## 6.10. Guidelines for Deep Tubewell Irrigation

### 6.10.1. General

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

### 6.10.2 LFCA and LFWY

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

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

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

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

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

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

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

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

<u>Electric Pump</u>

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

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

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

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

<u>Diesel Pump</u>

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

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

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

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

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

1) Jhapa

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

2) Mahottari

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

3) Banke

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

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

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

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

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

Note:GVP includes income from by-products

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

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

Note:GVP includes income from by-products

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

| | M.Paddy Rainfed | M.Packly Irrigated | Maize | Mustard | Wheat | Pulses (Lentil) | Potato | Others (Cauliflower) | Total |
|---|---|---|---|---|---|---|---|---|---|
| Without Project | | | | | | | | | |
| Yield(ton/ha) | 1.95 | - | 1.61 | 0.55 | 1.40 | 0.68 | - | - | |
| Price(Rs/ton) | 10.584 | - | 10.302 | 20.330 | 13.049 | 21.600 | - | - | |
| GPV(RS/ha) | 21.552 | - | 17.030 | 11.309 | 18.598 | 14.826 | - | - | |
| Production Cost(Rs/ha) | 9.618 | - | 8.626 | 6.593 | 10,575 | 3.763 | - | - | |
| NPV(Rs/ha) | 11.934 | - | 8.404 | 4.716 | 8.023 | 11.063 | - | - | |
| Cropping Area(ha) | 80 | - | 10 | 10 | 30 | 10 | - | - | 140 |
| Total NPV(RS1000) | 955 | - | 84 | 47 | 241 | 111 | - | - | 1.437 |
| With Project | | | | | | | | | |
| Yield(ton/ha) | - | 3.50 | 2.60 | 0.8 | 2.10 | 1.00 | 14.00 | 11.00 | |
| Price(Rs/ton) | - | 10.584 | 10.302 | 20.330 | 13.049 | 21.600 | 5.420 | 7.000 | |
| GPV(RS/ha) | - | 38.608 | 27.498 | 16.417 | 27.897 | 21.807 | 75.880 | 77.000 | |
| Production Cost(Rs/ha) | - | 13.428 | 13.058 | 10.680 | 13.491 | 6.058 | 22.546 | 19.934 | |
| NPV(Rs/ha) | - | 25.180 | 14.440 | 5.737 | 14.406 | 15.749 | 53.334 | 57.066 | |
| Cropping Area(ha) | - | 87 | 15 | 13 | 50 | 17 | 15 | 3 | 200 |
| Total NPV(RS1000) | - | 2.191 | 217 | 75 | 720 | 268 | 800 | 171 | 4.441 |
| Incremental NPV(Rs1000) | -955 | 2.191 | 133 | 27 | 480 | 157 | 800 | 171 | 3.004 |

Note:GVP includes income from by-products

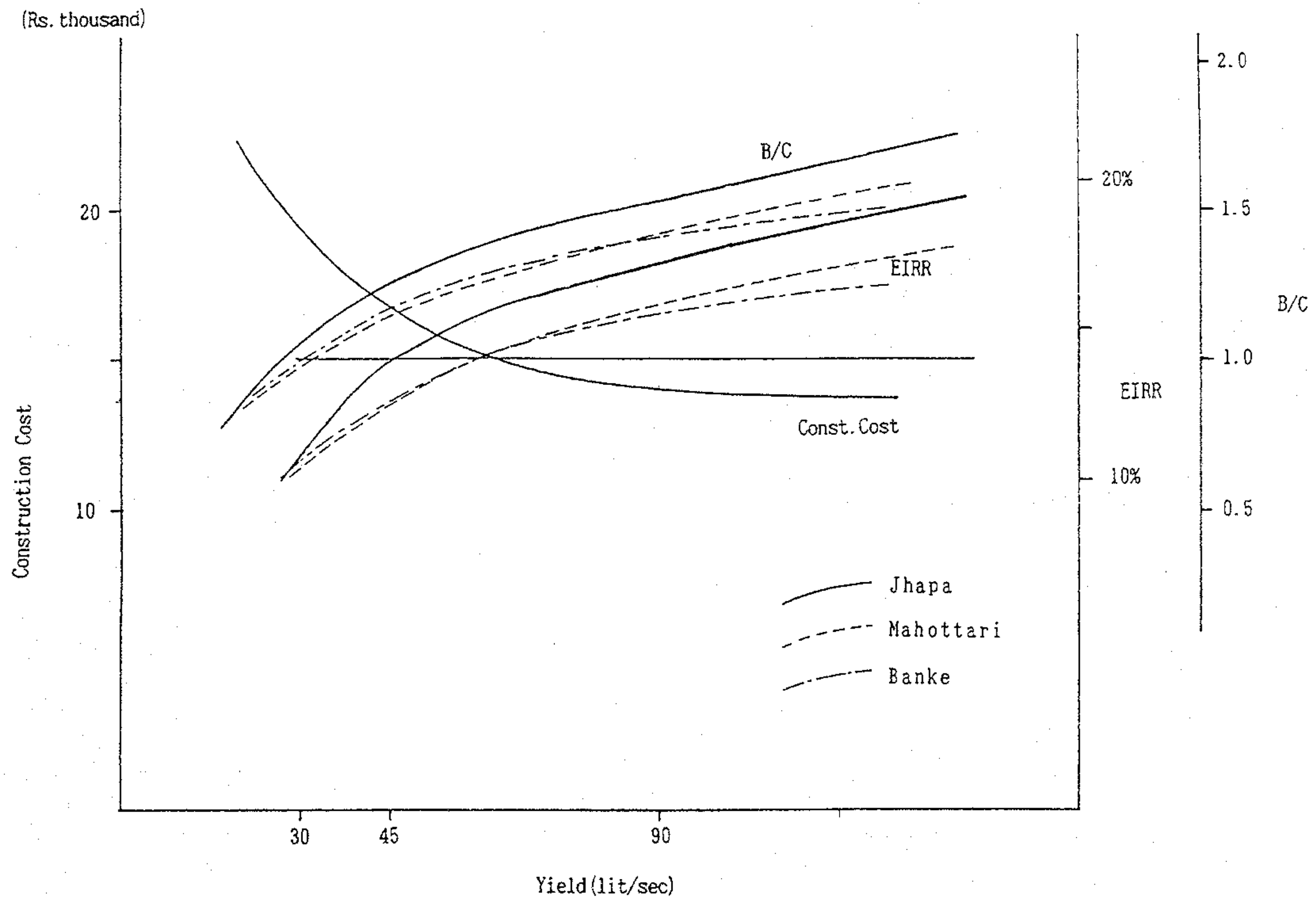


Figure 6.10.1 LFCA and LFWY (Electric Pump)

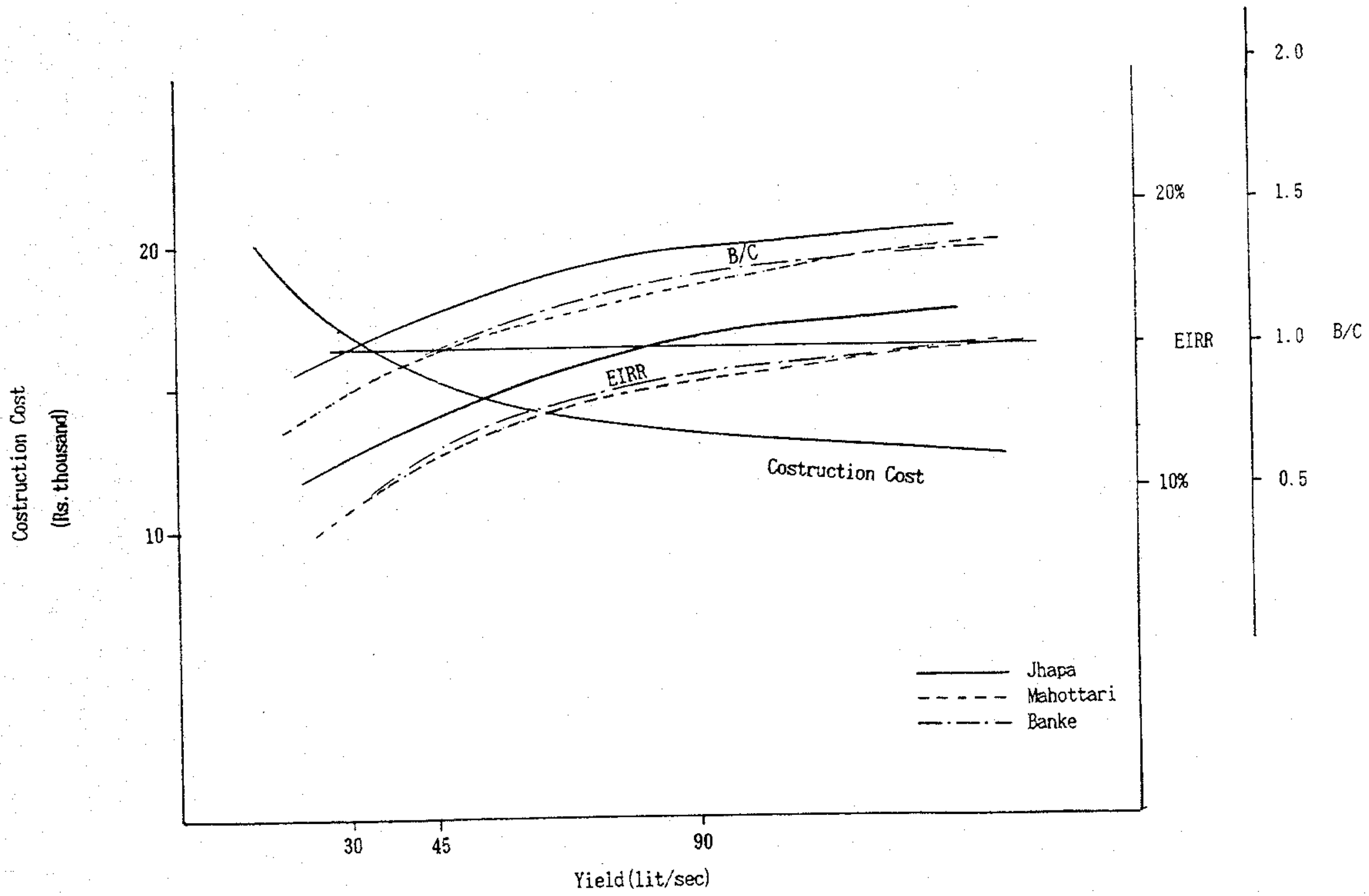


Figure 6.10.2 LCFA and LFWY(Diesel Pump)

6.10.3. Aquifers and Production Wells

(1) Aquifer Identification

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

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

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

(2) Production Well Design

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

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

(3) Construction of Production Wells

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

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

c) Casing and screen

- Casing

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

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

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

- Screen

The required pump discharge for DTW irrigation is around 100 l/s. Therefore a continuous wire-wrapped screen with the largest opening is to be used. As mentioned in the previous section, the required opening is at least 25%, and only the continuous wire-wrapped screen can meet this requirement. The strength of the screen for DTWs in the Terai must be seriously examined because of the examples of crushing accidents to the wire-wrapped screens. The three types of loads or force imposed on screens include column load (vertical compression), tensile load (extending load), and collapse pressure (horizontal force). Vertical compression and tensile force tend to occur when installing the casing and screen; horizontal stress on the screen occurs during gravel packing or development. The collapse of screens has also been reported due to earthquakes.
Resistance to horizontal pressure required for screens with a depth of 150 m in the Terai is 30 kg/cm2 when the safety factor is estimated at 100%. However, when the ordinary continuous wire-wrapped screen does not satisfy this figure. The use of reinforced screens is strongly recommended.

# CHAPTER SEVEN

# CONCLUSION AND RECOMMENDATION

# CHAPTER-SEVEN: CONCLUSION AND RECOMENDATION

## 7.1. Conclusion

### 7.1.1. General

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

### 7.1.2. Evaluation of Groundwater Resources

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

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

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

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

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

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

### 7.1.3. Master Plan for Deep Tubewell Irrigation

#### (1) Agricultural Development Plan

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

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

(2) Irrigation Plan

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

(3) Water Source Plan

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

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

(4) Facility Plan

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

(5) Project Plan

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

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

(6) Project implementation plan

The project implementation schedule is as follows.

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

(7) Organization, Operation and Maintenance System

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

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

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

(8) Environmental Consideration

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

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

(9) Project Cost

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

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

(10) Project Evaluation

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

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

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

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

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

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

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

(11) Guidelines for Deep Tubewell Irrigation

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

a) LFCA and LFWY

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

b) Aquifers

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

c) Design of production wells

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

d) Construction of production wells

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

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

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

## 7.2. Recommendations

### 7.2.1. General

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

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

### 7.2.2. Monitoring Work

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

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

### 7.2.3. Project Implementation in the Three Districts

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

(1) Jhapa District

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

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

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

(2) Mahottari District

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

(3) Banke District

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

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