No. 1

JAPAN INTERNATIONAL COOPERATION AGENCY
INDIA
CENTRAL GROUND WATER BOARD
MINISTRY OF WATER RESOURCES

BASIC DESIGN STUDY REPORT
ON
THE PROJECT FOR
EXPLOITATION OF GROUND WATER
IN
INDIA

SEPTEMBER, 1992

PACIFIC CONSULTANTS INTERNATIONAL

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PREFACE

In response to a request from the Government of India, the Government of Japan decided to conduct a Basic Design Study on the Exploitation of Ground Water in India and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to India a study team headed by Dr. Yuji Maruo, Senior Development Officer, JICA and constituted by members of Pacific Consultants International from July 12th to August 5th, 1992.

The team held discussions with the officials concerned of the Government of India, and conducted a field study 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 India for their close cooperation extended to the team.

September 30th, 1992

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency

September, 1992

Mr. Kensuke Yanagiya,
President
Japan International Cooperation Agency
Tokyo, Japan

Letter of Transmittal

We are pleased to submit to you the Basic Design Study Report on Exploitation of Ground Water in India.

This study has been made by Pacific Consultants International, based on a contract with JICA, from July 7th, 1992 to September 30th, 1992. Throughout the study we have taken into full consideration of the present situation in India, and have planned the most appropriate project in the scheme of Japan's grant aid.

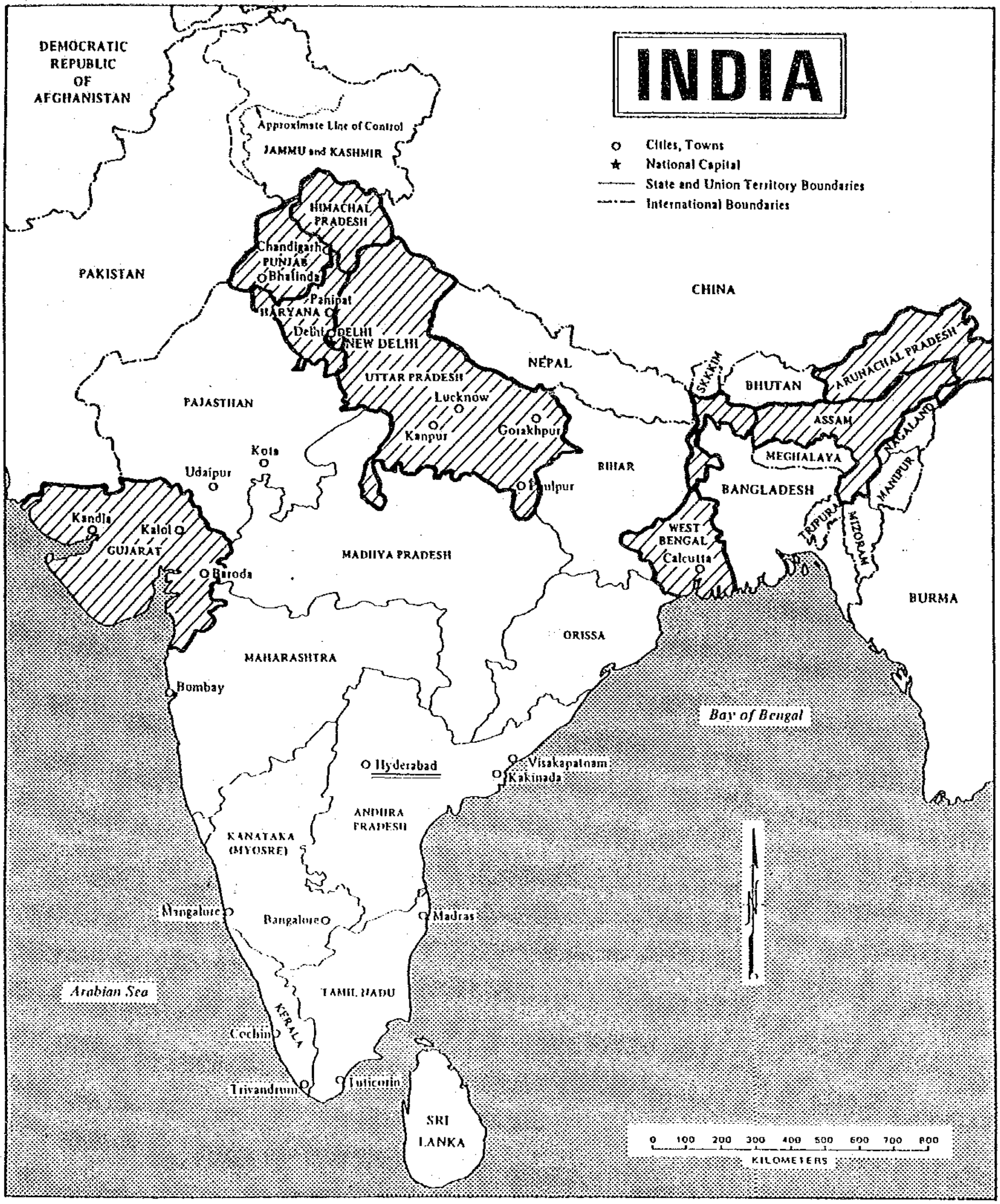
We wish to take this opportunity to express our sincere gratitude to the officials concerned of JICA, the Ministry of Foreign Affairs, and the Embassy of India in Japan. We also wish to express our deep gratitude to the officials concerned of the Ministry of Water Resources and Central Ground Water Board, the Government of India, JICA India office and the Embassy of Japan in India for their close cooperation and assistance during our study.

At last, we hope that this report will be effectively used for the promotion of the project.

Very truly yours,

Y. Yamasaki

Team leader, Yasumasa Yamasaki
Basic design study team on
Exploitation of Ground Water in India
Pacific Consultants International



Location Map

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Abbreviations

CGWB	:	Central Ground Water Board
JICA	:	Japan International Cooperation Agency
MWR	:	Ministry of Water Resources
E/N	:	Exchange of Notes
HFT	:	Himalayas Frontal Thrust
MBF	:	Main Boundary Fault
MCT	:	Main Central Thrust
DTW	:	Deep Tube Well
STW	:	Shallow Tube Well
VLF	:	Very Low Frequency
UNDP	:	United Nations Development Programme
CIDA	:	Canada International Development Agency
SIDA	:	Swedish International Development Agency
DR	:	Direct Rotary
DTH	:	Down the Hole
PC	:	Percussion
CRT	:	Cathode-Ray Tube
IFP	:	Instantaneous Floating Point Amplifier
AGC	:	Automatic Gain Control
GVW	:	Gross Vehicles Weight
DIA	:	Diameter
2DD	:	Double Sided Double Density
PCS	:	Pieces

SUMMARY

SUMMARY

India is located at 8°04' to 37°06'N latitude and 68°7' to 97°25' E longitude. The country covers an area of 3,287,263 km^2, and has a population of about 8.4 hundred million (1991). The climate is clearly divided into dry and rainy seasons.

In the project area, precipitation decreases from east to west; there is more than 5,000 mm per year in the eastern part and 1,300 mm per year in the western part.

The area has sufficient precipitation during the rainy season but, on the other hand, most rivers dry up during the dry season. Therefore, 80% of the drinking water and 50% of the irrigation water has been supplied by ground water. However, due to the difficulty of well drilling in the boulder formation area, the exploitation of ground water has been hampered. As a result, percussion type drilling rigs which can penetrate the boulder formation, and geophysical survey equipment were requested from the Government of Japan. On the basis of the request, the Government of Japan , in 1990, undertook the grant aid cooperation program to supply 4 units of percussion type drilling rigs and geophysical survey equipment.

In this Project, on the basis of the similar background of previous projects and for further promotion of ground water exploitation in the area, the Government of India requested (January, 1992) 3 units of percussion type drilling rigs and geophysical survey equipment from the Government of Japan under their grant aid programme. The rigs are to be used in the construction of wells in the project areas's boulder formation. The survey equipment is to be used in areas other than the project area on an "as needed" basis.

The open hole method was introduced using the rig supplied under the Phase I project. Within a 3 month period a 300 m drilling depth was reached. Using this drilling method proved to be effective in saving construction cost and reducing the construction period. The open hole method was highly valued by the Government of India. Based on the results, the Government of India changed a part of the contents of their request in 1992. The major changes were to the drilling method and drilling equipment.

The Central Ground Water Board (CGWB), the project's implementation agency, set the project's objectives to construct water wells by the rigs to be supplied by Japan, and to supply safe drinking and irrigation water that will not be depleted throughout the year.

The Government of Japan investigated the request and decided to conduct the Basic Design Study for the project. Based on this decision, the Japan International Cooperation Agency sent a study team to India for 25 days from 12 July to 5 August.

The study team conducted field surveys for the purpose of understanding the background of the request and the contents of the Project, for investigating the propriety of the Project under the grant aid cooperation of the Government of Japan, and to determine the optimum content and scale of the Project. The team also held a series of discussions pertaining to the Project with the officials concerned of the Government of India. The Memorandum of Discussions that included the confirmed and agreed upon basic items were signed by the representative of the Indian Government officials and the leader of the Basic Design Study Team. Based on the result of the filed surveys and the Memorandum of Discussions, further analyses were made in Japan.

As a result of the field survey, the series of discussions with Indian officials, and the analyses made in Japan, the following aspects were clarified:

(1) There is 1,300 mm to 5,000 mm of annual rainfall in the project area. However, as surface water only available during the rainy season, there is a high dependence on groundwater for secure safe drinking water and irrigation throughout the year.

(2) The main aquifer in the project area is boulder formation which has a discharge potentiality of more than 2,000 m^3/day.

(3) The implementation agency of the Project is the Central Ground Water Board (CGWB) under the Ministry of Water Resources, the Government of India. CGWB consists of the hydrogeological survey sector and the well construction sector with 12 regional office and 14 division offices throughout India.

(4) By the year 2005, CGWB plans to construct one exploratory well on each 125 km^2 in the boulder formation having an area of approximately 121,000 km^2. 968 exploratory wells are required to achieve the plan. 200 wells have already been drilled by CGWB. It is calculated that the remaining 768 wells will be drilled at the rate of 60 per year.

(5) Equipment supplied by Phase 1 project are kept and maintained at the Division-II/III office of the well construction sector. Each division office has a stockyard containing drilling equipment, a spare parts storage, and repair shop. The equipment is relatively

well-maintained. Therefore, it is expected that CGWB has the capability of maintaining the equipment prepared by this project.

(6) CGWB is already receiving aid from several other foreign governments. It will not be overlapped with this project.

(7) CGWB has a sufficient staff and budget and shows suitable growth for the project.

Based on the above aspects and the contents of the project, the basic design has been made.

Some problems were recognized in the CGWB's drilling plan. CGWB made their drilling plan to include the Jammu and Kashimir area. But Jammu and Kashimir are excluded from the Project area. Also, the capability of the provided rigs was overestimated. Therefore, the study team reexamined the drilling plan with CGWB and justified the revised drilling plan.

The Project is to obtain grant aid assistance for providing the drilling rigs and survey equipment that will enable CGWB to promote their project.

The objectives of the Project are to stabilize the livelihoods of rural people, to improve social conditions by supplying reliable, safe drinking and irrigation water that will not be depleted throughout the year.

The responsible agency for the project is the Ministry of Water Resources (MWR). Project implementation will be undertaken by the Central Ground Water Board (CGWB).

The features of the CGWB's drilling plan are as follows:

- Target year	:	2005
- Project area	:	Gujarat state and northern area 121,000 km^2
- Planned number of tube wells	:	768
- Pumping rate per tube well	:	1,458 m^3 (12h operation/day)
	:	2,187 m^3 (18h operation/day)
- Population Served	:	5,054,000 persons (12h./d)
	:	7,582,000 persons (18h./d)
- Irrigated area	:	16,604 ha (12h./d)
	:	24,906 ha (18h./d)

The equipment necessary to be newly provided under the project are as follows:

- Percussion type drilling rigs and tools	:	3 sets
- Open hole tools for provided rigs (for 3 units)	:	1 lot
- Crane trucks	:	3 units
- Pumping test equipment	:	3 sets
- Well logging equipment	:	4 sets
- Micro flow meters	:	4 sets
- Seismic survey equipment	:	1 set
- Deep resistivity survey equipment	:	1 set
- Signal averaging resistivity equipment	:	1 set
- VLF EMR equipment	:	1 set
- Spare parts	:	1 lot

15 months will be required to complete the project after signing the Exchange of Notes. This will include processing the Japanese grant aid, such as making the contract with a Japanese consultant company, and the procurement, transportation, and installation (including training) of equipment by a Japanese contractor.

By the end of the project target year (2005), the following amount of water will be available for drinking and irrigation if the above equipment is supplied by the project. The ratio of drinking water to irrigation is 2:8.

Operation Hours	12 Hours	18 Hours
Domestic Water (x 10^3 m^3)	83,019 (55,346)	124,528 (83,019)
Population Served (x 10^3 persons)	50,54 (3,369)	7,582 (5,055)
Water for Irrigation (x 10^3 m^3)	332,074 (221,383)	498,111 (332,074)
Irrigated Area (ha)	16,604 (11,069)	24,906 (16,604)

( ): expected amount/number by supplied equipment

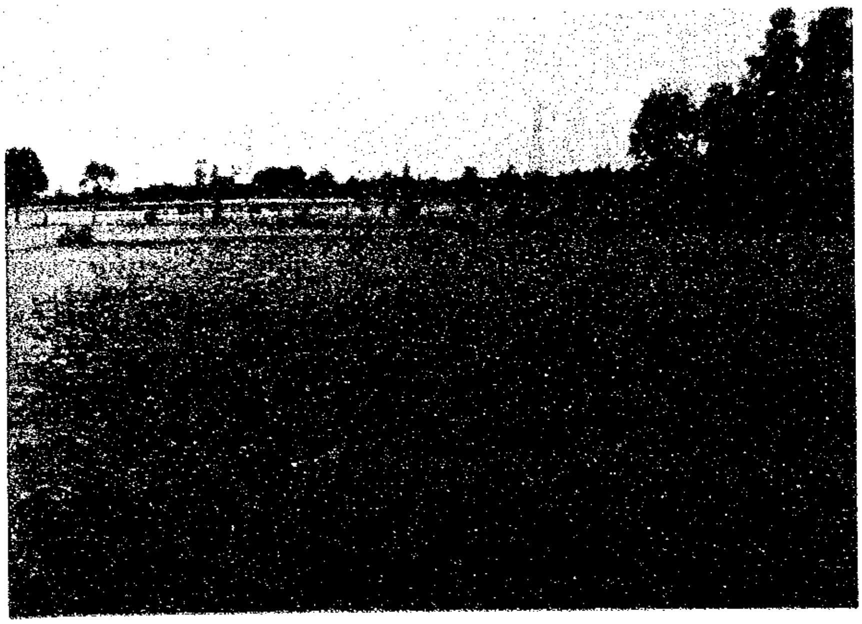
CGWB has the organization to maintain the supplied equipment. As of this time, however, their capability to maintain the geophysical survey equipment is not adequate. Thus, it will be necessary to make a technical transfer of the maintenance techniques to the Indian engineers.

It will also be necessary to provide a continuous technical transfer to upgrade the drilling techniques of the open hole method that replaces the cased hole method.

The total estimated maintenance cost, Rp.17,322,792/Year shall be borne by the Indian side.

The direct effects of the project will be to minimize drought damage by providing safe drinking water that will not be depleted throughout the year and to increase agriculture products by providing reliable stable water for irrigation.

In view of the points outlined above, it is deemed to be appropriate and extremely worthwhile to carry out the project with grant aid cooperation from the Government of Japan.



Un-cultivated field during dry season due to luck of water

[Himachal Pradesh]

The river dried up during dry season

[Haryana]

Boulder Formation in the project area

[Himachal Pradesh]

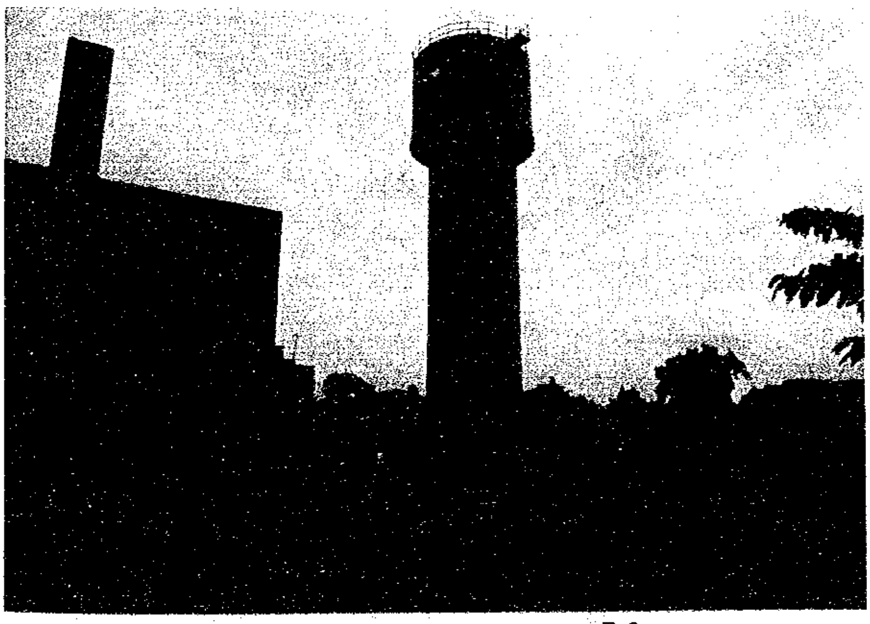
Cultivated field by irrigation water from Ganges river, even if dry season

[Uttar Pradesh]

(The area is not for project.)

Water supply facility constructed by state government using water well drilled by CGWB

[Ambala]



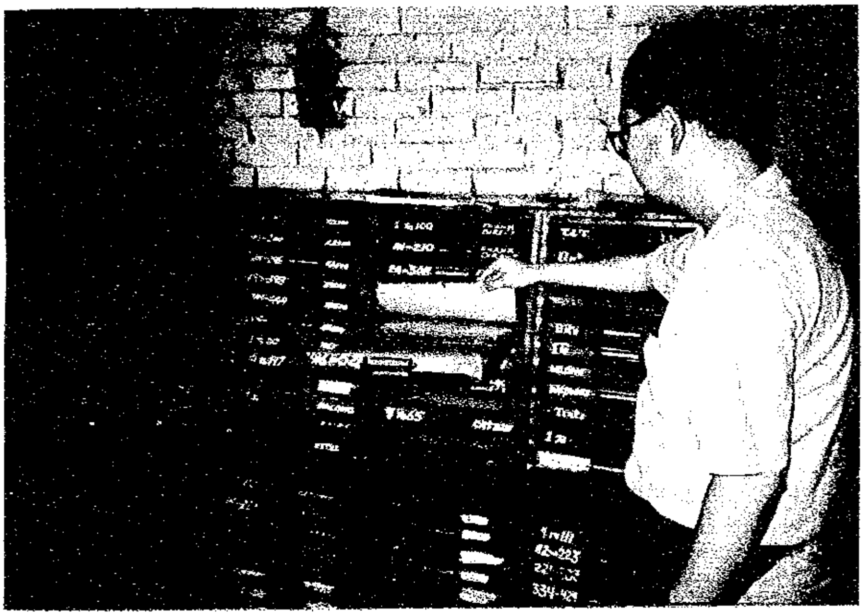
Elevated water tank for above facility

[Ambala]

Keeping conditions of spare parts provided by Phase-1 project.

At storehouse of Division II office.

[Ambala]



Keeping record of spare parts.

At storehouse of Division II office.

[Ambala]

Keeping conditions of spare parts.

At storehouse of Division III office.

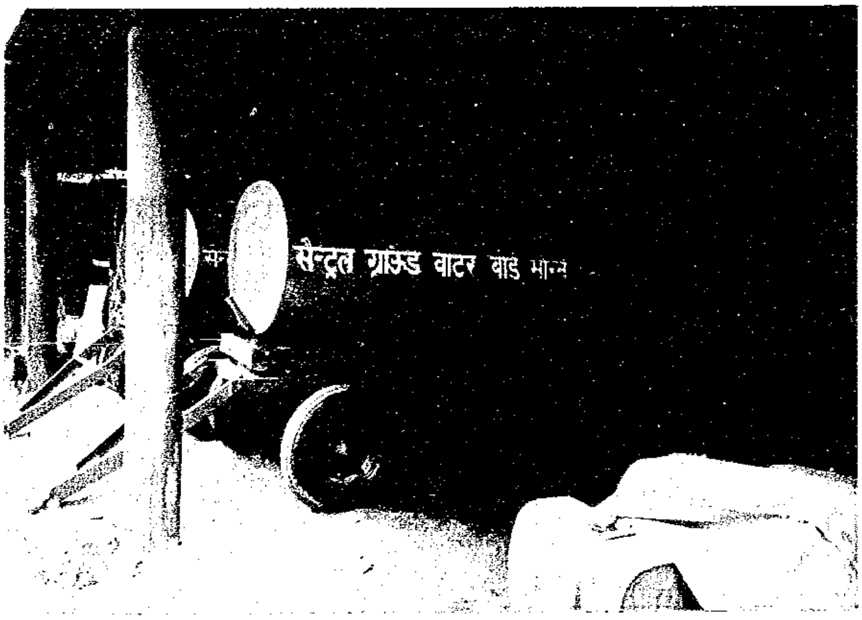
[Varanashi]

Work shop at Division II office.

[Ambala]

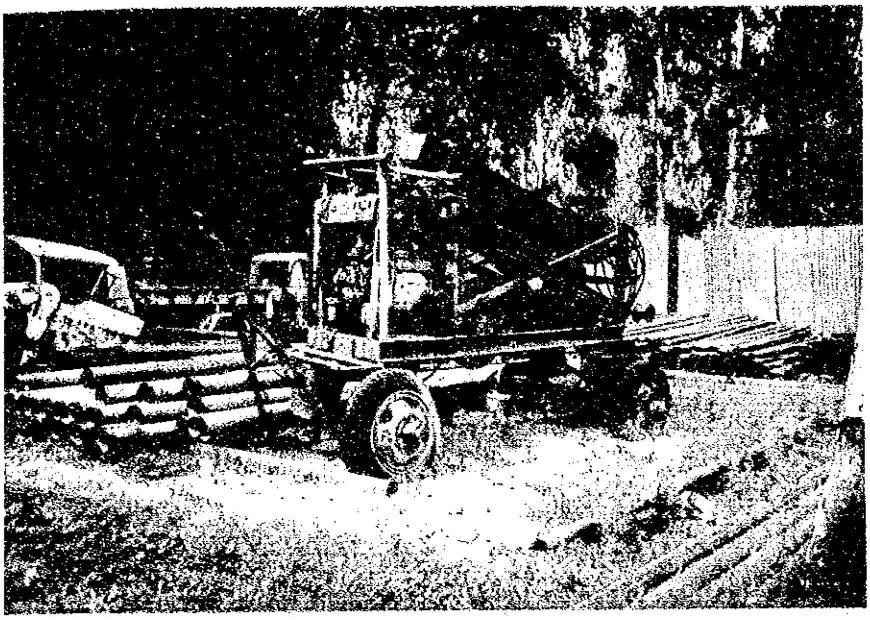
Work shop at Division II office.

[Ambala]



Water tank lorry manufactured by CGWB for the drilling rig which was provided by Phase-1 project.

[Ambala]



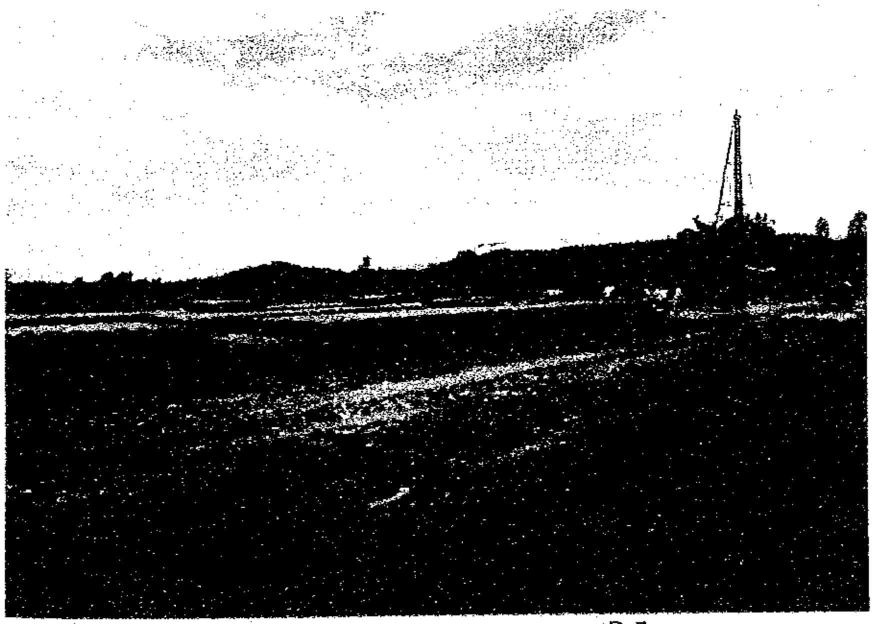
Unusable superannuated percussion drilling rig

[Ambala]

Drilling tools provided by Phase-1 project.

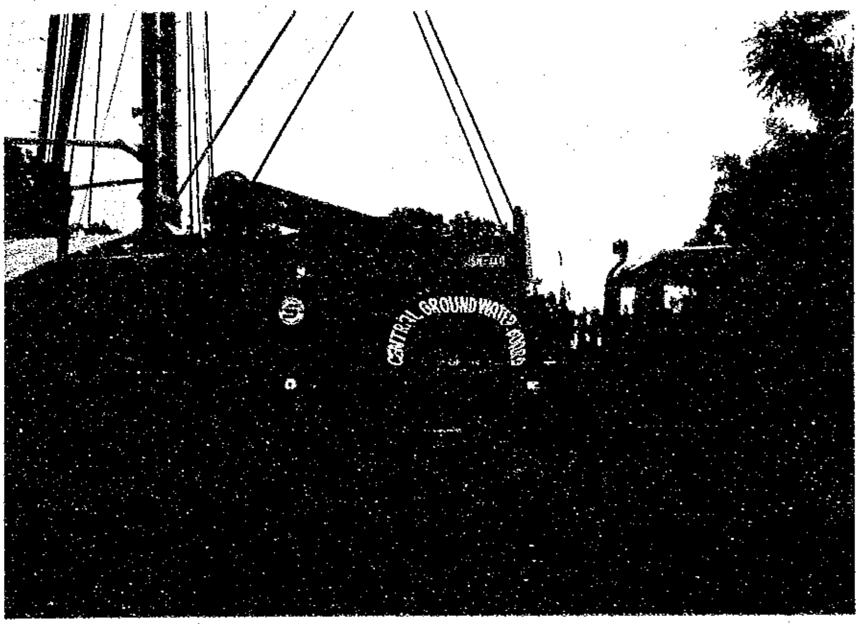
At storeyard of Division II office.

[Ambala]



Drive casing pipe for cased hole drilling provided by Phase-1 project

[Paonta Sahib]

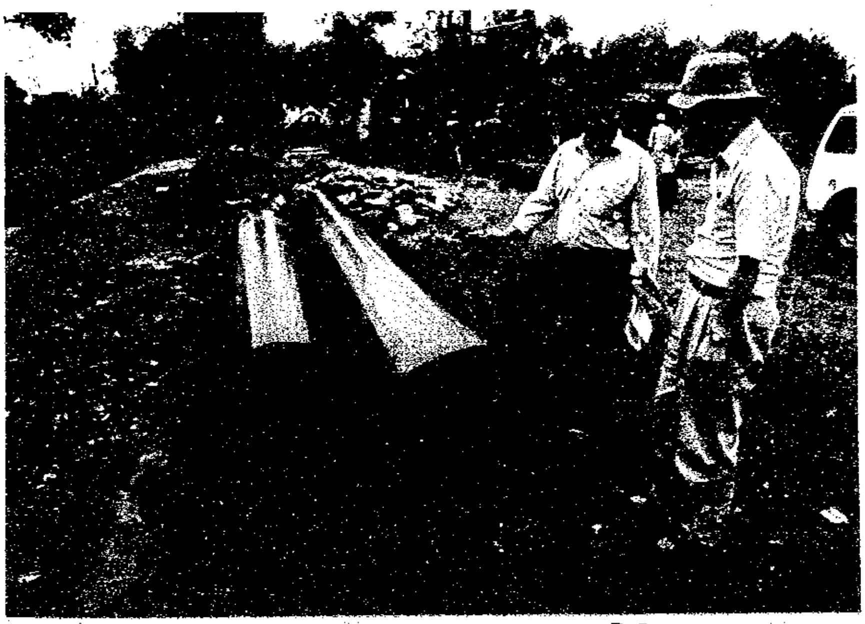


Percussion type drilling rig provided by Phase-1 project

[Paonta Sahib]

Drilling operation

[Paonta Sahib]



Drive casing pipe damaged by Boulder during cased hole drilling

[Paonta Sahib]

CHAPTER 1 INTRODUCTION

Chapter 1 Introduction

In 1988, the Government of India requested grant aid assistance from the Government of Japan to promote ground water development in the foothills of the Himalayan Belt to arrange the social infra-structure. The Government of Japan deemed the project's objective appropriate for Japanese grant aid, and four (4) drilling rigs and geophysical survey equipment were provided in 1990.

In 1992, the Government of India requested grant aid from the Government of Japan to provide drilling rigs and geophysical survey equipment as phase 2 project. The Government of Japan decided to execute the Basic Design Study on "The Project for Exploitation of Ground Water in India", and the Japan International Cooperation Agency dispatched a study team, headed by Dr. Yuji Maruo, from July 12th to August 5th, 1992.

The Study Team held a series of discussions on the Project with officials concerned of the Government of India and conducted studies through field surveys and data collection in the Project area which were necessary for the basic design as well as for understanding the background of the Request, the objectives and contents of the Project, and the water supply situations in the Area.

The major points agreed upon as a result of the discussions and field surveys were written up as the Memorandum of Discussions. On 4 August 1992, the document was signed by Dr. R. K. Prasad, the Chairman of Central Ground Water Board and Dr. Yuji Maruo, the Study Team leader.

Upon returning to Japan, the Study Team conducted the Project analysis based on the field survey results and examined the propriety and contents of the Project, the equipment that needed to be provided, and the Project implementation plan. The result was compiled in this report, the "Basic Design Study on the Project for Exploitation of Ground Water in India".

The list of the study team members, the field survey schedule, the list of organizations and persons contacted, and the Memorandum of Discussions are attached in the Appendix.

CHAPTER 2 BACKGROUND OF THE PROJECT

Chapter 2 Background of the Project

2.1 Background of the Project

The Eighth Plan (1992 - 1997) will aim at a 5.6 percent annual growth in the gross domestic product (GDP) involving a total investment of Rs. 792,000 crore (10 million), including Rs. 342,000 crore in the public sector investment. The two-year shift of the Five Year Plan, by treating the financial years 1990 - 1991 and 1991 - 1992 as annual plan periods, was necessitated by the political instability at the Center. It establishes critical goals for the Eighth Plan, giving priority to energy in the infrastructure sector, strengthening of road networks in the physical infrastructure, and reduction in time and cost overruns in all major and medium irrigation projects. In the social services area, the following items are aimed:

1) reduction of birth rate
2) reduction of infant mortality
3) improving nutritional status of pre-school children
4) universalisation of elementary education
5) provision of drinking water in all villages

The project area, the foothills of Himalayas, receives adequate rain during the monsoon period from June to September. However, these are devoid of any precipitation during the remaining period of the year. Most of the rivers in these areas are either ephemeral in nature or carry a subterranean flow. Therefore, approximately 50 percent of the water for the agriculture sector and 80 percent of the rural water supply sector depends on ground water.

CGWB planned to drill 768 wells to supply ground water for drinking and irrigation. There are water bearing formations having thicknesses of more than 300 m in the area. The aquifers consist of boulders, gravel and sand. Boulders hinder the progress of well construction to extract the ground water. Percussion type drilling rigs are suitable to drill such formations. In 1990, the Government of India was granted four (4) percussion type drilling rigs and geophysical survey equipment by Japan. However, the Government of India was in need of more rigs and other equipment to facilitate the progress of the ground water development in the project area.

In 1992, India requested Japan to donate three (3) drilling rigs and geophysical survey equipment. According to the request, geophysical survey equipment was to be applied to the hydrogeological study in the hard rock area as well as in the boulder formation area. The contents of the request was changed on 10th July, 1992 for the following reason:

CGWB has traditionally adopted the cased hole drilling method because the open hole drilling method was unknown in India. It takes very long time to drill using the cased hole drilling method as compared to the open hole drilling method. A drilling by the open hole method succeeded to drill the boulder formation up to a depth of 301 m in only three (3) months at Haldwani, Uttar Pradish State. It saves time and reduces the cost of constructing tubewells in such areas. CGWB were impressed by the results and decided to change their drilling method to open hole method.

2.2 Outline of the Request

In the projected area the local water supply depends heavily on the ground water resources, exemplified by the large supply ratios of ground water for potable water and irrigation water; 80% and 50%, respectively. The dependence mainly arises from the hydrologic situation where many rivers, except for the giant ones, tend to stay dry in the period other than the rainy season which prevails in the summer monsoon from June through September.

Ground water is born massively in the aquifers consisting of thick boulder deposits, called boulder formation*, at the foot of the Himalayas. However, the formation could not been efficiently managed with the previously availed conventional drilling method, so the test drilling scheme for the ground water development was seriously delayed. Consequently, the necessity for introducing some other pertinent drilling method was realized. As the percussion drilling method was regarded as being most effective for the boulder formation, the Government of India required the rig type for this method and the related equipment to expedite the test drilling work in this particular area.

The Project, formulated by the Government of India, will be equipped with the four (4) drilling rigs already provided in phase 1 under the grant aid assistance of Japan, and three (3) newly requested rigs. In addition, it includes some other drilling rigs previously acquired by CGWB. These equipments are to be operated in the test drilling work for the development of ground water in the boulder formation.

Geophysical survey equipment was provided in Phase 1, and the same items are also requested in this Phase. They are to be used in the hard rock area that spreads extensively in the central and southern part of the country.

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* "boulder formation" is not a recognised geologic formation name, but a conventional term implying the sandy gravel bed in general.

The items to be provided are listed in Table 2.2-1.

Table 2.2-1 Contents of Request

Original Request			Revised Request		
No.	Item	Unit	No.	Item	Unit
1	Truck Mounted Percussion Rigs	3	1	Truck Mounted Percussion Rigs	3
2	Drive Pipes (Cased hole tools)	2	2	Open-hole Drilling Tools*	1
3	Well Logging Equipment	6	3	Support Truck with 5 ton Crane	3
4	Micro Flow Meters	4	4	Submersible Pumps	3
5	Drill Stem Testers	1	5	Well Logging Equipment	4
6	Spare Parts	1	6	Micro Flow Meters	4
			7	24-channel Seismic Unit	1
			8	Deep Resistivity Unit	1
			9	Signal Averaging Resistivity Meter	1
			10	VLF EMR Equipment	1
			11	Spare Parts	1

* for 3 rigs prepared under the phase 1 project

2.3 Outline of the Project Area

1) Meteorology

Climate in India is mostly of tropical monsoon, consisting of four sub-seasons, as outlined below:

(1) Winter (January-February)
(2) Summer (March-May)
(3) Monsoon (June-September)
(4) Post-monsoon (October-December)

Regional climatic division is shown in Fig. 2.3-1. Temperature distribution is shown in Fig. 2.3-2. The annual rainfall distribution is shown in Fig. 2.3-3.

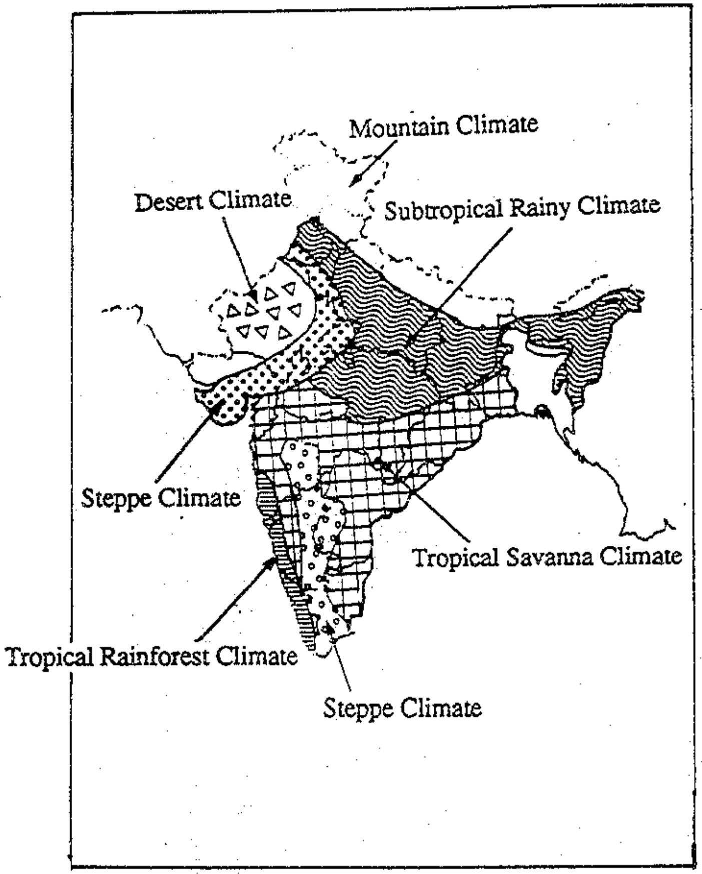


Fig. 2.3-1 Climate

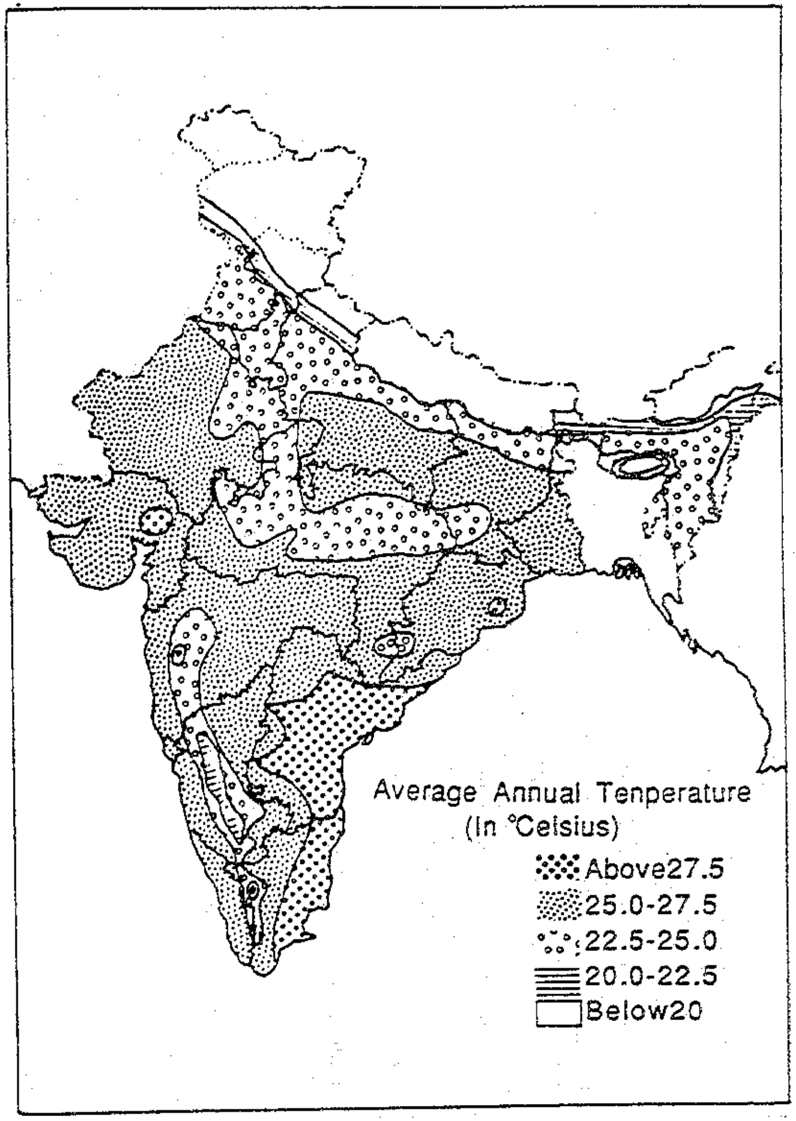


Fig. 2.3-2 Temperature

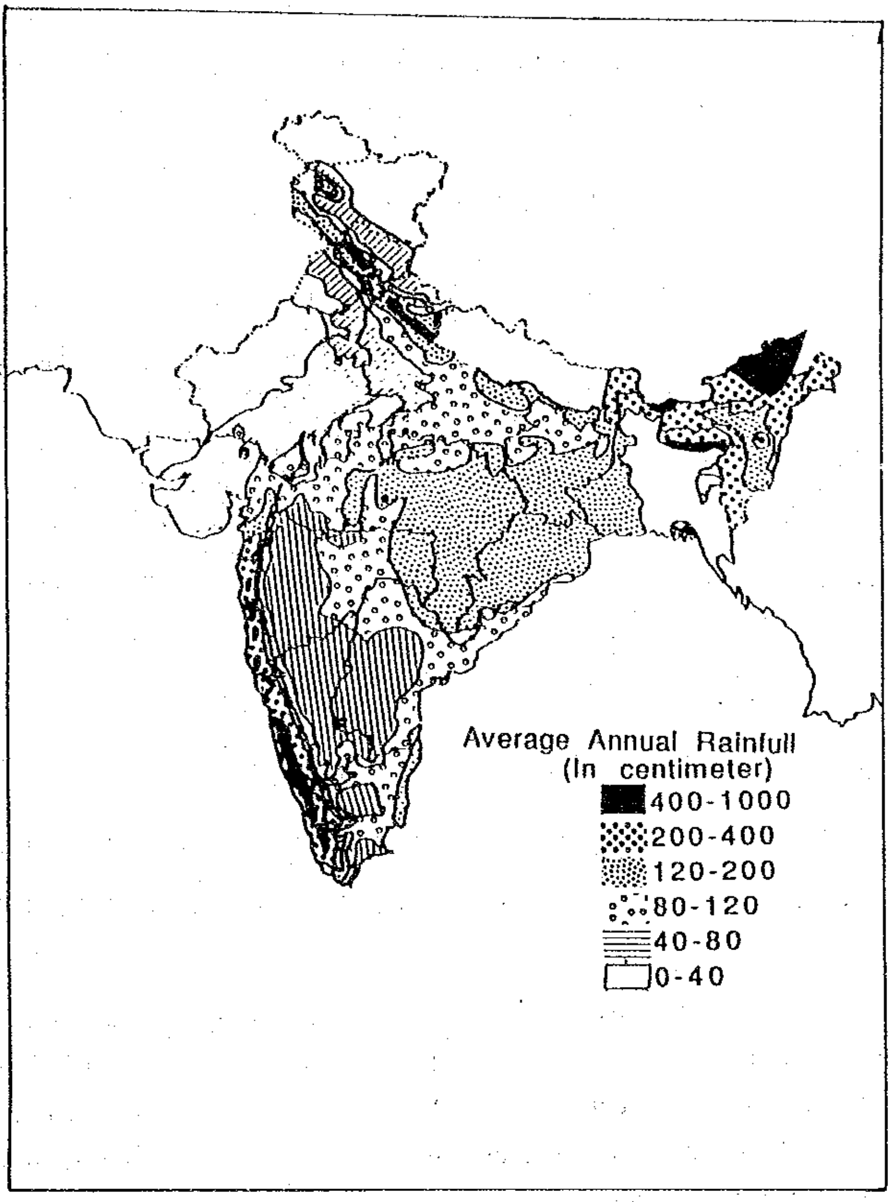


Fig. 2.3-3 Rainfall

Precipitation exceeds 5,000 mm/y in the eastern part of the project area, e.g., Assam, under the strong influence of the Bengal Bay Monsoon. But it attenuates to less than 1,000 mm/y in many localities in the west. Rain is concentrated over a relatively short period, spanning from June to September, in the west, and eventually aridity prevails there. In the west-most part, precipitation drops to less than 400 mm/y causing the development of deserts.

Precipitation and temperature data (averaged during the 1931 - 1960 period at several selected localities) are given in Table 2.3-1.

Table 2.3-1 Temperature and Rainfall (1931 - 1960)

State	Location	Temperature (°C)		Rainfall (mm)		
		Daily Max.	Daily Min.	Rainy Season	Dry Season	Annual
Himachal Pradesh	Shimla	17.1	10.1	2,787	993	3,780
Punjab	Amritsar	30.5	15.9	1,014	258	1,272
Haryana	Ambala	31.8	17.5	2,048	348	2,396
Uttar Pradesh	Lucknow	32.3	19.4	1,867	424	2,391
	Varanasi	32.2	19.8	2,109	446	2,555
West Bengal	Calcutta	31.8	22.1	2,501	909	3,410
Assam	Dhubri	28.3	20.4	3,669	1,704	5,373
Gujarat	Ahmedabad	34.2	20.5	1,998	120	2,118

The selected localities in the table are the state capitals or the subordinate large cities of the states involved in the project. However, some high altitude localities in the project area, e.g., Paonta Sahib in the Phase I drilling site, have quite a large annual temperature range of -3°C as winter minimum and + 44°C as summer maximum.

2) Hydrology

In the project area, two of the world's largest rivers, i.e., the Ganges and the Brahmaputra, flow and form a great alluvial plain. These rivers have head regions in the Himalayas and their flow rates are steady year round. Even during the dry season they do not decrease much. This is due to the melt water from the glaciers and the snow covers on the Himalayas. The wealth of the river water is also the source of the replenishment for the great regional ground water mass along them. In contrast, river-flows in the proper part of the subcontinent (discharging from the Deccan Plateau) are highly dependent on monsoon rains. They increase dramatically in the rainy season and cause floods. In the dry season they often go dry. The total annual discharge of the Ganges amounts to 5,015 billion m^3/y.

3) Geomorphology

There are three major geomorphological divisions of India: the Himalayas in the north, the alluvial plains in the middle and plateau highlands in the south. Most of the project area lies on a strip between the Himalaya Mountains and the alluvial plains.

The western end of the area (State of Gujarat) is an alluvial lowland with some swamps. It faces the Arabian Sea and 1st fringed by the Deccan Plateau inland. The middle part of the area consists of four states including Uttar Pradesh. Except for some localities occupied by the Himalayas, the middle part stretches mostly in the alluvial plain of the Ganges. The eastern end of the area, Assam state and two other states, mainly spreads on the alluvial plains (presently running amid) formed by the Ganges and the Brahmaputra. The northern tract is bounded by the Himalayas.

A north-south geomorphological cross section of the area neighbouring the Himalayas is illustrated in Fig. 2.3-4.

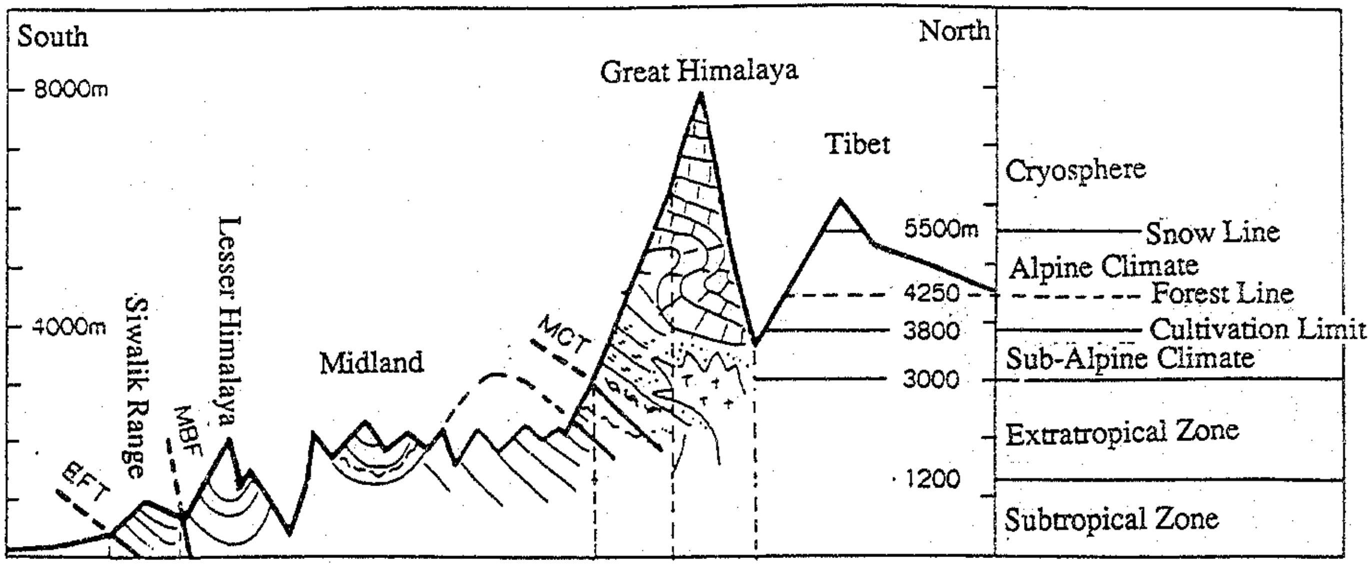


Fig. 2.3-4 Germorphological Cross-Section (Himalayas)

The boulder formation, the survey target of the present project, is thought to constitute the alluvial fans in the both wings of the project area.

4) Geology

The major geologic divisions of India comprise three units just as the geomorphological ones; the Himalayan belt, the Ganges alluvial plain and sub-continent proper.

A geological map is given in Fig. 2.3-5 and a geologic cross-section through the Himalayas is depicted in Fig. 2.3-6.

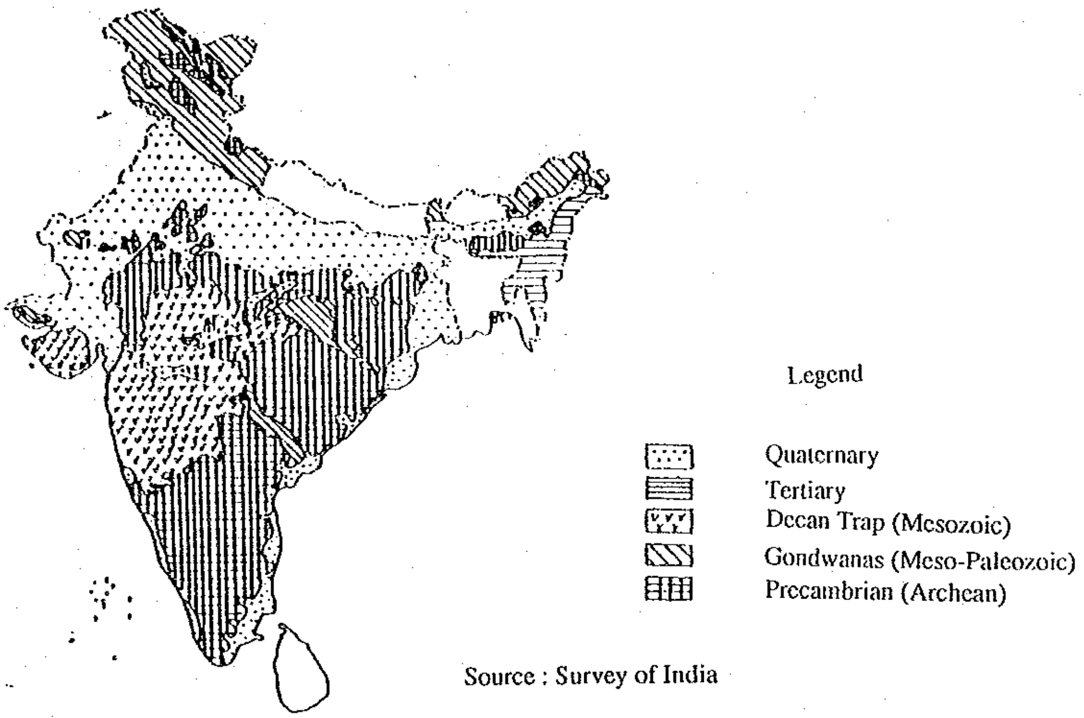
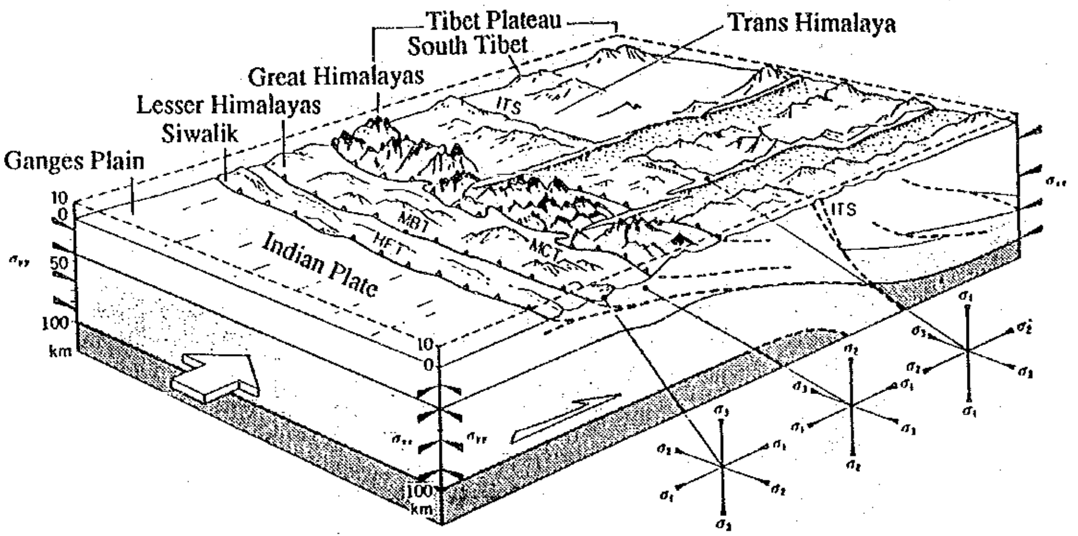


Fig. 2.3-5 Geological Map



Source : Sakai • Honda (1988)

Fig. 2.3-6 Geologic Cross-Section (Himalayas)

The predominant formations in the Himalayan belt are of Paleozoic and Mesozoic erathems, consisting of slate, sandstone and limestone. The frontal boundary hills of the Himalayas, known as the Siwalik hills, are made up of Siwalik system of coarse-grained sedimentary rocks with some boulder conglomerate at the Upper Siwalik system.

The Siwalik system is a molasse deposits formed in the postorogenic of the Himalayas. It consists of silt, sand and gravel produced by the denudation during the upheaval period.

The Siwalik system thrusts on the Ganges plain deposits forming the Himalayan Frontal Thrust (HFT) which develops between the Siwalik hills and the Ganges alluvial plain.

The Ganges plain alluvium is the deposits formed in the Indo-Ganges subsidence zone, the maximum thickness of which exceeds 2,000 m. The facies consists mainly of clay, sand and gravel. The northern fringe of the Ganges plain comprises composite fans formed by the rivers originated in the Siwalik and the Himalayas. The fan deposits include several beds of boulder formation. The thickness of the fan deposit is presumed to exceed 300 m without confirmation of the base so far. Once deep drilling was tried in Haldwani, Uttar Pradesh, down to 301 m into it, but it could not reach the base. The deposits decrease the grain size towards the south, and proceeds into the alluvium of the Ganges plain.

In the subcontinent proper, Precambrian older rocks are distributed extensively and consist of granite, quartzite and schist. In addition, in the mid-western part there are basaltic formations, called Deccan traps, that erupted in a large scale during the late Cretaceous. The areas of older rocks are called hard rock areas.

The target areas of the project include the partly Siwalik system, but largely composite fans located along the northern fringe of the Ganges plain. The distribution of the boulder formation, the major target of the survey, is shown in Fig. 2.3-7.

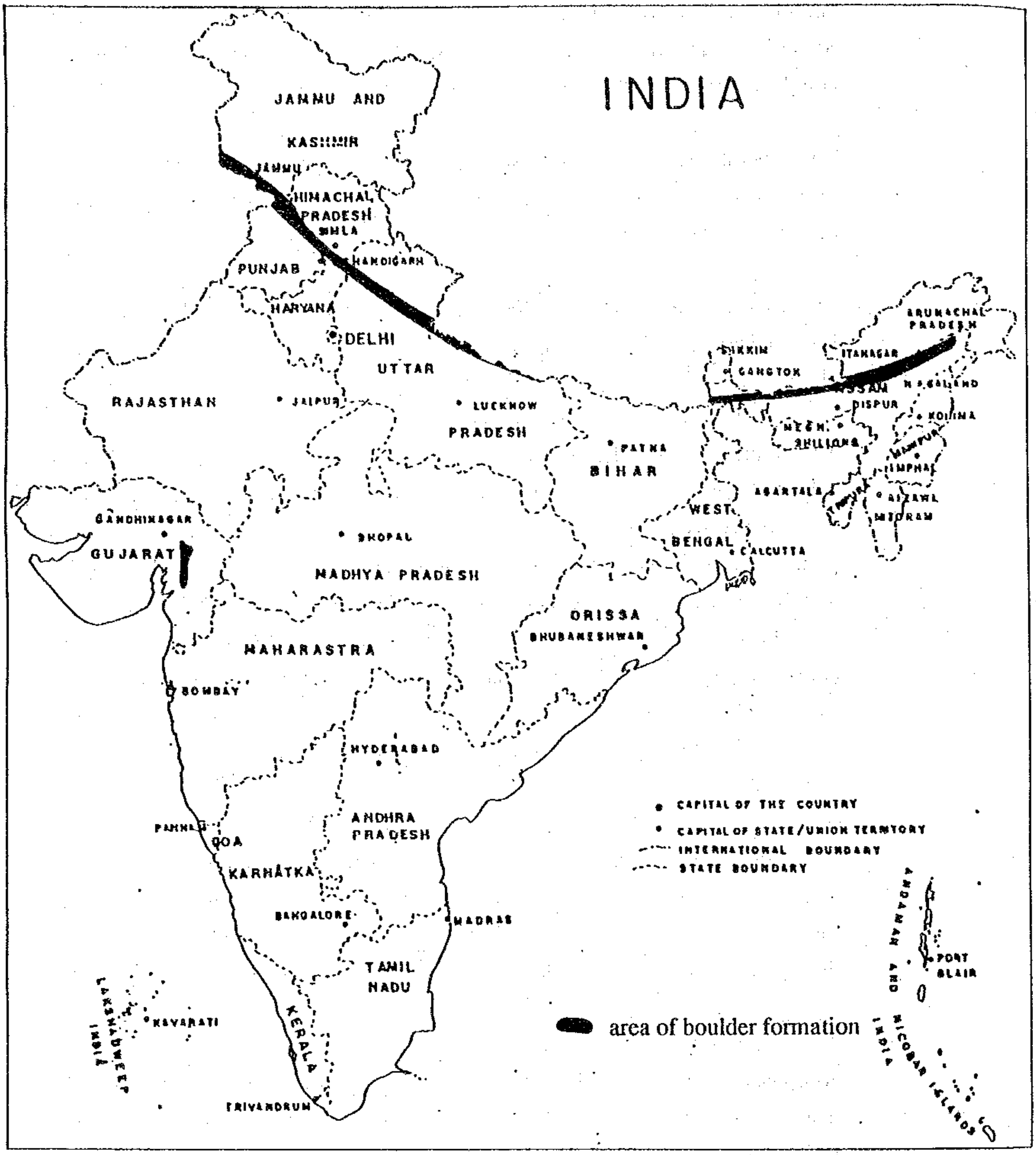


Fig. 2.3-7 Distribution of Boulder Formation

5) Hydrogeology

The occurrence of ground water in the older rock area in the Himalayas and the subcontinent proper is fissure water stored in the fissure zone of bedrock. Stratum water is formed in the pores of young depositional bed in the Ganges plain. Generally, fissure water is less abundant than stratum water. In the widely stretching Ganges plain, development of aquifers in the thick alluvium are already in progress. The yield capacity of a well in the alluvium is known to be more than 150 m^3/h. But in the Himalayas and in the subcontinent proper the capacity attainable is only around 20 m^3/h.

The hydrogeological characteristics of the project area can be stated as follows:

Ground water is stored in the boulder formation and alluvium. Aquifers are found at the shallow (within 10 m depth) and deep levels in both the boulder formation and alluvium. As the shallow aquifer is replenished with a limited amount of water, well draw-down is sometimes so large that continuous pumping becomes difficult in many wells. However, deep aquifers in the boulder formation hold excellent productivity due to the plentiful replenishment received from the Himalayan precipitation. In Haldwani, a well was drilled to 300 m depth by the rig provided in Phase I and its draw-down was 3.3 m at the pumpage of 121 m^3/h. This result testifies that the boulder formation is an excellent aquifer formation. In case of the Haldwani well, the static water level was 121 m below the ground surface, suggesting a general tendency of deeper water level in the boulder formation. The hydrogeological cross-sectional structure of the survey area is given in Fig. 2.3-8, together with that of Terai plain of Nepal.

Estimated yields of wells are more than 2,000 l/min in the boulder formation and 600 - 1,000 l/min in the hard rock area.

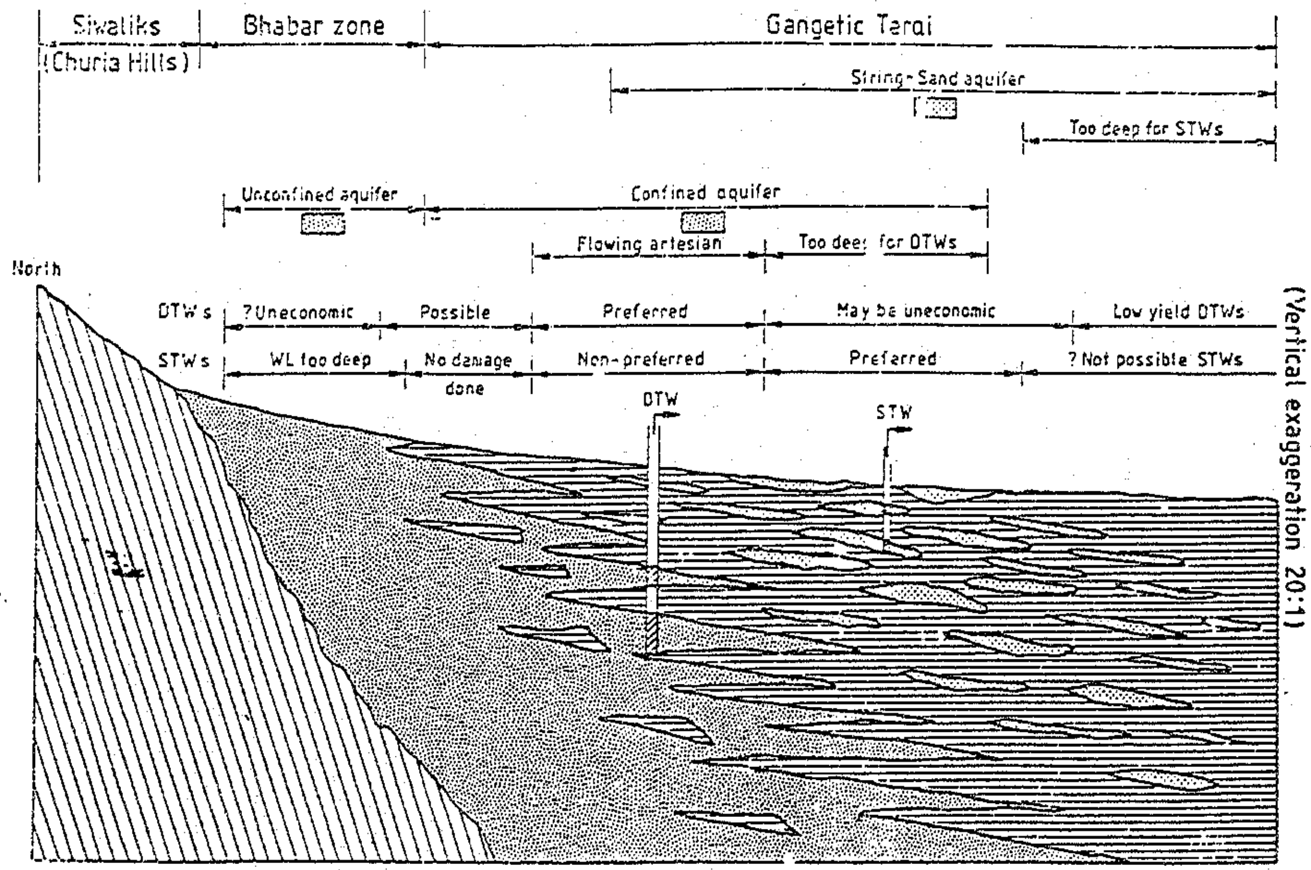


Fig.2.3-8 Schematic Hydrogeological Cross Section (Terai, Nepal)

6) Water Quality

Apart from the deep wells drilled by CGWB, there are hand-dug wells and other types of wells tapping the shallow aquifers in the Project area. Simple water tests were carried out at these wells located in Ambala and Lucknow. The results are presented in Table 2.3-2.

Table 2.3-2 Result of Simple Water Tests

Location	Well Name	Well Type	Ec (μs/cm)	Colonbacillus	pH	T (°C)
Ambala	Housing Board	DTW	162	not detected	7.1	30.3
	B.B.M.B Dhalkot	DTW	151	not detected	7.2	29.7
	Hand Pump	SW	188	countless	7.1	26.5
	Hand Pump in the Division II office	SW	172	countless	7.3	26.0
Lucknow	I.I.S.R Deposit	DTW	689	not detected	7.3	28.9
	NABARD	DTW	450	not detected	7.2	28.5
	Hand pump	SW	650	countless	6.8	26.7

DTW : Deep Tube Well
SW : Shallow Well

The electric conductivity drops within a range of 150 - 700 MS/cm, indicating fresh water both in shallow and deep wells. But the colonbacillus count in shallow well waters are numerous without exception, showing it to be hygienically unsuitable for potable water. This result clearly concludes the importance of deep wells for the supply of hygienically safe potable water.

Some aquifers in the Ganges plain were confirmed to store brackish water influenced by captured connate stratum water in the sandy gravel formation when the deposition had taken place.

CHAPTER 3 OUTLINE OF THE PROJECT

Chapter 3 Outline of the Project

3.1 Objective

In the project area, development of the ground water resources and construction of the infrastructure in the rural areas are not satisfactorily in progress. CGWB formulated a well-drilling project in which 1,000 test holes would be drilled by the year 2005. Ground water exploration and development are to be conducted in the scheme.

However, CGWB's present drilling capability into the boulder formation is limited up to 100 - 150 m depth due to the equipment in its possession. It is a serious minus factor when the formation thickness is considered to be greater than 300 m. The objective of the Project is to acquire the drilling rigs capable of operating in the boulder formation for the development of the ground water.

3.2 Examination of the Project

CGWB's original drilling plan for the project area is as follows:

(1) CGWB estimated a total area of 150,000 km^2 as being boulder formation. Altogether 1,200 test holes are to be drilled by the percussion type rigs. CGWB adopted one hole for every 125 km^2 as the test hole density.

(2) CGWB holds 8 medium-sized percussion type drilling rigs in addition to the rigs granted by Japan. So far about 200 holes have been drilled in the area where the boulder formation is relatively thin, leaving 1,000 holes for future drillings.

(3) The previously provided Japanese percussion rigs were operated by the open hole method and achieved excellent work in the boulder formation, completing a 300 m hole in 3 months. The cased hole method was conventional in India but less efficient. The open hole method was not known before this particular operation, and CGWB was highly impressed by the Japanese rig and method, estimating three times greater capability than the conventional drilling.

(4) Three rigs out of four rigs provided in phase 1 were equipped with cased hole drilling tools. Open hole drilling tools will be provided for these 3

rigs under the Project. If three more rigs are to be provided in this phase, the total force of Japanese rigs at CGWB will be seven. Each Japanese rig operates at three times greater capability than a conventional rig; thus, seven Japanese rigs are equivalent to 21 conventional ones. Shortly, reinforcement of the seven Japanese rigs will bring CGWB to acquire an equivalent rig force of 29 conventional rigs including 8 old rigs of their own.

(5) Within the scheme of the 8th five-year Plan, CGWB set up a drilling project in which 1,000 test holes will be sunk by the year 2005 i.e., in 13 years' time from 1992.

(6) Previously, 3 test holes a year were achievable by a single conventional rig. The present Project will strengthen CGWB to drill 87 test holes a year, i.e.,
29 rigs x 3 holes = 87 holes
This figure leads us to the total achievable number of test holes in 13 years calculated as 1,131, i.e.,
87 holes x 13 years = 1,131 holes > 1,000 holes.
The calculation confirms that the target figure, 1,000 holes in 13 years, for test drilling in the CGWB Project can be attained if three rigs are supplied in the present project.

During the joint discussion with CGWB, the following problems were recognized in the above stated CGWB Project:

(1) The estimated total area of the boulder formation (150,000 km^2) was found to include Jammu and Kashmir. This region was excluded in the CGWB Project area. Consequently, the total area was revised to 121,000 km^2.

(2) Since its introduction, the Japanese rig drilled a 300 m deep hole in 3 months. This accomplishment showed there is a potential of drilling 4 holes to 300 m depths every year. However, it was noticed that the derived figure was considerably less than the CGWB evaluation stated in (3) above, i.e.,
3 holes/year/rig x 3 = 9 holes/year/rig.

The study team examined the Project by considering the points presented above. The main conclusions are as follows:

(1) The distribution density of the test holes was adopted by CGWB at one hole per 125 km^2. The figure is regarded as reasonable for the exploration of ground water and regional hydrological structure when depositional environment of the boulder formation is considered.

(2) The actual survey area is reduced to 96,000 km^2, when corrected by the 200 test holes already drilled; 121,000 km^2 - 125 km^2 x 200 holes = 96,000 km^2. This areal figure prescribes the necessary number of test holes to be 768;
96,000 $km^2 \div$ 125 km^2/hole = 768 holes.

(3) The thickness of the boulder formation cannot be uniformly 300 m throughout the distribution area because of its depositional origin on the foothills. Distribution of thickness of the boulder formation has not been confirmed because the resistivity survey is not effective on the boulder formation. Only one well was dug up to 300 m in the formation. Considering that the boulder formation is a complex of fan deposits, it is assumed that the thickness of the formation is maximum at the central part of the fan and decreases toward the top and end part of the fan deposits. A tentative distribution structure of the formation thickness is assumed for practical purposes; three thickness groups, i.e., 100, 200 and 300 m, share equally 1/3 of the total area.

(4) On the basis of above condition, a drilling scheme is formulated as shown in Table 3.2-1.

Table 3.2-1 Drilling Scheme

Drilling depth	Area	Hole number	Operation period per hole	Total operation period
100 m	32,000 km^2		-	-
200 m	32,000 km^2	256	2 months	512 rig/month
300 m	32,000 km^2	256	3 months	768 rig/month
Total	96,000 km^2	512	-	1,280 rig/month

In order to estimate the necessary number for the granted rigs, 100 m depth class drilling is excluded from the calculation, because this depth is sufficiently manageable by CGWB's conventional drilling rigs. The necessary number is calculated to be 8.2 rig/year, i.e.,
1,280 rig•month ÷ 12 month ÷ 13 year = 8.2 rig/year.
The estimated rig number, 8.2, for attaining the project target is 1.2 rig less than the proposed granted rig number, 7.

(5) According to the rig supplier, who was commissioned in the project area, some improvement has to be made to the rigs to be granted in this phase. The following points were noticed through operational experience in phase 1:

i) The present drilling bit must be modified to the more effective one for drilling in the boulder formation.
ii) The weight of the present drilling bit can be increased.

(6) The drilling rate can certainly be increased by 10 % or more if such improvement as (5) is made.

(7) If such improvement as (6) is to be attained, the estimated rig number in (4) can be reduced to 7.4, i.e., 8.2 x 0.9 = 7.4. Even if there is some surplus in the estimated rig number, i.e., 0.4, this difference can be easily overcome as local operators become more experienced and improve the drilling capability.

(8) Finally, the rotary type drilling rig is not easily operated in boulder formations. Such as in the Project area. Therefore, the introduction of a percussion type drilling rig is indispensable for accomplishing efficient drilling work.

Through the examination above, the requested three (3) drilling rigs are considered to be a reasonable and adequate quantity.

Following is the examination made of the geophysical survey equipment:

Geophysical survey equipment will be used in the hard rock area in addition to the Project area proper. The hard rock area occupies 70% of the total territorial area of about 2.2 km^2 in India. Although 20% of it has already been covered by ground water survey, it is still necessary to extend survey work into the vast virgin area.

There are altogether 35 geophysicists in CGWB, who are in charge of the geophysical survey on ground water. These specialists do not seem to be fully utilizing their expertise due to the lack of equipment as is clearly indicated in the equipment inventory of CGWB (see Table 3.2-2). The geophysical survey is one of the important technologies for determining drilling positions and installation positions of strainers. In other words, the positions of aquifers in the finished bore hole.

The request for the equipment is regarded as being quite acceptable when considering the importance and urgency of ground water development in India.

Table 3.2-2 Geophysical Survey Equipment (after phase 1)

Equipment	Number
Resistivity Srurvey Unit	19
VLF Survey Unit	4
Seismic Survey Unit	3
Electro-Magnetic Survey Unit	2
Well Logging Equipment	9 (20)*

* : Nine (9) units are in working condition.

As the last part of the examination, the beneficial effects expected as a result of the execution of the Project, are discussed below:

(1) The pumping test at the newly drilled Haldwani well presented a discharge capacity of 2,025 l/min (2,916 m^3/d) or more. CGWB regarded this data as confined by the capacity of the submersible pump. They presumed greater value if the pump was replaced by one having a larger capacity.

(2) The aquifer properties of the boulder formation is assumed to be more or less similar throughout the occurrence area.

(3) CGWB's drilling plan calls for drilling 768 test holes in 13 year, i.e., 59 holes/y. The Japanese rigs will drill about 40 of them a year.

(4) A model calculation was tried using the data from the Haldwani test well as applicable to the entire boulder formation (Table 3.2-3). Potable water supply population and irrigable area were calculated for two kinds of pumping operation, (12 h/d and 18 h/d) on the basis of daily potable water demand to be 45 l/cap./d and annual irrigation demand to be 2,000 mm/y. The ratio between potable water and irrigation water was set at 2 : 8. The results are given in Table 3.2-3.

Table 3.2-3 Estimated Water Supply (one year)

Operation Hour	12 hours	18 hours
Extraction Rate	2,025l/min. x 720min. = 1,458(m^3) 1,458m3/hole x 60 hole = 87,480(m^3) 87,480m3/day x 365day = 31,930,200(m^3)	2,025l/min. x 1,080min. = 2,187(m^3) 2,187m3/hole x 60 hole = 131,220(m^3) 131,220m3/day x 365day = 47,895,300(m^3)
Domestic	6,386,040m^3	9,579,060m^3
Population Served	388,800person (259,200person)	583,200person (388,800person)
Water for Irrigation	25,544,160m^3	38,316,240m^3
Irrigated Area	1,277ha (851ha)	1,916ha (1,277ha)

Table 3.2-4 Developed Water from Project Well (Ultimate Volume at 2005)

Operation Hour	12 hours	18 hous
Ground Water to be Developed	415,093	622,639
Domestic Water (x 10^3 m^3)	83,019	124,528
Population Served (x 10^3 person)	5,054	7,582
Water for Irrigation (x 10^3 m^3)	332,074	498,111
Irrigated Area (ha)	16,604	24,906

(5) The total amounts of the developed ground water from the project wells at the end of the Project term (the year 2005) are shown in Table 3.2-4, assuming successful completion of drilling work by CGWB.

(6) The calculated results shown in Table 3.2-3 and 3.2-4 indicates a great beneficial effect to be produced by the completion of the Project. The repercussion effect is also expected to be considerable.

3.3 Project Description

1) Executing Agency and Operational Structure

Ground water development in India is managed by the Central Ground Water Board (CGWB), affiliated to the Ministry of Water Resources (MWR) of the Federal Government. CGWB is a governmental organization which directs and executes the scientific development and administration of ground water from the point of national interest. The activity of CGWB covers almost all the related fields, such as hydrogeological survey, test drilling, evaluation, development, administration, and so on. CGWB's actual activities can be categorized as follows:

1) Regional Hydrogeological survey
2) Test drilling (including logging and pumping test)
3) Monitoring of ground water level and quality

The data acquired through these activities are used in draughting and compilation work of hydrogeological maps, evaluation of ground water resources, formulation of ground water development project and others. In addition, CGWB advises the state government on formulating, financing and executing the ground water development project.

Within the CGWB organization, the director of foreign affairs of MWR assumes the position of president. The management is undertaken by a board consisting of a chairman, the chief hydrogeologist of hydrogeological survey division (vacant at present), the chief Engineer of drilling division, the head of the administration division and the head of the planning division. The head office is situated in New Delhi.

The general organization chart is shown in Fig. 3.3-1.

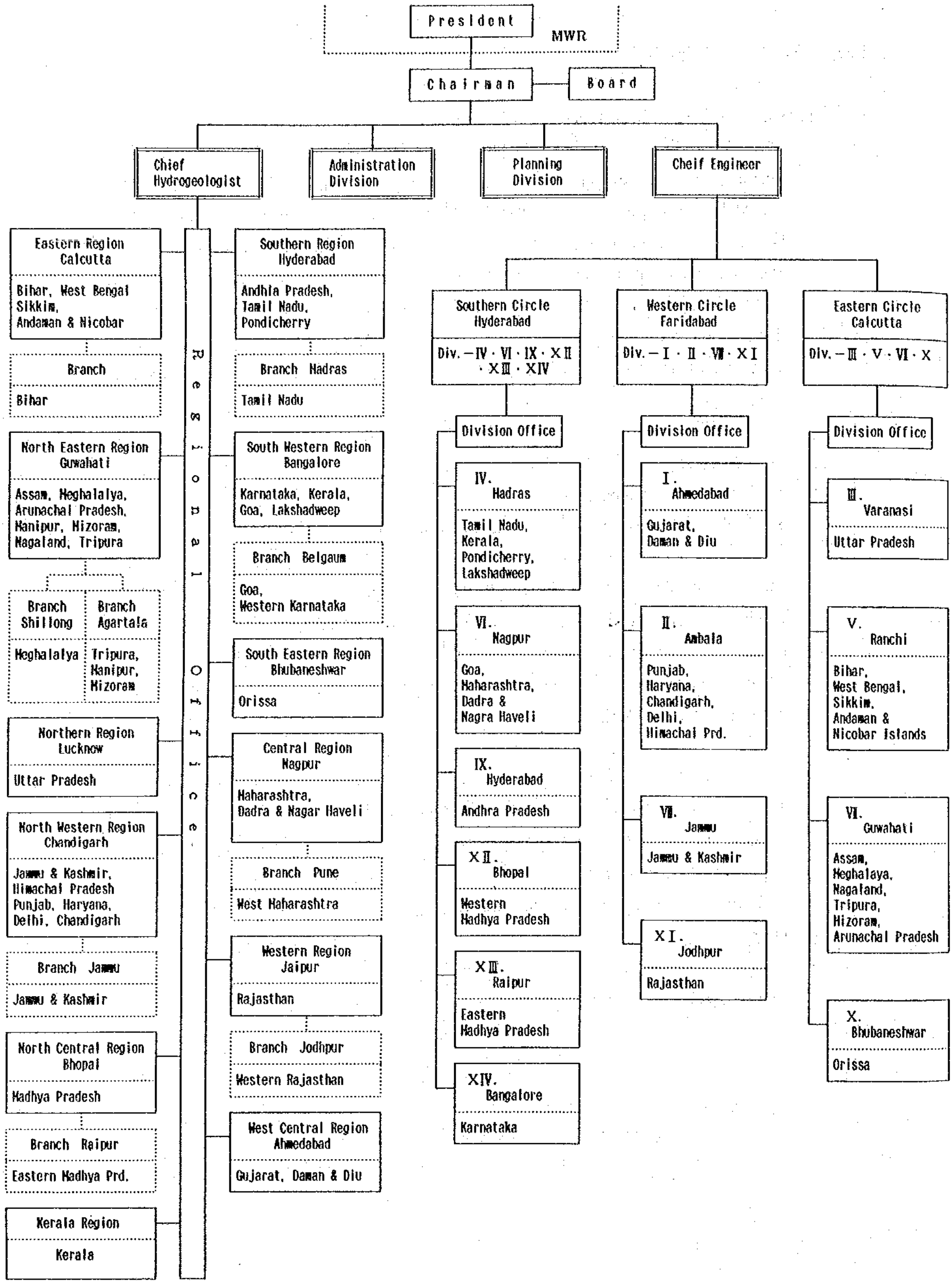


Fig 3.3-1 Organization Chart of CGWB

2) Operataion Scheme

As mentioned in the preceding chapters, the extension of irrigation and potable water supply in rural areas is one of the important items in the 8th Five-year Plan. In particular, the Project area is also the Five-year Plan area, where the highland development and the drought salvation work were assigned. These are the two tasks consistently pursued since the 7th Five-year Plan (1985 - 1990). CGWB's drilling project was formulated to meet these tasks in the previous Five-year Plan, setting the goal in the year 2005. However, due to the country-wide swarming drought disasters during the previous period, CGWB inevitably revised the original schedule and could only accomplish a greatly reduced number of drill holes.

The Project area consists of thick boulder deposits, the so-called boulder formation, which reflects strong local affiliation to the Himalayas. Drilling operations for ground water development have encountered many difficulties stemming from this formation.

Drilling into the boulder formation requires a large size percussion type drilling rig. CGWB formulated the following drilling plan in which percussion type drilling rigs, both already granted in phase 1 and requested in this phase, assume an important role.

Since the boulder formation occupies about 121,000 km^2 in the Project area and the facies characteristics require one test hole in every 125 km^2 for the satisfactory hydrogeologic exploration. In total, 968 test holes are to be drilled, i.e.,
120,000 $km^2 \div 125$ km^2/hole = 968 holes.
This total number can be divided and distributed to each intra-project state in proportion to the areal ratio of the boulder formation held in it. The predetermined test hole number for each state is given in Table 3.3-1. However, 200 of the 968 wells have been drilled by CGWB. The remaining 768 wells are planned on being drilled.

Table 3.3-1 Predetermined Test Hole Number

State	Area (km^2)	Number of Well
Himachal Pradesh	25,000	200
Punjab	8,000	64
Haryana	4,000	32
Uttar Pradesh	35,000	280
West Bengal	8,000	64
Assam	20,000	160
Arunachal Pradesh	15,000	120
Gujarat	6,000	48
Total	121,000	968

CGWB will hand over the test holes to the state government after finishing well-furnishing. The transferred test holes will be equipped with water supply facilities and operated as water supply wells. Conclusively speaking, CGWB can be said to bear the fundamental part of ground water development.

3) Staffing Plan

The number of CGWB's staff as of end of March 1992 is shown in Table 3.3-2. The staff has increased by 64 since the 1989 number of 5,282 in 1989. CGWB explained to the study team that they increased the size of their staff in response to the provided rigs under the phase 1 project. They will increase their staff again if the rigs are newly provided under the Project. It is necessary to increase the staff because CGWB executes drilling work on their own without employing any contractors. It is confirmed that CGWB has a proper staffing plan.

Table 3.3-2 Staff of CGWB

Group	Sanctioned	Filled	Vacant
A	392	309	83
B	320	267	53
C	2,623	2,317	306
D	2,011	1,840	171
Total	5,346	4,733	613

4) Plan of Budget

The expenditures of CGWB in 1985 - 1990, i.e., in the period of the 7th Five-year Plan, and the budget of 1990 - 1992 are shown in Table 3.3-3.

Table 3.3-3 Plan of Budget

(unit: lakh = 100,000 Rs)

Year	Salaries and Maintenance Expenditure	Equipment	Works	Buildings	Total
Expenditure					
1985 - 86	813.76	203.97	309.75	10.37	1337.85
1986 - 87	1003.89	1442.86	351.18	0.19	2798.12
1987 - 88	1282.78	1378.11	423.93	0.18	3085.11
1988 - 89	1461.76	1609.95	427.52	0.18	3499.41
1989 - 90	1542.80	631.75	475.00	19.00	2763.55
Total	6104.99	5266.64	1987.38	29.92	3483.93
Budget					
1990 - 91	1796.79	1137.40	475.31	4.81	3414.31
1991 - 92	2016.00	2963.40	550.00	50.00	5629.00
1992 - 93	2135.00	3370.11	600.00	100.00	6205.00

The annual expenditure and budget have been increasing at an agreeable rate, but a relatively high rate is noticed after 1990. This particular increase corresponds to the offer of granted equipment by Japan, reflected by the budgetary allocation.

Drilled well holes have been transferred to the related state governments. But CGWB collects charges from each related government to recover the construction cost. The charge is determined by the rank of the supply capacity of well. Well ranking and recovered cost are given in Table 3.3-4.

Table 3.3-4 Well Ranking and Recovered Cost

Rank	Extraction (US gallon/h)	Recovered Cost
A	more then 20	Full Account
B	10 - 20	Casing cost only
C	less than 10	Free of charge

5) Similar Drilling Projects and Aid from International Organizations

(1) Similar Drilling Projects

CGWB administrates all the ground water development work in India. It not only performs drilling work, but also supervises state government's drilling work.

The state government can only drill 100 ~ 150 m deep wells and depends on CGWB drilling projects for 300 m class wells.

Consequently, there is no overlapping of CGWB and state government projects.

(2) Aid from International Organizations

Other than Japanese aid given in phase 1, there is aid from UNDP, UK, USA, the Netherlands, Sweden, Canada, etc.

The foreign aid projects executed so far are listed in Table 3.3-5. Each project area is shown in Fig. 3.3-2.

Table 3.3-5 Foreign Aid Project List

Project Name	Year	Donner
Project for Gound Water Exploration in Bihar	1968 - 1971	Netherlands
Ground Water Studies in Rajasthan & Gujarat	1967 - 1971	UNDP
"	1971 - 1974	UNDP
Ground Water Project in Andhra Pradesh and Karnataka	1971 - 1975	Canada (CIDA)
Ground Water Studies in Noyil, Amravati and Ponnani River Basins	1975 - 1979	Sweden (SIDA)
Ground Water Studies in Ghaggar River Basin	1975 - 1979	UNDP
Water-Balance Studies in Upper Betwa River Basin	1975 - 1979	United Kingdom
Water-Banlance Studies in Coastal Kerala	1979 - 1984	Sweden (SIDA)
Pilot Projet on Artificial Recharge in Gurarat	1981 - 1988	UNDP

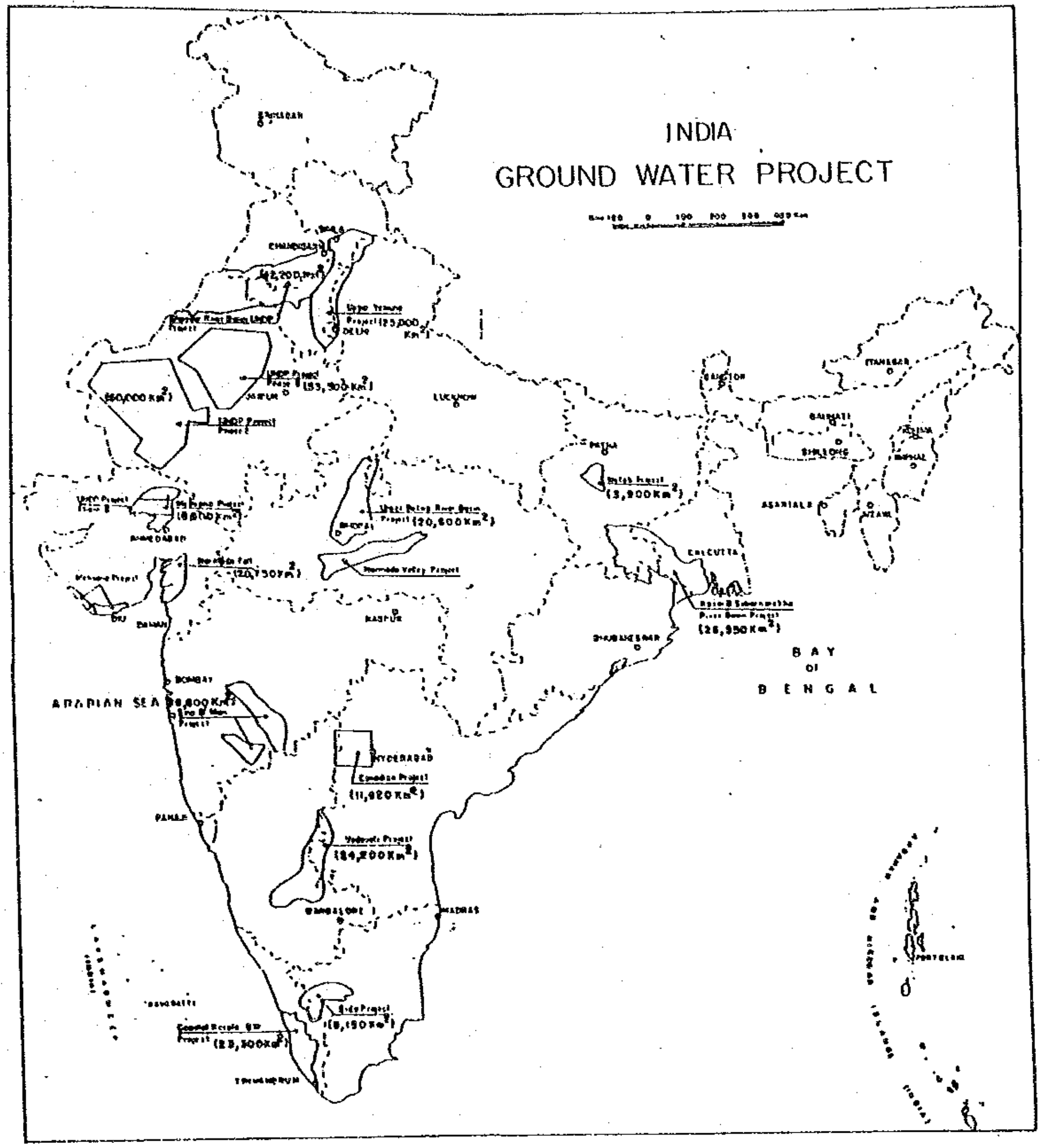


Fig. 3.3-2 Foreign Aid Project Area

6) Outline of Requested Equipment

The outline of equipment to be procured in the Project is as follows:

i) Percussion type drilling rigs and tools
ii) Open hole drilling tools for provided rigs (3 units)
iii) Crane trucks
iv) Submersible pumps
v) Well logging equipment
vi) Micro flowmeters
vii) Seismic equipment
viii) Deep resistivity equipment
ix) Signal averaging resistivity meters
x) VLF-EMR equipment
xi) Spare parts

Specifications and quantities shall be examined and determined in the following Chapter: Basic Design.

CHAPTER 4   BASIC DESIGN

Chapter 4 Basic Design

4.1 Design Policy

The Project aims at granting the necessary funds to purchase drilling rigs and survey equipment for supplying safe drinking water and irrigation water that will not be depleted throughout the year. The Project succeeds the phase 1 project executed in 1989 and 1990. Therefore, proper compatibility with the rigs and equipment provided in phase 1 project should be considered in equipment planning.

Additionally, various Indian situations, project area conditions and the rules of the Japanese grant aid system were considered as prerequisites for the basic design. As a result, the following design policies were established for the basic design:

1) To confirm the Indian ground water development policies, rules and standards.

2) To design economical facilities that will suit the standards of each project site.

3) To make project planning by taking into account the project area's climatic conditions, and the situation and usual practices of CGWB's drilling section.

4) To select such equipment suitable for high temperature conditions and long distance transference conditions as well as economic and easy maintenance.

5) To make a project implementation plan that can be adapted to CGWB's plan and operational conditions, such as the number of technical staff and team members and their technical levels.

6) To select such equipment that meet the specifications of the equipment that were provided under the phase 1 project by considering the standardization of CGWB's equipment, provision of spare parts, management and maintainability, ease of operation, and the efficiency of grant aid.

7) To exclude such equipment, if any, that will not be necessary for implementation of CGWB's drilling plan. To examine such equipment, even if the fund is not requested, that will be indispensable for implementation of CGWB's drilling plan and suitable for grant aid in order to include it in the Project's equipment provide programme.

4.2 Study and Examination on Design Criteria

Based on the above mentioned design policies, the following design criteria were examined to decide the number and specifications of equipment:

1) Target Aquifer to be Drilled

The target aquifer in the area is the 200 to 300 m thick boulder formation that is widely distributed throughout the area and covers 121,000 km^2 (see Fig. 2.3-7). The rigs to be provided will be used for drilling that formation. The maximum drilling depth is 300 m.

2) Drilling Programme

As mentioned in clause 3.2, 768 wells will be constructed by the year 2005 of these, 512 wells will be drilled by rigs already provided by the phase 1 project and rigs to be provided by the Project. Effective drilling methods should be applied to save the time because 39 wells are to be constructed per year.

3) Standard Design of Wells

To select the proper drilling rig and tools, it will first be necessary to decide upon the design of the well structures. Based on the results of the phase 1 project, the maximum thickness of the target formations is considered to be 300 m. Well diameters shall be 20 inches and 16 inches by taking into consideration the geological conditions, planned extraction, and the casing diameters to be provided. As the conductor pipe will be installed near the top of the borehole, the drilling diameters shall be 25 inches for the 20 inch wells and 18 inches for the 16 inch wells. The upper 10 m to 50 m of the wells shall be drilled using 25 inch bits or 18 inch bits. However, the actual drilling depth for the bits in use shall be decided upon by the driller who will take into account the hardness and weathering condition of the surface strata. The standard well structure designs are shown in fig. 4.2-1 and 4.2-2. Combination of the casing pipes is divided into 3 cases, although the well diameter is same the arrangement of the casing and screen can be selected to correspond to the extraction rate and purpose of the wells.

Basic design conditions are summarized as follow:

(1) Well diameters shall be 25 inches x 20 inches and 20 inches x 16 inches.

(2) Maximum drilling depth shall be 300 m. Conductor pipes shall be installed to the depth of 10 m to 50 m from the surface.

(3) Maximum pumping head is 150 m and the extraction rate is 2000 l/min. in pumping test. A submersible pump will be installed in the 10 inch casing pipe.

The diameters of drilling bits that were determined based on the above mentioned conditions are shown in Table 4.2-1.

Table 4.2-1 Diameter of Drilling Bit

Design No.	Bit Size, Conductor (inch)	Conductor Pipe Dia. (inch)	Bit Size, Casing (inch)	Upper Casing Dia. (inch)	Casing Pipe & Screen Dia. (inch)
A.	25	24	20	-	14
B.	25	24	20	14	12-3/4
C.	25	24	20	-	12-3/4
D.	20	18	16	12-3/4	10-3/4
E.	20	18	16	-	10-3/4
F.	20	18	16	12-3/4	8-5/8

Note: 1) Drilling Depth : Max. 300 m
2) conductor setting depth : Approx. 10 to 50 m

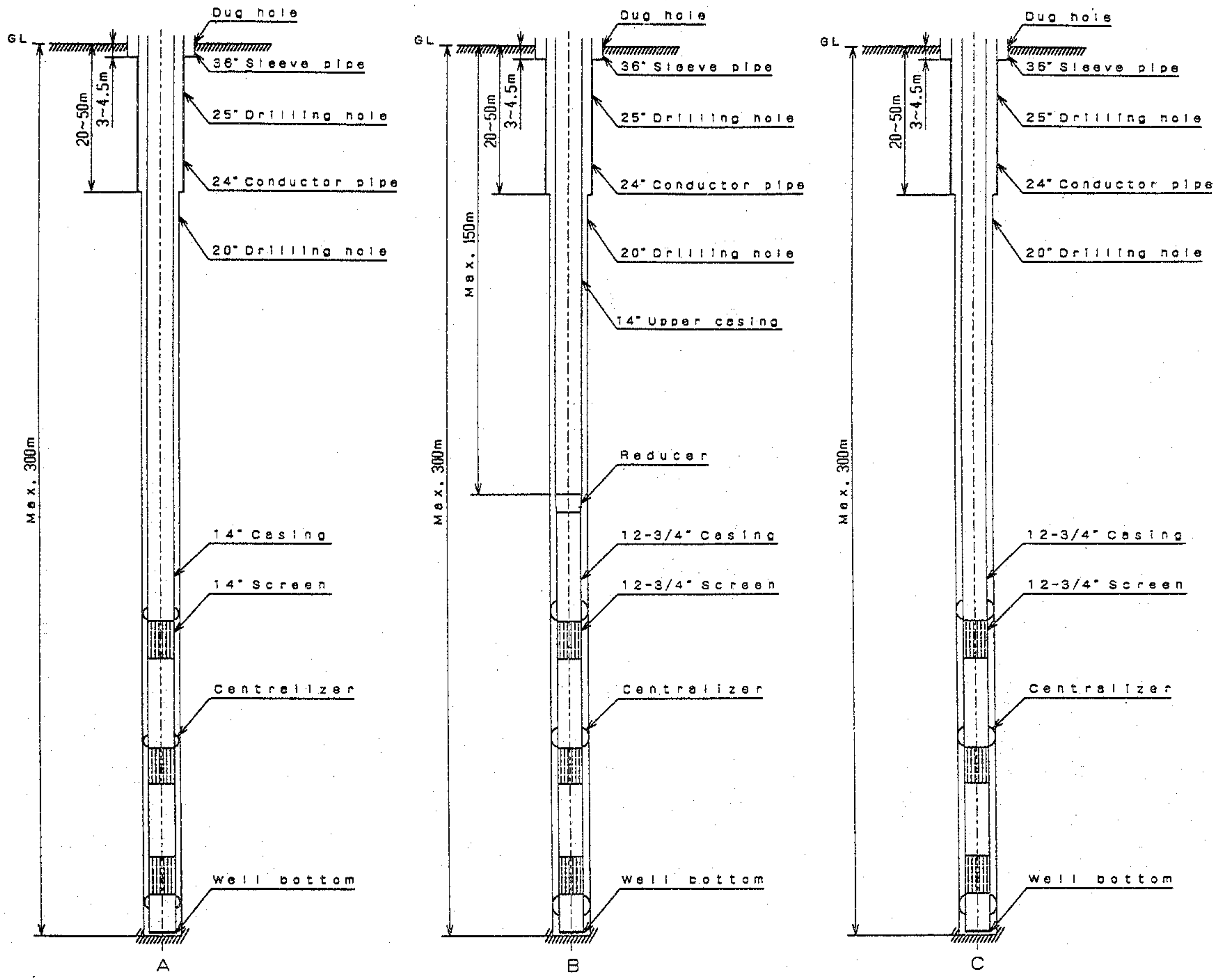


Fig. 4.2-1 Structure of the Borehole with 25"x20" Diameter

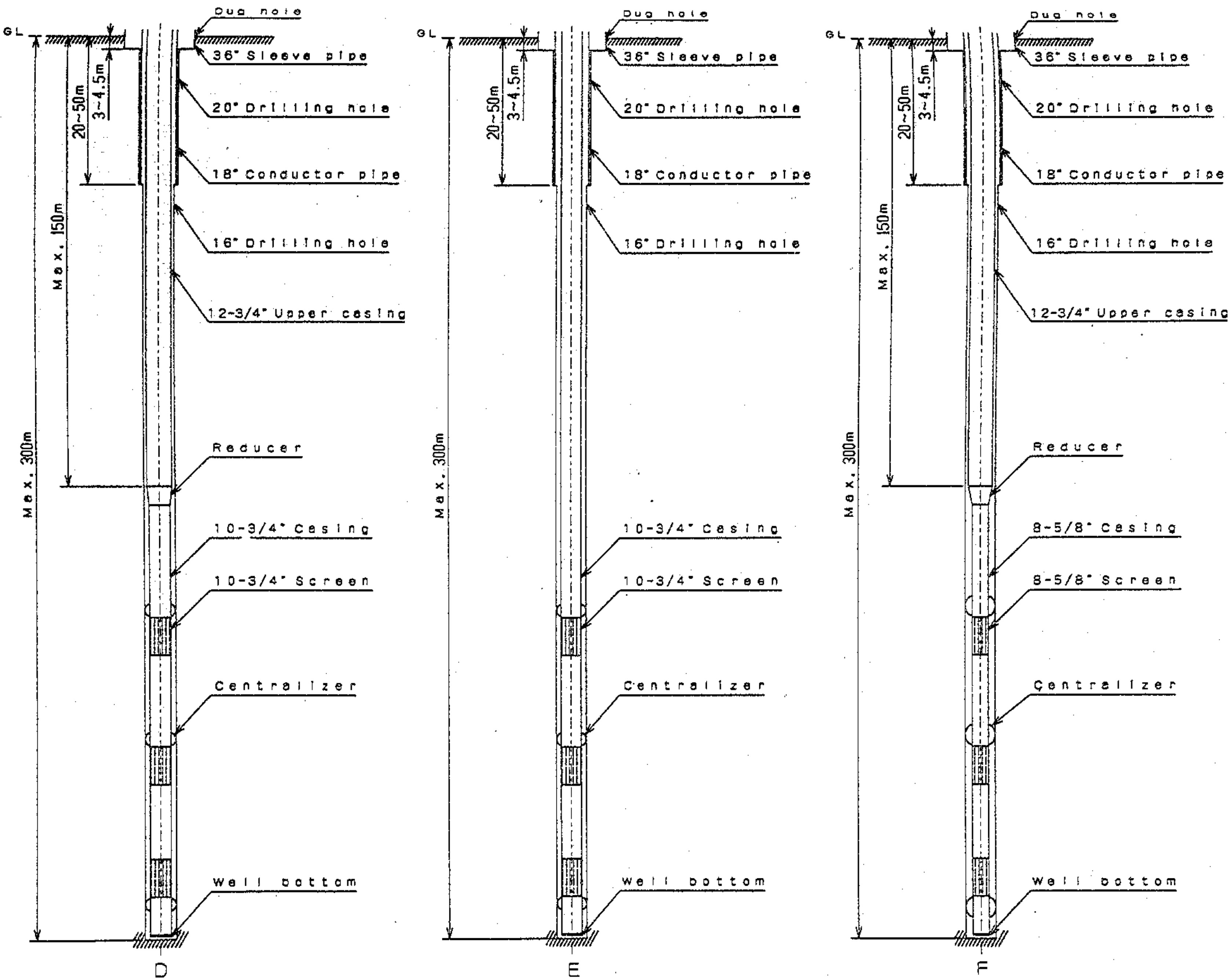


Fig. 4.2-2 Structure of the Borehole with 20"x16" Diameter

4.3 Equipment Plan

1) Selection of Major Equipment

Major equipment necessary for the Project were selected based on the previously described basic design plan.
The equipment necessary for the Project are as follows:

< Well Construction Equipment >

i) Percussion type drilling rigs and tools
ii) Open hole tools for provided rigs (for 3 units)
iii) crane trucks
iv) Pumping test equipment

< Geophysical Survey Equipment >

i) Well logging equipment
ii) Micro flow meters
iii) Seismic survey equipment
iv) Deep resistivity survey equipment
v) Signal averaging resistivity meters
vi) VLF EMR equipment

The type and capacity of the optimum drilling equipment is determined as follows.

(1) Percussion Type Drilling Rigs and Associated Tools

i) Type of Drilling Rig and Drilling Method

There are 2 methods of percussion drilling: the open hole method and the cased hole method. The cased hole method has been used in India. In this method, a hole is drilled with drive pipes to protect the hole wall. This method can prevent collapsion of the hole wall; however, pipe insertion and removal needs additional work which requires additional time, tools and cost.

The open hole method protects the hole wall by mud which is circulated to remove the cuttings. This method has been commonly used in Japan and it is possible to drill down to 500 m.

Fig. 4.3-1 summarizes the comparison of the drilling procedures and required tools of the 2 drilling methods. The cased hole drilling method needs one more work item of pipe insertion and requires more drilling tools in comparison to the open hole drilling method

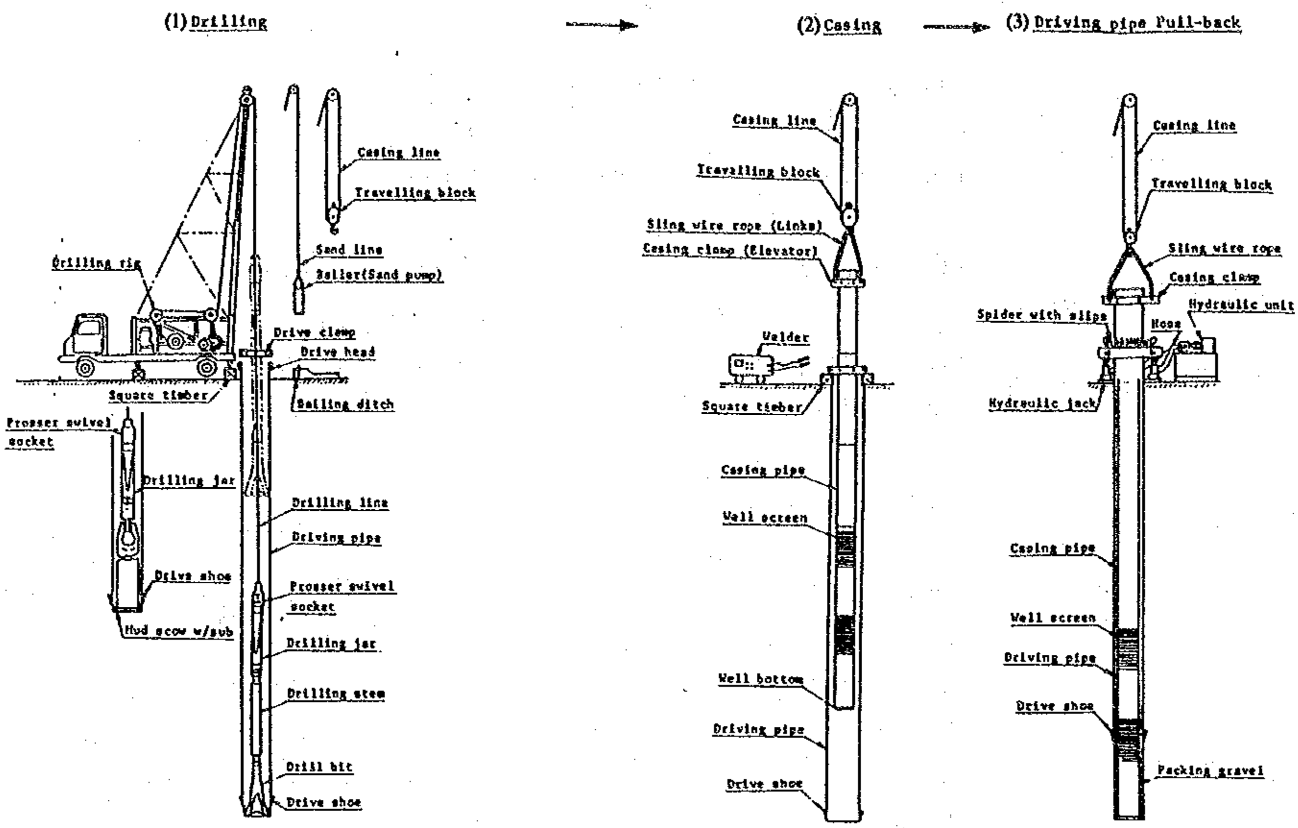
ii) Comparison of Construction Period.

According to the request of the Government of India, the tools for the cased hole drilling method were supplied accompanied by the 4 drilling machines in phase 1. In addition, a set of drilling tools for the open hole drilling method was also supplied for 1 drilling machine. The drilling record indicates that the drilling machine with the open hole drilling tools made a 300 m boring in 3 months while the drilling machines with the cased hole drilling tools could only bore 25-33 m in 3 months and 80 m in 11 months.

The cased hole drilling method is commonly practiced in India. The maximum depth of wells (150 m deep) drilled by CGWB in Jammu and Kashimir state in 1991 took 6 months. The 300 m well drilled by the open hole method by the drilling machine supplied in the phase 1 is the deepest well in recent records.

It would take 12 months (four times as long) to drill a 300 m deep well employing the cased holed drilling method vice the open hole method.

CASED HOLE METHOD



OPEN HOLE METHOD

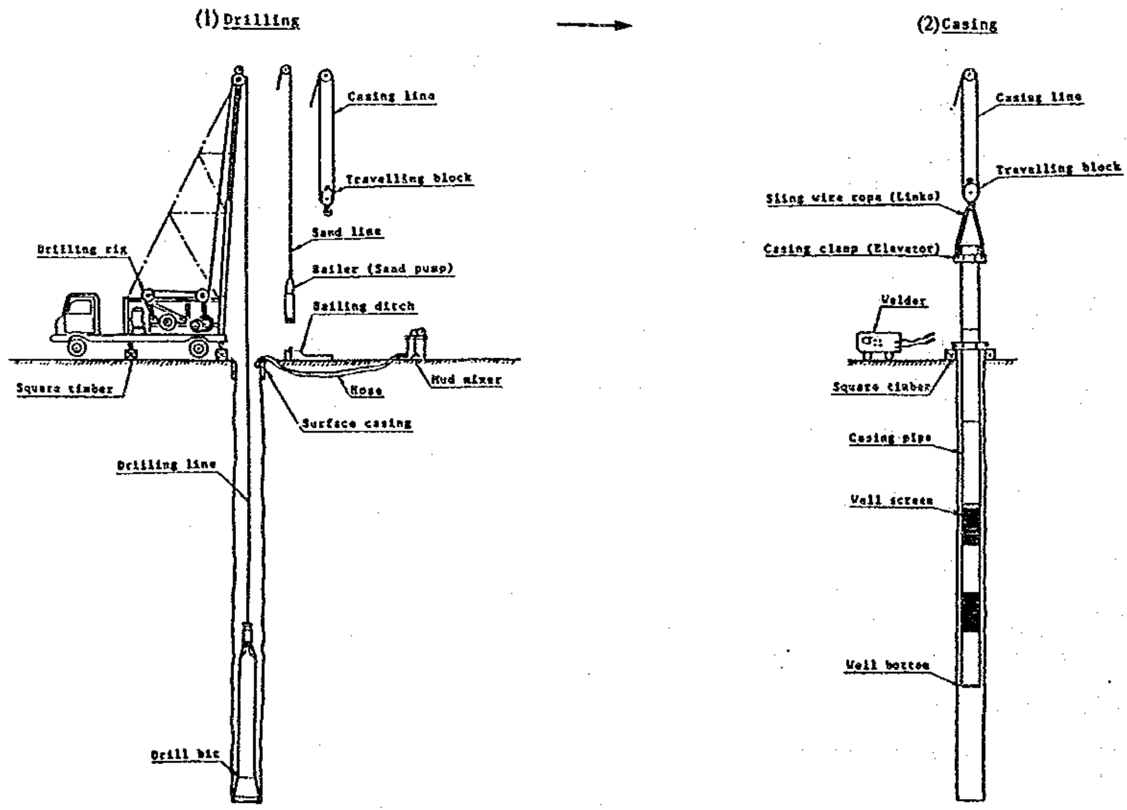


Fig. 4.3-1 Drilling Process and Tools

iii) Comparison of Drilling Costs

The cost of to drilling a 300 m deep well incurred by the open hole method is shown below:

1. Salaries and wages: (drilling team only)	Rp 152,000
2. Fuel:	Rp 91,000
3. Casings and screens:	Rp 316,000
4. Other materials:	Rp 60,000
Total	Rp 619,000

Based on the above records, the unit cost of each item is estimated as listed below:

1. Salaries and wages:	Rp 50,800/month/2 crews
2. Fuel:	Rp 30,000/month
3. Casings and screens:	Rp 1,053/m
4. Other materials:	Rp 20,000/100 m

The cost for CGBW to drill a cost of the well with 150 m deep well in Jammu and Kashimir state is estimated by the above unit cost as shown below:

1. Salaries and wages:	Rp 50,800 x 6 months	= Rp304,800
2. Fuel:	Rp 30,000 x 6 months	= Rp180,000
3. Casings and screens:	Rp 1,053 x 150m	= Rp157,950
4. Other materials:	Rp 20,000 x 1.5	= Rp 30,000
Total		= Rp672,750

Comparing the above estimated costs, it could be easily concluded that the well construction costs of the cased hole method is much higher than that of open hole method.

Although geological conditions and the type of casing and screen materials may influence the construction cost of a well, the construction costs of a well by the cased hole method is almost 2 times of that of the open hole method. The construction period of the cased hole method is estimated to be 4 times of that of the open