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

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 groundwater 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 perspectives, 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 groundwater 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.

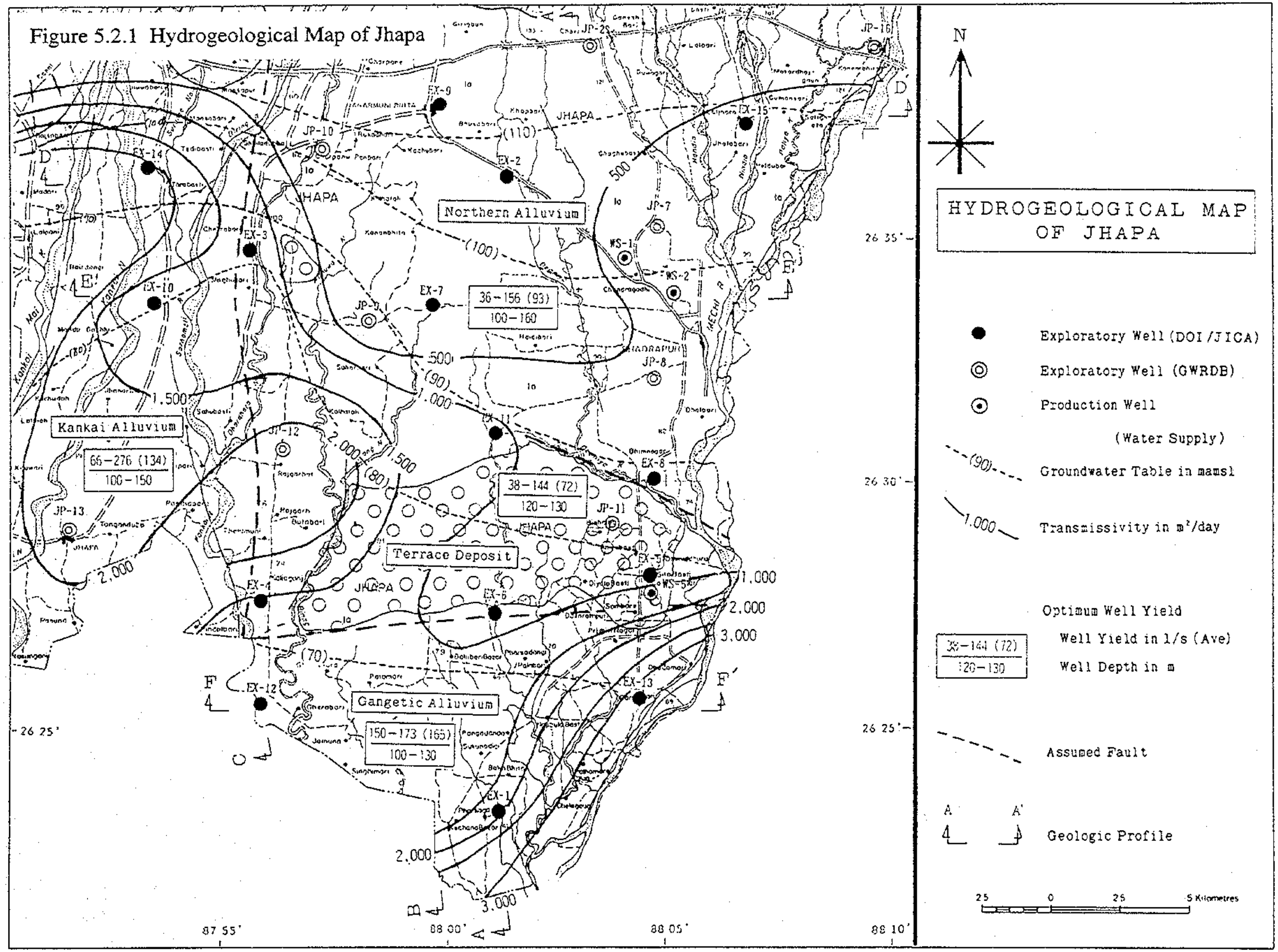


Figure 5.2.1 Hydrogeological Map of Jhapa

Figure 5.2.2. Geological Profile in Jhapa

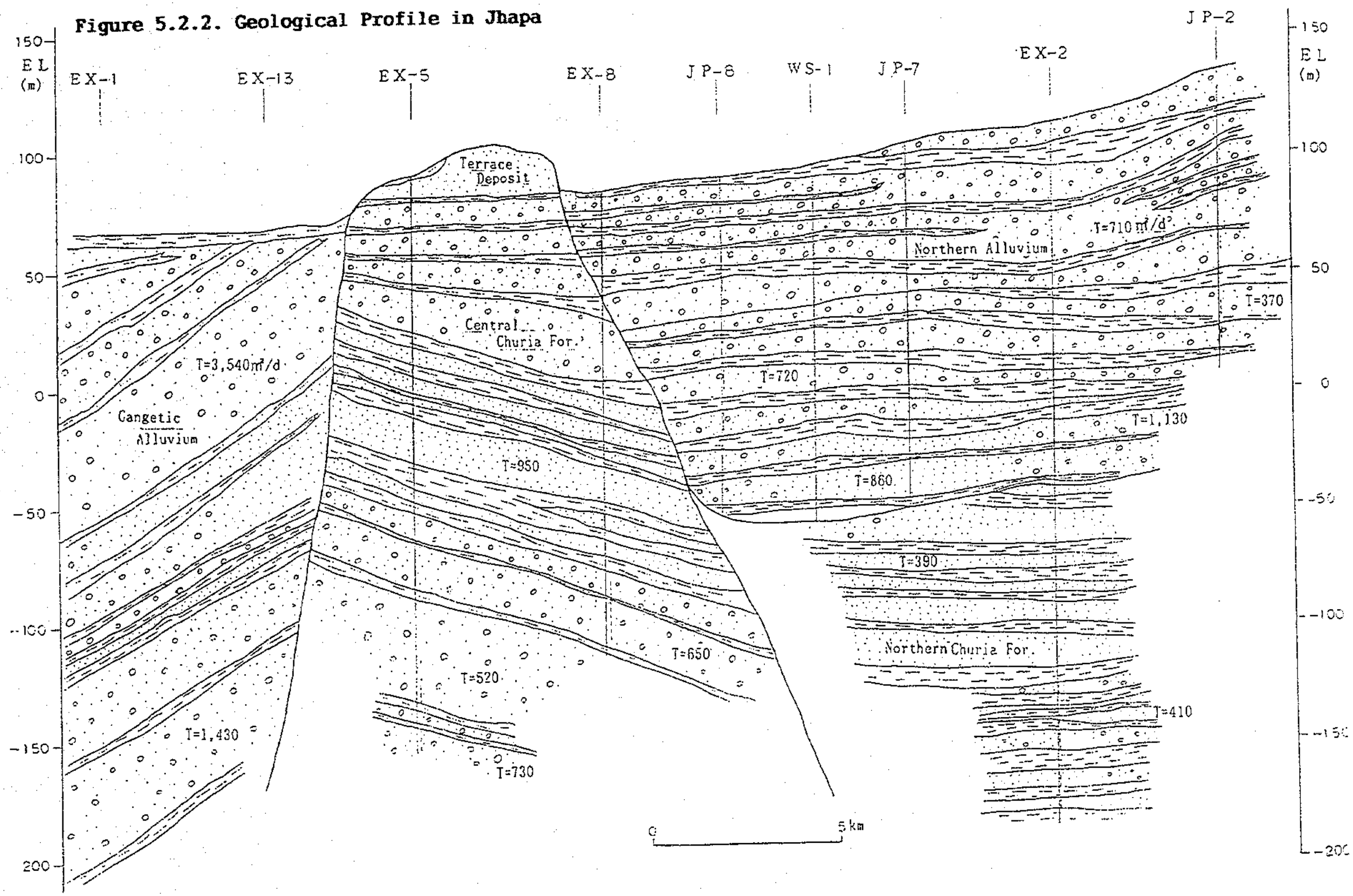
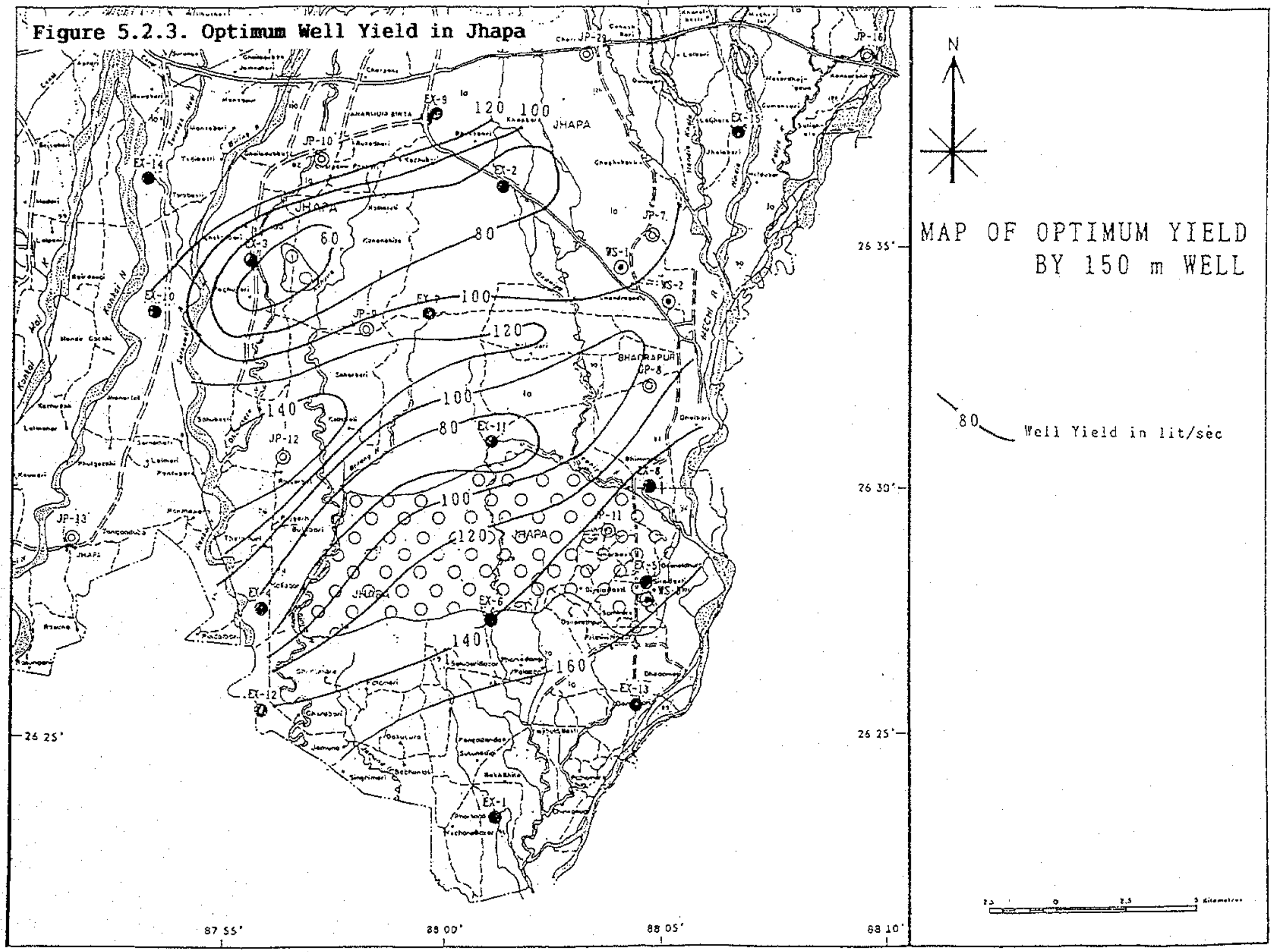


Figure 5.2.3. Optimum Well Yield in Jhapa



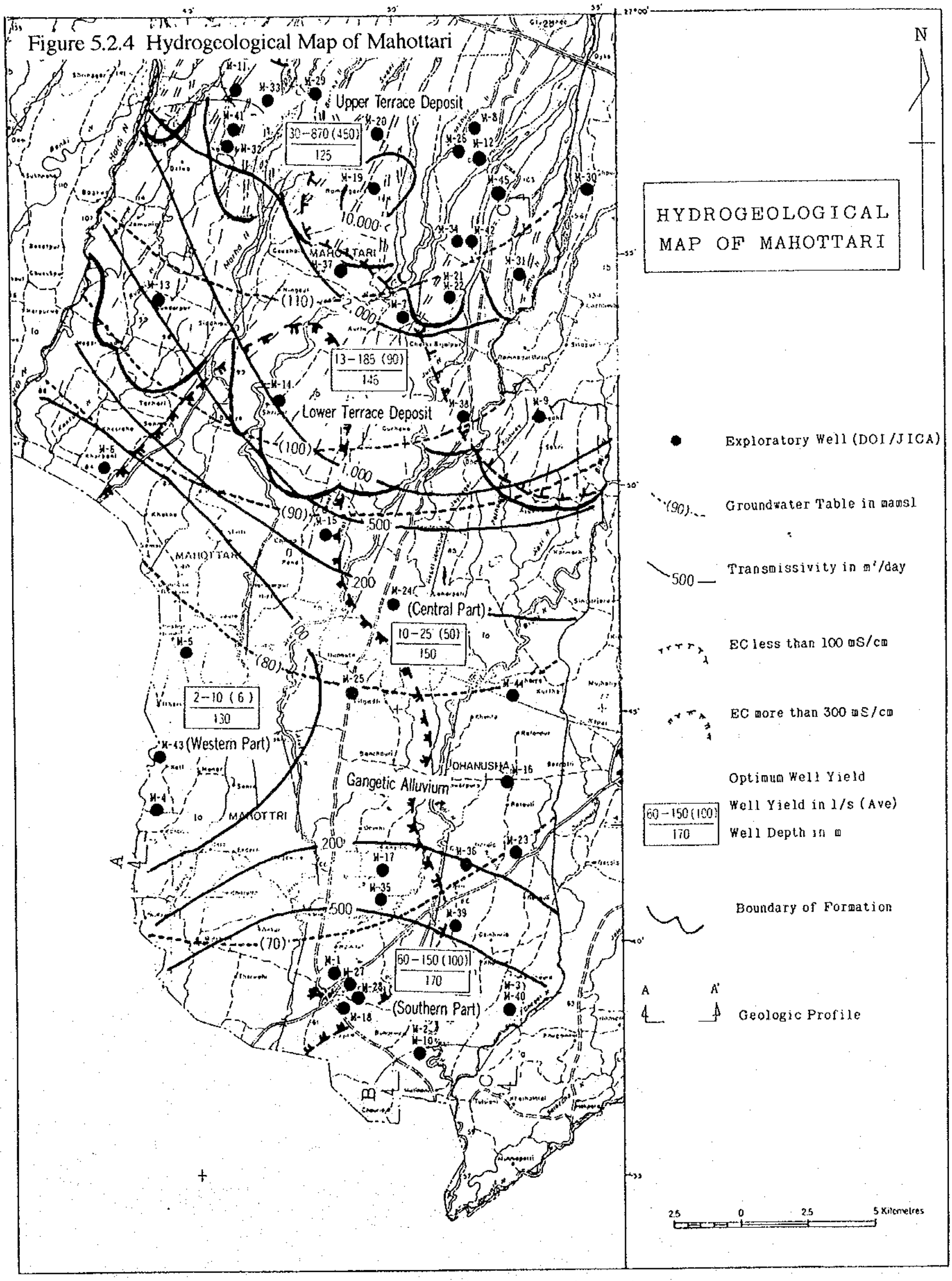
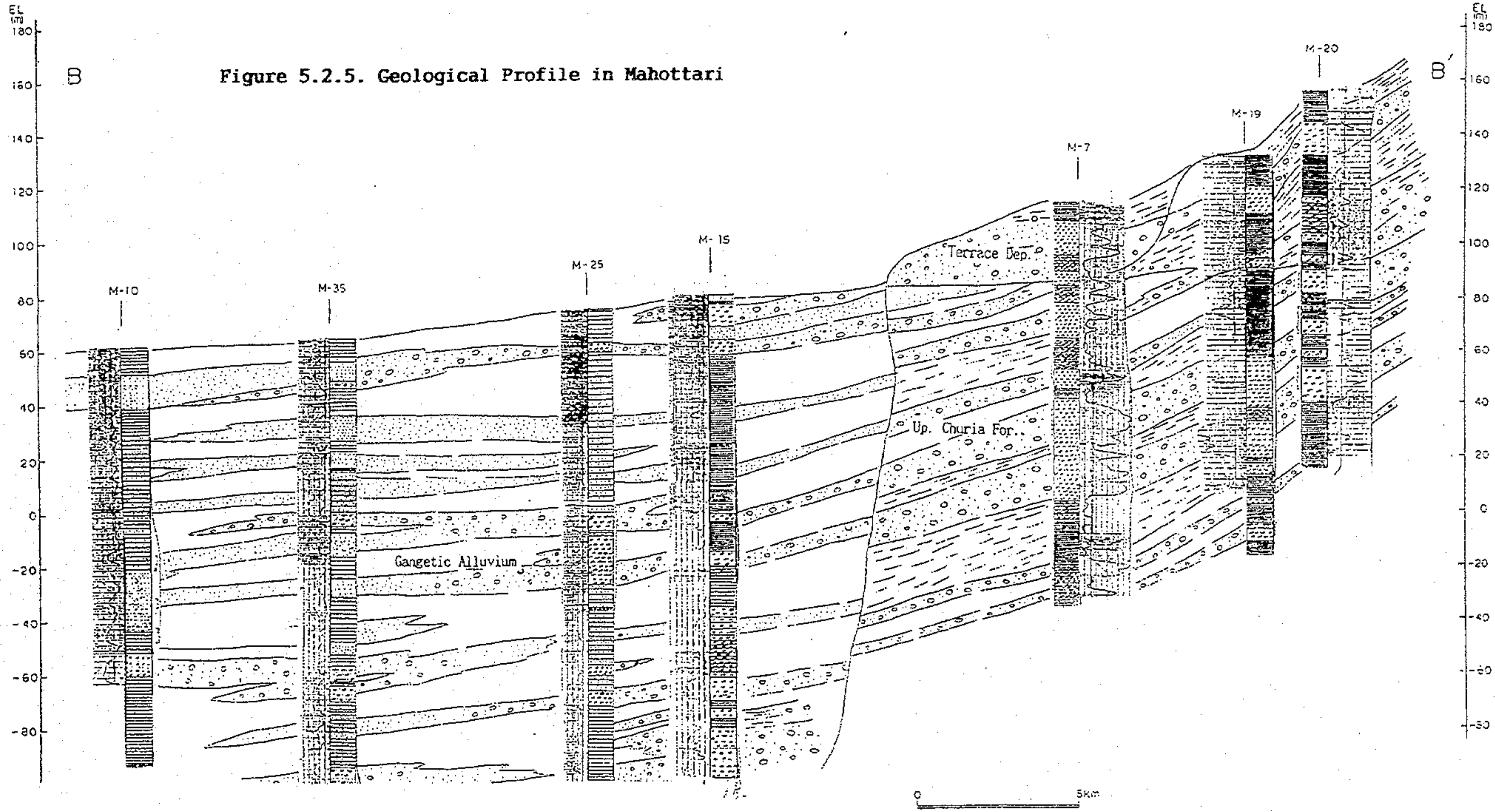


Figure 5.2.4 Hydrogeological Map of Mahottari

Figure 5.2.5. Geological Profile in Mahottari



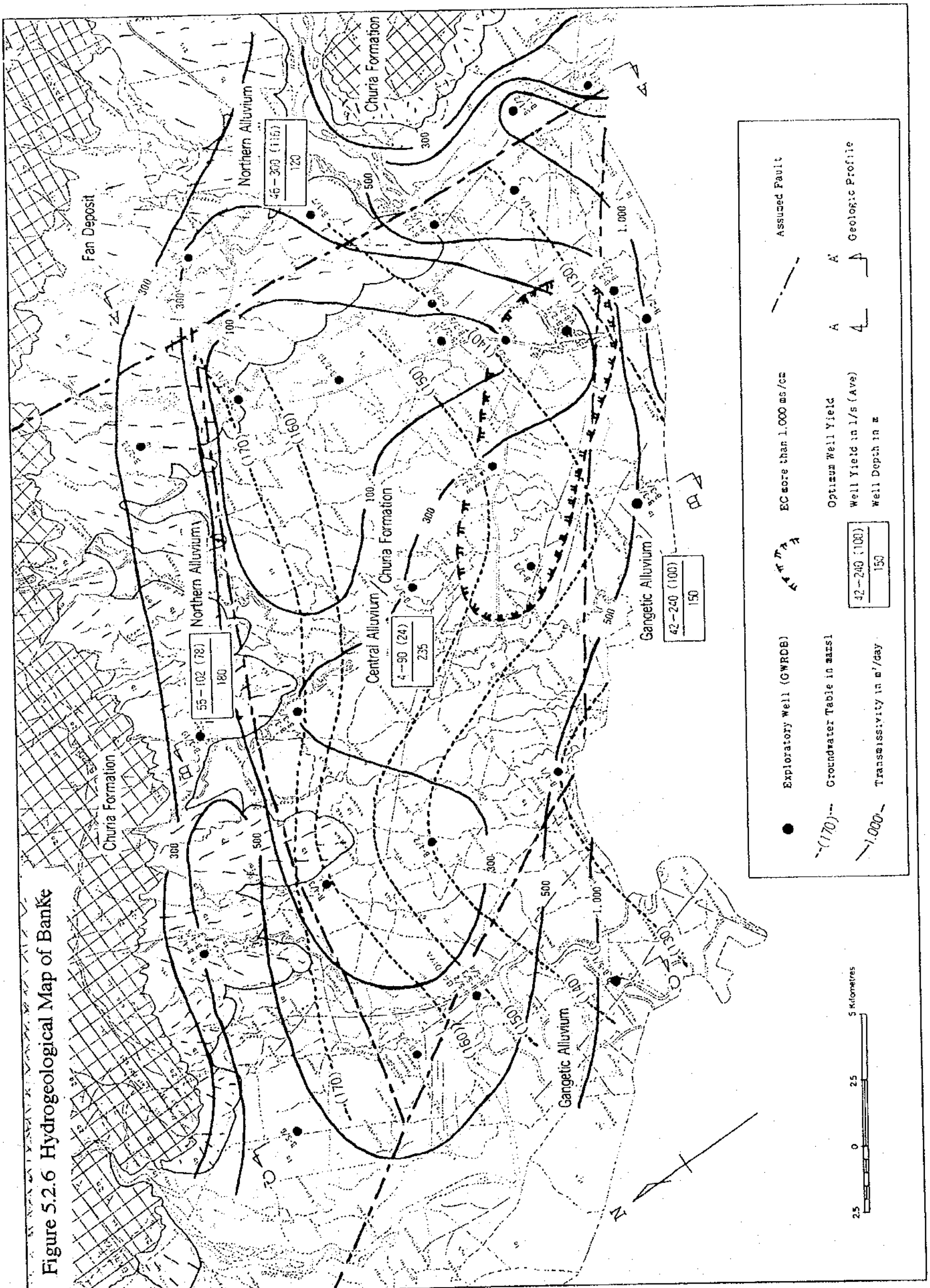
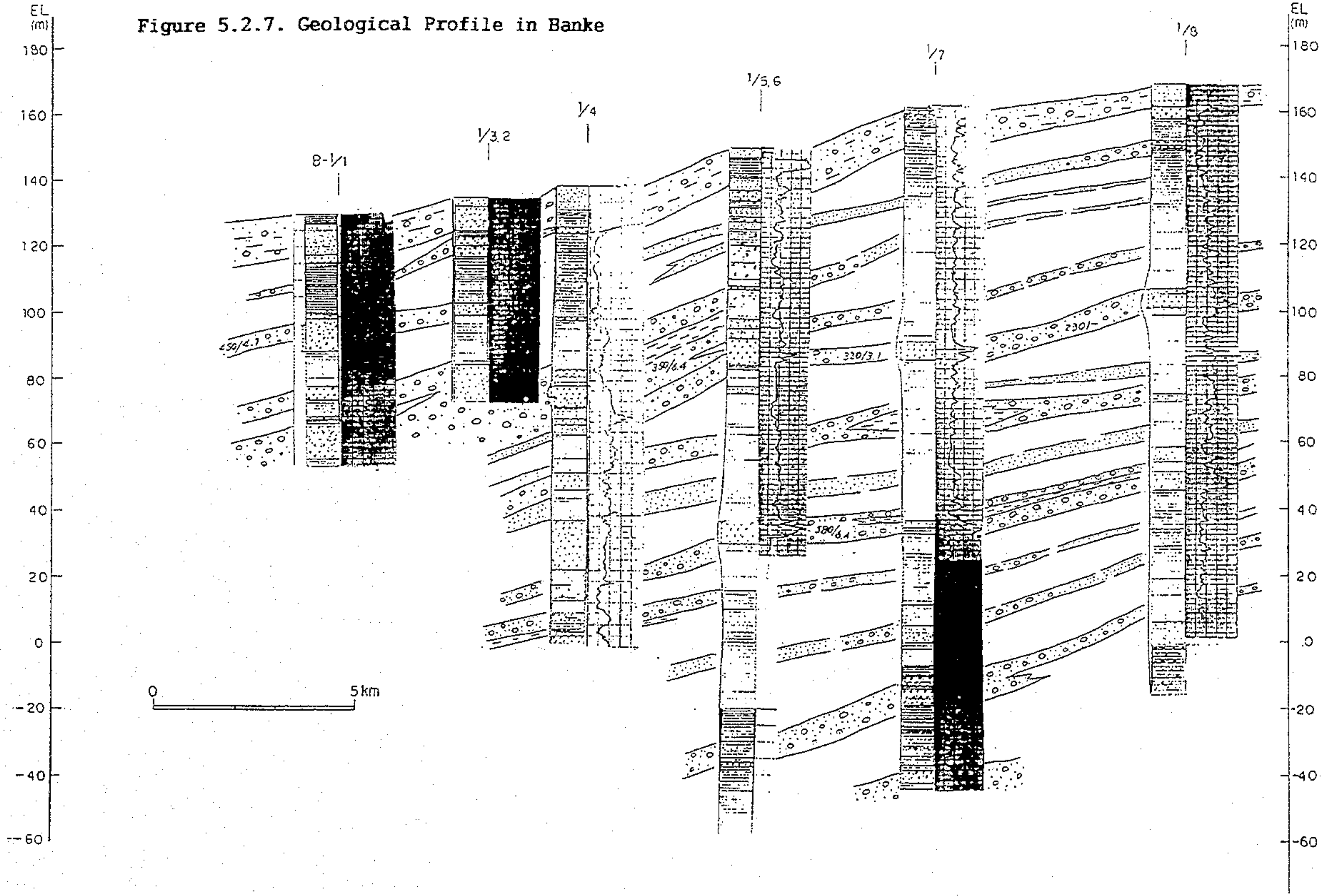


Figure 5.2.6 Hydrogeological Map of Banke

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.

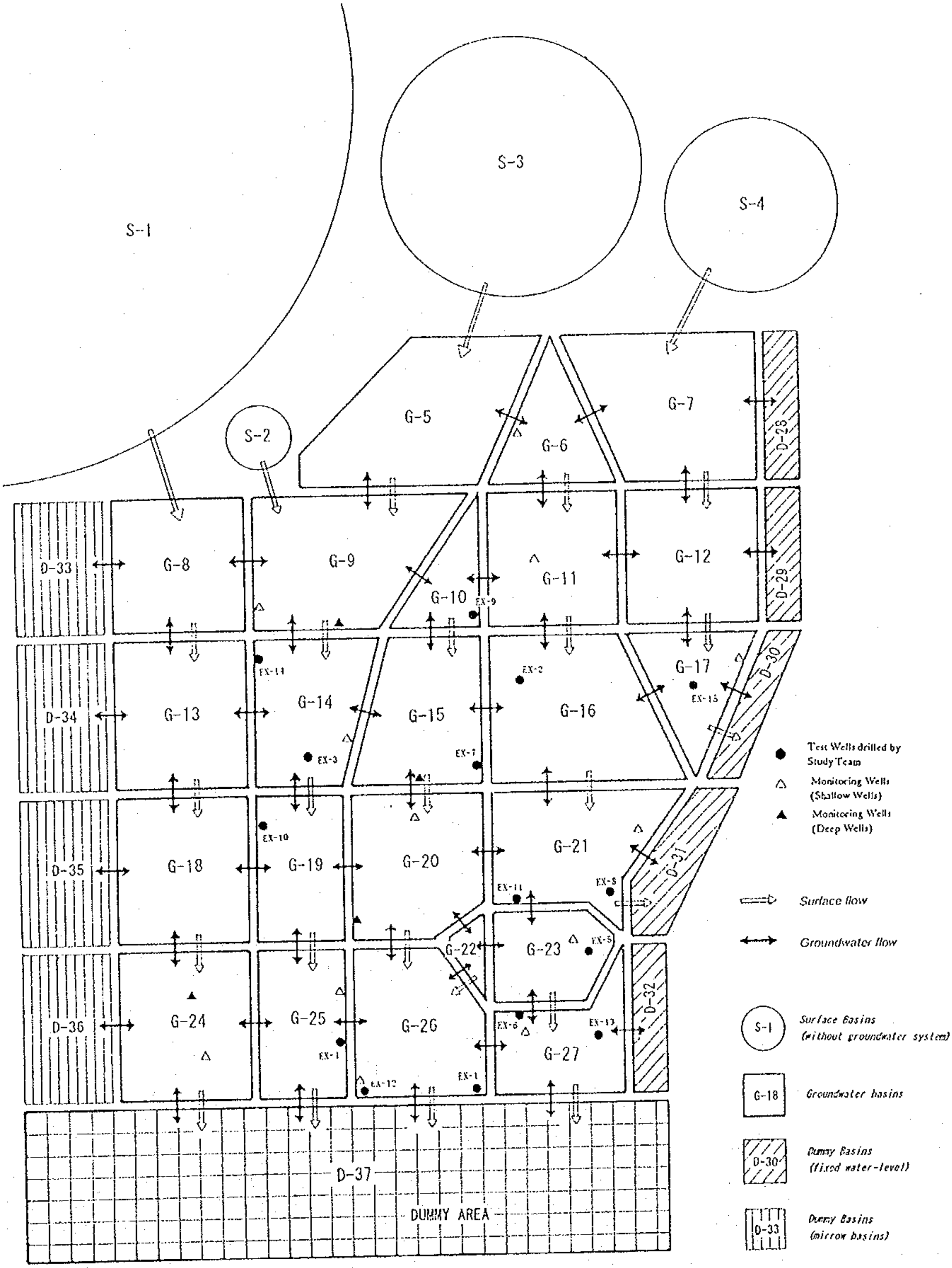
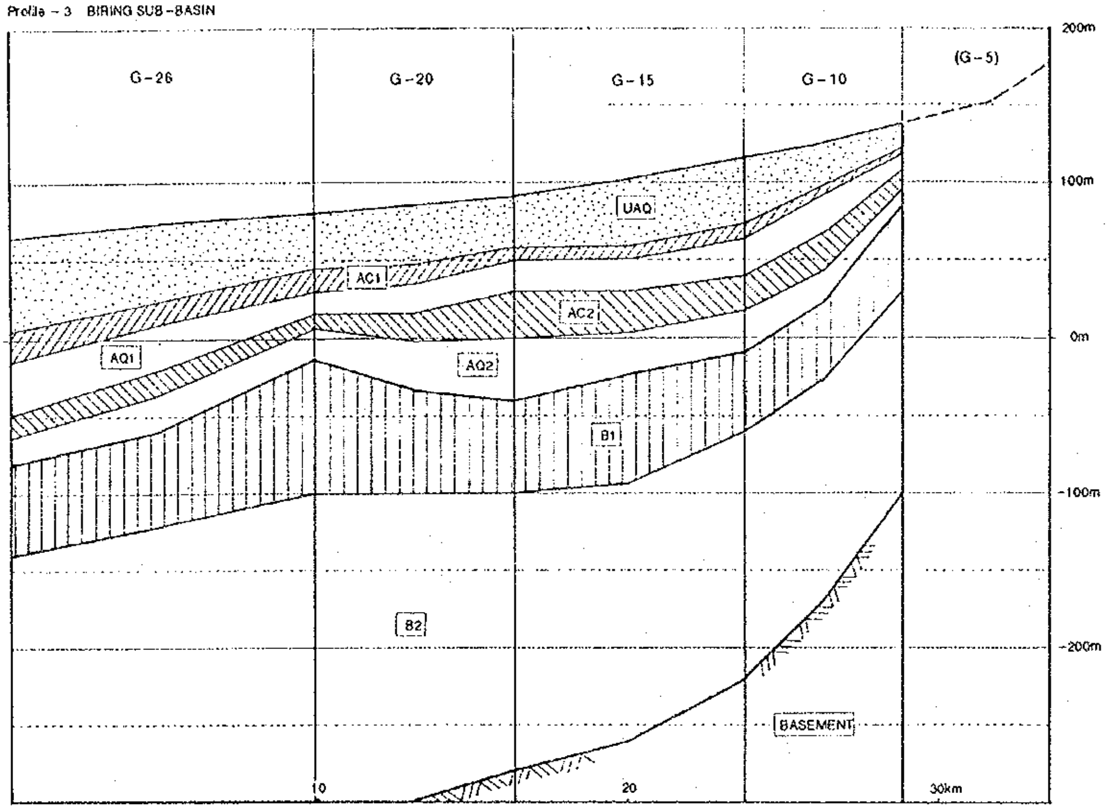


Figure 5.3.1 Sub-Basin Model



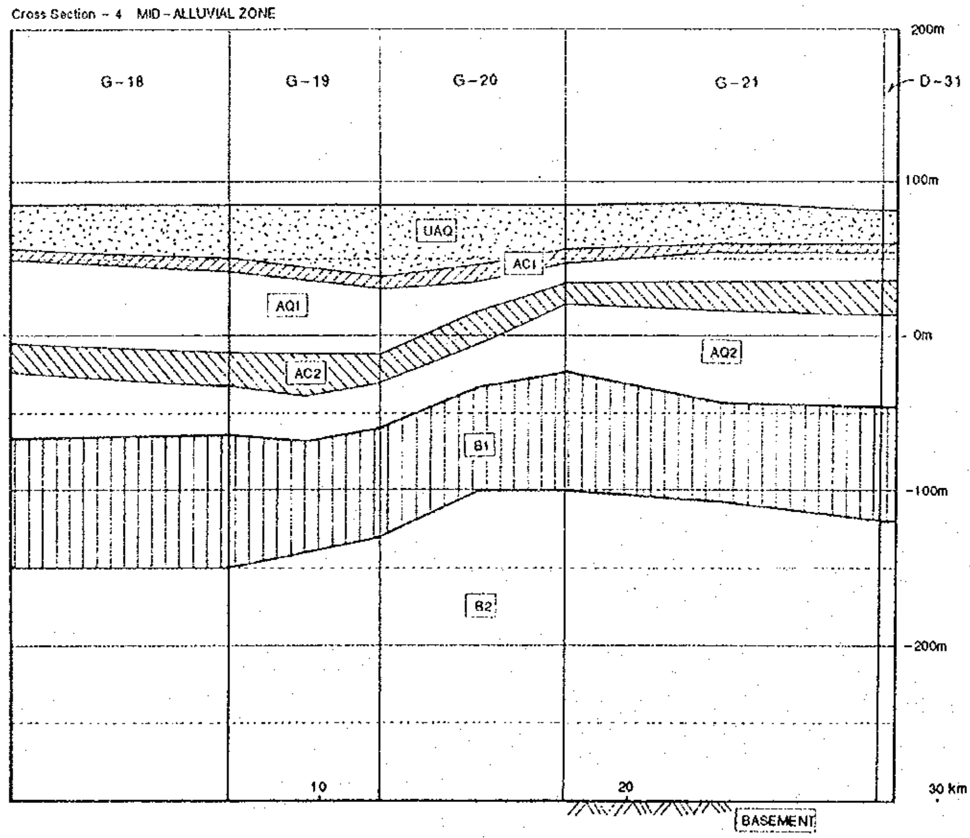


Figure 5.3.2 Aquifer Model

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.

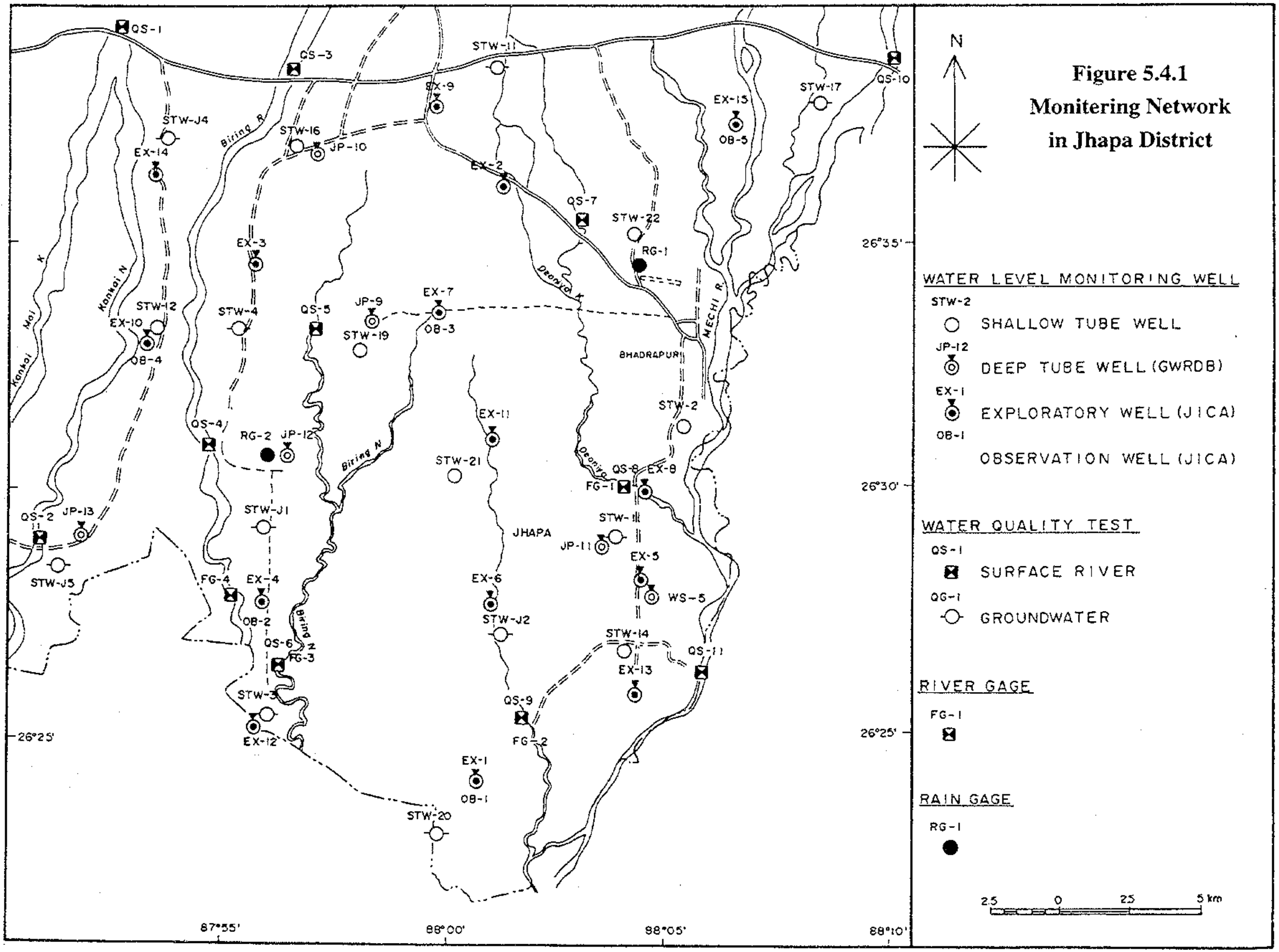


Figure 5.4.1
Monitering Network
in Jhapa District

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.

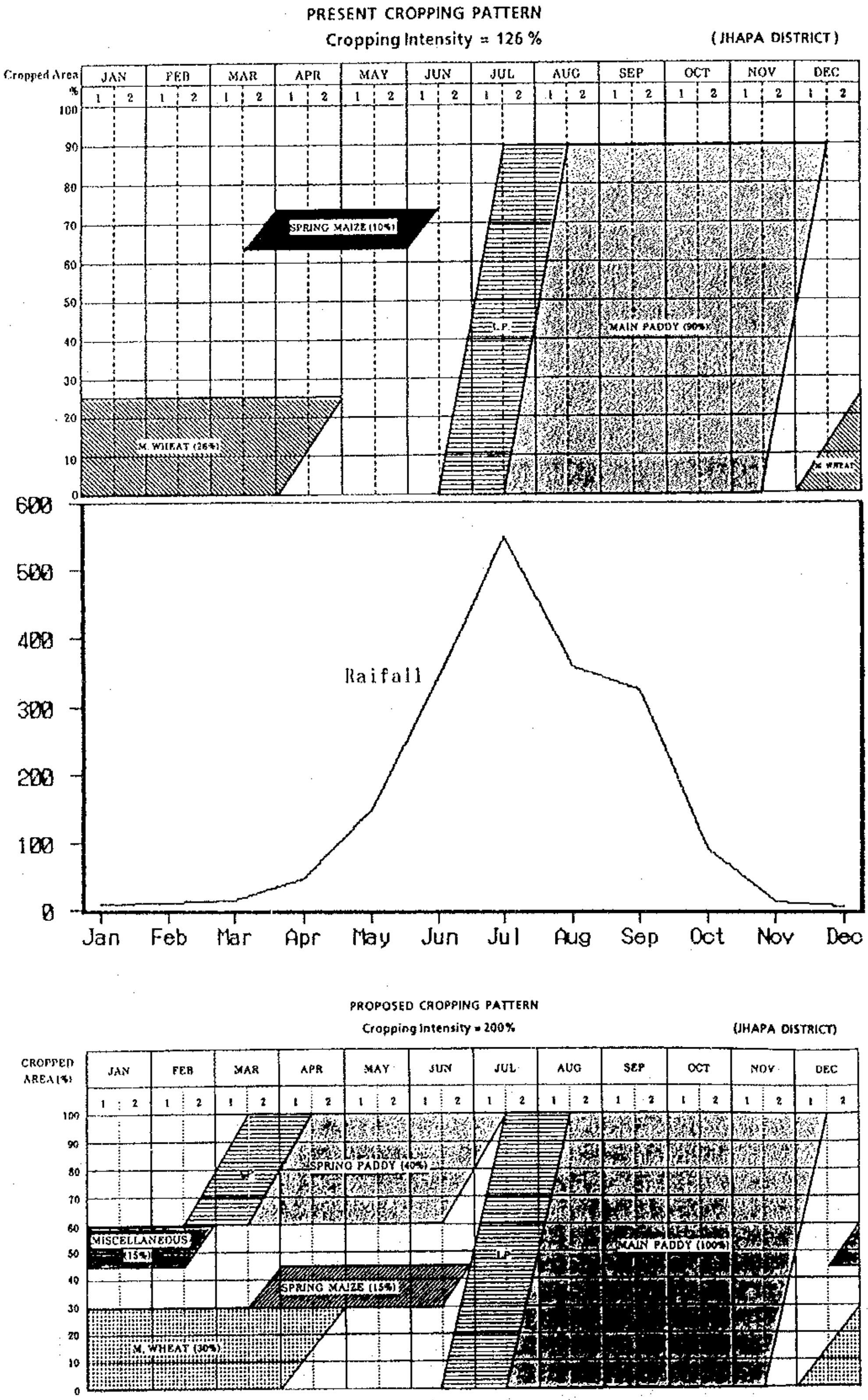


Figure 6.2.1 Current and Planned Cropping Patterns (Jhapa District)

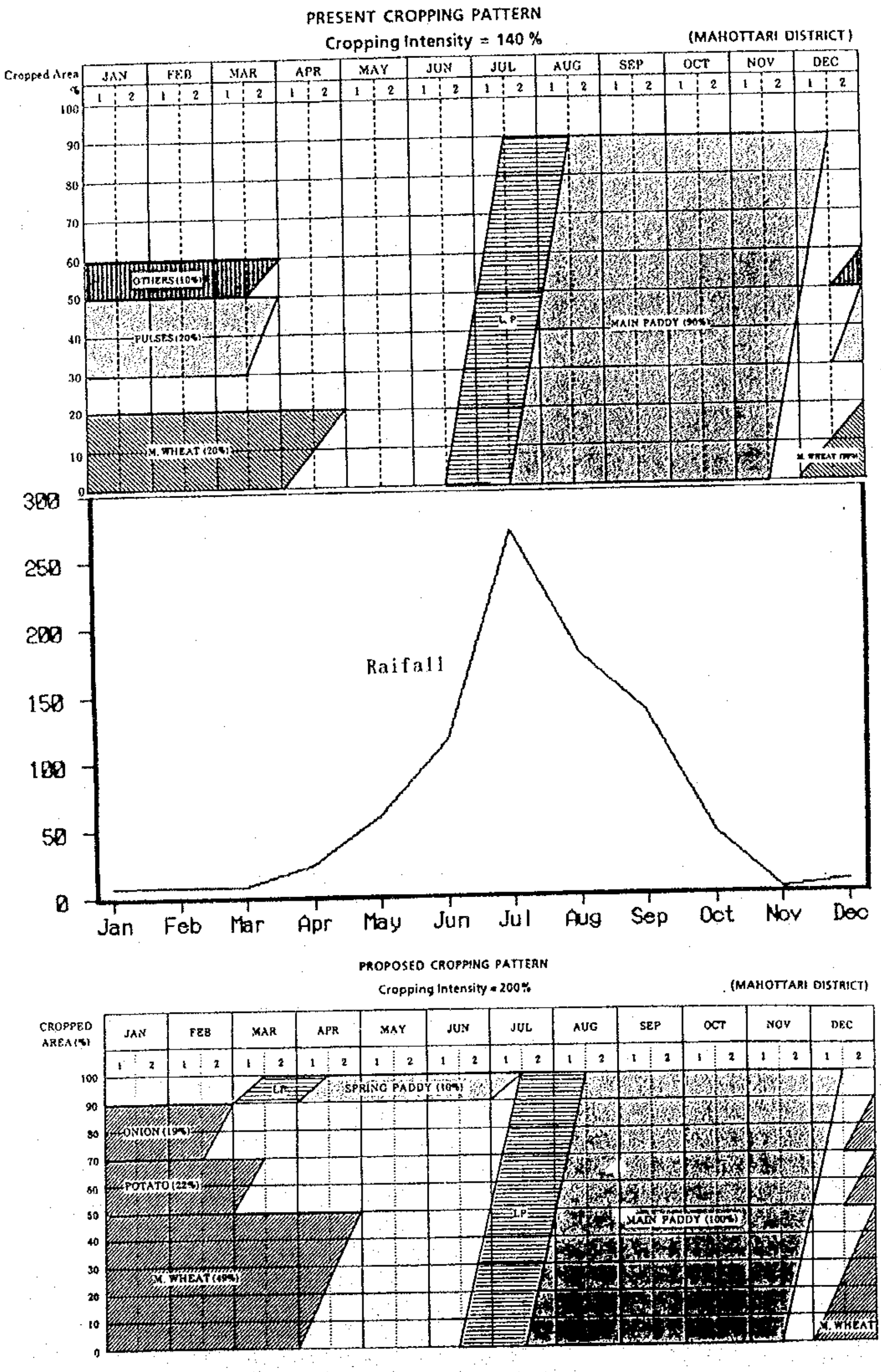


Figure 6.2.2 Current and Planned Cropping Patterns (Mahottari District)

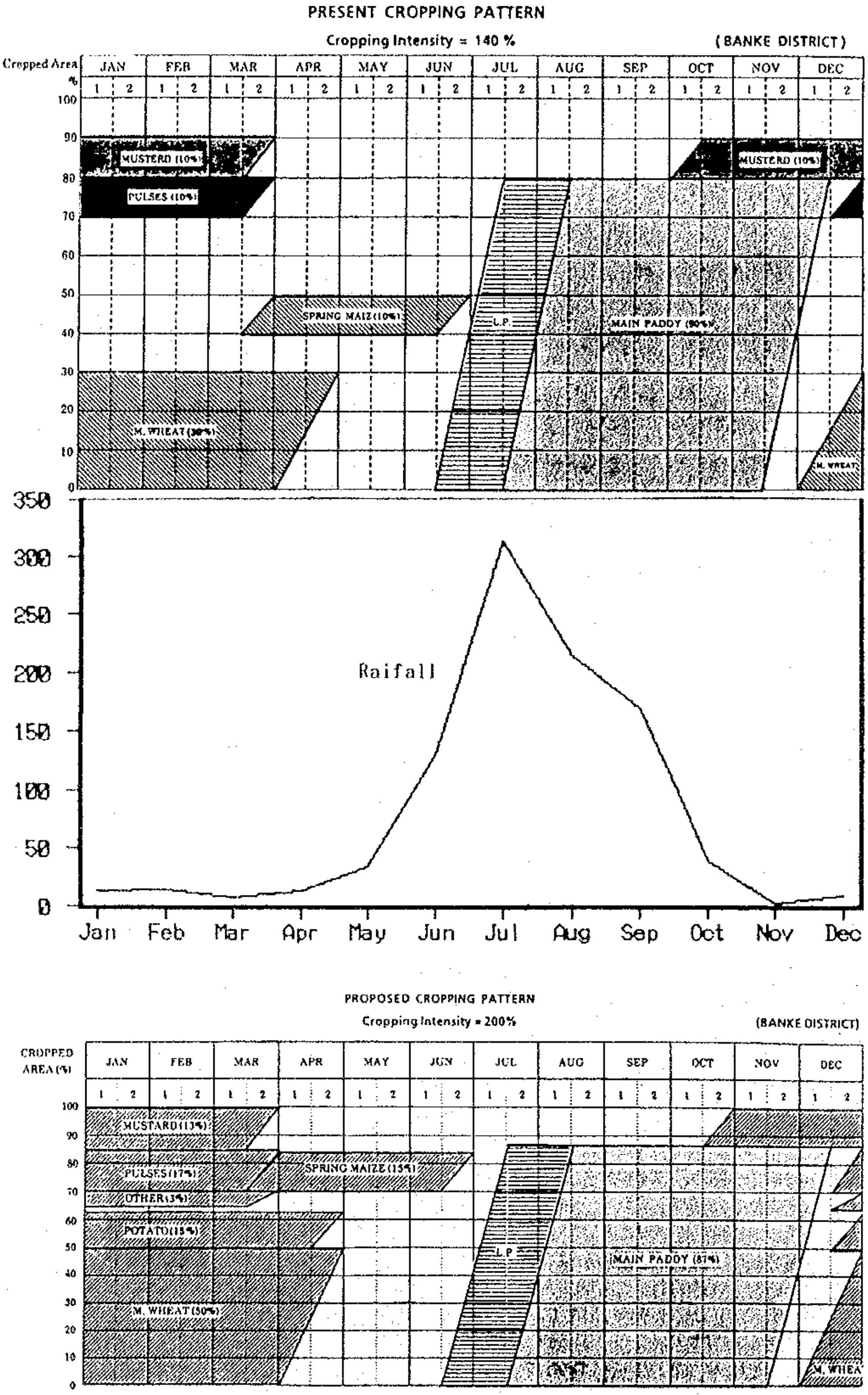


Figure 6.2.3 Current and Planned Cropping Patterns (Banke District)

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	7.5															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	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 = 6,100 (ha)	3,550	6,207	6,411	-								1,230	17,398
Total $V = 10^3m^3$		3,550	6,207	20,420	29,550	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 = 5,960 (ha)							202	10,509	6,918	15,291	8,011	285	41,216
	Wheat A = 4,000 (ha)	2,296	4,316	6,372	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.

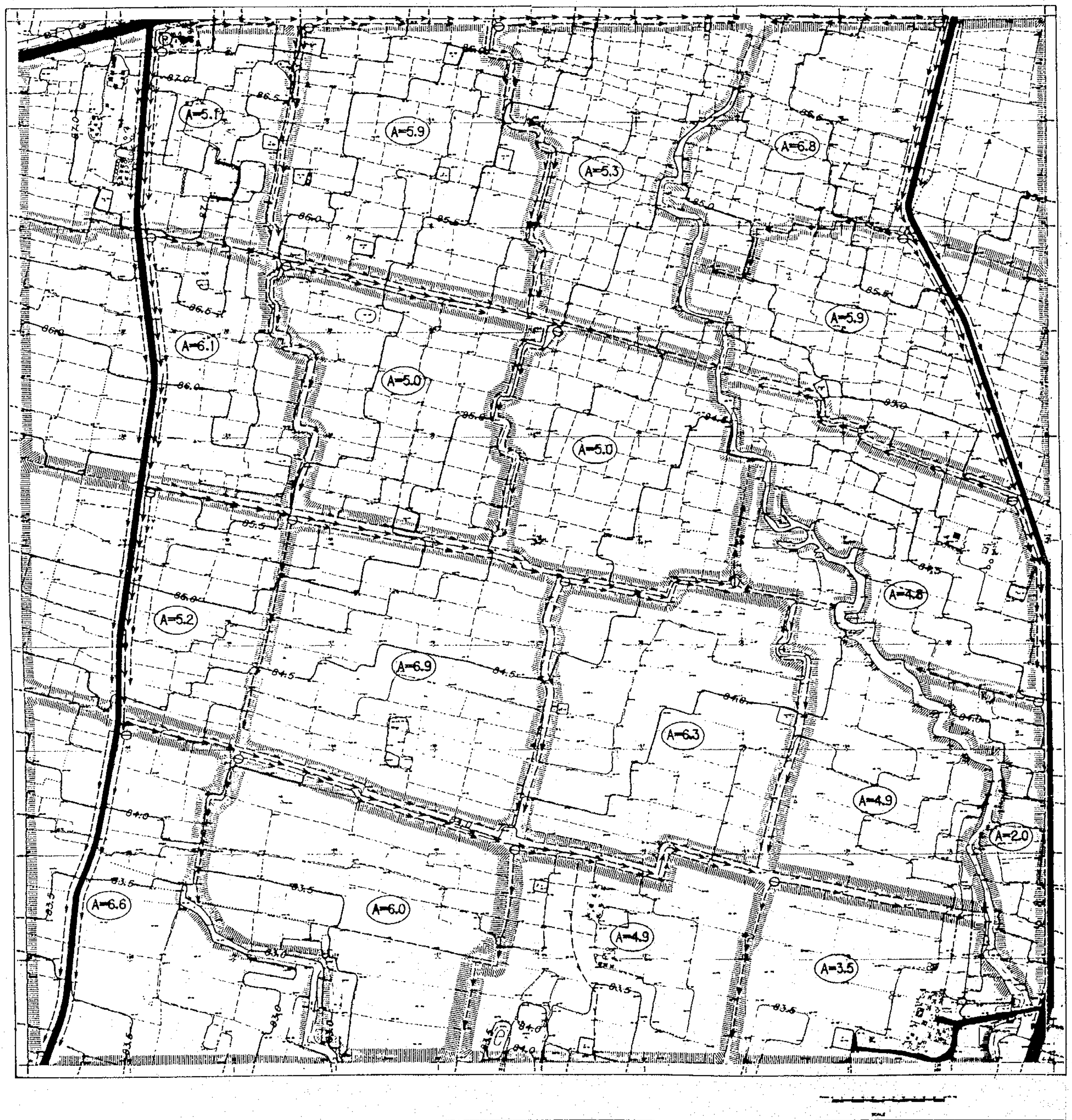
Based on economic evaluation related to the study area in each district, the greatest economic effects will occur in Jhapa area, followed by Banke and Mahottari. Given this fact, beginning the project in Jhapa area will yield the most effective results.

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



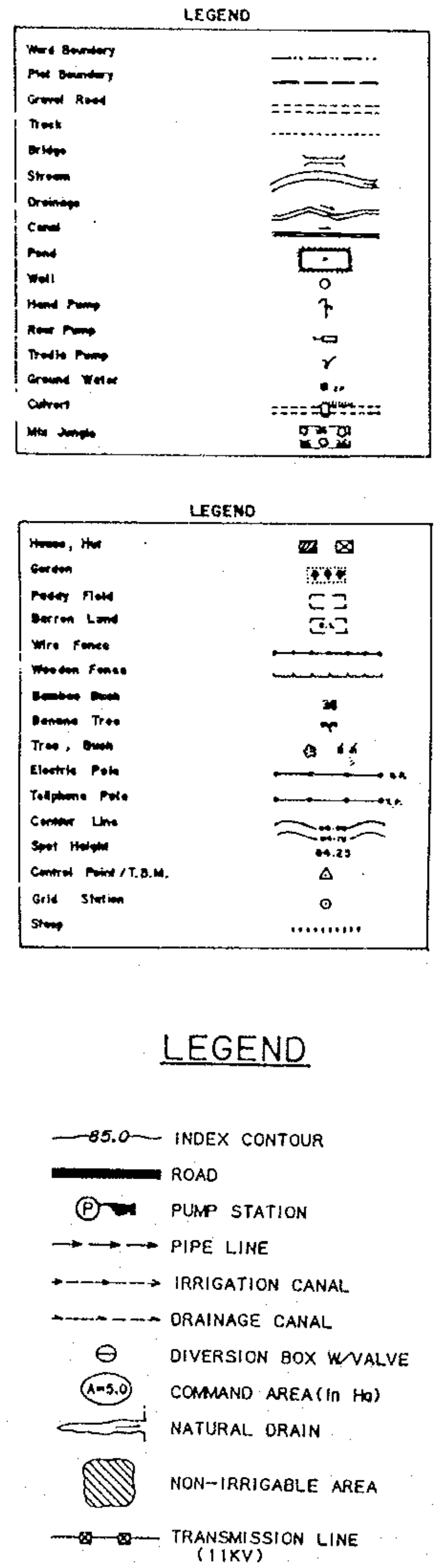
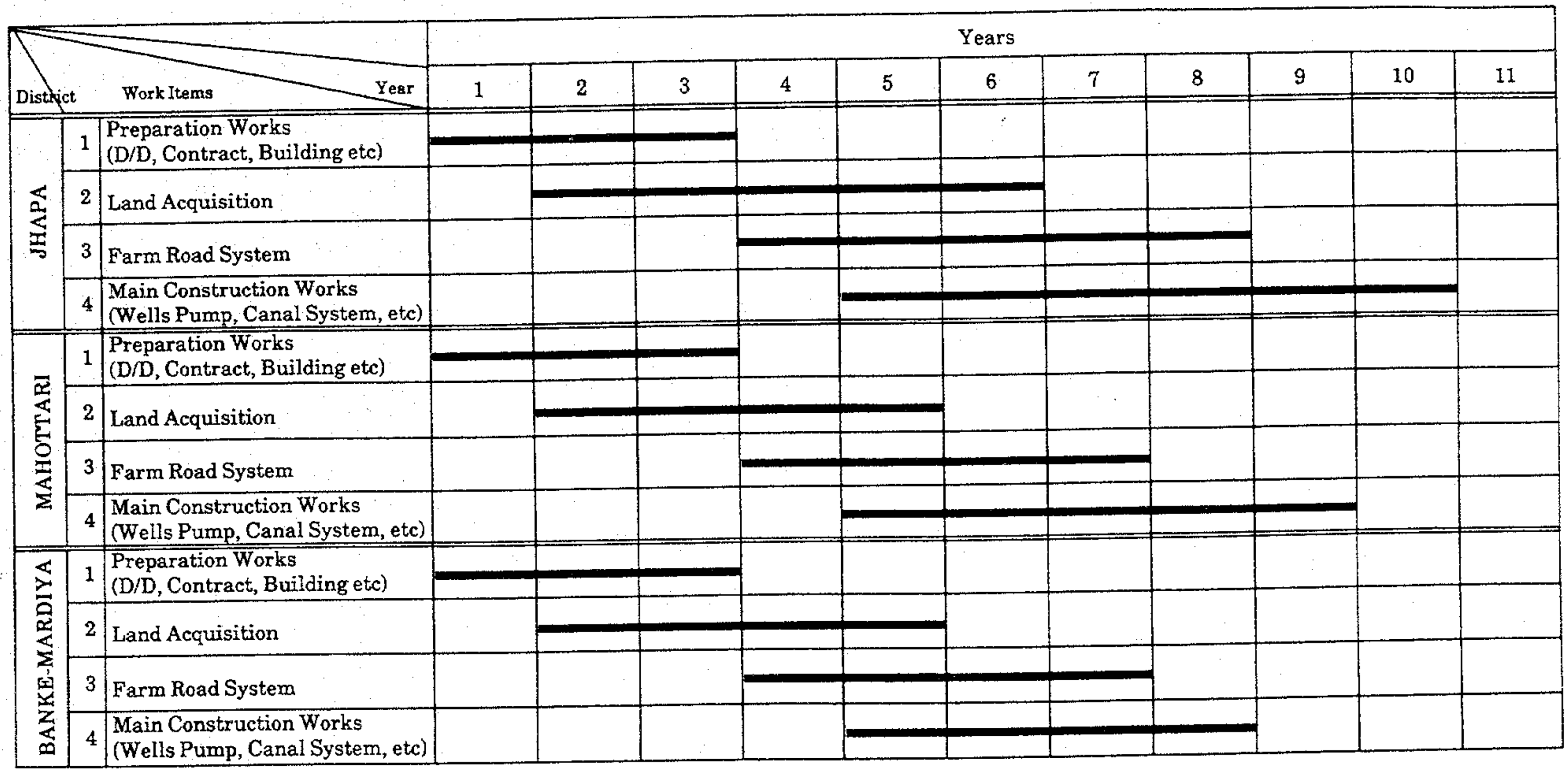


Figure 6.5.2 Project Implementation Schedule



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.

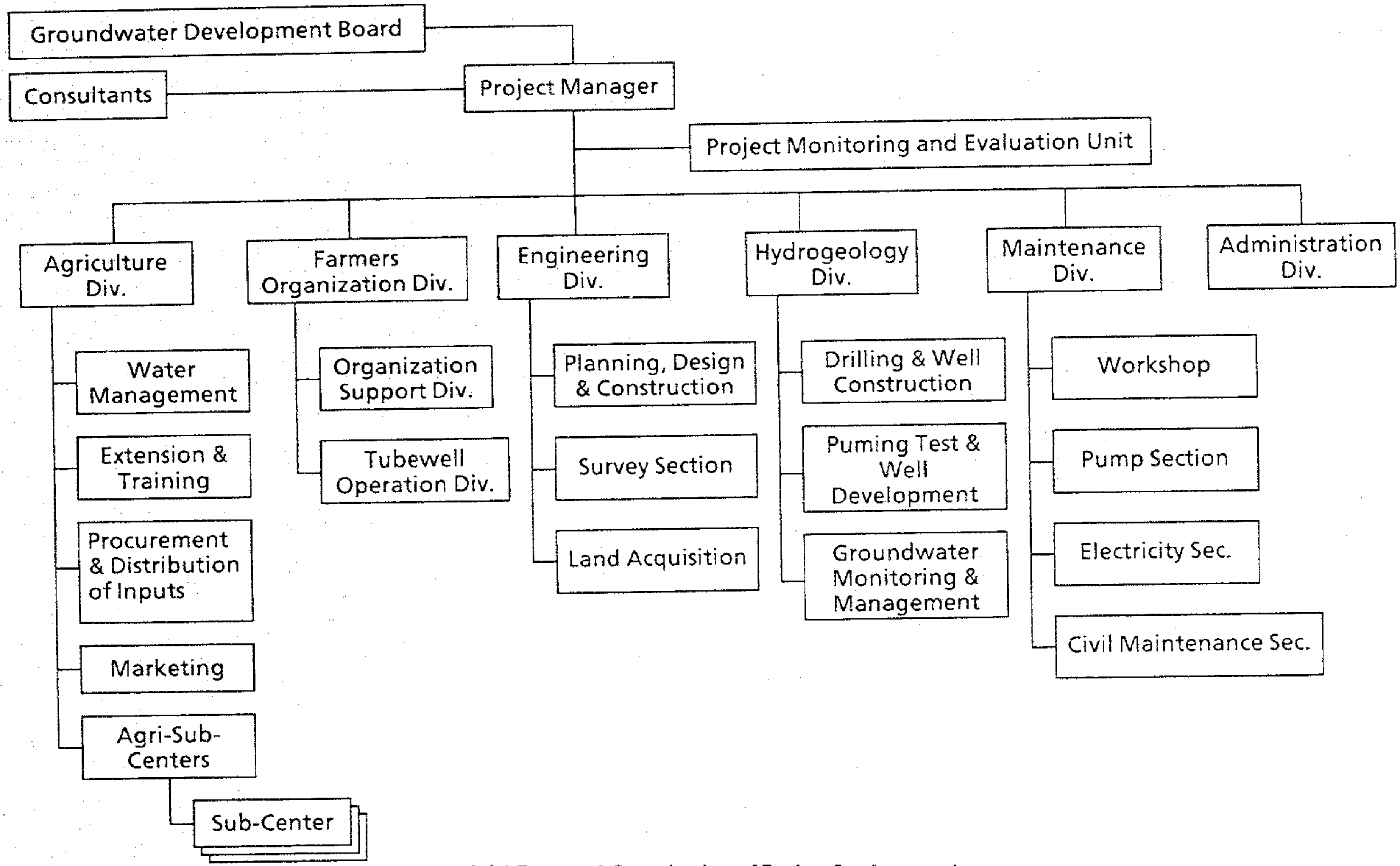


Figure 6.6.1 Proposed Organization of Project Implementation

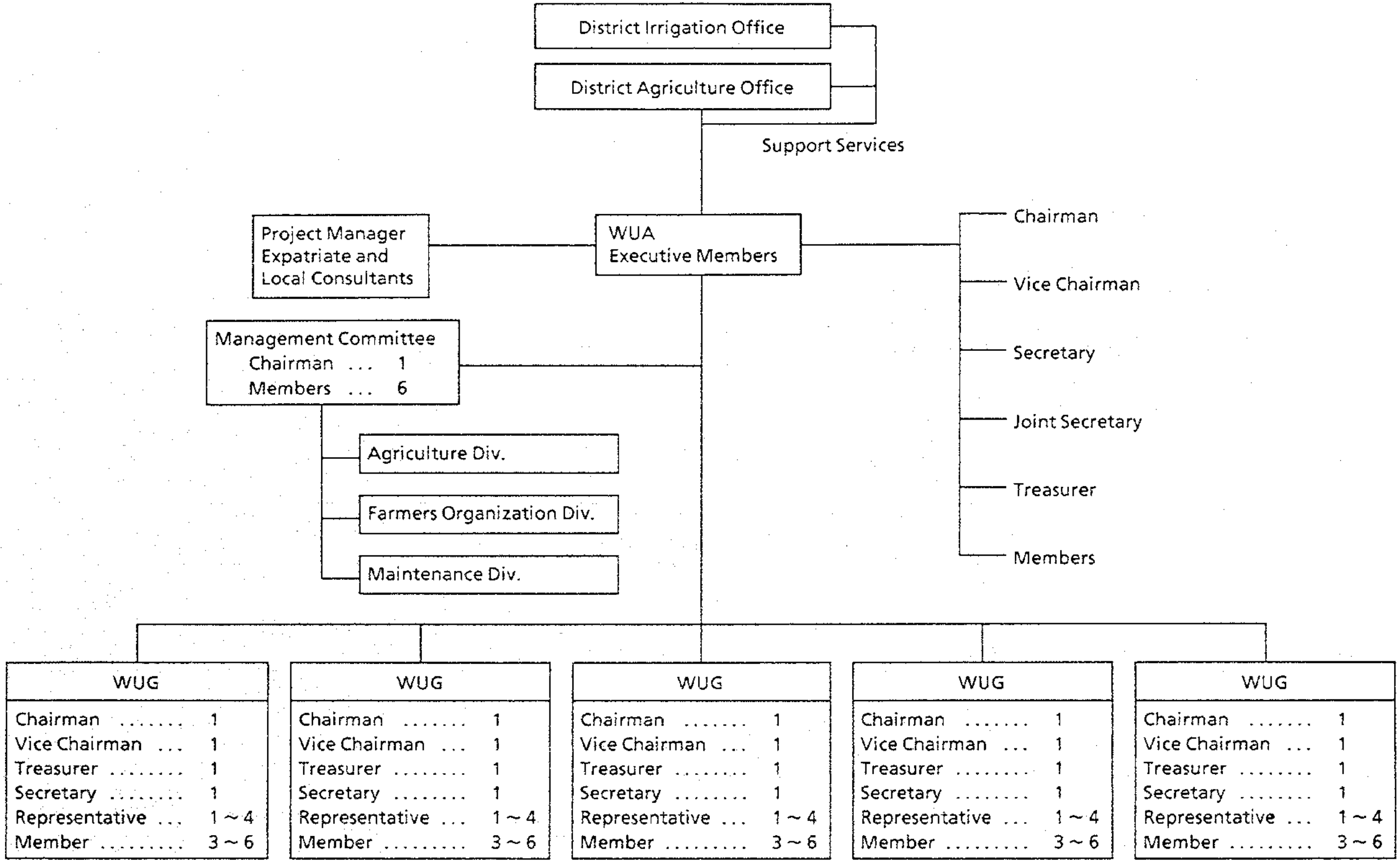


Figure 6.6.2 Proposed Water Users Organization

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

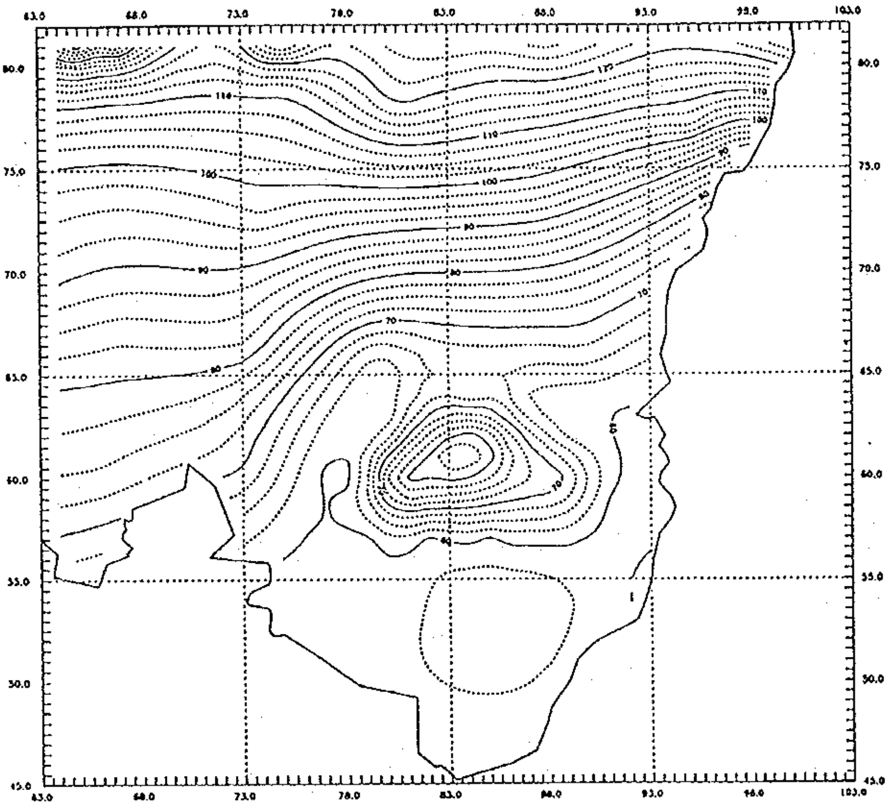
Land subsidence refers to compaction of clay layers because of a drawdown in the groundwater head. The result is land deformation and a deterioration of the social infrastructures, such as canals, roads, bridges, and building, which are most seriously damaged by groundwater development. Land subsidence 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.

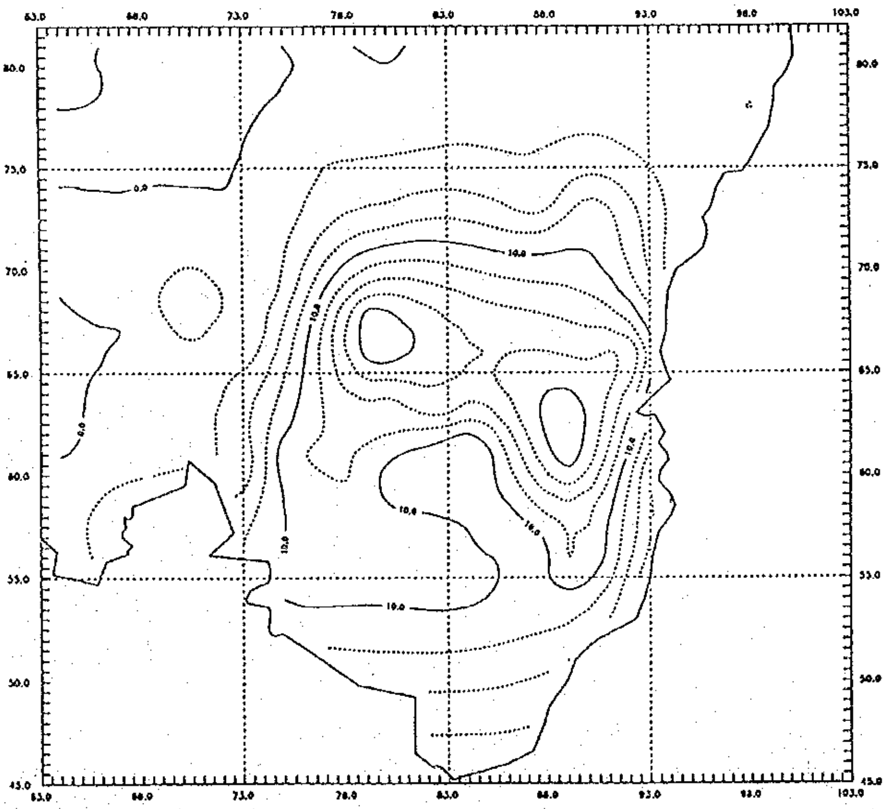
Figure 6.7.1 Groundwater Head Countour Under Pumping

(a) Groundwater Head on Unconfined Aquifer (UAQ)

Groundwater Head (UAQ) – full development –



(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)
Depth of well:
40 to 50 meters
q = 10 to 15 l/s
P = 5HP Diesel engine

DTW 700wells (73 ha/well)
Depth of well:
150 meters
q = 80 l/s (average value)
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 L/C	Cost F/C	Cost Total	Remarks
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	Replacement Cost	O & M Cost	Total (1)	(2)	(2)-(1)	D. Rate= 0.10 Project Cost	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 BIRR (Mahottari)

(Unit: Rs. Million)

Year	Project Cost				Project Benefit	Net Benefit	Present Worth Value			
	Initial Invest. Cost	Replacement Cost	O & M Cost	Total (1)	(2)	(2)-(1)	D. Rate= 0.10 Project Cost	0.10 Project Benefit	0.13 Net Benefit	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

BIRR= 13.5

B/C Ratio at 10% 1.29

Table 6.9.3 (3) Calculation of EIRR (Banke)

(Unit: Rs. Million)

Year	Project Cost				Project Benefit	Net Benefit	Present Worth Value			
	Initial Invest. Cost	Replacement Cost	O & M Cost	Total (1)	(2)	(2)-(1)	D. Rate=	0.10	0.14	0.15
							Project Cost	Project Benefit	Net Benefit	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