DEMOCRATIC REPUBLIC OF MADAGASCAR
MINISTRY OF INDUSTRIES, ENERGY AND MINES

GROUNDWATER DEVELOPMENT STUDY
IN
SOUTH-WESTERN REGION
OF
THE DEMOCRATIC REPUBLIC OF MADAGASCAR

VOLUME 1
SUMMARY REPORT

JULY 1991

JAPAN INTERNATIONAL COOPERATION AGENCY

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LIST OF REPORT

VOLUME 1 SUMMARY REPORT
VOLUME 2 MAIN REPORT
VOLUME 3 SUPPORTING REPORT (1)
VOLUME 4 SUPPORTING REPORT (2) -- DATABASE MANUAL
VOLUME 5 DATA BOOK

Preface

In response to a request from the Government of the Democratic Republic of Madagascar, the Government of Japan decided to conduct a Study on Groundwater Development in South-Western Region and entrusted the study to the Japan International Cooperation Agency(JICA).

JICA sent to Madagascar a study team headed by Dr. Masaichi Nakayama, Kokusai Kogyo Co., Ltd., on four occasions between September 1989 and March 1991.

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

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

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

July, 1991

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency

July, 1991

Mr. Kensuke YANAGIYA
President
Japan International Cooperation Agency

Dear Sir,

It is our pleasure to submit to you the Final Report of the Groundwater Development Study in South-Western Region of the Democratic Republic of Madagascar.

The field survey and analytical study were conducted during the period encompassed between September 1989 and March 1991.

The Final Report consists of five volumes: Volume one - Summary Report which succinctly describes the study and recommendations; Volume two - Main Report which describes the results of the study and analysis; Volumes three and four - Supporting Reports which contain hydrogeological maps, results of geophysical prospecting and water quality analysis, and a database manual; Volume five - Databook which contains data and information on geophysical prospecting, drilling and pumping tests.

We hope that implementation of the proposed groundwater development scheme would greatly contribute to improve the water supply conditions in the Southwestern Region of Madagascar.

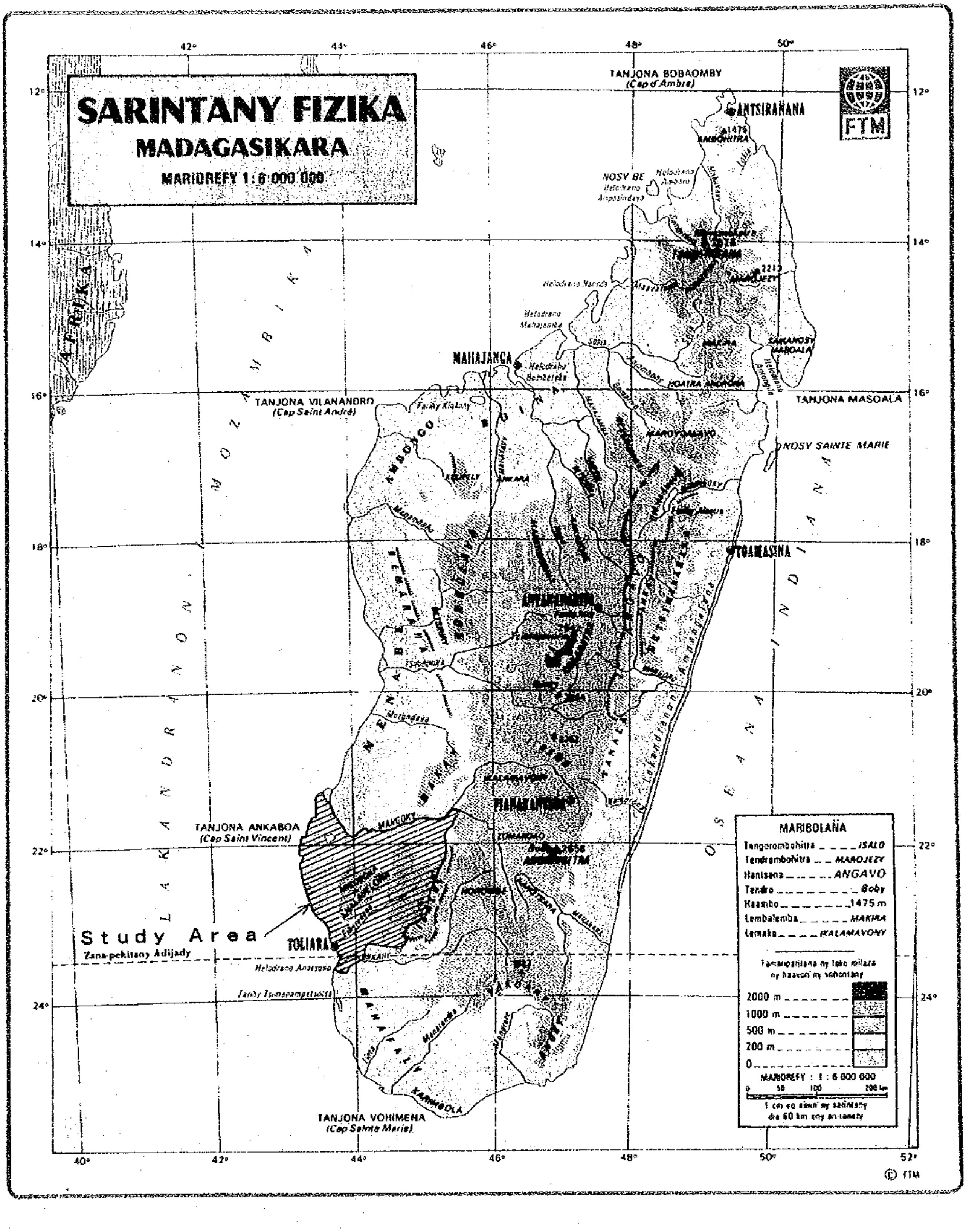
Finally, we take this opportunity to express our sincere gratitude to Japan International Cooperation Agency and the Embassy of Japan in Madagascar for their invaluable cooperation throughout the study period.

Respectfully yours,

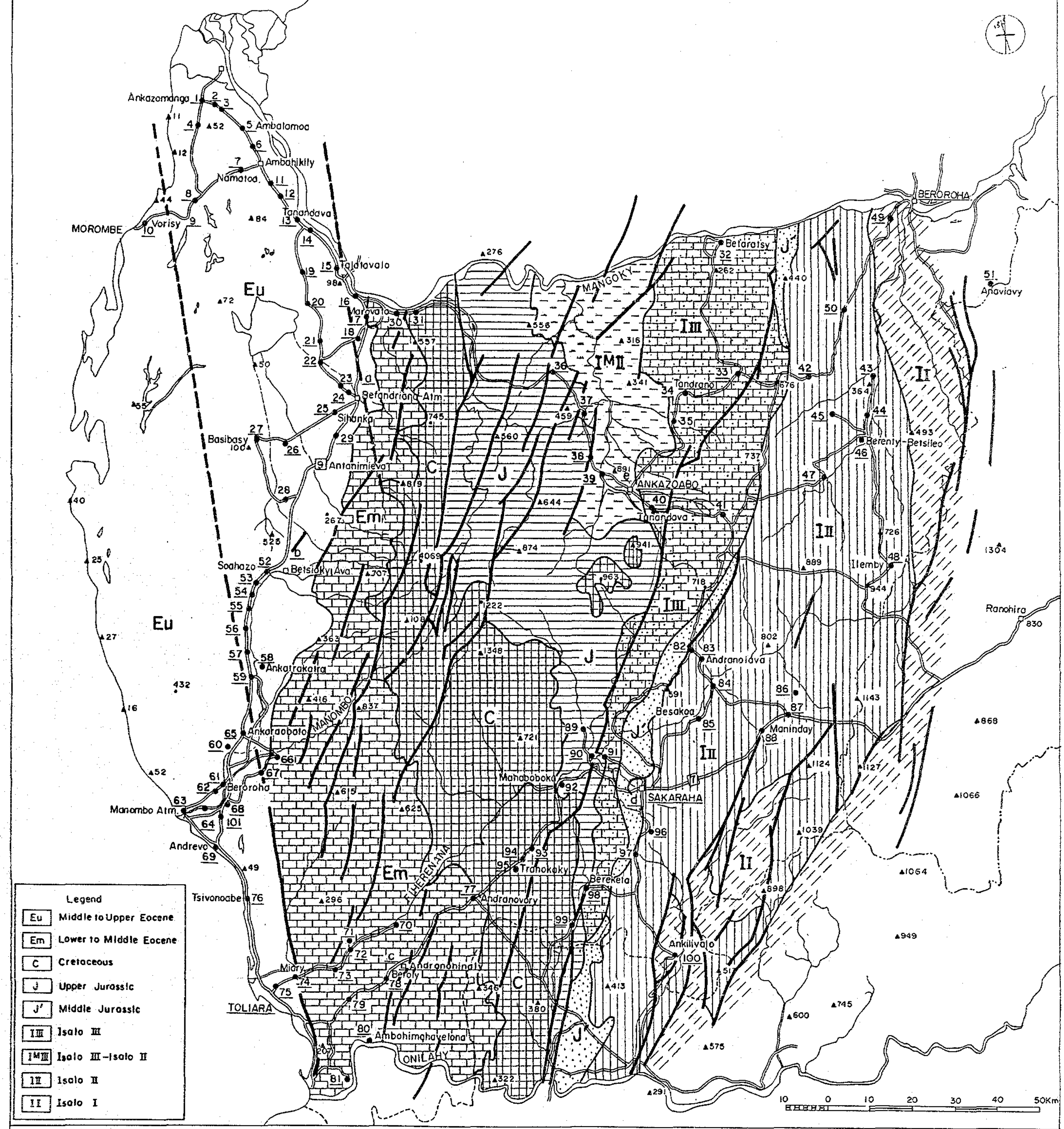
中山政一

Masaichi Nakayama
Leader, Study Team

LOCATION MAP OF STUDY AREA



Geological Map of the Study Area



No Villages	15 Talatavalo	II. Fiv. ANKAZOABO ATM	48 Ilemby	60 Ambondro	78 Befoly
I. Fiv. MOROMBE	16 Ambiky	32 Betaratsy	III. Fiv. BEROROHA	61 Beroroha	79 Ankororoka
1 Ankazomanga	17 Marovato	33 Andranomanintsy	49 Tanandava-Antaifasy	62 Antsomarify	80 Ambohimahavelona
2 Beadabo	18 Andranoboka	34 Tandrano	50 Anjamitikitra	63 Manombo-Atm	81 Manoroka
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5 Ambalamoa	21 Antranosatra	37 Mamakiala	52 Soahazo	66 Andoharano	82 Iaborana
6 Tsianihy	22 Manoy	38 Berenty-Ankilimasy	53 Analamisampy	67 Tsefanoka	83 Andranolava
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12 Berantala	28 Analatelo	44 Soatanimbary	59 Ampihamy	73 Ambolonkira	89 Bevoalavo
13 Tanandava	29 Mangotroka	45 Sahanory Atm		74 miary	90 Tanambao
14 Antsakoabe	30 Nosy-Ambositra	46 Berenty-Betsileo		75 Befanamy	91 Ambahimalitsy
	31 Tsiarimpioke	47 Ankilivalokely		76 Tsivonoabe	
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92 Mahaboboka
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1.1 Background and Objective

Background

The Madagascar Government, in its continuing commitment to ensure the economic well-being of its people, has formulated and implemented the Third Five-Year National Development Plan covering the period 1986-1990. The objectives of the Plan are the achievement of self-sufficiency in food supply, promotion of exports, and the increase in agricultural productivity. Attainment of these objectives is expected to lead to an improved standard of living.

Being an agricultural country where 80% of the population is rural, the Plan focuses attention upon these rural farming communities to effect a more balanced and sustainable economic growth.

A major thrust of the country's development efforts is the provision of potable water to the population by the year 2000. Toward this end, the Government has created a public corporation, the Jiro and Rano Malagasy (JIRAMA), as the agency responsible for the development, implementation and management of urban potable water systems and electrification projects. On the other hand, drinking water supply in rural areas is under the jurisdiction of MIEM.

While notable progress has been made with regards to the water sector, much work has yet to be done. At present, only 18% of the total population has access to potable water supply. Of this, almost 91% are in urban areas. In rural areas, therefore, water-borne and water-related diseases continue to take their toll upon the residents, particularly among the younger generation, hindering agricultural productivity and causing problems in the development of this sector.

A number of bilateral and multilateral aid agencies have provided assistance to the Madagascar Government in installing potable water supply systems in rural areas. Still, a large number of rural communities remain unserved, particularly the communities located between Onilahy River and Morondava City where the need for potable water is most acute, and thus given priority consideration.

Accordingly, the Government of Madagascar formulated a project idea designed to develop groundwater as a source of domestic water supply and to construct simple water supply systems for villages located between Onilahy River and Morondava City, targeting communities with a population between 500 and 3,000 people. The project would be implemented by the Department of Energy and Water of MIEM, depending on the results of a detailed study.

In August 1988, therefore, the Madagascar Government requested the assistance of the Japanese Government to carry out a study with the purpose of assessing the development potential of groundwater resources and preparing a groundwater development plan in the southwestern region of the country, specifically the region between Onilahy River and Morondava City.

On this basis, the Japanese Government through its development assistance arm, the Japan International Cooperation Agency, sent a preliminary study team in May 1989 to Madagascar and this mission drew up the Scope of Work for the execution of this Study.

Objective

The objectives of the Study are to evaluate the groundwater potential in the Study Area, to formulate a groundwater development plan for priority areas, and to implement technology transfer to counterpart engineers in the course of the Study.

1.2 Study Area

The Study Area is situated in the southwestern region of Madagascar, bounded in the north by the Mangoky River and in the south by the Onilahy River. This area of approximately 31,250 km^2 is called "Southern Mongoky Area" for water supply purposes, and is composed of 5 prefectures: Morombe, Ankazoabo, Sakaraha, Toliara(I) and Toliara (II). Geologically, this area is positioned in the southern part of Morondava Basin.

1.3 Study Description

The Study components described in the Scope of Work agreed upon between MIEM and JICA is presented below.

"The Study comprises following three (3) phases:

Phase I : Preliminary Analysis and Field Reconnaissance

The Study in this Phase I shall comprise a review and analysis of existing studies and data, and analysis of satellite image and aerial photos as well as conduct of the first field survey for the study area.

The results of survey and analysis mentioned above shall lead up to a revised hydrogeological map and to identified potential areas for the groundwater development.

Phase II : Analysis and Evaluation on Groundwater Resource

This Phase shall comprise conduct of the second field survey including geological survey, groundwater leveling, water quality analysis, geophysical survey, test drilling and pumping test, for the evaluation of groundwater resource potential and selection of priority areas for rural water supply development.

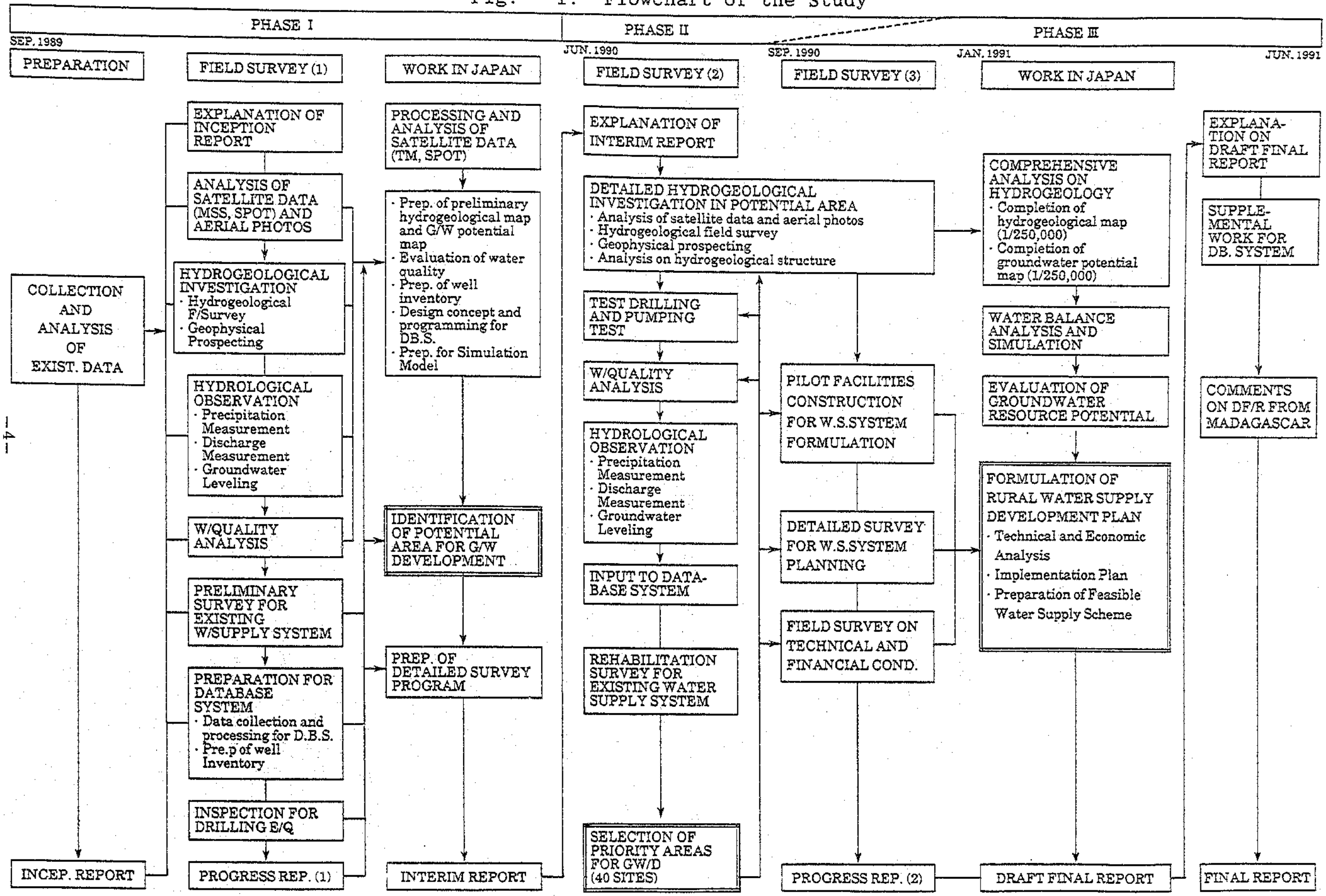
Phase III : Formulation of Rural Water Supply Development

This Phase shall comprise project formulation of rural water supply in the priority areas from the socioeconomic, technical and institutional aspects."

In addition to the above mentioned components, the Study activities include preparation of Inception Report, Progress Report (1), Interim Report, Progress Report (2), Draft Final Report, and Final Report.

The flowchart shown in Fig. 1 was prepared to fulfill the requirements of the above described Scope of Work.

Fig. 1. Flowchart of the Study



1.4 Study Team

The Study has been practically implemented by a joint study team composed of JICA Study Team members and MIEM personnel, over the period encompassing September 1989 to March 1991. The following list shows the principal persons who have participated in the Study.

JICA Study Team

	Name		Specialization/Designation
1.	NAKAYAMA Masaichi	:	Team Leader
2.	KANDA Atsuo	:	Co-Team Leader/Hydrogeologist
3.	SUGIYAMA Akira	:	Hydrogeologist
4.	OMORI Shoichi	:	Geologist/Remote Sensing Expert
5.	SETOJIMA Masahiro	:	Remote Sensing Expert
6.	YAMAGUCHI Masahiro	:	Hydrologist/Computer modeling Expert
7.	MEDINA Reynaldo Real	:	Hydrologist
8.	HIROZU Takayoshi	:	Water Quality Expert
9.	TANAKA Masatoshi	:	Geophysicist/Survey Expert
10.	KAJIWARA Susumu	:	Geophysicist
11.	TANABE Yoshitaka	:	Drilling Supervisor/Geologist
12.	NOMURA Shinji	:	Drilling Supervisor/Geologist
13.	FUJIWARA Kunio	:	Pilot Facilities/Rehabilitaion Expert
14.	NARITA Hiroatsu	:	Water Supply Planner
15.	ARAKAWA Shuji	:	Water Supply Facility Expert
16.	OBARA Masaru	:	Project Economist
17.	AOKI Hirochika	:	Translator/Interpreter

MIEM Counterparts

	Name		Specialization/Designation
1.	RANDRIANARISOA NHELSON	:	Team Leader
2.	RANDRIANARISON Justin	:	Vice Team Leader
3.	MELY CHRISTINE	:	Vice Team Leader
4.	RAJOELISAONINA Alfred	:	Geophysical Prospecting
5.	RABEMANANTSOA Boniface	:	Water Quality Analysis
6.	RAKOTONARIVO Solonirina	:	Remote Sensing and Geology
7.	TOGNIHAGNITSE (HANGY)	:	Water Supply Engineering and Socio-economics
8.	RAZAFINDRABETSIAVALONA Ndriana	:	Hydrology
9.	RABENANDRASANA Emmanuel	:	Hydrology and Database
10.	RALAIARIVONY Solofo Joel	:	Water Quality Analysis
11.	RAKOTOMAVO Marcel	:	Chief Driller
12.	RANDRIANANTOANDROHARISOANARIVO	:	Water Quality Analysis
13.	RASOLOMAMONJISOA Nathanael	:	Mechanic
14.	RAKOTOVAO Bernard	:	Assistant Chief Driller

15. RANDRIANARISOA Solo Christophe: Hydrology,Chief Driller
16. RANDRIAMANALINA Jacques : Chief Driller
17. RAKOTOFIRINGA Justin : Electrician
18. RANAIVOSON Albert : Geophysical Prospecting
19. RAMANATOANINA Gilbert : Water Supply Engineering
20. RAZAFINDRABE Pierre : Rehabilitation Survey
21. RAKOTOMALALA : Rehabilitation Survey
22. RAMILIJAONA Albert : Rehabilitation Survey
23. BOTO Francois : Geophysical Prospecting
24. RAKOTONDRAMANGA Jean Honore : Mechanic
25. RANDRIANARISOA Patrice : Geophysical Prospecting
26. RAKOTO ANDRIANALY Jules : Water Supply Engineering

1.5 Report Structure

The Final Report is composed of the following: Summary Report, Main Report, Supporting Report (1), Supporting Report (2) and Data Book.

Summary Report describes the outline of the Study. Main Report describes socioeconomic background, meteorology and hydrology, hydrogeology, detailed survey of the candidate villages, evaluation of the groundwater potential, groundwater developmet plan, and water supply plan and its implementation.

Supporting Report (1) includes hydrogeological map (scale 1:100,000), hydrogeological section and well logs. Supporting Report(2) includes database manual and groundwater simulation data. Other records collected or investigated in the Study are shown in the Data Book.

2. SOCIOECONOMIC AND SECTORAL BACKGROUND

2.1 Madagascar and Toliara Province

2.1.1 General

Madagascar, an island country of 592,000 km2, is administratively organized in four hierarchical levels of decentralized or autonomous communities, which in descending order are: FARITANY (Province), FIVONDRONAM-POKONTANY (Prefecture), FIRAISANA (District) and FOKONTANY (Village). There are six Provinces, 111 Prefectures, 1,252 Districts and 13,476 Villages in the country.

Toliara Province, with 161,405 km2 or roughly 27% of the country total area under a predominantly semi-arid climate, is divided into 21 Prefectures, 210 Districts and 2,027 Villages.

The last population census was taken in 1975, turning as a result 7,603,000 inhabitants in Madagascar. Projections based on the 1975 population census are 9,985,000 for 1985 and 11,443,000 for 1990. The average population growth rate is 2.76% per year, resulting from 44.2 per thousand gross birth rate and 16.6 per thousand gross mortality rate. Other social indicators include infant mortality estimated at 68 per thousand, and life expectancy estimated at 49.5 years for males and 51.1 years for females.

The overall population growth rate is a composite reflecting a faster growth rate in urban areas than in rural areas. Urban population grew absolutely and also increased relatively from 16.3% in 1975 to 19.1% in 1985 and 20.7% in 1990. Conversely, rural population, although larger in absolute terms, decreased relatively between 1975 and 1990.

In 1990, population younger than 15 years was estimated to comprise around 43.3%, while the population aged 65 years and over comprise around 3.6%. Hence, about 53% of the total population, or roughly 6 million people fall into the economically active age category. The high proportion of rural population suggests that the vast majority of the economically active population is engaged in productive activities in the primary sector.

The 1985 population of Toliara Province was estimated at 1,440,000 inhabitants, roughly 14% of the country total population. Although no data were available on the Toliara Province economically active population and its sectoral distribution, observations during the field survey indicated prevalence of the rural population, suggesting that the population is engaged basically in farming activities. In addition, noticeable service activities are micro-businesses such as road side stall merchants, street vendors, and transportation service operators.

2.1.2 Economy

A marked deterioration of the economy during the early 1980's prompted the Government of Madagascar to take a series of corrective measures, formulating an economic policy designed to achieve a gradual transformation of the centrally planned economy into an economy ruled by market forces. These corrective measures included domestic and foreign trade measures (lifting of price controls and restrictions on exports, simplifying export and import procedures), public sector measures (withdrawal of the State from productive activities, closing down unprofitable State owned enterprises), liberalization of the financial sector and periodic adjustment of the exchange rate. The economic policy implemented by the Government revitalized the economy as reflected in recent economic indicators.

In real terms, gross domestic product (GDP) at constant 1984 prices grew from 1,400 billion FMG in 1985 to 1,522 billion FMG in 1989, for an average growth rate of 2% per year during the four year period. However, the growth rate from 1988 to 1989 was a remarkable 3.82%, fueled by a strong 7% growth rate in the primary sector where rice production jumped from 2,149,000 ton in 1988 to 2,380,000 ton in 1989. The 1989 GDP breakdown showed the primary sector comprising 44%, the secondary sector 16% and the tertiary sector 40%. The World Bank reported the per capita gross national product of Madagascar as US$180 in 1988.

As a reflection of the economic situation of the country, the economy of Toliara Province is heavily dependent on the primary sector. However, activities in the primary sector are hampered by the long dry season lasting from May to October. This situation is aggravated in the case of small farmers without irrigation infrastructure which could offset, at least partially, the adverse effect of the harsh climate on small scale farming.

Farming activities, which are made possible mostly during the rainy half of the year, and the scarce development of the manufacturing sector appear to push people into the informal service sector, not only in urban areas but also along the main road in rural communities. However, even these service activities are hampered by the predominantly poor state of the road network, which restricts the traffic volume.

As the process of economic development advances, the shift of the rural population to urban areas will inevitably accelerate, and the manufacturing sector will necessarily have to be developed. Urbanization places a heavy demand on basic services like water supply, and manufacturing in general requires a reliable water source. From these viewpoints, the study to determine the development potential of groundwater resources in the southwestern region will undoubtedly have high potential benefits for the economy of Toliara Province.

2.1.3 Water Supply Sector

Only 18% of the population is estimated to be served with potable water supply, of which 16.5% in urban areas. Population centers of more than 2,000 inhabitants are classified as urban areas, 83% of which have their water supply facilities, even though 36% are in bad conditions. In reference to towns of less than 2,000 inhabitants, or rural areas, 16% are served with water supply but 12% are in bad conditions. Further, about 80% of water supplied to the rural population was estimated to be of unsatisfactory quality, giving rise to a significant incidence of water-borne diseases, especially among children.

Gastrointestinal diseases appear to be the third most important cause of morbidity and mortality in hospitals, requiring some 206,000 people to seek medical care, and causing 690 deaths in 1987. In addition, bilharziasis (schistosomiasis) patients accounted for 2.8% of hospitalizations in Toliara Province, while comprising only 0.9% in the whole country.

Water supply facilities in urban areas are composed of impounding works, treatment plants, and conduction, storage and distribution systems. In cities of over 2,000 inhabitants and capital cities of Prefectures, these facilities are under the responsibility of JIRAMA, and in certain cases under the District government. On the other hand, water supply systems for rural areas basically consist of wells with or without handpumps, directly from rivers, pumping from wells or rivers, collection and storage of rain water. These facilities are under the jurisdiction of MIEM or local governments.

As the needs of the water sector are generally accorded high priority, different government and non-governmental organizations have been taking cooperative actions to solve the most urgent problems. However, due to limited resources, the program has been rather modest in scope, centering around repair and rehabilitation of water supply facilities.

The three objectives of the 1986-1990 National Development Plan are food self-sufficiency, increase of exports, and improvement of living standards. The strategy to attain these objectives was outlined through six measures, one of which being the improvement of the social situation. Priority areas identified in the social aspect are health, quality of education, housing, potable water supply and sanitation.

The country has been striving to implement a coherent action geared toward accomplishing the objectives of the International Drinking Water Supply and Sanitation Decade. Within this framework, a World Bank/WHO mission conducted a study in 1982 and made recommendations for rural water supply and sanitation.

Within the water sector, the policy of the country has been to supply drinking water to all urban population centers by

1992, and to make water accessible to the rural population by the year 2000, so that one round trip to the water source takes no more than 15 minutes. The country recognizes the need for beneficiary communities to participate in the construction of water supply facilities according to their possibilities, that is, contributing construction materials, labor, etc. Also recognized is the need for users to pay water charges, to cover at least operation and maintenance costs.

The Government of Madagascar is in the process of formulating an updated water supply policy. To this effect, a World Bank mission visited the country in October 1990 to provide its invaluable assistance. Having set the procedure and timetable, an updated water supply policy for Madagascar is expected to be completed in early 1991.

2.2 Study Area

2.2.1 General

(1) Administration, Population, Infrastructure and Public Health

The overwhelming majority of the candidate villages proposed for the Study consists of FOKONTANY, the rest being distributed between FIRAISAMPOKONTANY and KOMITY.

FOKONTANY, which from the viewpoint of the rural water supply program is the most important unit, is a spontaneously formed community of considerable concentration. However, with the many constraints encountered, such as lack of institutional and financial capacity, its administrative capability remains limited.

The Study Area is almost flat with some rolling plains, where rural inhabitants have traditionally formed small and concentrative settlements. As an individual settlement, a FOKONTANY exhibits in most cases the characteristics of a self-sufficient society with its own minimum social infrastructures such as a primary school, a church, water sources, etc.

The survey shows the population of FOKONTANY to vary from around 500 to 3000. On the average, about 8 to 10 persons constitute a standard family.Change in FOKONTANY population due to immigration or emigration may be generally regarded as minor when compared with the natural growth rate.

Existing network of roads in the Study Area is unsatisfactory, both in coverage and in surface condition, to support and sustain sound social and economic activities in the region. The main roads traversing TOLIARA-SAKARAHA-IHOSY and TOLIARA-MOROMBE can hardly be regarded as all-weather type roads with their damaged pavement and bumpy surfaces. Secondary and tertiary (feeder) roads, which occasionally pass through river beds and swampland, have worse surfaces without any kind of regular maintenance.

Electrification of the region remains low and its real improvement in terms of capacity and coverage is hardly expected in the short term. At present, mini-power stations with engine generators are installed in TOLIARA City and SAKARAHA.

Telephone and telecommunication systems are not yet sufficiently developed in the Study Area. Modern microwave relay stations for telephone and television channels are installed in the southern area to connect TOLIARA to ANTANANARIVO and other cities.

Due to scarcity of reliable information, the actual state of public health in the Study Area could not be accurately ascertained. However, because of the short-supply of safe water, water-borne and water-related diseases were expected to be widespread in the Study Area.

The highly skewed distribution of medical facilities (e.g., hospitals, medical centers, dispensaries, maternity clinics, etc.) provide rural inhabitants very little opportunity to receive competent medical treatment.

(2) Economy

Most inhabitants in the Study Area are engaged in farming and livestock breeding. Cotton and rice are the main cash crops and the basic source of farmers income. With regards to livestock, cattle-raising is the most popular as it yields better economic returns and adds prestige to the owner, as cattle occupies an important place in the culture of Madagascar.

In agriculture, while irrigation farming has considerably been developed in the western and southern areas, farming remains largely rain-fed. The production of food crops is gradually increasing but has yet to reach the self-sufficiency level, particularly for rice which is the nation's staple food.

As to the levels of income among rural inhabitants, no reliable record or information was available.

2.2.2 Water Supply Sector

Water supply services are reduced by public entities and private entrepreneurs. Two public sector entities are responsible for the provision of potable water in the Study Area. MIEM takes on the task of supplying safe water to the rural areas, while JIRAMA, a public corporation which operates within the purview of MIEM, takes charge of water-works in the urban area of TOLIARA.

There are at present a few urban-type water supply systems in TOLIARA and Morombe. In the case of TOLIARA, water source is groundwater from limestone aquifer with pumping stations located in MIARY and ANDRANOMENA. Their facilities consist of pumps and storage tanks which are of too small capacities to meet even present demand. This problem is further aggravated by a distribution main which is over twenty years old and which needs immediate replacement. Water supply service is provided by house connections and public hydrant. JIRAMA takes resposibility for the operation and maintenance of all services, establishing the water fee system and maintenance organization.

In the private sector, water vendors, using tractor 200 liter drums on trailers or trucks and tank lorries, are active along Route 7.
Most of village people in the rural area takes water from traditional sources such as underflow water in dry river bed, surface water from rivers, brooks, and irrigation canals and shallow well. These water sources are very convenient since they are located usually only a few hundred meters away from settlements. However, most of these water sources are contaminated, and their continued use by villagers is considered to be due to an insufficient awareness on health and sanitation.

Foreign aid agencies supported the construction of tube-wells in the region in 1963, but had the experience of finding many of the handpumps turned into useless scraps after only a few years.

MIEM Toliara branch has a resposibility to give technical support to the construction, operation and mainteneance of water supply facilities in rural areas. However, their activities are constrained to a considerable degree by the insufficient availability of budget, machinery, spare parts, equipments and technical staffs.

3. HYDROGEOLOGICAL INVESTIGATIONS

3.1 Topography and Vegetation

(1) Topography

Fig. 2 shows topographical zone in the Study Area. The topography of the area is characterized by some massifs extending in the NNE-SSW direction. Isalo massif and Tangorombohitr massif, both with approximate length of 60 km, are located in the eastern margin of the Study Area. These massifs are at present separated by a wide valley of Ilakata River, a branch of Imalto River, even though originally the two massifs formed a continuous mountain chain. A steep cliff continuously borders the edge of these mountains. Complicated deep valleys have been formed between both massifs. Some flat top mountains are independently distributed in the area.

Only part of Isalo massif is contained in the Study Area, but it is the principal recharge area of Isahena and Malio rivers, which have their watershed located in the eastern side of the massif. On the other hand, the Tangorombohitr watershed is located in the western part of the massif, thereby contributing only partially to the recharge of Isahena and Malio rivers.

Lambosina massif is extended over 100km, with a very gentle slope. The western side of this massif is a very steep cliff, while the eastern side is a very long and gentle slope. This slope is the principal drainage basin of the right bank of Sakanavaka River. Two massifs sandwiching Sakondry River were originally formed by Lambosina massif as a continuous body, but it was eroded and divided by Fiherenana and Sakondry rivers.

Analavelona massif is 35km in width and 100km in length. Since the watershed is skewed to the west, the eastern slope is long, being the principal discharge basin of the right bank of Fiherenana River. The northern part of the massif includes Herea plateau, which is the principal drainage basin of Sakanavaka River.

Mikoboka massif is 25km wide in its central part. This

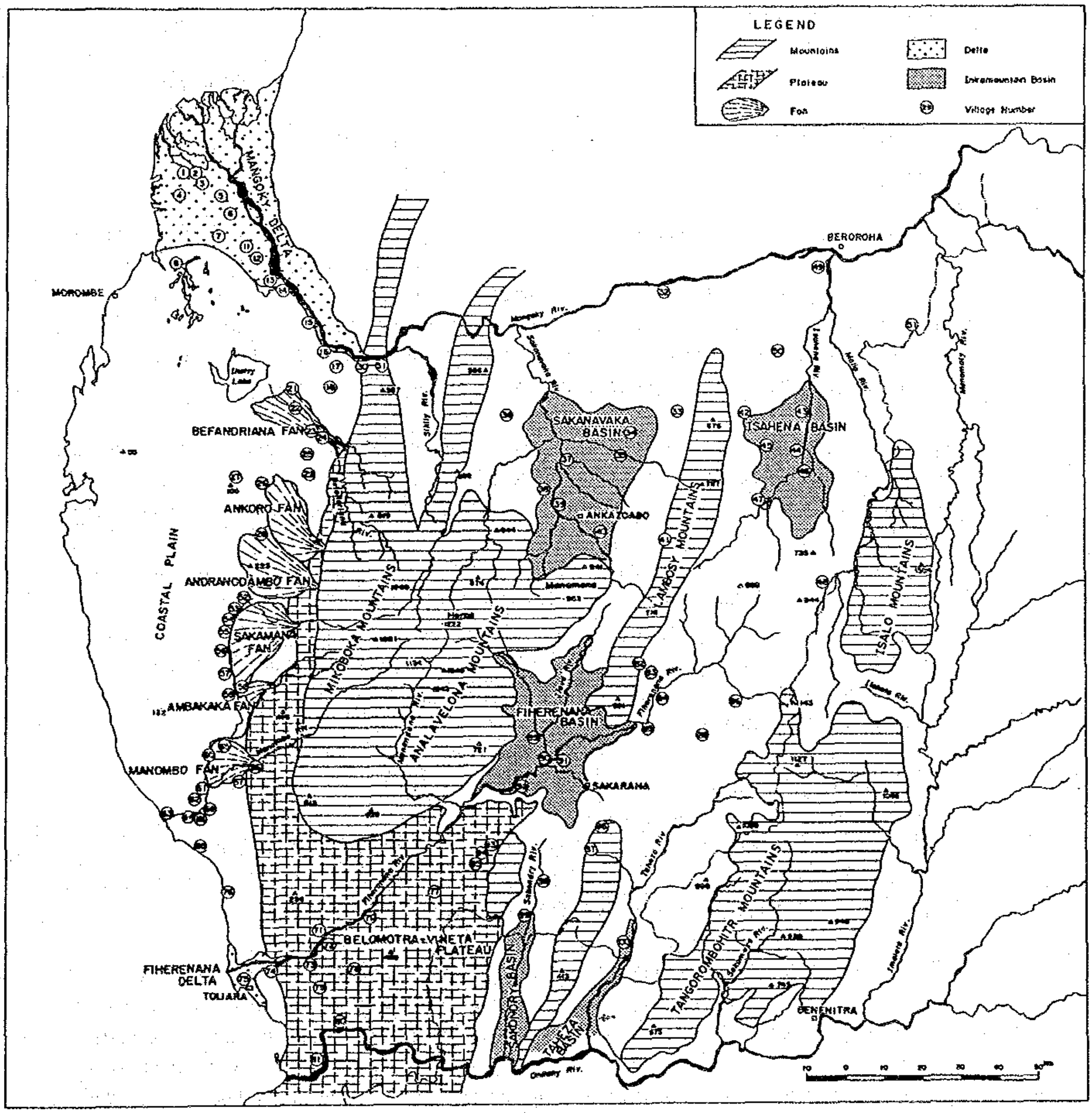


Fig. 2. Landform Classification Map

massif forms two branch chains in the northern part and sandwiches the valley of Sikily River, extending to the northern part of Mangoky River. The watershed of this massif (1,000m-1,100m in altitude) is skewed to the east, whereby the western slope is long, being the principal drainage basin of rivers flowing toward the coast. There is a deep straight valley between the upper reaches of both Manombo and Sikily rivers. There is no valley between Mikoboka massif and Analavelona massif.

Between the western side of Mikoboka massif and the southern side of Analavelona massif, the Belomotra-Vineta plateau slopes gently to the south. This plateau is extended almost 60km south of Analavelona, crossing the Onilahy River. This plateau is basically flat, but it includes very deep valleys in complicated patterns.

The western part of the mentioned plateau is a very wide continuous plain (Coastal plain), with an average elevation of less than 200m, reaching the coast in the southern portion. There is a big delta in the northern margin, and a small delta by Fiherenana River in the southern margin, which is located in the coastal plain. The width of this plateau is around 70km in the northern part, becoming gradually narrower toward the south. The above mentioned Belomotra-Vineta plateau faces directly the sea in the mouth of Onilahy River.

In the eastern side of an imaginary line from Lake Ihotry to the mouth of Manombo River, there are six fans from north to south along the western margin of Mikoboka mountain. This zone is divided by the river system into Lake Ihotry basin and Manombo River basin.

There are other basins in the Study Area. The basins formed in the middle reaches of Isahena, Sakanavaka and Fiherenana rivers, classified as poligon-shaped intramountain basins, are eroded by many branch rivers. The boundary between these basins and surrounding mountains is not clear. On the other hand, the basins formed in the lower reaches of Taheza and Sakondry rivers, classified as valley plain, are narrow and straight.

(2) Vegetation

The vegetation of a catchment area is a very important factor for groundwater recharge. Cattle and sheep graze in the Study Area, and deforestation to open up new land for farming and grazing has rapidly advanced in the past 10 years. Grazing land is burned every year, leaving little chance for reforestation. There are irrigation intake facilities, which were damaged by cyclone flooding, on Mangoky River in January-February 1972, and on Fiherenana River in December of 1966 and 1989. This problem suggests that deforestation has a direct influence on river condition.

Fig. 3 shows the forest distribution as land cover classification map produced by LANDSAT TM data. According to this map, forest area remains only in the western part of the coastal plain, Belomotra-Vineta plateau, the area from the western slope of Analavelona massif to Herea plateau, and the area between the upper reaches of Fiherenana and Taheza rivers. The vegetation cover of the coastal plain and the Belomotra-Vineta plateau is composed of bush, which is considered to contribute little to groundwater recharge.

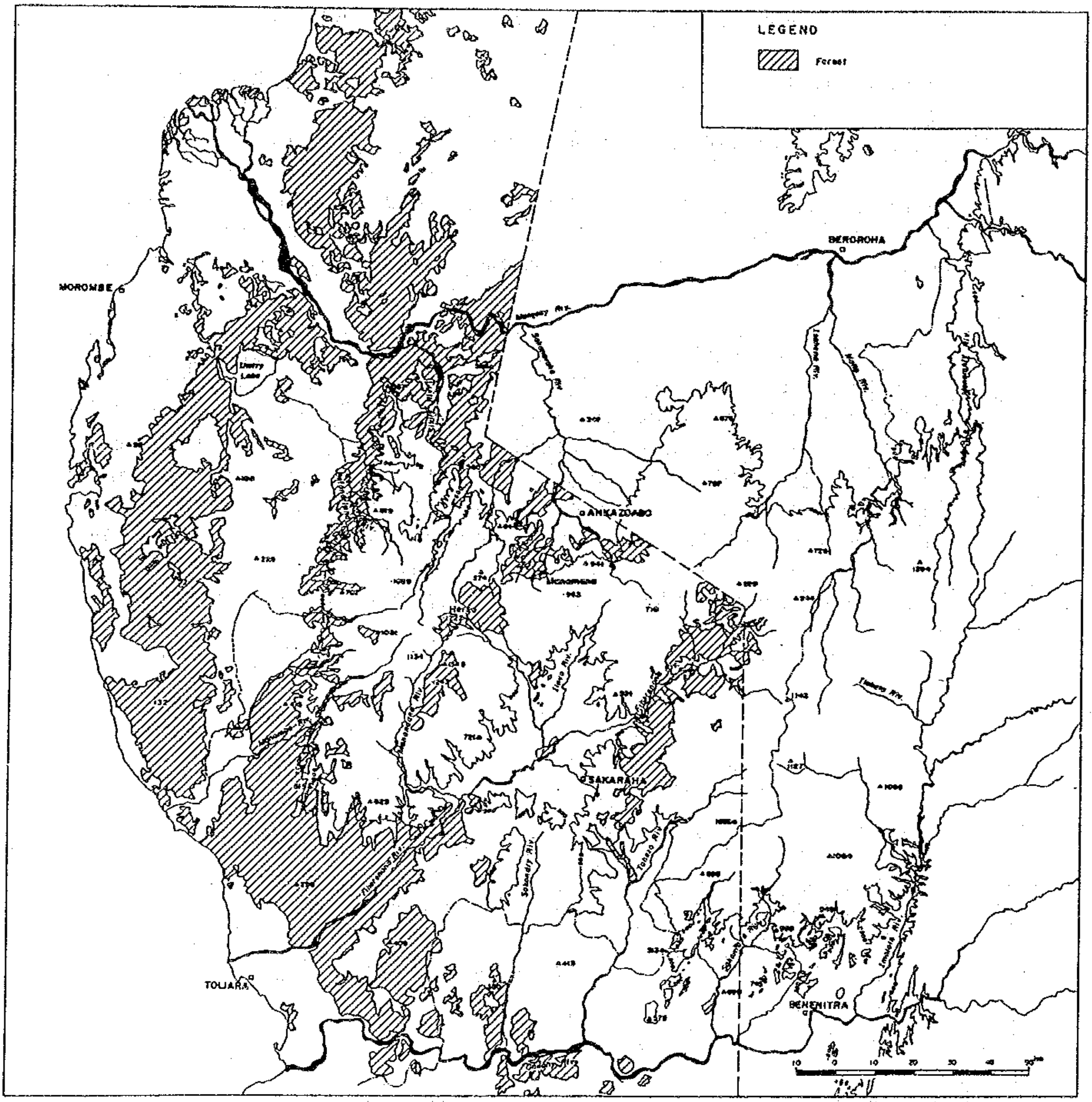


Fig. 3. Forest Distribution Interpreted on LANDSAT TM Data

Table-1 Stratigraphic Classification

Geological Time		Stratigraphic Classification	
Cenozoic	Quaternary	Quaternary System	Fluviatile Deposits
			Sand dune
			Alluvial-fan Deposits
	Neogene	Neogene System	
	Paleogene (Eocene)	Eocene Series	Middle & Upper
			Lower
Mesozoic	Cretaceous	Cretaceous System	Upper
			Lower
	Jurassic	Marine Jurassic System	
		Isalo Group	Upper
			Middle
			Lower
	Triassic	Sakamena Group	
Paleozoic	Permian		
	Carboniferous	Sakoa Group	
Precambrian		Precambrian System	

3.2 Geology

(1) Stratigraphy and lithofacies

The classification method of strata and age of each stratum underlying the Study Area varies somewhat depending on materials. Table 1 shows classification of ages and the stratigraphy adopted in this report.

The Precambrian system is composed of hard metamorphic rocks and plutonic rocks exposed in a limited area at the eastern margin of the Study Area. The Sakoa and Sakamena Groups of the Carboniferous and Permian periods, respectively, are in unconformable or fault contact with the Precambrian system. Of the two groups, the Sakoa Group begins with basal tillite and is mainly composed of continental deposits, while the Sakamena Group is composed of continental deposits associated with lagoon sediments and marine deposits, indicating that the sedimentary environment changed during the sedimentation of the group.

Of the Jurassic system, the part composed mainly of continental deposits are collectively called Isalo Group and gradually changes into the underlying Sakamena Group. The Lower and Middle Isalo Groups consist mainly of arkose sandstone, which is low in solidity, and exhibit cross-bedding and conglomerate, but the Upper Isalo Group shows mixed facies of continental and marine origins. The marine Jurassic system shows the contemporaneous heterotopic facies of the Upper Isalo Group and is composed mainly of limestone and calcareous sandstone, containing sandstone of continental origin at a considerable rate.

The Cretaceous system is divided into the Upper and Lower subsystems, and no large time gap is observed between the lower subsystem and the Jurassic system.The Lower Cretaceous system begins with limestone but is thin. The Upper Cretaceous system occupies the main part of the Cretaceous system and is composed of thick continental sandstone overlain by limestone. The Upper Cretaceous system is interbedded with several basalt beds. The thickest basalt bed reaches 100m or more and has a wide distribution of 100km in the north-south direction and 100km or more in the east-west direction. Since the strata directly above the basalt beds have undergone thermal metamorphism, the basalt beds are considered to be sheet intruded into the Upper Cretaceous system.

While the lower section of the Eocene series is composed mainly of limestone over the whole Study Area, the Middle and Upper Eocene series consist of marly limestone, marl, marly sandstone, sandstone, etc. Marine deposits are dominant in the southern part of the region, while continental deposits predominate in the northern part. In addition, basalt necks intruding into the Eocene series are everywhere on the coastal plain.

Although the Neogene system is limited in distribution and its accurate age is unknown, there are marine deposits resting unconformably upon the Eocene series, and continental deposits unconformably overlying the Isalo Group.

The Quaternary System is composed of alluvial-fan deposits, sand beds forming new and old sand-dunes, fluviatile deposits, etc. Of the deposits, the alluvial-fan deposits were expected to be distributed in the 6 alluvial fans identified from the topographical maps and satellite images, but no typical alluvial-fan deposit was found, except partially developed ones, as a result of this investigation.

Although the already existing geological maps classified sandy veneer rocks as members of the Quaternary system and showed their distributions, the rocks were regarded as surface soil and excluded from this hydrogeological map and stratigraphic table.

(2) Geological Structure

The geological structure of this region is summarized below.

The upper boundary of the Precambrian basement, widely ex posed on the east side of the Isalo Mountain, steeply slopes westward and is overlain by Paleozoic and younger strata of 5,000-8,000m in total thickness. Since these strata generally dip westward at gentle dip angles, newer strata show up gradually toward the west. However, the zonal structure is disturbed by several fault systems.
The first system is composed of a group of north-south

faults developed in echelon at the western margin of the Precambrian basement. Since the Carboniferous Sakoa and Permian-Triassic Sakamena Groups occupy only the west side of this group of faults, it is considered that the main activity of the fault group took place early in the Paleozoic period.

The second fault system is the Ilovo Fault which longitudinally cuts the central part of the Study Area in the NNE-SSW direction. Since the fault not only bounds the western distribution of the Paleozoic and Lower Jurassic systems, but also displaces the Middle and Upper Jurassic systems of marine origin, it is considered that the main activity of the fault started during the Paleozoic period and continued to and after the Jurassic period.

The third fault system is a group of faults running in the NNE-SSW direction in both Analavelona and Mikoboka Mountain districts. Alternating westerly dipping and easterly dipping faults form horsts and grabens. Since this group of faults displaces the Eocene series and, at the same time, controls the arrangement of the basalt necks, it seems that the main faulting took place after the Eocene period caused by volcanic activities.

The fourth fault system is a group of faults running in the Tangorombohitr Mountain district in the NNE-SSW direction. This group of faults also forms horsts and grabens as the third fault system does, but the horsts are covered with the continental Neogene system. Therefore, it is considered that the main activity of this fault system took place after the Neogene period.

The fifth fault system is a group of faults (Toliara Fault) which bounds the western extension of the Belomotra-Vineta plateau. While the northern extension of the fault system from the Manombo River had to be estimated, it becomes clear from the interpretation of satellite images made during the course of this investigation that the fault system reaches the western margin of Lake Ihotry. The faults run in parallel with each other in the N-S to NNW-SSE direction and, since they cut Tertiary faults, they are considered to be the latest in the region.

3.3 Climate

(1) General climate

The climate of Madagascar is distinguished into the rainy season lasting from November to March, and the dry season lasting from April to October. The mean annual temperature in the coastal area is about 24°C, while it is about 22°C in the mountain area. Lowest mean temperature is 18-20°C in June in both areas, and the highest mean temperature is 25-29°C in October-November. The daily maximum and minimum temperatures are 14-31 °C in the coastal area and 10-30 °C in the mountain area.

(2) Rainfall

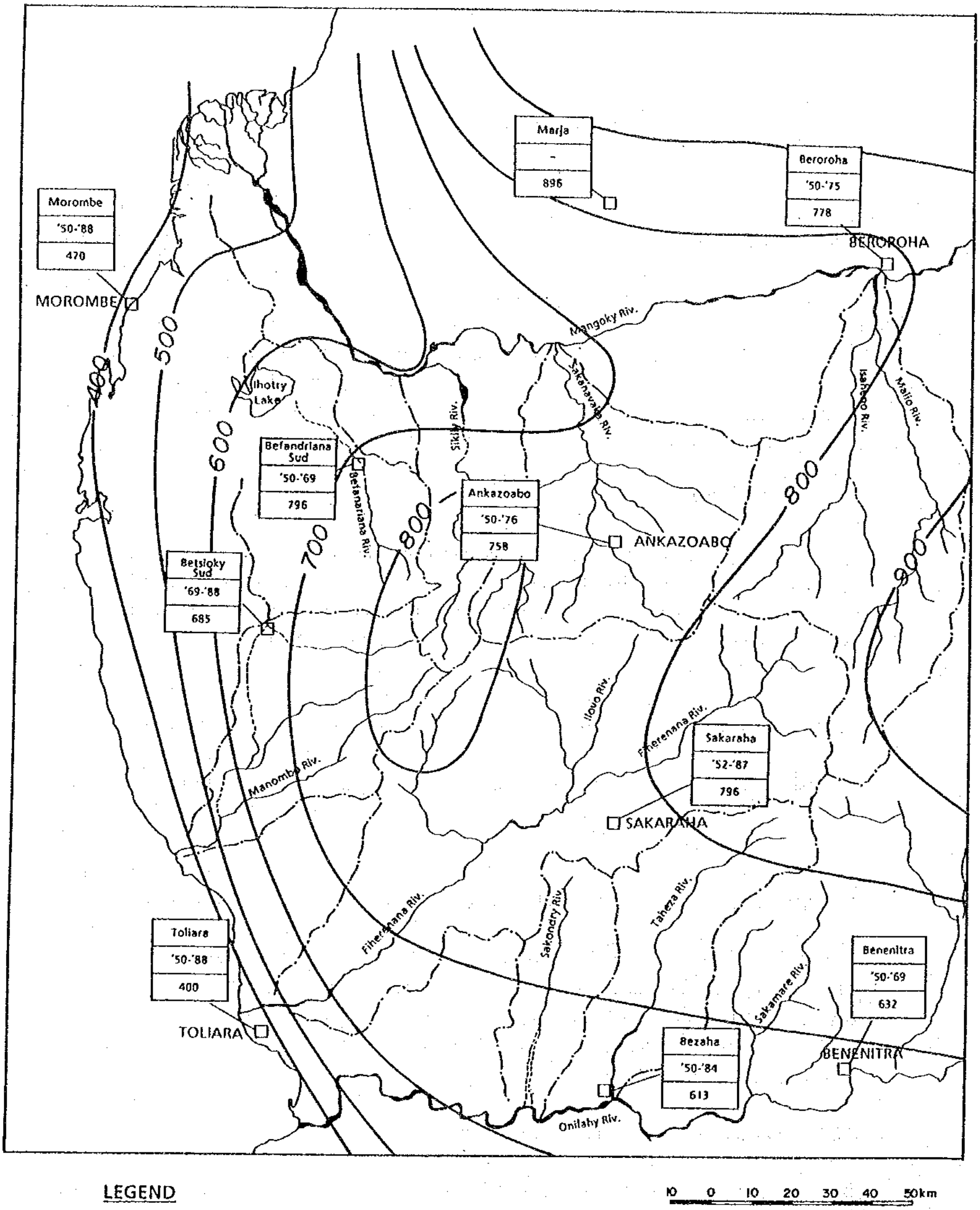
The coastal area has a three-month rainy season from December to February, each month with more than 75mm, while the mountainous area has a five-month rainy season from November to March, with more than 100mm per month.

The coastal area has a mean annual total rainfall ranging from 383mm in Toliara to 418mm in Morombe, while the mountainous area has it varying from 633mm in Bezaha to 973mm in Ranohira. Thus, the annual isohyets are decreasing from east to west of the Study Area, as shown in Fig. 4.

In the rainy season, rain making disturbances are more frequent with abundant cumulus clouds, producing heavy downpours and thunderstorms. Most rainfalls occur in the afternoon and early evening. Night rains are also frequent. Rainfall periods are rather short, lasting for a few days, alternating with periods of clear sky, and it is influenced by cyclones blowing from the northwestern direction every year.

(3) Evaporation and Evapotranspiration

Daily evaporation has been measured using Piche evaporimeter at three stations, namely, Toliara, Morombe and Ranohira. No Class A evaporation pan was installed in the Study Area. Piche evaporimeter is not recommended for hydrology in arid zones.



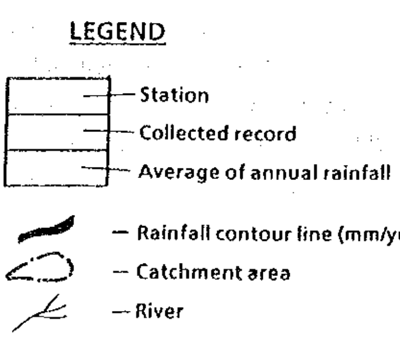


Fig. 4. Location of Meteorological Stations and Annual Isohyet

Thornthwaite and modified Penman method were used to calculate evapotranspiration. Results are almost twice of annual rainfall, for example 1,664 mm in Ranohira.

(4) Climatic Type

From the hydrological viewpoint, Koppen's classification probably gives the most comprehensive account of the variety of climatological regimes in the tropics. Based on the above rainfall and temperature characteristics, the Study Area is classified as having the Savanna-Steppe climate. Rainfall shortage is explained by this area being behind the trade wind blowing from the east. On the other hand, cyclone increases annual rainfall in the area between Mikoboka Masiff and Mongoky river.

3.4 Streamflow

(1) General Condition and Discharge Records

As shown in Fig. 4, two big rivers exist in the Study Area--the Mangoky River and Onilahy River, both flowing from east to west. The Mangoky River serves as the northern boundary of the Study Area, while the Onilahy River serves as its southern limit. Catchment area for Mangoky River at Bevoay Gaging Station is around 54,000km^2; for Onilahy River at Tongobory Gaging Station, about 29,000km^2.

Between Mangoky and Onilahy Rivers are the Manombo River, the Fiherenana River and many seasonal rivers. The Manombo River originates from the Mikoboka Mountains, with a catchment area of 380km^2 above Andoharano Village. The catchment area of Fiherenana River covers the Analavelona Mountains on the north, and the catchment area's eastern edge lies almost at the center of the area between Sakaraha and Ranohira. Many small seasonal rivers existing in the coastal area originate from the Mikoboka Mountains.

The discharge observations were being performed well in most of these stations before they were closed in the sixties. Some stations have been reopened starting in 1983, but records are insufficient for the analysis of surface water characteristics.

(2) Field Inspections and Discharge Measurements

According to field inspections, deforestation by cattle and sheep grazing, slash and burn agriculture, and firewood supply to big cities like Toliara and Sakaraha are rapidly advancing in the upper reaches of catchment areas.

Basically, this area is highly susceptible to erosin because of the dry climate, fragile soil, and high rainfall intensity. As a result, large volumes of sediments are deposited not only in the downstreams, but also in the upper reaches.

One of the characteristics of arid zone's river consists of groundwater being recharged by river water during the dry season, when the groundwater level falls below the river bed level. Therefore, the dry season river discharge decreases from upstream to downstream, and may completely disappear (e.g. Fiherenana River). This fact should be taken into account in estimating the base flow. Conversely, during the rainy season, when the groundwater level rises above the river bed level, groundwater contributes to river discharge.

In June-July and September-October 1990, spot measurements were performed in order to understand the general flow conditions of seven rivers. Results of spot measurements are presented in the following Table.

River	Observation Point	Catchment Area (km^2)	Specific Discharge Jun-Jul ($l/sec/km^2$)	Sep-Oct ($l/sec/km^2$)
Sakanavaka	Ankazoabo	332	-	6.02
Malio	Confluence	2046	5.99	6.23
Isahena	Malio and Isahena	1870	2.54	1.28
Sakondry	Junction with Route 10	727	-	1.10
Taheza	Upper portion of Barrage	1600	9.34	9.63
Fiherenana	Antaralava	2157	4.34	3.16
	Behompy	6755	1.39	0.47
Manombo	Andoharano	508	4.14	2.52

Results of spot measurements indicate the following.

- Discharge of Isahena river is smaller than Malio river's because the catchment area of Malio river includes Isalo massif, and areal rainfall should be bigger than Isahena river catchment area.

- Specific discharge of the Sakanavaka river is almost the same as Malio river's. However, this point, Ankazoabo is located in the upstreams, while Malio's point is in the downstreams. Therefore, areal average of Sakanavaka will be smaller than Malio's.

- The discharge of Sakondry river is very small in comparison with Taheza river, due to the same reason as above, and additionally, rainfall volume is bigger in the upstream catchment area. Geologically, the Sakondry river basin includes a great deal of marl, which is considered as impermeable material.

- Measurements of Fiherenana river were taken at Antaralava and Behompy. In the case of Behompy, it is estimated that weathered limestone exists under the sand deposit, whereby the possibility of recharging from river to groundwater is high.

(3) Discharge record

Fig. 5 shows monthly discharge observations in principal rivers. Runoff is mostly dependent on rainfall, and starts increasing in November. Peak amount is observed in January, while discharge remains almost the same during May - October. This season with steady discharge is considered as base flow season.

Fig. 6 shows the discharge at Behompy (Fiherenana River) and Betroka (Onilahy River) stations. Water flow starts increasing from the middle of November and peaks in February. Flow amount starts decreasing from April, and the amount of base flow during April-October can be considered as almost the same. It is clear that the rainfall flows out immediately or with some delay, reaches a peak and thereafter keeps a steady flow as base flow.
Annual runoff coefficient is calculated in both stations with estimated areal rainfall. The coefficients in Behompy and Betroka are 20 % and 18 %, respectively.

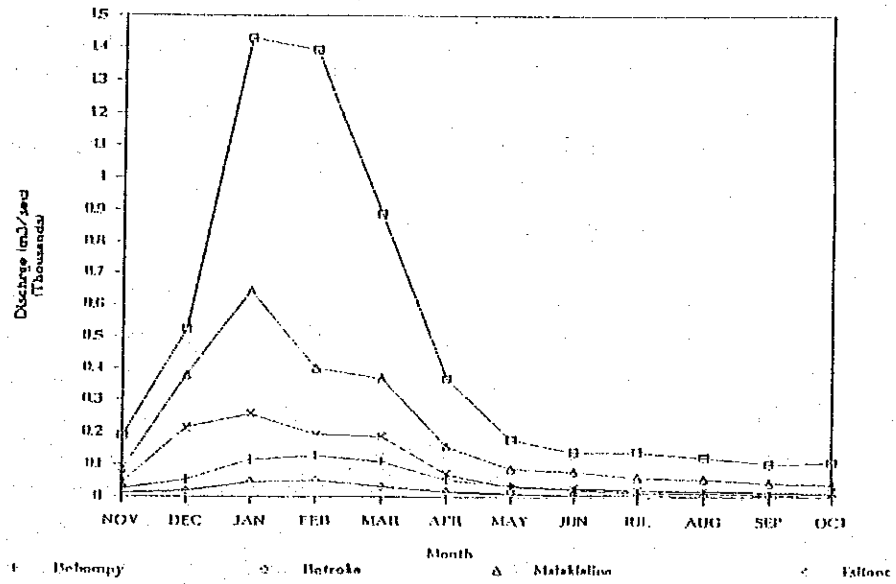


Fig. 5. Monthly Discharge

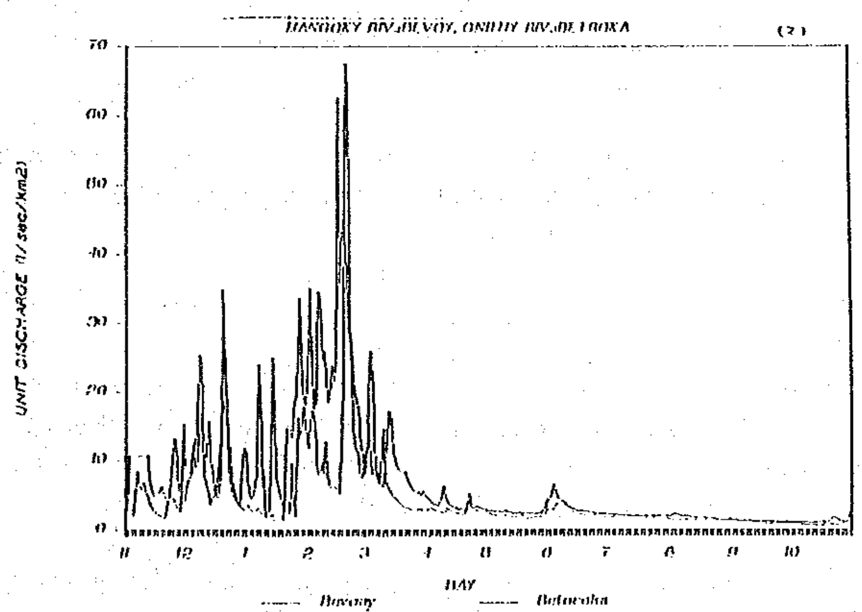


Fig. 6. Daily Discharge

3.5 Existing Wells and Groundwater Levelling

(1) Existing wells

In the Study Area, there are wells with casing (borehole), wells with conrete lining, and shalow wells constructed by foreign aid and MIEM. All boreholes were constructed by U.S. AID in the 1960's. However, no records remain on such data as yield and production, quality of water, static and pumping water levels.

Most boreholes were completed between 1965 and 1970, and only 10 out of 65 boreholes are still working. Twenty six (26) of the 55 remaining boreholes were completely damaged and mostly filled-in with sand. Most of the 29 wells (of the 55 boreholes) with damaged handpumps were either abandoned or filled-in. (Wells were sometimes abandoned mainly because of the 'salty' taste of water.) According to the village people, these wells lasted only for about 10 years, basically because of mechanical and generator failures.

Most boreholes are 15 to 30m deep with groundwater levels varying from 5 to 25m. The deepest borehole exists in Andranohinaly village (219m); this borehole has also the lowest groundwater level (207m). The depth of most dug wells is less than 10m.

Since the actual positions of screens in all boreholes were unknown due to lack of drilling records, the locations of the aquifers could not be determined.

(2) Groundwater Leveling

Simultaneous groundwater levelings were performed at the onset of the rainy season in October and November 1989, during the rainy season in February and March 1990, and the dry season in June and July 1990.

From the onset and towards the end of the rainy season, the groundwater levels in most wells rose by one to two meters. Obtained results suggest that these wells are tapping unconfined aquifers, in which pronounced big fluctuations of groundwater levels occur as a quick response to rainfall.

Results of Miary show a very slow response to rainfall, suggesting that this well might be drawing water from a confined aquifer.

In order to analyze groundwater behavior through the year, automatic water level recorders were installed at two existing and three test wells in the following villages.

Village	Well depth	Date installed	Remarks
- Soahazo	34.0	4.90	(test well)
- Ankaraobato	75.5	3.40	(test well)
- Anbatolily	17.5	2.7-3.9	(existing well)
- Maninday	73.5	16.29	(test well)
- Sakaraha	32.0	10.30-10.40	(existing well)

The results of Soahazo, Ankaraobato, Anbatolily and Maninday show some coincidence between rainfall and groundwater level. The record at Sakaraha showed a very slow response to rainfall, suggesting that this well might be drawing water from a confined aquifer. The recharge of this aquifer may not be influenced by precipitation.

3.6 Geophysical Prospecting

In order to investigate hydrogeological structure, two methods of geophysical prospecting were used: electrical resistivity sounding and VLF magneto-telluric survey. Survey sites and survey points were selected based on the hydrogeological conditions resulting from the LANDSAT and SPOT image data analysis, the aero-photo interpretations, geological field reconnaissance and the reviews and analysis of existing hydrogeological data and information.

(1) Electrical Resistivity Sounding

Electrical resistivity sounding was performed to analyze hydrogeological structure, aquifer characteristics and groundwater development potentiality. From the results of this sounding and additional hydrogeological analyses, the sites and depth for test drilling were determind.

As the conclusion of the results of electrical resistivity sounding and its hydrogeological interpretation, along with the results of test drilling and pumping test, the following correlations between apparent electric resistivity values and lithofacies are generally found in the Study Area.

Lithofacies	Resistivity ohm-m	Remarks
Clayey marl	3-6........	Generally poor aquifer
Marl	5-25.......	
Sandy marl	4-30.......	
Mudstone	10-30......	
Silty or muddy sandstone	8-30.......	Locally productive aquifer
Marly sandstone	20-82......	In general, highly productive aquifer
Alternation of sandstone and marl or mudstone	17-384.....	
Marly limestone	33-99......	
Sandstone & gravelly sandstone	80-2,200...	Highly productive aquifer (if less than 1,000 Ω-m)
Limestone	95-6,030...	
Basaltic rocks	28-1,120...	

3.6.2 VLF Magneto-Telluric Survey (WADI Type)

As shown in the hydrogeological map, there are many faults and fracture zones in the Study Area, and some of them control directly or indirectly the existence of groundwater in aquifers. In this study, VLF magneto-telluric survey was employed to investigate groundwater controlled by those faults or fracture zones.

Survey points were very limited due to limiting conditions such as the scattered distribution of fault and fracture, and the instrument performing poorly against strong sunlight in the field work. However, even from these limited survey results, this new approach is considered useful for investigating special zones with specific objectives.

Fig. 7 shows the hydrogeological cross section of Toliara

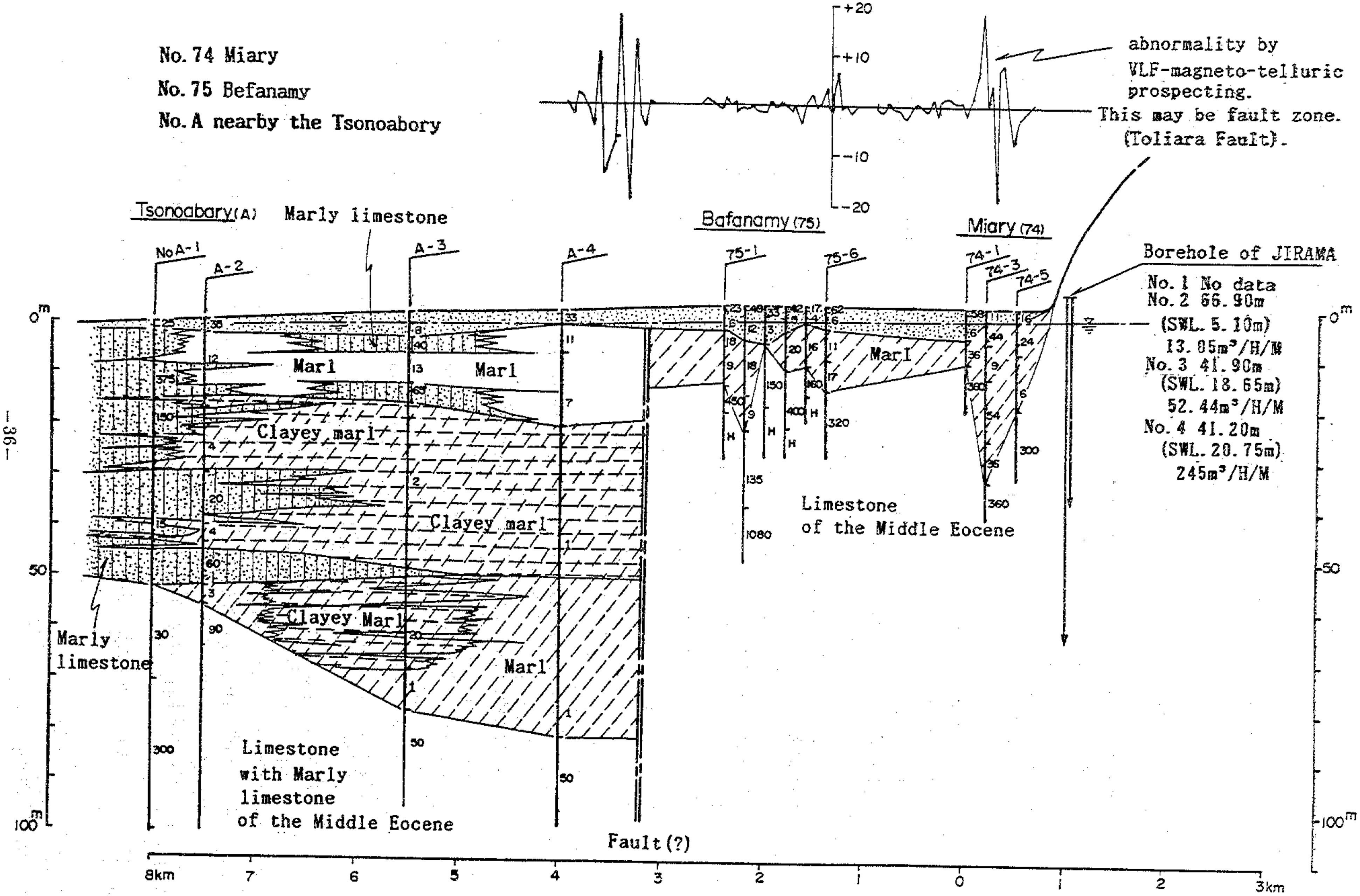


Fig. 7. Hydrogeological Section of Toliara Plain

Fig. 7 shows the hydrogeological cross section of Toliara Plain interpreted from the results of electrical resistivity sounding and VLF magneto-telluric survey. It was confirmed that this survey method would be useful in probing a fault or a fracture zone. Actually, the main source of the water supply system in Toliara City is the groundwater from limestone aquifer at Miary, which is controlled by Toliara fault and its fractured zone.

3.7 Test Drilling and Pumping Test

(1) Test drilling

After completion of the necessary investigations in Phase II, the target sites for test drilling were finally selected, as shown in Fig. 8, with the following purposes.

a. To investigate the groundwater level and hydraulic aquifer characteristics and to evaluate the overall potential of groundwater resources in the Study Area.

b. To examine the groundwater for suitability as drinking water, and to clarify the groundwater flow mechanism by comparing the chemical components of the groundwater in different regions and in different aquifers.

c. To select the priority areas and to formulate a groundwater development plan for the selected priority areas.

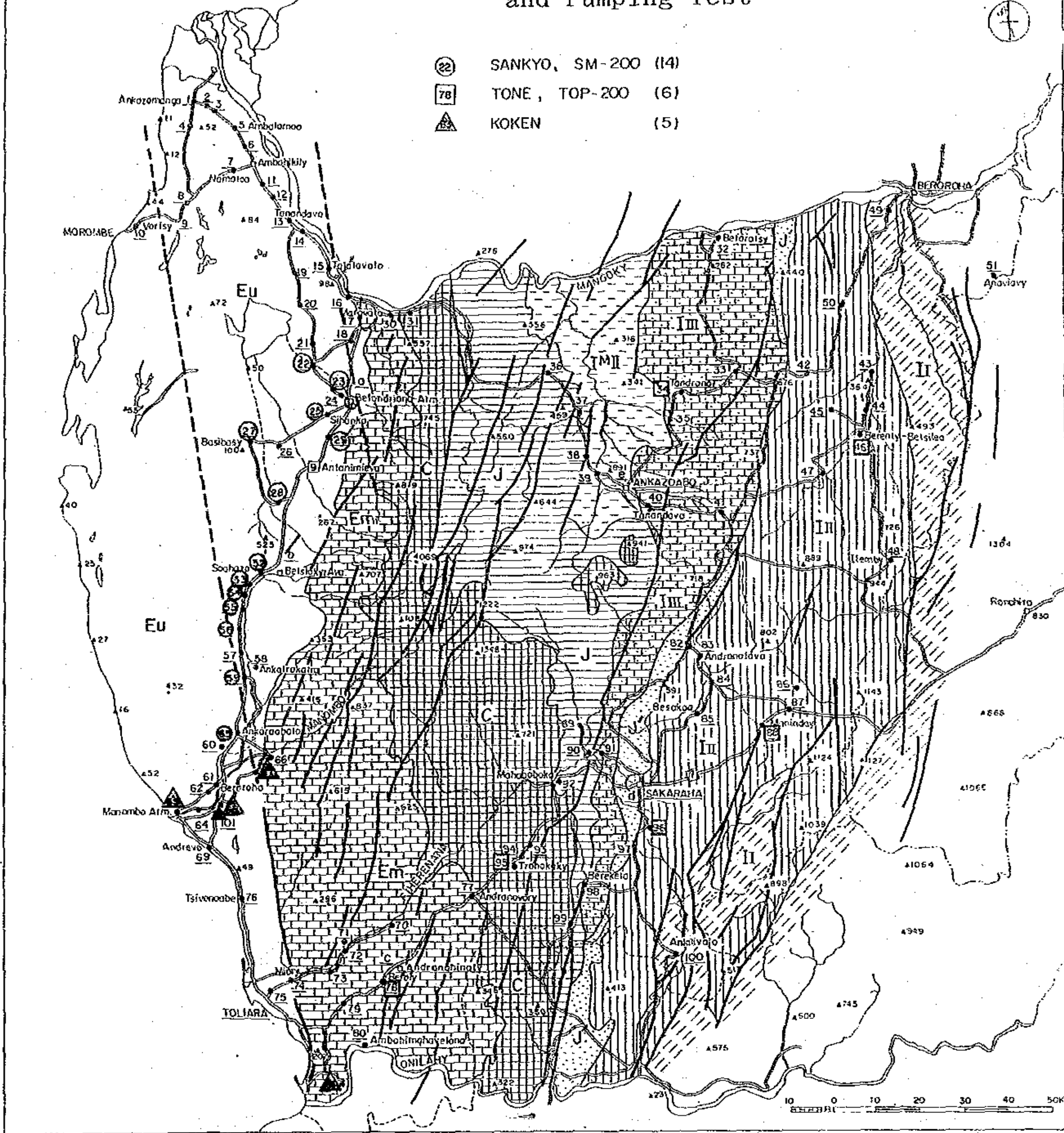
The test drilling survey along with pumping test started on 19 June 1990 and finished on 1st November 1990. The cumulative drilling depth of 26 test wells was 2,096 m.

(2) Pumping Test

As for the pumping test, the step drawdown, the constant rate and the recovery tests were carried out at 25 drilled boreholes using two submersible motor pumps, in order to estimate aquifer properties.

The number of steps, the duration of pumping, and other pumping conditions are shown in Table 2, and the main aquifer properties in the Study Area are summarized by region and by aquifer type in Table 3.

Fig. 8. Location of Test Drilling and Pumping Test



No Villages

I. Fiv. MOROMBE

1 Ankazomanga
2 Beadabo
3 befasy
4 Ankilifolo(1)
5 Ambalamoa
6 Tsianihy
7 Manatoa
8 Mangolovolo
9 Ankida
10 Vorisy
11 Andranomanitsy
12 Barantala
13 Tanandava
14 Antsakoabe
15 Talatavalo
16 Ambiky
17 Marovato
18 Andranoboka
19 Satrambondro
20 Mahavozokely
21 Antranosatra
22 Manoy
23 Ampoza
24 Ankilifolo(2)
25 Sihanaka
26 Bemoka
27 Basibasy
28 Analatelo
29 Mangotroka
30 Nosy-Ambositra
31 Tsiarimploke

II. Fiv. ANKAZOABO ATM

32 Betaratsy
33 Andranomanintsy
34 Tandrano
35 Ampandranitsetaky
36 Andranomafana
37 Manakiala
38 Berenty-Ankilimasy
39 Betsinofo
40 Tanandava
41 Ampoza
42 Ipetsa Atm
43 Mandabe Atm
44 Soatanimbary
45 Sahanory Atm
46 Berenty-Betsileo
47 Ankilivalokely
48 Ilemby

III. Fiv. BEROROHA

49 Tanandava-Antaifasy
50 Anjamitikitra
51 Anaviavy

IV. Fiv. TOLIARA I/II

52 Soahazo
53 Analamisampy
54 Belitsaka
55 Ampasikibo
56 Namaboha
57 Antseva
58 Ankilimiavotoka
59 Ampihamy
60 Ambondro
61 Beroroha
62 Antsomarify
63 Manombo-Atm
64 Antandroka
65 Ankaraobato
66 Andoharano
67 Tsefanoka
68 Benetsy
69 Andrevo
70 Anjamala
71 Ampihalia
72 Behompy
73 Ambolonkira
74 miary
75 Befanamy
76 Tsivonoabe
77 Andranovory
78 Befoly
79 Ankororoka
80 Ambohimahavelona
81 Manoroka
101 Ankilimalinika

V. Fiv. SAKARAHA

82 Iaborana
83 Andranolava
84 Lamboakandro
85 Besakoa(1)
86 Besakoa(2)
87 Ampandra
88 Maninday
89 Bevoalavo
90 Tanambao
91 Ambahimalitsy
92 Mahaboboka
93 Mahasoa
94 Andamasiny-Vineta
95 Tranokaky
96 Analamary
97 Antanimora
98 Bereketa
99 Ankilimitraloka
100 Ankilivalo

a Befandriana
b Betsioky Nord
c Andranohinaly
d Sakaraha
e Ankazoabo

Table 2. Results of Test Drilling and Pumping Test (1)

Well No. & Location	Results of Test Drilling: Drilling Rig	Started / Com-pleted	Drilled Depth m	S.W.L. (GL-m)	Screen Position (GL-m)	Lithofacies of Aquifer	Results of Pumping Test: P/Discharge (Q) l/min.	Drawdown (S) m	Specific capacity l/min./m	Transmissivity m²/min.: Theis	Jacob	Recovery	Water Quality: Electric Conductivity μs/cm	Cl mg/l	pH
22 Manoy	SANKYO SM-200	25.08.90 31.08.90	42.0	8.37	① 18.4~ 38.4 (4")	① medium~coarse sandstone & small gravelly sandstone	280(~309)	12.16	23.03	4.46x10^{-2}	4.34x10^{-2}	9.32x10^{-2}	1,520	286	7.1
23 Ampoza	SANKYO SM-200	18.08.90 24.08.90	50.0	5.28	① 15.5~ 23.5 (4") ② 31.5~ 47.5 (4")	① medium sandstone ② medium~coarse sandstone	283(~310)	9.92	28.53	4.69x10^{-2}	4.71x10^{-2}	8.38x10^{-2}	368	12	7.3
25 Sibanaka	SANKYO SM-200	01.09.90 06.09.90	41.0	5.74	① 19.5~ 39.5 (4")	① medium~coarse sandstone	300(~307)	1.86	161.29	3.62x10^{-1}	4.32x10^{-1}	3.33x10^{-1}	310	11	7.5
27 Basibasy	SANKYO SM-200	29.09.90 06.10.90	83.0	14.49	① 51.5~ 79.5 (4")	① sandy marl & limestone	201(~222)	29.78	6.75	3.89x10^{-3}	9.76x10^{-3}	1.47x10^{-2}	2,740	720	6.8
28 Analatelo	SANKYO SM-200	14.09.90 01.10.90	35.0	3.18	① 11.5~ 31.5 (4")	① alternation of sandy marl, sandy limestone & limestone	301(~321)	0.06	5,016.67	-	-	-	362	12	7.4
29 Mangotroka	SANKYO SM-200	07.09.90 13.09.90	41.0	3.57	① 14.5~ 38.5 (4")	① medium~coarse sandstone	336	1.72	195.35	-	1.14x10^{-0}	1.31x10^{-0}	141	12	7.0
52 Soahazo 52-1	SANKYO SM-200	03.07.90 12.07.90	76.0	36.17	① 47.1~ 63.1 (4")	① sandy marl	130(~293)	1.08	120.37	-	1.13x10^{-0}	8.20x10^{-1}	1,080	70	7.3
52 Soahazo 52-2	SANKYO SM-200	13.07.90 17.07.90	34.0	4.90	① 7.1~ 15.1 (4") ② 23.1~ 27.1 (4")	① medium~coarse sandstone ② sandy marl	167	5.72	29.20	4.12x10^{-2}	4.69x10^{-2}	7.25x10^{-2}	3,630	252	7.4
53 Analamisampy	SANKYO SM-200	18.07.90 25.07.90	71.0	13.11	① 7.5~ 11.5 (4") ② 31.5~ 35.5 (4") ③ 43.5~ 47.5 (4") ④ 51.5~ 55.5 (4") ⑤ 59.5~ 67.5 (4")	① sandy limestone ②,⑤ medium sandstone & sandy marl ③ sandstone ④ sandy marl	30(~112)	8.09	3.71	3.18x10^{-3}	3.20x10^{-3}	6.84x10^{-3}	1,350	206	7.2
54 Belitsaka	SANKYO SM-200	26.07.90 31.07.90	66.0	12.78	① 31.5~ 47.5 (4") ② 55.5~ 59.5 (4")	① medium sandstone & sandy marl ② coarse sandstone	200(~270)	14.70	13.61	1.08x10^{-2}	1.08x10^{-2}	8.65x10^{-3}	2,080	444	7.0
55 Ampasikibo	SANKYO SM-200	01.08.90 06.08.90	50.0	9.16	① 23.5~ 43.5 (4")	① sandy marl	280(~287)	6.96	40.23	1.30x10^{-1}	8.71x10^{-2}	1.22x10^{-1}	817	22	7.2
56 Namaboha	SANKYO SM-200	07.08.90 15.08.90	83.0	16.50	① 39.5~ 47.5 (4") ② 63.5~ 73.5 (4")	① medium~coarse sandstone ② sandy marl & sandy limestone	247(~268)	16.67	14.82	3.17x10^{-2}	3.10x10^{-2}	6.43x10^{-2}	975	95	7.3
59 Ampihamy	SANKYO SM-200	07.10.90 14.10.90	53.0	8.30	① 23.5~ 51.5 (4")	① medium~coarse sandstone	296(~315)	7.03	42.11	-	3.45x10^{-1}	5.64x10^{-1}	996	86	7.2
65 Ankaraobato	SANKYO SM-200	24.06.90 02.07.90	75.5	3.40	① 15.2~ 19.2 (4") ② 47.2~ 51.2 (4") ③ 55.2~ 75.2 (4")	① coarse sandstone ② sandy marl ③ medium~coarse sandstone & limestone	339(~361)	2.93	115.70	1.49x10^{-1}	1.67x10^{-1}	1.46x10^{-1}	849	62	7.2
— Befandriana	SANKYO SM-200	19.09.90 22.09.90	53.0	12.30	① 18.0~ 26.0 (6") ② 33.0~ 38.0 (6")	①,② medium~coarse sandstone	300	0.985	304.57	6.28x10^{-1}	6.54x10^{-1}	5.38x10^{-1}	565	16	7.1
63 Manombo-Atm	KOKEN	26.09.90 30.09.90	27.0	4.53	① 11.5~ 23.5 (6")	① 11.5~19.0 medium~coarse sandstone 19.0~21.0 gravelly sandstone 23.0~23.5 fissured limestone	165(~263)	0.39	423.08	-	-	2.36x10^{-0}	1,000	62	7.2
67 Tsefanoka	KOKEN	08.10.90 12.10.90	45.0	24.30	① 22.0~ 42.0 (4")	① 23~28 marly limestone 28~36 coarse sandstone 36~42 limestone > sandstone	142(~144)	3.05	46.56	1.23x10^{-1}	1.18x10^{-1}	2.17x10^{-1}	602	10	7.4
68 Benetsy	KOKEN	01.10.90 06.10.90	72.0	13.51	① 39.5~ 43.5 (6") ② 47.5~ 51.5 (6") ③ 59.5~ 67.5 (6")	①,②,③ brown coarse sandstone with thine marly sandstone	158(~161)	2.015	78.41	-	2.33x10^{-1}	1.65x10^{-1}	977	58	7.4
101 Ankilimalinika	KOKEN	22.10.90 28.10.90	66.0	14.35	① 42.0~ 62.0 (4")	① 42~47 sandy marl 47~52 coarse sandstone 58~60 coarse sandstone with thine marl	152(~155)	1.67	91.02	-	3.02x10^{-1}	2.38x10^{-1}	2,458	134	7.5
81 Manoroka	KOKEN	15.10.90 20.10.90	58.0	5.23	① 30.0~ 50.0 (4")	① 30~37 coarse sandstone 37~40 porous limestone 40~43 coarse sandstone 43~50 fissured limestone	158	0.000	-	-	-	-	1,210	95	7.4

Table 2. Results of Test Drilling and Pumping Test (2)

Well No. & Location	Results of Test Drilling: Drilling Rig	Started / Com-pleted	Drilled Depth m	S.W.L. (GL-m)	Screen Position (GL-m)	Lithofacies of Aquifer	Results of Pumping Test: P/Discharge (Q) l/min.	Drawdown (S) m	Specific capacity l/min./m	Transmissivity m²/min.: Theis	Jacob	Recovery	Water Quality: Electric Conductivity μs/cm	Cl mg/l	pH
78 Befoly	TONE TOP-200	19.06.90 15.09.90	226.5	178.56	①183.5~195.5 (6") ②224.5~226.5 open hole (5⁵/₈")	Porous & fissured limestone ① 10l/min., ②100l/min.	(air lifting) 110	–	–	–	–	–	403	14	7.8
95 Iranokaky	TONE TOP-200	14.07.90 23.07.90	181.1	16.57	① 35.5~ 55.5 (6") ② 59.5~ 63.5 (6") ③ 75.5~ 83.5 (6") ④ 99.5~103.5 (6") ⑤115.5~135.5 (6")	①~④ fractured basalt (C-3) ⑤ fractured basalt & fine sandstone	38.7(~110)	3.32	11.65	8.88×10^{-3}	5.05×10^{-3}	8.04×10^{-3}	894	62	7.5
34 Iandrano	TONE TOP-200	16.08.90 28.08.90	150.1	32.72	① 35.5~ 39.5 (6") ② 99.5~103.5 (6") ③107.5~119.5 (6") ④135.5~139.5 (6")	① fine to medium sandstone (IⅢ) ②,③ fine sandstone ④ fine sandstone & silty sandstone	300(~650)	7.20	41.67	8.46×10^{-2}	8.45×10^{-2}	6.86×10^{-2}	410	15	7.4
46 Berenty-Betsileo	TONE TOP-200	29.08.90 07.09.90	140.0	15.54	① 39.5~ 43.5 (6") ② 59.5~ 63.5 (6") ③ 71.5~ 75.5 (6") ④ 79.5~ 91.5 (6") ⑤107.5~111.5 (6") ⑥127.5~131.5 (6")	① marl to marly sandstone ②,⑥ fine sandstone (with medium s.s.) ③ silty sandstone & sandy marl ④ silty sandstone ⑤ marly sandstone (IⅡ)	68(~ 80)	44.45	1.53	2.76×10^{-3}	3.55×10^{-3}	3.27×10^{-3}	2,190	248	8.4
88 Maninday	TONE TOP-200	25.07.90 31.07.90	73.5	16.29	① 15.5~ 31.5 (6") ② 35.5~ 43.5 (6") ③ 51.5~ 55.5 (6")	① weathered coarse sandstone & gravelly sandstone (IⅡ) ②,③ weathered coarse sandstone	360(~480)	8.27	43.53	5.97×10^{-2}	8.23×10^{-2}	5.26×10^{-2}	106	10	6.9
96 Analamary	TONE TOP-200	01.08.90 10.08.90	204.0	35.00	① 31.5~ 39.5 (6") ② 51.5~ 55.5 (6") ③ 59.5~ 75.5 (6") ④135.5~139.5 (6") ⑤163.5~167.5 (6")	① weathered coarse sandstone ②~④ coarse sandstone ⑤ coarse sandstone with fine sandstone beds (Isalo Ⅱ F.)	360(~600)	8.62	41.76	5.16×10^{-2}	5.06×10^{-2}	3.92×10^{-2}	142	8	6.4

Table 3. Main Aquifer Properties

Aquifer		Specific capacity (l/min./m)	Transmissivity (m^2/min.)			Remarks
			Theis	Jacob	Recovery	
Neritic sediments of the Middle to Upper Eocene	Befandriana area	6.75–304.57 (119.92)	8.89×10^{-3}–6.28×10^{-1} (2.18×10^{-1})	9.76×10^{-3}–6.54×10^{-1} (3.88×10^{-1})	1.47×10^{-2}–5.38×10^{-1} (3.95×10^{-1})	Except Analatelo(28)
	Soahazo area	13.61–120.37 (43.39)	1.08×10^{-2}–1.30×10^{-1} (5.34×10^{-2})	1.08×10^{-2}–1.13×10^{0} (2.75×10^{-1})	8.65×10^{-3}–8.20×10^{-1} (2.75×10^{-1})	Except Analamisampy(53)
	Benetsy area	46.56–115.70 (82.92)	1.23×10^{-1}–1.49×10^{-1} (1.36×10^{-1})	1.18×10^{-1}–3.02×10^{-1} (2.05×10^{-1})	1.46×10^{-1}–2.38×10^{-1} (1.92×10^{-1})	
Limestone of the Lower to Middle Eocene		217.50–5016.67 (2122.92)	—	—	2.36×10^{0} –	※1 T(av.): 2.59×10^{0} m^2/min.
Basaltic rocks of the Upper Cretaceous		11.65	8.88×10^{-3}	5.05×10^{-3}	8.04×10^{-3}	
Continental deposits of the Middle Jurassic		41.67	8.46×10^{-2}	8.45×10^{-2}	6.86×10^{-2}	Isalo²Ⅲ F.
Continental deposits of the Lower Jurassic		41.76– 43.53 (42.65)	5.06×10^{-2}–5.97×10^{-2} (5.57×10^{-2})	5.16×10^{-2}–8.23×10^{-2} (6.65×10^{-2})	3.92×10^{-2}–5.26×10^{-2} (4.59×10^{-2})	Isalo Ⅱ F. Except Berenty(46)

(　　) : Average value

※1 : Estimated value from the borehole records of Analatelo(28), Manombo(63) and Miary No2 to No4 of JIRAMA.

3.8 Water quality analysis

3.8.1 Chemical quality

As shown in Fig. 9, salty water unsuitable for drinking is drawn from shallow wells of less than 30m in some parts of the Study Area. The salty tasting groundwater is distributed in 5 main areas: (a) area from Lake Ihotry, through Manoy(22), Basibasy(27), Soahazo(52), Belitsaka(54); (b) the area of Benetsy(68), Ankilimalini ka(101) and Andrevo(69) and their surroundings;(c) the coastal zone of Toliara;(d) the surrounding area of Mahabo-boka(92); and (e) the surrounding area of Berenty-Betsileo(46).

The ion components of the groundwater from shallow wells in these areas are of the Sodium-chlorine (NaCl:IV) Type, Sodium-sulphate(Na_2SO4:IV)Type, Calcium-sulphate(CaSO4:III) and Calcium-chlorine(CaCl2:III) Type, which are recognized as the sea water type, fossil water type and similar type. Test drilling results clarified that the hydrogeological properties of the so-called salty tasting groundwater in the western region of the Study Area are as follows.

(a) The groundwater from shallow aquifers of thin sand stone confined by thick marl and dolomitic marl is generally salty.

(b) The groundwater from the majority of wells shallower than 30 m is strongly salty compared to the groundwater from deeper aquifers. As shown in Fig. 10, the chemical component of the groundwater from deeper aquifers moves from sea water-fossil water type (NaCl:IV Type) to confined fresh groundwater type (NaHCO3:II Type).

(c) The groundwater in the coastal zone is highly salty due to the influence of sea water (Fig. 11).

The chemical quality of groundwater samples taken from newly drilled boreholes is generally good as drinking water, except the groundwater from the borehole at Basiba-

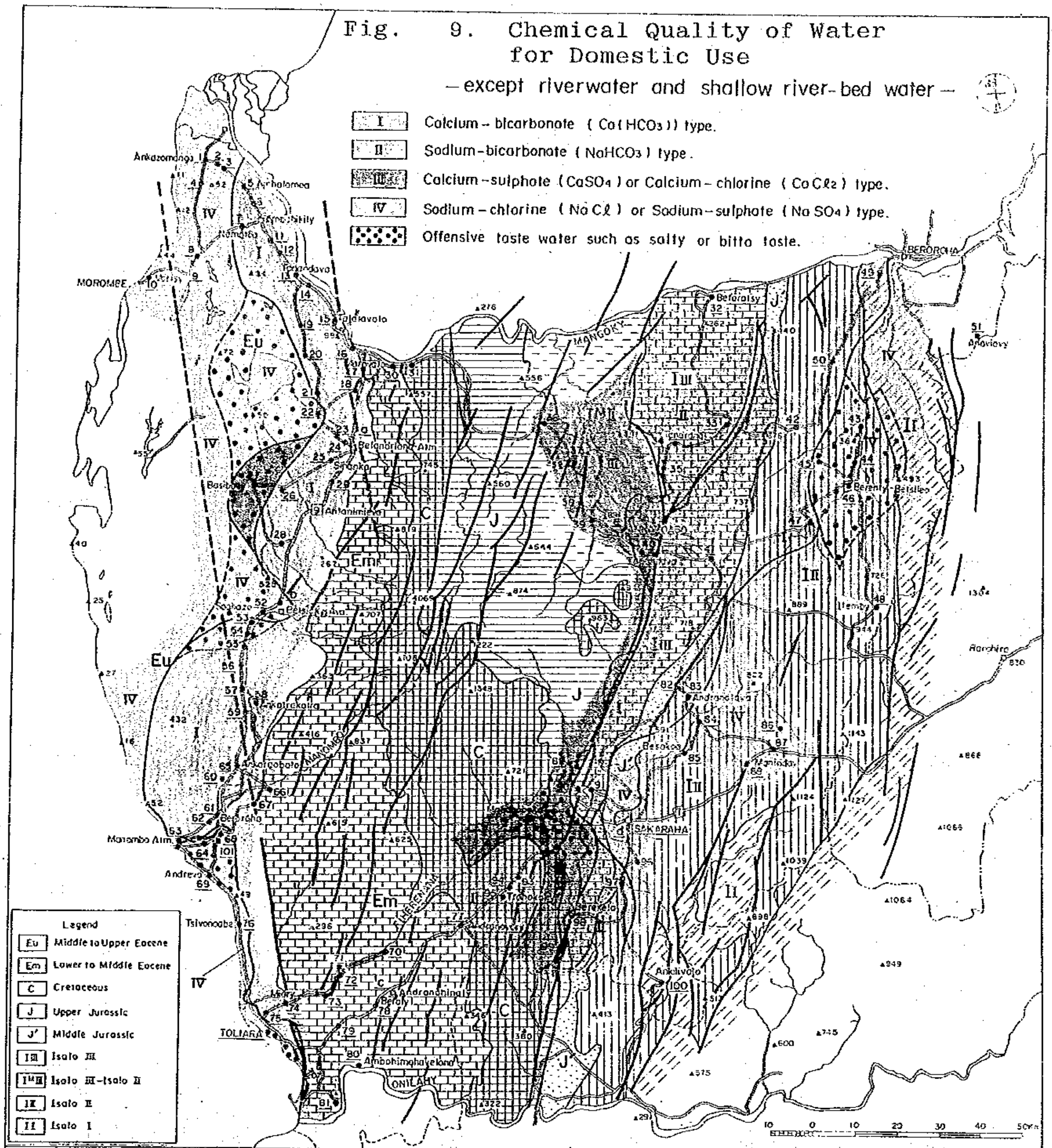


Fig. 9. Chemical Quality of Water for Domestic Use
— except riverwater and shallow river-bed water —

No Villages

I. Fiv. MOROMBE

1 Ankazomanga
2 Beadabo
3 befasy
4 Ankilifolo(1)
5 Ambalamoa
6 Tsianihy
7 Namatoa
8 Mangolovolo
9 Ankida
10 Vorisy
11 Andranomanitsy
12 Berantala
13 Tanandava
14 Antsakoabe
15 Tafatavalo
16 Ambiky
17 Marovato
18 Andranoboka
19 Satrambondro
20 Mahavozokely
21 Antranosatra
22 Manoy
23 Ampoza
24 Ankilifolo(2)
25 Sihanaka
26 Bemoka
27 Basibasy
28 Analatelo
29 Mangotroka
30 Nosy-Ambositra
31 Tsiarimpioke

II. Fiv. ANKAZOABO ATM

32 Betaratsy
33 Andranomanintsy
34 Tandrano
35 Ampandramitsetaky
36 Andranomafana
37 Manakiala
38 Berenty-Ankilimasy
39 Betsinefo
40 Tanandava
41 Ampoza
42 Ipetsa Atm
43 Mandabe Atm
44 Soatanimbary
45 Sahanory Atn
46 Berenty-Betsileo
47 Ankilivalokely
48 Ileaby

III. Fiv. BERORAHA

49 Tanandava-Antaifasy
50 Anjamitikitra
51 Anaviavy

IV. Fiv. TOLIARA I / II

52 Soabazo
53 Analamisampy
54 Belitsaka
55 Ampasikibo
56 Namaboha
57 Antseva
58 Ankilimiavotoka
59 Ampihamy
60 Ambondro
61 Beroroha
62 Antsomarify
63 Manombo-Atm
64 Antandroka
65 Ankaraobato
66 Andoharano
67 Tsefanoka
68 Benetsy
69 Andrevo
70 Anjamala
71 Ampihalia
72 Behompy
73 Ambolonkira
74 miary
75 Befanamy
76 Tsivonoabe
77 Andranovory
78 Befoly
79 Ankororoka
80 Ambohimahavelona
81 Manoroka
101 Ankilimalinika

V. Fiv. SAKARAHA

82 Iaborana
83 Andranolava
84 Lambomakandro
85 Besakoa(1)
86 Besakoa(2)
87 Ampandra
88 Maninday
89 Bevoalavo
90 Tanambao
91 Ambahimalitsy
92 Mahaboboka
93 Mahasoa
94 Andamasiny-Vineta
95 Tranokaky
96 Analamary
97 Antanimora
98 Bereketa
99 Ankilimitraloka
100 Ankilivato

a Befandriana
b Betsioky Nord
c Andranohinaly
d Sakaraha
e Ankazoabo

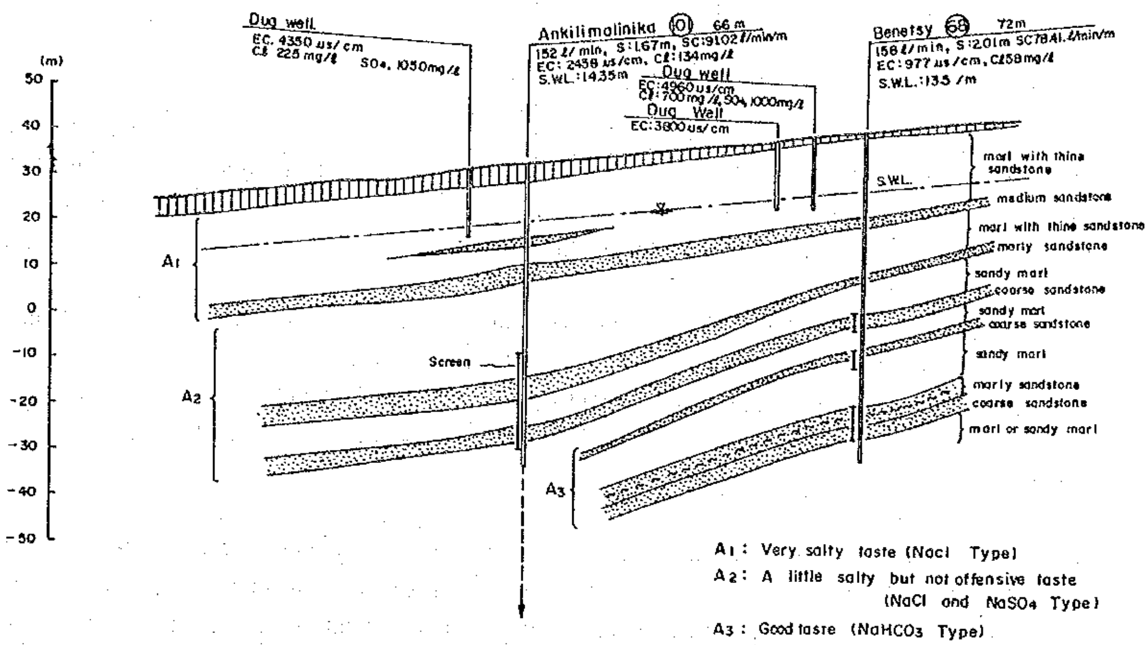
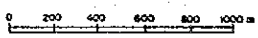


Fig. 10. Hydrogeological Cross Section between Ankilimalinika and Benetsy



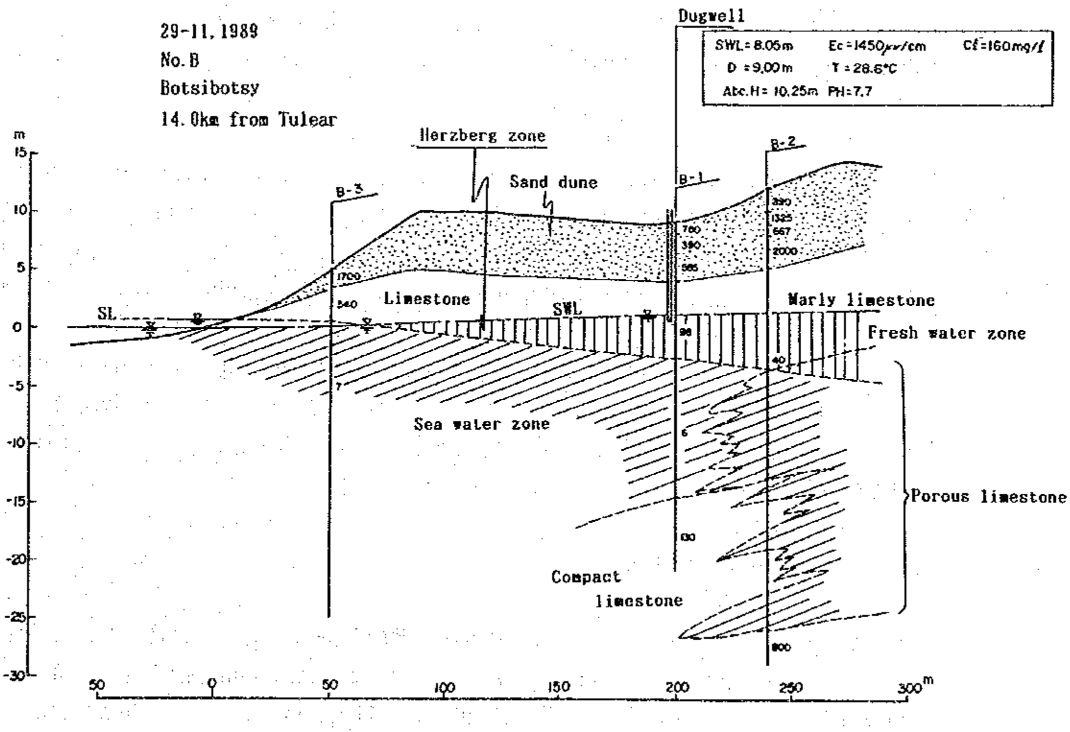


Fig. 11. Hydrogeological Structure of the Coastal Area

sy.

At Berenty-Betsileo(46), the water from the newly drilled borehole was not good enough, due mainly to its salty taste. However, the chemical quality of this groundwater meets the standard for drinking water.

The properties of chemical components of groundwater samples taken from newly drilled boreholes are summarized below by region and by aquifer, in addition to the above mentioned descriptions of the so-called salty tasting groundwater (Fig. 12).

(a) The groundwater in the western region of the Study Area, which is composed of neritic sediments of the Middle to Upper Eocene, has the chemical component of unconfined fresh groundwater type $Ca(HCO_3)_2$:I Type) that is smilar to that of the stream water, except for the groundwater from the above mentioned area of salty water.

(b) The groundwater from the aquifer of the Lower Eocene limestone and the Upper Cretaceous basaltic rocks has the chemical component of unconfined fresh groundwater type ($Ca(HCO3)_2$:I Type). The dissolved contents range from a low of 202 mg/l in limestone to a high of 447 mg/l in basaltic rocks, and water quality is good enough for drinking.

(c) The chemical component of groundwater from the aquifer of Lower Jurassic continental sediments (Isalo II) moves from sea water-fossil water type (NaCl:I Type) of shallow groundwater in wells of less than 30 m, to confined fresh groundwater type (NaHCO3:II Type) in deeper wells, and the water quality is generally good for drinking. However, the water at Berenty-Betsileo(46) is not so good for drinking, due mainly to its salty taste (Dissolved content:1,100 mg/l).

3.8.2 Tritium Concentration

In order to estimate the groundwater age and to consider the groundwater flow mechanism, 5 groundwater samples from the newly drilled boreholes at Manoy(22), Soahazo(52),

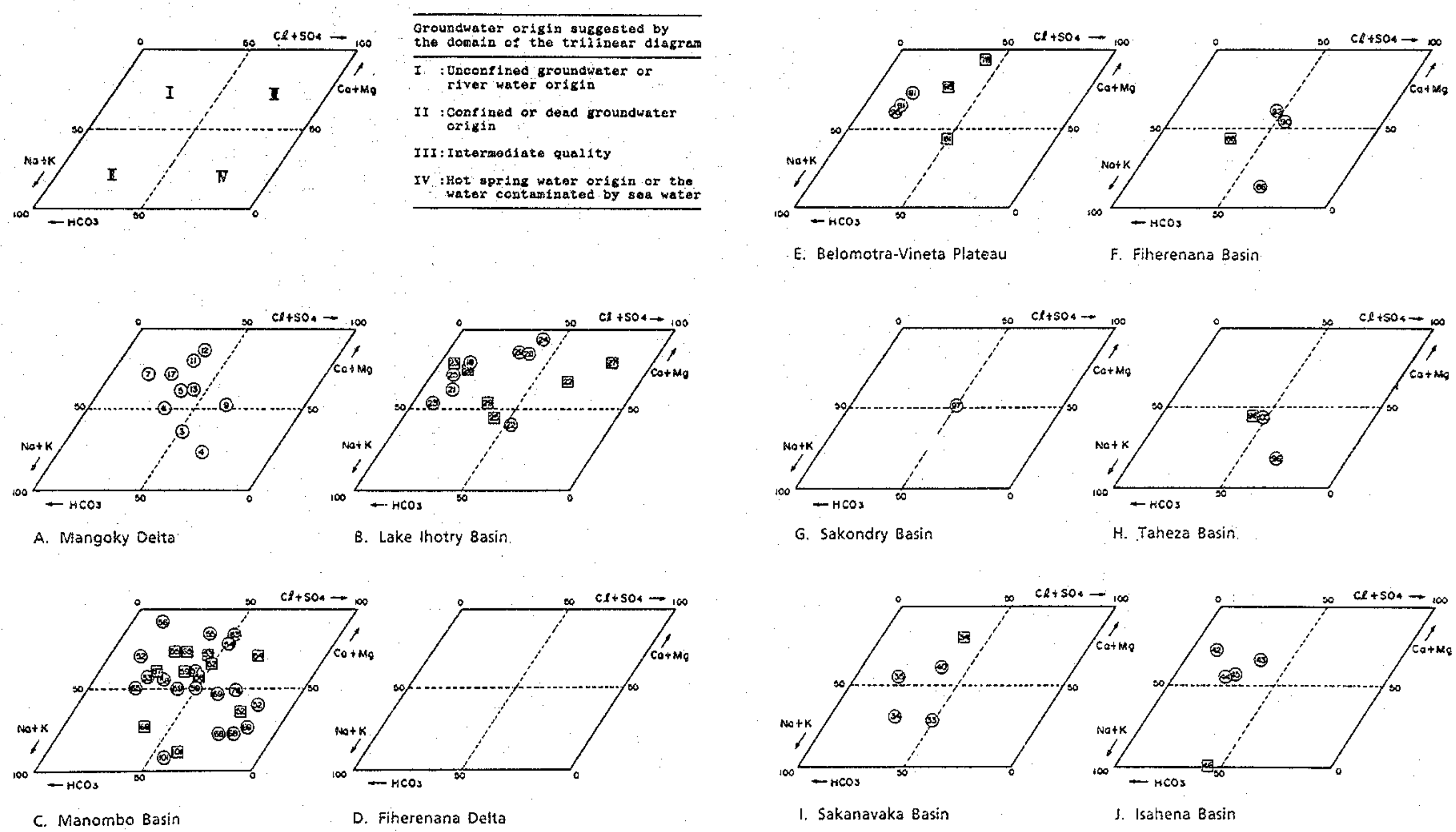


Fig. 12. Water Quality

Befoly(78), Tranokaky(95), and Maninday(88) were taken to Japan to analyze the radioisotope(H3). The results of this analysis are shown in Table 4 and Fig. 13.

Analysis results indicate that tritium concentration in the groundwater of the Study Area is generally low, ranging from 0.96TR to 3.66TR. The following considerations can be made.

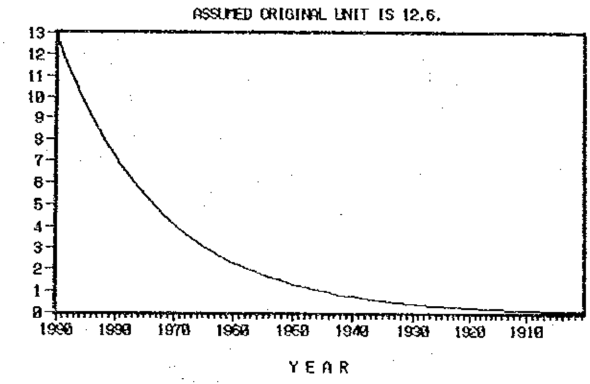
(1) According to the hydrogeological environment in Manoy(22) and Soahazo(52), groundwater in these areas is contained in unconfined shallow aquifer recharged by rainfall in localized zone. However, ion component is Sodium-Chlorine (NaCl:IV Type), and the value of tritium concentration is low, 0.96TR-1.05TR. Therefore, it is considered that the aquifer took a long time to arrive where is as regional or intermediate flow, and there is some influence of fossil water.

(2) Main aquifer of Tranokaky is in fissured basaltic rocks of the Upper Cretaceous. The ion component is Calcium-bicarbonate($Ca(HCO_3)_2$:I Type), and tritium concentration is 1.65 TR. Therefore, it is considered that this aquifer is recharged in the skirt of the southern mountain, and the circulation period is estimated to be around 35 years.

(3) Groundwater of Befoly (78) is contained in unconfined aquifer in limestone of the Lower Eocene. In the case of Maninday(88), groundwater is contained in continental sandstone of the Lower Jurassic(Isalo II). The ion component belongs to the calcium-bicarbonate ($Ca(HCO_3)_2$:I Type) in Befoly, and the sodium-bicarbonate(NaHCO3: II Type) in Maninday. Their tritium concentrations are 3.54-3.66 TR, and recharge circulation period is estimated to be 20-25 years. Limestone of the Lower Eocene and continental sandstone of the Lower Jurassic compose most of the aquifer and are widely distributed in most of the Study Area.

Table 4. Tritium Concentration

Sampling Place (No. of Borehole)	Aquifer		Tr Value
	Aquifer Characteristics	Screen Position (GL-m)	
Manoy (no. 22)	·Medium to coarse sandstone of the Middle to Upper Eocene ·Unconfined aquifer	①18.4-38.4	0.96 (±0.07)
Soahazo (No. 52-1)	·Sandy marl with medium to coarse s·and-stone of the Middle to Upper Eocene ·Weakly confined aquifer	①47.1-63.1	1.05 (±0.07)
Befoly (No. 78)	·Weakly fissured and porous limestone of the Lower Eocene ·Unconfined aquifer	①183.5-195.5 ②224.5-226.5 (Open hole)	3.54 (±0.11)
Tranokaky (No. 95)	·Fractured basalt and fine sandstone of the Upper Cretaceous ·Weakly confined aquifer	①35.5-55.5 ④99.5-103.5 ②59.5-63.5 ⑤115.5-135.5 ③75.5-83.5	1.65 (±0.07)
Maninday (No. 88)	·Weathered coarse sandstone of the Lower Jurassic ·Mainly unconfined aquifer	①15.5-31.5 ②35.5-43.5 ③51.5-55.5	3.66 (±0.12)



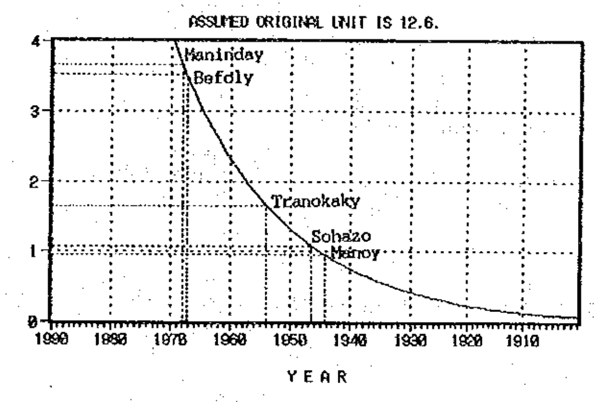


Fig. 13. Decay Curve of Tritium

4. DATABASE

As shown in Fig. 14, a database was prepared in order to preserve hydrological and hydrogeological data, and to insure potential effective usage of the data relating to the groundwater development plan.

There are three types of data included in the data base: meteorological data, hydrological data and hydrogeological data. The basic functions of the database are data entry, file management, data revision and data output.

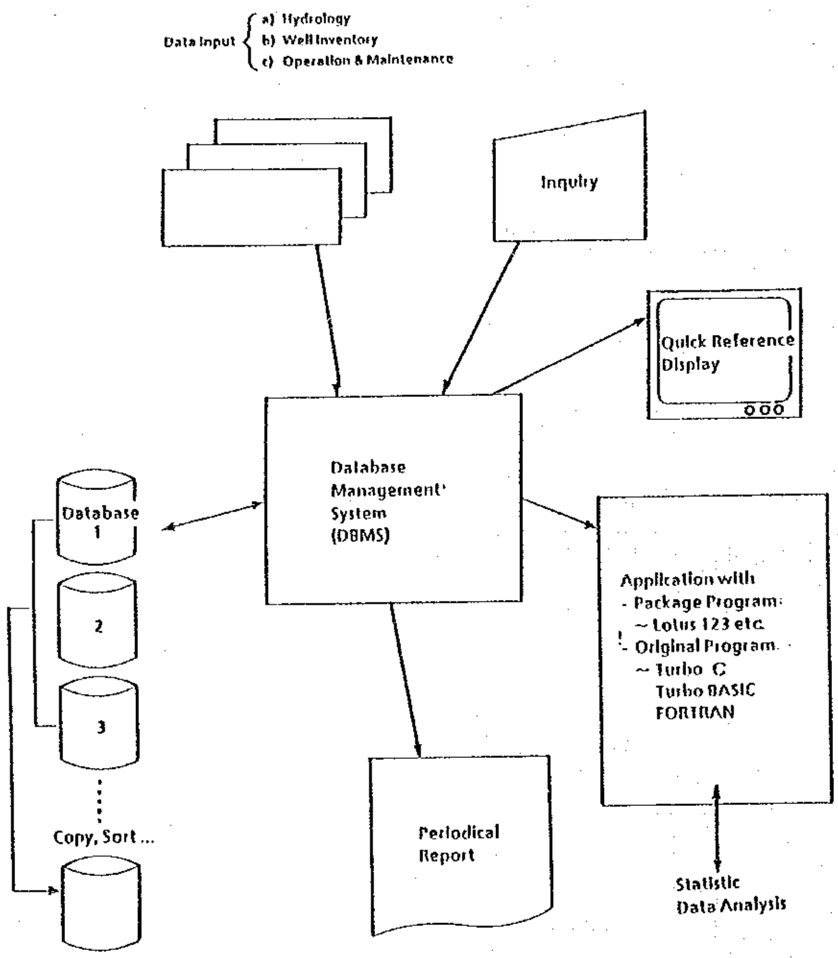


Fig. 14. Outline of Database System

5. REHABILITATION SURVEY

The rehabilitation survey was implemented in the following eight villages: Befandriana, Betsioky, Andranohinaly, Andranovory, Sakaraha, Ankazoabo, Bereketa, and Mahaboboka.

Detailed survey results are shown in Table 5, and the outline of countermeasures is as follws.

(a) Borehole

Most of the wells were drilled by the "cased hole drilling method". It is very difficult to rehabilitate the well constructed by this method because little or no gravel packing surround the screen.

An exception is Sakaraha's well, but one new well should be drilled in this town in the future, because the recovery of the well was not enough.

(b) Intake facilities

Existing pumps and generators cannot be repaired to be utilized in these villages. The reason is that no countermeasures were taken, while in use even for easy prob lems concerning machinery operation and maintenance.

(c) Storage tank and distribution facilities

Seven steel tanks and one concrete tank exist in different villages. Their common problem is small leakage, which can be repaired, except for one steel tank in Sakaraha.

(d) Distribution facilities

Four villages have distribution lines of more than a few hundred meters in lengh, and public hydrants. Three villages have only public hydrants. However, all of them must be replaced.

Table 5. Results of Rehabilitation Survey (1)

Village	Facility	Existing Condition & Points to be rehabilitated	Remarks
Befandriana	Well:depth 64m, telescopic type, GWL=12.6m	Discharge was improved to 30 l/min by well rehabilitation, but smaller than original 233 l/min	Model Rehabilitation Work was implemented (Details in Sec 6)
	Elevated steel tank Q=21m3, H=3m	Leaking from joint, Drainage valve is broken	
	Distribution Pipe Communal base:1	"Replace"	
	Distribution Tank (1.2 x 6 x 7m)	No surface mortar No Drainage	
	Pump, Engine house	Pump:replace, Generater:Overhaul House:replace	
Betsioky	Well:depth 90m, telescopic type, GWL=59.4m	Discharge is small, Water quality is no good(EC=2800), lower part of casing is full of sand	Need to drill 150m for new installation Aquifer estimate 120m
	Elevated steel tank Q=16m3, H=2.2m	Leaking from joint	
	Distribution Pipe 2-300m of PVC	"Replace"	
	Communal base with 3 faucets	"Replace"	
Andranohi-naly	Well:depth 220m, 6" casing GWL=207m	No information	
	Elevated steel tank Q=11m3, H=3m	Leaking from joint, Drainage valve is broken	
	Communal base:1 with 3 faucets	"Replace"	
	Pump, Engine house	"Replace"	
Andranovory	Well:depth 136m, telescopic type, GWL=12.6m	Discharge was improved to 40 l/min by well rehabilitation, but casing is broken	
	Elevated steel tank Q=15m3	Tank has no problem, but concrete base is cracked	
	Communal base:1 with 3 faucets	Good condition	
	Pump, Engine house	"Replace"	

Table 5. Results of Rehabilitation Survey (2)

Village	Facility	Existing Condition & Points to be rehabilitated	Remarks
Sakaraha	Well:depth 31m, telescopic type, GWL=10.7m	Discharge was improved by 40 l/min to 140 l/min by well rehabilitation (Originally 400 l/min)	Capacity of existing well is not enough
	Elevated steel tank 2 Tank 1: Q=24.6m3 H=6 m Tank 2: Q=10m3 H=4 m	Leaking from joint, Drainage	
	Distribution Pipe:2km Communal base: 14	"Replace"	
Ankazoabo	Well:depth 27.3 m telescopic type, GWL=12.4m	Discharge was improved to 80 l/min by well rehabilitation; originally 120 l/min, Screen is broken	
	Elevated steel tank Q=40m3, H=3.0m	Leaking from joint	
	Distribution Pipe 1500 m	"Replace"	
	Communal base with 3 faucets	"Replace"	
	Pump, Engine house	"Replace"	
Bereketa	2 dug well Well 1: 40 l/min Well 2: 30 l/min	No capacity in dry season	
	Elevated concrete tank Distribution pipe 100m	No problem "Replace"	
	Communal base:1 with 12 faucets	"Replace"	
	Pump, Engine house	"Replace"	
Andranovory	Well with handpump	Water quality is poor	

6. PILOT FACILITIES

Four pilot facilities for water supply system were constructed in order to evaluate construction materials, ability of local contractors, and operation and maintenance capacity of village and local organization.

Outline of pilot water supply facilities is shown in the following Table 6.

Type	Item	Content	Village
A	- Elevated tank - Distribution pipe - Communal faucet - Submergible motor pump - Generator & Storage house	Volume: 16 m3, Height:2.6 m Length: 360 m, ø48 mm 3 sets with 12 valves Pump position: 106 m(B.G.S) 11 kVA 18 m2	Tranokaky Population :1000 Around 90 km from Toliara
B	- Elevated tank - Distribution pipe - Communal faucet - Solar pump & Storage house	Volume: 16 m3, Height:1.2 m Length: 25 m, ø48 mm 1 set with 4 valves Pump position: 36 m(B.G.S) Module 18 sets 18 m2	Soahazo Population :5000 Around 130 km from Toliara
C	Handpump Japanese		Namaboha, Ampasikibo Belitsaka, Analamisampy Analatelo
	Local		Manoy, Manombo Ampoza, Benetsy Sihanaka, Ankilimalinika Basibasy, Manoroka Mangotroka, Analamary Ampihamy
D	- Well Rehabilitation - Elevated tank - Distribution pipe - Communal faucet - Submergible motor pump - Generator & Storage house	 Length: 7.4 m, ø48 mm 1 set Pump position: 24 m(B.G.S) 12.5 kVA 12 m2	Befandriana Population : 3000 Around 200 km from Toliara Existing facilities were constructed in 1960's by USAID

Operation and maintenance capacity of villagers and local

organizations is discussed in Chapter 8.
Capacity of solar pump was confirmed as 9-10 m3/day under fine weather condition.