			55360	61268	34880	300			151808	
Long An					3544				3544	
Total		2000	55693	123537	75377	300	18726	28195	303828	

Note: *1; Class I means discharge of more than 10,000 m^3/day.

*2; Class II means discharge of 100 - 10,000 m^3/day.

*3; Some figures are revised by JICA Study Team according to study result.

Source: Hydro-Geology division No. 8-Geology Sub-division No. 806 (1993)

Table 3.7 Development Potential of Groundwater in the Study Area

Province	Area (km2)	Annual Rainfall (mm/year)*****	Rainfall Vol. (m3/year)	Runoff Coeff. (runoff/rain)	Runoff Vol. (m3/year)	Evapotranspiration (m3/year)****	Groundwater (m3/year)	Grounwater (m3/day)	Groundwater (m3/day/km2)
Ninh Thuan	3,430.4	1,000.0	2,916,714,752.0	0.3	952,307,367.0	1,852,416,000.0	111,991,385.0	306,826.0	89.4
Binh Thuan	7,992.0	1,524.0	10,354,195,440.0	0.3	3,142,498,316.0	4,315,680,000.0	2,896,017,124.0	7,934,293.0	992.8
Dac Lac*	3,841.2	2,765.0	9,028,433,304.0	0.5	4,437,474,969.0	2,074,248,000.0	2,516,710,335.0	6,895,097.0	1,795.0
Lam Dong**	7,531.2	2,150.0	13,763,268,000.0	0.5	6,998,621,778.0	4,066,848,000.0	2,697,798,222.0	7,391,228.0	981.4
Ho Chi Minh City	2,090.3	1,889.0	3,356,467,871.0	0.3	941,489,238.0	1,128,762,000.0	1,286,216,633.0	3,523,881.0	1,685.8
Song Be	9,519.4	2,313.0	18,711,570,625.0	0.5	8,495,053,064.0	5,140,476,000.0	5,076,041,561.0	13,906,963.0	1,460.9
Tay Ninh	4,020.0	1,882.0	6,432,160,800.0	0.3	1,966,311,557.0	2,170,800,000.0	2,295,049,243.0	6,287,806.0	1,564.1
Dong Nai	5,864.4	2,238.0	11,157,343,542.0	0.4	4,591,246,868.0	3,166,776,000.0	3,399,320,674.0	9,313,207.0	1,588.1
Ba Ria-Vung Tau	1,956.6	1,863.0	3,098,706,552.0	0.3	852,144,302.0	1,056,564,000.0	1,189,998,250.0	3,260,269.0	1,666.3
Long An***	2,225.5	1,614.0	3,053,352,618.0	0.3	839,671,970.0	1,201,770,000.0	1,011,910,648.0	2,772,358.0	1,245.7
Total	48,471.0		81,872,213,504.0		33,216,819,429.0	26,174,340,000.0	22,481,054,075.0	61,591,928.0	13,069.5

* 19.4% of the total land area

** 74.0% of the total land area

*** 51.3% of the total land area

**** Evapotranspiration is estimated at 3 mm/day.

***** Rainfall for rainy season is calculated as 80% of annual rainfall.

Table 3.8 Development Potential of Groundwater through the Dry Season in the Study Area Estimated by Hydro-Geology Division No. 8

(unit: m^3/day)

Province	Types of water bearing strata						Total	Rate(%)
	TSD < 1			1 < TSD < 1.5	1.5 < TSD < 4	TSD < 4		
	Q1	Q2	Q1+Q2					
Tay Ninh	1217991	2718404	3936395				3936395	21.4
Song Be	1344254	967569	2311823				2311823	12.6
Dac Lac	-	-	-	-	-	-	-	-
Lam Dong	3179002	421188	3600190				3600190	19.6
Ninh Thuan	433814	108030	541844	13620			555464	3
Binh Thuan	1042481	525630	1568111	60840			1628951	8.9
Ba Ria-Vung Tau	396796	431362	828158	1608	1974	9570	841310	4.6
Dong Nai	1747785	784967	2532752	7956	8568	13322	2562598	13.9
Ho Chi Minh City	324130	1448867	1772997	143147	256380	774728	2947252	16
Long An	-	-	-	-	-	-	-	-
Total	9686253	7406017	17092270	227171	266922	797620	18383983	100
Rate(%)	52.7	40.3	93	1.2	1.5	4.3	100	

Note: *: means no available data

Q1: Total volume of groundwater flowing through each province

Q2: Volume of groundwater storaged inside aquifers of each province

TSD<1 g/l: Fresh water, TSD = 1-1.5 g/l: slightly brackish water

TSD=1.5-4 g/l: brackish water, TSD > 4 g/l: salinity water

Source: Hydro - Geology division No. 8 - Geology Sub - division No. 806 (1993)

Table 3.9 Monthly Groundwater Flowing through the Provinces in the Study Area
Estimated by Hydro-Geology Division No. 8

Unit: $x10^6m^3$/day

Province	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Monthly Average
Tay Ninh	1.72	1.67	1.45	1.2	1.27	2.2	3.93	5.5	4.52	5.37	4.52	2.62	3
Song Be	1.91	1.86	1.62	1.34	1.42	2.44	4.36	6.12	5.02	5.97	5.02	2.91	3.33
Dac Lac	-	-	-	-	-	-	-	-	-	-	-	-	-
Lam Dong	4.53	4.41	3.84	3.17	3.36	5.8	10.36	11.95	11.95	11.95	11.95	6.92	7.92
Ninh Thuan	0.62	0.6	0.52	0.43	0.46	0.79	1.42	1.64	1.64	1.64	1.64	0.95	1.08
Binh Thuan	1.48	1.44	1.25	1.04	1.4	1.89	3.38	3.9	3.9	3.9	3.9	2.26	2.61
Ba Ria-Vung Tau	0.57	0.56	0.48	0.4	0.42	0.73	1.25	1.51	1.51	1.51	1.51	0.87	0.99
Dong Nai	2.48	2.41	2.1	1.74	1.84	3.18	5.67	6.54	6.54	6.54	6.54	3.78	4.33
Ho Chi Minh City	0.48	0.46	0.4	0.33	0.35	0.61	1.09	1.26	1.26	1.26	1.26	0.73	0.83
Long An*	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	13.79	13.41	11.66	9.65	10.52	17.64	31.46	38.42	36.34	38.14	36.34	21.04	24.09

Note : * means no available data

Source: Hydro - Geology division No. 8 - Geology Sub - division No. 806 (1993)

Table 3.10 Districts with High Development Potential of Groundwater for Water Supply

Province	Proposed district	Aquifer	Capacity of well discharge (m^3/hour)*	Remarks Well depth	Water quality*
Tay Ninh	Duong Minh Chau	Sand (N2)	50	70-80	Fe2+>0.3 mg/l, pH around 5.5
	Tan Bien	-ditto-	-ditto-	-ditto-	
	Tan Chau	-ditto-	-ditto-	-ditto-	-ditto-
Song Be	Tan Uyen	Sand (N2)	15	50-60	-ditto-
	Loc Ninh	Basalt (bN2-QII)	15	70-90	Fe2+>0.3 mg/l, pH<6.5
	Bu Dang	-ditto-	-ditto-	-ditto-	pH=4.2-5.0
	Ben Cat	-ditto-	-ditto-	-ditto-	-ditto-
Dac Lac	Dak R'lap	-ditto-	-ditto-	-ditto-	-ditto-
Lam Dong	Lam Ha	Basalt (bN2-QII)	30	60-80	-ditto-
	Cat Tien	-ditto-	-ditto-	-ditto-	Fe2+ 0.3 mg/l
Ba Ria-Vung Tau	Xuyen Moc	Basalt (bQII-QV)	15	60-80	-ditto-
Dong Nai	Thong Nhat	Sand(N2) or Basalt (bQII-QV)	15	60-80	-ditto-
	Vinh An				
Ho Chi Minh Cit	Can Gio	Sand (N2 or N1)	50	100-200*	-ditto-
Long An	Can Duoc	-ditto-	-ditto-	250-300	Fe2+>0.3 mg/l

Note: * Estimated by JICA Study Team