JAPAN INTERNATIONAL COOPERATION AGENCY(JICA)
THE DEPARTMENT OF IRRIGATION,
THE MINISTRY OF WATER RESOURCES
HIS MAJESTY'S GOVERNMENT OF NEPAL

THE MASTER PLAN STUDY ON THE TERAI GROUNDWATER RESOURCES EVALUATION AND DEVELOPMENT PROJECT FOR IRRIGATION

FINAL REPORT

VOLUME I : MAIN REPORT

MARCH, 1995

SANYU CONSULTANTS INC.

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PREFACE

In response to a request from His Majesty's Government of Nepal, the Government of Japan decided to conduct a Master Plan Study on the Terai Groundwater Resources Evaluation and Development Project for Irrigation and entrusted the study to Japan International Cooperation Agency (JICA).

JICA sent a study team headed by Mr. Mitsuru YOSHIKAWA, Sanyu Consultants Inc., to Nepal six times between November, 1991 and December, 1995.

The team held discussions with the officials concerned of His Majesty's Government of Nepal, 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 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 His Majesty's Government of Nepal for their close cooperation extended to the team.

March, 1995

Kimio Fujita
President
Japan International Cooperation Agency

March, 1995

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

Letter of Transmittal

Dear Sir,

We are pleased to submit the master plan report on the Terai Groundwater Resources Evaluation and Development Project for Irrigation. The report is compiled to reflect the advice and suggestions of the authorities concerned of the Government of Japan and your Agency as well as the formulation of the above mentioned project. Also comments made by the Department of Irrigation of His Majesty's Government of Nepal during the discussions which were held in Kathmandu, are reflected in the report.

The study had been carried out in the three districts of Jhapa, Mahottari, and Banke (including a part of Bardiya). Based on this study, the groundwater potential is considered to be sufficient for deep tubewell irrigation. It has also been confirmed under the study that a deep tubewell irrigation plan is economically feasible.

In regard to Jhapa District, immediate implementation of project for 30 irrigation units (4,500 ha) is recommended for the purpose of demonstration and corroboration of DTW irrigation in the Eastern Terai. As the other two districts require detailed groundwater resource evaluation, further surveys and studies on a feasibility study level should be conducted.

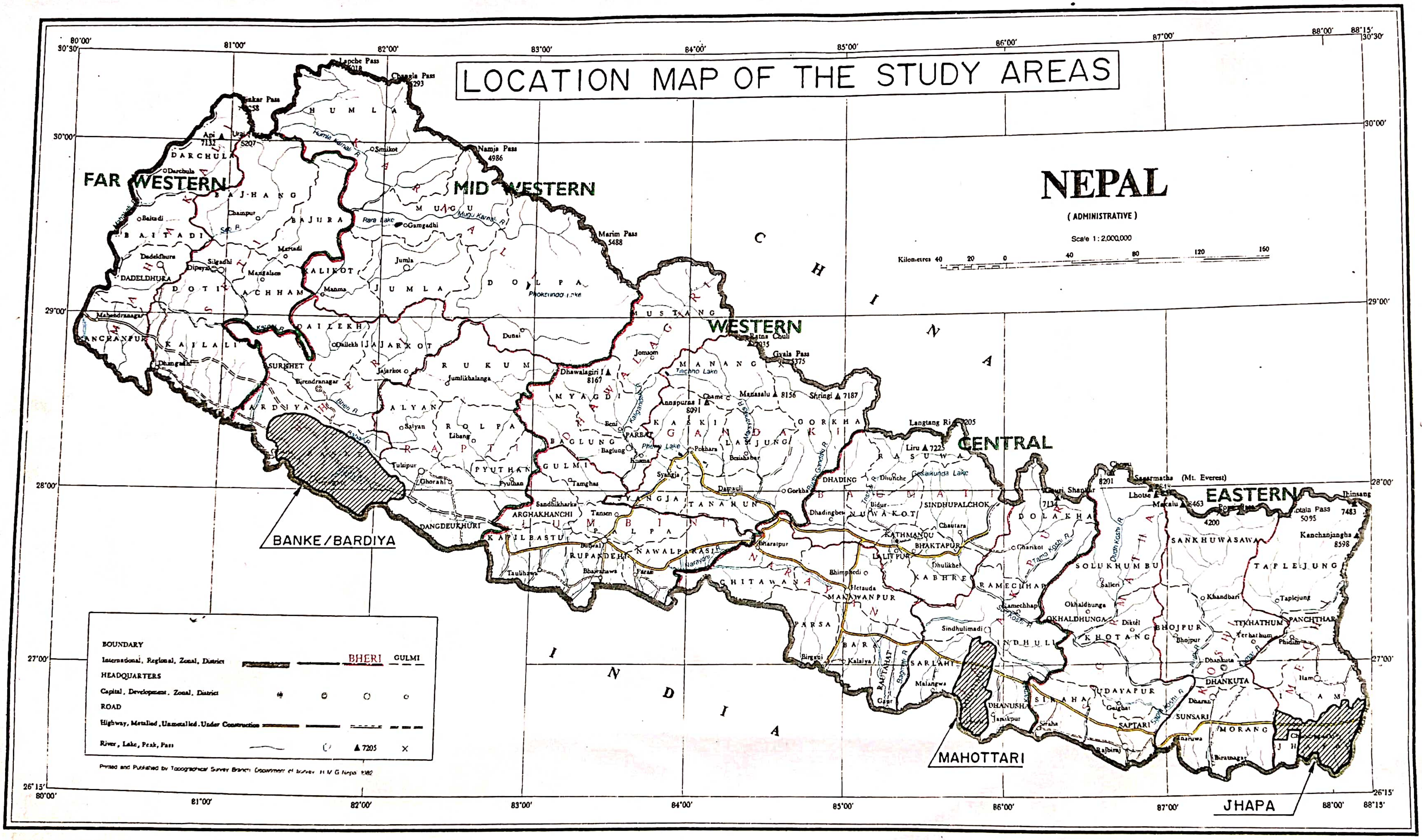
We wish to take this opportunity to express our sincere gratitude to your Agency, the Ministry of Foreign Affairs, the Ministry of Agriculture, Forestry and Fisheries. We also wish to express our deep gratitude to the Department of Irrigation and other authorities concerned of His Majesty's Government of Nepal for the close cooperation and assistance extended to us during our investigation and study.

Very truly yours,

吉川 満

Mitsuru YOSHIKAWA
Team Leader
Master Plan Study on the
Terai Groundwater Resources Evaluation
and Development Project for Irrigation

Second Edition



Summary

Summary

1. Background

The food self-sufficiency of the Kingdom of Nepal has been declined as a result of the stagnating agricultural production and population growth. In order to address this situation, one of the major goals of the government's National Development Plan is to increase agricultural production, mainly through the expansion of irrigated agriculture.

The Department of Irrigation of the Ministry of Water Resources, which is responsible for irrigation development in Nepal, is operating a "Deep Tubewell Irrigation Project" to develop the abundant deep-seated groundwater resources in the Terai as one of the water resources for irrigation. As a series of projects, the Department of Irrigation requested, through the Government of Nepal, to the Government of Japan to conduct the "Master Plan Study on Terai Groundwater Resources Evaluation and Development Project for Irrigation." In response to this request, the Government of Japan implemented the Study through the Japan International Cooperation Agency.

2. The Study

The Study covered the three districts of Jhapa, Mahottari, and Banke (includes a part of Bardiya), which are located in the east, central, and western parts of the Terai. The Terai is located in the southern part of Nepal forming the granary of nation. The major objectives of this Study include "selection of areas irrigable by deep tubewell," "evaluation of groundwater resources," and "establishment of a master plan related to deep tubewell irrigation." The Study Team dispatched by JICA conducted this Study over a 36 month period, from October 1991 to July 1994, together with counterpart personnel from the Department of Irrigation.

3. The Study Areas

The Study Team selected and conducted the necessary studies in the southeastern part of Jhapa District (command area 17,000 ha); in two irrigable areas in the southern (4,000 ha) and northern part (3,000 ha) of Mahottari District (total 7,000 ha); and in the southern part (8,000 ha) of Banke District.

4. The Scope of Study

This Study covers the fields related to deep tubewell irrigation, which include the socio-economy, meteorology, hydrology, topography, geology, hydrogeology, groundwater, agri-

culture, and irrigation in the Study Areas and adjacent areas. Specifically, intensive field studies were conducted for the Study Areas in Jhapa District as the "representative area." This Study consists of meteorological and hydrological observations, drilling and testing of exploratory wells (total of 20 wells, maximum depth 300 m), groundwater observation, and agricultural and irrigation studies (includes topographical survey of the sample area).

Based on the results of the above Study, the Study Team worked out an "evaluation of groundwater resources," "formulation of master plan for deep tubewell irrigation," " formulation of guideline for deep tubewell irrigation," as well as the formulation of a "database" related to meteorology, hydrology and hydrogeology; and the formulation of a plan for a "monitoring network operation."

5. Nepal in Overview

(1) Natural Environment

Nepal situates at the center of the Southern slope of Himalayan Mountains and is a landlocked country surrounded by China to the north and India to the east, west, and south. Nepal occupies an area of approximately 147,000 km2. The topography and geology can be classified into five zones, which stretch in parallel to the Himalayan Arc. These zones consists of, from south to north, alluvial and diluvial sedimentary layers in the Terai which is the granary of Nepal; the Churia Hills which consist of sedimentary layers up to the Pleistocene; mountainous areas of Precambrian rock; the Himalayas; and the Himalayan hinterland.

The wide range of meteorological conditions from the tropical type in the Terai to the alpine type in the mountain areas can be observed in Nepal. The extreme precipitation ranges from 6,000 mm to 250 mm annually depending on the area. Mean precipitation is in the range of 1,500 mm to 2,500 mm, and 80% of the precipitation is concentrated in the monsoon period between June and September. All of the rivers flowing through Nepal are tributaries of the Ganges River. The rivers that originate in the Himalayas flow throughout a year, and other rivers flow seasonally through the monsoon period. Meteorological and hydrological observations in Nepal are conducted by the Department of Meteorology and Hydrology of the Ministry of Water Resources, and observation records are published on an irregular basis.

(2) Socio-economy

The population of Nepal as of 1991 is 18.49 million. The annual population growth is 2.1%, and the population density is 126 per km2.

Agriculture is the predominant industry in Nepal occupying 49% of the gross domestic product in 1991/92 and 81% of the economically active population. The gross national product in 1991/92 was 126.2 billion Rs (approximately US$3 billion) and US $180 per capita.

(3) Agriculture

Major agricultural products in Nepal consists of rice, maize, wheat, barley, millet and pulses. Approximately 2.9 million ha were cultivated in 1992/93 and 4.9 million tons of grain and 330,000 tons of other cash crops were produced. Until the middle of the 1980s Nepal was a food exporting country; however, the rate of food self-sufficiency has dropped to 85% to 90% because of a demand increase caused by population growth in recent years. The gross farmland area in Nepal as of 1989/90 is approximately 3 million ha, of which 42% (1.2 million ha) is located in the Terai. The irrigable area reaches to 2.2 million ha nationwide, but the net irrigated area at present is 940,000 ha, of which 65% of the area (610,000 ha) is located in the Terai.

(4) Political and Administrative System

Nepal's political system is a constitutional monarchy. The country's constitution was issued in 1962, and the partyless Panchayat (political council) system was established. The king dissolved the Panchayat System in 1990, and a new constitution based on a multi-party system was created in 1991. Shortly after a new government was elected through the general election. His Majesty's Government of Nepal consists of 21 ministries and agencies under the Council of the Ministers which is chaired by the prime minister. Nepal is divided into five development regions, 14 development zones, and 75 districts as development and administrative units. The central ministries and agencies in charge of development projects have offices in each region for supervising these projects.

Among the government agencies, the Department of Irrigation of the Ministry of Water Resources is responsible for the planning and execution of new irrigation projects as well as the operation and maintenance of completed large-scale projects. The Department of Irrigation consists of central bureaus which include Irrigation Management, Large & Middle-Scale Irrigation Projects, Groundwater Utilization, Planning and River Training, as well as a Project Management Department for each national project and a Regional Irrigation Directorate which supervise the District Irrigation Offices in the five development regions. The Department of Agriculture of the Ministry of Agriculture is responsible for agricultural extension programs. The Agricultural Development Bank of Nepal offers financial assistance to the agricultural sector. One example of this financial assistance is the loans provided for the Shallow Well Irrigation Program, which covered

61,000 ha by 1988. The Agricultural Inputs Corporation is responsible for the import and distribution of chemical fertilizers, improved seeds, agro-chemicals, and farm machinery.

(5) National Development Plans

Seven plans were implemented under the Panchayat System beginning with the First National Development Plan in 1956. Having evaluated and reviewed the existing results of previous plans, the new government has established the "Eighth National Development Plan (1992-1997)." The major targets of this plan include the sustainable economic growth, the alleviation of poverty and the reduction of regional imbalances, while priority measures include the intensification and diversification of agriculture, the energy development, the development of rural infrastructures, the employment generation and human resources development, and the regulation of population growth.

His Majesty's Government of Nepal formulated a "Program for the Fulfillment of Basic Needs (1985-2000)" in order to satisfy basic needs in six sectors, including food, clothing, housing, health, education, and security by the year 2000. The food production plan, which is related to the most important basic need, outlines the major food production target at 6.6 million tons (9.8 million tons unprocessed) based on the minimum requirement of 2,250 calories/capita/day and an estimated population of 23 million by the year 2000. This target represents a two-fold increase of production in 4.8 million ton at 1984/85, and an annual average increase rate of production at 6.5% must be achieve to accomplish this goal. Irrigation facilities, improved seed, and improved agricultural practices are necessary in order to achieve this target, and irrigated farmland must be increased to 1.25 million ha.

Upon the establishment of the Program for the Fulfillment of Basic Needs, the Department of Irrigation established in 1990 the "Master Plan for Irrigation Development in Nepal" with the cooperation of the United Nations and the World Bank. A major target of this plan includes the expansion of irrigable areas to 1.25 million ha by the year 2000 based on government projects, which means irrigating an additional 60,000 ha of farmland every year. Other major measures include the management improvement of existing irrigation projects; groundwater irrigation in Terai; medium- and small-scale surface water irrigation in Terai; small-scale irrigation in hilly areas; and large-scale surface water irrigation in Terai.

6. The Study Areas

(1) Irrigable Areas by Deep Tubewell

The objective of the "Phase I" study in the Master Plan Study is to select areas irrigable by deep tubewell in the target districts and a representative area with the highest potential among others.

Through a review of the existing data related meteorology, hydrology, topography, hydrogeology, the agricultural society, agriculture, and the social infrastructure, areas irrigable by deep tubewell were selected after field inspection and discussions with Department of Irrigation. These areas include the southeast part of Jhapa District (net command area of 17,000 ha), two irrigable areas in the northern and southern part of Mahottari District (total of 7,000 ha), and the southern part (8,000 ha) of Banke District (include a part of Bardiya District). The representative area, which is the Study Area for the "Phase II" study, is selected in the southeast part of Jhapa District.

(2) Natural Environment

Jhapa District situates in the southeastern edge of Nepal, facing India to the south and to the east. The total area is 1,600 km2, and the Kankai River flows toward south through the central part of the district. The majority of the district is located on the alluvial Terai (altitude 80 mags to 120 mags), while a portion is also located in the Churia Hills in the north and the Terrace consisting of the central forest zone. The geology of Jhapa District is divided into an alluvium layer, terrace deposits, and the Churia Formation. The alluvium is composed of sand and gravel beds in the north, and alternating of beds of sand, gravel, silt, and clay in the plain area. The thickness of the alluvium layer in the northern part of the Terrace may be 150 m or more and the Churia Formation is deemed to underlie it. The Gangetic alluvium, which extends south of the terrace, has abundant gravel beds with single thicknesses of 50 m and a total layer thickness of 300 m or more. The thickness of the terrace deposit is approximately 10 m and consists of sand, silt, and clay. Although the Churia Formation is not exposed at the surface, the results of exploratory wells show that the Upper Churia Formation consists of clay, silt, sand, and gravel. Annual precipitation in Jhapa District is highest in the Terai at 1,600 mm to 3,600 mm, with an average of approximately 2,500 mm. Precipitation in July during the monsoon period exceeds 700 mm. The mean average temperature is 15°C to 29°C, and the average maximum and minimum temperatures are 38°C and 5°C respectively. The major rivers in this district include Ratuwa Khola, Kamal, Kankai, Biring, and Mechi. Kankai and Mechi are the largest rivers, originating in the mountain areas. A runoff discharge station is located at Mainachuri (basin area 1,180 km2) on the Kankai River. According to the runoff discharge analysis over a 14 year period, the runoff discharge is 2.79 billion m3, as opposed to an annual precipitation of 3.75 billion m3, which means that the runoff coefficient is 74%. The runoff coefficient for the Deoniya and Budhajhora rivers, as conducted by the Study, are 70% and 89% respectively. Both rivers are seasonal in nature and more than 90% of the runoff discharge is observed during the monsoon season.

The majority of Mahottari District is located on the Terai with an area of approximately 1,000 km2. Several rivers flow to the south-southeast on a seasonal basis. The altitude of this district is among the lowest in Nepal, with the altitude at the southern edge below 60 mamsl. The geology of the plain in this district consists of terrace deposits and alluvial layers. The Churia Formation is distributed in the northern hills, and the terrace deposits consist of clay, silt and gravel, but its thickness is unknown. According the deep tubewell record, the Southern Terai alluvium consists of alternating beds of sand and gravel where clay and silt are dominant. The annual precipitation of this district ranges from 600 mm to 2,600 mm, with an annual average of 1,310 mm. The monthly average temperature is 15°C to 30°C, and the average maximum and minimum temperatures are 39°C and 5°C respectively. The rivers flowing through this district include Bighi, Ratu, Janpha, Marha, and Hardi Nadi. Although some rivers flow throughout the year fed by groundwater, the rivers are generally seasonal in nature. Runoff discharge observation has not been conducted for these rivers.

The Study Area in Banke District, including the east bank area of Babai River in Bardiya District, is approximately 3,200 km2, which is the largest among three districts. One of the largest rivers, Rapti flows through the central part of the district. The minimum altitude of the area is 130 mamsl, but the overall area is located at higher altitudes. The geology of Banke District consists of the alluvium, terrace deposits and the Churia Formation. The alluvium layer can be divided into the Northern, Central, and Southern Ganges. The Northern Alluvium has a thickness of more than 200 m and consists of fan gravel and clay beds. The thickness of the Central Alluvium is approximately 30 m and the lower part is possibly a Churia Formation. Gangetic Alluvium has a record of drilling beyond 300 m and consists of sand and gravel where clay and silt are dominant. The Churia Formation consists of semi-consolidated shale, sandstone and conglomerate in the hills east of Rapti; however, silt and sandstone which belong to the lower Churia Formation are distributed north of Babai River. The annual precipitation in this district ranges from 500 mm to 2,600 mm, with an average of 1,386 mm. The monthly average temperature is 15°C to 30°C, and the average maximum and minimum temperatures are 41°C and 3°C respectively. The rivers flowing through this district include the Rapti, Manda, Dundawa Nala, Kirin, and Babai. Rapti and Babai rivers originate in the mountain area and flow throughout the year. Regular runoff discharge observations have been conducted in both rivers.

(3) Socio-Economy

The Terai occupies 14% of the land area of Nepal and 42% of the farmland. The plain consists of five development regions, 20 districts, and five industrial districts. The Terai holds 47% of the nation's population and 45% of the number of households. The industries located in this plain include agriculture, agricultural product processing, cement, and shoe manufacturing.

Jhapa District consists of nine administrative sectors, two towns and 49 villages. Its total area is 156,500 ha with farmland of 105,121 ha. The study area is 29,700 ha and includes 16 villages. The population of this district is 594,000 (1991), and the population density is 379 person/km2. The number of households is 111,000 and the average household consists of 5.4 persons. Sixty-six percent of the economically active population are engaged in agriculture. This district is noted as a production area for rice and tea, and other industries include agricultural product processing.

Mahottari District consists of nine administrative sectors, one town, and 77 villages. The total area is 101,000 ha with a farmland of 67,800 ha. The study area is 9,800 ha (2 residential areas) and includes 17 villages. The population of this district is 440,000 (1991), and the population density is 434 person/km2. The number of households is 80,400 and the average household consists of 5.5 persons. Seventy-nine percent of the economically active population are engaged in agriculture, and industries include agriculture and agricultural product processing.

Banke District consists of nine administrative sectors, one town, and 46 villages. The total area is 226,000 ha with a farmland of 49,000 ha. The study area is 12,100 ha. The population of this district is 286,000 (1991), and the population density is 126 person/km2. The number of households is 49,100 and the average household consists of 5.8 persons. Sixty-eight percent of the economically active population are engaged in agriculture, and industries include agriculture and forestry.

(4) Agriculture and Irrigation

The Terai consists of five types of soil including sandy loam/clay loam, silt loam/clay loam, loam/sandy loam/silt loam and sandy loam/loam. Major grain products (1992/93) in the Terai include rice at 1.84 million tons (71% of national total), wheat 430,000 tons (57%) and maize 330,000 tons (25%). More than 30% of the livestock is raised in this area. Forty percent (610,000 ha) of the 1.24 million ha of farmland in the Terai is irrigated which represents 65% of the irrigated farmland nationwide.

The farmland of Jhapa District is 105,000 ha and the irrigated farmland is 47,900 ha. The cropping intensity is 151%. The number of farm households including landless farmers (1991/92) is 74,700 and the average farms size is 1.41 ha/farm. Farm households less than one hectare occupy 52% of the total number of farms. There are approximately 12,000 farm households in the Study Area. The dominant cropping patterns in this district are "monsoon paddy-wheat" or "spring paddy-monsoon paddy-wheat" for irrigated farmland. For rainfed farmland, the dominant crops are "monsoon paddy-fallow" or "monsoon paddy-pulses/oilseed crops" or "maize-pulses/oilseed crops/millet". Monsoon paddy-fallow is most dominant in the Study Area and the cropping intensity is only 126%. Major products (1992/93) in this district include paddy at 203,000 tons (7.8% of national total), maize 18,600 tons (1.4%), wheat 13,100 tons (1.7%), potatoes 13,000 tons (1.8%), and tobacco 730 tons (12.1%). The production for paddy is the highest among the 75 districts nationwide. Paddy is marketed via farm households-brokers-wholesalers-rice polishers-retailers-consumers. Vegetables are occasionally sold directly to retailers or consumers from farm households. There is a district agricultural development office, six agricultural service centers, two agricultural research stations, one branch of the Agricultural Development Bank of Nepal, as agriculture supporting agencies including two branches of the Agricultural Inputs Corporation, and 27 cooperative societies as farmer organizations.

The farmland in Mahottari District is 63,800 ha and the irrigated farmland is 17,300 ha. The cropping intensity is 171%. The number of farm household including landless farmers (1991/92) is 58,600 and the average farms size is 1.09 ha/farm. Farm households less than one hectare occupy 60% of the total number of farms. There are approximately 6,400 farm households in the Study Area. The dominant cropping patterns in this district are "spring paddy-monsoon paddy-wheat" or "spring paddy-monsoon paddy-maize" for irrigated farmland. For rainfed farmland, "monsoon paddy-fallow" or "monsoon paddy-wheat-fallow" are the dominant patterns. "Monsoon paddy-fallow" dominates in the Study Area.
Major products (1992/93) in this district include paddy at 52,000 tons (2.0% of national total), maize 8,200 tons (0.6%), wheat 26,500 tons (3.5%), tobacco 1,200 tons (19.1%), and pulses 9,500 tons (4.7%). The marketing system of agricultural products is similar to Jhapa District. There are six agricultural service centers under the supervision of the Regional Agriculture Directorate in Kathmandu, two agricultural research stations, one branch of the Agricultural Development Bank of Nepal, one branch of the Agricultural Inputs Corporation and 31 cooperative societies.

The farmland in the Banke District is 49,100 ha and the irrigated farmland is 3,300 ha. The ratio of irrigation area is the lowest compared with the other two districts, and the cropping intensity is 142%. The number of farm household including landless farmers (1991/92) is 35,900 and the average farms size is 1.37 ha/farm. Farm households less than one hectare occupy 50% of the total number of farms. There are approximately 5,900 farm households in the Study Area. The dominant cropping patterns in this district are "monsoon paddy-fallow" or "maize-millet-mustard" or "pigeon peas".
Major products (1992/93) in this district include paddy at 36,000 tons (1.4 % of national total), maize 21,000 tons (1.6%), wheat 10,400 tons (1.4%), and potatoes 4,600 tons (0.6%). The marketing of agricultural products is basically similar to the other two districts. There are a District Agriculture Office, four agricultural service centers, two agricultural research stations, one branch of the Agricultural Development Bank of Nepal, as agriculture supporting agencies including one branch of the Agricultural Inputs Corporation and 17 cooperative societies.

(5) Social Infrastructure

Each area is accessible by air from Kathmandu. It is an overnight journey to the Jhapa and Banke districts using the highway which runs east and west through the Terai , and it takes one day to Mahottari District. All-weather roads in the three districts are very poor, and the majority of the roads are mud which are impossible for vehicle traffic during the rainy season.

The power transmission network in Nepal consists of a 132 KV, 33 KV, 11 KV, and 220V power transmission lines.

Jhapa District has 132 KV and 33 KV transmission lines which run along the E-W Highway and power is transformed to 11 KV at Birtamod. It is possible to use power from the power transmission line near the highway. There is a future plan to extend three 11 KV lines to areas south of the highway.

The power in Mahottari District is transformed from 132 KV and 33 KV lines running along the highway at Jaleswar, and the power is used only in the adjacent areas. Construction to expand the system is currently underway in the southern area, and power will be distributed to the overall southern area in the future.

The Kohalpur and Nepalganj substations are located in Banke District, and a 11 KV line extends to the east; this line will be further extended to the Western Bardiya District in the future.

Wireless telephone relay stations in every district in Nepal are connected with Kathmandu. There are 775 telephone lines in Jhapa District,165 in Mahottari District, and 1,310 in Banke District.

7. Evaluation of Groundwater Resources

In the Phase I Study, the clarification of hydrogeological and groundwater conditions in three districts was made by mean of review of the existing groundwater studies and deep tubewell records; and then an average yield of standard deep tubewell by each district were evaluated as shown below:
The definition of standard deep tubewell is to be 150 m depth, 250 mm casing diameter, 15 m drawdown, 20 % screen opening, 3 cm/sec critical flow velocity and 30 m screen length.

Areas		;	Average Yield (1/s)
Jhapa		;	91
Mahottari	(south)	;	66
	(north)	;	97
Banke		;	110

The average yield in Jhapa, 91 l/s was reevaluated to be 120 l/s based upon the pumping test made on the explanatory and existing deep tubewell conducted during the Phase II Study.

As per the representative area selected in Jhapa District, a dynamic mathematical model was constructed for simulation studies of groundwater resource evaluation. The model covered a basin area of 719 km2 inclusive of the representative area and adjacent; and characterized in the results of detailed surveys in topography, meteorology, hydrology, hydrogeology and so forth. Applying the constructed model, the groundwater resource was evaluated through simulation studies for a 14-year period in the current and future conditions.
As the results of simulation studies, the current mean hydrologic balance in the study basin is shown as 1,903 million m3/annum (MCM/a) (100%) of rainfall, 555 MCM/a (29%) of evapo-transpiration, 3,790 MCM/a of surface inflow (inclusive of inflow from the Kankai River), 4,874 MCM/a of surface outflow, 1,048 MCM/a (57%) of a difference between in- and out-flows, 369 MCM/a (19%) of groundwater recharge; and 3 MCM/a of groundwater draft. A total expenditure reaches to 105% against the total revenue (rainfall). This is caused by the difference of total storage in the basin during a 14-year period. Focusing on the balance in the groundwater system, out of 369 MCM/a of recharge, 3 MCM/a is only pumped up for use, and the remained 360 MCM/a flows out of the basin.

In case that the irrigation (with peak water requirement at 0.8 l/s/ha) is conducted in a full-scale (17,000 ha), the total water requirement in the design year is reached at 131 MCM/a or 36% of the mean groundwater recharge of the basin. In accordance with simulation studies in case of a full-scale development for 14-year period, the groundwater heads at every aquifers never reach to the critical level set forth at 30m below the ground surface. Another case of simulation shows that a groundwater draft at 206 MCM/a or 57% of the mean groundwater recharge or 1.35 times of the designed water requirement is necessary to reach at the critical heads. As the simulation studies concluded, the groundwater resource in the study basin in Jhapa is deemed to be some 200 MCM/a; and 35% surplus be left even in case that the full-scale development of DTW irrigation has been spread out.

Any simulation study has never been constructed for Mahottari and Banke. However, the groundwater potential in Mahottari is deemed to be same level in Jhapa since there is not so much difference between both districts in the groundwater environment such as meteorology, hydrology hydrogeology and so forth.
A large-scale groundwater development in Banke district seems to be limited only at the southern strip as the rainfall and river density are far less than in other districts and the Gangetic aquifers are spread out only at the strip.

8. Master Plan for Deep Tubewell Irrigation Development

(1) Agricultural Development Plan

The basic strategies of the Agricultural Development Plan include a crop diversification, expansion of productivity and an improvement in farm incomes. The scheduled cropping pattern and intensity in the study areas are summarized as below:

District	Jhapa	Mahottari	Banke
Cropping Pattern			
(without project)	Wheat • Maize • Monsoon paddy	Pulses • Wheat • Monsoon paddy	Mustard • Pulses • Maize • Wheat • Monsoon paddy
(with project)	Wheat • Maize • Spring paddy • Monsoon paddy	Onions • Potatoes • Wheat Spring Paddy • Monsoon paddy	Mustard • Pulses • Potatoes • Maize • Monsoon paddy
Cropping Intensity			
(without project)	126%	140%	140%
(with project)	200%	200%	200%

(2) Irrigation Plan

Based on conditions in each district, including precipitation, soils, and cropping patterns, the peak irrigation water requirement (facility design discharge) for each district is determined as follows: Jhapa 0.8 l/s/ha; Mahottari 1.0 l/s/ha; and Banke 0.7 l/s/ha. The annual water requirement for the design year on the irrigation area in each district is as follows: Jhapa 131 MCM; Mahottari 72 MCM; and Banke 66 MCM.

(3) Water Sources Plan

The number of irrigation units which cover the average command area of deep tubewell and the overall study area, determined by the average yield of a standard deep tubewell (depth 130-150 m; diameter 250 mm; water drawdown 20 m) are summarized as follows;

District	Jhapa	Mahottari (south)	Mahottari (north)	Banke
Deep tubewell yield (l/s)	120	66	97	110
Average command area (ha)	150	66	97	157
Number of irrigation units	113	31	61	51

(4) Facility Plan

The irrigation unit will be required to have following facilities: water source facility (deep tubewell, pump equipment, power transmission line within the unit), distribution system (pipeline system, valve etc.), on-farm canal (command area 4-6 ha), drainage system (unit discharge 4 l/s/ha, density 40 m/ha), village road (width 6 m, density 4-5 m/ha), and connecting road (width 3 m, density 4-5 m/ha).

(5) Project Plan

Based on the above facility plan, the project plan is summarized as follows:

Items	Jhapa	Mahottari	Banke
Irrigable area (ha)	17,000	7,000	8,000
Beneficial Farm Household	12,080	6,420	5,850
Beneficial Population	64,750	35,180	33,930
Number of deep tubewells	113	92	51
Pump stations			
• Number of pumps	113	92	51
• Total length of power transmission line (km)	170	70	80
Pipeline system			
• Total length (km)	680	300	320
• Number of valves	4,070	1,750	1,940
Total length of on-farm canals (km)	1,240	560	610
Total length of drainage system (km)	770	330	360
Total length of road (km)	170	74	77
Number of buildings	2	2	2

The implementation schedule for this project is planned as follows:

Items	Jhapa	Mahottari	Banke
Overall schedule (year)	10	9	8
Project preparation (year)	3	3	3
Land acquisition (year)	5	4	4
Road construction (year)	4	4	4
Facility construction (year)	6	5	4

(6) Organization, Operation and Maintenance System

The project executing agency is to be the Department of Irrigation, and the project is managed by a project office established in each area. The Project Office consists of the Agriculture, Farmers' Organization, Engineering, Operation and Maintenance, and Administrative Divisions. An agricultural subcenter is established under the Agricultural Division, which is in charge of the extension, the training and communication with farmers.

Throughout the project implementation period, the Farmer's Organization Division of the Project Office will provide guidance of establishment of and management of the Water User's Group which consists of every beneficial farmers within an irrigation unit and the Water User's Association which is composed of the Water User's Groups within the project area. During the initial period of project implementation, the operation and maintenance of pumps is the responsibility of the Project Office, but this will gradually be transferred to the Water Users' Association. At the completion of the project, the functions of each division, including the Agriculture, Farmers' Organization, and the Operation and Maintenance Divisions, will be transferred to the Water Users' Association. All functions (excluding the Engineering Division) including operation and maintenance, extension services, purchase of inputs, distribution, and marketing of agricultural products will be transferred to the Water Users' Association.

(7) Environmental Consideration

The most important environmental impact by this project is the existing groundwater right. According to the simulation in Jhapa District, a maximum 20 m groundwater drawdown may occur. The groundwater drawdown will affect the yield of domestic shallow well and the existing deep tubewells for town water supply. Countermeasures such as converting water sources will, therefore, be necessary during the execution of the project.

The potential for other environmental impacts related to groundwater development, including water pollution and land subsidence, is considered to be small.

(8) Project Cost

Based on the unit prices employed in recent construction works by DOI, the total project cost in each area, including construction cost, equipment cost, engineering and administrative fees, contingencies and price escalation are estimated as follows:

Jhapa	:	Rs 2.889 billion	(US$57.8 million, US$3,400/ha)
Mahottari	:	Rs 1.584 billion	(US$31.7 million, US$4,500/ha)
Banke	:	Rs 1.510 billion	(US$30.2 million, US$3,800/ha)

(9) Project Evaluation

The financial and economic costs for construction and annual operation and maintenance in each area are estimated as follows:

(unit: million Rs)

		Construction cost		Annual operation and maintenance cost	
		Financial cost	Economic cost	Financial cost	Economic cost
Jhapa Area	:	2,889	1,932	39	36
Mahottari Area	:	1,584	1,098	21	19
Banke Area	:	1,510	1,019	16	15

The incremental agricultural benefits (unit: million RS/year) are evaluated as follows: Jhapa Area 585; Mahottari Area 203; and Banke Area 210.

As a result of a comparison between the above construction cost and incremental agricultural production benefits, the economic internal rate of return in each area is evaluated as follows; and projects in each area are considered to be economically feasible.

		Economic Internal Rate of Return (%)
Jhapa Area	:	21.0
Mahottari Area	:	13.5
Banke Area	:	14.3

As a result of financial analysis of a farm household, disposable income of the average farm household in each area without and with the project are as follows:

		Farm Size (ha)	Disposable Income (Rs)
Jhapa Area	(Without project) :	1.41	1,473
	(With project) :	1.41	2,680
	(Difference) :		1,207
Mahottari Area	(Without project) :	1.09	6,769
	(With project) :	1.09	8,581
	(Difference) :		1,812
Banke Area	(Without project) :	1.37	4,790
	(With project) :	1.37	9,038
	(Difference) :		4,248

(10) Guidelines for Deep Tubewell Irrigation

As a result of the above, the following two items are considered important as the guideline for the formulation of a deep tubewell irrigation plan in the Terai:

"LFCA and LFWY"

An economical Least Feasible Command Area dominated by one deep tubewell in the Terai is 30 ha, both east and west, as far as an electric pump is applied. And, the Least Feasible Well Yield necessary to irrigate this area is 30 l/s.

Based on these figures, deep tubewell irrigation is not considered economically appropriate for an area where the deep tubewell potential is less than 30 l/s.

"Aquifer and Production Well"

The deep tubewell yield of 60-100 l/s can be obtained in the alluvial aquifer in the Terai. However, the Churia aquifer may be of low permeability and low transmissivity, and the prescribed deep tubewell yield may not be obtained. Therefore, a sufficient hydrogeological examination is necessary to determine the distribution of the Churia Formation when formulating a deep tubewell irrigation plan.

Details of the production wells with yields up to 120 l/s in the Terai alluvial aquifer are as follows: screen diameter 250 mm; opening 25%; total length 30 m; total housing length 50 m; and tubewell depth 100-150 m.

The cost-efficient drilling method for production wells in the boulder including area in the Bhabar Zone is the percussion method. The rotary method can be used in the other areas. The circulation fluid should be carefully selected for production well drilling: Ordinary bentonite fluid can be used when the water head is below the surface. However, a combined fluid of bentonite and barite should be used when the water level shows high artesian pressure. The use of excessively dense circulation fluid must be avoided as it will significantly reduce the well yield. The screens used for production wells in the Terai must be a reinforced wire-wrapped, with an opening of 25% or more and a collapse pressure resistance of 30 kg/cm2 or greater. Stainless steel is desirable depending on the water quality.

9. Conclusion and Recommendations

As a result of this Master Plan Study, the groundwater potential in the study areas is considered to be sufficient for deep tubewell irrigation. Furthermore, it has been confirmed that a deep tubewell irrigation plan is economically feasible.

This Study demonstrates the time-series observations for groundwater use, meteorology, hydrology, and groundwater behaviors are essential in the evaluation of groundwater resources. The establishment of observatory network and sustainable time-series observation in the three districts are strongly recommended for the Department of Irrigation in order to formulate proper DTW irrigation projects.

In regard to Jhapa District, an immediate implementation of project for 30 irrigation units (4,500 ha) is recommended for the purpose of demonstration and corroboration of DTW irrigation in the Eastern Terai.

As the other two districts require detailed groundwater resource evaluations, further surveys and studies in a feasibility study level are recommended to conduct. From the viewpoint of feasibility, this should be performed in Banke District first, followed by Mahottari.

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<u>Abbreviation</u>

ADB	:	Asian Development Bank
ADB/N	:	Agricultural Development Bank/Nepal
AIC	:	Agricultural Inputs Corporation
AMD	:	Agricultural Marketing Division
AO	:	Association Organizer
ASD	:	Agricultural Statistics Division
BNP	:	Program for Fulfillment of Basic Needs
CBS	:	Central Bureau of Statistics
CDO	:	Chief District Officer
CDR	:	Central Development Region
DMH	:	Department of Meteorology and Hydrology
DOA	:	Department of Agriculture
DOI	:	Department of Irrigation
DTW	:	Deep Tubewell
DTWIP	:	Deep Tubewell Irrigation Project
EIRR	:	Economic Internal Rate of Return
ESE	:	East-south-east
E-W	:	East-west
GCA	:	Gross Command Area
GDP	:	Gross Domestic Product
GNP	:	Gross National Product
GOJ	:	Government of Japan
GWRDB	:	Ground Water Resources Development Board
GWRDP	:	Ground Water Resources Development
HMGN	:	His Majesty's Government of Nepal
HYV	:	High Yielding Variety
IAP	:	Intensive Irrigation and Agriculture Program
IDA	:	International Development Association
JADP	:	Janakpur Zone Agricultural Development Project
JICA	:	Japan International Cooperation Agency
JTA	:	Junior Technical assistants
LLDC	:	Least Level Development Country
MOA	:	Ministry of Agriculture
MOWR	:	Ministry of Water Resources
MPID	:	Mater Plan for Irrigation Development in Nepal
MSL	:	Mean Sea Level
NCA	:	Net Command Area
NNE	:	North-north-east
O&M	:	Operation and Maintenance
PVC	:	Polyvinyl Chloride
SSW	:	South-south-west
STW	:	Shallow Tubewell
STWIP	:	Shallow Tubewell Irrigation Program
SWL	:	Static Water Level
TIATSP	:	Tubewell Irrigation Agriculture Training and Services Project
UNDP	:	United Nation Development Program
UPVC	:	Unplastixised Polyvinyl Chloride
ASAID	:	United State Agency for International Development
WNW	:	West-north-west
WUA	:	Water Users Association
WUG	:	Water Users Group

Glossary

a	:	Annum
av.	:	Average
bgl	:	Below ground level
mags	:	Meter above ground surface
masl	:	Meter above sea level
m	:	Meter(s)
mm	:	Milli-meter(s)
km	:	Kilo-meter(s)
km2	:	Square kilometer(s)
sq.km	:	Square kilometer(s)
m3	:	Cubic meter(s)
cu.m	:	Cubic meter(s)
MCM	:	Million cubic meter(s)
t	:	Ton(s)
Mt	:	Metric ton(s)
kg	:	Kilogram(s)
ha	:	Hectare(s)
°C	:	Degree centigrade
%	:	Percent
yr	:	Year(s)
hr	:	Hour(s)
min	:	Minute(s)
sec	:	Second(s)
l	:	Liter(s)
S/cm	:	Siemens per centimeter(s)
in	:	Inch(es)
“	:	Inch(es)
kw	:	Kilowatt(s)
KVA	:	Kilo-volt-ampere
Rs	:	Nepal Rupee(s) (US$0.02; ¥2.24; End of 1993)
MRs	:	Million Rupee(s)
¥	:	Japanese Yen(s) (Rs0.446; US$0.0089; End of 1993)
M¥	:	Million Yen
US$	:	US Dollar(s) (Rs50.0; ¥112; End of 1993)
M$	:	Million Dollar
EC	:	Electric Conductivity
k	:	Permeability (Water Conductivity)
pH	:	Potential of Hydrogen
S	:	Storage Coefficient
T	:	Transmissivity
ND	:	Nominal Diameter
ID	:	Internal Diameter
OD	:	Outer Diameter
MAX.	:	Maximum
MIN.	:	Minimum

CHAPTER ONE

INTRODUCTION

CHAPTER-ONE: INTRODUCTION

This report summarizes the results of the "Master Plan Study on the Terai Groundwater Evaluation and Development Project for Irrigation" which was requested by His Majesty's Government of Nepal (HMGN) and conducted by Japan International Cooperation Agency (JICA).

Major objectives of the study include the evaluation of groundwater resources, the formulation of master plan of deep tubewell (DTW) irrigation projects in Jhapa, Mahattori and Banke (inclusive of a part of Bardiya) Districts which situate in the eastern, central and western Terai respectively.

The study divided into two phases.
The "Phase I Study" aimed mainly at selection of areas irrigable by DTW in each District as well as a "representative area" with the highest groundwater potential amongst the selected irrigable areas. As the result of the study the southeastern area in Jhapa District has been selected as the "representative area".
The "Phase II Study" was to cover an intensive survey and study on the representative area, formulation of master plan and guideline for DTW irrigation and so forth. The intensive survey includes the establishment of monitoring network; monitoring of meteo-hydrology and groundwater; geophysical prospecting; drilling and testing of 20 exploratory deep tubewells; topo-mapping of a sample area; socio-economic and agricultural survey; and so forth. Based upon the results of survey, the evaluation of groundwater resources, formation of master plan and guideline for DTW irrigation were conducted. A series of systems in groundwater monitoring, meteo-hydrological and hydrogeological database and groundwater management were constructed.

Through the study period, technical transfers have been conducted for the counterpart personnel of Department of Irrigation (DOI) in the On-The-Job basis and the training in Japan.

The "Phase I" and "Phase II" studies were conducted from October 1991 to March 1992 and from September 1992 to September 1994 respectively.
The total study was conducted over a 36-month period.

This report is volume one of three volumes as below;

Volume One	:	Main Report
Volume Two	:	Sector Report
Volume Three	:	Appendices

The Study Team wishes to express its deep appreciation to the officers of the Department of Irrigation of the Ministry of Water Resources, particularly to the counterpart personnel, and the officers of related agencies of Japan.

CHAPTER TWO

THE STUDY

CHAPTER-TWO: THE STUDY

2.1. Background of the Study

In the current Eighth National Development Plan, His Majesty's Government of Nepal (HMGN) formulated a major plan to drastically transform rainfed farmland into irrigated land and to establish a basis for the expansion of food production in Nepal.

In order to implement this plan, the Department of Irrigation (DOI) of the Ministry of Water Resources (MOWR) which is responsible for irrigation development of Nepal has been engaged in surface and groundwater development schemes in the Terai where has the highest development potential in Nepal in terms of land, water resources and agriculture. DOI, however, faces various constraints in coordinating,implementing and managing groundwater development through deep tubewells.*

In this connection, HMGN requested in 1988 for the Government of Japan to extend its technical cooperation for the Master Plan Study on Terai Groundwater Resources Evaluation and Development Project for Irrigation (the Study). In response to this request, the Government of Japan sent, through the Japan International Cooperation Agency (JICA), a preliminary survey team to Nepal in March 1991 and made discussions with DOI in relation to the scope of the work involved.

Based on these discussions, JICA organized an implementing team (the Study Team) for the Study. The Study Team submitted an Inception Report to DOI in October 1991 which outlined the plans of approach and operation of the Study. Both parties agreed to the plan of approach and operation of the Study and work was immediately begun by a joint team consisting of the Study Team and the counterpart personnel from DOI.

* The definition of deep tubewell (DTW) and shallow tubewell (STW) is set forth, in many countries, at a depth of 30 m (100 feet). This definition in Nepal is not clear. A well in depth of 40 to 50 m is often called a STW when it taps water within the first unconfined aquifer or the installed pump is a centrifugal type. While, a tubewell drilled to 50 m or more and installed deep-well type pump (mostly a vertical turbine type) is called a DTW.

2.2. Scope of the Study

The scope of the study and the plan of operation agreed upon between JICA and HMGN are as listed below:

(1) Objectives

The objectives of the Study are as follows:

- to evaluate the groundwater potential in the three districts of Jhapa, Mahottari, and Banke, which are located in the Terai;
- to formulate a project master plan on groundwater development in a selected district where the groundwater potential is highest; and
- to carry out technology transfers to the Nepalese counterpart personnel during the course of the Study.

(2) The Study Area

The study area includes the following three districts:

- Jhapa District, excluding the area covered by the Kankai Irrigation Project.
- Mahottari District.
- Banke District, including a part of the Bardiya District on the left bank of the Babai River.

(3) Scope of the Study

The scope of the Study set forth in the scope of work includes the following:

a) Phase I Study

- to collect and review the existing data and information,
- to examine topography, meteorology, hydrology, geology, soil, agriculture, irrigation, organization, hydrogeology, groundwater resources, and the existing irrigation projects and water resources development plan in three target districts,
- to evaluate the groundwater resources for irrigation,
- to identify the groundwater irrigation potential,
- to formulate a technical and management concept for groundwater irrigation; and
- to select a "representative area" which has the highest potential for deep tubewell development for irrigation.

b) Phase II Study

- to conduct hydrogeological surveys, geophysical prospecting, drilling of exploratory wells, groundwater monitoring and evaluation of groundwater resources in the selected representative area,
- to formulate a plan for groundwater monitoring in the representative area,
- to formulate a plan for the development and management of groundwater in the representative area; and

- to formulate a master plan for deep tubewell irrigation projects in the target districts.

(4) Implementation of the Study

Implementation of the Study was carried out by the Study Team organized by JICA together with the counterpart personnel from DOI.

(5) Plan of Operation for the Study

a) Schedule of the Study

The Study is divided into two phases and stages as listed below.

Table 2.2.1 Schedule of the Study

Phase	Stage	Schedule of Work	Report Schedule
I	Preparatory Work	Oct. 1991	Inception
	Field Work (I)	Nov. 1991 to Jan. 1992	Progress (I)
	Home Work (I)	Feb. to March 1992	
II	Field Work (II)	Sept. 1992 to May 1993	Interim/Progress (II)
	Home Work (II)	Aug. to Sept. 1993	
	Field Work (III)	Oct. 1993 to Jan. 1994	Progress (III)
	Home Work (III)	June to July 1994	
	Report Explanation	Dec. 1994	Draft Final Report
	Report Submission	Mar. 1995	Final Report

b) Outline of the Phase I Study

- Preparatory Works
  - [1] Review of the existing data and information
  - [2] Formulation of the plan of operation
  - [3] Preparation of the Inception Report
- Field Work (I)
  - [4] Explanation and discussion of the Inception Report
  - [5] Collection and review of related data and information
  - [6] Field inspection
  - [7] Provisional discussion on the selection of a representative area
  - [8] Investigation on subcontracts for the drilling of exploratory wells
  - [9] Preparation and discussion of the Progress Report (I)

- Home Work (I)
  - [10] Review of the existing plans for water resource development and irrigation projects
  - [11] Evaluation of the groundwater potential for irrigation
  - [12] Formulation of a basic strategy for the development and management of groundwater resources
  - [13] Selection of potential areas and a representative area in the target districts
  - [14] Preparation of an Interim Report

c) Outline of Phase II Study

- Field Work (II)
  - [15] Explanation and discussion on the Interim Report
  - [16] Geophysical prospecting
  - [17] Drilling and testing of the exploratory wells
  - [18] Meteo-hydrological and groundwater observations
  - [19] Survey on agriculture and irrigation
  - [20] Preparation and discussion of the Progress Report (II)
- Home Work (II)
  - [21] Analysis of the results of Field Work (II)
  - [22] Examination of the additional field investigation
- Field Work (III)
  - [23] Collection and review of the supplementary data and information
  - [24] Additional meteo-hydrological and groundwater surveys
  - [25] Analysis of the surface water balance
  - [26] Analysis of the groundwater balance
  - [27] Formulation of a basic strategy for groundwater resource development
  - [28] Preparation and discussion of the Progress Report (III)
- Home Work (III)
  - [29] Comprehensive evaluation of the groundwater resources
  - [30] Formulation of a master plan for deep tubewell irrigation in the representative area
  - [31] Formulation of a plan of operation and management for groundwater monitoring network
  - [32] Formulation of a plan for a hydrogeological and meteo-hydrological database
  - [33] Formulation of guidelines for deep tubewell irrigation for the two areas other than the representative area
  - [34] Preparation of a Draft Final Report
- Final Report
  - [35] Explanation and discussion of the Draft Final Report
  - [36] Preparation and submission of the Final Report

CHAPTER THREE

NEPAL IN OVERVIEW

CHAPTER THREE: NEPAL IN OVERVIEW

3.1. Natural Environment

3.1.1. Topography and Geology

The Himalayan Range swings in an enormous arc at the north of the Indian subcontinent. The Kingdom of Nepal situates close to the central part of this arc. Nepal is a land-locked mountainous country which shares common boundaries with China to the north and India to the south, east and west.

The country has a rectangular feature, located in between the latitudes of N26° 21' 35" and N30° 26' 55", and a longitude of 80° 03' 51" E to 88° 12' 21" E. The average axis is 885 km in the east-west and 193 km in the north-south, with a total area of approximately 147,000 km2.

Nepal's topographical features, geological characteristics, and climatologic zoning are closely related due to the presence of the Himalayas.

The topography and geology are divided into the following five areas, which parallel the Himalayan arc:

(1) Terai

The Terai is a plain area with an altitude ranging from 60 m to 200 m at the southern end and a north-south width of 20 km to 50 km. The plain consists of the Gangetic alluvial beds of clay, sand and gravel, which is brought down from the Himalayan mountains and its foothills. The Terai has abundant land and water resources and is considered as the granary of Nepal.

(2) Churia Hills

The Churia Hills skirt the Terai with an altitude less than 1,300 m. Its north-south width is 20 km to 30 km. The Churia Hills consist of the Churia Formation, which is composed of sandstone, conglomerate and silt formed in the Miocene to Pleistocene age.

Some geological texts call this formation as "Siwalik Formation", which, in the Report, is referred to as "Churia Formation" meaning the formation consists of the Churia Hills.

(3) Mahabharat Hills and Midlands

Topographically, Nepal is divided into the Midlands in the central part of the country (north-south width, 40 km to 60 km) and the Mahabharat Hills (north-south width, 30 km to 40 km). Geologically, these areas belong to the Midlands Zone and consists of granite and schist in the Precambrian age.

(4) Himalayan Mountains

The Himalayan mountain range includes the major summits of the Eastern Himalayas and consists of gneiss and migmatite.

(5) Inner Himalayan Valley

The higher peaks of Sagarmatha (Everest), Dhaulagiri and Annapurna massif underlie in the inner Himalaya and the area underlain by sedimentary rocks such as limestone and dolomite, and intruded granite of geologic age from Cambrian to Cretaceous.

3.1.2. Meteorology and Hydrology

(1) Meteorology

Nepal lies near the northern limit of the tropics; but because of the exceptionally rugged terrain, the climatic range varies greatly, from summer tropical heat and humidity of the Terai, to a colder dry continental and alpine winter climate of the middle and northern mountainous regions.

The mean annual precipitation ranges from more than 6,000 mm along the southern slope of the Annapurna Range in the central Nepal, to less than 250 mm in the north-central region near the Tibetan Plateau. Varying precipitation amounts, from 1,500 mm and 2,500 mm, dominate a majority of the country, with a distinct maximum along the southern slope of the Mahabharat and Himalayan ranges in the eastern two-thirds of the country; however, minimum precipitation stretches east and west across the middle of the country. On an average, approximately 80% of the precipitation is confined to the monsoon period, from June to September.

The maximum temperature in the summer and late spring ranges from more than 40°C in the Terai to about 28°C in the mid-region of the country. The winter average maximum and minimum temperatures in the Terai range from a mild 23°C to a brisk 7°C, while the central valleys experience a chilly 12°C maximum and a -0°C minimum. Much colder temperatures prevail at higher elevations.

(2) Hydrology

All rivers in Nepal are tributaries of the Ganges River, which flows into India. Discharge hydrographs for most rivers are sharp during the monsoon season between July and September, but significantly drop in November and are at their lowest in February. The discharge begins to increase again as the snow melts.

Snowfed rivers are mostly perennial in nature; however, the fluctuation between their low and high flows is often very large due to heavy rainfall during the monsoon season.

Most of the rivers in the Terai are seasonal, being nearly dry in winter but active during the monsoon season. The main source of water for these rivers is rainfall.

(3) Meteorological and Hydrological Stations

Department of Meteorology and Hydrology (DMH) of Ministry of Water Resources which is responsible for monitoring and recording of meteorology and hydrology in Nepal, has recorded data which includes precipitation, temperature, humidity, wind, sunshine, and river discharge.

Meteorological monitoring began in 1947 at several locations, and as of 1990, there are 215 stations measuring rainfall in Nepal. Among these stations, approximately 40 stations measure agro-meteorological data such as temperature, humidity, sunshine, wind, and evaporation. Meteorological data is made available in part by the "Climatological Records of Nepal," which is published by DMH on an irregular basis. Furthermore, only monthly data is made available by this publication though the measurements are taken on a daily basis.

Hydrological measurements began at the Karnali River in 1960, and there are approximately 40 stations currently measuring the water discharge of the major rivers. Hydrological data is made available in part by the "Surface Water Records of Nepal," published by DMH; however, publication ceased in 1976.

3.2. Socio-Economy

The population of Nepal as of 1991 is 18.49 million, and the annual population growth rate since 1981 has been 2.1%. Nepal occupies an area of 147,000 km2 and has a population density of 126/km2 (1991).

Nepal is an culturally diverse country composed of many races and ethnic groups. These people can be divided into Tibet-Nepalese and India-Nepalese races. The Tibet-Nepalese races, which settled mainly in the hill and mountain districts, are represented by Tibetan and ancient Nepalese groups. Similarly, the India-Nepalese races, which settled mainly on the Terai, are represented by Nepalese and Indian groups.

The agricultural sector forms the mainstay of Nepal's economy, contributing 49% of the GDP in 1991/92, compared with other sectors such as construction and manufacturing. As of 1991/92, Nepal's GDP is 126.2 billion Rs (approx. US$ 3 billion) and US$180 per capita.

Foreign trade in 1991/1992 reflected a deficit of Rs 19 billion, with exports and imported valued at Rs 13.9 and 32.9 billion, respectively.

3.3. Agriculture

Six food grains, including paddy, maize, wheat, barley, millet, and pulses, dominate agricultural production of Nepal. In 1992/1993, approximately 2.9 million ha of farmland were cropped, producing some 4.9 million ton of food grains and about 3.3 million ton of other cash crops.

Livestock also plays an important role in Nepal's economy. The total number of cattle and buffalo is 9.31 million, or approximately 4.2 head per household.

Until the mid-1980s, Nepal was a food-grain exporter. In recent year, however, food demand has exceeded production. Nepal is estimated to be 85% to 90% self-sufficient in the production of food grains. Farming is carried out under irrigated conditions in large areas of the Terai and in smaller areas in the hill and mountain districts. Rainfed agriculture dominates in the latter areas. The total arable area in Nepal was 2.97 million ha in 1989/1990, of which 1.2 million ha, or 42%, are located in the Terai region. The irrigable land area has reached 2.2 million ha. The actual irrigated area in Nepal is 940,000 ha, of which 610,000, or 65%, are also located in the Terai region. The productivity of the agricultural land in most parts of Nepal is significantly lower than in neighboring countries.

3.4. Political and Administrative System

3.4.1. Political System

The Kingdom of Nepal is a constitutional monarchy. Its written constitution was set forth in 1962, establishing a party-less Panchayat System, after many political and administrative attempts following the royal takeover in 1951. In accordance with the 1962 constitution, there are three levels of Panchayats, or political councils - village, district, and national assemblies.

In April 1990 a pro-democracy movement was initiated, and His Majesty the King dissolved the Rastriya Panchayat and the Panchayat System in mid-April 1990. An interim government was formed to create a new constitution, and a new constitution based on a multi-party system was set forth in early 1991.

3.4.2. Administrative System

(1) His Majesty's Government

HMGN is composed of 21 ministries, including among others, ministries for finance, law and justice, foreign affairs, local government, defense, agriculture, and water resources, as well as a National Planning Commission in the Secretariat of the Council of Ministers, under the chairmanship of the prime minister.

(2) Local Administration

Nepal is divided into five development regions, 14 zones and 75 districts for administrative and development purposes, as shown in Figure 3.4.1. Each development region consists of two to three zones and several districts. Each district is divided into nine wards, with several villages. Most ministries related to development sector have regional and district offices.

(3) Government Agencies Related to the Irrigation Subsector

Government agencies have been actively involved in new irrigation schemes and in assisting farmer groups to construct or rehabilitate low-cost Farmer Managed Irrigation Systems (FMIS). DOI has been the leading agency involved in the development of new irrigation works, though the Agriculture Development Bank of Nepal (ADB/N) now plays an important role in promoting and financing the Shallow Tubewell (STW) Development Program.

a) MOWR and DOI

MOWR is responsible for the planning and implementation of HMGN's policy for the development, management, control, and conservation of water resources and electric power. MOWR is composed of the Secretary's Administration, Department of Irrigation, Department of Meteorology & Hydrology, Groundwater Resources Development Board, Nepal Electricity Authority, and the Water & Energy Commission.

DOI, within MOWR, is the most important government agency involved in the irrigation subsector. Its mandate is to plan and implement new irrigation schemes as well as to manage large completed projects. DOI is composed of five central divisions: Irrigation Management & Water Utilization; Medium & Large-Scale Irrigation; Groundwater Utilization; Planning; and River Training. As well as these divisions, there is a Project Management Board for each national project and a Regional Irrigation Directorate which supervises several District Irrigation Office in each of the five development regions.

b) Department of Agriculture (DOA)

DOA is responsible for agricultural extension programs throughout the nation, with exception of the project-specific programs for several of the large projects managed by DOI in the Terai.

c) ADB/N

ADB/N is responsible for the provision of agricultural credit on an organized basis throughout Nepal. Its STW program, through which subsidies are provided to individual farmers to construct STWs, has reportedly been successful. ADB/N reports that the STW program had provided irrigation facilities to an estimated net command area (NCA) of 61,000 ha by mid 1988.

d) Agricultural Inputs Corporation (AIC)

AIC is responsible for the importation and distribution of chemical fertilizers, improved seeds, agro-chemicals, and farm machinery.

No. of Districts

		Far Westrn	Mid Western	Western	Central	Eastern	Total
	Terai	2	3	3	7	5	20
	Hill	4	7	11	9	8	39
	Mountain	3	5	2	3	3	16
	Total	9	15	16	19	16	75

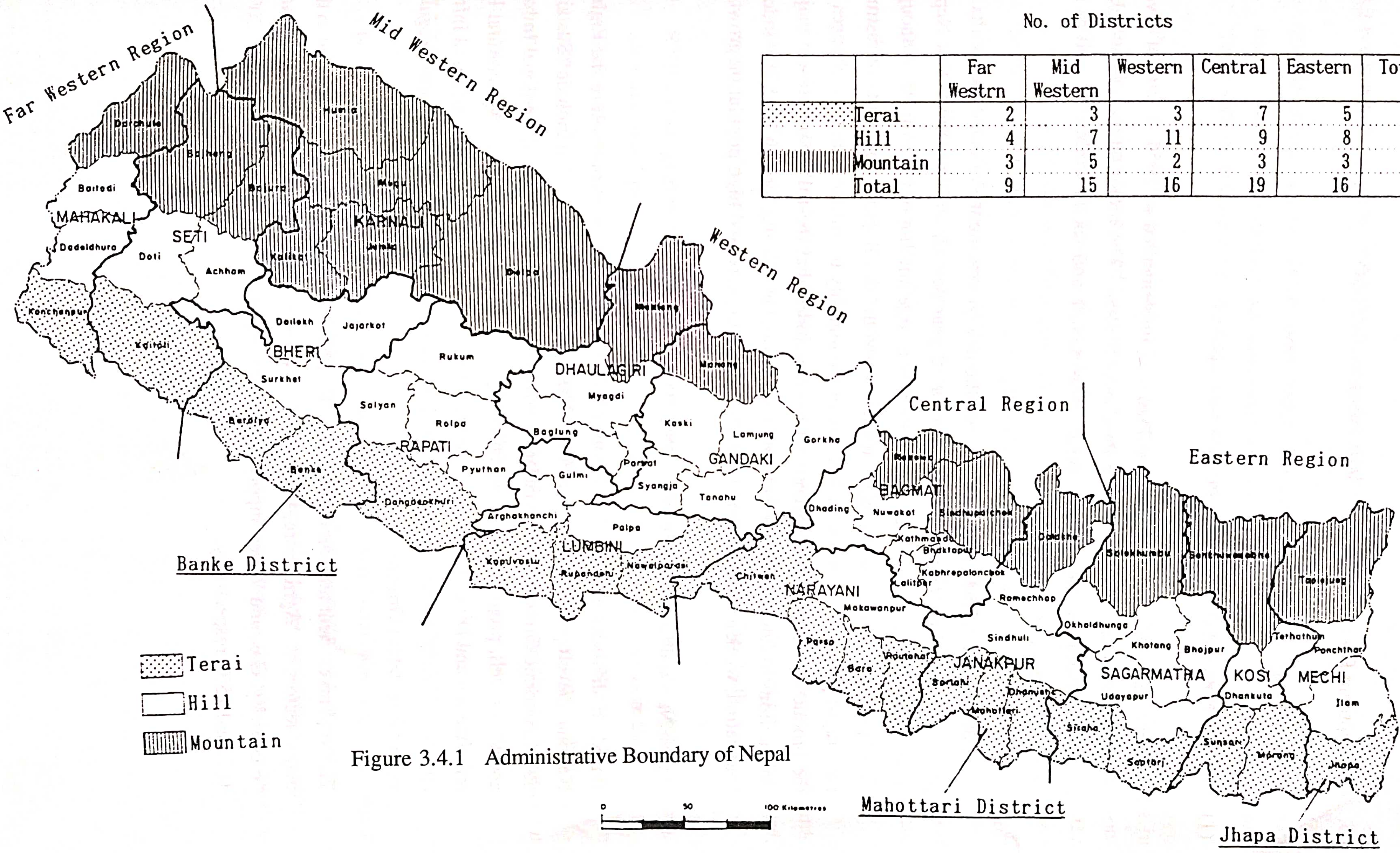


Figure 3.4.1 Administrative Boundary of Nepal

3.5. Development Plan

3.5.1. National Development Plan

(1) Previous National Development Plans

Since the First National Development Plan was implemented in 1956, a total of seven plans have been promoted under the Panchayat System. The major targets of each plan included the improvement of the social infrastructure and social welfare as well as an increase in agricultural production.

After dissolution of the Panchayat System, the new government evaluated the results of previous national development plans over a 30 year period, and concluded that Nepal remains one of the poorest countries, even after a large amount of investment. Although slight progress is observed throughout society and the development of social infrastructure, rapid progress is impossible because of the inability to initiate structural changes in the production sector. The government has concluded that the following present major obstructions to future development: low savings rate, increasing foreign debt, low industrialization, weak agricultural productivity, limited exports, and high population growth.

(2) Eighth National Development Plan (1992-1997)

Based on an assessment of the previous plans, the government is promoting the Eighth National Development Plan (1992-1997). The major targets of this plan include "Sustainable Economic Growth," "Alleviation of Poverty," and a "Reduction of Regional Imbalances"; as well, programs receiving special priority in the plan include "Agricultural Intensification and Diversification," "Energy Development," "Development of Rural Infrastructure," "Employment Generation and Human Resource Development," and "Regulation of Population Growth."

The total investment amount of the plan is Rs 170 billion, which is being allocated to the major sectors of "Agriculture, Irrigation, and Forestry," "Finance & Real Estate" and "Electricity, Gas, and Water Supply" and "Traffic and Communications" are 26%, 20%, 16% and 15%, respectively.

3.5.2 Basic Needs Program (1985-2000, hereafter BNP)

HMGN established the "BNP (1985-2000)," beginning with the Sixth National Development Plan, in order to meet the basic needs of its people in six sectors by the year 2000. These sectors include food, clothing, housing, health, education, and security.

Food is the most important basic item among the basic needs. The food production plan in this program is determined based on the minimum requirement of 2,250 calories/person/day. The program emphasis is to satisfy the necessary caloric requirements through the provision of inexpensive food produce, such as maize, wheat, millet, barley, pulses, and potatoes. The required domestic food production is 6.6 million tons, or 9.8 million tons on an unprocessed basis, based on the required caloric intake from grains, pulses, and potatoes and the population increase by the year 2000 (estimated at 23 million). The food production volume in 1984/85 was 4.8 million tons, and an annual average rate of increase at 6.5% is required in order to achieve the goal of this program.

In order to meet the above target, development and the wide use of improved seeds, improved agricultural practices, farmer education, and technical innovations are necessary, accompanied by an increase in irrigated farmland to 1.25 million ha by the year 2000.

BNP's main goal is to achieve self-sufficiency in the six major grain products. The program also highlights the diversification of agriculture in hilly regions where the self-sufficiency rate is especially low. In order to achieve these goals, it is necessary to provide irrigation facilities, improved seeds, agro-chemical, farm machinery, agricultural financing, storage facilities, and other agricultural expansion measures; and this will require an investment estimated at Rs 46.420 billion (1984/1985 value).

3.5.3. Master Plan for Irrigation Development

Following BNP, a master plan for irrigation development in Nepal was prepared in early 1990 with the assistance of UNDP/World Bank. The plan was designed to provide a long-term strategy for irrigation development; to develop short-term investment programs within this long-term strategy; and to provide a sound database and planning methodology.

(1) Objectives and Targets

The Master plan has established two goals, which are the same described in BNP, for the irrigation subsector: a food grain production goal and an irrigated area development goal.

The first goal is to produce food sufficient to meet the minimum daily requirement of 2,250 calories per capita per day by the year 2000. This is equivalent to the production of 9.8 million tons of food grains, or approximately double the actual production of the mid-1980s.

The second goal calls for an expansion of the areas benefiting from government-assisted irrigation, from the 1987 level of 434,000 ha to a total area of 1,250,000 ha by the year 2000. The implied rate for implementation of newly irrigated areas is 60,000 ha/year or greater. The maximum sustained rate of development achieved during the Sixth National Development Plan was only 35,000 ha/year.

(2) Available Investment Options

Nepal's irrigation investment programs to date have emphasized in construction of new large projects in the Terai and small to medium projects in the hills; assistance to existing Farmer Managed Irrigation Systems (FMIS) in all areas; and promotion of groundwater development in the Terai. The strategy now set forth is for irrigation management and agricultural support programs; low-cost demand-driven assistance to FMISs; and the development of new small schemes and shallow tubewells.

Because of BNP's emphasis on food production targets, investment options in the master plan have evaluated food grain-dominated cropping patterns and related assumptions.

The evaluated investment options are listed in descending order below.

a) Irrigation Management Improvements for Existing Projects

Relatively low-investment costs can be effective in the improvement of existing irrigation. The investment priority is as follows:

- Transfer DOI's small-scale irrigation projects to Water Users' Groups (WUG).
- Assistance to existing FMIS.
- Irrigation management programs and some rehabilitation works in DOI's large-scale projects in the Terai.

b) Groundwater Irrigation in the Terai

Three development models were considered, including shallow tubewells (STW), deep tubewells (DTW) based on large projects, and DTW on small projects; and approximately 90,000 ha of the estimated 290,000 ha potential has been developed by STW irrigation, while about 2,000 ha of estimated 70,000 ha potential has been developed by DTW irrigation.

- Shallow Tubewells

Economic analyses indicate that EIRRs of over 40% can be realized from STW investment in rainfed areas, and that EIRRs of over 20% can be obtained from conjunctive use areas. Financial analyses confirm that standard STW investment is attractive to irrigable farmholdings larger than 1.0 ha. Promotion of group ownership and/or water sales is needed to expand the service area per STW and to permit small holdings to receive the benefits from STW irrigation.

- Deep Tubewells, large-scale project model

Experience with the Bhairawa-Lumbini DTW project indicates that large-scale DTW project models can generate relatively high benefits. Project-specific irrigation management and agricultural support programs promote the attainment of future levels of agricultural production and command area utilization, and the operating costs are minimized by the use of electric motors. EIRR's of over 20% are indicated for this DTW model for future levels and approximately 10% for the present level. Problems have been encountered in achieving full recovery of O&M costs for DTW projects operated by DOI; however, DOI intends to address this problem through programs which promote the formation of WUGs and profitable cash cropping.

- Deep Tubewells, small-scale project model

Individual DTWs can be developed to serve 60 ha to 120 ha, based on group ownership of wells, pumping equipment, and the distribution system. Analyses indicates that such investments are comparable with the large-scale DTW model. Problems have arisen for many small-scale DTWs in only partial use of the command areas because of the reluctance of farmers to cover the operating costs.

c) Small- and Medium-Scale Surface Water Projects in the Terai

The potential for small- and medium-scale surface water projects in the Terai is limited as the water resources of the many small Terai streams have already been exploited by existing DOI projects and FMISs. The most economic form of irrigation investment in small-scale surface projects is the rehabilitation of existing FMISs using low-cost implementation models.

d) Small-Scale Irrigation Projects in the Hill and Mountain Districts

Some 70,000 ha of irrigable land is available for new irrigation projects in the hills and mountains. Investment in new projects can be economically viable: EIRR'S of 10% to 20% can be realized as long as costs are consistent with the expected benefits.

e) Large-Scale Surface Water Irrigation Projects in the Terai

Some 80% of the irrigable land resources in Nepal as well as most of the potential areas for expanding irrigation are in the Terai.

HMGN, therefore, places a high priority on implementing large-scale surface irrigation projects in the Terai, utilizing the area's surface water resources.

Seven large-scale surface water projects have been completed, or are currently under construction, and seven other potential projects have been economically assessed.

(3) Proposed Strategies and Programs for the Irrigation Subsector

In the master plan, four long-term objectives to guide the development of the irrigation subsectors are recommended as follows:

- to increase agricultural production and benefits from existing irrigated lands by combining the agricultural and irrigation management programs;
- to improve the delivery efficiency of irrigation-related services through institutional improvements within government agencies and the maximum possible use of the private sector;
- to implement small- and medium-scale irrigation projects which meet sound technical and economic criteria; and
- to select and implement new large-scale irrigation projects in the Terai as a mean of significantly augmenting national agricultural production.

(4) Investment Program Options for the 1990s

The recommended investment program for DOI is based on the Cost-Effective Program, but it also incorporates elements of the DOI Official Program. Budgetary items are divided into the following three categories: "Core Items," "Highest Priority Projects and Programs," and "Additional Projects and Programs."

The recommended investment program includes all of the items in the first category; most of the items in the second; and selected items depending on the availability of external financing and the experience of DOI's implementation capacity in the third.

The recommended approach in formulating the investment program for the irrigation subsector is intended to emphasize selection of cost-effective investments.

CHAPTER FOUR

THE STUDY AREA

CHAPTER FOUR: THE STUDY AREA

4.1. Selection of Area Irrigable by DTW

The Phase I study aimed to select, through review of the existing data and information, an area (around 10,000 ha size) irrigable only by DTW in each district under the study exclusive of those areas where surface-water and STW are available, and to decide a representative area where the groundwater potential is higher than any other.

The representative area thus selected is to be covered by Phase II study composed of further survey and studies in meteorology, hydrology, hydrogeology, groundwater, agriculture, irrigation, formulation of master plan and so forth.

A definition is set forth in this study that DTW is to exploit groundwater stored in confined aquifers deeper than the uppermost unconfined aquifer which extend to around 40-m depth from the ground surface.

The result of Phase I study is as summarized in Table 4.1.1. and Figures 4.1.1. to 4.1.3. Although there are no remarkable differences in the DTW yield among three districts under the study, they could be listed in the order of Banke, Mahottari and Jhapa. While, the potentials of groundwater recharge were deemed to be excellent in Jhapa and Mahottari; and poor in Banke in view from the density of rivers flowing down in the districts, based on the preliminary field reconnaissance of the areas.

The acreage of irrigable area around 10,000 ha are in the southeastern area (17,000 ha) and the western area (10,000 ha) in Jhapa, the southern and northern areas (7,000 ha in total) in Mahottari and the southern strip (8,000 ha) in Banke. The situation in social infrastructure such as road, power supply, tele-communication is not so much difference in three districts.

As the results of integrated conclusion on the conditions mentioned above and consultation with DOI, the southeastern area in Jhapa District was finally selected as the "representative area".

Table 4.1.1 Groundwater Potential for Deep Tubewell Irrigation in Three Districts

Districts	Jhapa	Mahottari	Banke
Location of Irrigable Area	Southeast/West	South/North	South
Transmissivity (m2/day)	1,660/1,660	820/5,500	1,000
Average Well Yield (l/s)	91/91	66/ 97	110
Irrigable Area (ha)	17,000/10,000	4,000/3,000	8,000
Future Road Plan	Yes	Yes	No
Future Power Plan	No	No	Yes

The general features of the districts under the study and the selected irrigable areas in each district are outlined in the following paragraphs.

Figure 4.1.1
MAP OF IRRIGATION POTENTIAL IN JHAPA DISTRICT

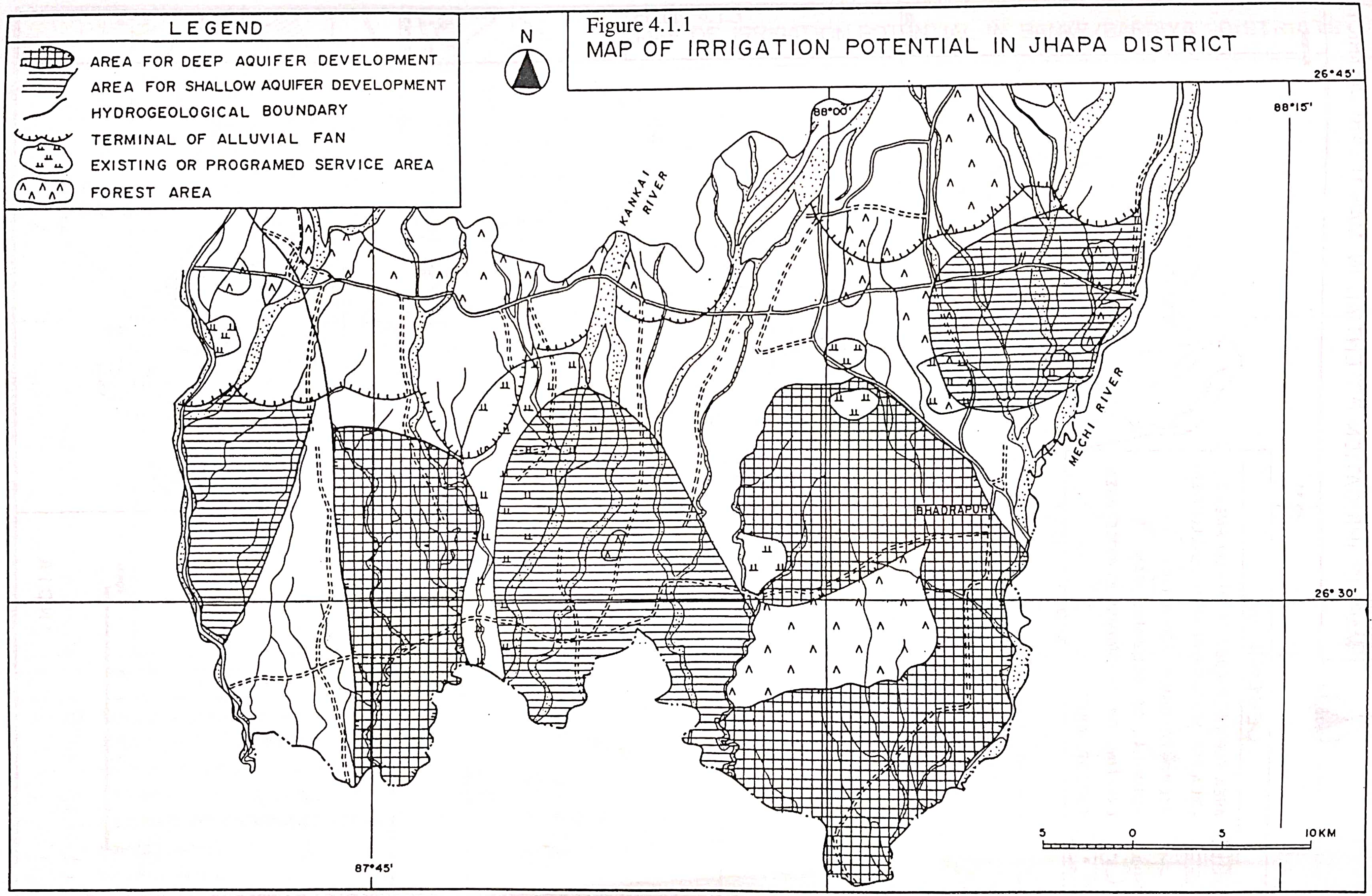


Figure 4.1.2
MAP OF IRRIGATION POTENTIAL IN MAHOTTARI DISTRICT

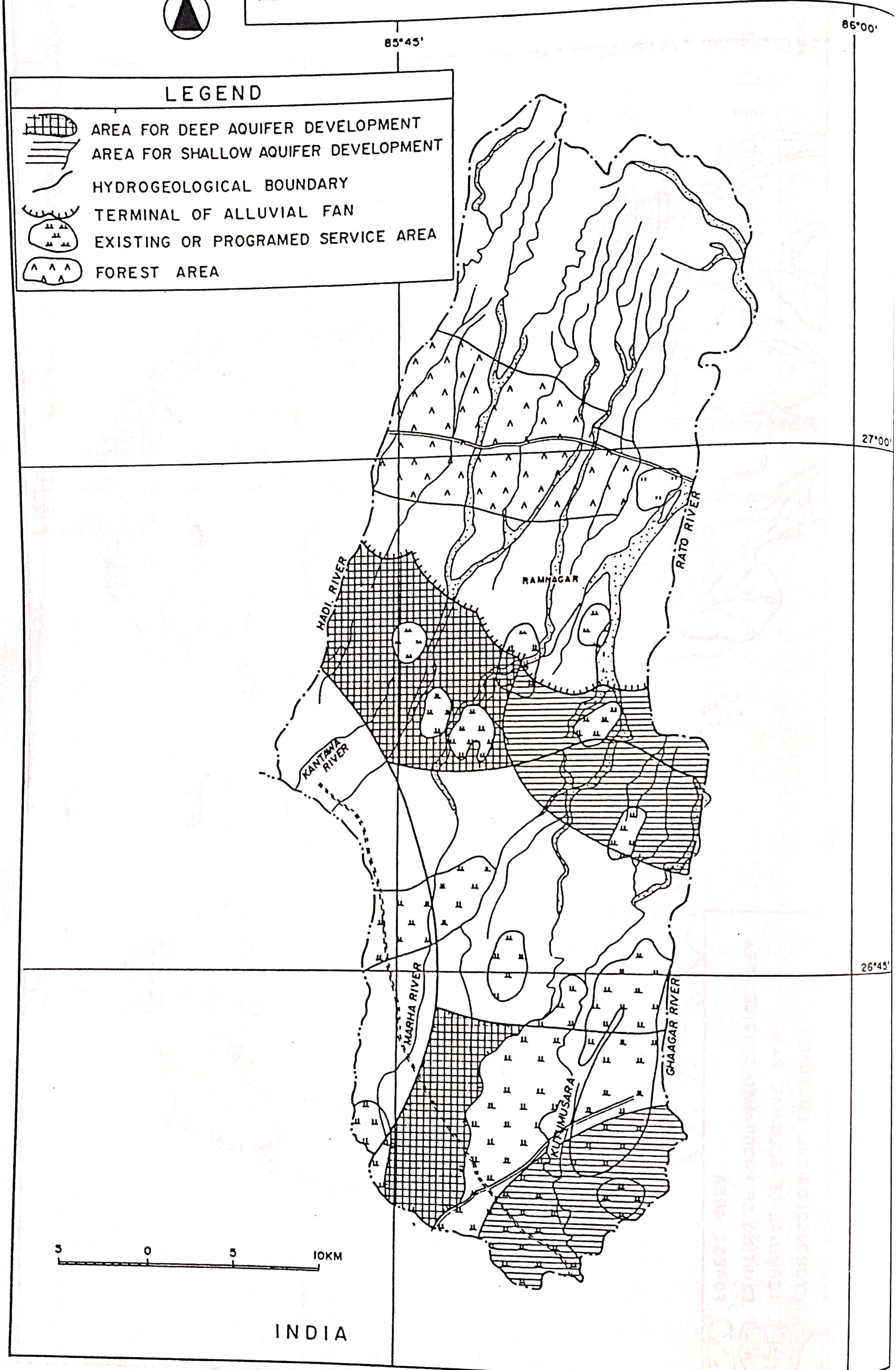
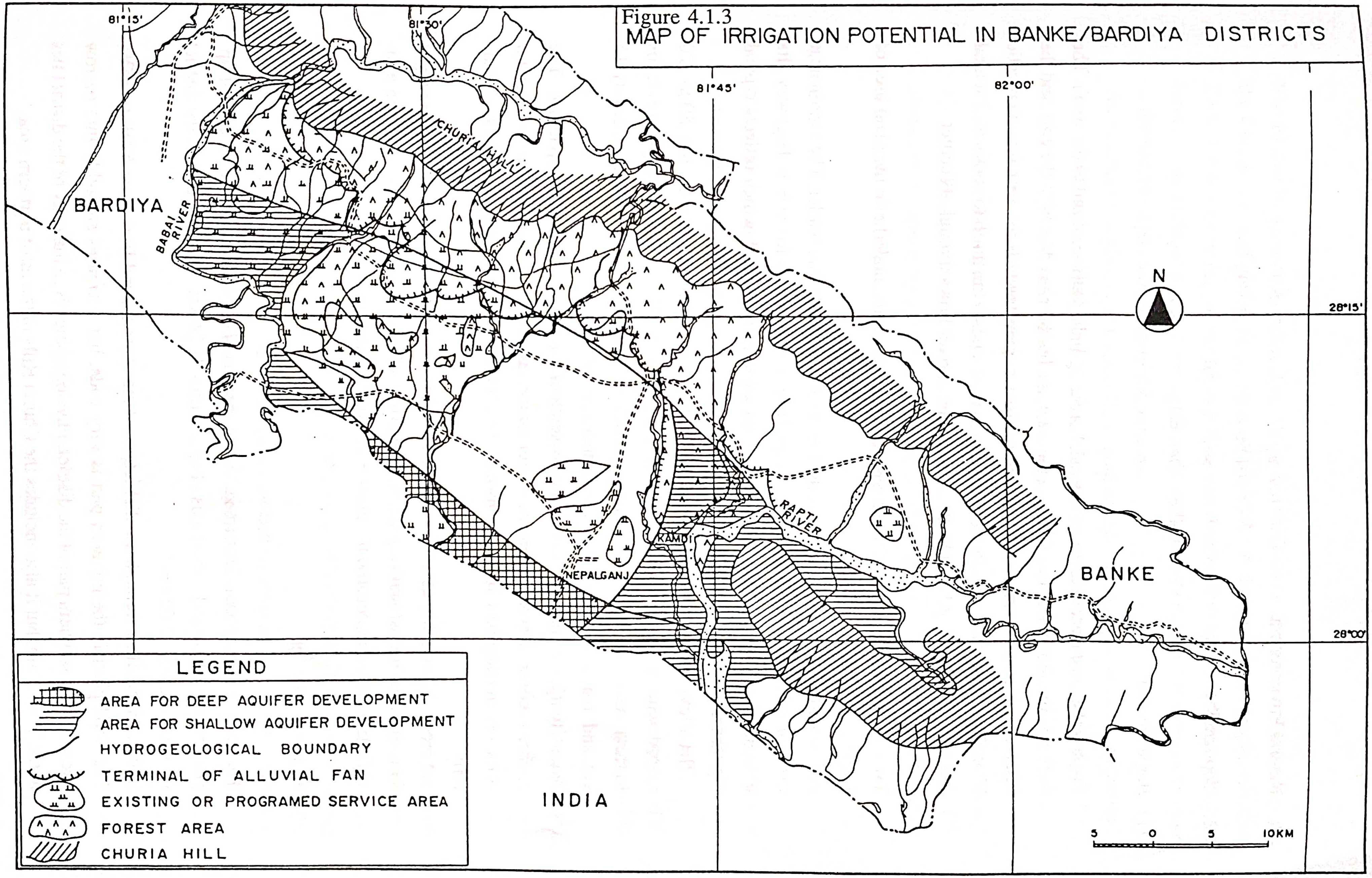


Figure 4.1.3
MAP OF IRRIGATION POTENTIAL IN BANKE/BARDIYA DISTRICTS



4.2. Natural Environment

4.2.1. Topography

(1) Jhapa District

Jhapa is the most eastern district in Nepal, bordering India to the east and to the south. The district is limited by Ratuwa Khola in the west, the border river Mechi in the east, and the Churia Hills in the north; and the southern district opens towards the vast Indo-Gangetic Plain. The district extends 56 km from east to west, and 49 km north to south, with a total area of approximately 1,606 km2, and the Kankai river flows through its center.

Two topographic units, an alluvial plain and terrace terrain, underlie in the plain area of Jhapa District.
A broad alluvial plain extends from the Churia Hills to the Indian border. The terrain near the Churia Hills is an undulating, fan-shaped terrain that extends to the E-W Highway. Its altitude ranges from 120 to 210 mamsl, with a gradient of 1/100, which reflects typical topographic features of the Bhabar Zone.
A flat alluvial plain extends south of the Bhabar Zone; its altitude ranges from 80 to 120 mamsl, with gradient of 0.3/100, which is gentler than the Bhabar Zone. The plain extends to the forest-covered terrace terrain south of Bhadrapur, at a width of approximately 15 km, and marshy land appears in the southern part of the zone.
A widely uplifted terrace terrain extends south of the study area near Prithivinagar. The terrace is covered by thick forests, except for the eastern part. Small-scale terrace terrain is located in Dangibari, in the northwestern part of the region, and it is utilized for agriculture.
A broad alluvial plain extends south of the terrace, up to the border. Its altitude ranges from 60 to 80 mamsl, with a gradient of 0.2/100, which is gentler than the northern alluvial plain. Topographically, the plain is part of the Gangetic alluvial plain.

(2) Mahottari District

The outline of Mahottari District is like a long, flat N-S ellipse, with a long axis of approximately 62 km and a short axis of approximately 24 km. The total area of the district is approximately 1,002 km2.
Several rivers flow through the district; most are seasonal and flow from NNE to SSW. The flood plain in the northern part is very wide, but decreases smoothly into narrow streams in the southern part of the district. Physiographically, a majority of the district lies in the Terai Plain, but it also includes the Churia Hills in the most northern area.

The Bhabar Zone, with its original fan shape and thick forest covering, lies at the foot of the Churia Hills and gently inclines toward the SSW. Although not topographically distinct, the terrace terrain of the Bhabar Zone can divided into upper, middle, and lower terrace. The geological age of the higher and middle terrace may be Pleistocene because of the laterite deposited on top of the terraces.

The southern margin of the Bhabar Zone gradates into a marshy area and is a transition zone to the Southern Terai Plain. There is no actual marsh in the area but the ground slope becomes gentler and many of gravelly flood plains terminate at the southern edge of the area, and many of shallow wells at the southern margin are artesian.

The Southern Terai Plain occupies almost half of the Mahottari District, or approximately 400 km2. The land is nearly flat and many streams heavily meander toward the south. The altitude of the area is the lowest among the entire Terai Zone in Nepal, with the elevation of less than 60 mamsl at the southern end of the district.

(3) Banke District

The study area includes the entire Banke District and a part of Bardiya District, the east bank area of the Babai River. The total study area is 3,230 km2, which is the largest area among three study districts.

The area is bordered by the Babai River to the west, by the Churia Hills to the north and to the east, and by the Indo-Nepal border to the south, with its long axis approximately 80 km in a east-west direction and 40 km in a north-south direction.

The Rapti River, one of Nepal's major rivers, flows through the area. Besides the Rapti and Babai rivers, there are many minor rivers such as the Bharda Nala as well as other small seasonal rivers.

The Terai Plain in this area lies at a high altitude and is approximately 130 mamsl in its lowest point. The Bhabar Zone in this district occupies a very large area, lying primarily between the E-W Highway and the Churia Hills and the east side of the Dundawa Nala. The zone is roughly estimated at 640 km2, including the terraces and a wide valley along the Rapti.

The very flat Southern Terai Plain lies in a narrow belt, approximately 5 to 8 km in width, along the Indian border, and its altitude is less than 150 mamsl.

4.2.2. Geology

(1) Jhapa District

The Study Area is underlain by alluvium, terrace deposits and the Churia Formation, with only exposures of the first two at the surface.
Alluvium in the Bhabar Zone is composed mainly of sand and gravel in shallow areas, with a depth of more than 20 m, which increases to 150 m or more in the south, alternating with beds of sand, gravel, and silt.
The Northern Alluvium, north of the terrace, is 150 m or more in thickness and is deemed to be underlain by the Upper Churia Formation as mentioned later. Gangetic Alluvium in the south is mostly thick sand and gravel beds, more than 300 m thick, with single beds thicker than 50 m.
The terrace deposits are composed of clay, silt and coarse sand of approximate 10 m thickness.

Churia Formation does not expose on the ground surface. However, borehole samples reveal that the Upper Churia Formation underlying the alluvial plain is composed of unconsolidated clay, silt, sand and gravel. This is the new interpretation on the geological log of Terai Plain, which is discussed in detail at the section 5.2. Hydrogeology and groundwater.

(2) Mahottari District

The geology of the alluvial plain of the Mahottari District consists of terrace deposits and Gangetic Alluvium. Although the Churia Formation underlies in the northern hills, the Upper Churia Formation is probably overlain by the terrace deposits and composed of unconsolidated clay, silt, sand, and gravel.

(3) Banke District

The area is underlain by the Churia Formation; and the terrace and alluvium deposits. The alluvial deposits can be subdivided into Northern Alluvium in the Bhabar Zone, Central Alluvium in the undulating plains and Gangetic Alluvium in the southern strip.

Drilling to a 200-m depth penetrated unconsolidated sand and gravel layers and silt layer in the Northern Alluvial area. The Central Alluvium is deemed to be 30 m thick, and layers underlain are probably the Churia Formation.

Drilling record to a 300-m depth reveals that the Gangetic Alluvium is composed of unconsolidated clay, silt, sand, gravel, and that it is more permeable than the other alluvial formation.

The Churia Formation is composed of slightly consolidated shale, sandstone and conglomerate in the east of the Rapti River; however, in the north of the Babai River, it is composed of well-consolidated shale and sandstone.

4.2.3. Meteorology and Hydrology

(1) Jhapa District

a) Meteorology

The Jhapa District lies mostly in the Terai Plain and is broadly demarcated by the foothills of Mahabharat in the north and the Mechi River in the east. The altitude of the district ranges from 63 m to 476 mamsl. A glimpse of long-term average data reveals that the district is generally characterized by a subtropical to tropical climate.

The area receives abundant rainfall compared with the other districts in the Terai Plain as a result of the monsoon which carries high humidity from the east. The annual precipitation, averaged by the Thiessen Network, based on the Kankai, Sanischare, Anarmanibirta, and Chandragadhi stations, ranges from 1,600 mm to 3,600 mm, with an average of approximately 2,500 mm, as shown in Figure 4.2.1. The mean monthly precipitation during the winter is approximately 10 mm to 20 mm, increasing to over 700 mm in July during the monsoon season.

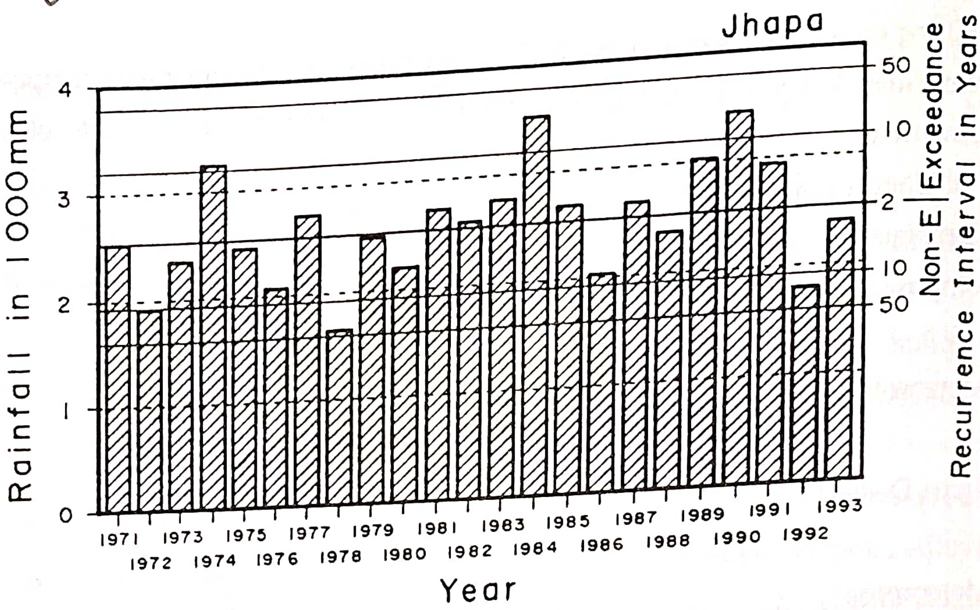


Figure 4.2.1 Annual Rainfall Averaged by the Thiessen Network (Jhapa)

Based on the above annual rainfall, the drought frequency is analysed by the Gumbel Method. As shown below, this area is relatively abundant in rainfall: 1,911 mm in 10 year recurrence interval ; 1,762 mm in 20 year recurrence interval.

Recurrence interval, year :	2	5	10	15	20	30	50	100
Probable annual rainfall, mm:	2524	2110	1911	1819	1762	1692	1616	1533

The district's coldest temperatures occur in December and January; mild temperatures occur in April and May; and high temperatures and high humidity occur between June and August. The mean monthly temperatures range from 15°C to 29°C, and the mean monthly minimum temperature drops to 5°C, while the mean monthly maximum temperature reaches to 38°C. The humidity drops between 60% and 70% during March and April, immediately before the monsoon period; humidity rapidly rises at the beginning of the monsoon and shows 80% to 90% during the monsoon period.

The sunshine hours are 4-6 hours per day during the monsoon period and greater than 7 hours during the other seasons. The maximum sunshine hours reach 9 hours during May. The wind velocity has been measured at Biratnagar, located at the boundary of western India, and Kankai. The wind velocity at Kankai is 1.0 to maximum 4.0 km/hr and 2.0 to maximum 9.0 km/hr at Biratnagar, which shows the wind velocity for the latter to be approximately double.

Although evaporation is not measured in the district, according to the records at the Tarahara observation station, located 55 km west of Kankai, the maximum monthly mean evaporation is 6 mm/day immediately before the monsoon period, approximately 5 mm/day during the monsoon period, and a minimum of 2 mm/day during the winter.

b) Hydrology

All of the rivers and streams in the district, whether seasonally or perennially, are rainfed. Five major rivers, Ratuwa, Kamal, Kankai, Biring and Mechi flow through the district. Among these rivers, the Kankai and Mechi are the largest. The minor rivers are seasonal and mostly the tributaries of the major rivers.

Some hydrological data is available only for the Kankai River, which is largest in the district. The river's gauging station is located at Mainachuli and covers a drainage area of 1,180 km2. According to the water balance calculation of the past 14 years, the annual mean precipitation is 3.750 billion m3, while the annual average discharge is 2.786 billion m3, and the runoff coefficient is 74%. According to DMH the discharge coefficient reported at this station is between 60% and 70%.

During this Study, the runoff discharge at Deoniya River and Budhajhora River was measured between January 1993 and January 1994. The runoff coefficients are 70% and 89%, respectively, which are considerable discharge amounts. Furthermore, more than 90% of the discharge is confined during the monsoon season.

(2) Mahottari District

a) Meteorology

As a result of the varying topographical characteristics in the ground elevation, which ranges from 56 m to 904 mamsl, there is little uniformity in the climate within the district. The district experiences tropical, subtropical, and mostly mild temperate types of climate. In general, the hot and humid climate are the dominating features of the district during the summer months, and the air becomes very humid when the monsoon rain begins in June. In the winter, the climate is mild and comfortable for a couple of weeks and generally dry in terms of precipitation.

There are no meteorological stations in the district, but there is one precipitation station at Gaushara. The records of the meteorological station at Janakpur Airport, in the adjacent Dhanusha District, may be applicable to the southern part of the Mahottari District. Similarly, precipitation data from the Tulsi station in Dhanusha District may be applicable to the northern part of the district.

Based on the data from these stations, the annual precipitation ranges from approximately

600 mm to 2,600 mm. The mean monthly precipitation ranges from trace in the winter to as high as 480 mm in July during the monsoon season. The following shows a time-series annual precipitation at the Janakpur Airport station.

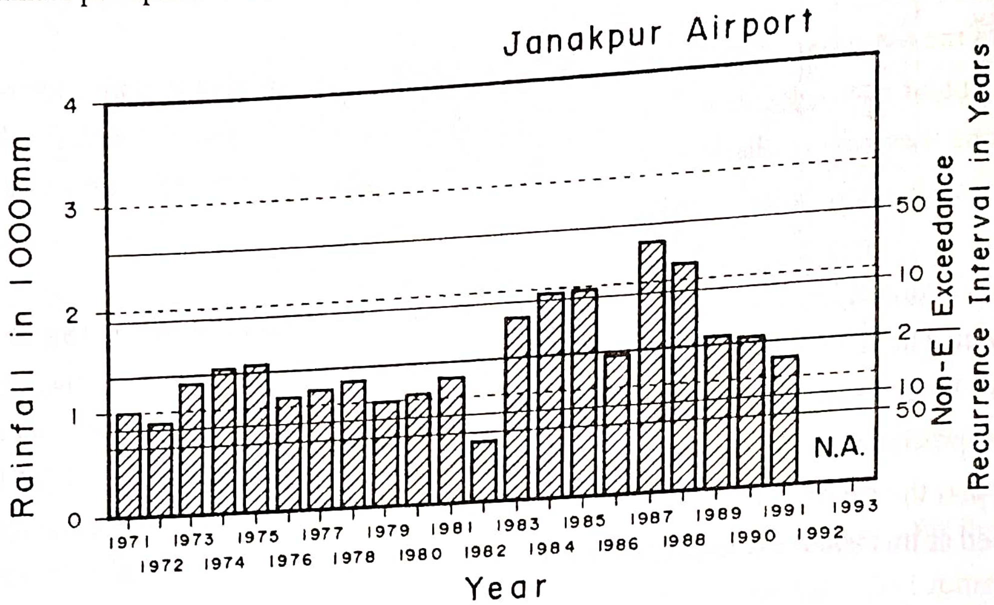


Figure 4.2.2 Annual Rainfall at Janakpur Airport Station

Based on the above, the drought frequency is analysed using the Gumbel Method. As shown below, the 10 year recurrence interval is 858 mm and the 20 year recurrence interval is 774 mm, which is approximately 1,000 mm less than those in Jhapa District.

Recurrence interval, year :	2	5	10	15	20	30	50	100
Probable annual rainfall, mm:	1310	987	858	804	774	738	703	669

Temperature records are available at Janakpur Airport Station. The mean temperature ranges from 15°C to about 30°C, and the minimum and maximum temperatures are approximately 5°C and 39°C, respectively. The humidity drops to approximately 65% immediately before the monsoon period; humidity rapidly rises at the beginning of the monsoon and shows 80% to 90% during the monsoon period.

In regard to the agricultural meteorology data, including sunshine hours, wind velocity, and evaporation, records are available between 1976 and 1983 at the Hardi Nadi observation station located in the north of Janakpur Airport. Sunshine hours are 6-7 per day during the monsoon period and more than 8 hours per day during the rest of the year. The maximum sunshine hours reaches 10 hours during May. The wind velocity is 2-4 km/hr during the winter, with a maximum of 10 km/hr during the monsoon period. Evaporation is a maximum 7 mm immediately before the monsoon period, approximately 5 mm during the monsoon period, and a minimum of 2 mm during the winter.

b) Hydrology

All of the rivers in the district originate in the Churia Hills. Rainfall is the main source of water for both perennial and seasonal rivers, and most of the rivers are dry during the winter season, except for the perennial rivers, which include the Bighi, Ratu, Janpha, Marha, and the Hardi Nadi. Rivers are fed by groundwater during the winter season.

No rivers in the district have been gauged so far, and hydrological data in the district is not available. However, runoff discharge records are available for the Bagmati River and Kamala River, which flow a distance of 30 km toward the west and the east, respectively, from the district border. The Bagmati River station is located at Paurai, and the gauge for the Kamala River is located at Chisapani. The drainage areas of each station are 1,750 km2 and 1,590 km2, respectively.

(3) Banke District

a) Meteorology

The entire district is under the influence of humid subtropic and tropic monsoon climates. Significant differences in temperature and rainfall has been observed, based on the topography which varies in ground elevation from 132 m to 1,131 mamsl. Because of the existence of the Churia Range and the Bhabar region at its foothills, the northern part of the district has relatively low temperatures and a higher degree of precipitation compared with the southern part. The southern part of the district is famous for its tropical climate, with extremely hot summers and warm winters. The maximum temperature in Nepalganji has occasionally been reported at 48°C.

Seven meteorological stations are located in and around the district. Based on the station records, the annual precipitation varies from 500 mm to 2,600 mm, while the mean monthly rainfall ranges from trace in the winter to about 600 mm during the monsoon season. The following shows a time-series annual rainfall at the Khajura station.

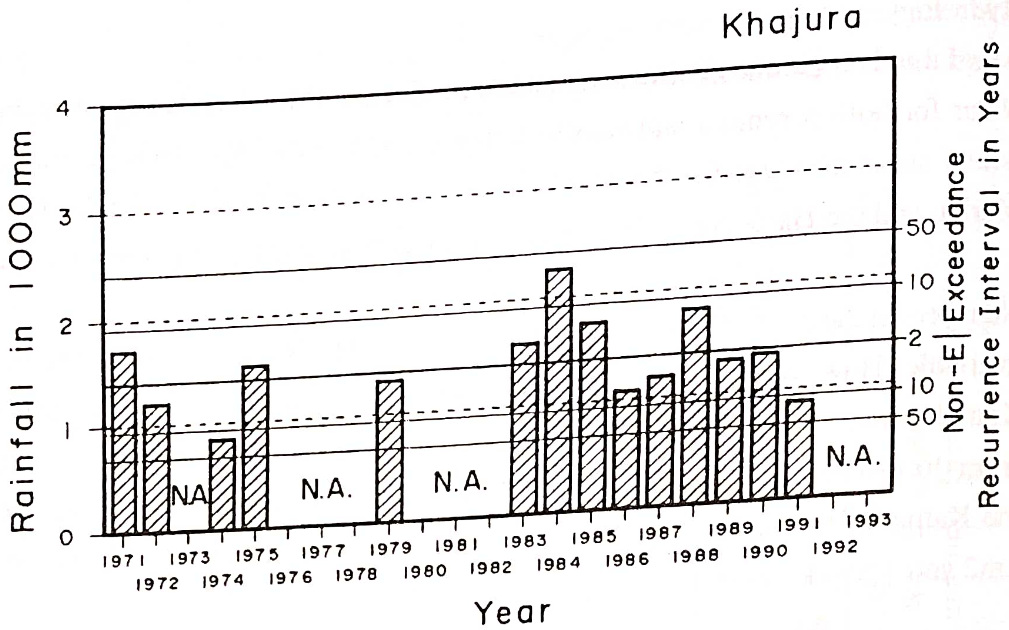


Figure 4.2.3 Annual Rainfall at the Khajura Station

Based on the annual rainfall at Khajura, the drought frequency is analyzed by the Gumbel Method. As shown below, the 10 year recurrence interval is 957 mm and the 20 recurrence year is 866 mm, which is approximately 900 mm less than those in Jhapa district.

Recurrence interval, year :	2	5	10	15	20	30	50	100
Probable annual rainfall, mm:	1386	1087	957	900	866	826	785	742

The mean monthly temperature at the Khajura station ranges from 15°C to 30°C, and the mean minimum and maximum temperatures are approximately 3°C and exceeding 41°C.

The meteorological data for agriculture at the Khajura station show the sunshine hours to be 6-7 hr/day during the monsoon period and more than 8 hr/day during the rest of the year. The wind velocity is 2-3 km/hr during the winter and a maximum of 7 km/hr during the monsoon period. Evaporation is a maximum of 8 mm immediately before the monsoon period, approximately 5 mm during the monsoon, and a minimum of 2 mm during the winter.

b) Hydrology

The major rivers in the district are the Rapti, Manda, Dundwa, Kirin, and the Babai; the minor rivers are tributaries of these rivers. With the exceptions of the Rapti and Babai rivers, all other rivers originate in the Churia Range and flow southward. Rapti River and Babai River, which are the largest rivers in the district, originate in the hill region. The two rivers flow east to west in the hill region, enter the district from its eastern border, and flows directly south.

The runoff discharge for the Rapti and Babai rivers has been gauged regularly. The Rapti station is located at Jalkundi and the Babai station at Bargadha. Their drainage areas are 5,150 km2 and 3,000 km2, respectively.

(4) Database

A database (JDBASE) has been created during the study period for the inventory of precipitation, river discharge, groundwater level, and well constants using Lotus 1 2 3 for the meteohydrological stations. As well, a program to detect these items and to plot precipitation, river discharge, and groundwater levels on a screen has been developed. The database and program in the attached floppy disc were handed over to DOI; its operation manual is shown in Appendix 3.

4.3. Socio-Economy

4.3.1. Terai

(1) District Division

The Terai, which is the northern stretch of the Indo- Ganges Plain, occupies 14.3% of Nepal and 41.6% of Nepal's cultivated area. The plain can be divided into five development regions and 20 districts. The districts of Jhapa, Mahottari and Banke, in which the study areas are selected, belong to the Eastern, Central and Mid-Western Development Regions, respectively.

(2) Population and Number of Households

As of 1991, the total population in the Terai accounted for 47% of the national population, followed by the hill districts at a rate of 46%. The Terai also accounts for 45% of the number of households in the country, followed by the hill districts' 47%; and the annual population growth in the area since 1981 has been 2.8%, which is higher than the national average (2.1%).

(3) Industrial Structure

In order to promote industrial development, HMGN has established 11 industrial districts throughout the country. There are five industrial districts in the Terai Plain and the remaining six districts are located in the hill districts. Existing industries, excluding the shoe and cement industries, are agriculture-based, such as rice and sugar mills, tobacco, and jute.

4.3.2. Jhapa District

(1) Administrative Division

The Jhapa District is divided into nine sectors, composed of 49 villages and two towns. The district's total area is 156,500 ha, of which 105,121 ha are cultivated. The Study Area extends 29,700 ha, covering 16 villages (refer to Figure 4.3.1 (1)).

(2) Population and Number of Households

As of 1991, the population is 593,737, with a density of 379 persons/km2. The population has grown at the rate of 2.15% per year, which is similar to the national average and the highest among the three study districts, which include Mahottari and Banke. The total number of households is 110,939, with 5.36 members on an average. The average village population is 11,640, with 2,170 families; and 66% of the economically active population are engaged in the agricultural sector as of 1991.

(3) Industrial Structure

This district is known as the paddy and tea producing district in the country. Agri-based industries are the major industries in the district. There are 762 rice/oilseed extract mills, 47 bakeries, and 2 jute, 40 tea, and 5 milk processing factories, among others. Rice mills are often combined with oilseed extract mills.

4.3.3. Mahottari District

(1) Administrative Division

The Mahottari District is divided into nine sectors, composed of 77 villages and one town. The district's area is 101,238 ha, of which 63,754 hectares are cultivated. The Study Area extends to two separate areas, covering a total of 9,800 ha, with 17 villages (refer to Figure 4.3.2).

(2) Population and Number of Households

As of 1991, the population is 440,146, with a density of 434 persons/km2, which is the highest among the three districts. The average growth rate since 1981 is 2.0%, which is lower than the national average of 2.1% and the lowest among the three districts. The total number of household is 80,396, with 5.48 members on average. The average village population is 5,640, with 1,030 families; and 79% of the economically active population are working in the agricultural sector.

(3) Industrial Structure

There are 176 rice/oilseed extract mills located in the District.

4.3.4. Banke District

(1) Administrative Division

The Banke District is divided into nine sectors, composed of 46 villages and one town. The district's area is 225,836 ha, of which 49,072 ha are cultivated. The Study Area extends to 12,100 ha (refer to Figure 4.3.3).

(2) Population and Number of Households

The current population is 285,604; the district's population growth is 3.36%, which is the highest among the three districts. The population density is 126 persons/km2, which is the lowest among the three districts, though slightly higher than the national average of 125/km2. The total number of households is 49,059, with 5.8 persons on average. The average village population is 6,070, with 1,040 households, and 68% of the economically active population are employed in the agricultural sector.

(3) Industrial Structure

Agri- and forestry-based industries are located in the district include 247 rice/oilseed extract mills, 5 sawmills, 4 textile factories, 28 bakeries, and 4 milk processing factories, among others.

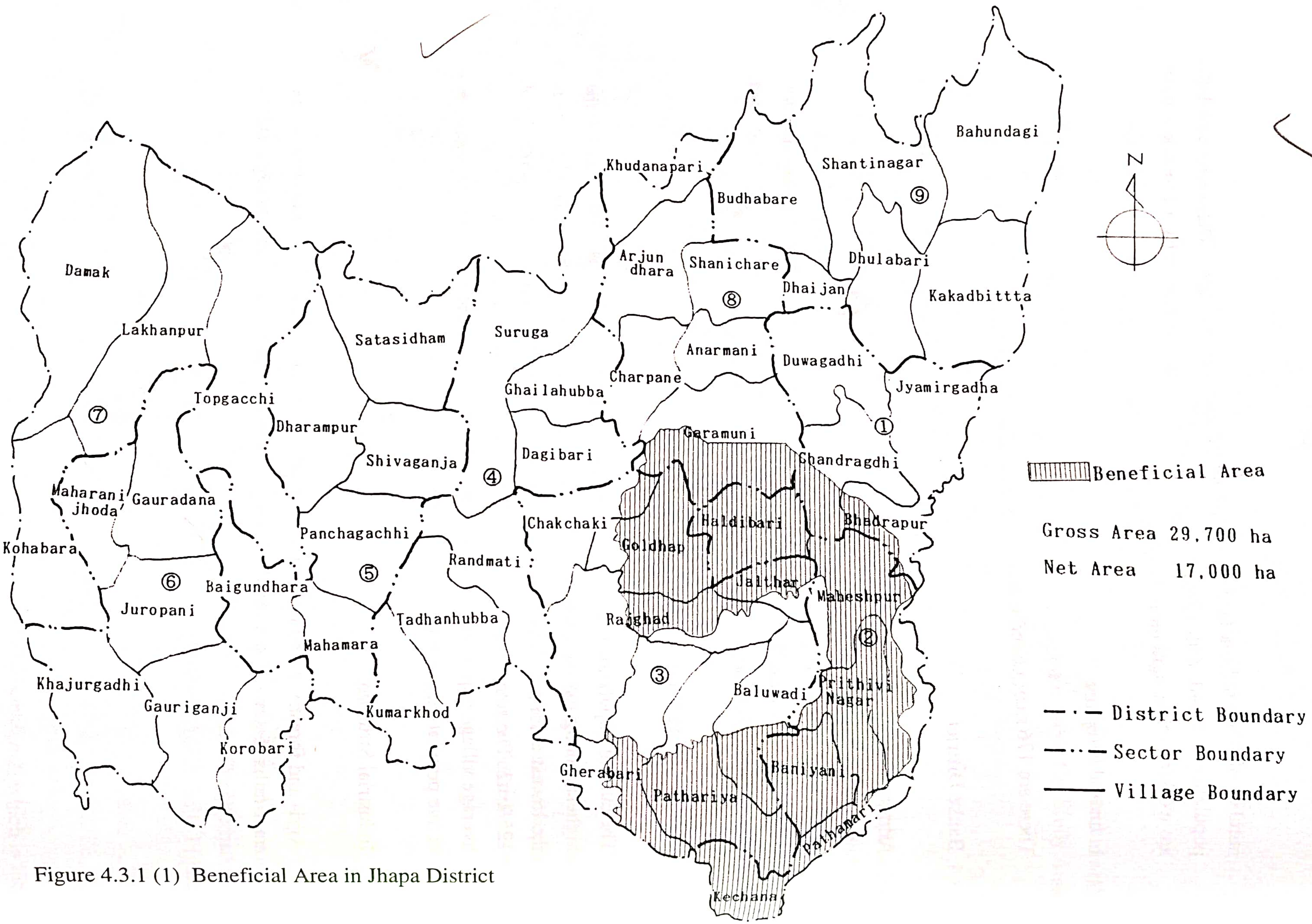


Figure 4.3.1 (1) Beneficial Area in Jhapa District

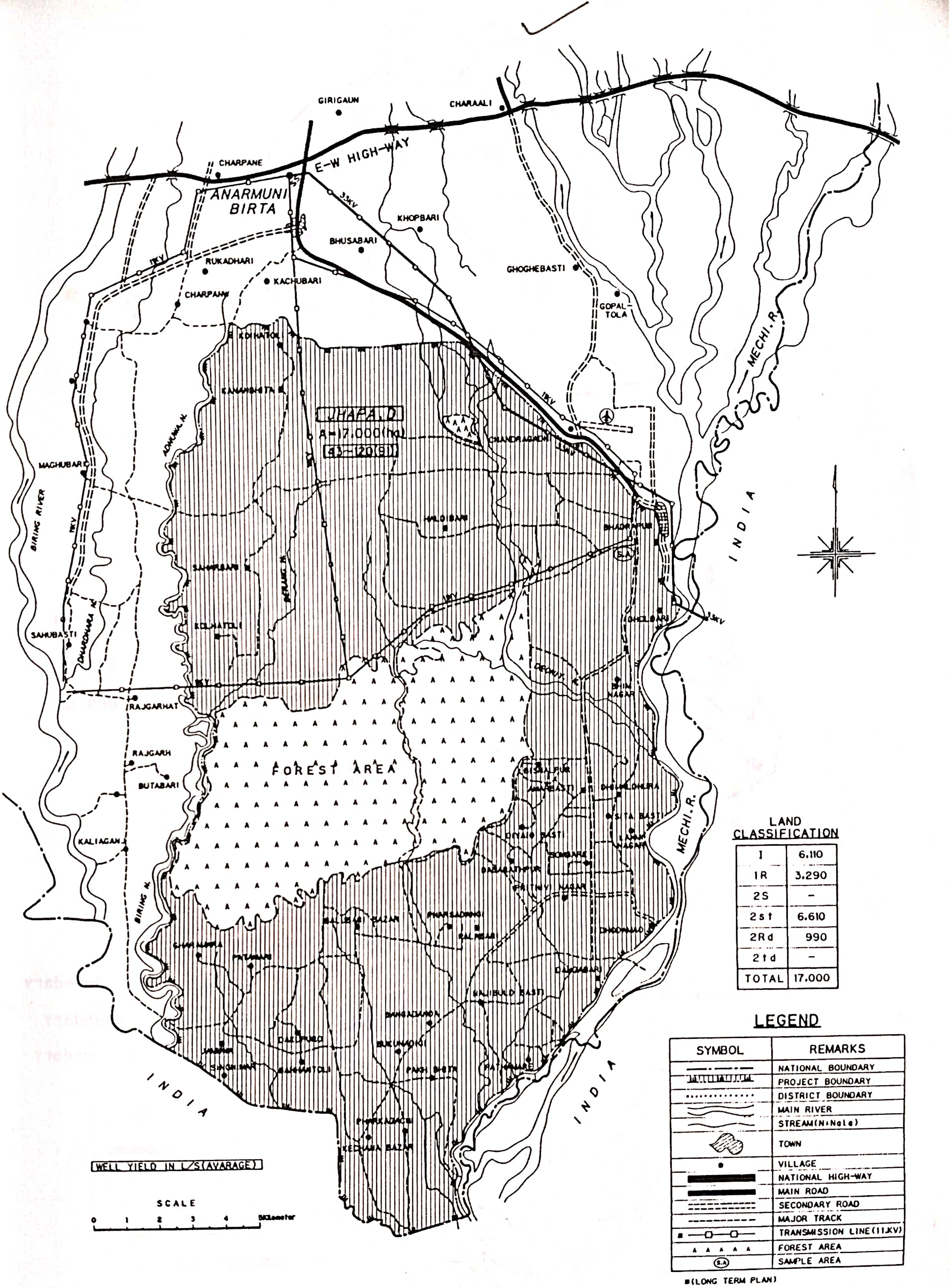


Figure 4.3.1 (2) Beneficial Area in Jhapa District

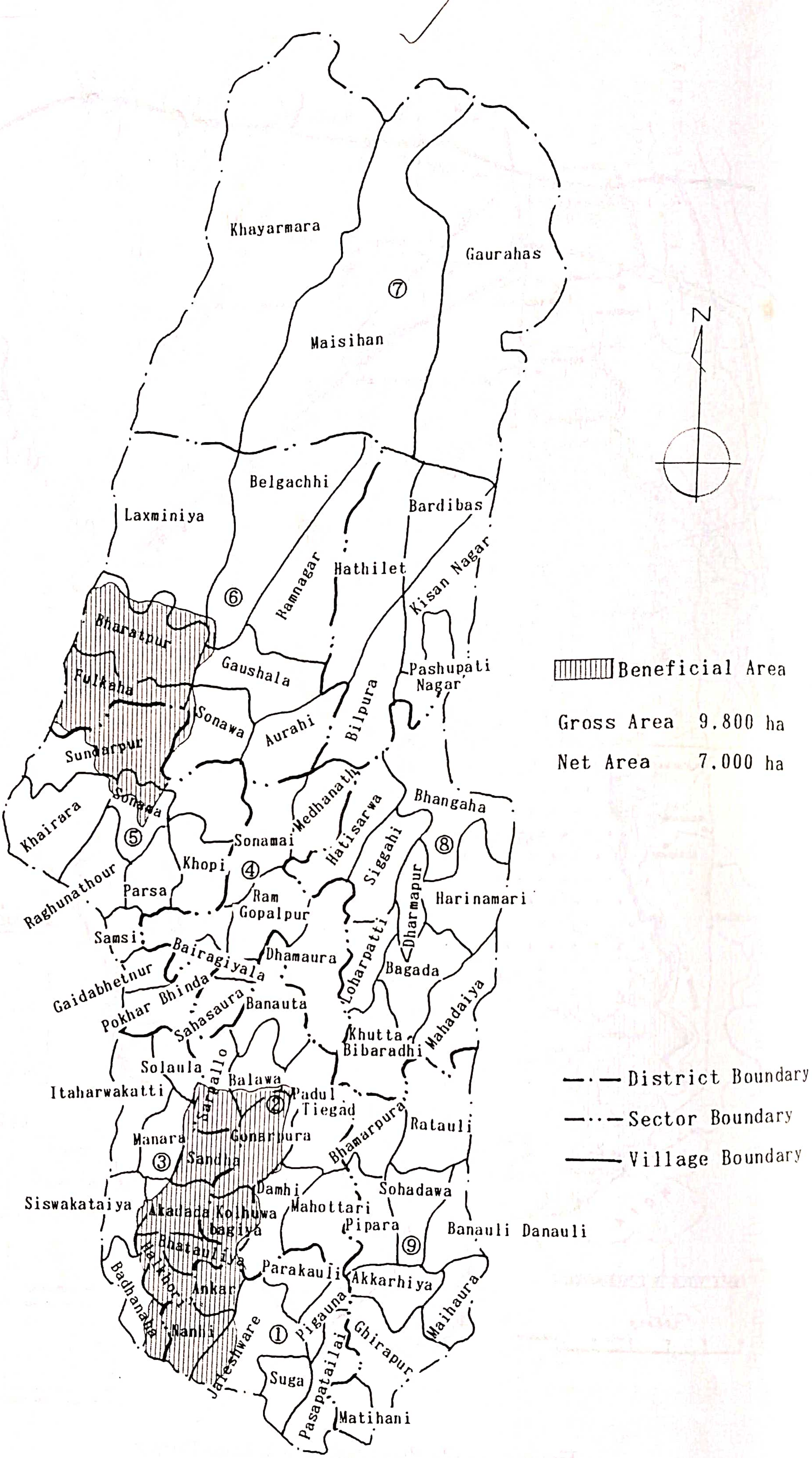


Figure 4.3.2 (1) Beneficial Area in Mahottari District

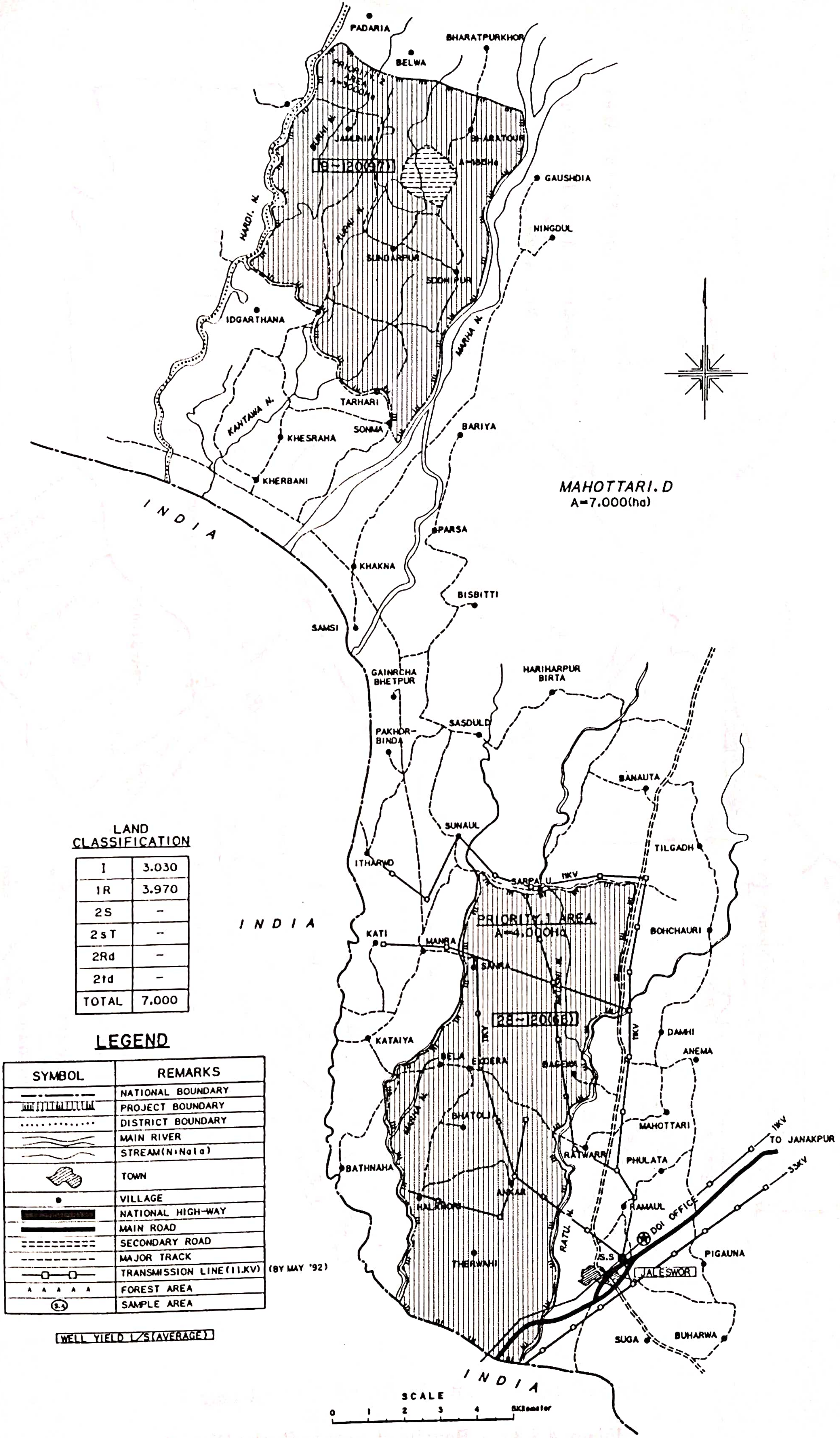


Figure 4.3.2 (2) Beneficial Area in Mahottari District

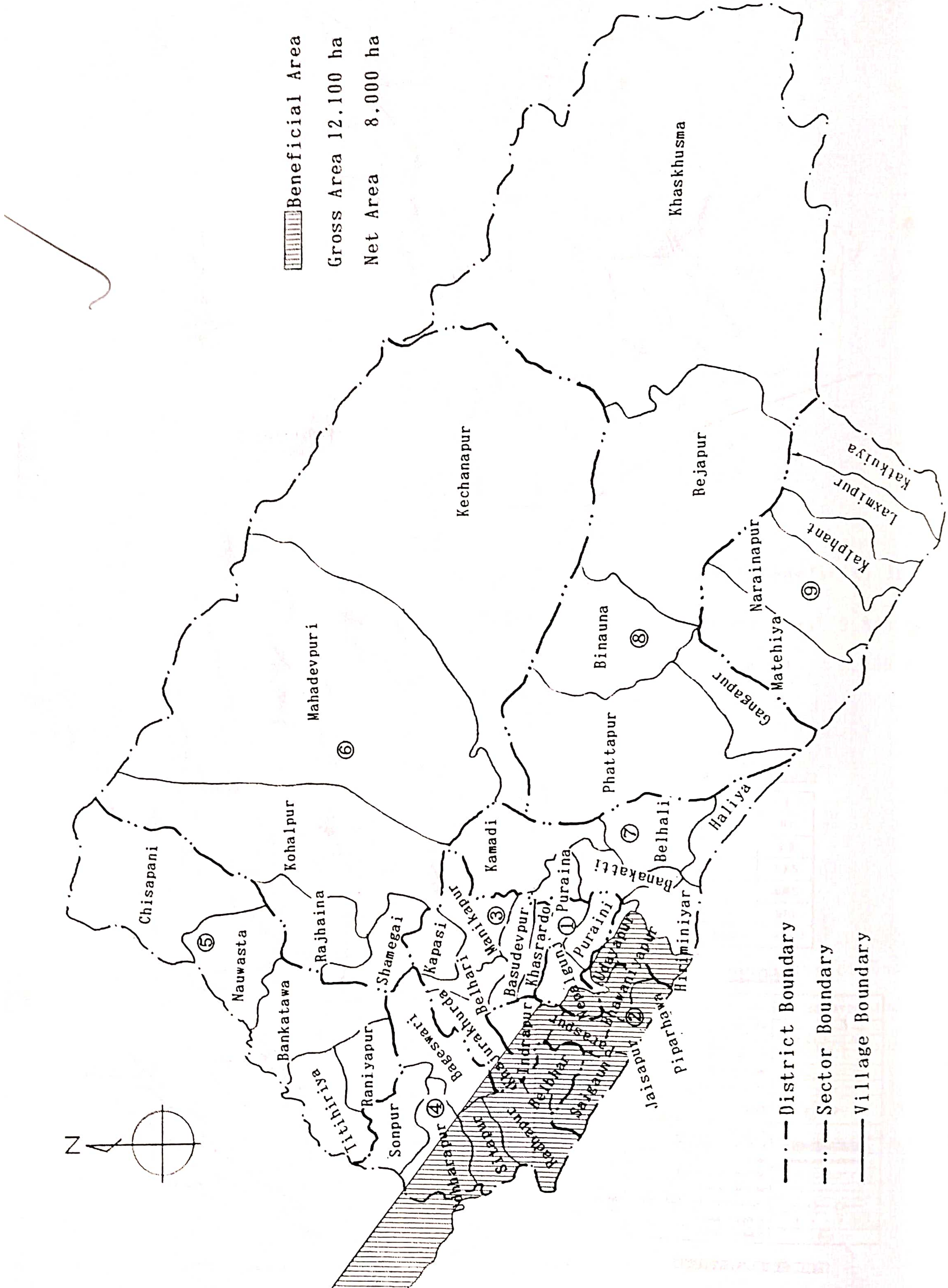


Figure 4.3.3 (1) Beneficial Area in Banke District

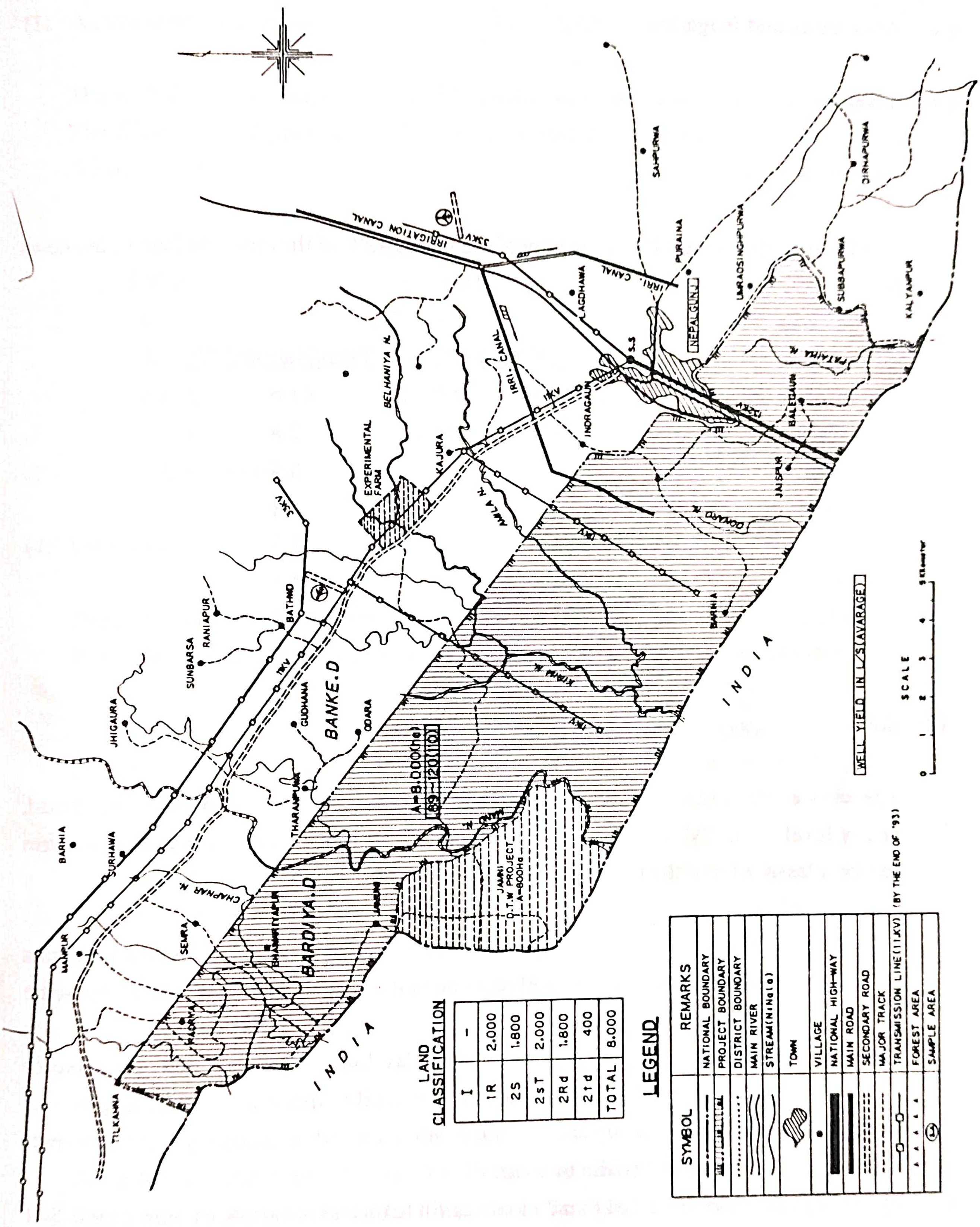


Figure 4.3.3 (2) Beneficial Area in Banke District

4.4. Agriculture and Irrigation

4.4.1. Terai

(1) Cultivated Area

The Terai accounts for 14% of the nation's land and 42% of the cultivated areas, as shown below.

	Acreage (1,000 ha)	Terai/National (%)
Cultivated area	1,234.6	41.6
Grazing land	49.7	2.8
Forest	591.3	10.5
Bush	1.4	0.2
Non-cultivated	117.1	11.9
Others	116.1	4.3
Total	2,110.2	14.3

(MOA, 1990)

(2) Soil

The soils of the Terai are developed mostly on recent alluvial sediments of the broad, nearly level to gently undulating plain in the southern part of the country. Soil textures can be classified into the following four types.

Type (I) Textures are mostly sandy loam to clay loam, and occasionally silty clay loam and silty clay textures. Soil reaction is moderately acidic to neutral, but some portions are alkaline.

Type (II) Textures are mostly silt loam, silty clay loam, silty clay, and occasionally sandy loam to loam. Soil reaction is neutral to moderately alkaline.

Type (III) Textures are mostly sandy loam or silt loam and occasionally loam. Soil reaction is slightly acidic to neutral.

Type (IV) Textures are mostly sandy loam or silt loam and occasionally loamy sand. Soil reaction is slightly acidic to mildly alkaline.

(3) Agricultural Production

Major food grain production in 1992/93, nationwide and in the Terai, is outlined below. The Terai shows higher production in paddy and wheat and is noted as the granary of Nepal.

	National	Terai
Paddy	2,584,900 t	1,840,620 t (71%)
Maize	1,290,500	325,440 (25%)
Millet	236,750	14,340 (6%)
Wheat	765,000	432,720 (57%)
Barley	27,610	2,860 (10%)

(MOA, 1993)

(4) Livestock

The number of livestock in 1992/93, nationwide and in the Terai, is listed below; the Terai Plain also produces 32% of the nation's milk.

	National	Terai
Cattle	6,237,231	2,256,660 (36.2%)
Buffalo	3,072,682	972,959 (31.7%)
Sheep	911,279	142,406 (15.6%)
Goat	5,451,710	1,545,170 (28.3%)
Pigs	604,902	170,224 (28.1%)
Ducks	391,718	334,466 (85.4%)
Milk Production	876,594 (t)	280,063 (31.9%)

(MOA, 1993)

(5) Irrigation

According to agricultural statistics for 1990, there are 608,877 ha of irrigated land in the Terai, which is 49% of the 1.235 million ha of farmland in the plain area. This figure is higher than the national average of 32%. Furthermore, 65% of the nation's total irrigated area of 941,299 ha are concentrated to the Terai because of land conditions.

4.4.2. Jhapa District

(1) Farmland and Land Use

The Jhapa District boats the largest farmland area, mounting to 105,121 hectares, out of three districts under the study. The use of farmlands of the Jhapa District consists mostly of the production of cereals, with rice being planted in the arable areas of flat lands and maize in the terraces. Since the climatic conditions of the area in question are favorable, as mentioned previously in this report, at places where the water availability conditions are appropriate it is possible to plant rice throughout the year. As things now stand, however, in the southeastern and southwestern parts of the Jhapa District only monoculture farming is being practiced during the rain season. The planted area by crop prevailing currently in this region is shown in the followings. From these data, it can be seen that the cropping intensity of the Jhapa District mounts to 151%.

Cereals	132,362 ha
Pulses	2,497
Root crops	2,514
Cash crops	7,061
Oilseed crops	5,898
Peppers	1,403
Vegetables	2,486
Fruit	4,491
Others	346
Total	159,058

(CBS, 1993)

(2) Soils

Alluvium is widely distributed throughout the Jhapa District. And there is predominance of sandy loam (clay content of 12.2 to 25%) and clay loam (clay content of 37.5 to 50%). The water holding capacity is good, and the soil has characteristics suited for irrigation. The chemical properties of the soil ranges from weak alkaline to neutral, and the content of humus is of the order of 0.2 to 5%. The content of nitrogen is rather low, and phosphates and potassium ranges from medium to high.

As per the soil conditions, there are no restrictions in particular against the cultivation of crops, and generally speaking there are large patches of farmland (Khet) suited for the cultivation of rice. However, there are also patches of farmland that are not suited for cultivation of rice (Bari), and the cropping pattern comprising other kinds of crops, mainly maize, is predominant in those areas.

(3) Number of Farm Households and Land Holding

The number of farm households is 74,727, including landless farmers, and the average farm size is 1.41 ha, based on the National Sample Census of Agriculture in 1991/92.

Farmers who own less than one hectare occupy 52% of the total number of farm households, as shown below.

Landless	1,104	(1.5%)
Less than 0.1 ha	9,326	(12.4%)
0.1-0.2	4,663	(6.2%)
0.2-0.5	10,062	(13.4%)
0.5-1.0	13,620	(18.2%)
1.0-2.0	18,324	(24.5%)
2.0-3.0	9,898	(13.2%)
3.0-4.0	2,986	(4.0%)
4.0-5.0	2,004	(2.7%)
5.0-10	2,413	(3.2%)
Above 10 ha	327	(0.4%)
Total	74,727	

(CBS, 1993)

The number of farm household in the Study Area is estimated at 12,080.

(4) Present Cropping Patterns

Major grain crops in Jhapa District are paddy rice, maize and wheat. Within the category of vegetables, potatoes are the most important crop. The predominant cropping pattern is described in the followings. Double and triple cropping is possible in irrigated farmland, but in rain-fed farmlands the predominance of single crop of rice during the rain season becomes unavoidable.

Irrigated Area	Monsoon Paddy-Wheat Spring Paddy-Monsoon Paddy-Wheat
Rainfed Area	Monsoon Paddy-Fallow Monsoon Paddy-Pulses/Oilseed Crops Maize-Pulses/Oilseed Crops/Millet

As for the monsoon paddy, the planting is made from July to mid August, and the harvesting period is from mid November to mid December. Maize, which is the second most important crop after rice, has its seeds sown since mid March, and the harvesting is made about mid June. In most of the cases, the rain-fed farmlands remain fallow after the rice cultivation during the rain season, but crops that require small amounts of waters, such as beans, mustard and the like are being planted in some areas. As a general rule, potatoes are planted from August to November, and are harvested in the second half of February. The cultivation of mustard, which is an oil crop, is being practiced very popularly as a second crop after the harvesting of rice, which is planted during the rain season in the rain-fed farmlands.

The cropping pattern which is predominant in the study areas consists of the "monsoon paddy - fallow" sequence, out of the various kinds of cropping patterns mentioned above. The other kinds of crops that are being planted popularly are barnyard grass, beans and the like. Figure 6.2.1 shows the cropping pattern that is being practiced currently in the study area. It consists of monsoon paddy, spring maize and wheat. The present cropping intensity is of the order of 126%, which is lower than the mean value prevailing in the Jhapa District as a whole.

(5) Agricultural Production

The following table shows the crop production in Jhapa District in 1992/93. Jhapa District produces the highest amount of paddy among the three study districts and is responsible for 7.8% of the nation's paddy production, which is also the highest among 75 districts in Nepal. Maize, wheat, and potatoes follow paddy, and the tobacco represents 12% of the national production.

	Production (t)	Ratio to National (%)
Paddy	202,630	7.8
Maize	18,630	1.4
Millet	2,190	0.9
Wheat	13,090	1.7
Barley	20	0.1
Oil-seed crops	1,790	1.9
Potatoes	12,960	1.8
Tobacco	730	12.1
Sugarcane	5,500	0.4
Pulses	890	0.4

(MOA, 1993)

(6) Farming Practice

As a general rule, plowing and paddling are carried out 2 or 3 times, by using buffalo or draft cattle as motive force. There is practically no use of agricultural machinery within the study areas. The timing of farming mentioned above varies from year to year depending on rainfall, the availability of cattle and manpower, etc. The required nursery area is of the order of 6 to 7% of the paddy field, and the nursery period takes approximately one month. The transplanting is widely practiced in this area. Weeding during the growing period is not so common. Weeds are seen very often in the paddy fields. It is presumed that the expensive price of the herbicides is the problem lying in the background of the said situation. In the same way as in the case of herbicides, the use of chemical fertilizes is also extremely limited, and the kind of fertilizer that is being used consists mostly of manure.

Harvesting is carried out by man power inclusive of women and children. Man power required for harvesting rice is of the order of 20 man-day per hectare. Harvested rice is submitted to preliminary drying during 5 to 6 days at the paddy field. After that, it is transported to the farm houses, where it is threshed by making use of cattle power or man power. Finally, the paddy is dried at the yards of the farm houses or on the roads. Most of the villages are equipped with a small rice mill, where the threshing operation is carried out. Frequently, these rice mills are also used for squeezing oil from the oil seeds. Part of the paddy is kept as seed, which is planted in the next year.

Water buffaloes and cattle play an important role as a motive force for plowing, transportation, marketing and other kinds of work. On the other hand, women and children are important work force for the sake of such farming activities as harvesting, transportation, obtainment of animal feeds and the like.

After the harvesting of monsoon paddy, which is the principal crop, other kinds of upland crops such as wheat, mustard, beans, vegetables and the like are planted in some fields. As a general rule, plowing and leveling work are carried out 2 or 3 times before seeding the said crops.

(7) Marketing

Paddy is marketed in the following manner: farmer-middleman-wholesaler/miller-retailer-consumer. Vegetables are sold to retailers directly or marketed by farmers at the nearest local market. Crops are transported by cattle carts, bicycles, and human power.

(8) Livestock

Animal husbandry is not being practiced in commercial basis, but cattle and water buffaloes are an important motive force for farming and transportation because the use of agricultural machinery is very low in the country. Moreover, the sale of milk and calf is a source of 20% to 30% of the total farm income. On the other hand, poultry consisting of chicken, ducks and the like is being raised at the yard of almost every farmhouse. The composition of the flock of livestock of the Jhapa District as of 1992/93 is shown in the followings. The number of heads of cattle and water buffaloes that exist currently within the Jhapa District is the largest out of three Districts under the study. Therefore, the production of milk is also the largest out of the Districts.

	Number	Milk Production (ton)
Cattle	191,340	14,507
Buffalo	75,986	13,362
Sheep	51	
Goats	105,788	
Pigs	22,357	
Chickens	178,031	
Ducks	25,183	

(MOA, 1993)

(9) Farm Economy

Generally speaking, farm size less than 0.50 hectares is classified as small farm in Nepal. In the Jhapa District, the farms belonging to this category account for 32% of the total. Besides these small farms, there are 1,104 landless farm households.

According to the World Bank, it is presumed that 74% of the households of the rural areas of Nepal live on incomes below poverty line. According to the NPC, the poverty line at the Terai is estimated to be of the order of Rs28,000 per year for a household of 6 persons. According to data collected by the Study Team that authored this report, the annual income of a farm household ranges from Rs13,200 to Rs60,000, depending on the size of the farm. In view of the said figures as well as the existence of landless farmers, it is presumed that the rate of poverty incidence of farms is quite high also in the Jhapa District.

The agricultural production of the Jhapa District consists mostly of cereals, but the price levels of oil seeds, beans and vegetables tend to be higher compared with rice and maize. Income related to livestock account for 20% to 30% of the total farm income.

(10) Irrigation

Jhapa District has an arable land area of 105,121 hectares, with 47,854 hectares of irrigated land. In other words, 46% of the arable land of Jhapa District is being irrigated by rivers, wells and other sources. The irrigation rate of Jhapa District is the highest of three Districts under the study.

Jhapa District belongs to a subtropical climate, and its geology is an alluvium, crossed from the north to the south by many rivers of various sizes, including the Kankai and the Mechi. Jhapa District, therefore, has better conditions of irrigation than any other Districts under the study, and that is resulting into a larger percentage of irrigated areas compared with the other Districts. The irrigation projects that are operating presently in Jhapa District are mostly surface water type, including the Kankai Irrigation Project.

(11) Food Balance

According to the District Profile of 1988, the state of supply and demand of food in Jhapa District consists of a production of 97,041 tons compared with a demand of 96,841 tons. As can be seen, there is a surplus of 200 tons. The agriculture production in the District deemed to be unstable since the agriculture in the District depends largely on the rainfed condition; and is subject to be affected in some year by drought or flood.

(12) Supporting Services

a) Agricultural Development Office (ADO)

Jhapa's ADO office is under the control of Regional Agricultural Office in Dhankuta. There are six agricultural service centers and 11 subcenters under District ADO, which support farming activities. Junior technicians (JT) and junior technical assistants (JTA) are assigned to guide leader farmers who are selected by farmers and pass on agricultural techniques to other farmers. The main activities of the JTs and JTAs include training, demonstration, exhibitions, and visiting farmers on their fields.

b) Agricultural Research Station

There are two research stations - the Pakhribas Regional Research Station and the Rampur Multi-Purpose Farm Station. These stations research crop development, cropping patterns, the distribution of nurseries, experiments in the fields and training for farmers.

c) Agricultural Development Bank (ADB/N)

To support the farmers with credit, a branch office of ADB/N is located in Chandragadhi. Three types of credit are provided to farmers: short-, medium- and long-term loans, and the current interest rates are 16% to 19%. Despite this public service, many farmers use private loans at higher interest rates.

Since 1975 the ADB/N is carrying out the Small Farmer Development Program (SFDP). This program aims at promoting the alleviation of poverty, the improvement of the education level and the formation of leadership among small farmers. Within the context of that program, the ADB/N is providing financing that covers groups of small farmers, including the landless ones. The monetary resources provided by the said financing program are utilized for such initiatives as equipment of irrigation facilities, the transfer of cropping technology, the training related to household industry, etc. to exert impact of various kinds, such as the improvement of the living standards of the rural households, the creation of employment opportunities, etc., within the rural society.

d) Agricultural Inputs Corporation (AIC)

AIC, whose head office is located in Kathmandu, has 12 zonal offices and 73 branch offices. Two branch offices are located in Jhapa, Damak, and Bhadrapur. AIC functions in distributing farm inputs such as seeds, fertilizer, agro-chemicals, and machinery to farmers through cooperatives.

(13) Farmers' Organization

The representative Farmers' Organization is a cooperative which functions in distributing agricultural inputs provided from AIC to farmers, procuring paddy from members, and selling to Nepal Agriculture Corporation (NAC). There are 27 cooperatives at present in Jhapa District.

4.4.3. Mahottari District

(1) Farmland and Land Use

The acreage of the farmland in Mahottari District is 63,754 ha, which is the largest next to Jhapa District. Present cropping intensity in the district is estimated at 171% as shown below:

Cereals	77,711	ha
Pulses	19,190	
Root crops	1,263	
Cash crops	1,945	
Oilseed crops	4,892	
Peppers	769	
Vegetables	1,315	
Fruit	1,955	
Others	5	
Total	109,045	

(CBS, 1993)

(2) Soils

Similar to Jhapa District, the soil type is classified as Type (I). Soil textures are sandy loam or clay loam, and soil reaction is weak-acid to neutral.

(3) Number of Farm Households and Land Holdings

According to the National Sample Census of Agriculture in 1991/92, there are 58,559 farm households in the district, including landless farmers: this is second to Jhapa among the three districts.

The ratio of farm households who owns less than one hectare is 60%, the top among three districts, and the average farm size is 1.09 ha, which is the smallest among the three districts. The number of farm households by farm size is shown as follows:

Landless	485 (0.8%)
Less than 0.1 ha	3,516 (6.0%)
0.1-0.2	7,002 (12.0%)
0.2-0.5	13,611 (23.2%)
0.5-1.0	13,605 (23.2%)
1.0-2.0	11,398 (19.5%)
2.0-3.0	4,365 (7.5%)
3.0-4.0	2,031 (3.5%)
4.0-5.0	1,364 (2.3%)
5.0-10	1,000 (1.7%)
Above 10 ha	182 (0.3%)
Total	58,559

(CBS, 1993)

The number of farm households in the Study Area is estimated at 6,420.

(4) Present Cropping Patterns

The following cropping patterns are observed in the district.

Irrigated Areas	Spring Paddy-Monsoon Paddy-Wheat
	Spring Paddy-Monsoon Paddy-Maize
	Spring Paddy-Monsoon Paddy-Pulses/Oilseed Crops
	Monsoon Paddy-Wheat-Pulses
	Monsoon Paddy-Potato-Pulses
Rainfed Areas	Monsoon Paddy-Fallow
	Monsoon Paddy-Wheat Fallow
	Monsoon Paddy-Pulses-Fallow
	Monsoon Paddy-Oilseed Crops-Fallow
	Maize-Pulses/Oilseed Crops/Millet

In the Study Area, the pattern of Monsoon Paddy-Fallow is dominant, and pulses, as represented by pigeon peas, and wheat are also planted. Plowing for monsoon paddy begins in the middle of June, after the land is soaked with rainfall, and crops are harvested from mid November to the mid December (refer to Figure 6.2.2 in Chapter 6).

(5) Agricultural Production

Mahottari District produced 3.5% of the wheat, 19.9% of the tobacco, and 4.7% of the pulses of national production in 1992/93 as shown below:

	Production (t)	Ratio to National (%)
Paddy	52,140	2.0
Maize	8,200	0.6
Millet	1,960	0.8
Wheat	26,510	3.5
Barley	220	0.8
Oilseed crops	2,360	2.5
Potatoes	8,140	1.1
Tobacco	1,200	19.9
Sugarcane	43,610	3.2
Pulses	9,540	4.7

(MOA, 1993)

(6) Marketing

The marketing of paddy is similar to that in Jhapa District: farmer-middleman-wholesaler/ miller-retailer- consumer. Vegetables and milk are sold directly by farmers to the nearest local market or sold directly to retailers; transportation is dependent on cattle carts, bi-cycles, and manpower.

(7) Livestock

The number of cattle and buffalo, along with milk production is one half that of Jhapa District as shown below:

	Number	Milk Production (t)
Cattle	97,854	4,190
Buffalo	39,882	8,918
Sheep	1,258	
Goats	106,065	
Pigs	1,970	
Chickens	85,016	
Ducks	6,671	

(MOA, 1993)

(8) Irrigation

Of the district's 63,754 ha of farmland, 17,313 ha, or 27%, are irrigated, which is second to Jhapa's 46% among the three districts.

(9) Food Balance

Food production in Mahottari District is 73,635 tons, while demand is 57,006 tons. There is a 16,629 ton surplus according to the District Profile in 1988.

(10) Supporting Services

a) ADO
Mahottari's ADO is under the control of the Regional Agricultural Office in Kathmandu. There are six agricultural service centers and 11 subservice centers under District ADO, and JTs and JTAs are dispatched to provide agricultural extension services to the selected leader farmers, who in turn guide other farmers.

b) Agricultural Research Stations
There are two agricultural research stations - a horticulture research station in Janakpur and a multi-purpose farm station in Rampur. These research stations are in charge of experimental crop testing, the distribution of nurseries as well as extension activities and others.

c) ADB/N
ADB/N, located in Jaleswar, supports short-, medium- and long-term credit for farmers.

d) AIC
The AIC branch office at Jaleswar supplies agricultural inputs such as seeds, fertilizer, agro-chemicals, and machinery to farmers through cooperatives.

(11) Farmer's Organization

There are 31 cooperatives with 1,110 members, which act as representative farmers' organizations through which farm inputs procured by AIC are distributed to farmers.

4.4.4. Banke District

(1) Farmland and Land Use

The acreage of farmland in Banke District is the smallest of the three districts at 49,072 ha. The present cropping intensity in 1991/92 is estimated at 142% as shown below:

Cereals	51,745 ha
Pulses	12,079
Root crops	555
Cash crops	29
Oilseed crops	4,253
Peppers	126
Vegetables	468
Fruit	323
Others	58
Total	69,618

(CBS, 1993)

(2) Soils

The soil type is classified as Type (I). The soil textures are sandy loam or clay loam, and soil reaction is weak acid to neutral.

(3) Number of Farm households and Land Holdings

As of 1991/92, there are 35,912 farm households, with an average size of 1.37 ha. The average farm size is the second largest among the three districts, following Jhapa District; and farmers who own less than one hectare accounts for 50% of the total.

Landless	694	(1.9%)
Less than 0.1 ha	2,372	(6.6%)
0.1-0.2	1,369	(3.8%)
0.2-0.5	4,899	(13.6%)
0.5-1.0	8,718	(24.3%)
1.0-2.0	9,701	(27.0%)
2.0-3.0	4,899	(13.6%)
3.0-4.0	1,659	(4.6%)

4.0-5.0	675 (1.9%)
5.0-10	810 (2.3%)
Above 10 ha	116 (0.3%)
Total	35,912

(CBS, 1993)

The number of farm households in the Study Area is estimated at 5,850.

(4) Cropping Patterns

The following cropping patterns are dominant in the district.

Monsoon Paddy-Fallow
Maize/Millet-Mustard
Pigeon Pea
Monsoon Paddy-Cereals

Figure 6.2.3 in Chapter 6 shows the present cropping pattern in the Study Area. Cultivation for monsoon paddy begins with the preparation of nursery beds, after the land is soaked by rainfall. Paddy is harvested from the mid November to mid December when wet season is over.

(5) Agricultural Production

The ratio of agricultural production in 1992/93 is 4.2% for pulses and 1.4% for paddy. The amount of rainfall and irrigated area are both the smallest among the three districts, and as a result, cropping conditions in the district are poor.

	Production (t)	Ratio to National (%)
Paddy	36,120	1.4
Maize	20,710	1.6
Wheat	10,400	1.4
Barley	20	0.1
Oilseed crops	2,430	2.6
Potatoes	4,600	0.6
Tobacco	40	0.7
Sugarcane	4,270	0.3
Pulses	8,580	4.2

(MOA, 1993)

(6) Marketing

The marketing channels for paddy and other crops are similar to the other two districts: farmer-wholesaler/miller-retailer-consumer. Vegetables and milk are transported to the nearest local market by farmers using cattle carts, bicycles, and human power.

(7) Livestock

The number of sheep is the largest among three districts, but milk production by cattle and buffalo is the lowest as shown in the following:

	Number	Milk Production (ton)
Cattle	81,342	2,437
Buffalo	53,326	7,483
Sheep	10,274	
Goats	81,120	
Pigs	11,197	
Chickens	109,476	
Ducks	1,505	

(MOA, 1993)

(8) Irrigation

Irrigated areas in Banke District represent only 3,317 ha or 6.8% of the cultivated areas in 1991/92, which is the lowest among three districts.

(9) Food Balance

Food production in Banke District is 48,079 tons, while demand is 45,757 tons. There is a 2,322 ton surplus according to District Profile in 1988.

(10) Supporting Services

a) ADO

Banke's ADO is under the control of the Regional Agricultural Office at Surkhet. District ADO is composed of seven divisions, including a crop, horticulture, livestock, and a fishery division, among others. There are four agricultural service centers and nine subcenters distributed under ADO, and JTs and JTAs are assigned to guide leader farmers who are selected from among the farmers.

b) Agricultural Research Station

There are two research stations - a regional research station in Nepalganj and a multipurpose farm station in Surkhet. These stations function in the development of crops, the distribution of nurseries, crop testing in fields, and so on.

c) ADB/N

ADB/N's District Office is located in Nepalganj and offers agricultural credit and deposit services. Recently, ADB/N's services have emphasized the Small Farmer Development Program (SFDP).

d) AIC

AIC's District Office in Nepalganj supplies agricultural inputs and agricultural machinery to farmers through cooperatives.

(11) Farmers' Organization

At present there are 17 cooperatives with 11,518 members to distribute agricultural inputs provided by AIC.

4.5 Infrastructure

4.5.1. Accessibility

(1) Air Route

In the case of Jhapa District, a local air field is located at Chandragadhi, with direct flights from Katmandu four times a week. Another access route is the 115 km drive via Biratnagar in Morang District, which also has daily flights from Katmandu. There is no airport in Mahottari District, but Janakpur in Dhanusha is available to access the site by driving 15 km. Janakpur Airport has a daily flight from Katmandu, and Nepalganji, capital of Banke District, has an airport which receives daily flights from Katmandu.

(2) Land Route

The main transportation route in the Terai is the "E-W Highway," which runs through the Terai Plain from Kakarbitta on the eastern border, to Mahendranagar on the western border, both of which border India. Although the highway is a paved surface road, considerable sections of the road are in rough condition as a result of the poor repair work performed so far. In order to access to the sites, two routes join the E-W Highway crossing the Mahabharat Range: one route is via Mugling to Bharatpur Junction and the other is via Daman Pass to Hetauda Junction.

The land route to Jhapa District is approximately 530 km via the shorter route and takes one full day or two days. The route of the Mahottari District is approximately 310 km through Daman Pass and 400 km via Mugling; a one day drive is sufficient to arrive at the site from any route. For Banke District, the distance is between 530 km and 550 km but it takes two to three days to go to Nepalganj as the route passes through mountainous areas in long sections.

4.5.2. Road Conditions

(1) General

Roads in Nepal are classified and managed as below;

1) Pitched road .... paved road

2) Gravel road .... gravel constructed

3) Mud road .... mud constructed

Among these road types, paved and gravel roads are adequate for vehicle traffic throughout the year, but mud roads are not suitable for vehicles during the rainy season.

(2) Jhapa District

Paved roads extend only 106 km, including 50 km of the highway. Most of the road system in the district is either gravel or mud roads, and the portion of gravel road is less than a quarter of the entire road system. Vehicles can use mud roads during the dry season but only if there are bridges to cross the small rivers.

There is no future plan to construct new roads in the district, and the current National Development Plan suggests only the extension of gravel roads and the repair of mud roads.

(3) Mahottari District

Two paved roads - the E-W Highway in the north and the Janakpur-Jaleswar road in the south - pass through the district. Most of the road system consists of mud roads, which are concentrated in the southern half, rough in the mid-north, and non-existent in the far north.

Only three gravel roads run south from the highway but these do not reach to the southern paved road.

The construction of two gravel roads connecting the two paved roads is planned for the district.

(4) Banke District

The road system in this district is the poorest among the three districts, as there is no road system in almost half of the district. Although the district has the largest area among the three, there is only 16 km of paved road and only 30 km of gravel roads; and the condition of the mud road system is remarkably poor, as there are many discontinuities and the road sometimes abruptly disappears into farmland.

There is only one mud road along the eastern bank of the Rapti, but no bridge crossing. As a future plan, two of the main mud roads are to be graveled and paved throughout: one is from Nepalganj to Balapur across the Rapti; the other shorter route is from the Nepalganj-Gulariya road to the E-W Highway.

4.5.3. Power Supply

(1) General

The power supply system is composed of four kinds of power lines: 132 KV, 33 KV, and 11 KV transmission lines, and a 220V distribution line.

At present, the power line network in all three districts is very thin, including the entire Terai Plain.

(2) Jhapa District

The major power line is a 33 KV line, which runs along the highway and terminates at the transformer substation in Birtmod. The substation transforms the power into 11 KV, which is delivered to Kakarbitta further along the highway to Sanischari in the north and Chandragadhi in the south. The line also extends to India, across the Mechi River, south of Badrapur. The power is distributed to nearby houses by reducing the voltage 220V via a power transformer on the electric pole in major town, such as Birtmod and Chandragadhi; however, power transmission lines have not be established further away from the highway (refer to Figure 4.3.1 (2)).

There is a future long-term plan to connect the E-W Highway area with the southern-most area by three 11 KV lines along the existing N-S gravel roads.

(3) Mahottari District

In the north, 132 KV and 33 KV lines pass along the highway, but there are no distribution lines. In the south, a 33 KV line passes along the Janakpur-Jaleswar road and branches at Jaleswar to Sursand and to Madwapur, both of which are in India. Only the villagers around Jaleswar benefit from electricity at the present time (refer to Figure 4.3.2 (2)).

In the future, a 11 KV line network will distribute power to the people living in the south-eastern corner of the district.

(4) Banke District

The 132 KV transmission line reaches Kohalpur, where a main transformer substation is located, from the central region along the highway. Another substation is located at Nepalganj, from where a 132 KV line extends to India. Both substations are connected by 33 KV and 11 KV lines. The 11 KV line further extends south across the border from Nepalganj and west to Gudhana and the resettlement area (refer to Figure 4.3.3 (2)).

As a future plan, the main transmission line will be extended to the west as far as Karnari, and 33 KV and 11 KV lines will connect Gulariya.

4.5.4. Telecommunication

In almost all districts in Nepal, there is at least one telephone exchange and one wireless station directly connected to Kathmandu, usually at the district center. Besides these, several public and private calling offices are located mainly in the large towns. Although local telephones have increased since 1951, their number remains small. In the three target district, there are only 775 telephones in Jhapa, 165 in Mahottari, and 1,310 in Banke.

4.5.5. Water Supply

The water supply system, including the sewerage system, is one of the least developed infrastructures in the country. In the Terai Plain, only a few towns, mostly regional or district centers, have pipe-born water supply systems. However, the Terai Plain is rich in rainfall and groundwater; and the residents can utilize the abundant surface water during the rainy season, and groundwater is available during the dry season through dug and shallow wells.

In Jhapa District, only Chandragadhi/Badrapur has a water supply system based on DTW. Three other major towns - Damak, Sanischare, and Kakarbitta - have future plans to build a water supply system but these plans have been suspended. In Mahottari District, Jaleswar and Rajikhor have a pipe-born water supply system by DTWs, and some of villages along the E-W Highway near the Ratu River have water supply systems using surface water. Within Banke District, only Nepalganj has a water supply system using groundwater resource.

4.6. Existing Groundwater Irrigation Projects

4.6.1. Bhairawa-Lumbini Groundwater Irrigation Project (BLGIP)

(1) Outline of Project

BLGIP covers Rupandehi District in Western Terai to irrigate approximately 21,000 ha by deep tubewells (DTW). The project is financed by the World Bank. The project has been implemented by DOI, based on financing provided by the World Bank. The project began in 1982 and the third stage is currently being implemented. The outline of each phase of project is as follows.

	No. of DTW	Irrigation Area (ha)	Area/DTW(ha)
1st Stage	64	7,680	120
2nd Stage	38	4,560	120
3rd Stage	73	8,720	120
	175		

The average size of farms is 1.3 ha. Irrigation water is supplied to fields through buried pipelines. Water Users' Association (WUA) have been established to provide better water distribution and maintenance of the irrigation facilities. Operation and maintenance (O & M) is being transferred to the WUAs. WUAs collect Rs 400 per ha/year from their members for O & M of irrigation facilities such as DTWs and pumps. The energy source for the pumps is electricity.

The major crops include monsoon paddy, wheat, oilseeds, pulses, and vegetables. The area for spring paddy is estimated at less than 25% of the command area. According to the staff of the three agricultural subcenters, pulses and vegetables are more profitable crop than paddy. As for paddy, HYV is dominant in the area. The following shows the procedure of yields increases for HYV paddy before and after the project.

Irrigation Impact in BLGIP (unit: ton/ha)

Before Project	1981/82	1984/85	1987/88	1991/92	1992/93
1.80	2.60	4.20	4.63	4.50	4.18

(Source: BLGIP)

In addition to DTWs, farm roads which are not seen in other districts have also been constructed, and transportation has been improved not only for crops but also for general traffic.

Regarding agricultural extension services, three DOI's agricultural subcenters are located in the area to give farmers guidance on new farming technology and training in water use, and so on.

(2) Project Evaluation

The evaluation of BLGIP made by the Study Team as a whole is as below:

a) Irrigation Impact

The most significant effect of DTW irrigation is the increase of crop production. For example, the productivity of HYV paddy has been 1.8 ton/ha without project. Under the conditions with project, it has been successively increased and has reached a stable and high level of 4.0 ton/ha since 1984/85. Therefore, it can be evaluated that the DTW irrigation largely contribute to increasing the agricultural production of the project area. In addition, the situation that the irrigation water becomes stably available throughout a year gives a relief to the beneficial farmers in that they are assured their income worthy of the investment for inputs to an extent. And, this relief contributes to increase the cropping intensity, high productivity and stable production.

b) Increase of Farm Income

The DTW irrigation gives another psychological impact to the beneficial farmers. As a matter of fact, the increases of cropping intensity and crop production and cropping bring the increase of farm income. This brings a desirable cycle in the up-grading of living standard, improvement of education and health cares; and then another volition to expand production.

c) Extension Services

It is pointed out that the extension services played an important role in the increase of crop production as well as the introduction of irrigation. The services cover guidance and so forth to the beneficial farmers. The services have been extended by the extension workers from the agricultural sub-centers allocated in the project area.

d) Role of WUA

The operation cost of DTW pump is collected, as irrigation charge, from WUA organized by all beneficial farmers. The recovery rate of irrigation charge at present is said to be 85%.

The role of WUA is appreciated not only in the O&M activity but also in the generation of common sense of solidarity and mutual communication between the member farmers. DOI is now transferring the O&M function to WUA.

e) Problems

The energy source of DTW pump in the project depends on the electric power. The bulk power supply in Nepal is not so stable now .

The beneficial farmer intends to cultivate, in a dry season, pulses and vegetables which are more beneficial than spring paddy since it requires much more water, more power and irrigation charge than the monsoon paddy. It is afraid that those expansion of profit-oriented agriculture may spoil the role of Terai to supply major food-grains as the granary of the Kingdom.

The project, being the pilot large-scale DTW irrigation scheme into Terai with its salient characteristics of a small investment with quick return model, is highly appreciated, as a whole, brings not only direct impacts in increases of crop production and farm income but indirect effects in the concept in farm economy, building of solidarity in the farmers society and so forth, although the project includes the said problems.

4.6.2. Feasibility Study on Birganj Groundwater Irrigation Project

The Birganj Groundwater Irrigation Project is planned as a part of the Narayani Irrigation Development Project, and a feasibility study on the project was completed in 1993 under the auspices of World Bank.

The project area is located in the Central Development Region, covering 32,900 ha and the districts of Bara and Parsa. Though the irrigable area represents 13,840 ha, the results of the study show that it would be most economical to apply a cropping intensity of 185% to an irrigation acreage of 7,250 ha. Combined irrigation methods using groundwater and surface water have been applied to FMISI for 1,200 ha and SDIS for 970 ha, and 5,080 ha of rainfed areas are planned for irrigation by groundwater. The project includes the construction of 90 km of farm roads. Groundwater is projected to be pumped from 200 STWs and 70 DTWs in order to irrigate monsoon paddy, wheat, sugarcane, maize, and vegetables.

The total project cost is estimated at Rs1.587 billion (US$31.7 million), and an eight year construction period is projected, including design and planning. EIRR is estimated at 20.5%.

CHAPTER FIVE

EVALUATION AND DEVELOPMENT OF GROUNDWATER RESOURCES

CHAPTER-FIVE: EVALUATION AND DEVELOPMENT OF GROUNDWATER RESOURCES

5.1 Basic Strategy

When establishing basin-wide groundwater development, it is necessary to examine;

(1) whether groundwater yield will satisfy the Project's water requirement;
(2) whether the groundwater use is cost-effective; and
(3) whether the water quality suits the water use.

Along with these basic requirements, it is necessary to examine from a broad, long-term perspective;

(4) whether a sharp drawdown in the groundwater head will occur;
(5) whether the groundwater resources will be depleted in the future; and
(6) whether the quality of groundwater will deteriorate in the future.

As the item (1) above is related to the "physical characteristics of the aquifer", it is necessary to identify and evaluate the hydraulic characteristics, including the structure, extent, size, potential and storativity of aquifers.

Item (2) is related to the "cost-effectiveness of groundwater use" and is evaluated through a comparison of costs for the construction, operation and maintenance on the water intake facilities (wells and pumps) and the benefits accrued from these facilities. This item is also strongly related to the above "physical characteristics".

Item (3) is related to the "hydrochemistry of groundwater". If the water quality does not match the purpose of use and requires treatment, the cost-effectiveness will be affected.

Items (4) and (5), as well as being related to the "physical characteristics of the aquifer", are also related to the basin-wide "groundwater resource". Groundwater is a renewable resource within the hydrological cycle. Sustainable development is possible as far as it is within the recharge potential. Therefore the recharge potential has the same meaning as "groundwater resource". The understanding of "hydrological behavior of groundwater" is essential for this evaluation. This understanding is also important for determining a "groundwater resource management" and an "environmental impact evaluation".

Simulations are effective for understanding the basin-wide hydrological behavior of groundwater. The advance in recent hardware and software has made simulation for present condition and future forecast possible using a mathematical model for basin-wide water balance which integrates the surface and subsurface systems. This simulation model should reproduce the hydrological behavior of the present groundwater and can be used for the management of future "groundwater resource conservation".

Item (6) may takes place when brine enters into the basin area. This is related to (4) and (5); however, this often occurs secondarily as a result of a sharp drawdown in the ground-water head or the exhaustion of groundwater resources.

Items (4) to (6) are related to "environmental impact", which includes elements of the natural environment such as the eco-system and soil contamination as well as the socio-economic environment (ie., existing water rights).

This chapter outlines the examination results for each Study Area from the above per-spectives, except for the environmental impact of groundwater development, which is discussed in the following chapter.

5.2. Hydrogeology and Groundwater

5.2.1. Jhapa District

(1) Hydrogeological Survey

The following surveys were conducted to clarify the hydrogeological conditions of the district.

a) Geophysical Prospecting

Magneto-Telluric Prospecting ———— 196 sites

Resistivity Prospecting ———— 190 sites

b) Exploratory Well Drilling

The objectives of the work are to clarify the hydrogeological conditions and the ground-water potential of the Study Area. These objectives include;

- setting up hydrogeological units
- obtaining the vertical and horizontal extent of the aquifers
- obtaining aquifer characteristics and potential
- obtaining groundwater quality

The exploratory wells were designed to grasp the potential of the aquifers at each 50 m depth, from 100 m to a maximum 300 m; and the total number of wells was 15. Five observation wells were attached at the different well depths and equipped with pressure-type automatic water level recorders. The location of each exploratory well is shown in Figure 5.2.1.

Two types of borehole loggings, resistivity and natural gamma ray were conducted in the drilled exploratory wells.

The steel casings and reinforced continuous wire-wrapped screens of 150 mm diameter were installed to complete the wells. Three types of pumping tests, constant yield, re-covery and step-drawdown tests were conducted after the completion of wells. Water samples for quality analysis were collected at final stage of the test.

c) Groundwater Monitoring

The water level measurement were conducted at 30 wells, which include 18 shallow wells, 6 deep wells of GWRDB, 2 water supply project production wells, and 11 project exploratory wells.

Measuring covered a 14-month period beginning at the end of November 1992 and until early February 1994. The measurements were performed manually once a week.

d) Discharge Measurement of Artesian Flows

Measurement were conducted at four project artesian wells at weekly intervals.

e) Pumping Test

The aquifers were tested by three types of pump testing: the step drawdown, constant-rate, and recovery tests. The wells tested include 15 exploratory wells, 4 existing wells of GWRDB, and one water supply well.

f) Water Quality Analysis

Water quality analysis for rivers water and groundwater were conducted by an in-situ kit and laboratory testing. The samples were collected from following sites.

- 11 spots at 8 rivers
- 10 shallow wells
- 10 deep wells

(2) Aquifer

Through above mentioned hydrogeological survey and reviewing of existing data/ reference, two types of large-scale aquifer systems; the Alluvial and the Upper Churia formation systems, are revealed by the Study Team.
As illustrated in Figure 5.5.2., the deposits in the Study Area are classified into two groups of upper and lower. Although both groups are unconsolidated, the lower group is distinct by heavy density, high seismic velocity, quite different groundwater quality contained, very thick consequence of clay layer, etc. The lower group, which used to be included in alluvial deposits, may be the upper-most part of Churia Formation, and it uplifted very nearly to the ground surface by large geological tectonics (probably a first Himalayan front thrust). And this interpretation just fits the groundwater balance simulation(explained later) and, therefore, the Study Team proposed this new interpretation, though it is not yet accepted by authority of geology in Nepal.

The alluvial aquifer group comprises of Northern Alluvium in the Bhabar and marshy zones, Kankai Alluvium in the Kankai flood plain, and Gangetic Alluvium along the Indian border south of the terrace. These are lithologically well traced in north-south and west-east directions. As pointed out later, the alluvium shows excellent groundwater potential in terms of quality and quantity.

The Northern Alluvium is estimated to be 100 m thick and is underlain by the Upper Churia Formation, with regular alternating beds of clay/silt and sand/gravel. The composition rate of sand and gravel beds is approximately 60%.
The estimated thickness of the Kankai Alluvium is 110 m, and it is also underlain by the Upper Churia Formation. The lithology of this alluvium is similar to Northern Alluvium, and the composition rate of sand/gravel beds is 76% on an average among the exploratory wells.
The thickness of the Gangetic Alluvium exceeds 300 m. The depth to reach the underlying Churia Formation is not identified. The Gangetic Formation is composed of sand/gravel, alternating with clay/silt, and the composition rate of the permeable bed is approximately 77%, which is highest rate among the other alluvial formations.

The Upper Churia Formation is sub-divided into North, West, and Central, based on the correlation of drilling logs of GWRDB and the exploratory wells. These formations are composed of regular alternating beds of clay/silt and sand/gravel. The composition rate of the permeable bed is approximately 50% and the thickness of each single bed ranges from 7 m to 9 m. The Central Sub-Formation underlies the shallow depth in the terrace area because of the uplifting caused by faults or thrusts along the north and south edges of the terrace. A presence of these faults is supported by the results of magneto-telluric prospecting and seismic data of DMG and by the heavy artesian groundwater (with a high temperature of 33.5°C) flowing from the two exploratory wells, EX-8 and EX-1, which are located on both sides of the terrace (see Figure 5.2.1 Hydrogeological Map of Jhapa, and Figure 5.2.2 Geological Profile of Jhapa). The thickness of these formations is summarized as follows:

Table 5.2.1 Summary of Aquifers and Aquicludes in Jhapa

Name of Formation	Thickness of Aquifer			Thickness of Aquicludes		
	Total (m)	Single (m)	Rate (%)	Total (m)	Single (m)	Rate (%)
ALLUVIUM						
North For.	103	10	61	67	7	39
Kankai For.	111	12	76	36	4	24
Gangetic For.	209	17	77	62	6	23
Average	141	13	71	55	6	29
CHURIA FOR.						
North For.	78	7	52	73	6	48
West For.	99	8	42	134	10	58
Central For.	158	11	66	83	6	34
Average	112	9	53	97	7	47

The results of pumping tests reveals that the transmissivity of each formation is consistent with the lithological characteristics of the geological formation. Gangetic and Kankai alluviums indicate excellent transmissivity where aquifers are recharged by surface rivers. The Churia Formation shows comparatively low transmissivity, except for the Western Churia where surface river systems are concentrated. The summary of transmissivity of each geological formation is listed as follows.

Table 5.2.2 Transmissivity of Aquifers in Jhapa

Name of formation	Transmissivity (m2/d)	Name of Tested Wells
Gangetic Alluvium	1,240 - 3,540	EX-1,-12, -13
Kankai Alluvium	1,700 - 2,230	EX-10,-14
Northern Alluvium	700 - 1,130	EX-11,-15
Northern Churia	380 - 710	EX-2,-7,-9
Central Churia	520 - 730	EX-5,-6,-8
Western Churia	1,200 - 1,240	EX-3,-4

(3) Groundwater Quality

Hydrochemistry has greatly contributed to the understanding of the flow of groundwater. In interpreting the water quality data, analyses must be correlated with one another as well as related information. As the subsurface flow begins from shallow to deeper unconfined groundwater, the water quality undergoes three modifications: oxidization to reduction, dissolution, and base exchange. These processes of water quality change is referred to as the "hydrochemical evolution of groundwater."

The water from deep wells in Jhapa District can be classified into the following four categories:

Group A: Aquifer underlies the Kankai Alluvium and is directly subject to recharge from the Kankai River.

Group B: Aquifer underlies the Northern Churia Formation and is subject to artesian conditions in the northern alluvial plain.

Group C: Aquifer underlies the Central Churia Formation and is under heavy artesian conditions in the terrace.

Group D: Aquifer underlies the Gangetic Alluvium and is under heavy artesian conditions, and the recharge zone is located far from wells.

Groups A and B are within the region of "Carbonate Hardness". Groups C and D are in the "Carbonate Alkali" region. Those groups spread on a linear line in the tri-linear diagram (refer to Figure 2.4.4 in Sector Report).

The groundwater artesian pressure and the distance from the recharge area increases from A to D.

An excess concentration of iron (Fe) and manganese (Mn) is identified as per the drinking standards of WHO, especially Mn in well depths from 100 m to 150 m. The question arises whether this is caused by the aquifers themselves or by contamination from the shallow aquifers. The water samples from aquifers more than 250 m are within the limitations of WHO's drinking standards.

The water temperature of wells more than 200 m in depth, which are located on the north and south edges of the forest- covered terrace, is 33°C. This is unlike other wells which show a temperature of approximately 26°C.

(4) Groundwater Potential and Development

Based on the specific capacity obtained by the tests on the exploratory and existing wells, the optimum yield of a standard DTW by the respective geological formations is evaluated as shown in the following table. The specific capacities per unit depth of respective aquifer are applied in the estimation of optimum yield of standard DTW.
The standard DTW is specified as 250mm of casing size, 30m of screen length, 50m of housing length and 20m of drawdown. The required depth of standard DTW is determined by each thickness of respective aquifer plus the lengths of screen and housing specified above.
While, the theoretical yield of standard DTW is also estimated adopting Theis' nonequilibrium equation under the conditions of 20m drawdown and a 120-day pumping duration. The drawdown at one-km radius is calculated as well.
All the estimates are summarized in the table shown below:

Table 5.2.3 Evaluation of Groundwater Potential in Jhapa

Name of Formation	By Specific Capacity (s=20m)		By Theis (r=1km, t=120 day)	
	Optimum Yield (lit/sec)	Re.Well Depth (m)	Yield (lit/sec)	Drawdown (m)
ALLUVIUM				
Gangetic	150 - 173 (165)	100-130	34 - 198 (85)	5.81 - 7.02
Northern	36 - 156 (93)	100-160	34 - 198 (85)	5.47 - 6.50
Kankai	66 - 276 (134)	100-150	114 - 330 (223)	5.74 - 6.67
CHURIA FOR.				
Northern	42 - 66 (53)	220-230	66 - 71 (68)	5.24 - 5.29
Central	38 - 144 (72)	120-130	79 - 180 (112)	5.35 - 5.86
Western	60	260-270	153 - 158 (156)	6.09 - 6.11

Remarks: Re = required; Theis = nonequilibrium equation
s = drawdown; r = distance from pumped well
t = pumping time; ( ) = average value

The table shows that the optimum DTW yield of alluvium range from 93-165 l/s on an average and that DTWs require a maximum depth of 160 m. Groundwater development in the Churia Formation is not recommended because the required depth of wells is greater than 200 m, except for the Central Formation in the terrace where the average yield is 72 l/sec at a 130 m well depth.

Figure 5.2.3 represents a map of the optimum yield by 150 m DTW based on exploratory and existing deep wells. The figure shows that a well yield of more than 80 l/s is located south of Chandragadhi and increases to the south. The average yield of a standard DTW in this area with a depth of 150 m is 120 l/s.

5.2.2. Mahottari Area

(1) Aquifer

Major deep aquifers in Mahottari District are the Upper Churia Formation in the Bhabar Zone and the Gangetic Alluvium in southern part of the Terai Plain (see Figure 5.2.4 Hydrogeological Map of Mahottari).

The Upper Churia Formation spread out in the north of District, is overlain by terrace deposits in the Bhabar Zone and is composed of regularly alternating beds of unconsolidated clay/silt and sand/gravel. The average composition rate of the permeable bed is 63% and decreases to 58% toward the south.

The Gangetic Alluvium is composed of regularly alternating beds of clay/silt and sand/gravel, and the total thickness exceeds 200 m based on the exploratory wells of GWRDB. Gravel beds are responsible for 52% of the composition rate on an average, which decreases toward the south. Transmissivity and storativity also have the same tendency in decrease from north to south (see Figures 5.2.4 and 5.2.5).

Table 5.2.4 Evaluation of Groundwater Potential in Mahottari

Name of Formation	Well Depth (m)	Per. Bed (%)	Tested Data		Standard Well Yield (l/s)
			T (m2/day)	S.C. (l/s/m)	
Churia Formation					
North	125	60	5,970	14.9	447
South	146	58	1,310	3.0	90
Gangetic Alluvium					
Center	150	53	290	1.7	51
South	170	48	500	3.3	99
West	130	54	17	0.2	6

Remarks: Per=permeable T=transmissivity S.C.=specific capacity

(2) Water Quality

The pH, EC, and water temperature were measured in the deep artesian wells of GWRDB. The results show a high water temperature at 27°C was measured at a shallow depth to 36m, and the temperatures for other samples were between 25°C to 26°C.

The lower value of EC at 120 and 86 mS/cm was measured at the southern end of the Bhabar Zone. In general, EC increases toward SWW and attains a maximum of 390 mS/cm.

(3) Groundwater Potential and Development

Based on the data from 45 exploratory wells drilled by GWRDB, the specific capacity of the Upper Churia Formation ranges from 0.4 to 29 l/s/m, with an average of 13 l/s/m; it ranges from 0.06 to 5.0 l/s/m, with an average of 1.7 l/s/m, in the Gangetic Alluvium. South of the Gangetic Alluvium, which has a large groundwater yield capacity, the specific capacity is a maximum of 5 l/s/m. On the western edge of the area, the specific capacity is only 0.2 l/s/m on average, which has less yield capacity.

In general, transmissivity is consistent with the specific capacity in the area. The average transmissivity in the Upper Churia Formation is 4,800 m2/day. It changes in Gangetic Alluvium, that is, 500 m2/day in the south, 290 m2/day in the central, and 410 m2/day on an average. On the western edge of the area, transmissivity is 17 m2/day on an average.

The groundwater potential is evaluated based on the standard DTW design, that includes 150 m well depth, 250 mm diameter, 30 m screen length, and 20m drawdown. The results are shown in Table 5.2.4. The possible yield by standard DTW in the Bhabar Zone is calculated at more than 120 l/s, with 97 l/s on average. This area forms an alluvial fan and is covered by thick forest; direct infiltration by rivers through flood deposits in broadly extended river beds contribute to the recharge into the Bhabar Deposits and the Gangetic Alluvium.

The second highest potential area is found in the southern part of the Terai Plain. The estimated yield for standard DTW in the Gangetic Alluvium is 57-151 1 l/s, with an average of 99 l/s.

In the most part of the central and western areas, the groundwater potential is low as development areas for DTW irrigation. Their average potential yield is 19 l/s and 6 l/s, respectively.

The groundwater level of the Bhabar Zone reaches 34 m in the north, but it only several meters deep in the south. The groundwater in the Gangetic alluvial aquifer in the central part of the district is generally confined. The maximum artesian head reaches 8.67 m above the surface at M-15 well.

5.2.3. Banke Area

(1) Aquifer

Three major aquifers underlie in Banke District: Northern Alluvium, Central Churia Formation, and Gangetic Alluvium.

The exploratory wells of GWRDB/USAID reveal that the thickness of the Northern Alluvium is greater than 200 m, and consists of thick clay beds, intercalated by thin sand/gravel beds. The average transmissivity and specific capacity of the aquifers are 700 m2/day and 3.5 l/s/m, respectively. The average single bed thickness of the gravel layer and the composition rate are 15 m and 17%, respectively. The lithologic gap, e.g., intercalation of siltstone fragments and the difference in groundwater potential, is clearly recognized between the Northern Alluvial Formation and the Central Churia Formation. A difference in water quality as well as lithology is also significant between the two formations.

The Central Churia Formation, which underlies the central part of the Gangetic flood plain, is characterized by its thick impervious clay beds which contain siltstone fragments. The thickness of the formation is more than 400 m, based on the exploratory wells of GWRDB/USAID. The extent of the formation, tending in a northwesterly direction, is well traced in an 18 km width, from the west bank of the Rapti River to the Babai River.

The average transmissivity and specific capacity of the aquifer at a depth of 60 m to 200 m is 210 m2/day and 1.1 l/s/m, respectively. The composition rate of the formation's permeable beds is approximately 18% based on the exploratory wells.

There is a strong possibility that the formation correlates with the Churia Formation because of the large amount of siltstone fragments and the characteristics of the aquifer, eg., transmissivity and specific capacity are very low compared with the adjacent alluvial formations.

Gangetic Alluvium spreads out south of the central Gangetic flood plain, in a 5 km width along the Indian border.

According to the geological logs of the exploratory well drilled by GWRDB/USAID, with a depth greater than 300 m, the alluvium is characterized by thick fine sand and sandy clay beds. No siltstone fragments are observed based on the exploratory well logs. Two major aquifer groups, from the ground surface to 40 mbgs, and from 150 m to 250 mbgs, underlie in this formation.

The average transmissivity and specific capacity of the aquifers at more than 60 m are 1,100 m2/day and 3.8 l/s/m, respectively. The groundwater potential in Banke District is listed as follows (see Figures 5.2.6 and 5.2.7).

Table 5.2.5 Evaluation of Groundwater Potential in Banke

Name of Formation	Well Depth (m)	Per. Bed (%)	Tested Data		Standard Well Yield (l/s)
			T (m2/day)	S.C. (l/s/m)	
Churia Formation					
Central	240	21	170	0.79	24
Alluvium					
Rapti	120	47	900	3.86	116
North	180	21	390	2.62	79
Gangetic	150	32	750	3.28	98

Remarks: Per=permeable T=transmissivity S.C.=specific capacity

(2) Groundwater Quality

Laboratory testing was conducted on water samples taken from the 29 exploratory wells of GWRDB in 1979. Results show that all samples meet the WHO Drinking Water Standards, except for well B-5/4, whose Fe content slightly exceeds the standard of 0.3 mg/l. Ten samples indicate more than 500 mg/l of TDS, which exceeds the standard of 500 mg/l, especially for well B-2/6 near Nepalganj, which is 872 mg/l. Most wells in northern part of the Bhabar Zone are suitable for drinking purposes.

The chemical quality of the water samples reveal that the Northern and Gangetic Alluvium near the Rapti and Babai flood plains, as well as the Gangetic Alluvial plain, are subject to recharge from the surface river system. The samples from the Upper Churia Formation underlying the central part of the alluvial plain are plotted on a region of deep groundwater of the trilinear diagram. The same hydrochemical characteristics are observed between water samples from the alluvium and Churia Formations in Jhapa District.

(3) Groundwater Potential and Development

The artesian conditions in the Northern Alluvium in the Bhabar Zone show high pressure in the east. The groundwater head in the Central Churia Formation distributed in the Central Terai Plain is low at 10 m or deeper in subsurface.

The Gangetic Alluvium, located in the Southern Terai, along the Indian border, shows the highest groundwater potential. The transmissivity ranges from 250 to 2,060 m2/day, with an average of 750 m2/day, and the average specific capacity is 3.8 l/s/m. The estimated yield from standard DTW with a 30 m screen ranges from 25 to 240 l/s, with an average of 100 l/s.

The Northern Alluvium, distributed in the Bhabar Zone, shows the second highest groundwater potential. The transmissivity ranges from 80 to 3,050 m2/day, with an average of 180 m2/day, and the average specific capacity is 3.6 l/s/m. The calculated yield from standard DTW with a 30 m screen ranges from 12 to 300 l/s, with an average of 107 l/s.

The groundwater potential of the Central Churia Formation, which underlies the Central Alluvial Plain, is quite low compared with other formations because of its low composition rate of permeable beds. The average transmissivity and possible well yield are 170 m2/day and 24 l/s, respectively.

The groundwater potential in the Gangetic Alluvium in the Southern Terai and the Northern Alluvium in the Bhabar Zone can be adapted for irrigation if the well yield is 70 l/s, with a specific capacity and transmissivity of 2.3 l/s and 500 m2/day, respectively.

Figure 5.2.1 Hydrogeological Map of Jhapa

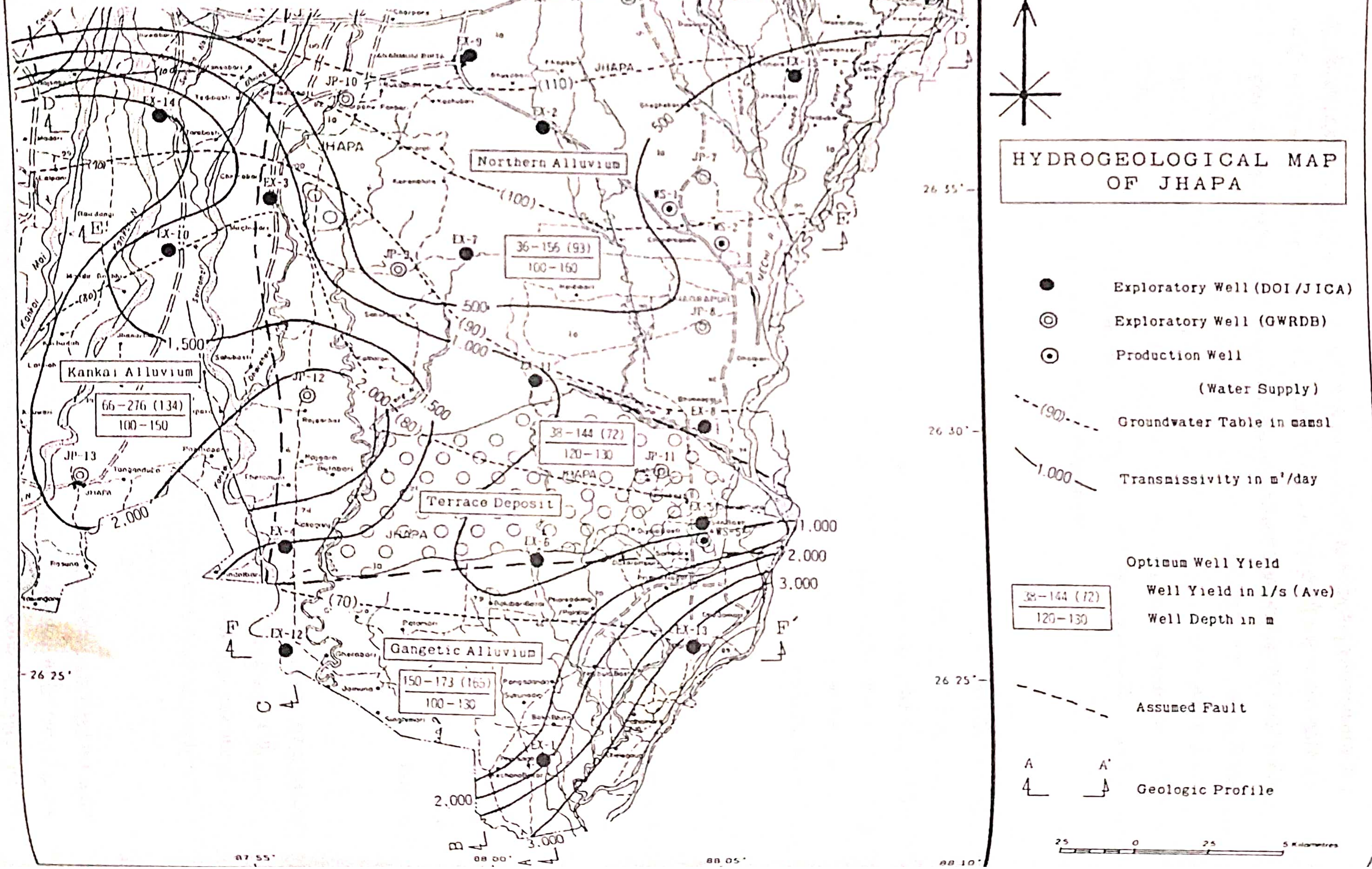
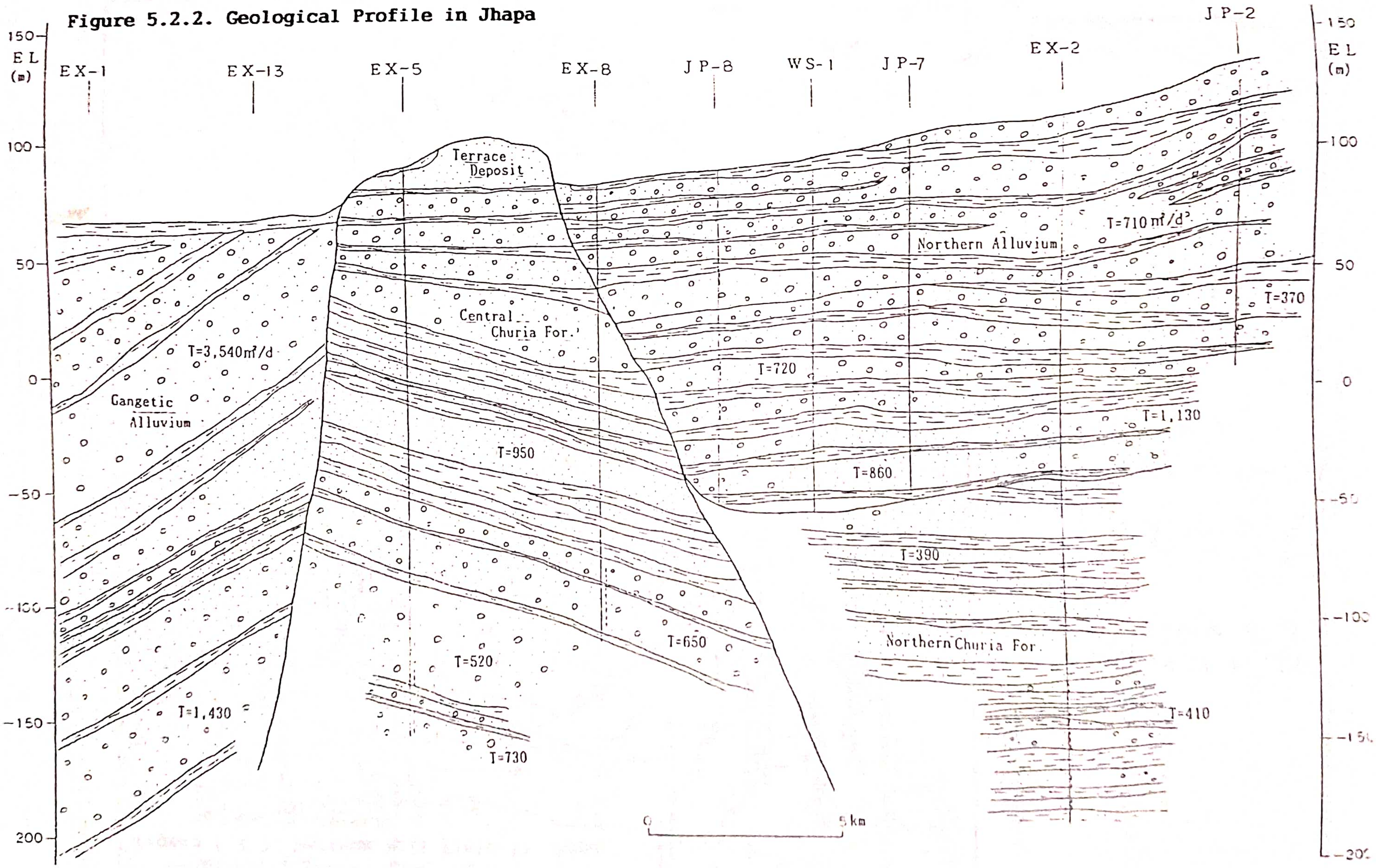


Figure 5.2.2. Geological Profile in Jhapa



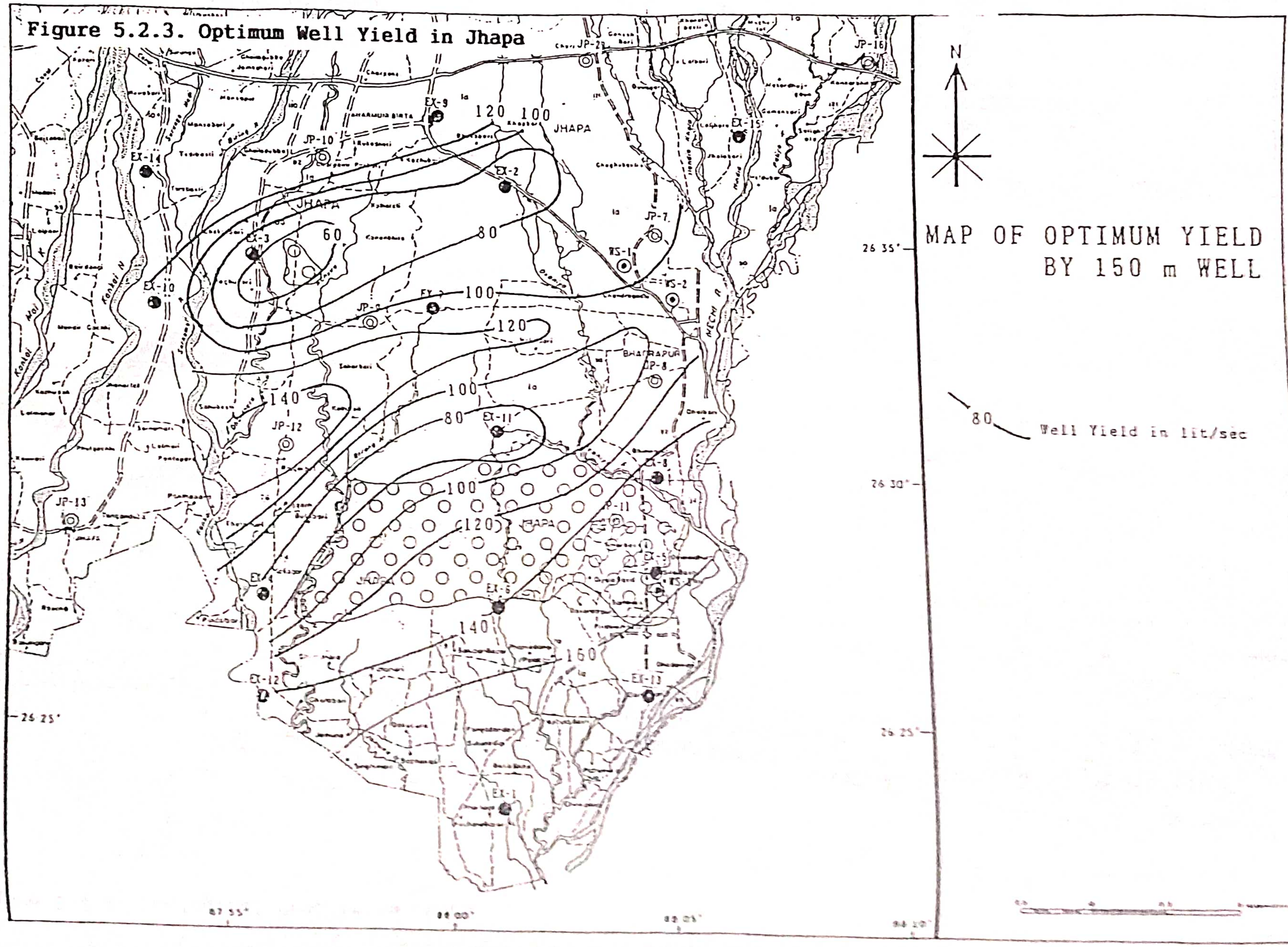


Figure 5.2.3. Optimum Well Yield in Jhapa

Figure 5.2.4 Hydrogeological Map of Mahottari

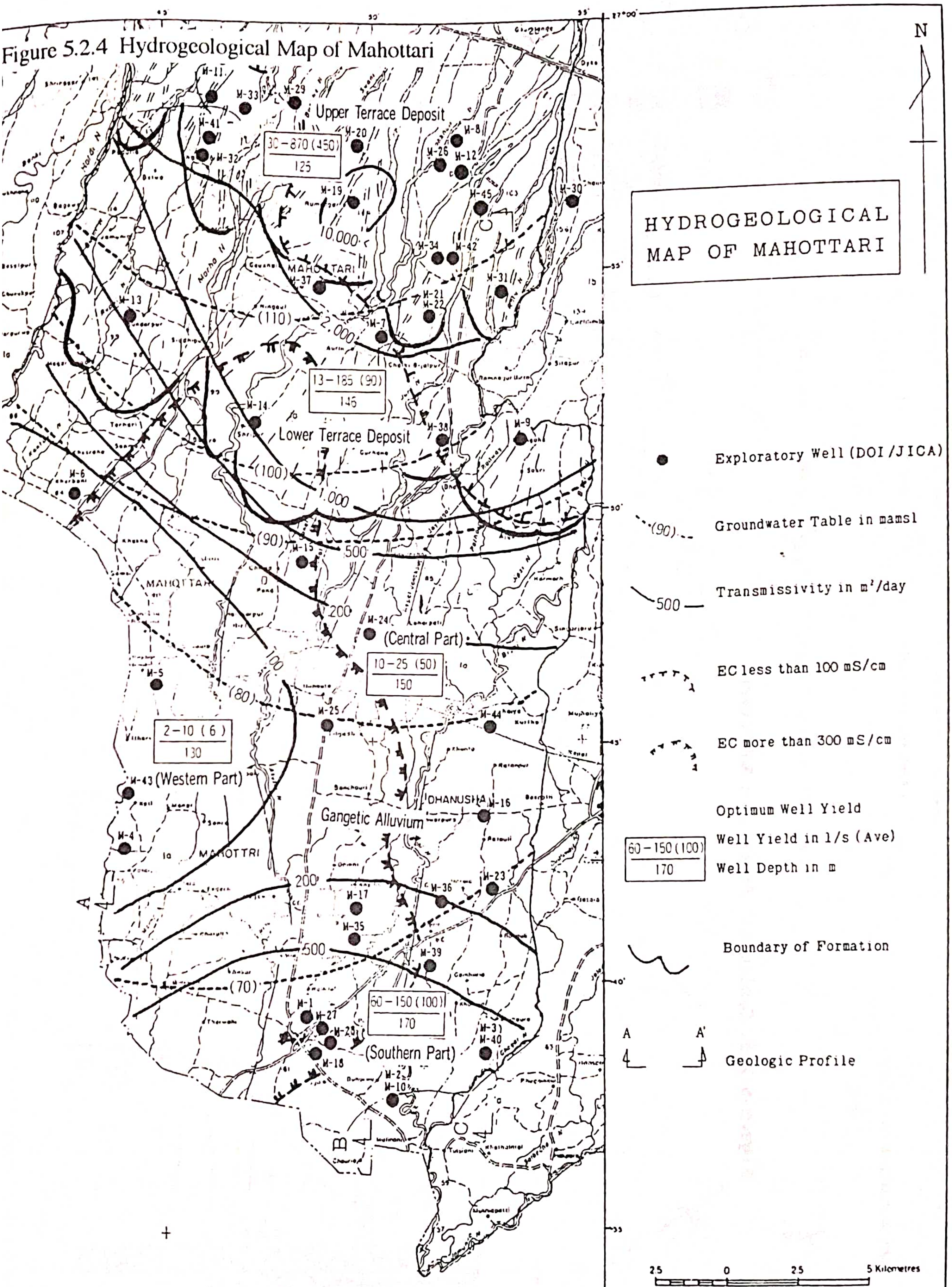
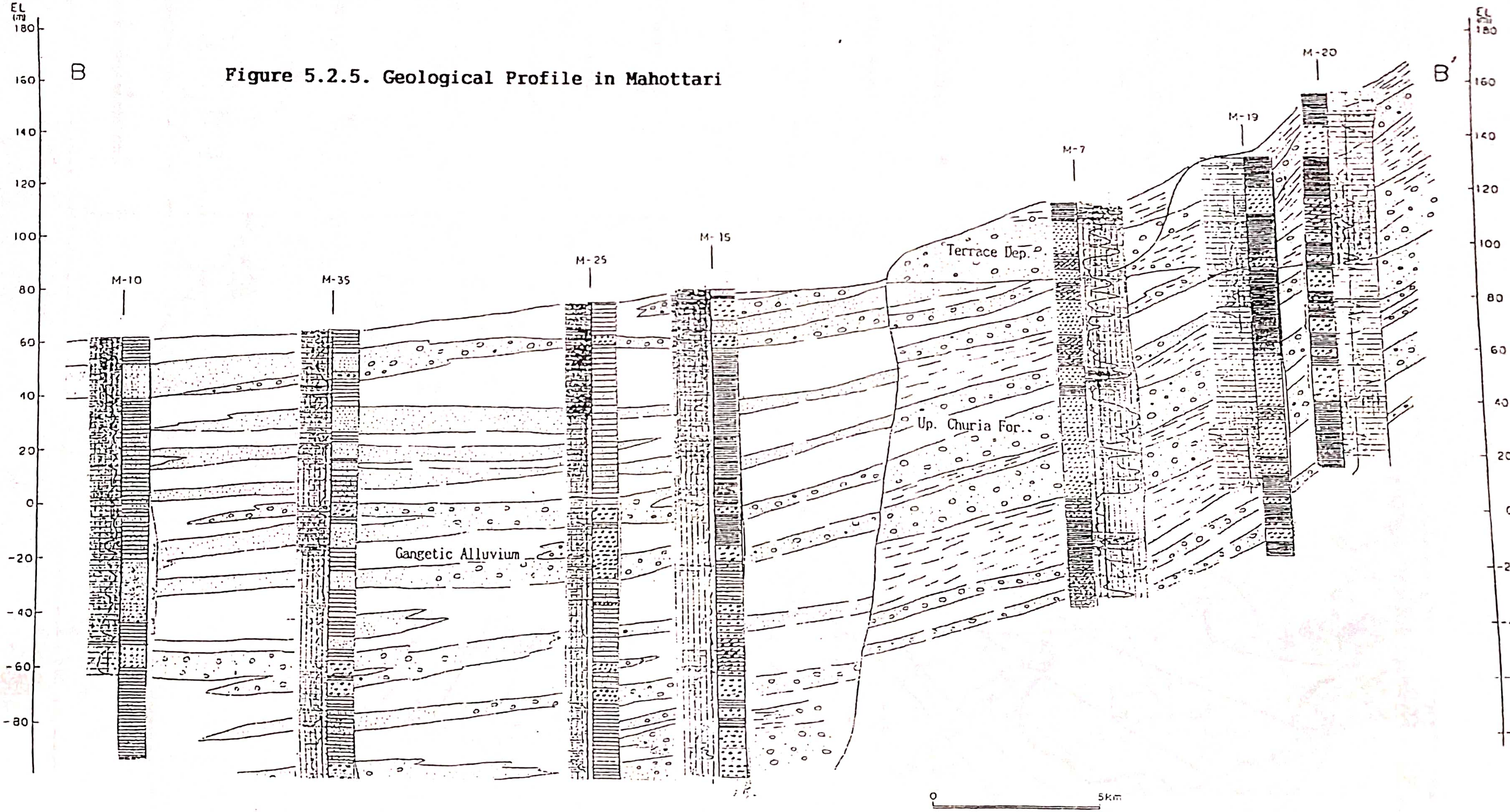


Figure 5.2.5. Geological Profile in Mahottari



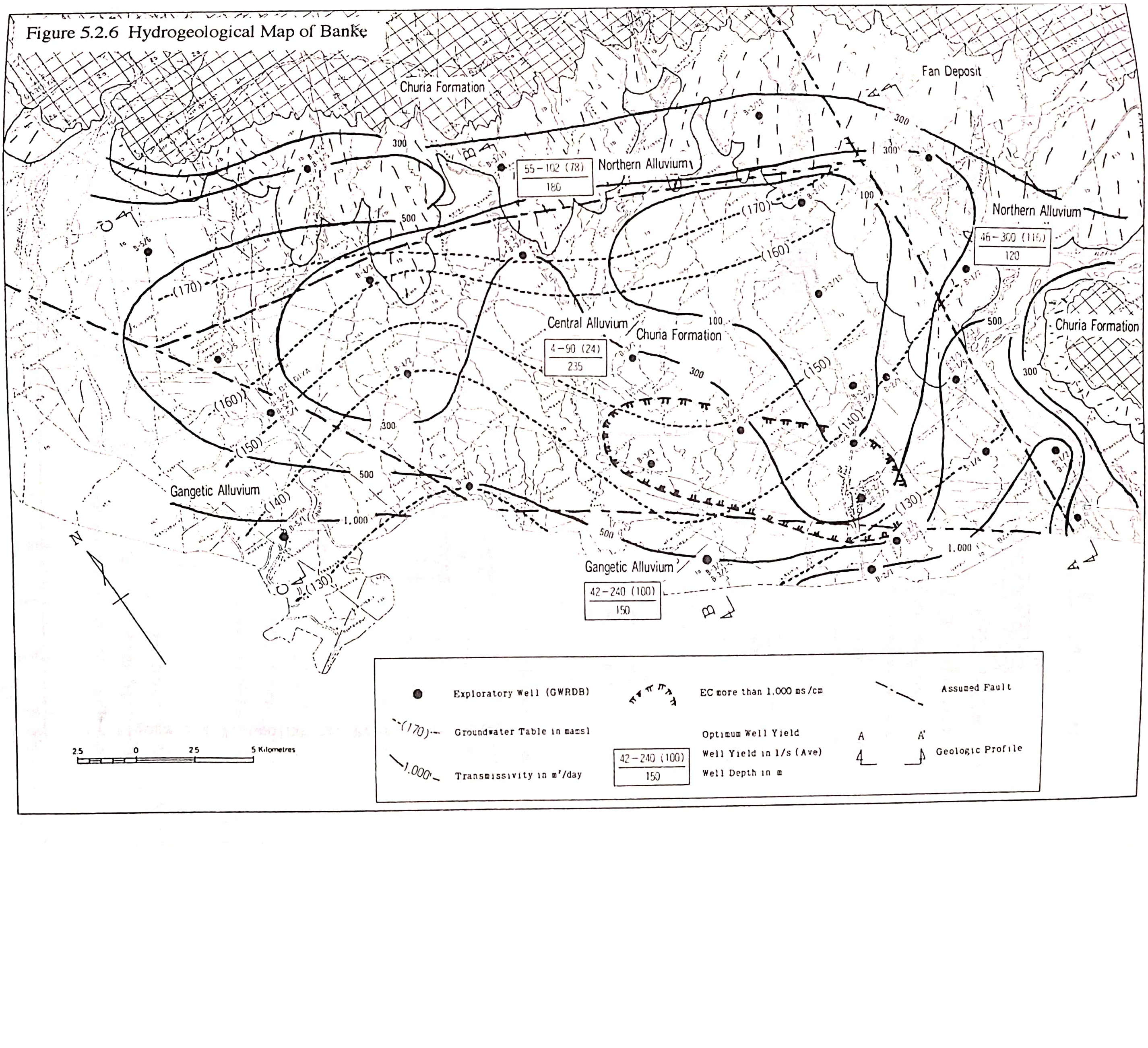


Figure 5.2.6 Hydrogeological Map of Banke

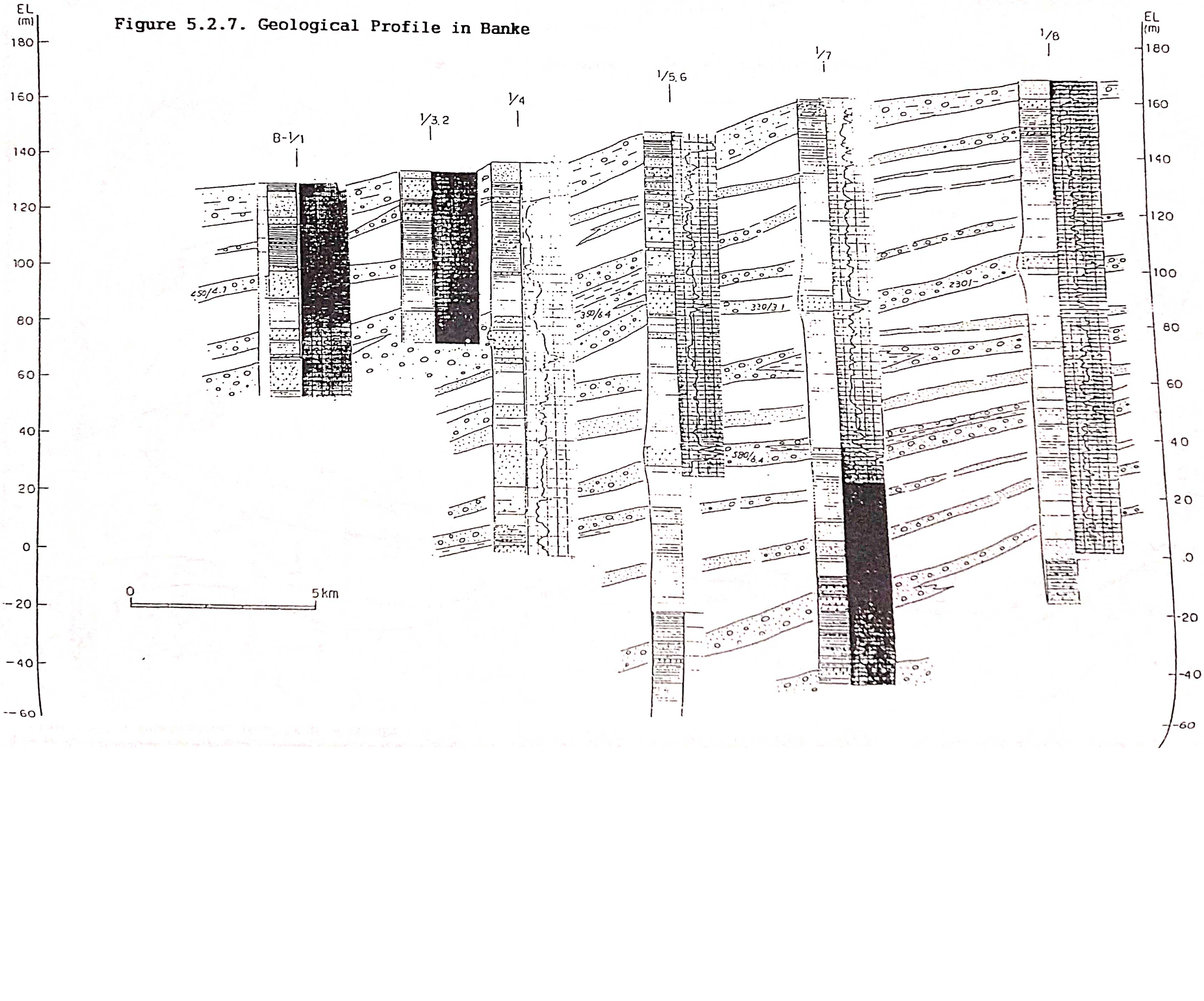


Figure 5.2.7. Geological Profile in Banke

5.3. Evaluation and Development of Groundwater Resources

5.3.1. Introduction

In order to evaluate the groundwater resources and to clarify an appropriate development potential in the Representative Area, a simulation model for hydrologic balance analysis integrating both the surface and subsurface systems simultaneously was constructed applying the "synthetic storage model (STML)". The simulation studies were conducted for the current and future hydrologic balances of Area. The results of simulation study and the deduction of groundwater resource evaluation for other two Districts are stated in this Paragraph.

5.3.2. Outline of the Simulation Study

(1) Synthetic Storage Model (STML)

The synthetic storage model was developed to make the above simulation possible on a practical use basis.

STML is a mathematical model that simultaneously deals with a basin-wide hydrological balance analysis of surface and subsurface systems in an unsteady and quasi three-dimensional state. In regard to the groundwater system, analysis is possible not only for unconfined aquifers which relate to the surface system, but also for confined multi-layer aquifers which includes aquicludes. Thus, this model can be applied to solve the phenomena such as multi-phase density flow, underground dams, substance balance, and so on. The concept of the model is explained in below.

The basin of concern is divided into sub-basins in arbitrary rectangles, based on the characteristics of the topography, drainage system, hydrogeology, water and land uses, and so on. The upstream and downstream relationship of the surface flow system in neighboring sub-basins have previously been defined.

For the groundwater system, the aquifers and aquicludes are grouped based on the hydrogeological conditions and the water drafts from aquifers at different depths. The aquifer groups at the same level in the neighboring sub-basin have also previously been defined.

The surface system is represented by an exponential serial depletion model, one which is well known as the "Tank Model," which can be explained under the concept of the inflow, storage, and outflow of water in a container (tank) with orifices. The lowest orifice in the lowest tank plays the role of the groundwater recharge.
Groundwater storage takes place at the uppermost unconfined aquifer and confined aquifers separated by leaky aquicludes.

In a common hydraulic analysis which applies potential solutions such as FEM and FDM, the water head is initially defined and groundwater storage secondarily defined. This model initially defines the change in storage (balance) of an aquifer in a sub-basin, and the water head is derived through the relationship between the water storage and head which have been previously defined. This methodology is the most specific part of the model and from which the model name is derived.

The balance of storativity in an aquifer of a sub-basin is the sum of the recharge from the surface systems, the leakance through contacted aquiclude(s), the inflow and outflow from/to the aquifer at the same level in neighboring sub-basin(s), and the draft. The components, except for the recharge and the draft, are estimated by Darcy's Principle, ie., the product of permeability of an aquifer or aquiclude, the seepage area, and the hydraulic gradient.

The model constructed is identified through trial runs of models to meet with the actual hydrological behaviors observed by time-series hydrograph of the surface runoff for the surface system and groundwater heads at each aquifer for the groundwater system. Needless to say, the artificial drafts from each aquifer must be determined as precisely as possible in order to identify the model.

(2) STML for Jhapa District

The representative area in Jhapa District is subdivided into a total of 37 sub-basins: 32 major sub-basins, 4 sub-basins on the western side beyond the Kankai (a mirror domain), and a dummy basin at the lower end of the model area, as shown in Figure 5.3.1.

Aquifers in the area are classified as one unconfined aquifer and three confined aquifers interbedded by three confining layers, as shown in Figure 5.3.2. The lowest layer underlying the third aquifer is to be an impervious basement.

(3) Input and Verification Data

a) Input parameters

The model's hydrological parameters are based on precipitation, evapotranspiration, and draft. Daily precipitation data for the area were available, observed at Chandragadhi (over a 14 year period from 1980 to 1993). For the potential of evapotranspiration, the mean monthly pan evaporation data measured near the Study Area, at Tarahara, was applied. The current groundwater draft in the area is very small. The groundwater draft for shallow wells is around 3,860 m3/day throughout the entire area and approximately 2,260 m3/day for two of the water supply DTWs at Chandragadhi.

b) Verification data

The parameters to verify the model include a time-series groundwater hydrograph for the groundwater system and time- series observation data on river runoff for the surface system.

Groundwater hydrographs, manually observed in the monitoring wells under the Project for approximately one year, along with four automatic records of the observatory wells drilled by the Team, comprise all of the available data.

For the river runoff, four years (1987-1990) of daily runoff data for the Kankai River was available, along with runoff record of close to a year (Feb.1993 - June 1994) measured by the Team at the Deoniya and Bakhbitta rivers.

(4) Model Parameters and Trial

There are two kinds of model parameters, one for the overall model and one for each sub-basin model.

The overall parameters contain the number of sub-basins, total running year, beginning year and month, and the parameters on rain and draft, and so on.

The sub-basin parameters include the area, cumulative area, surface connection, subsurface connection, surface tank structure, parameters on rainfall/evapotranspiration/draft, structure of groundwater system, and so on.

Trial runs modify these parameters one by one until the simulated runoff or groundwater movement match the verification data. The parameters of the sub-basins, which have no verification data, are applied from neighboring or similar sub-basin data.

5.3.3. Current Hydrologic Balance

(1) Results of the Simulation

The trial runs for groundwater sub-basins reveal some of the characteristics of the groundwater systems in the Study Area. First, the shape of the outlets related to unconfined aquifers is not linear but trumpet shaped, upward from a certain level. This means that the runoff coefficient becomes larger quadratically based on the rise in the water level. This feature comes from the characteristics of the groundwater hydrograph that very slowly levels down during the long dry season and abruptly levels up at the beginning of the rainy season and smoothly levels down at the end of the rainy season.

Second, the leakance of the aquicludes is very large in general as each water level of the confined aquifers reflects the movement of the water table of unconfined aquifers, accurately, but at different levels.

And third, the water level, especially for unconfined aquifers, is too sensitive to the rainfall at the beginning of rainy season, but not for all groundwater sub-basins. In one special case (sub-basin No. 24), the groundwater level turns upward from the end of April when 40 mm of rain was observed, but this is practically the first rainfall. In many other cases, the water level raises abruptly from late May, and the total rainfall until this period is 133 mm, in 12 isolated times. In these cases, the constructed model does not fit the verification data, which causes slightly delays.

(2) Surface Water Balance

Surface water balances for pure surface sub-basins, which are fixed prior to the subsurface system, are summarized in Table 5.3.1.

In the case of sub-basin No.1, which is the largest surface basin in the area, the total rainfall is 3,750 MCM/a (3,173 mm), with a rainfall parameter of 1.2. Among the total volume, 963 MCM (815 mm) is lost by evapotranspiration and almost all of the remaining volume (2,786 MCM) flows to the downstream sub-basin (No. 8). The runoff coefficient in this case is calculated as 74.3%. The yearly rainfall varies heavily throughout the 14 years, from 6,182 MCM (5,232 mm) during the wettest year, to 2,381 MCM (2,015 mm) during the driest; and the difference between the driest and the wettest year was approximately 2.6 times. The runoff coefficient is influenced by precipitation and varies from 80.4 during the wettest year to 68.5% during the driest year.

In the other small basins, the average annual runoff coefficient is approximately 71%, ranging from 78% during the wettest year to 60% during the driest year. For the Deoniya and Bhakbitta rivers,17.7% and 8.5%, respectively, of the rainfall recharges the groundwater and almost all of the volume flows out.

(3) Groundwater Balance

The monthly groundwater balance and the surface water balance are attached in the Appendix and summarized as Table 5.3.2. As shown in the table, the evapotranspiration rate ranges from 640 mm (460.1 MCM,1992) to 939 mm (674.7 MCM,1990), with an average of 771.5 mm. Recharge volumes from the surface system to the sub-surface system vary widely from 205.4 to 384.3 MCM/a and ranges from 17.0% to 12.3%, with the average coefficient being 14.0% for 14 years.

Table 5.3.1 Surface Water Balance

(Averaged for 14 years) (unit : MCM/a)

River	Area (km2)	Rainfall (MCM)	Surface Inflow	Evapotrans-piration	Surface Outflow	Groundwater Recharge	Groundwater Outflow	Draft
KANKAI RIVER	1181.54	3,750.2	0.0	963.3	2,785.9	0.0	0.0	0.0
DEONIYA R.	175.23	463.9	293.6	139.8	536.8	82.1	80.1	1.3
BHAKBITTA R.	94.96	251.4	67.1	68.7	224.9	21.3	21.2	0.2

(The most rainy year :1990)

River	Area (km2)	Rainfall (MCM)	Surface Inflow	Evapotrans-piration	Surface Outflow	Groundwater Recharge	Groundwater Outflow	Draft
KANKAI RIVER	1181.54	6,181.8	0.0	1,147.2	4,963.0	0.0	0.0	0.0
DEONIYA R.	175.23	764.3	555.0	167.6	1,029.5	117.7	113.6	1.3
BHAKBITTA R.	94.96	414.1	121.3	85.6	418.2	31.6	29.7	0.2

(The most dry year:1992)

River	Area (km2)	Rainfall (MCM)	Surface Inflow	Evapotrans-piration	Surface Outflow	Groundwater Recharge	Groundwater Outflow	Draft
KANKAI RIVER	1181.54	2,380.6	0.0	791.8	1,631.2	0.0	0.0	0.0
DEONIYA R.	175.23	294.3	150.9	116.5	267.4	63.2	63.3	1.3
BHAKBITTA R.	94.96	159.5	37.1	56.7	123.8	16.1	17.1	0.2

Table 5.3.2 Summary of Water Balance

(Present Condition)

Year	Total Area	Rainfall	Evapotrns-piration	Surface Water Inflow	Surface Water Outflow	Groundwater Recharge	Groundwater Outflow	Groundwater Draft
1980	718.89	1,870.5	578.2	3,614.3	4,648.7	272.9	254.0	2.3
1981	718.89	1,833.2	522.9	3,767.6	4,869.5	211.4	214.9	2.3
1982	718.89	2,057.6	495.9	4,480.5	5,798.2	242.9	234.6	2.3
1983	718.89	1,800.8	539.4	3,540.6	4,532.8	265.6	259.4	2.3
1984	718.89	2,570.9	564.7	5,704.4	7,409.7	302.9	285.5	2.3
1985	718.89	2,104.9	592.7	4,165.7	5,354.5	300.5	289.0	2.3
1986	718.89	1,260.3	521.1	2,085.0	2,632.3	216.5	222.4	2.3
1987	718.89	1,387.5	533.5	2,344.0	2,987.9	210.1	206.1	2.3
1988	718.89	1,722.4	632.6	3,026.7	3,841.8	274.3	268.3	2.3
1989	718.89	1,862.4	549.7	3,678.9	4,717.6	273.9	270.6	2.3
1990	718.89	3,134.4	674.7	6,958.9	9,029.7	384.3	365.3	2.3
1991	718.89	2,098.3	530.2	4,420.8	5,702.8	288.9	287.3	2.3
1992	718.89	1,207.1	460.1	2,062.8	2,606.3	205.4	209.7	2.3
1993	718.89	1,728.2	568.6	3,207.8	4,100.3	263.6	253.3	2.3
Average	(MCM/a)	1,902.8	554.6	3,789.9	4,873.7	265.2	258.6	2.3
	(mm/a)	2,646.8	771.5	5,271.8	6,779.5	368.9	359.7	3.2

Since the surface runoff is very high in wet years, the recharge coefficient has an inverse proportion to the rainfall, and the difference is 1.9 times the highest/lowest ratio compared with 2.6 times for rainfall. However, the considerable recharge volume in the area flows smoothly out, and the flow-out coefficient is almost 97.5% in the present conditions.

Groundwater is currently being extracted from nine sub-basins, but the total amount is only 2.3 MCM/a, which is a negligibly small amount compared with the irrigation water demand explained later.

5.3.4. Evaluation of Groundwater Resources

(1) Conditions of the Simulation Study

To evaluate the groundwater resources, water balance simulations are carried out for the following five cases:

Case-1) under pumping conditions with the designed irrigation water demand
Case-2) x 1.25 times of above designed demand
Case-3) x 1.5 times of above designed demand
Case-4) x 1.75 times of above designed demand
Case-5) x 2.0 times of above designed demand

The irrigation water demand is calculated in the paragraph 6.3. The irrigation water demand for spring paddy, wheat, and maize is multiplied by 0.4, 0.3, and 0.15, respectively, according to the cropping area, and the figures are used as shown in the table below.

Table 5.3.3. Irrigation Water Requirement

(UNIT : mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	(Sum)
Main Paddy							108.1	243.5	176.0	175.6	90.4	6.7	800.3
Spring Paddy			44.3	110.4	95.9	46.2	3.7						300.5
Main Wheat	14.4	24.0	25.9	6.3								5.7	76.2
Spring Maize			14.2	25.2	26.5	14.4							80.3
Total	14.4	24.0	84.3	141.9	122.4	60.6	111.8	243.5	176.0	175.6	90.4	12.4	1,257.3

Because the sub-basin division does not conform to the boundary of the irrigable area, the net irrigable area is shared by a total of seven sub-basins by the area ratio.

The effective rainfall is to be greater than 5.0 mm and the ceiling is set at 80.0 mm; and 80% of the rainfall is treated as the actual effective rainfall to reduce the water demand.

The target aquifers to be withdrawn are confined aquifers 1 and 2, as a rule; the uppermost unconfined aquifer and the Churia aquifer are excluded from the target.

The control level of the drawdown is set at 30 m below the surface. The drawdown is measured by the average water level of aquifers 1 and 2, and pumping is to be stopped when the drawdown reaches at that level.

(2) Evaluation of Groundwater Resources

The results of the simulation are summarized in Table 5.3.4, as shown below.

Table 5.3.4 Summarized Groundwater Potential

Sub-basin	Case-1	Case-2	Case-3	Case-4	Case-5
No.15	O (16m)	O (16m)	O (22m)	O (24m)	O (30m)
No.16	O (10m)	O (13m)	O (16m)	O (19m)	O (23m)
No.20	O (17m)	O (26m)	▲	X	X
No.21	O (22m)	O (26m)	O (30m)	X	X
No.23	O (23m)	O (28m)	▲	X	X
No.26	O (14m)	O (18m)	O (22m)	O (26m)	O (30m)
No.27	O (19m)	O (24m)	O (30m)	O (30m)	X

O Possible
() Max. drawdwon
▲ Shortage in some years
X Shortage in most years

As shown in Table 5.3.4, there is no shortage year throughout the 14 year simulation when pumping water necessary for the irrigation demand as well as for the current groundwater use (case-1). In case-2, the situation is very similar to the first case, but the maximum drawdown is deep. However, for case 3, which pumps 1.5 times the required demand, pumping is impossible in certain parts over several years for sub-basin 20 and 23. When setting the pumping demand at a higher rate, sub-basins 15, 16, 26, and 27 do not experience problems, but the central part of the Study Area experiences a shortage almost every year.

From the above examination, the groundwater potential of the target irrigable area is 1.35 times of the designed irrigation water demand, approximately 206 MCM/year on an average. Therefore, it can be said that the groundwater potential of the area is sufficient to plan groundwater irrigation, and that it is possible to plan further extensions in the future.

Table 5.3.5 shows the water balance under 1.35 times during the 14 year simulation.

Table 5.3.5 Groundwater Balance under Maximum Draft

(Water demand x 1.35)

Year	Area * (km2)	Rainfall (MCM)	Evapotrans. (MCM)	Recharge (MCM)	Outflow (MCM)	Draft (MCM)	Note
1980	1098.8	2,858.9	946.3	381.9	248.2	169.5	
1981		2,801.8	873.5	306.3	128.8	246.8	
1982		3,144.5	833.7	344.7	89.0	268.7	
1983		2,752.4	891.0	371.8	136.2	228.2	
1984		3,929.1	925.5	430.1	174.0	219.1	
1985		3,217.0	963.1	421.6	193.7	190.5	
1986		1,926.0	865.7	310.5	119.8	224.8	
1987		2,147.9	880.9	300.9	103.3	196.0	
1988		2,632.5	1,010.4	389.5	196.8	179.2	
1989		2,846.8	908.6	384.5	181.1	202.4	
1990		4,790.5	1,076.1	537.2	307.1	146.3	The wet yea
1991		3,207.2	883.3	404.8	211.3	210.6	
1992		1,844.7	784.1	292.1	99.5	232.4	The dry yea
1993		2,641.4	928.1	370.7	168.0	171.3	
Average	(MCM)	2,910.1	912.2	374.8	168.3	206.1	
	(mm)	2,648.4	830.1	341.1	153.2	187.6	

*: The area excludes surface basins (No.1 - 4)

(3) Potential on Shallow Aquifer

The outer zone surrounding the irrigable area (in the study area of Jhapa District) is classified into the areas where shallow groundwater irrigation is possible. The study on the groundwater potential of shallow aquifers in the surrounding zone has been conducted. The results are a maximum groundwater potential of 160 MCM/year for a total of 19,000 ha of the surrounding zone, in addition to the potential of more than 200 MCM/year from deep aquifers in the irrigable area.

5.3.5. Development of Groundwater Resources

(1) General

As described above, the groundwater potential of the representative area in Jhapa District is sufficient for groundwater irrigation, as formulated in this Project, and the area has an excess potential of approximately 35% without developing the Churia Aquifer. It is possible to develop approximately 206 MCM/a of groundwater in the entire irrigable area (17,000 ha).

The hydrogeological conditions in other two districts, Mahottari and Banke, are not particularly different from the conditions in Jhapa District, as these districts are all located in the Terai Plain. In this section, the groundwater potential of the other two districts is estimated based on the results of the study in Jhapa District. The following procedures for groundwater development are outlined below.

(2) Mahottari District

The hydrogeological conditions of Mahottari District are similar to Jhapa District, with the Babhar Zone, Marshy Zone, and Gangetic Plain (Southern Terai) gradually changing.

The aquifer condition, as represented by transmissivity in the target area, is slightly weaker than in Jhapa; however, the rainfall conditions which control the recharge of groundwater is almost same as Jhapa District. These conditions suggest that the groundwater potential of the area are almost the same as the ones in Jhapa District, and this means that the same irrigation plan can be applied to Mahottari District.

For evaluation of the groundwater potential in Mahottari District, the same methodology applied in Jhapa District can be used, along with the same aquifer classification and target aquifers. However, the target groundwater basin involves the neighboring Dhanusha District as both the surface and subsurface system of the target area is connected from/to the Dhanusha District.

(3) Banke District

Although the basic hydrogeological conditions, consisting of the Babhar Zone, Marshy Zone, and Gangetic Plain, are almost the same as the other two districts, the details of the structure are slightly different from the others; that is, the Churia Formation is deemed to lie at a very shallow level in the current farmland areas, and outcrops as mountains or terraces are seen in the northern and eastern part of the district.

As a result of these conditions, thick and dominant Quaternary aquifers are expected only at the southern edge of the area. In the central part of the area, Quaternary aquifers including unconfined aquifer are mostly thin and complicated. Under this situation, the same irrigation system as the one in Jhapa District is not applicable, except in the southern belt along the Indian border. The upper part of the Churia Formation consists of unconsolidated layers, and its lower part is one on the most excellent aquifers in the Terai Plain. These situations suggest that the Gangetic aquifer should be the target aquifer in the southern belt, and that the Churia aquifer should be developed in the central part of the area.

Besides the hydrogeological conditions, the annual rainfall in the district is smaller than the other two districts, therefore, a thorough groundwater balance study, including the Churia Aquifer, is requested for future groundwater irrigation in this district.

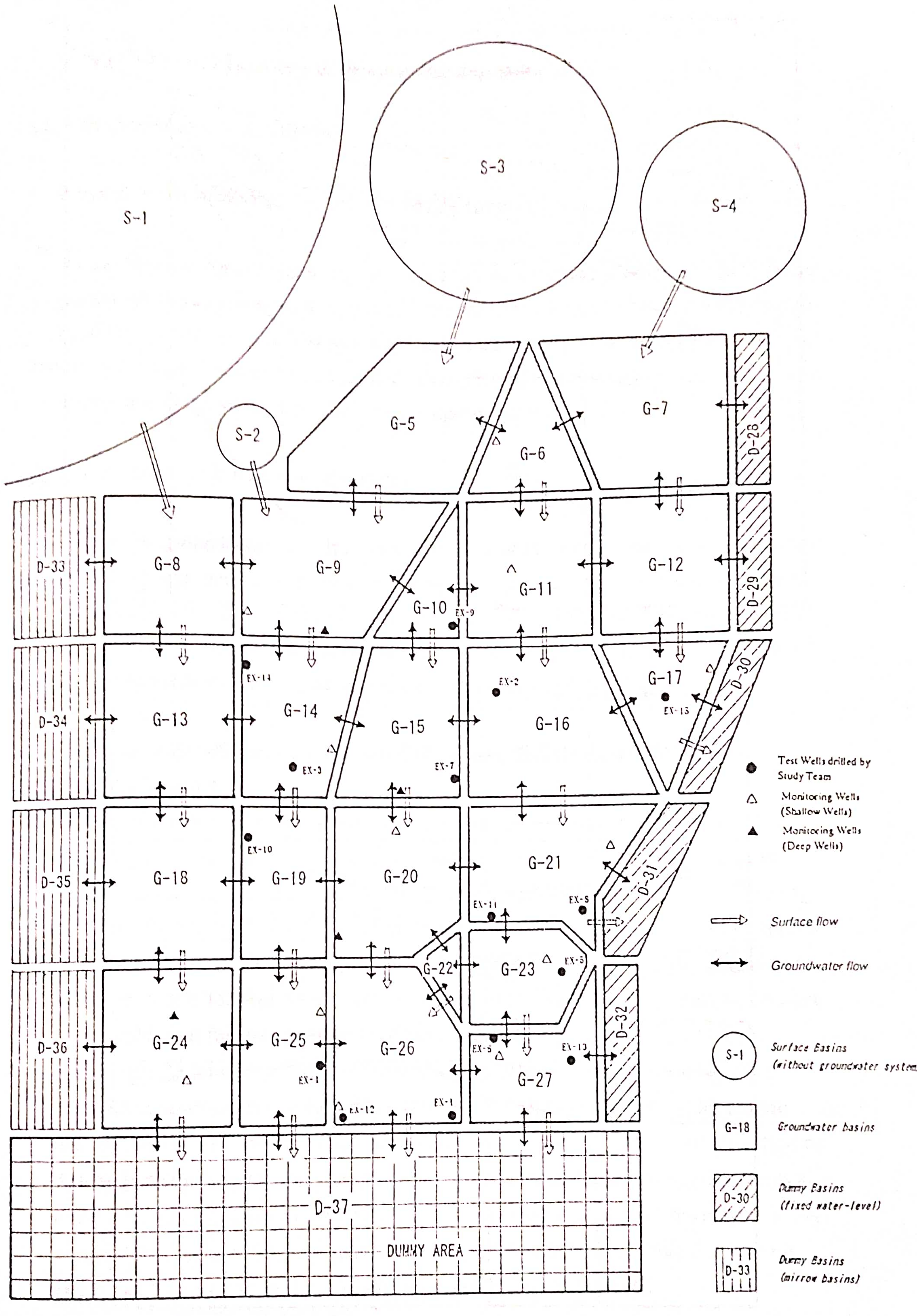
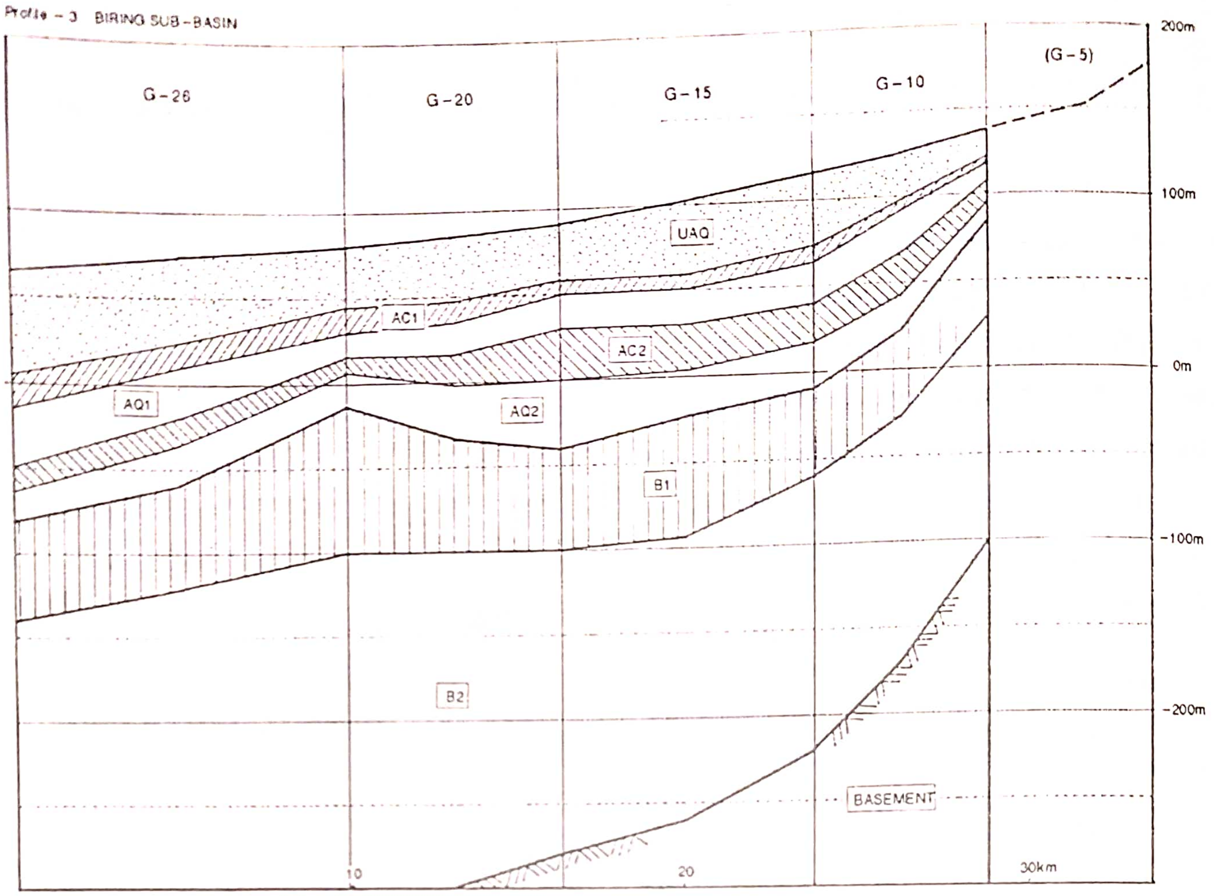


Figure 5.3.1 Sub-Basin Model



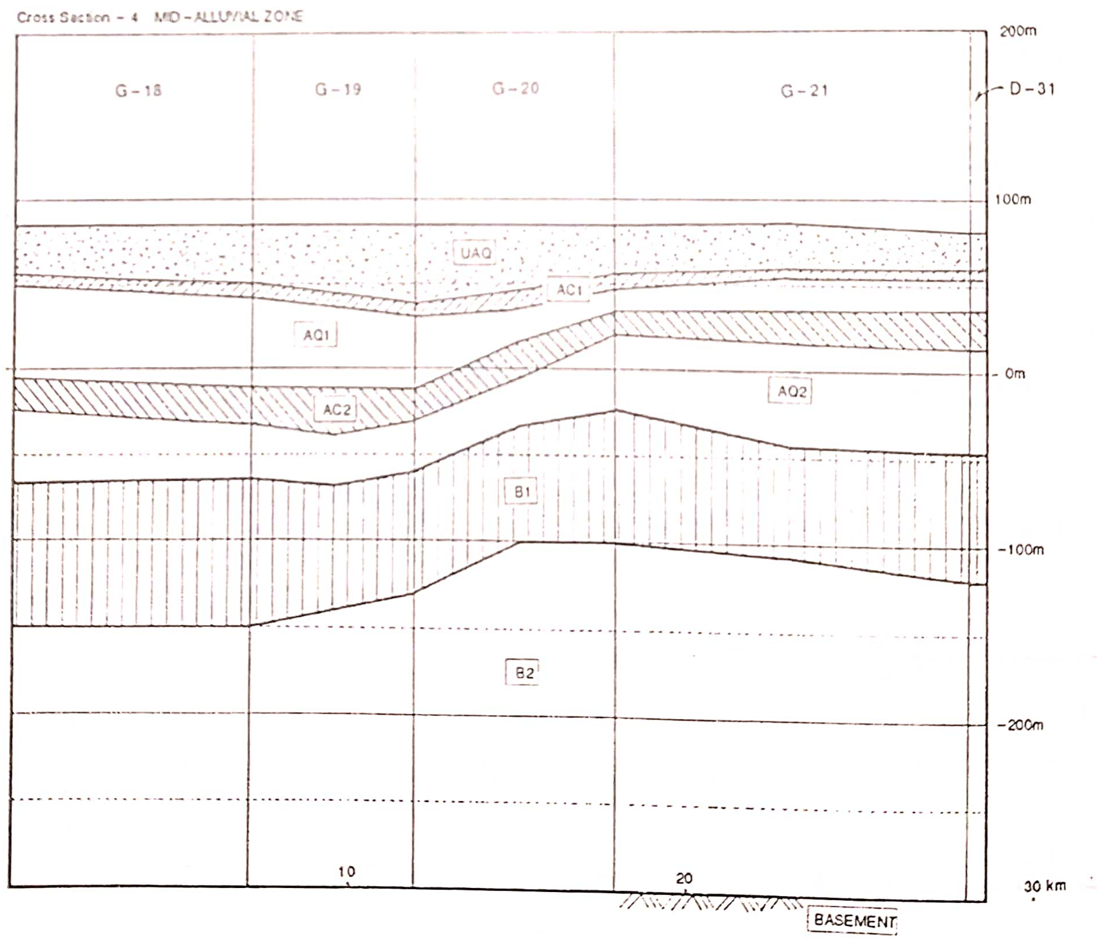


Figure 5.3.2 Aquifer Model

5.4. Management and Monitoring of Groundwater Resources

5.4.1. Management of Groundwater Resources

(1) Concept for Groundwater Conservation Management

As mentioned in the paragraph 5.1, groundwater conservation management which allows sustainable development within a permissible range of environmental impact is summarized as "resource volume", "water head" and "water quality". Because resource volume and water head are similar in meaning because of their close relationship, water head management is a synonym for the resource management.

(2) Conservation of Groundwater Resources

Sustainable groundwater resource development should be implemented within the range of long-term groundwater recharge by recognizing groundwater is an element of the hydrological cycle. It is not necessary for the range of development to be an average recharge value over a certain period, but development can be conducted to a stochastic maximum value within an allowable range in environmental impact.

The basin-wide behavior of groundwater is far more flexible for development than it is generally believed.
Any aquifer may be considered to be a type of storage reservoir. The concept in "carry-over storage" may, therefore, be adopted for the groundwater development in basin-wide size. The development is not needed to be set forth within a level where its storage is always replenished to the full level in the beginning of a water year. The development could be set forth at a level which could be replenished to its full-storage within a wet hydrologic cycle following a drought cycle. The groundwater development in a drought cycle could be at the maximum level of basin capacity in this case.
Along with the advance of "leakage theory", it is clarified the basin-wide recharge potential depends largely in the vertical direction through the aquclude system more than that in the horizontal direction through the aquifer system. The theory also clarified that the recharge potential of a basin is at a low level when the development remains at a low level and that it is increased in accordance with the extension of development. As a matter of fact, the recharge potential of any groundwater basin is limited to a certain extent, but it is unclear until the development reaches a certain level.

Application of a simulation model is convenient to continuously monitor basin-wide groundwater resources and their behavior mentioned above. The model must be capable of handling time-series and unsteady state in the hydrological cycle, including precipitation, evapotranspiration, surface run-off, groundwater recharge, storage, flow, and draft; and it must easy to alter the model parameters. The STML constructed for Jhapa District possesses the above capability and can be used as a tool for conservation management of groundwater resources.

However, as this model is identified through the verification data collected in a very short period of time, it must be tuned up based on further hydrographs which include precipitation, river discharge, draft, and the groundwater head based on sub-basins and layers. As mentioned above, the basin-wide recharge potential is related to the degree of development, and sharpening the model at each Project implementation stage is necessary.

For the other two districts it will be necessary to construct similar simulation models in the future.

It has already been mentioned that conservation and management of groundwater resources have the same meaning as water head management.
In the simulation of the groundwater resource evaluation for this Study, the control groundwater head is defined as the average groundwater head of the first and second confined aquifers and is set at 30 m depth. The actual control groundwater head, however, should be examined again when development shows the characteristics of each sub-basin and aquifer.

(3) Conservation and Management of Water Quality

As a result of development, the groundwater quality may become polluted by adjacent brine or the absorption of ground pollutants. These pollution problems, however, are not predicted in the Terai.
Nevertheless, water quality monitoring is essential as an environmental impact is expected as a result of pollution from chemical fertilizers or agro-chemical residuals from agricultural development in the Terai.

5.4.2. Monitoring of Groundwater Resources

Based on the concept of groundwater resource management, as mentioned in the previous paragraph, a monitoring of the following items is necessary.

- Precipitation (representative points in the districts, daily)
- River runoff (representative rivers in the district, daily)

- Groundwater head (representative sub-basin, daily, based on aquifer)
- Pump discharge (purpose, sub-basin, monthly, aquifer: measurements by a cumulative flow meter is desirable for production wells in this Project)
- Water quality (representative exploratory wells and rivers, seasonal)

Observation stations for the above items in Jhapa District should be reorganized in the future based on the characteristics of the sub-basins and the degree of development. It is recommended, however, that the DOI maintain the observation network established by the Study Team and continue these observations (See Figure 5.4.1).

Additional studies are necessary for the other two districts and an observation network should be planned in the process.
The Study Team has indicated the importance of accumulating time-series hydrographs in the example of Jhapa District, and it is recommended that DOI at least begin and continue the observation of the groundwater head at several points.

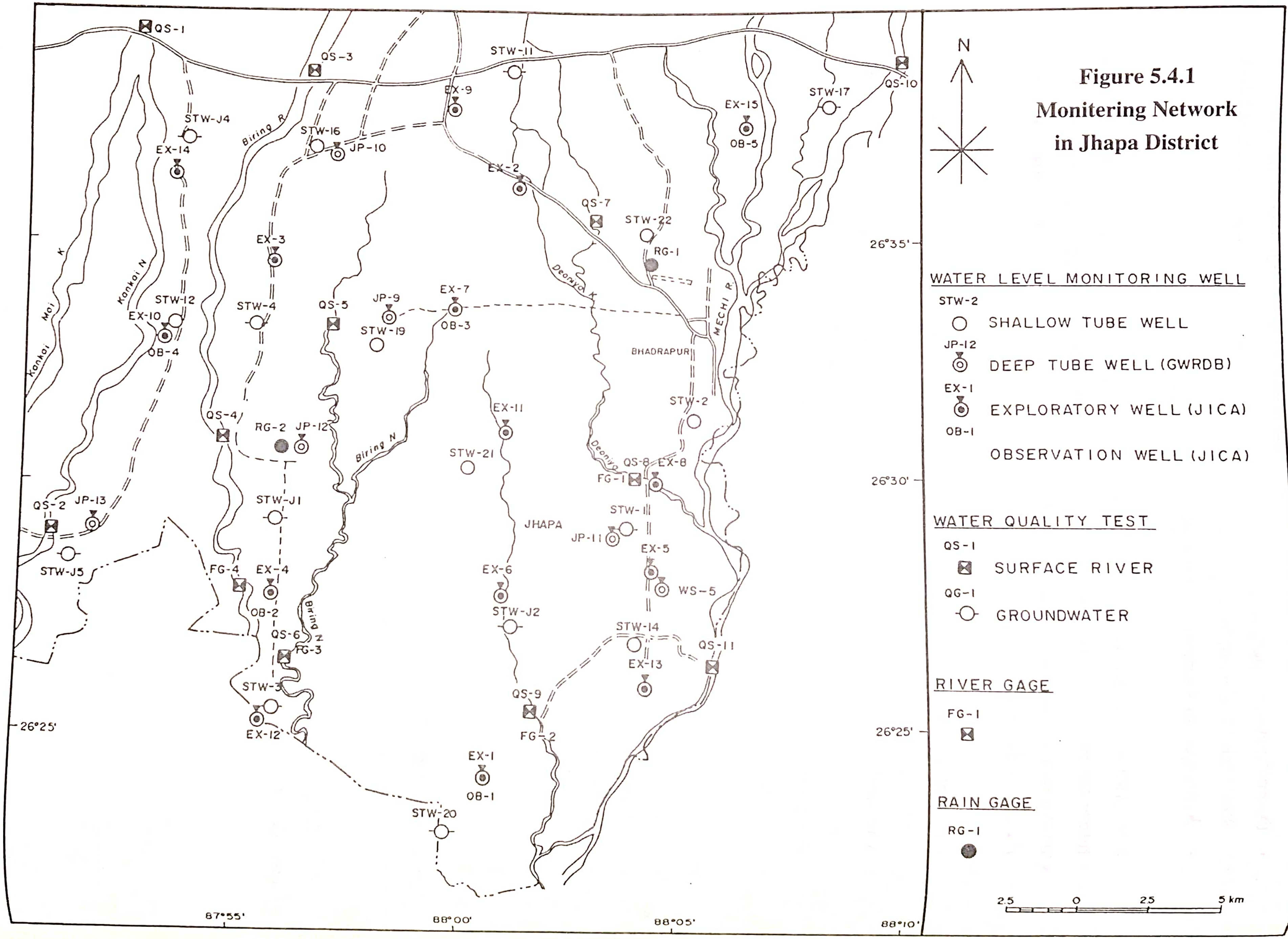


Figure 5.4.1
Monitering Network
in Jhapa District

CHAPTER SIX

MASTER PLAN

CHAPTER SIX: MASTER PLAN

6.1. Basic Strategy

Under the background of a declination in the food self-sufficiency caused by a population growth and a stagnation in agricultural productivity, HMGN has taken national measures over the past 30 years which focus on the development of irrigated agriculture in order to expand agricultural production. However, the surface water resources development, particularly any water storage scheme for irrigation in dry season, has been restricted due with an impasse of coordination in the international water right.

The irrigation policy set forth in the Eighth Plan (1992~1997) is to expand 294,000 ha of new irrigated land implementing multipurpose, medium and large scale projects by the governmental agencies, and small scale projects by the joint participation of government and user's group.

The tubewell irrigation has been implemented in the Terai where is blessed with land and groundwater resources aiming a quick-return with a small initial investment. The small scale STW projects have been remarkably and successfully extended by individual farmers and farmer's groups under the encouragement by HMGN and the financing by ADB/N. The STW irrigation meets to a small scale project, and is not undertaken by the force account basis by the governmental agencies.

The Bailawa-Lumbini Groundwater Irrigation Project implementing by DOI is the pioneer of a large DTW irrigation project in the governmental level. DOI has already corroborated the effectiveness and excellent economy of a large DTW irrigation project through this project, and formulating the succeeding projects in same nature in the Terai.

This study aims to fomulate a large DTW irrigation project in three selected districts in the Terai exclusive of STW development. As the result of this study shows as well as the foregoing projects, the economy of DTW irrigation is in general remarkable when certain conditions are cleared; and it may be expected a scale merit that the economic feasibility becomes higher when the irrigable area commanded by a unit irrigation system is larger.

As stated in the previous chapter, it was clarified that he deep groundwater resource for irrigation in the Terai would be sufficiently available in case certain hydrogeological conditions are fulfilled. Upon the basis of this fact and the said background, the master plan of DTW irrigation for the target Districts which is described in this chapter is to be formulated under the following strategy:

(1) Agricultural development plan for crop diversification, expansion of agricultural production, productivity, and farm incomes.
(2) Rational and water-saving-type irrigation plan.
(3) Rational and realistic project plans.
(4) Organization and O&M plans led by farmers and assisted by the government.
(5) Environmental considerations especially related to groundwater development.
(6) Realistic project evaluations.
(7) Establishment of DTW irrigation guidelines which can be applied to the overall Terai.

6.2. Agricultural Development Plan

6.2.1. Agricultural conditions and constraints

The outline of the agricultural conditions and the constraints prevailing in the irrigable areas of the target Districts under this project are described in the followings.

(1) Jhapa District

The cropping intensity of this area at present is as low as 126%. The fact result from the largest constraint of the absence of water source and irrigation facility to extend the cropping in the dry season. The constraint is reflecting in the present limited cropping pattern in the monsoon paddy and wheat in the dry season in a small extent.
Moreover, the situation that the small farmers holding less than 1.0 ha of farmland occupy 52%, makes another constraint on farm income due to surplus labor force in the dry season though there is some employment opportunity for surplus labor in the busy farming season in larger farms. The sole measure to evacuate from the situation is to provide agricultural infrastructure which suits the natural conditions such as climate, soils, etc. and is composed mainly of irrigation and drainage facilities; and the reinforcement of extension and support services. Thus, the drastic improvement could be expected over cropping intensity, crop production, integrated use of surplus labor force; and then the farm economy in the target area.

(2) Mahottari District

Cropping intensity in Mahottari District as a whole is estimated to be 171%, but that in the irrigable area under the study is as low as 140%. The difference of intensity between irrigated area and study area becomes larger. In terms of crop yield, the study area remains at a low level compared with other areas within the District, as was seen in Jhapa. It is considered that the major factor restricting agriculture in a rainfed area is to be water. In order to encourage farmers by increasing their income and expanding agricultural production, the provision of farming infrastructure, particularly the irrigation facility, and the sustainable and systematic extension and support services are to be necessary.

(3) Banke District

Both the farmland area and cropping intensity (142%) in the District as a whole are smallest among three Districts under the study. The intensity in the study area is as low as 140%. It is assumed that the situation derives from the fact that the district receives only a half of annual rainfall, and has less irrigated land than Jhapa. The prevailing cropping is, therefore, limited to paddy only in monsoon season and small amount of pulses and maize both of which are low water consumption crops. The paddy production is lower than any other district under the study; and shares only 1.4% to that of the national total. In order to clear the high hurdle under the said worst condition in agriculture, the first priority must be placed at the expansion of irrigation facility and other farming infrastructure.

6.2.2. Increase of Cropping Intensity

The increase of cropping intensity is the one of the basic factors in the measures to improve agricultural productivity. Although the expansion of land reclamation is also an important factor, an increment of cropping intensity is a more realistic measure compared with the many restrictive conditions due to topography, meteorology and social conditions. The current cropping intensity in each district remains in a range of 120% to 140%.

Meteorological condition represents the most significant restriction in terms of cropping intensity. The intensity during the monsoon period in the Terai is almost 100%, but significantly drops during the dry period. This also affects the selection of crops. The target of this plan is to ensure 200% cropping intensity through the introduction of irrigation projects (refer to figures 6.2.1-6.2.3).

6.2.3. Increment of Crop Production

The increase of crop yield per hectare is another important factor in the increment of crop production. In reference to the values taken by the preceding project and others, the target yield of crop production in this Project is determined as follows:

(1) Jhapa District

Crop name	Without Project (A) (ton/ha)	With Project (B) (ton/ha)	Increase (B/A)
Paddy	2.45	4.00	1.63
Wheat	1.59	2.70	1.70
Maize	1.31	2.70	2.10

(2) Mahottari District

Crop name	Without Project (A) (ton/ha)	With Project (B) (ton/ha)	Increase (B/A)
Paddy	2.12	3.40	1.60
Wheat	1.48	2.60	1.76
Potatoes	10.08	12.00	1.19

(3) Banke District

Crop name	Without Project (A) (ton/ha)	Without Project (B) (ton/ha)	Increase (B/A)
Paddy	1.94	3.50	1.80
Wheat	1.40	2.10	1.50
Maize	1.61	2.60	1.61
Potatoes	11.98	14.00	1.17
Pulses	0.68	1.00	1.47

6.2.4. Crop Diversification

The farming and cropping are greatly affected by the meteorological conditions. The cropping pattern in the Terai during the monsoon period is mainly paddy. Cash crops including maize, pulses, oilseeds, onions, and potatoes are introduced during the dry season. The introduction of irrigation may diversify the current unified crop pattern. The following summarizes the features and changes of cropping during the dry season.

(1) Jhapa District

The introduction of spring paddy and vegetable as cash crops is recommended for the dry season in this district. The production of maize and wheat will double when an irrigation is introduced.

(2) Mahottari District

The production of monsoon paddy will be stabilized during the monsoon season, and spring paddy (10%), onions, and potatoes are introduced during the dry season upon the introduction of irrigation.

(3) Banke District

Rather than introduction of spring paddy, irrigation water is deemed necessary for the stabilization of production of dry season crops currently being planted. Potatoes are to be introduced as a major cash crop.

The cropping intensity and cropping calendar at present are shown in Figures 6.2.1 to 6.2.3.

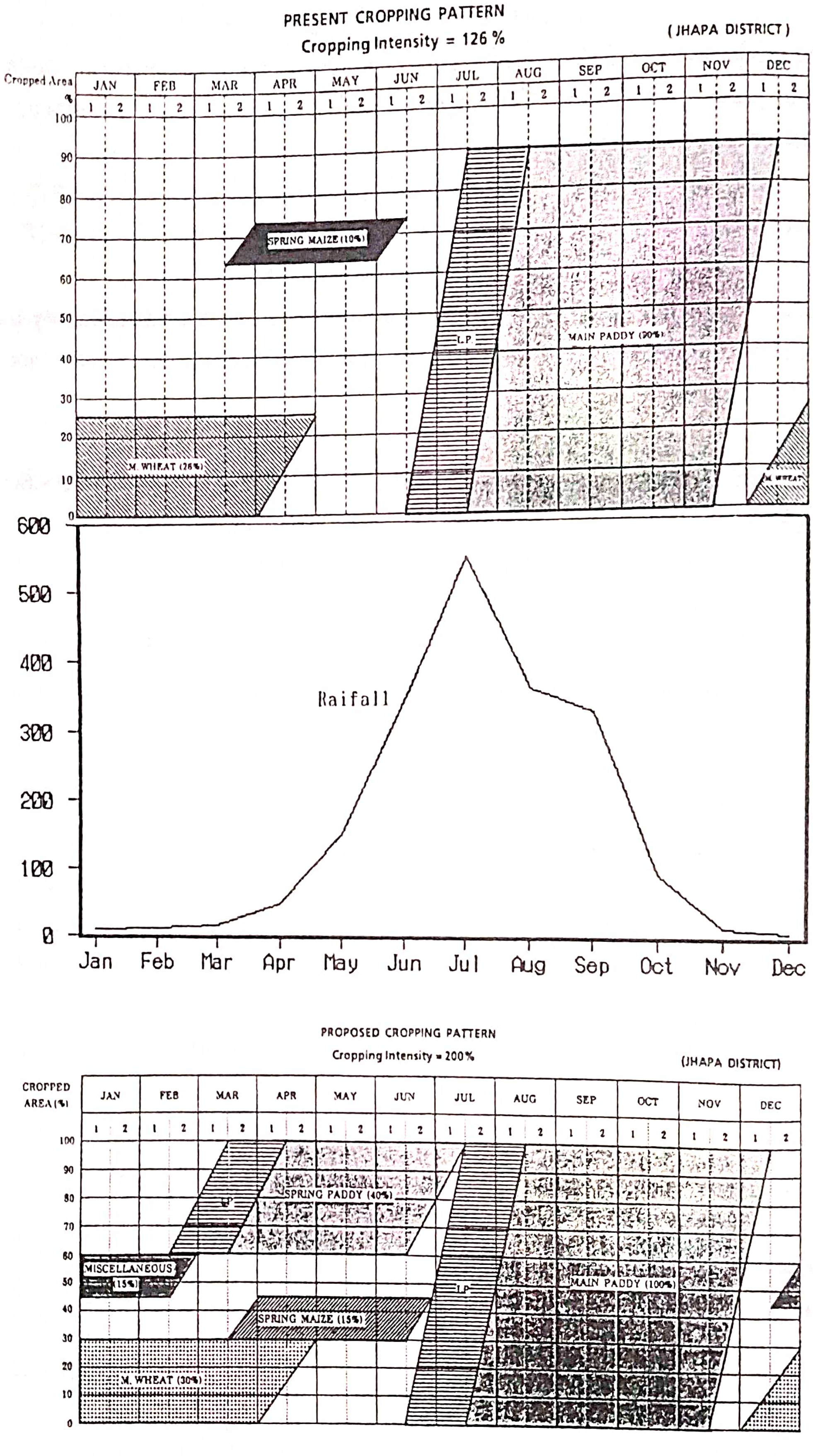


Figure 6.2.1 Current and Planned Cropping Patterns (Jhapa District)

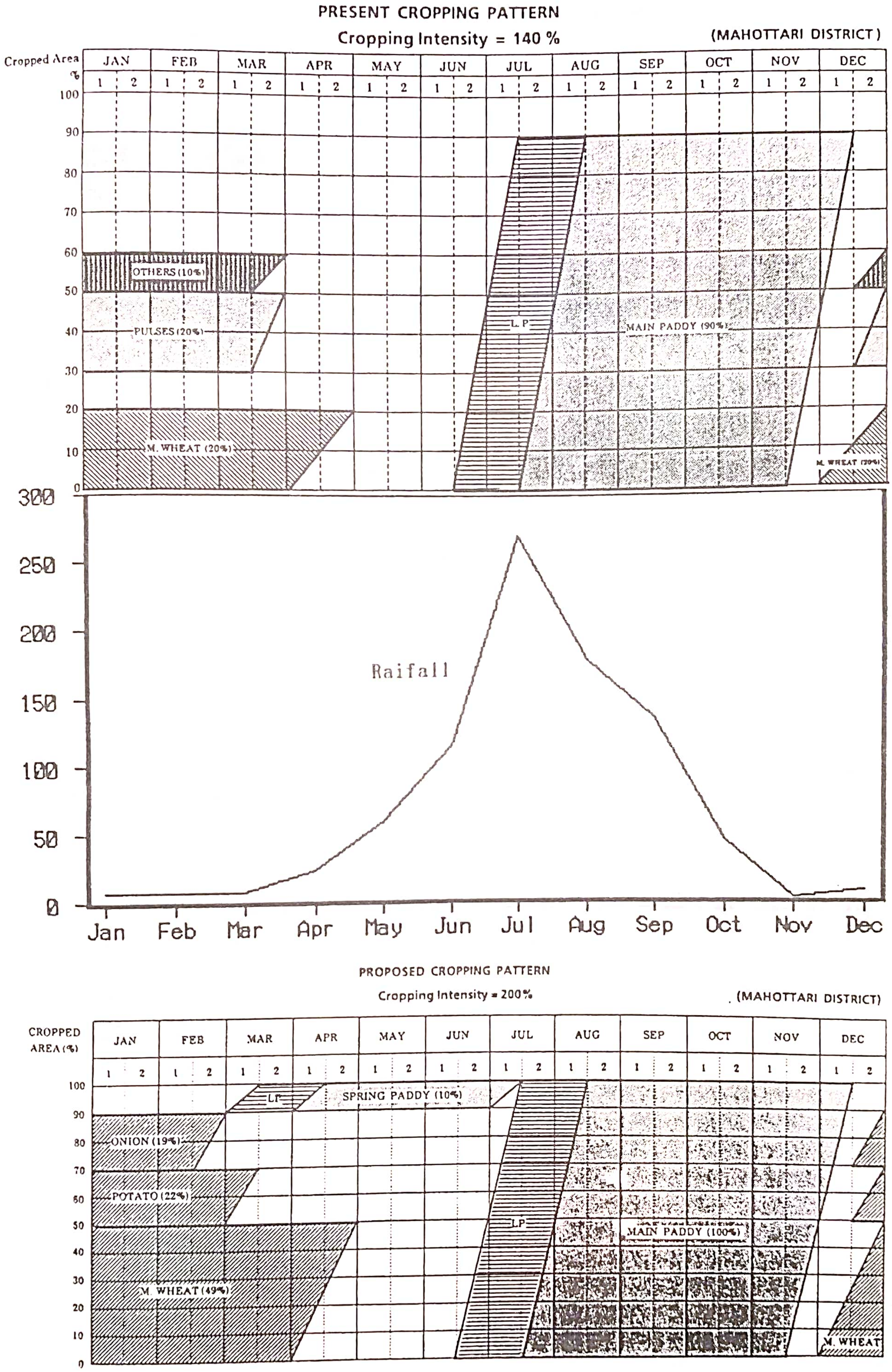


Figure 6.2.2 Current and Planned Cropping Patterns (Mahottari District)

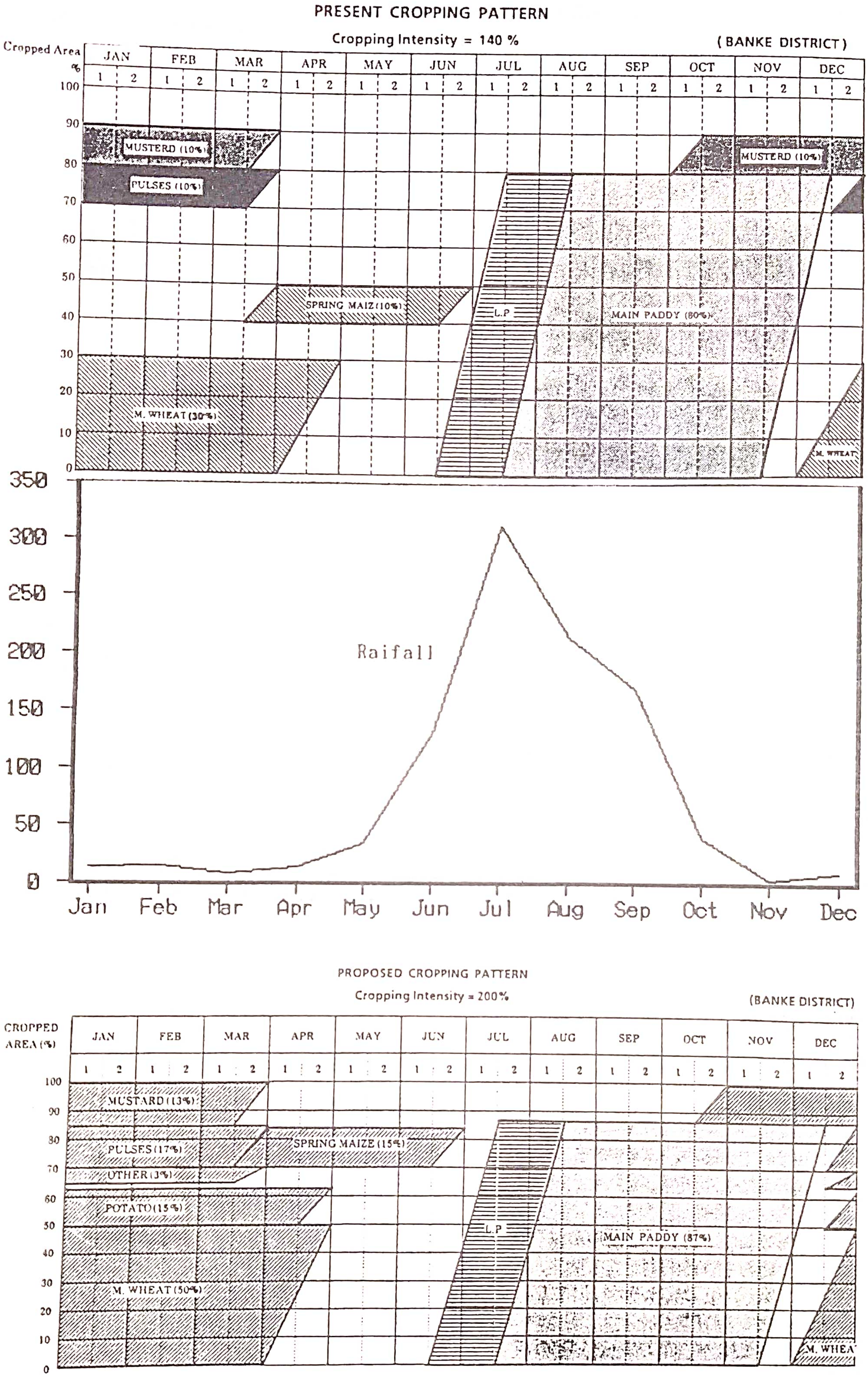


Figure 6.2.3 Current and Planned Cropping Patterns (Banke District)

6.3. Irrigation Plan

6.3.1. Irrigation Water Requirement

Evapotranspiration (ETo), which is the basis of the irrigation water requirement, was calculated based on the procedures shown in the Technical Paper No. 24 of FAO adapting the meteorological data obtained near or in the study area. The percolation rate in the paddy fields, puddling water requirements, and irrigation efficiency are determined based on the figures used in the foregoing projects in the Terai.

The values for each item are summarized as follows.

(1) Evapotranspiration

Priority Sub-area \ Month		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total (m·m/year)
JHAPA	ETo = (m·m/day)	2.0	2.9	4.3	5.5	5.4	4.4	3.8	4.1	3.6	3.6	3.0	2.1	
	(m·m/month)	62.0	81.2	133.3	165.0	167.4	132.0	117.8	127.1	108.0	111.6	90.0	65.1	1,360.5
MAHOTTARI	ETo = (m·m/day)	2.1	2.9	4.9	6.9	7.1	5.7	5.3	5.0	4.3	3.9	2.7	2.3	
	(m·m/month)	65.1	81.2	151.9	207.0	220.1	171.0	164.3	155.0	129.0	120.9	81.0	71.3	1,617.8
BANKE	ETo = (m·m/day)	1.8	2.7	4.3	6.4	7.3	6.4	4.8	4.6	4.1	3.8	2.6	1.8	
	(m·m/month)	55.8	75.6	133.3	192.0	226.3	192.0	148.8	142.6	123.0	117.8	78.0	55.8	1,541.0

(2) Percolation Rate in Paddy Field : 2.0 mm

(3) Puddling Water Requirement :150 mm

(4) Pre-irrigation Water in Upland Crops : 60 mm (mainly for maize)

(5) Irrigation Efficiency : 70% for paddy, 60% for dry season crop

(2) to (5) are applied in common for the three study areas.

(6) Design Discharge

The design discharges for irrigation facility (facility discharge) by each area were estimated based upon the water requirement for the selected representative crops, which were monsoon paddy, spring paddy, wheat (winter crop) and maize (spring crop); and effective rainfall by each area.

The estimated discharges by each area are as below;

(a) Jhapa study area : 0.8 l/s/ha,

(b) Mahottari study area : 1.1 l/s/ha; and

(c) Banke study area : 0.7 l/s/ha.

The details of design facility discharges by each area are shown in Table 6.3.1.

(7) Annual Water Demand (design year: 10 year recurrence interval)

The annual irrigation water demand based on the cropping pattern and cropping intensity in each area are shown below.

(a) Jhapa : 130.8 MCM

(b) Mahottari : 72.4 MCM

(c) Banke : 66.7 MCM

The details of annual water demand by each area are shown in Table 6.3.2.

6.3.2. Water Source Development

The water source is to be deep groundwater taken through DTWs. Based upon the actual DTW test and available hydrological data, the design yield of standard DTW is estimated by each area. In accordance with the design yield and the peak water requirement by area, the mean unit irrigable area by DTW (mean acreage of irrigation unit) is estimated by study area. The design yield and mean unit irrigable area by study area are as below:

(a) Jhapa		:	120 l/s (120/0.8=150 ha)
(b) Mahottari	A1	:	66 l/s (66/1.0=66 ha)
	A2	:	97 l/s (97/1.0=97 ha)
(c) Banke		:	110 l/s (110/0.7=157 ha)

Values in ( ) show the irrigable area/DTW.

Based on further examinations, the specifications of the above DTW are as follows:

Depth of the well	:	130-150 m
Diameter of well	:	250 mm
Standard drawdown	:	20 m from the ground surface
DTW interval	:	1.0 km

6.3.3. Water Distribution Plan

(1) Water Delivery System

The irrigable area commanded by one DTW is referred to as an irrigation unit. The acreage of irrigation unit is determined by the yield of DTW and the design discharge. The irrigation unit is determined in the range of 60 ha to 160 ha for these study areas. The water delivery system within the irrigation unit is connected by a pipeline system from a pump station to an irrigation block (valve command area; 4 ha to 6 ha). An alfalfa valve is connected to the irrigation block and pipeline, and the discharge is adjusted by operating the valve.

Although the loop type pipeline system has been taken in the preceding DTW project, the fish-bone type pipeline system is considered in this study.
In order to select one of those types of pipeline layout, there are many factors; such as topography, shape and acreage of beneficial area, type and number of water source, mode of water use, density of valves within the system and so forth. It is, in general, said that the loop type is advantageous to apply in case of system in high density of valves in a small size, small and flat service area, multiple water sources and so forth. The fish-bone type is said to be appropriate to any case in low density of valves in a relatively large size, large service area in slope, single water source and so forth.

The major reason why fish-bone type is selected in this study area are as below;

- total length of pipeline becomes smaller than the loop layout,
- the discharge rate at each valve in a system could be manageable in view of relatively low valve density,
- an irrigation unit covers comparatively large acreage (60 to 160 ha)
- water source is single; and then
- the advantage in loop layout is deemed to be small.

It is, however, recommended that the final decision for layout type of pipeline is to be made basing on actual conditions of individual irrigation project in the further design stage.

(2) Water Distribution System

In order to distribute irrigation water after the valve said above, the terminal irrigation canal (an open earth canal) is to be constructed in one or two upper sides of each irrigation block.

The on-farm canal after the terminal canal is small-sized in both section area and length, and to be constructed by the beneficial farmer himself, and excluded from the project component.

Table 6.3.1 Facility Discharge in Each District

TABLE

(Unit: ℓ/s/ha and ℓ/s)

District	Crop	JAN.		FEB.		MAR.		APR.		MAY		JUN.		JUL.		AUG.		SEP.		OCT.		NOV.		DEC.		Remarks
JHAPA	Spring Maize A = 15 (ha)						1.1	0.9	0.9	0.5	0.5	-	-													ℓ/s/ha
							16.5	13.5	13.5	7.5	7.6															ℓ/s
	Spring Paddy A = 40 (ha)						1.1	1.6	1.2	0.7	0.8															ℓ/s/ha
							44	64	48	28	32															ℓ/s
	Main Paddy A = 100 (ha)															0.2	-	-	-	0.6	0.6	0.6	0.3	0.1	-	ℓ/s/ha
																20				60	60	60	30	10		ℓ/s
	Wheat A = 30 (ha)	0.2	0.3	0.5	0.5	0.6	0.4	-	-															-	0.1	ℓ/s/ha
		6	9	15	15	18	12																		3	ℓ/s
	Total	6	9	15	15	18	73	*78	62	36	40					20				60	60	60	30	10	3	ℓ/s
MAHOTTARI	Spring Paddy A = 10 (ha)							1.5	2.3	1.4	1.4	0.8	0.4													ℓ/s/ha
								15	23	14	14	8	4													ℓ/s
	Main Paddy A = 100 (ha)														0.2	1.0	0.6	0.6	0.6	0.8	0.8	0.6	0.3	0.1	-	ℓ/s/ha
															20	* 100	60	60	60	80	80	60	30	10		ℓ/s
	Wheat A = 49 (ha)	0.2	0.3	0.6	0.6	0.7	0.4	0.1	-																	ℓ/s/ha
		9.8	14.7	29.4	29.4	34.3	19.6	4.9	-																	ℓ/s
	Total	10	15	30	30	34	20	20	23	14	14	8	4		20	100	60	60	60	80	80	60	30	10		ℓ/s
BANKE-BARDIYA	Spring Maize A = 15 (ha)						1.1	1.2	1.2	1.3	1.3	0.6														ℓ/s/ha
							16.5	18.0	18.0	19.5	19.5	9.0														ℓ/s
	Main Paddy A = 87 (ha)															0.8	0.4	0.4	0.4	0.8	0.8	0.6	0.3	-		ℓ/s/ha
																69.6	34.8	34.8	34.8	69.6	69.6	52.2	26.1	-		ℓ/s
	Wheat A = 50 (ha)	0.2	0.3	0.4	0.5	0.6	0.4	0.1	0.1																	ℓ/s/ha
		10	15	20	25	30	20	5	5							*70	35	35	35	70	70	52	26			ℓ/s
	Total	10	15	20	25	30	37	23	23	20	20	9				70	35	35	35	70	70	52	26			ℓ/s

Note: Beneficial area is fixed as a hundred hectares
Acreage of each cropping area are estimated by the percentage of cropped area in proposed cropping pattern.
* JHAPA D.D 0.8ℓ/s/ha * MAHOTTARI D.D 1.0ℓ/s/ha *BANKE-BARDIYA D.D 0.7ℓ/s/ha

Table 6.3.2 Irrigation Water Demand in Each District

TABLE

District	Crop	Month: JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	Total/Year (10^3m^3)
JHAPA	Spring Maize A = 2,550 (ha)			3,782	5,830	3,241								12,853
	Spring Paddy A = 6,800 (ha)			10,227	23,820	13,532	-	-						47,579
	Main Paddy A = 17,000 (ha)							-	4,420	-	27,591	19,805	1,122	52,938
	Wheat A = 5,100 (ha)	3,550	6,207	6,411	-								1,230	17,398
Total $V = 10^3m^3$		3,550	6,207	20,420	29,650	16,773	-	-	4,420	-	27,591	19,805	2,352	130,768
MAHOTTARI	Spring Paddy A = 700 (ha)				3,512	2,548	1,138	-						7,198
	Main Paddy A = 7,000 (ha)							2,093	14,672	10,122	15,372	8,351	427	51,037
	Wheat A = 3,430 (ha)	2,518	4,981	5,204	521								892	14,116
Total $V = 10^3m^3$		2,518	4,981	5,204	4,033	2,548	1,138	2,093	14,672	10,122	15,372	8,351	1,319	72,351
BANKE-BARDIYA	Spring Maize A = 1,200 (ha)			1,832	3,724	4,294	926							10,776
	Main Paddy A = 6,960 (ha)							202	10,509	6,918	15,291	8,011	285	41,216
	Wheat A = 4,000 (ha)	2,296	4,316	5,372	1,012								680	13,676
Total $V = 10^3m^3$		2,296	4,316	7,204	4,736	4,294	926	202	10,509	6,918	15,291	8,011	965	65,668

Note : Arable land of Priority Sub-area for District

JHAPA : 17,000 (ha)
MAHOTTARI : 7,000 (ha)
BANKE-BARDIYA : 8,000 (ha)

6.4. Drainage and Road Plans

6.4.1. Drainage Plan

The current drainage system is very poor in the study area, and the excessive water during the monsoon season is drained over plot to plot, which causes local flooding. In order to solve this problem, drainage networks are organized within an irrigation block as a drainage unit. A facility plan is established with a drainage discharge rate of approximately 4 l/sec/ha (based on an example of the preceding project). The canal intensity is approximately 40 m/ha based on the model design in the sample area.

6.4.2. Road Plan

The enhancement and upgrading of agricultural road facilities are necessary not only in this study area but throughout the entire Terai. Road development in the study area will help reduce farm labor and also significantly reduce the construction period for the project implementation stage.

Construction of main village and on-farm roads should begin immediately after the commencement of project works. Based on an example of the preceding project, the road network will be organized with the irrigation units at the center by connecting village roads with a width of 6.0 m and on-farm roads with a width of 3.0 m. The density of the road network is 4 to 5 m/ha based on an example of the previous project.

6.5. Project Plan

6.5.1. Basic Strategy

The most significant feature of the DTW irrigation is the self-sufficient, independent system in a command area of each DTW. The DTW irrigation project is essentially a grouping of the above individual systems, regardless of the size of the project area.

Therefore, the formulation of plan is to be based on the design of necessary facilities within a standard irrigation unit.

From the above perspective, a sample area (100 ha acreage) is determined in the representative area; a topographical map is created based on the survey (scale 1:1,000); and the standard design for the required facilities is constructed (refer to Fig. 6.5.1).

The following paragraphs discuss the project plan based on the above standard design and examples from the preceding project.

6.5.2. Project Component

The major project components are as follows:

(1) DTW

The average yield of DTW in each study area is different but the design and dimension of DTW for each study area is same.

(2) Pump Facility

Pumps require a high head of 30 m. Considering the spare parts' supply, operation, and maintenance, a vertical shaft turbine pump already widely used in Terai will be used. An electric motor will be used from the viewpoint of economy of operation and maintenance. Ancillary facilities include a pump and operator house and an elevated water tank. The required distance for the power transmission line is estimated from the example of the preceding project.

(3) Pipeline System

A pipeline system is applied for water delivery to irrigation blocks. The total length, pipe diameter and type of pipe determined based on the standard design of the sample area.

(4) Terminal Irrigation Canal System

The type of canal system, total length, and canal cross-section are determined based on the standard design of the sample area.

(5) Drainage System

The layout, cross-section, and total length of drainage canal are determined based on the standard design of the sample area.

(6) Road Network

The layout, total length, and paving type of road network are determined based on examples of the preceding project.

6.5.3. Quantities of Project Works

Based on the standard design in the sample area, and similar preceding projects in the Terai Plain, the quantities of project works required in each study area are determined and summarized in Table 6.5.1.

6.5.4. Project Implementation Plan

The project implementation schedule is determined based on the project components and quantities of works in each study area. Figure 6.5.2 summarizes the scheduled project implementation preparation and program inclusive of preparatory and construction works.

The preparation stages, such as the detailed design, preparation of tender documents, tenders, and construction of offices, will require three years for each study area. Organizing WUGs and land acquisition for roads and canals will require five years in Jhapa and four years in the other two study area. Road construction will be implemented prior to facility construction. This construction will require five years in Jhapa and four years in the other two areas. The facility construction, such as wells, transmission lines, canals, and drainage, will require six years in Jhapa study area, five years in Mahottari study area, and four years in Banke study area respectively.

Based on the above, the total project period for Jhapa area estimated at 10 years, nine years for Mahottari area, and eight years for Banke area.

Based on economic evaluation related to the study area in each district, the greatest economic effects will occur in Jhapa area, followed by Banke and Mahottari. Given this fact, beginning the project in Jhapa area will yield the most effective results.

Table 6.5.1 Proposed Project Quantities List

Work Items / Project	JHAPA	MAHOTTARI	BANKE-BARDIYA	Remarks
	A = 17,000 ha	A = 7,000 ha	A = 8,000 ha	
1. Deep-Tube Well				A; Irrigable Area
Well Depth	130 m	130 m	130 m	
Length of Casing	50 m	50 m	50 m	
ND of Casing	250 mm	250 mm	250 mm	
Length of Screen	30 m	30 m	30 m	
Housing	L = 50 m D = 400 mm	L = 50 m D = 400 mm	L = 50 m D = 400 mm	
No of Well	113	92	51	
2. Pump Facility				
Type of Pump	Shaft Turbine Pump	Shaft Turbine Pump	Shaft Turbine Pump	
Total Head	30 m	30 m : 30 m	30 m	
Diameter	250 mm	250 mm : 200 mm	250 mm	
Out-put of Motor	65 kw	54 kw : 35 kw	57 kw	
No. of Pump	113	31 : 61	51	
Length of Power-line	170 km	70 km	80 km	11 KV line
No. of Transformer	113	92	51	11 KV/400 V
3. Pipe line System				
Length of Pipeline	680 km	300 km	320 km	
Diameter (D)	100-400 mm	100-350 mm	100-400 mm	
Type of Pipe	PVC	PVC	PVC	
No. of Valve	4,070 Set	1,750 Set	1,940 Set	Alfalfa Valve ø = 100mm
4. Terminal Canals	1,240 km	560 km	610 km	Earth Canal
5. Drainage System	770 km	330 km	360 km	
6. Road System	170 km	74 km	77 km	Village Road
7. Building	2	2	2	

FIG. MODEL OF IRRIGATION UNIT (CASE STUDY I)

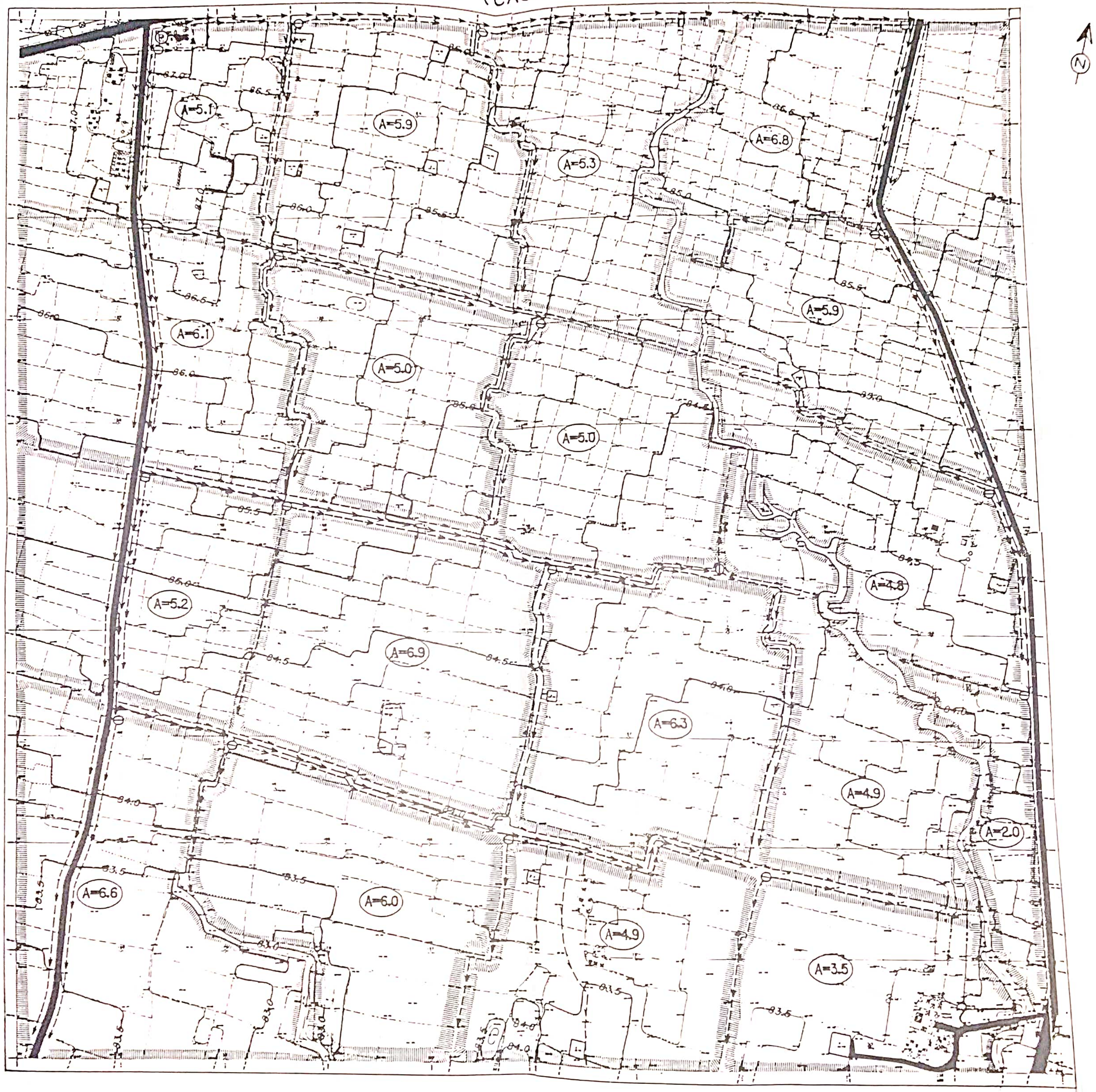


Figure 6.5.1 Model Design in the Irrigation Unit

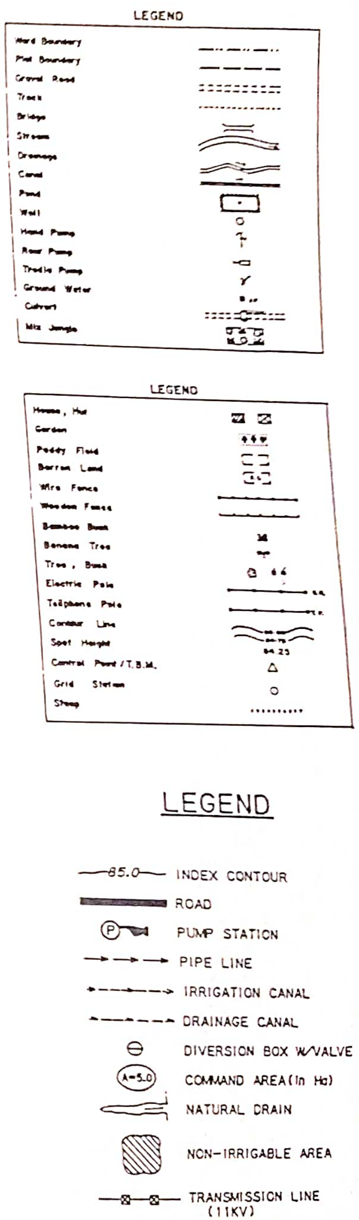
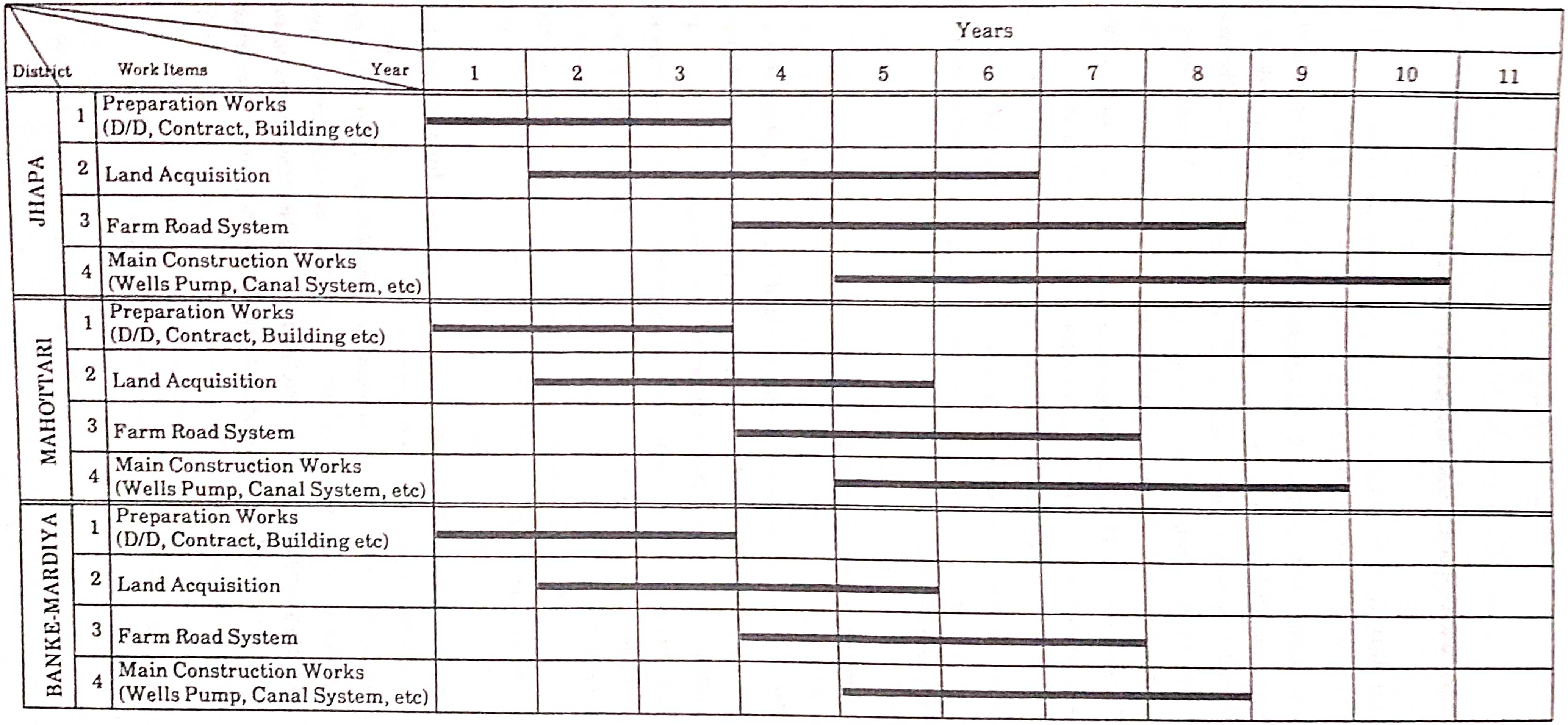


Figure 6.5.2 Project Implementation Schedule



6.6. Organization, Operation and Maintenance System

6.6.1. Basic Strategy

In accordance with Irrigation Regulation Act (1988) and Irrigation Policy (1992), a water users group (WUG) is to be organized by all beneficial farmers in order to operate, maintain and manage an irrigation facility. The irrigation policy in the Eighth Plan sets forth that the farmers group is to be involved in a large project where necessary.

The present plan is characterized that the project in each area consists of 51 to 113 irrigation units which are composed of 66 to 150 ha of commanding area.

Basing upon the said policies and characteristics of project, the basic strategy for the systems of project implementation and operation/maintenance of completed facility are to be as below:

(1) Project Implementing Agency

The implementing agency of the project is DOI. The actual implementation is undertaken by the project office established in each project area. The project office is composed of divisions for project implementation inclusive of divisions for extension service, farmers organization and O&M which undertake the training of WUG's staff through the project period for the handover of those function to WUGs and WUA upon the completion of project.

(2) Farmers Organization

The O&M of completed irrigation facilities is undertaken by WUG (composed of around 100 farmers) organized by each irrigation unit (DTW). In order to unified the necessary extension and supporting services, a water users association (WUA) which is organized by WUGs is established by each project area. The said organization is operated by the water charge collected from all beneficial farmers. However, the extension, supporting and other services by the governmental agencies is indispensable for the sound operation of farmers organization.

(3) Women in Development

DOI and farmers organizations are to actively take a policy of the involvement of "role of women" in the beneficial farmers into the project implementation and O&M as well in view of "women's participation into development".

6.6.2. Organization of Project Implementation

The project implementation agency is to be DOI. To ensure the success of the irrigation project, close contact with the agricultural administrative agencies, including the Ministry of Agriculture and ADO, is essential, together with the provision of assistance, instruction and cooperation to the Water Users' Association to be established.

The administration of current irrigation is handled by the district irrigation office (DIO). In order to implement a systematic irrigation development project as an area, project offices other than DIO should be established to manage and supervise the project. The establishment of a specialized project office under DOI is proposed for the implementation of this project. The project manager would implement projects with the cooperation of DIO and other agencies (Figure 6.6.1). The Project Office consists of the Agricultural, Farmers' Organization, Engineering, Hydrogeology, Maintenance and Administrative Divisions. Under the Agricultural Division, agricultural subcenters would be established within the irrigation area in order to train and instruct farmers.

Upon the completion of each project, the functions of the Agricultural, Farmers' Organization, and the Maintenance Divisions will be transferred to WUA, and the functions of the Hydrogeological Division will be transferred DIO. The project offices will provide training for WUA's staff beginning at the project implementation stage in order to prepare for the transfer of functions.

6.6.3. Operation and Maintenance of Irrigation Facilities

The facilities to be constructed in this project include DTWs, pump stations, pipe lines, and farm ditches. The main canal will be buried pipelines but the farm ditches are open canals. The Project Office is responsible for the operation and maintenance of main and lateral canals, and farm ditches are maintained by beneficiary farm households. The operation and maintenance of pump facilities will be under the responsibility of the Project Office for the first several years of this project. As this function will be transferred to the WUGs in the near future, the Project Office (Farmers' Organization Division) will provide training to the farmers in terms of operating and maintaining pumps, canals, water distribution, and other irrigation facilities. The facilities mentioned above are part of each irrigation unit, the individual system by each well, therefore a WUG will be established by each irrigation unit, and a WUA will be established to supervise the WUGs (refer to Fig. 6.6.2).

The collection of a water charge from the beneficiaries is essential for the operation and maintenance of facilities as well as the operation of WUGs. WUGs will collect fees based on the registration of land, and fair water distribution will be the basis for 100% fee collection.

6.6.4. Water Users' Group and Water Users' Association

WUG and WUA are important farmers' organizations for the irrigation projects. Success of irrigation projects in each district will depend on the operation of the WUG. The fair distribution of irrigation water will increase farmers' incomes as a result of an increase in crop intensity and crop yield. Beneficiaries will in turn be willing to pay for water charges, and irrigation facilities can be operated and maintained. It is important to offer education and training before the completion of the project in order for farmers to understand the necessity of the WUG, the meaning of the water charges, and necessity of fair water distribution. The Farmers' Organization Division in the Project Office will play a central role in these responsibilities.

The policy to transfer the operation and maintenance of irrigation facilities to WUGs and WUA is the one of the irrigation policies in the Eighth National Development Plan (1992-1997). Based on this policy, the functions of WUG are as follows:

- collection of water charges
- participation in WUA
- accept assistance services from DOI and ADO
- water use adjustment in areas
- operation of a joint workshop (pump repair)
- operation and maintenance of pump
- maintenance of power transmission line
- hold regular meetings for beneficiaries
- maintenance of open canal
- procurement and distribution of farm input materials
- involvement in product marketing

Upon completion of the project, WUA will take over the functions of each division of the Project Office, including the Agricultural Division, Farmers' Organization, and the Maintenance Division, and implement these activities. The activities by WUA require governmental assistance through the irrigation and agricultural offices at the district level.

6.6.5. Women in Development (WID)

Women of the rural areas of Nepal are playing roles of various kinds, not only within the household but also in connection with the agricultural production. Within the household, it is the duty of the women not only to handle such house-keeping activities as cooking, looking after children, washing clothes, cleaning the house, etc., but also to take care of such backbreaking duties as transporting drinking water and animal feeds. In connection with the farming work, Nepalese women provide contribution to the household economy by helping not only their own farm but also the planting and harvesting work of other farms. Female work force is seen also at construction sites of Nepal. As can be seen from the facts mentioned above, the role played by female work force in the rural areas of Nepal is very important, but in terms of daily wages, women laborer receive barely 25 Rupees a day, compared with the 35 Rupees received by their male counterparts.

However, the role played by women within the development process can not be neglected under any circumstances. Women must play a proper role as "bearers of the development process" and at the same time they must enjoy the benefits brought about by the development, as "beneficiaries of the development process". That would contribute to promote the welfare and the position of the women, and to make the development still more effective and significant.

Concurrently with the implementation of DTW irrigation project, it will be possible to transform the Nepalese agriculture from the rain-season-centered type, that has been practiced conventionally, into a round-the-year type in which crops will be available also during the dry season. Such transformation in the agriculture of the country is expected to contribute to increase the employment opportunity of the Nepalese women. Moreover, the development of DTW is expected to alleviate the drinking water transportation work that is being taken charge by women. As can be seen, the implementation of this project will bring about direct benefits to the Nepalese women as "beneficiaries of the development".

In connection with the role to be played by women as "bearers of the development process", it is proposed that the steps mentioned in the followings be taken, with the object of not only promoting the participation of women in the present project, but also elevating their technical skill level, education level and social position, so as to transform them into an active element within the development process, instead of keeping them limited to the role of passive beneficiaries.

- To promote the participation of women in the operation and maintenance of the irrigation facilities on the farm
- To promote the participation of women in the agricultural extension and training programs
- To promote the participation of women in the WUG and other organizations for collective activity of the farmers.

The promotion of the activity of women in groups is also proposed. For example, women have the possibility of playing an extremely important role for increasing the income level of rural households and for protecting the environment, through the activities mentioned in the followings.

- Nursery growing for afforestation
- Pig raising
- Processing of rice

It is presumed that the financial support of the ADB/N and other organizations will be required in order to promote activities of this kind to be carried out by women.

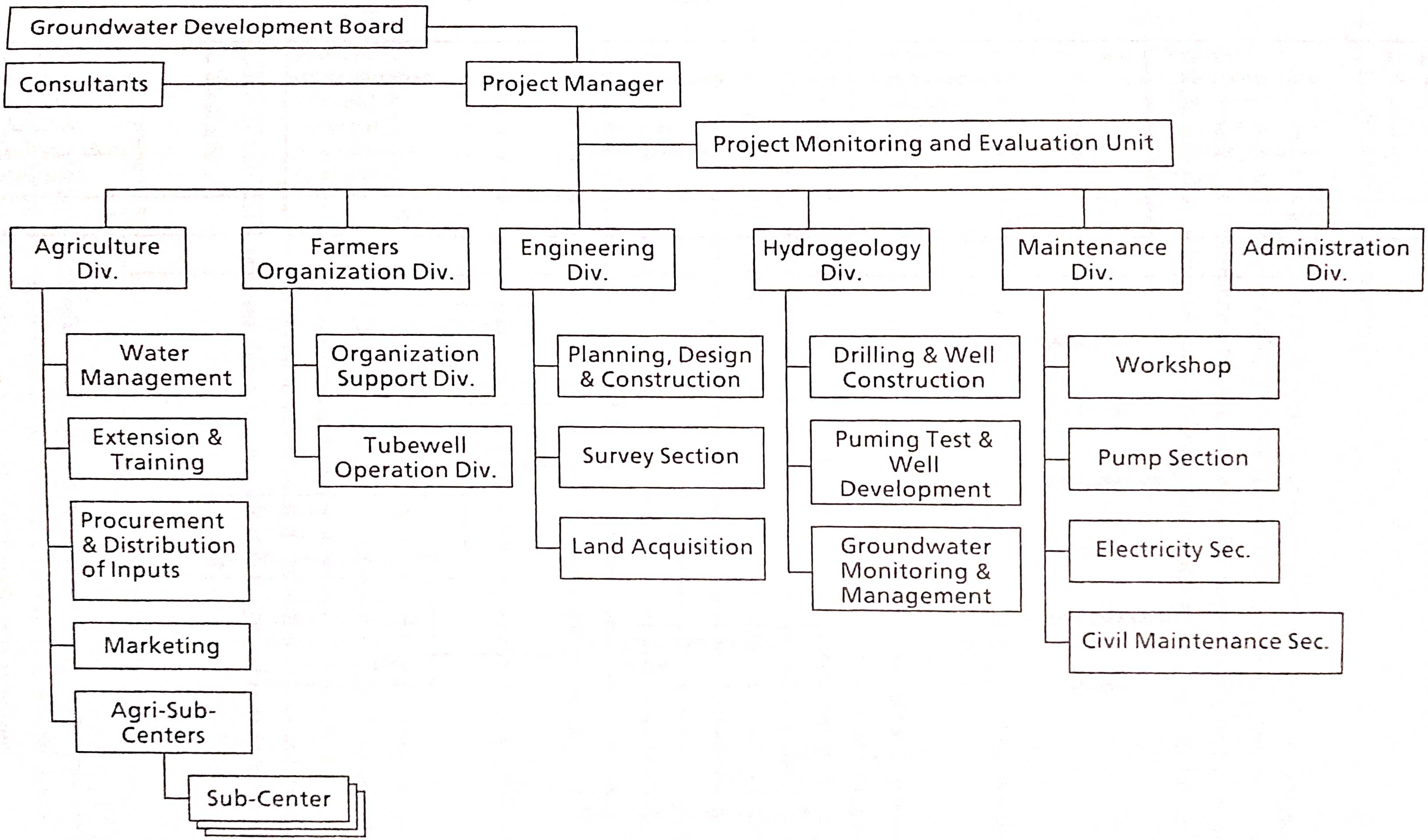


Figure 6.6.1 Proposed Organization of Project Implementation

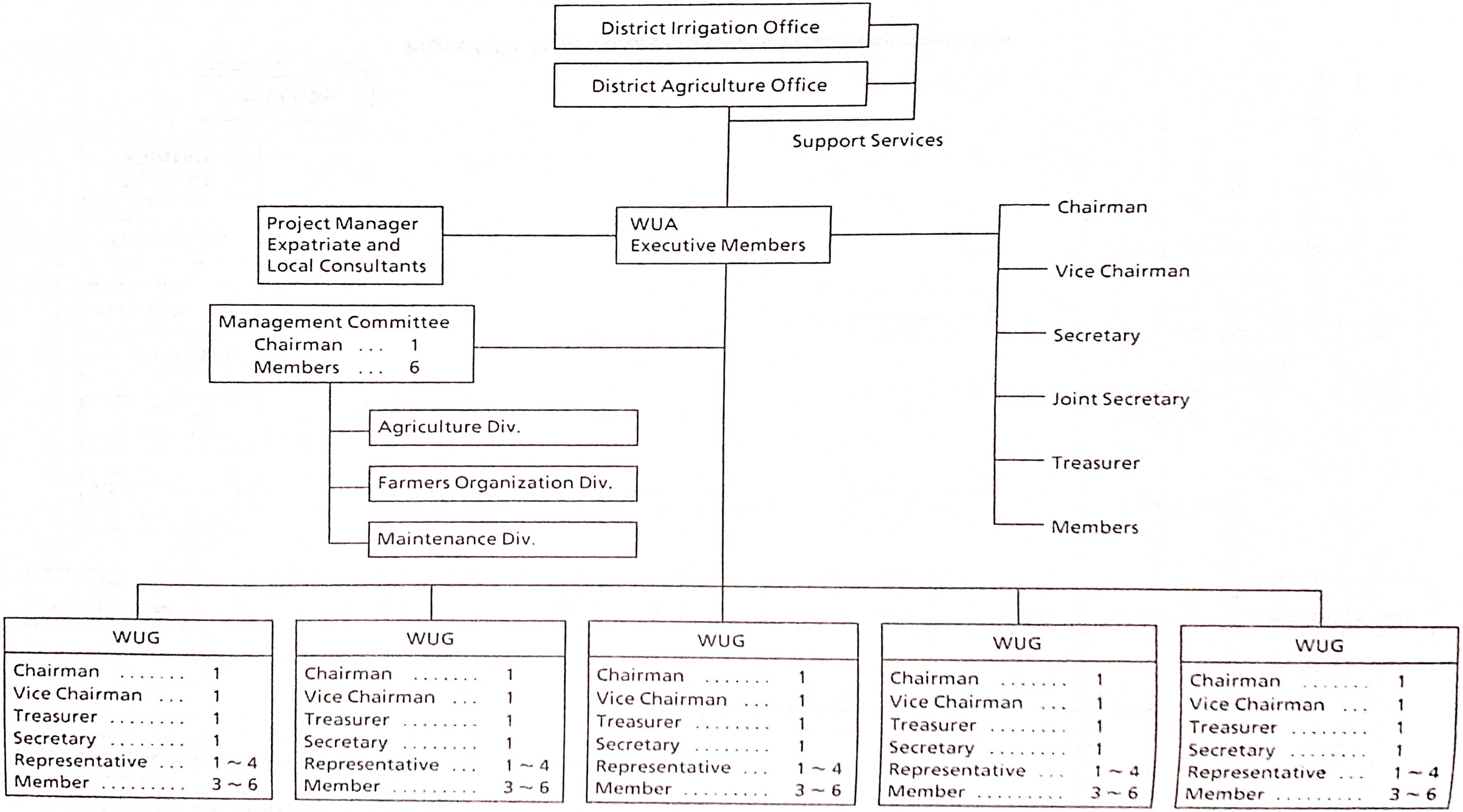


Figure 6.6.2 Proposed Water Users Organization

6.7. Environmental Considerations

Environmental considerations in groundwater development include (1) water rights, (2) groundwater, (3) water pollution, (4) noise and vibration, and (5) land subsidence (JICA, Environmental Consideration Guidelines, 1994). The environment impact of the above items related to groundwater development in this project are estimated and countermeasures are discussed.

(1) Water Rights

New groundwater development may interfere the water right of existing well due to groundwater head drawdown and then reduction of pumping capacity.

The current groundwater use in Jhapa District includes two DTWs at the Chandragadhi water supply located north of the project area, domestic water use by shallow dug wells, and small-scale irrigation projects using spring water in the northern part of the area. Based on the groundwater development simulation for the project area, the maximum groundwater head drawdown, compared with the current water head, is 20 m in every aquifer in the northern terrace and approximately 10 m further north and in the southern area (refer to Fig. 6.7.1). The water head drawdown will influence spring water and shallow dug well to some extent. Therefore a careful evaluation in the process of project implementation as well as compensation, such as water source transfers, are necessary. For domestic water use in the project area, DTW for irrigation can be used.

In Banke District, groundwater use is DTWs for water supply for Nepalganj and domestic water from shallow dug wells.

Irrigation by deep tubewells is fairly developed in Mahottari District. Although simulations have not been conducted in these areas, considerations similar to those in Jhapa District are necessary as a significant groundwater head drawdown is expected.
There is no agreement in regard to groundwater rights between Nepal and India. Any dispute from India, therefore, is not expected due with the groundwater development in Nepal side.

(2) Groundwater

This environmental item refers to the groundwater head drawdown caused by excessive pumping, depleting groundwater resources, and water pollution caused by the intrusion of brine. The groundwater head drawdown is discussed in the previous section.

The simulation shows that there is sufficient groundwater resources in Jhapa District for the degree of development. Although the other two districts are expected to be similar in this regard, future examinations must be conducted to confirm this point.

There are no pollutants, such as brine, in the three project areas, and groundwater pollution due to groundwater development is not expected. However, excessive use of chemical fertilizers or agro-chemicals may accumulate in the groundwater system. Careful monitoring of groundwater resources and appropriate countermeasures are essential.

(3) Water Pollution

This refers to surface water and groundwater pollution caused by mud water and oil entering rivers or aquifers as a result of the construction of irrigation facilities such as deep tubewells.

(4) Noise and Vibration

This refers to the noise and vibration caused during the construction of irrigation facilities such as deep tubewells. Noise and vibration are caused especially by deep tubewell drilling machines and construction vehicles. Careful consideration is necessary when undertaking construction near schools, hospitals, public facilities, or animal barns.

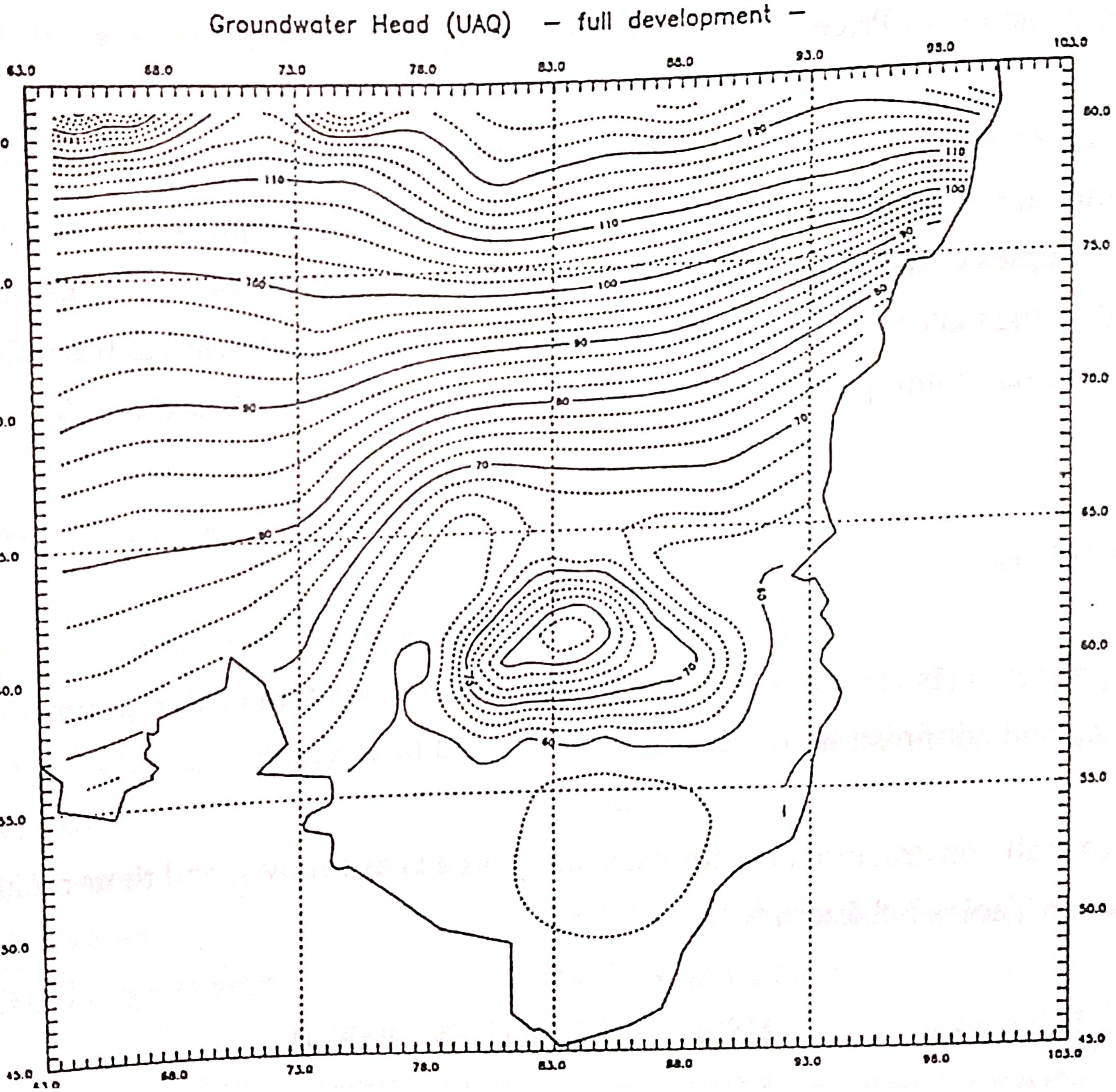
(5) Land Subsidence

Land subsidence refers to compaction of clay layers because of a drawdown in the groundwater head. The result is land deformation and a deterioration of the social infrastructures, such as canals, roads, bridges, and building, which are most seriously damaged by groundwater development. Land subsidence is a phenomenon which occurs in the weak alluvial sedimentary zones dominated by clay formed at the mouth of rivers.

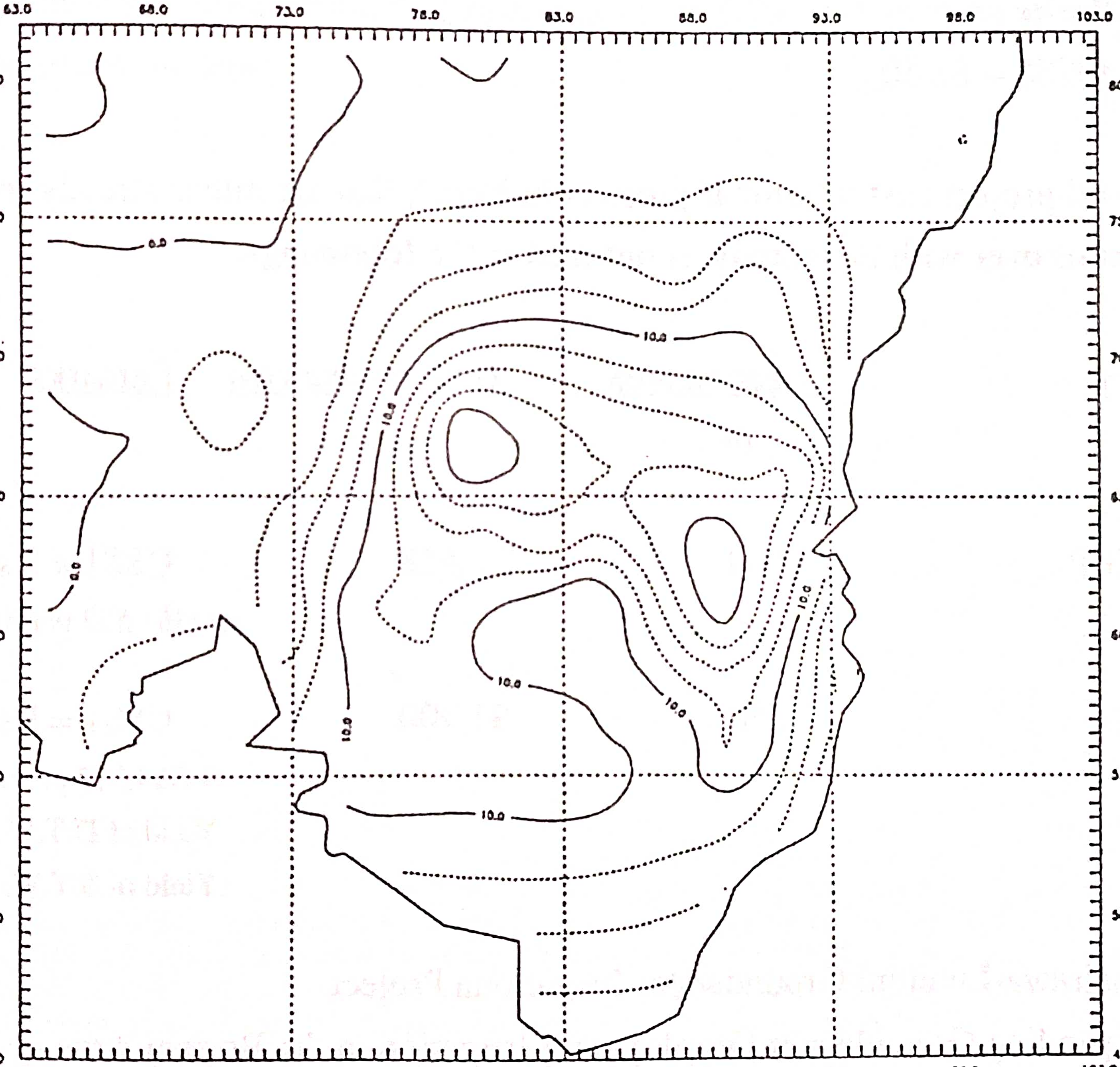
Gravel dominates within the alluvial sedimentary layer in the Terai Plain. As the clay layers have been already been compacted, there is little possibility of damage caused by land subsidence.

Figure 6.7.1 Groundwater Head Countour Under Pumping

(a) Groundwater Head on Unconfined Aquifer (UAQ)



(b) Drawdown from the normal condition



6.8. Project Cost Estimation

6.8.1. Quantity and Unit Price

Prior to the project cost estimation for the three project areas, quantities for the project facilities are estimated based on the facility layout in the sample area (mentioned earlier) and examples of the previous plans. The unit prices for the construction cost is determined based on the materials used in the previous plans and data collected in the field study. The index for basic unit prices, such as labor and material cost, is based on 1993 prices.

6.8.2. Project Cost

The project costs are estimated based on direct construction cost, equipment cost, engineering and administrative fees, contingency and price escalation.

The overall construction cost for each study area is as follows; and their breakdowns are shown in Tables 6.8.1 to 6.8.3.

1. Jhapa area : US$57.8 million (US$3,400/ha)
2. Mahottari area : US$31.7 million (US$4,500/ha)
3. Banke area : US$ 30.2 million (US$3,800/ha)

1 US$ = Rs 50

The total project cost of similar projects in Nepal, that are either already in operation at present or over with their study, is outlined in the followings:

Project	Irrigation area (ha)	Total project cost (US$1000)	Remarks
* BLGIP	14,600	22,658	US$1 = Rs 12 (US$1,552 per ha as of 1979)
** EGDI	7,250	31,700	US$1 = Rs 50 (US$4,372 per ha as of 1993) Yield of D.T.W. = 80 l/s Yield of S.T.W. = 12 l/s

* Bhairawa-Lumbini Groundwater Irrigationa Project

** Expanding Groundwater Development Irrigation in the Briganj Area

The total project cost of the BLGIP shown in the table above was estimated in 1979. It would increase to the figure shown in the followings, if a conversion is made to the current cost levels by adopting a escalation factor of 4.0.

US$1,552 x 4 = US$6,208/ha

On the other hand, EGDI has its irrigation water resources classified in three categories shown in the followings.

STW	DTW	Total
2,130ha	5,120ha	7,250ha

The specifications of the wells are shown in the followings.

STW 200 wells (10 ha/well)	DTW 700wells (73 ha/well)
Depth of well:	Depth of well:
40 to 50 meters	150 meters
q = 10 to 15 l/s	q = 80 l/s (average value)
P = 5HP Diesel engine	P = 50 KW motor

As can be seen, the well yield at each well is smaller. As a consequence the cost of the irrigation projects mentioned above becomes more expensive in comparison with DTW irrigation under the study.

Table 6.8.1 Overall Project Cost List for Jhapa Area

JHAPA DISTRICT PRIORITY SUB-AREA (150 ha/D.T.W Q = 120ℓ/s)

Summary of Project Cost Estimate

TABLE

(Unit: 1,000 NRs)

No.	Work Items	Cost L/C	Cost F/C	Cost Total	Remarks
1	Well Development	219	1,297	1,516	T.A = 17,000 ha L/C; Local Currency F/C; Foreign Currency
2	Pump Station	1,076	2,886	3,962	
3	Irrigation Canal System	1,295	948	2,243	
4	Drainage System	380	87	467	
5	Farm Road System	1,535	1,023	2,558	
6	Land Acquisition	2,100	-	2,100	
	Total (1-6)	6,605	6,241	12,846	Cost of One D.T.W Area
7	Whole Area Cost	746,365	705,233	1,451,598	No of D.T.W: 113
8	Building for O & M	7,527	3,980	11,507	
9	Procurement of O&M and Office Equipment	2,940	52,170	55,110	
10	Technical Support	108,030	304,530	412,560	
11	Project Administration	107,730		107,730	
12	Total Investment Cost	972,592	1,065,913	2,038,505	(7 - 11)
	US Dollar Equivalent	19,452	21,318	40,770	(×1,000)
	Per (ha)	1,144	1,254	2,398	≒ 2,400 US$/ha
13	Physical Contingencies	97,259	106,591	203,850	(12 × 0.10)
14	Price Escalation	486,296	159,887	646,183	
15	Total Project Cost	1,556,147	1,332,391	2,888,538	
	US Dollar Equivalent	31,123	26,648	57,771	(× 1,000)

Table 6.8.2 Overall Project Cost List for Mahottari Area

MAHOTTARI DISTRICT PRIORITY SUB-AREA A_1 (66 ha/D.T.W Q = 66 ℓ/s)
A_2 (97 ha/D.T.W Q = 97 ℓ/s)

Summary of Project Cost Estimate

TABLE

(Unit: 1,000 NRs)

No.	Work Items	Cost L/C	Cost F/C	Cost Total	Remarks
1	Well Development A_1	219	1,297	1,516	T.A= 7,000 ha
	Well Development A_2	219	1,297	1,516	L/C; Local Currency F/C; Foreign Currency
2	Pump Station A_1	697	1,625	2,322	A_1; 4,000 ha
	Pump Station A_2	864	2,250	3,114	A_2; 3,000 ha
3	Irrigation Canal System A_1	604	442	1,046	
	Irrigation Canal System A_2	837	613	1,450	
4	Drainage System A_1	177	41	218	
	Drainage System A_2	245	56	301	
5	Farm Road System A_1	716	477	1,193	
	Farm Road System A_2	992	662	1,654	
6	Land Acquisition A_1	990	-	990	
	Land Acquisition A_2	1,380	-	1,380	
	Total A_1 (1-6)	3,403	3,882	7,285	Cost of One D.T.W Area
	Total A_2 (1-6)	4,537	4,878	9,415	Cost of One D.T.W Area
7	Whole Area Cost A_1	207,583	236,802	444,385	No of D.T.W: 61
	A_2	140,647	151,218	291,865	No of D.T.W: 31
	Total (A_1 + A_2)	348,230	388,020	736,250	
8	Building for O & M	5,018	2,653	7,671	
9	Procurement of O&M and Office Equipment	1,960	34,780	36,740	
10	Technical Support	72,020	203,020	275,040	
11	Project Administration	71,820	-	71,820	
12	Total Investment Cost	499,048	628,473	1,127,521	(7 - 11)
	US Dollar Equivalent	9,981	12,569	22,550	(×1,000)
	Per (ha)	1,426	1,796	3,222	≒ 3,200 US$/ha
13	Physical Contingencies	49,905	62,847	112,752	(12 × 0.10)
14	Price Escalation	249,524	94,271	343,795	
15	Total Project Cost	798,447	785,591	1,584,068	
	US Dollar Equivalent	15,970	15,712	31,682	(× 1,000)

Table 6.8.3 Overall Project Cost List for Banke Area

BANKE-DARDIYA DISTRICT PRIORITY SUB-AREA (157 ha/D.T.W Q = 110ℓ/s)

Summary of Project Cost Estimate

TABLE

(Unit: 1,000 NRs)

No.	Work Items	Cost			Remarks
		L/C	F/C	Total	
1	Well Development	219	1,297	1,516	T.A = 8,000 ha L/C; Local Currency F/C; Foreign Currency
2	Pump Station	1,072	2,776	3,848	
3	Irrigation Canal System	1,381	1,011	2,392	
4	Drainage System	405	93	498	
5	Farm Road System	1,637	1,091	2,728	
6	Land Acquisition	2,250	-	2,250	
	Total (1-6)	6,964	6,268	13,232	Cost of One D.T.W Area
7	Whole Area Cost	355,164	319,668	674,832	No of D.T.W: 51
8	Building for O & M	5,018	2,653	7,671	
9	Procurement of O&M and Office Equipment	1,960	34,780	36,740	
10	Technical Support	72,020	203,020	275,040	
11	Project Administration	71,820	-	71,820	
12	Total Investment Cost	505,982	560,121	1,066,103	
	US Dollar Equivalent	10,120	11,202	21,322	(×1,000)
	Per (ha)	1,265	1,400	2,665	≒ 2,700 US$/ha
13	Physical Contingencies	50,598	56,012	106,610	(12 × 0.10)
14	Price Escalation	252,991	84,018	337,009	
15	Total Project Cost	809,571	700,151	1,509,722	
	US Dollar Equivalent	16,191	14,003	30,194	(× 1,000)

6.9. Project Evaluation

6.9.1. General

Agriculture is the mainstay of Nepal's economy, and as of 1991, 91% of the population live in rural areas and on incomes derived from the agricultural sector. Therefore, it can be said that an improvement in the living standard of farm households, through the implementation of irrigation projects, will lead to a rise in the income of the vast majority of people.

The objective of the Project is to expand irrigated agriculture by means of development of deep groundwater resource in the three districts of Jhapa, Mahottari, and Banke in the Terai. These objectives coincide with the policies of the Eighth National Development Plan (1992-1997), which aims at sustainable economic growth, the alleviation of poverty, and a reduction in regional imbalances.

In this chapter, a financial and economic analysis based on the private and national economy has been carried out for the project cost, operation and maintenance cost, and the benefits generated from DTW irrigation. Project life for the evaluation is 50 years, and the replacement cost for DTWs, pumps, and O & M equipment is calculated at 20, 15, and 10 years, respectively.

6.9.2. Project Cost

The total project cost for the three project areas is estimated as follows (refer to Chapter 6.8 for details):

(unit: Rs million)

	Financial	Economic
Jhapa	2,889	1,932
Mahottari	1,584	1,098
Banke	1,510	1,019

The tax for transfer expenditures is deducted from the local portion of the financial project cost. The local portion of the financial project cost is converted to the border price by multiplying by the standard conversion factor (SCF), which is calculated from the amount of exports and imports in the past five years. As a result, SCF was estimated at 0.911. The annual operation and maintenance costs are estimated as follows:

(unit: Rs million/year)

	Financial	Economic
Jhapa	39	36
Mahottari	21	19
Banke	16	15

6.9.3. Project Benefits

(1) Agricultural Benefits

Agricultural benefits generated by DTW irrigation are expected from the increase of crop yields, cropping intensity and production, which will be realized by the stable distribution of irrigation water and agricultural extension services. Agricultural benefits in the three project areas are estimated as follows (refer to Table 6.9.2 for details). The financial and economic prices of crops and agricultural inputs are shown in Appendix 4.7.

	Net Irrigable Area (ha)	Agricultural Benefit (Rs. million)
Jhapa	17,000	585
Mahottari	7,000	203
Banke	8,000	210

(2) Socio-Economic Impact

Along with the benefits which can be measured, such as crop production benefits, the following socio-economic benefits are expected.

- Agricultural production in the Terai increased by the Project will contribute to Nepal's self-sufficiency in foods.
- Living standards and nutritional levels of farm households will be improved by an increase in farm incomes.
- The Project will contribute to the alleviation of poverty, which is one of the main policies of the Eighth Development Plan.
- Regional imbalances will be reduced.
- Results of DTW irrigation in the three areas will affect the surrounding areas and farms in terms of cropping techniques, farm management, and so on, and become model cases of DTW irrigation in the Terai.
- Harmony and communication among the beneficiaries will be generated by establishing WUGs and WUAs in the areas.

6.9.4. Economic and Financial Analysis of the Project

(1) Economic Internal Rate of Return (EIRR)

EIRR was estimated based on a comparison of the project costs and benefits in the three areas, and the projects are judged to be economically feasible (refer to Table 6.9.3).

	EIRR(%)
Jhapa	21.0
Mahottari	13.5
Banke	14.3

(2) Financial Analysis of Typical Farms

A financial analysis, with and without the project, was carried out to compare the living standards of typical farms in the three areas. Farm budgets are expected to improve as a result of the DTW irrigation projects, as shown below.

	Jhapa	Mahottari	Banke
a) Without Project			
Farm Size (ha)	1.41	1.09	1.37
Farm Income (Rs)	12,504	15,916	15,844
Off-farm Income (Rs)	521	838	273
Living Expenses (Rs)	11,552	9,984	11,328
Disposable Income (Rs)	1,473	6,769	4,790
b) With Project			
Farm Size (ha)	1.41	1.09	1.37
Farm Income (Rs)	44,825	46,547	51,313
Off-farm Income (Rs)	1,868	2,450	885
Living Expenses (Rs)	44,013	40,416	43,160
Disposable Income (Rs)	2,680	8,581	9,038

Table 6.9.1 (1) Economic Project Costs (Jhapa)

(Rs. 1000)

Description	LC	FC	Total
1) Well Development	22,545	146,561	169,106
2) Pump Stations	110,767	326,118	436,885
3) Irrigation Canal System	133,311	107,124	240,435
4) Drainage System	39,118	9,831	289,384
5) Farm Road System	158,018	115,599	322,566
6) Land Acquisition	0	0	273,617
7) Building for O & M	6,857	3,980	10,837
8) Procurement of O & M			0
and Office Equipments	2,678	52,170	54,848
9) Technical Support	98,415	304,530	402,945
10) Project Administration	98,142	0	98,142
11) Total Investment Cost	669,851	1,065,913	1,735,764
12) Physical Contingencies	89,572	106,591	196,163
13) Price Escalation	0	0	0
Total Project Cost	759,423	1,172,504	1,931,927

Table 6.9.1 (2) Economic Project Costs (Mahottari)

(Rs. 1000)

Description	LC	FC	Total
1) Well Development	18,355	119,324	137,679
2) Pump Stations	63,133	168,875	232,008
3) Irrigation Canal System	57,177	45,965	103,142
4) Drainage System	16,755	4,237	20,992
5) Farm Road System	67,804	49,619	117,423
6) Land Acquisition	0	0	0
7) Building for O & M	4,571	2,653	7,224
8) Procurement of O & M			0
and Office Equipments	1,786	34,780	36,566
9) Technical Support	65,610	203,020	268,630
10) Project Administration	65,428	0	65,428
11) Toatl Investment Cost	360,619	628,473	989,092
12) Physical Contingencies	45,791	62,847	108,638
13) Price Escalation	0	0	0
Total Project Cost	406,410	691,320	1,097,730

Table 6.9.1 (3) Economic Project Costs (Banke)

(Rs. 1000)

Description	LC	FC	Total
1) Well Development	10,175	66,147	76,322
2) Pump Stations	49,806	141,576	191,382
3) Irrigation Canal System	64,163	51,561	115,724
4) Drainage System	18,817	4,743	23,560
5) Farm Road System	76,055	55,641	131,696
6) Land Acquisition	0	0	0
7) Building for O & M	4,571	2,653	7,224
8) Procurement of O & M			0
and Office Equipments	1,786	34,780	36,566
9) Technical Support	65,610	203,020	268,630
10) Project Administration	65,428	0	65,428
11) Toatl Investment Cost	356,411	560,121	916,532
12) Physical Contingencies	46,095	56,012	102,107
13) Price Escalation	0	0	0
Total Project Cost	402,506	616,133	1,018,639

Table 6.9.2 (1) Incremental Agricultural Benefit (Jhapa)

	M. Paddy Rainfed	M. Paddy Irrigated	S. Paddy Irrigated	Maize	Wheat	Miscellaneous (Mustard)	Total
Without Project							
Yield (ton/ha)	2.33	-	-	1.31	1.59	-	
Price (Rs/ton)	10,106	-	-	9,567	12,312	-	
GPV (RS/ha)	24,321	-	-	12,815	19,951	-	
Production Cost (Rs/ha)	8,935	-	-	7,368	10,588	-	
NPV (Rs/ha)	15,386	-	-	5,447	9,363	-	
Cropping Area (ha)	15,300	-	-	1,700	4,420	-	21,420
Total NPV (RS1000)	235,406	-	-	9,260	41,384	-	286,050
With Project							
Yield (ton/ha)	-	4.00	3.80	2.70	2.70	0.80	
Price (Rs/ton)	-	10,106	10,106	9,567	12,312	23,110	
GPV (RS/ha)	-	42,152	39,987	26,412	33,880	18,673	
Production Cost (Rs/ha)	-	12,839	10,276	11,168	12,895	9,055	
NPV (Rs/ha)	-	29,313	29,711	15,244	20,985	9,618	
Cropping Area (ha)	-	17,000	6,800	2,550	5,100	2,550	34,000
Total NPV (RS1000)	-	498,321	202,035	38,872	107,024	24,526	870,777
Incremental NPV (Rs1000)	-235,406	498,321	202,035	29,612	65,639	24,526	584,727

Note:GVP includes income from by-products

Table 6.9.2 (2) Incremental Agricultural Benefit (Mahottari)

	M. Paddy Rainfed	M. Paddy Irrigated	S. Paddy Irrigated	Wheat	Pulses (Lentil)	Onion	Potato	Others (Oilseeds)	Total
Without Project									
Yield (ton/ha)	2.29	-	-	1.48	0.60	-	-	0.54	
Price (Rs/ton)	10,361	-	-	12,704	14,940	-	-	23,480	
GPV (RS/ha)	24,733	-	-	19,212	9,086	-	-	12,805	
Production Cost (Rs/ha)	9,338	-	-	11,479	3,673	-	-	6,483	
NPV (Rs/ha)	15,395	-	-	7,733	5,413	-	-	6,322	
Cropping Area (ha)	6,300	-	-	1,400	1,400	-	-	700	9,800
Total NPV (RS1000)	96,989	-	-	10,826	7,578	-	-	4,425	119,818
With Project									
Yield (ton/ha)	-	3.40	3.60	2.60	-	13.00	12.00	-	
Price (Rs/ton)	-	10,361	10,361	12,704	-	4,140	4,530	-	
GPV (RS/ha)	-	36,837	38,983	33,751	-	53,820	54,360	-	
Production Cost (Rs/ha)	-	12,697	10,584	13,583	-	26,899	35,598	-	
NPV (Rs/ha)	-	24,140	28,399	20,168	-	26,921	18,762	-	
Cropping Area (ha)	-	7,000	700	3,430	-	1,330	1,540	-	14,000
Total NPV (RS1000)	-	168,980	19,879	69,176	-	35,805	28,893	-	322,734
Incremental NPV (Rs1000)	-96,989	168,980	19,879	58,350	-7,578	35,805	28,893	-4,425	202,916

Table 6.9.2 (3) Incremental Agricultural Benefit (Banke)

	M. Paddy Rainfed	M. Paddy Irrigated	Maize	Mustard	Wheat	Pulses (Lentil)	Potato	Others (Cauliflower)	Total
Without Project									
Yield (ton/ha)	1.95	-	1.61	0.55	1.40	0.68	-	-	
Price (Rs/ton)	10,584	-	10,302	20,330	13,049	21,600	-	-	
GPV (RS/ha)	21,552	-	17,030	11,309	18,598	14,826	-	-	
Production Cost (Rs/ha)	9,618	-	8,626	6,593	10,575	3,763	-	-	
NPV (Rs/ha)	11,934	-	8,404	4,716	8,023	11,063	-	-	
Cropping Area (ha)	6,400	-	800	800	2,400	800	-	-	11,200
Total NPV (RS1000)	76,378	-	6,723	3,773	19,255	8,850	-	-	114,979
With Project									
Yield (ton/ha)	-	3.50	2.60	0.80	2.10	1.00	14.00	11.00	
Price (Rs/ton)	-	10,584	10,302	20,330	13,049	21,600	3,600	7,000	
GPV (RS/ha)	-	38,608	27,498	16,417	27,897	21,807	50,400	77,000	
Production Cost (Rs/ha)	-	13,428	13,058	10,680	13,491	6,058	22,546	19,934	
NPV (Rs/ha)	-	25,180	14,440	5,737	14,406	15,749	27,854	57,066	
Cropping Area (ha)	-	6,960	1,200	1,040	4,000	1,360	1,200	240	16,000
Total NPV (RS1000)	-	175,253	17,328	5,966	57,624	21,419	33,425	13,696	324,711
Incremental NPV (Rs1000)	-76,378	175,253	10,605	2,194	38,369	12,568	33,425	13,696	209,731

Note:GVP includes income from by-products

Table 6.9.3 (1) Calculation of EIRR (Jhapa)

(Unit: Rs. Million)

Year	Project Cost				Project Benefit	Net Benefit	Present Worth Value			
	Initial Invest. Cost	Replace-ment Cost	O & M Cost	Total (1)	(2)	(2)-(1)	D. Rate= Project Cost	0.10 Project Benefit	0.20 Net Benefit	0.21 Net Benefit
1	138	0	0	138	0	-138	125.5	0.0	-115.0	-114.0
2	166	0	0	166	0	-166	137.2	0.0	-115.3	-113.4
3	154	0	0	154	0	-154	115.7	0.0	-89.1	-86.9
4	116	0	0	116	0	-116	79.2	0.0	-55.9	-54.1
5	254	0	0	254	0	-254	157.7	0.0	-102.1	-97.9
6	256	0	10	266	257	-9	150.2	145.1	-3.0	-2.9
7	252	0	15	267	310	43	137.0	159.1	12.0	11.3
8	252	0	22	274	380	106	127.8	177.3	24.7	23.1
9	185	0	29	214	432	218	90.8	183.2	42.2	39.2
10	160	0	36	196	473	277	75.6	182.4	44.7	41.2
11	0	0	36	36	508	472	12.6	178.1	63.5	58.0
12	0	22	36	58	531	473	18.5	169.2	53.1	48.0
13	0	16	36	52	549	497	15.1	159.0	46.5	41.7
14	0	16	36	52	561	509	13.7	147.7	39.6	35.3
15	0	0	36	36	569	533	8.6	136.2	34.6	30.5
16	0	0	36	36	573	537	7.8	124.7	29.0	25.4
17	0	0	36	36	585	549	7.1	115.7	24.7	21.5
18	0	0	36	36	585	549	6.5	105.2	20.6	17.8
19	0	0	36	36	585	549	5.9	95.7	17.2	14.7
20	0	74	36	110	585	475	16.4	87.0	12.4	10.5
21	0	74	36	110	585	475	14.9	79.1	10.3	8.7
22	0	96	36	132	585	453	16.2	71.9	8.2	6.8
23	0	90	36	126	585	459	14.1	65.3	6.9	5.7
24	0	90	36	126	585	459	12.8	59.4	5.8	4.7
25	0	95	36	131	585	454	12.1	54.0	4.8	3.9
26	0	29	36	65	585	520	5.5	49.1	4.5	3.7
27	0	29	36	65	585	520	5.0	44.6	3.8	3.0
28	0	29	36	65	585	520	4.5	40.6	3.2	2.5
29	0	29	36	65	585	520	4.1	36.9	2.6	2.1
30	0	25	36	61	585	524	3.5	33.5	2.2	1.7
31	0	0	36	36	585	549	1.9	30.5	1.9	1.5
32	0	22	36	58	585	527	2.7	27.7	1.5	1.2
33	0	16	36	52	585	533	2.2	25.2	1.3	1.0
34	0	16	36	52	585	533	2.0	22.9	1.1	0.8
35	0	74	36	110	585	475	3.9	20.8	0.8	0.6
36	0	74	36	110	585	475	3.6	18.9	0.7	0.5
37	0	74	36	110	585	475	3.2	17.2	0.6	0.4
38	0	74	36	110	585	475	2.9	15.6	0.5	0.3
39	0	74	36	110	585	475	2.7	14.2	0.4	0.3
40	0	66	36	102	585	483	2.3	12.9	0.3	0.2
41	0	0	36	36	585	549	0.7	11.8	0.3	0.2
42	0	22	36	58	585	527	1.1	10.7	0.2	0.2
43	0	16	36	52	585	533	0.9	9.7	0.2	0.1
44	0	16	36	52	585	533	0.8	8.8	0.2	0.1
45	0	0	36	36	585	549	0.5	8.0	0.2	0.1
46	0	0	36	36	585	549	0.4	7.3	0.1	0.1
47	0	0	36	36	585	549	0.4	6.6	0.1	0.1
48	0	0	36	36	585	549	0.4	6.0	0.1	0.1
49	0	0	36	36	585	549	0.3	5.5	0.1	0.0
50	0	99	36	135	585	450	1.2	5.0	0.0	0.0
Total	1,933	1,357	1,552	4,842	25,033	20,191	1,435.4	2,985.2	47.4	-0.4
								EIRR=		21.0
								B/C Ratio at 10%		2.08

Table 6.9.3 (2) Calculation of EIRR (Mahottari)

(Unit: Rs. Million)

Year	Project Cost: Initial Invest. Cost	Project Cost: Replacement Cost	Project Cost: O & M Cost	Project Cost: Total (1)	Project Benefit (2)	Net Benefit (2)-(1)	Present Worth Value: D. Rate= 0.10 Project Cost	Present Worth Value: D. Rate= 0.10 Project Benefit	Present Worth Value: 0.13 Net Benefit	Present Worth Value: 0.14 Net Benefit
1	93	0	0	93	0	-93	84.5	0.0	-82.3	-81.6
2	115	0	0	115	0	-115	95.0	0.0	-90.1	-88.5
3	111	0	0	111	0	-111	83.4	0.0	-76.9	-74.9
4	65	0	0	65	0	-65	44.4	0.0	-39.9	-38.5
5	159	0	0	159	0	-159	98.7	0.0	-86.3	-82.6
6	157	0	6	163	91	-72	92.0	51.4	-34.6	-32.8
7	157	0	12	169	132	-37	86.7	67.7	-15.7	-14.8
8	121	0	19	140	162	22	65.3	75.6	8.3	7.7
9	118	0	19	137	183	46	58.1	77.6	15.3	14.1
10	0	0	19	19	193	174	7.3	74.4	51.3	46.9
11	0	0	19	19	198	179	6.7	69.4	46.7	42.4
12	0	18	19	37	203	166	11.8	64.7	38.3	34.5
13	0	18	19	37	203	166	10.7	58.8	33.9	30.2
14	0	0	19	19	203	184	5.0	53.5	33.2	29.4
15	0	0	19	19	203	184	4.5	48.6	29.4	25.8
16	0	0	19	19	203	184	4.1	44.2	26.0	22.6
17	0	0	19	19	203	184	3.8	40.2	23.0	19.8
18	0	0	19	19	203	184	3.4	36.5	20.4	17.4
19	0	0	19	19	203	184	3.1	33.2	18.0	15.3
20	0	46	19	65	203	138	9.7	30.2	12.0	10.0
21	0	46	19	65	203	138	8.8	27.4	10.6	8.8
22	0	64	19	83	203	120	10.2	24.9	8.2	6.7
23	0	64	19	83	203	120	9.3	22.7	7.2	5.9
24	0	46	19	65	203	138	6.6	20.6	7.3	5.9
25	0	44	19	63	203	140	5.8	18.7	6.6	5.3
26	0	44	19	63	203	140	5.3	17.0	5.8	4.6
27	0	44	19	63	203	140	4.8	15.5	5.2	4.1
28	0	44	19	63	203	140	4.4	14.1	4.6	3.6
29	0	28	19	47	203	156	3.0	12.8	4.5	3.5
30	0	0	19	19	203	184	1.1	11.6	4.7	3.6
31	0	0	19	19	203	184	1.0	10.6	4.2	3.2
32	0	18	19	37	203	166	1.8	9.6	3.3	2.5
33	0	18	19	37	203	166	1.6	8.7	2.9	2.2
34	0	0	19	19	203	184	0.7	7.9	2.9	2.1
35	0	46	19	65	203	138	2.3	7.2	1.9	1.4
36	0	46	19	65	203	138	2.1	6.6	1.7	1.2
37	0	46	19	65	203	138	1.9	6.0	1.5	1.1
38	0	46	19	65	203	138	1.7	5.4	1.3	0.9
39	0	46	19	65	203	138	1.6	4.9	1.2	0.8
40	0	0	19	19	203	184	0.4	4.5	1.4	1.0
41	0	0	19	19	203	184	0.4	4.1	1.2	0.9
42	0	18	19	37	203	166	0.7	3.7	1.0	0.7
43	0	18	19	37	203	166	0.6	3.4	0.9	0.6
44	0	0	19	19	203	184	0.3	3.1	0.8	0.6
45	0	28	19	47	203	156	0.6	2.8	0.6	0.4
46	0	28	19	47	203	156	0.6	2.5	0.6	0.4
47	0	28	19	47	203	156	0.5	2.3	0.5	0.3
48	0	28	19	47	203	156	0.5	2.1	0.4	0.3
49	0	28	19	47	203	156	0.4	1.9	0.4	0.3
50	0	62	19	81	203	122	0.7	1.7	0.3	0.2
Total	1,096	1,010	835	2,941	8,876	5,935	858.0	1,110.3	23.8	-24.4

EIRR= 13.5

B/C Ratio at 10% 1.29

Table 6.9.3 (3) Calculation of EIRR (Banke)

(Unit: Rs. Million)

Year	Project Cost: Initial Invest. Cost	Project Cost: Replacement Cost	Project Cost: O & M Cost	Project Cost: Total (1)	Project Benefit (2)	Net Benefit (2)-(1)	Present Worth Value, D. Rate= 0.10: Project Cost	Present Worth Value, D. Rate= 0.10: Project Benefit	0.14: Net Benefit	0.15: Net Benefit
1	93	0	0	93	0	-93	84.5	0.0	-81.6	-80.9
2	116	0	0	116	0	-116	95.9	0.0	-89.3	-87.7
3	112	0	0	112	0	-112	84.1	0.0	-75.6	-73.6
4	61	0	0	61	0	-61	41.7	0.0	-36.1	-34.9
5	173	0	0	173	0	-173	107.4	0.0	-89.9	-86.0
6	170	0	5	175	95	-80	98.8	53.6	-36.4	-34.6
7	170	0	10	180	126	-54	92.4	64.7	-21.6	-20.3
8	121	0	15	136	158	22	63.4	73.7	7.7	7.2
9	0	0	15	15	174	159	6.4	73.8	48.9	45.2
10	0	0	15	15	189	174	5.8	72.9	46.9	43.0
11	0	0	15	15	197	182	5.3	69.0	43.1	39.1
12	0	18	15	33	204	171	10.5	65.0	35.5	32.0
13	0	18	15	33	206	173	9.6	59.7	31.5	28.1
14	0	0	15	15	210	195	3.9	55.3	31.1	27.6
15	0	0	15	15	210	195	3.6	50.3	27.3	24.0
16	0	0	15	15	210	195	3.3	45.7	24.0	20.8
17	0	0	15	15	210	195	3.0	41.5	21.0	18.1
18	0	0	15	15	210	195	2.7	37.8	18.4	15.8
19	0	0	15	15	210	195	2.5	34.3	16.2	13.7
20	0	48	15	63	210	147	9.4	31.2	10.7	9.0
21	0	48	15	63	210	147	8.5	28.4	9.4	7.8
22	0	66	15	81	210	129	10.0	25.8	7.2	6.0
23	0	66	15	81	210	129	9.0	23.5	6.3	5.2
24	0	0	15	15	210	195	1.5	21.3	8.4	6.8
25	0	36	15	51	210	159	4.7	19.4	6.0	4.8
26	0	36	15	51	210	159	4.3	17.6	5.3	4.2
27	0	36	15	51	210	159	3.9	16.0	4.6	3.7
28	0	36	15	51	210	159	3.5	14.6	4.1	3.2
29	0	0	15	15	210	195	0.9	13.2	4.4	3.4
30	0	0	15	15	210	195	0.9	12.0	3.8	2.9
31	0	0	15	15	210	195	0.8	10.9	3.4	2.6
32	0	18	15	33	210	177	1.6	9.9	2.7	2.0
33	0	18	15	33	210	177	1.4	9.0	2.3	1.8
34	0	0	15	15	210	195	0.6	8.2	2.3	1.7
35	0	48	15	63	210	147	2.2	7.5	1.5	1.1
36	0	48	15	63	210	147	2.0	6.8	1.3	1.0
37	0	48	15	63	210	147	1.9	6.2	1.2	0.8
38	0	48	15	63	210	147	1.7	5.6	1.0	0.7
39	0	0	15	15	210	195	0.4	5.1	1.2	0.8
40	0	0	15	15	210	195	0.3	4.6	1.0	0.7
41	0	0	15	15	210	195	0.3	4.2	0.9	0.6
42	0	18	15	33	210	177	0.6	3.8	0.7	0.5
43	0	18	15	33	210	177	0.5	3.5	0.6	0.4
44	0	0	15	15	210	195	0.2	3.2	0.6	0.4
45	0	19	15	34	210	176	0.5	2.9	0.5	0.3
46	0	19	15	34	210	176	0.4	2.6	0.4	0.3
47	0	19	15	34	210	176	0.4	2.4	0.4	0.2
48	0	19	15	34	210	176	0.4	2.2	0.3	0.2
49	0	0	15	15	210	195	0.1	2.0	0.3	0.2
50	0	65	15	80	210	130	0.7	1.8	0.2	0.1
Total	1,016	813	660	2,489	9,119	6,630	798.2	1,122.8	14.2	-29.9
							EIRR=			14.3
							B/C Ratio at 10%			1.41

6.10. Guidelines for Deep Tubewell Irrigation

6.10.1. General

The guideline is to apply for DTW irrigation in the Terai.
The guideline consists of the following two items.
The first guideline is related to "LFCA," which is an economically appropriate command area for one DTW facility, as well as related to "LFWY," which is an appropriate well yield for irrigation in this command area.
The second guideline is related to the "evaluation of aquifer capacity", the "design of production wells," and the "construction of production wells"in the Terai.

6.10.2 LFCA and LFWY

The purpose of studying guidelines for the DTW irrigation project is to study the least feasible command area (LFCA) irrigable by one DTW and to grasp the least feasible well yield (LFWY) in order to offer the materials for assessing the economic feasibility of DTW irrigation projects in a planning stage.
LFCA is considered as the least feasible command area irrigable by one DTW under various conditions such as nature, the socio-economy, and agriculture in the project areas. After determining the LCFA, LFWY can be estimated automatically as the water requirements necessary for LCFA.

An economic analysis has been carried out based on the same conditions used in section 6.9 "Project Evaluation," and the representative area of Jhapa District has been selected for the study. The conditions used in the study are shown below:

Command area by one DTW	: 100 ha
Cropping Intensity without project	: 126%
Cropping Intensity with project	: 200%
Cropping patterns	: Refer to Figure 6.2.1
Farmgate Prices	: Refer to Chap. 8 (vol.-2)
Production Costs	: Refer to Appendix 4 (vol.-3)
Project Life	: 50 years
Construction Period	: 1 year
Power Source	: Electricity
Replacement	
DTW	: 20 years
Pumps	: 15 years
OM Equipment	: 10 years

The following three cases are analyzed in regard to the yield of DTWs and the number of pump stations:

	DTW Yield	Pump Stations
Case-1	90 lit/sec	1 place
Case-2	45	2
Case-3	30	3

The project costs for each case are estimated per 100 ha for a) irrigated by one DTW, b) irrigated by two DTW, and c) irrigated by three DTW. These cost estimations are based on a topographical map of the sample area.

When estimating the economic project cost, the land acquisition cost and price escalation cost are excluded as transfer expenditures, and local portions in the financial project cost are converted to international prices multiplying by SCF.

The following shows the economic project cost and O & M costs per 100 ha for the three cases:

Electric Pump

Project Costs (Unit: Rs 1,000/100 ha)

	Case-1	Case-2	Case-3
LC	5,129	5,727	6,358
FC	8,901	10,956	13,308
Total	14,030	16,683	19,666

O & M Costs (Unit: Rs 1,000/100 ha/year)

	Case-1	Case-2	Case-3
LC	200	287	344
FC	25	35	42
Total	225	322	386

Diesel Pump

Project Costs (Unit: Rs 1,000/100 ha)

	Case-1	Case-2	Case-3
LC	7,558	8,483	9,187
FC	8,445	9,804	11,157
Total	16,003	18,287	20,344

O & M Costs (Unit: Rs 1,000/100 ha/year)

	Case-1	Case-2	Case-3
LC	513	692	807
FC	57	76	89
Total	570	768	896

Increased agricultural impact per 100 ha is shown in Table 6.10.1. and 6.10.2. Under the above conditions, the EIRR and B/C for the three cases are estimated as listed below.

1) Jhapa

	Electric Pump			Diesel Pump		
	Case-1	Case-2	Case-3	Case-1	Case-2	Case-3
EIRR(%)	16.77	13.94	11.75	15.29	12.53	10.69
B/C	1.53	1.26	1.07	1.33	1.12	0.99

2) Mahottari

	Case-1	Case-2	Case-3	Case-1	Case-2	Case-3
EIRR(%)	15.51	12.69	10.53	13.86	11.04	9.17
B/C	1.38	1.14	0.97	1.20	1.01	0.89

3) Banke

	Case-1	Case-2	Case-3	Case-1	Case-2	Case-3
EIRR(%)	15.59	12.81	1.67	13.98	11.21	9.37
B/C	1.40	1.15	0.98	1.22	1.01	0.90

Base on the economic analysis, the following facts are clarified:

- the number of pump stations can be reduced where the well yield is large;
- the annual O & M costs will be higher where the well yield is small and the number of pump stations is large;
- the total length of the buried pipelines will be longer where the well yield is high and the number of pump stations is small;
- EIRR and B/C ratios will be higher where the DTW yield is high; and lower where the yield of the DTW is small (refer to Figure 6.10.1);
- the B/C ratio will be less than 1.0 where the well yield is approximately 30 l/sec in the case of electric pump;
- LFCA is estimated at approximately 30 ha; and
- LFWY will be approximately 30 l/sec also in the case of electric pump.
- In the case of diesel pump, LAFA is approximately 45 ha, and LFWY is around 45 l/sec.

Table 6.10.1 (1) Increase in Agricultural Benefits (Jhapa)

	M. Paddy Rainfed	M. Paddy Irrigated	S. Paddy Irrigated	Maize	Wheat	Miscellaneous (Mustard)	Total
Without Project							
Yield (ton/ha)	2.33	-	-	1.31	1.59	-	
Price (Rs/ton)	10,106	-	-	9,567	12,312	-	
GPV (RS/ha)	24,321	-	-	12,815	19,951	-	
Production Cost (Rs/ha)	8,935	-	-	7,368	10,588	-	
NPV (Rs/ha)	15,386	-	-	5,447	9,363	-	
Cropping Area (ha)	90	-	-	10	26	-	126
Total NPV (RS1000)	1,385	-	-	54	243	-	1,683
With Project							
Yield (ton/ha)	-	4.00	3.80	2.70	2.70	0.80	
Price (Rs/ton)	-	10,106	10,106	9,567	12,312	23,110	
GPV (RS/ha)	-	42,152	39,987	26,412	33,880	18,673	
Production Cost (Rs/ha)	-	12,839	10,276	11,168	12,895	9,055	
NPV (Rs/ha)	-	29,313	29,711	15,244	20,985	9,618	
Cropping Area (ha)	-	100	40	15	30	15	200
Total NPV (RS1000)	-	2,931	1,188	229	630	144	5,122
Incremental NPV (Rs1000)	-1,385	2,931	1,188	174	386	144	3,440

Note: GVP includes income from by-products

Table 6.10.1 (2) Increase in Agricultural Benefits (Mahottari)

	M. Paddy Rainfed	M. Paddy Irrigated	S. Paddy Irrigated	Wheat	Pulses (Lentil)	Onion	Potato	Others (Oilseeds)	Total
Without Project									
Yield (ton/ha)	2.29	-	-	1.48	0.60	-	-	0.54	
Price (Rs/ton)	10,361	-	-	12,704	14,940	-	-	23,480	
GPV (RS/ha)	24,733	-	-	19,212	9,086	-	-	12,805	
Production Cost (Rs/ha)	9,338	-	-	11,479	3,673	-	-	6,483	
NPV (Rs/ha)	15,395	-	-	7,733	5,413	-	-	6,322	
Cropping Area (ha)	90	-	-	20	20	-	-	10	140
Total NPV (RS1000)	1,386	-	-	155	108	-	-	63	1,712
With Project									
Yield (ton/ha)	-	3.40	3.60	2.60	-	13.00	12.00	-	
Price (Rs/ton)	-	10,361	10,361	12,704	-	4,140	4,530	-	
GPV (RS/ha)	-	36,837	38,983	33,751	-	53,820	54,360	-	
Production Cost (Rs/ha)	-	12,697	10,584	13,583	-	26,899	35,598	-	
NPV (Rs/ha)	-	24,140	28,399	20,168	-	26,921	18,762	-	
Cropping Area (ha)	-	100	10	49	-	19	22	-	200
Total NPV (RS1000)	-	2,414	284	988	-	511	413	-	4,610
Incremental NPV (Rs1000)	-1,386	2,414	284	834	-108	511	413	-63	2,899

Note: GVP includes income from by-products

Table 6.10.1 (3) Increase in Agricultural Benefits (Banke)

	M. Paddy Rainfed	M. Paddy Irrigated	Maize	Mustard	Wheat	Pulses (Lentil)	Potato	Others (Cauliflower)	Total
Without Project									
Yield (ton/ha)	1.95	-	1.61	0.55	1.40	0.68	-	-	
Price (Rs/ton)	10.584	-	10.302	20.330	13.049	21.600	-	-	
GPV (RS/ha)	21.552	-	17.030	11.309	18.598	14.826	-	-	
Production Cost (Rs/ha)	9.618	-	8.626	6.593	10.575	3.763	-	-	
NPV (Rs/ha)	11.934	-	8.404	4.716	8.023	11.063	-	-	
Cropping Area (ha)	80	-	10	10	30	10	-	-	140
Total NPV (RS1000)	955	-	84	47	241	111	-	-	1.437
With Project									
Yield (ton/ha)	-	3.50	2.60	0.8	2.10	1.00	14.00	11.00	
Price (Rs/ton)	-	10.584	10.302	20.330	13.049	21.600	5.420	7.000	
GPV (RS/ha)	-	38.608	27.498	16.417	27.897	21.807	75.880	77.000	
Production Cost (Rs/ha)	-	13.428	13.058	10.680	13.491	6.058	22.546	19.934	
NPV (Rs/ha)	-	25.180	14.440	5.737	14.406	15.749	53.334	57.066	
Cropping Area (ha)	-	87	15	13	50	17	15	3	200
Total NPV (RS1000)	-	2.191	217	75	720	268	800	171	4.441
Incremental NPV (Rs1000)	-955	2.191	133	27	480	157	800	171	3.004

Note:GVP includes income from by-products

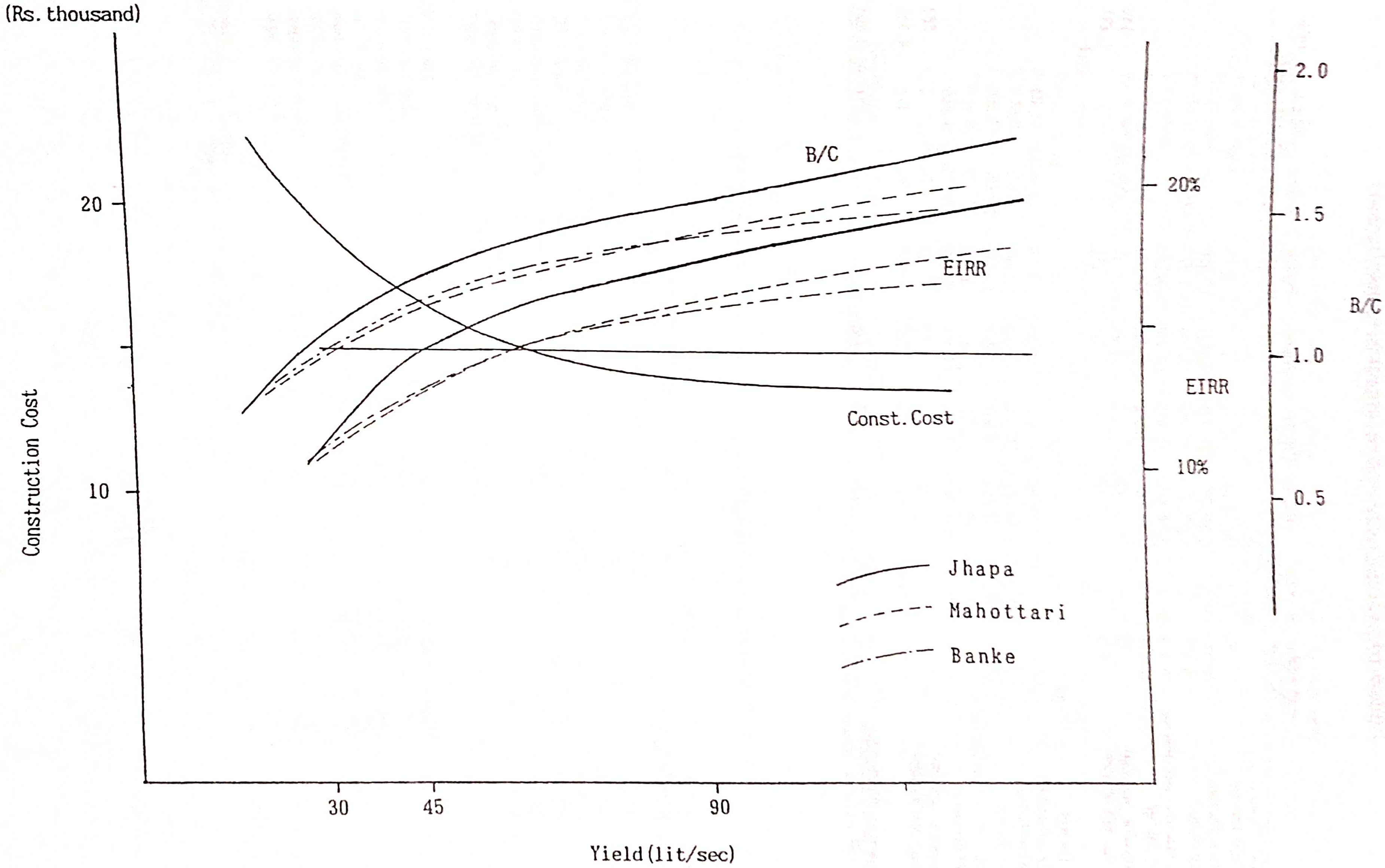


Figure 6.10.1 LFCA and LFWY (Electric Pump)

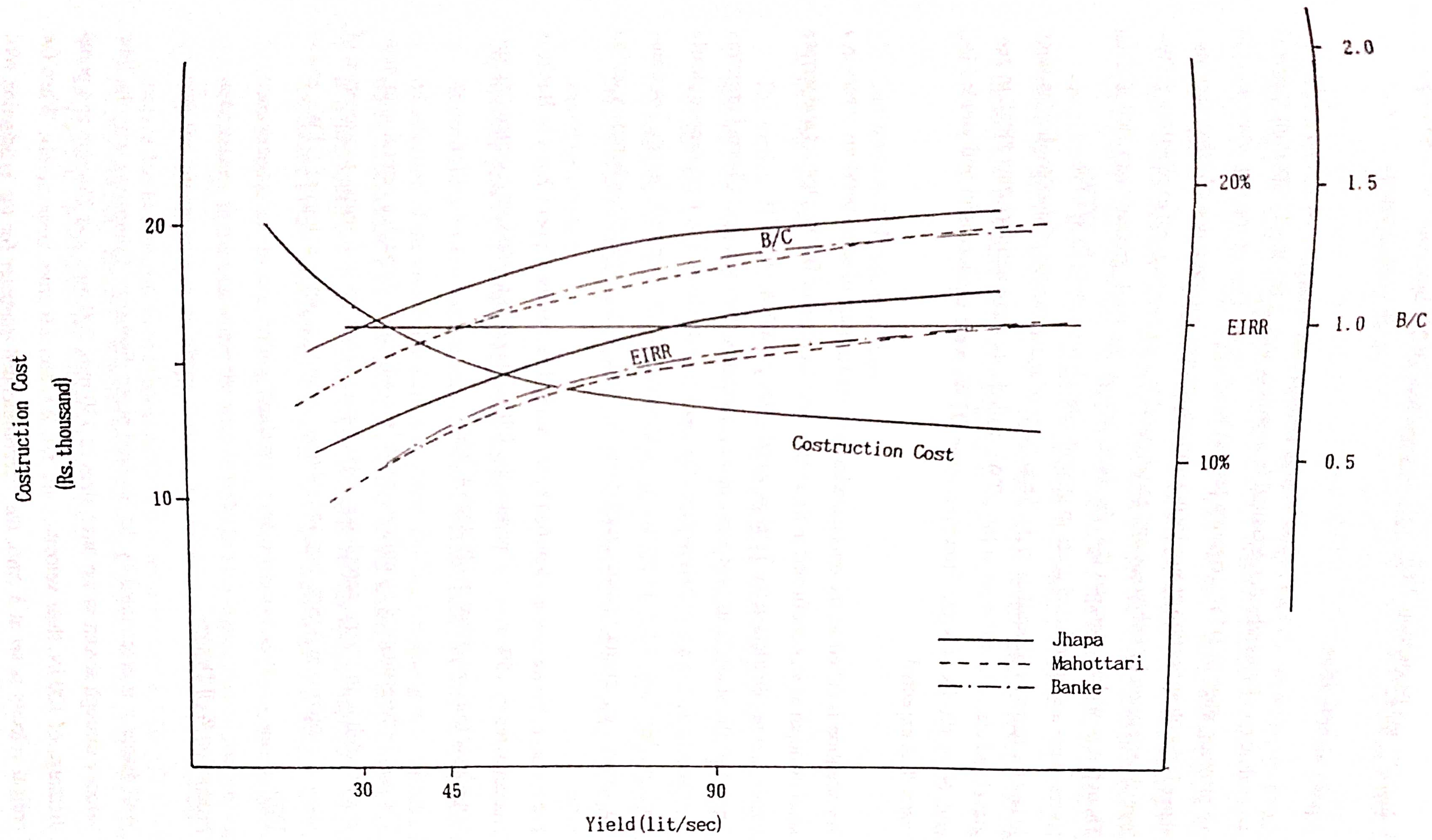


Figure 6.10.2 LCFA and LFWY (Diesel Pump)

6.10.3. Aquifers and Production Wells

(1) Aquifer Identification

An evaluation of groundwater potential in a project area is the most important aspect in the planning stage of DTW irrigation project in the Terai. One of the important ways of above is the identification of aquifer unit through proper interpretation of subsurface geological correlation by lothologic and geophysical logs of existing and exploratory DTWs. Though it is widely believed that the Terai lies on the thick groundwater rich alluvial layers, there are some failed cases in groundwater development by DTWs.
In fact the majority of aquifers in the Terai made of an alternation of unconsolidated sand/ gravel and clay/silt, and most of the DTWs drilled into these aquifers may yield, in general, 60 to 100 l/s of water. However, some DTWs were unsuccessful and yielded less water than expected.

An attention is called on the understanding to the existence of semi-pervious layers in a shallow depth as was confirmed in the central alluvial plain of Banke District and terrace terrain in other districts in the Terai as stated in the preceding chapters.
Therefore, the Study Team proposes a new interpretation that the Upper Churia Formation is subject to lie down in a shallow depth than widely understood. The formation is clearly distinguished from Alluvium by its low composition rate of permeable layers, low transmissivity, high seismic velocity, high resistivity, high density and hydrochemistry and so forth.
For instance, the formation identified by the Study Team as the Upper Churia in Banke is characterized by 15% of rate of permeable, 200 m2/day of transmissivity; containing siltstone layer as is described in lithological logs.

The said hydrogeological identification can be easily made through a careful interpretation of satellite imergery, aerophotos, topographic and geological maps, examination of result of geophysical prospecting and lithological and geophysical logs of DTWs, and so forth.

(2) Production Well Design

Well diameter is determined by the required pump discharge. Comparing with the flow velocity through screen in the three sizes of 150 mm, 200 mm, and 250 mm at a pump discharge of 120 l/s, their velocities are 3.4, 2.5, and 2.0 cm/s, respectively. When the critical velocity is set at 3 cm/s, the "recommended diameter for the production well becomes 250 mm." When the followings are set forth - well diameter 250 m, screen opening 25%, well yield 120 l/s, and entrance velocity 2 cm/s - the "required screen length comes to approximately 31 m."

The required well depth is the required aquifer length plus the housing-pipe length. The housing-pipe length is appropriate at 50 m, which is the length that the water drawdown is added to the lowest static water level throughout the year. When the pump discharge is determined at 120 l/s, a majority of the well depths are within 100 m in alluvial plain. The areas with a required well depth of 100-130 m include the terrace area in Jhapa District, the southern alluvium plain in Mahottari District, and the Babar Zone in Banke. In the central part of Banke, the necessary well depth is estimated at 288 m.
From the above explanation, the required well depth in the Terai, in general, is approximately 130 m, with a pump discharge up to 120 l/s.

(3) Construction of Production Wells

a) Drilling method
The method for well drilling is to be in accordance with the geology. The percussion method is appropriate in the Babar Zone where the distribution of boulders is expected. In the Southern Terai, the formation is fine grain which allows the use of the mud-circulating rotary method. Except for special cases, the project area consists of alternating beds of unconsolidated sand/gravel; and clay/silt, therefore, the most cost-effective drilling rig should be selected.

b) Specific gravity of drilling circulating fluids
As the drilling area consists of unconsolidated beds and underlies confined aquifers, careful selection of the circulating fluid is essential. Drilling circulating fluid includes fresh water, clay-added water (bentonite), polymer-added water, and clay (bentonite)- and polymer-added water. The fluid composed of only the clay and polymer additives is to be considered for unconsolidated beds in the Terai. For areas where the static water level is maintained at the surface, drilling fluids which include heavy additives, such as barite, are unnecessary. In the area where the artesian water head is higher than the surface, such as near the terrace area in the Jhapa District, where artesian water head is measured at 9 mags, a denser bentonite fluid or barite additive is necessary. Using a drilling fluid with an excessive density, however, requires special attention due to the loss of drilling fluid, the clogging of aquifers, and the higher pumping costs.

c) Casing and screen

- Casing

The selection of casing and screen materials is to be based on the estimated life span of a minimum of 25 years for production wells. Groundwater quality is also important in the selection of casing materials. If rust or scale is generated on the screen or casing, their yield and life span will be affected. Therefore water quality evaluation related to this point is important.

The water quality which may cause a problem on DTW in the Jhapa District is located in the alluvial plain of the Kankai River. Otherwise, there are no groundwater quality problems. The material for the screens should be stainless steel in areas where the quality of water may be a problem.

The water quality in Mahottari District requires a water quality evaluation because of its slightly higher pH content.

The water quality in Banke District has been analysed by GWRDB/USAID. According to this analysis, the pH for a majority of the wells is very high at 7.5 or greater. Another water quality evaluation is required when using the water in this area.

- Screen

The required pump discharge for DTW irrigation is around 100 l/s. Therefore a continuous wire-wrapped screen with the largest opening is to be used. As mentioned in the previous section, the required opening is at least 25%, and only the continuous wire-wrapped screen can meet this requirement. The strength of the screen for DTWs in the Terai must be seriously examined because of the examples of crushing accidents to the wire-wrapped screens. The three types of loads or force imposed on screens include column load (vertical compression), tensile load (extending load), and collapse pressure (horizontal force). Vertical compression and tensile force tend to occur when installing the casing and screen; horizontal stress on the screen occurs during gravel packing or development. The collapse of screens has also been reported due to earthquakes.

Resistance to horizontal pressure required for screens with a depth of 150 m in the Terai is 30 kg/cm2 when the safety factor is estimated at 100%. However, when the ordinary continuous wire-wrapped screen does not satisfy this figure. The use of reinforced screens is strongly recommended.

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATION

CHAPTER-SEVEN: CONCLUSION AND RECOMENDATION

7.1. Conclusion

7.1.1. General

This chapter concludes with the groundwater resource evaluation and the master plan for DTW irrigation, which are the major purposes of this Master Plan Study.

7.1.2. Evaluation of Groundwater Resources

The evaluation of groundwater resource in Phase I study was made through the hydrogeological and the groundwater conditions in the three target districts based on the existing groundwater studies and DTWs information in the three areas. The average yield of standard DTWs is evaluated as follows:

District		Deep Tubewell Yield (l/s)
Jhapa		91
Mahottari	(South)	66
	(North)	97
Banke		110

A simulation model for hydrological balance has been constructed based on the results of a detailed study of the topography, meteorology, hydrology, and hydrogeology of the representative area selected in southeastern Jhapa District. The model covers an area (719 km2), which includes the representative area and adjacent areas. A simulation under the present and the future conditions has been projected over a 14 year period and the ground-water resources were evaluated. The results show the average current water balance (unit: million m3/year) in the representative area as follows: evapotranspiration 555 (29%); the inflow and discharge of surface water (including the Kankai River) 3,790 and 4,874, with a difference of 1,084 (57%); the groundwater recharge volume 369 (19%), the groundwa-ter runoff 360, and the groundwater draft 3, among precipitation 1,903 (100%). The groundwater recharge from the subsurface system is 360 million m3 on an annual aver-age, but groundwater use is only 3 million m3, which means that most of the groundwater recharged is discharged outside of the area.

When the representative area (17,000 ha) is irrigated (peak demand: 0.8 l/s/ha), the water demand for a 10 year recurrence interval is 131 million m3, which is only 36% of the above groundwater recharge. The simulation using this pumping demand shows no groundwater shortage over the 14 year period (critical drawdown is set at 30 m). Based on the simulation, the pumping of 206 million m3 water, which is approximately 1.35 times the designed water demand, is required to reach the level of critical drawdown. From the above results, groundwater resources in the Jhapa District are approximately 200 million m3 annually, and there is a 35% surplus even after the full-scale implementation of this irrigation project.

In regard to the Mahottari and Banke districts, simulations similar to the one applied to Jhapa District have not been conducted. The groundwater environment in Mahottari, including meteorology, hydrology, and hydrogeology, is similar to that in Jhapa District. Therefore, it is believed there is similar groundwater potential in the District.

Banke District has less precipitation compared with other two districts. The Gangetic alluvium layer with its high groundwater potential is only distributed in the southern strip, therefore, large-scale groundwater development in the district is limited to the strip.

7.1.3. Master Plan for Deep Tubewell Irrigation

(1) Agricultural Development Plan

The basic strategies of the agricultural development plan include a diversification of crops, expansion of productivity, and the increase of farm incomes. A summary of the planned patterns and intensity of cropping in the three study areas is shown below:

Districts	Jhapa	Mahottari	Banke
Crop pattern (without project)	Wheat, maize, monsoon paddy	Pulses, wheat, monsoon paddy	Mustard, pulses, maize, wheat, monsoon paddy
(with project)	Wheat, maize, dry paddy, monsoon paddy	Onions, potatoes, wheat, monsoon paddy, dry paddy	Mustard, pulses, potatoes, maize, monsoon paddy
Crop intensity (without project) (with project)	126% 200%	140% 200%	140% 200%

(2) Irrigation Plan

From the conditions in each district, including precipitation, soil, and cropping patterns, the peak irrigation water requirements in each district are as follows (facility design discharge): 0.8 l/s/ha for Jhapa; 1.0 l/s/ha for Mahottari: and 0.7 l/s/ha for Banke. The annual water demand in a 10 year recurrence interval, based on the irrigable areas in each district, are 131 million m3 for Jhapa, 72 million m3 for Mahottari, and 66 million m3 for Banke.

(3) Water Source Plan

The number of irrigation units which cover each of the entire irrigable area and the average commanding area of DTW, which is determined by the average yield and the unit water demand of standard DTWs (depth 130-150 m, diameter 250 mm, drawdown 20 m), are summarized as follows:

Districts	Jhapa	Mahottari		Banke
		(South)	(North)	
Deep tubewell yield (l/s)	120	66	97	110
Average command area (ha)	150	66	97	157
Number of irrigation units	113	31	61	51

(4) Facility Plan

The facilities required for an irrigation unit per DTW is as follows: water source facility (well, pump station, power transmission line); water distribution system (pipeline system and valve); on-farm canal (command area 4-6 ha); drainage canal (unit drainage volume 4 l/s/ha; density 4-5 m/ha); village road (width 6 m, density 4-5 m/ha); and on-farm road (width 3 m, density 4-5 m/ha).

(5) Project Plan

From the above facility plan, the project dimensions can be summarized as follows:

Districts	Jhapa	Mahottari	Banke
Irrigable area (ha)	17,000	7,000	8,000
Number of deep tubewells	113	92	51
Pump station			
• Number of pumps	113	92	51
• Total length of power transmission lines (km)	170	70	80
Pipeline System			
• Total length (km)	680	300	320
• Number of valves	4,070	1,750	1,940
Total length of on-farm canals (km)	1.240	560	610
Total length of drainage canals (km)	770	330	350
Total length of road network (km)	170	74	77
Number of buildings	2	2	2

(6) Project implementation plan

The project implementation schedule is as follows.

Districts		Jhapa	Mahottari	Banke
Overall schedule	(year)	10	9	8
Project preparation	(year)	3	3	3
Land acquisition	(year)	5	4	4
Road construction	(year)	4	4	4
Facility construction	(year)	6	5	4

(7) Organization, Operation and Maintenance System

The project execution body is the Department of Irrigation. The Project Office established by each district to implement the Project includes the Agricultural, Farmers' Organization, Engineering, Hydrogeology, Maintenance and Administrative Divisions. Under the Agricultural Division, which is in charge of the extention services. Agricultural subcenters are established to maintain close communication with farmers in each district.

Through the implementation of Project, the Farmers' Organization Division in the Project Office will organize and guide the operation and management of WUG, which consists of all beneficial farmers by each irrigation unit, as well as WUA, which consists of WUGs in each area.

During the initial period of Project implementation, operation and maintenance of pump stations are the responsibility of the Project Office, but this function will be gradually transferred to WUG. Upon completion of the Project, the functions of the Agricultural Farmers' Organization and the Maintenance Divisions will be transferred to WUA. All functions (excluding technical services) including operation and management, extention services, purchase and distribution of inputs, and the marketing of agricultural products will be transferred to WUA.

(8) Environmental Consideration

The most important environmental item in this Project is the existing water right related to groundwater. According to the simulation in Jhapa District, a maximum 20 m groundwater head drawdown may occur. This groundwater head drawdown may affect existing water source wells and yields from shallow dug wells for domestic use. Countermeasures for these problems, such as water source transfers, will be necessary in the process of project implementation.

Other environmental items related to groundwater development, such as water pollution and land subsidence, are not viewed as serious problems.

(9) Project Cost

The overall project cost in the each district, including direct construction cost, equipment cost, engineering and administrative fees, contingency and price escalation are as follows:

Jhapa District	:	Rs 2.988 billion (US$57.8 million, US$3,400/ha)
Mahottari District	:	Rs1.584 billion (US$ 31.7 million, US$4,500/ha)
Banke District	:	Rs1.510 billion (US$30.2 million, US$3,800/ha)

(10) Project Evaluation

The financial and economic costs of construction and the annual operation and maintenance cost in each district are estimated as follows:

	Construction cost		Annual operation and maintenance cost	
	Financial cost	Economic cost	Financial cost	Economic cost
Jhapa District	2,889	1,932	39	36
Mahottari District	1,584	1,098	21	19
Banke District	1,510	1,019	16	15

The agricultural production benefits (unit: million Rs/year) are evaluated at 585 for Jhapa District, 203 for Mahottari District, and 210 for Banke District.

As a result of a comparison of the above project costs and the agricultural production benefits, the economic internal rate of return in each project is evaluated as follows, which shows the projects in all three districts to be economically viable.

		Economic Internal Rate of Return (%)
Jhapa District	:	21.0
Mahottari	:	13.5
Banke	:	14.3

As a result of a financial analysis, the disposable incomes of the average farm households in each district, before and after the Project, are as follows:

		Farm (ha)	Disposable income (Rs.)
Jhapa District	(without project) :	1.41	1,473
	(with project) :	1.41	2,680
	(difference)		1,207
Mahottari District	(without project) :	1.09	6,769
	(with project) :	1.09	8,581
	(difference)		1,812
Banke District	(without project) :	1.37	4,790
	(with project) :	1.37	9,038
	(difference)		4,248

(11) Guidelines for Deep Tubewell Irrigation

As a result of the above examination, the following two items are important as guideline related to the planning stage of a DTW irrigation in the Terai.

a) LFCA and LFWY

LFCA, which is the economically appropriate command area of one DTW in the Terai, is approximately 30 ha, both east and west, as far as an electric pump is applied. The LFWY which is the DTW yield necessary to irrigate this LFCA is 30 l/s. Given this fact, DTW irrigation is not considered economically viable in the areas where the DTW yield is less than 30 l/s.

b) Aquifers

The alluvial aquifers in the Terai can obtain a DTW yield of 60-100 l/s. The Churia aquifer, however, has a low composition rate of permeable beds and low transmissivity. Therefore, the prescribed DTW yield may not be obtained. Sufficient hydrogeological examination is necessary in regard to the distribution of the Churia Formation when planning a DTW irrigation project.

c) Design of production wells

The details of production well up to a 120 l/s yield in the alluvial aquifers in the Terai are: screen diameter 250 mm, opening 25%, total length 30 m, total length of housing 50 m, and well depth 100-130 m.

d) Construction of production wells

The percussion method is cost-effective for the boulder distribution area in the Bhabar zone, while the rotary method is cost-effective in the other areas.

The selection of circulation fluid must be carefully considered for drilling of production wells. Bentonite fluid can be used where the static groundwater head is below the surface. A mixed fluid of bentonite and barite should be used when the artesian head is above the surface. Circulation fluids with excessive densities must be avoided as they will significantly reduce the yield of production wells.

The screen used for production wells in the Terai should be: reinforced wire-wrapped with an opening of 25% or greater; withstand collapse pressure of 30 kg/cm2 or greater; and stainless steel should be used depending on the water quality.

7.2. Recommendations

7.2.1. General

As mentioned above, this Study shows that the groundwater potential in the three study area is sufficient to operate DTW irrigation; it also shows that the implementation of a DTW irrigation project in this area is economically viable.

This chapter discusses the recommendations for implementation of the Project for the three study areas in the future.

7.2.2. Monitoring Work

One of the methods for groundwater resource evaluation was applied and demonstrated during this Study. This evaluation shows that it is necessary to identify natural conditions that include topography, geology, meteorology, hydrology, hydrogeology, and groundwater. It is also essential to identify the hydrological behavior of groundwater and a time-series hydrograph and groundwater use. Among the various hydrographs, the groundwater hydrograph is the only one that shows the hydrological behavior of groundwater. Therefore it is the most important information when evaluating groundwater resources.

The urgent establishment of a monitoring network as well as continuous observation in the three study areas are strongly recommended to DOI.

7.2.3. Project Implementation in the Three Districts

The studies necessary for future project implementation in the Study Areas are proposed as below:

(1) Jhapa District

The survey and study related to the development and evaluation of groundwater resources implemented to this district is considered to be beyond the master plan stage, reaching the stage of a feasibility study. This Project is economically appropriate and will contribute to the expansion of agricultural production, the diversification of agriculture, and the regional economy as a whole, which are major targets in the Eight National Development Plan. As well, the corroboration and demonstration effects of DTW irrigation in the district will be very high. Therefore, the DOI should promote an immediate implementation of a model project for 30 irrigation units (4,500 ha).

Farmers in the project area are eager to introduce irrigated agriculture, but they do not have any experience in irrigation practice through surface water, shallow wells, or deep tubewell, and WUGs are not as yet organized. A large amount of preparatory works is needed prior to the implementation of project inclusive of the preparation of topomap, inventory of land ownership, motivation of beneficial farmers, identification of each irrigation unit and then organization of each WUG. The DOI is deemed to have sufficient experience and capabilities from the previous projects in which to meet these responsibilities.

As previously stated, in order to achieve the successful result of the project, scrupulous governmental support services are indispensable for the extension and O&M works mainly rendered by WUA. DOI has to formulate, in cooperation with DOA, a WUA support program inclusive of definite measures; and to present the program to the donor agency of project finance in advance.

(2) Mahottari District

Mahottari District has a relatively large number of existing deep tubewells. And as such, there is a great amount of hydrogeological and groundwater information available. However, the economical priority of this district is the lowest among the three districts under the study, following Banke District. As with Banke, further feasibility study is necessary primarily to evaluate the groundwater resources.

(3) Banke District

According to the economic evaluation in the Study, the priority of the Banke District follows that of Jhapa District. Although the district strongly requires the introduction of DTW irrigation, they have little information related to the hydrogeological and groundwater conditions in the irrigable area. Before the implementation of the Project, a feasibility study is essential, including a hydrogeological study with drilling of exploratory wells and a thorough groundwater resource evaluation. The DOI should promptly conduct a feasibility study in this district.

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