mean monthly value of the data is used as evapotranspiration.

The current groundwater draft in the area is small, mostly shallow tubewells for domestic use and for cattle. The groundwater survey concluded that the total groundwater use through shallow wells is around 3,860 m3/day throughout the entire area. The current draft amount is divided into each sub-basin by the area ratio. Two of water supply wells are working only at Chandragadhi, pumping up about 2,260 m3/day in total, and the draft from each well is divided into the No.16 and No. 21 sub-basins. Additional draft is noted in the following section.

Concerning the verification data, the groundwater hydrograph is the most basic source of data, but unfortunately there has been no reliable observation data for a long period of time. Groundwater hydrographs for approximately one year, which have been manually observed in the monitoring wells under the Project, and four automatic records of observatory wells drilled by the Team, include all of the available data.
As for the river runoff, only the Kankai has daily records and the Study Team has been able to obtain daily discharge data for four years, from 1987 to 1990. During the study period, the Study Team attempted to take runoff data at Saranamati, Biring, Deoniya, and Bakbitta by setting flood gauges; however, only two gauges at Deoniya and Bakbitta have been recovered. The number of runoff records is three, and two of these three are for one year periods only.

This data is arranged into data files:

RAIN.DAT ..... daily rainfall data
DRF.DAT .... draft data
DV.DAT .... observed groundwater level and runoff data

Besides this data, evaporation data is included in GENERAL.DAT (explained later), and additional draft data is in another file. Further details on the program and data files are given in Appendix 1.

3.3.4. Model Parameters

(1) Outline

The simulation program requires several kinds of model parameters to begin calculations, and the parameters are classified into two categories:

General Parameters .... overall parameters
Basin Parameters .... peculiar to each sub-basin

These two set of parameters are arranged into a favorable form for computing and are collected in GENERAL.DAT and BASIN.DAT files, respectively.

The GENERAL.DAT file contains the overall parameters or data such as the number of sub-basins, total running year, beginning year and month, data basin parameters (presence of verification data), monthly evaporation potential, and so on. The parameters contained in the file are common data for all sub-basins or for formulating the total model, therefore once the parameters are set up based on the model study, they are no longer needed to modify the trial run, until the total model itself is revised.

The BASIN.DAT includes all sub-basin data from No.1 to No.37. The number of parameters for groundwater sub-basins is different from the parameters for surface sub-basins as the latter have no connected groundwater system.

The common parameters for the surface and groundwater sub-basins include,

a) area and cumulated area from upstream (km2)
b) downstream sub-basin No.
c) number of surface tanks
d) presence of groundwater system
e) presence of draft
f) parameters on draft, rain, and additional draft
g) presence of verification data (for all aquifers and river runoff)
h) parameter on evaporation (for all surface tanks)
i) initial heads of surface tanks (for all surface tanks) (mm)
j) runoff coefficients (for all outlets of surface tanks)
k) orifice heights (for all outlets of surface tanks) (mm)
l) destinations of outlet (for all outlets of surface tanks)

Parameters of the groundwater system include,

m) X and Y lengths, ground elevation of sub-basin (m)
n) thickness of aquifers (for all aquifers) (m)
o) base elevation of aquifers (-ditto-) (m)
p) thickness of aquicludes (for all aquicludes) (m)
q) groundwater connection (for four directions)
r) specific yield (for all aquifers)
s) runoff coefficients (for all aquifers)
t) leakance (for all aquicludes)
u) orifice heights (for unconfined aquifer, 4 directions) (m)

v) initial groundwater heads (for all aquifers) (m)
w) parameter on runoff coefficient

Among these parameters, a), b), d), e), f), g), h), l) in the surface sub-basin parameters and m), n), o), p), q), u) in the groundwater sub-basins are fixed by the model, and the parameters c) and i) in the surface and v) in the groundwater basin are semi-automatically obtained as a result of the trial run. This means that only j) runoff coefficients, k) orifice heights in surface basin, r) specific yields, s) runoff coefficients, and t) leakances in subsurface basin are variable parameters. The trial run modifies these parameters one by one until the calculated runoff or groundwater movement fits the verification data. Parameters (or structures) of sub-basins which have no verification data are applied from the neighboring or similar sub-basin data.

(2) Fixed Model Parameters on Surface Sub-basins

There are four surface sub-basins (No.1 to No. 4), but only sub-basin No.1 has verification data from the head of the Kankai canal, from 1987 to 1990. Trial runs for surface sub-basin are therefore operated only for the sub-basin. As a result, the No.1 sub-basin model is identified as a three tank model, as shown in Figure 3.3.8; the area of the No.1 sub-basin is large compared with the other three surface sub-basins (approximately 7 to 17 times), so that the model parameters of the No.1 sub-basin cannot be applied to the other sub-basins. Along with the official runoff records, the Study Team obtained runoff records for one year at No. 21 and No. 27 sub-basins by an automatic recorder, and these sub-basins are not so different from the surface basins in their area size. Therefore, the trial runs for the runoff analysis are first operated in the groundwater sub-basins, and the results are applied as model parameters for these. All of the fixed models are illustrated in Figure 3.3.8, together with the model of the No.1 sub-basin.

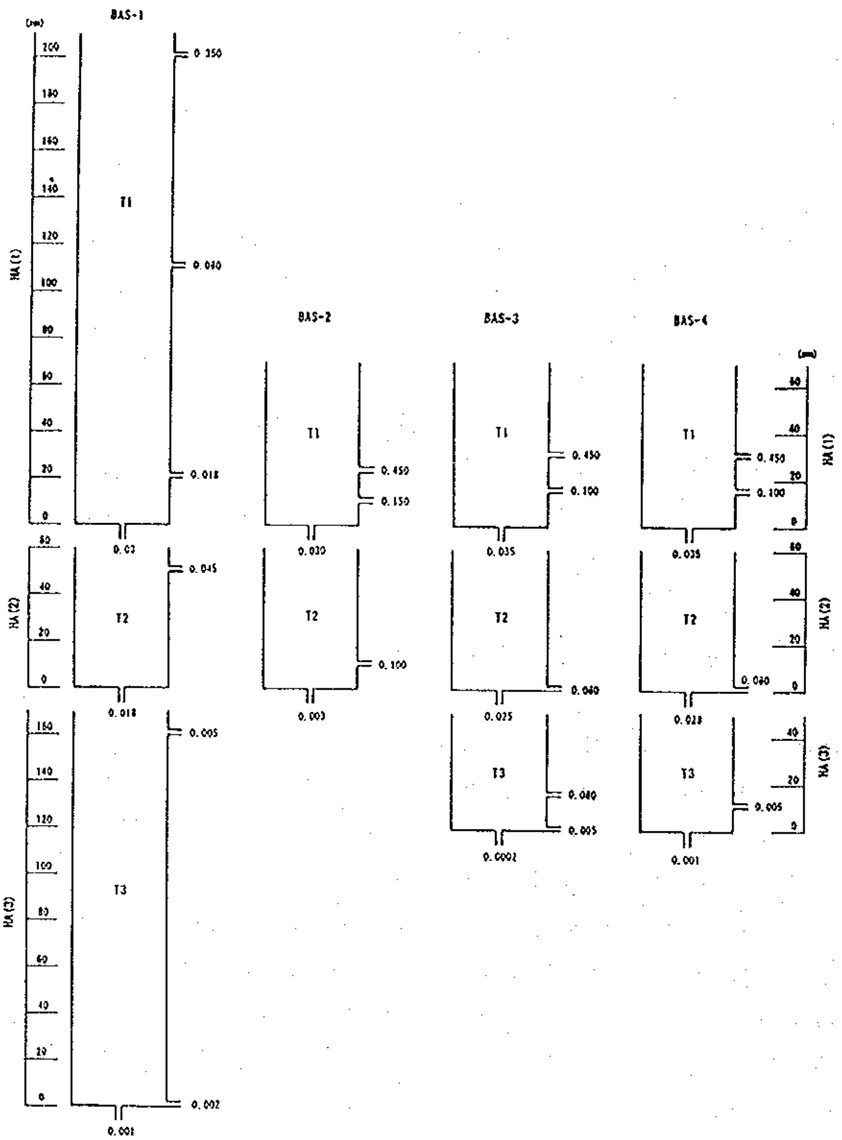


Figure 3.3.8 Surface Sub-basin Models

(3) Model Parameters on Groundwater Sub-basins

Prior to conducting the groundwater analysis, surface runoff analyses are conducted on No. 21 and No. 27 sub-basins, as mentioned above. The surface tank parameters obtained from the trial runs are applied to the other groundwater sub-basins provisionally. The groundwater sub-basins are then treated in the trial runs for both surface and subsurface systems simultaneously. In the course of the trial run, the parameters of the surface tanks are also modified to meet the properties of each sub-basin.

For the groundwater systems, runoff coefficients (permeability coefficients), recharge from the surface system, subordinately specific yields (storage coefficients), and leakances are modified one direction by one direction, one aquifer by one aquifer, and so forth, until the model meets the verification data within a tolerable error range. The final result, or the identified storage model, is shown in the Appendix. Some of the results are shown in Table 3.3.3, and the typical models are illustrated in Figure 3.3.9.

(4) Characteristics of the Area

The trial runs for groundwater sub-basins reveal characteristics of the groundwater systems in the Study Area.

First, the shape of outlets related to unconfined aquifer is not linear, but trumpet-shaped, upward from a certain level (refer to Figure 3.3.9). This means that the runoff coefficient becomes large and large quadratically according to an increase in the water level. This feature comes from the characteristics of the groundwater hydrograph that show a very slow level decrease in the long dry season; an abrupt level increase at the beginning of the rainy season; and a rather smooth level decrease after the rainy season.

Second, leakance of the aquicludes are very large in general because the water level of the confined aquifers reflects the movement of the unconfined aquifer's water table, accurately but at a different level.

Third, the water level, especially for unconfined aquifers, is too sensitive to rainfall at the beginning of rainy season; however this is not true for all groundwater sub-basins. In a special case (sub-basin No. 24), the groundwater level turns upward from the end of April when 40 mm of rain are observed, however this is practically the first rain. In many other cases, the water level rises abruptly from later May, and the total rainfall up until the time is 133 mm, isolated 12 times. In these cases the constructed model cannot fit the verification data, which causes slight delays.

Table 3.3.3. MODEL PARAMETER OF GROUNDWATER SYSTEM

```
******** SUB-BASIN NO. 8   (CASE  1)  ********

                     AREA =  48.365 SQ.KM
            RAINFALL RATE =    1.00
      CONNECT TO D/S BASIN = 13
           NUMBER OF TANKS =  2
              RATE OF DRAFR =      .00
         ADDITIONAL DRAFT =      .00 CUM/DAY
TANK DIMENSIONS
TANK NO. 1  COEFFICIENTS       .0400      .0100      .3500      .0000
            HEIGHTS            .000     15.000     60.000       .000
            NOUT              0          13         13         13
            INITIAL W.L.       .000
            RATE OF ET         .700
TANK NO. 2  COEFFICIENTS       .0001      .0050      .0220      .8000
            HEIGHTS            .000       .000    205.000    215.000
            NOUT              0          13         0          13
            INITIAL W.L.    150.000
            RATE OF ET         .550
GW TANK INTERCONNECTION   0         13          9          33
        ******** AQUIFER NO. 1 ********
            COEFFICIENTS      5.000     10.000      5.000      5.000
            G-HEIGHT           .000     80.000     90.000     85.000
            AQUIFER THICK     30.00
            AQUIFR HEIGHT     85.00
            AQUICL. THICK      1.00
            ACL. LEAKANCE   3.00E-01
            SPEC. YIELD       .03000
            INITIAL W.L.    113.300
            GROUND LEVEL     115.00
            MAX. STORAGE   43528500.0
        ******** AQUIFER NO. 2 ********
            COEFFICIENTS       .500       .100       .100       .100
            AQUIFER THICK      1.00
            AQUIFR HEIGHT     83.00
            AQUICL. THICK      1.90
            ACL. LEAKANCE   1.58E-04
            SPEC. YIELD       .00100
            INITIAL W.L.    112.700
        ******** AQUIFER NO. 3 ********
            COEFFICIENTS       .500       .100       .100       .100
            AQUIFER THICK     29.00
            AQUIFR HEIGHT     52.10
            AQUICL. THICK     38.00
            ACL. LEAKANCE   2.63E-06
            SPEC. YIELD       .00010
            INITIAL W.L.    112.500
        ******** AQUIFER NO. 4 ********
            COEFFICIENTS      1.000       .100       .100       .100
            AQUIFER THICK     15.00
            AQUIFR HEIGHT      -.90
            SPEC. YIELD       .00080
            INITIAL W.L.    112.000
```

```
******** SUB-BASIN NO. 9   (CASE  1)  ********

                     AREA =  56.512 SQ.KM
            RAINFALL RATE =    1.00
      CONNECT TO D/S BASIN = 14
           NUMBER OF TANKS =  2
              RATE OF DRAFR =      .00
         ADDITIONAL DRAFT =      .00 CUM/DAY
TANK DIMENSIONS
TANK NO. 1  COEFFICIENTS       .0300      .0100      .3000      .0000
            HEIGHTS            .000     15.000     60.000       .000
            NOUT              0          14         14         14
            INITIAL W.L.       .000
            RATE OF ET         .700
TANK NO. 2  COEFFICIENTS       .0500      .0050      .0000      .6000
            HEIGHTS            .000       .000    100.000      6.000
            NOUT              0          14         0          14
            INITIAL W.L.       .000
            RATE OF ET         .550
GW TANK INTERCONNECTION   5         14         10           8
        ******** AQUIFER NO. 1 ********
            COEFFICIENTS      5.000     25.000      1.500      5.000
            G-HEIGHT        100.000     70.000     95.000     90.000
            AQUIFER THICK     22.00
            AQUIFR HEIGHT     93.00
            AQUICL. THICK      3.00
            ACL. LEAKANCE   1.00E-03
            SPEC. YIELD       .03000
            INITIAL W.L.    113.500
            GROUND LEVEL     115.00
            MAX. STORAGE   37297920.0
        ******** AQUIFER NO. 2 ********
            COEFFICIENTS       .100      2.000       .500       .100
            AQUIFER THICK     30.00
            AQUIFR HEIGHT     60.00
            AQUICL. THICK     15.00
            ACL. LEAKANCE   5.33E-06
            SPEC. YIELD       .00010
            INITIAL W.L.    113.700
        ******** AQUIFER NO. 3 ********
            COEFFICIENTS       .200      1.500      1.000       .100
            AQUIFER THICK     25.00
            AQUIFR HEIGHT     20.00
            AQUICL. THICK     80.00
            ACL. LEAKANCE   3.13E-06
            SPEC. YIELD       .00050
            INITIAL W.L.    113.800
        ******** AQUIFER NO. 4 ********
            COEFFICIENTS       .100       .100       .500       .300
            AQUIFER THICK     90.00
            AQUIFR HEIGHT   -150.00
            SPEC. YIELD       .00100
```

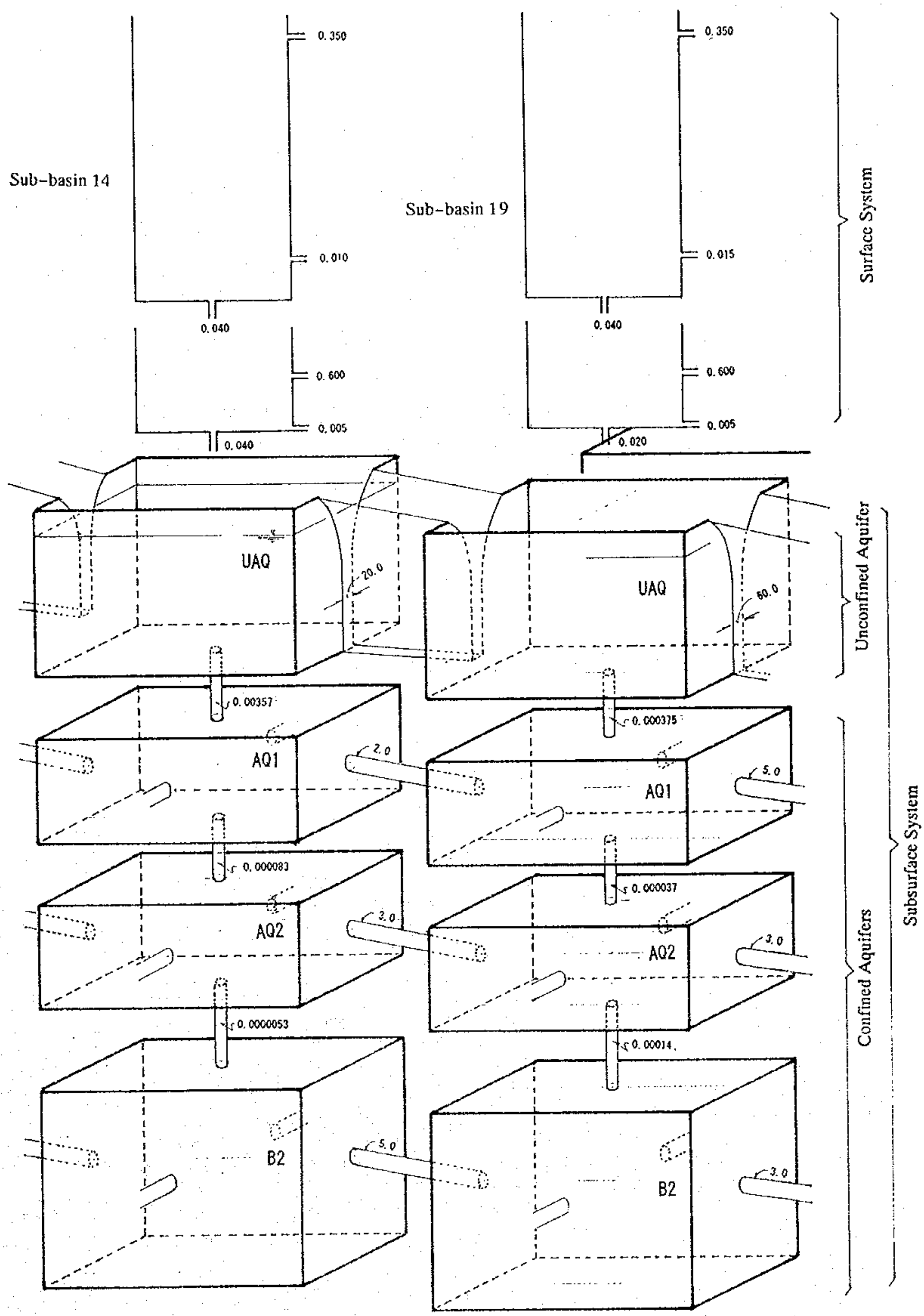
```
******** SUB-BASIN NO.17   (CASE  1)  ********

                     AREA =  51.765 SQ.KM
            RAINFALL RATE =    1.00
      CONNECT TO D/S BASIN = 30
           NUMBER OF TANKS =  2
              RATE OF DRAFR =      .00
         ADDITIONAL DRAFT =      .00 CUM/DAY
TANK DIMENSIONS
TANK NO. 1  COEFFICIENTS       .0100      .0150      .4000      .0000
            HEIGHTS            .000     15.000     60.000       .000
            NOUT              0          30         30         30
            INITIAL W.L.       .000
            RATE OF ET         .700
TANK NO. 2  COEFFICIENTS       .2500      .0020      .0000      .6000
            HEIGHTS            .000       .000    220.000     20.000
            NOUT              0          30         0          30
            INITIAL W.L.       .000
            RATE OF ET         .550
GW TANK INTERCONNECTION  12          0         30          16
        ******** AQUIFER NO. 1 ********
            COEFFICIENTS     15.000       .000     28.000      5.000
            G-HEIGHT         93.000     62.000     78.000     76.000
            AQUIFER THICK     29.00
            AQUIFR HEIGHT     77.00
            AQUICL. THICK      8.00
            ACL. LEAKANCE   1.56E-01
            SPEC. YIELD       .02500
            INITIAL W.L.    105.500
            GROUND LEVEL     107.60
            MAX. STORAGE   39600220.0
        ******** AQUIFER NO. 2 ********
            COEFFICIENTS      1.500       .000      2.000      1.000
            AQUIFER THICK      9.00
            AQUIFR HEIGHT     60.00
            AQUICL. THICK     18.00
            ACL. LEAKANCE   5.56E-05
            SPEC. YIELD       .00020
            INITIAL W.L.    104.900
        ******** AQUIFER NO. 3 ********
            COEFFICIENTS      1.000       .000      2.000      1.000
            AQUIFER THICK     27.00
            AQUIFR HEIGHT     15.00
            AQUICL. THICK     79.00
            ACL. LEAKANCE   1.01E-05
            SPEC. YIELD       .00010
            INITIAL W.L.    104.200
        ******** AQUIFER NO. 4 ********
            COEFFICIENTS       .200       .000      2.000      1.000
            AQUIFER THICK    164.00
            AQUIFR HEIGHT   -228.00
            SPEC. YIELD       .00020
            INITIAL W.L.    102.000
```

```
******** SUB-BASIN NO.18   (CASE  1)  ********

                     AREA =  44.648 SQ.KM
            RAINFALL RATE =    1.00
      CONNECT TO D/S BASIN = 24
           NUMBER OF TANKS =  2
              RATE OF DRAFR =      .00
         ADDITIONAL DRAFT =      .00 CUM/DAY
TANK DIMENSIONS
TANK NO. 1  COEFFICIENTS       .0300      .1000      .3500      .0000
            HEIGHTS            .000     15.000     60.000       .000
            NOUT              0          24         24         24
            INITIAL W.L.    180.000
            RATE OF ET         .700
TANK NO. 2  COEFFICIENTS       .0001      .0020      .0200      .6000
            HEIGHTS            .000       .000    300.000    320.000
            NOUT              0          24         0          24
            INITIAL W.L.    170.000
            RATE OF ET         .550
GW TANK INTERCONNECTION  13         24         19          35
        ******** AQUIFER NO. 1 ********
            COEFFICIENTS     10.000     40.000      1.000      1.000
            G-HEIGHT         60.000     46.000     50.000     56.000
            AQUIFER THICK     32.00
            AQUIFR HEIGHT     53.00
            AQUICL. THICK      7.00
            ACL. LEAKANCE   7.14E-03
            SPEC. YIELD       .02000
            INITIAL W.L.     83.500
            GROUND LEVEL      85.00
            MAX. STORAGE   28574720.0
        ******** AQUIFER NO. 2 ********
            COEFFICIENTS      1.500      5.000      1.000      1.000
            AQUIFER THICK     53.00
            AQUIFR HEIGHT     -7.00
            AQUICL. THICK     21.00
            ACL. LEAKANCE   1.43E-06
            SPEC. YIELD       .00010
            INITIAL W.L.     83.700
        ******** AQUIFER NO. 3 ********
            COEFFICIENTS      1.500       .500       .100       .100
            AQUIFER THICK     37.00
            AQUIFR HEIGHT    -65.00
            AQUICL. THICK     85.00
            ACL. LEAKANCE   2.12E-06
            SPEC. YIELD       .00010
            INITIAL W.L.     85.900
        ******** AQUIFER NO. 4 ********
            COEFFICIENTS       .200       .200       .100       .100
            AQUIFER THICK    150.00
            AQUIFR HEIGHT   -300.00
            SPEC. YIELD       .00100
            INITIAL W.L.     85.100
```

Figure 3.3.9. Sub-basin Model



3.4. The Groundwater Balance

3.4.1. Current Hydrologic Balance

(1) Results of the Trial Run

The storage models once identified by the verification data for one year (1993) are again modified by a long-term run through a 14 year period, from 1980 to 1993, and finally fixed. Some of the results of the long-term simulated surface and groundwater hydrographs are shown in Figure 3.4.1, and the remaining results are attached in Appendix-2.

The verification data in the figure on the hydrographs is occasionally far apart from the simulation curves (not matching well), but this represents the gap in the elevation between the monitoring well and the representative elevation of the sub-basin. To make the comparison easier, the hydrography for the unconfined aquifer is adjusted: The elevation is adjusted up or down to the level of the representative elevation, parallel to the original curve.

(2) Surface Water Balance

Surface water balances for the Kankai, Deoniya, and Bhakbitta rivers are summarized in Table 3.4.1.

Table 3.4.1 Summary of Surface Water Balance

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

River	Area (km2)	Rainfall (MCM)	Surface Inflow	Evapotrans-piration	Surface Outflow	Groundwater		Draft
						Recharge	Outflow	
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

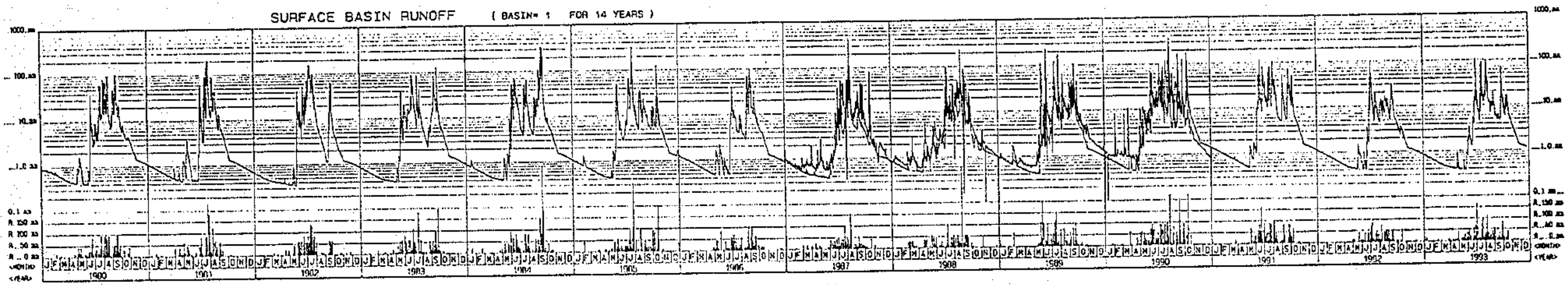
(The most rainy year : 1990)

River	Area (km2)	Rainfall (MCM)	Surface Inflow	Evapotrans-piration	Surface Outflow	Groundwater		Draft
						Recharge	Outflow	
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		Draft
						Recharge	Outflow	
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

Figure 3.4.1. (a) SURFACE WATER BALANCE



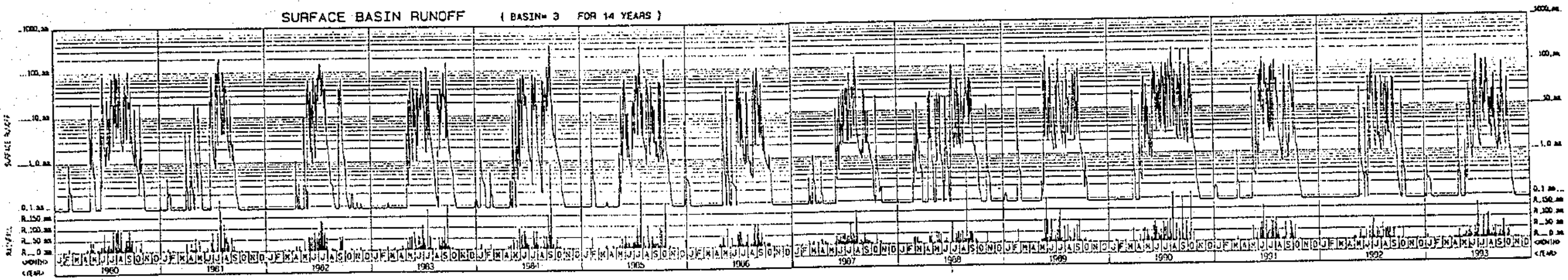
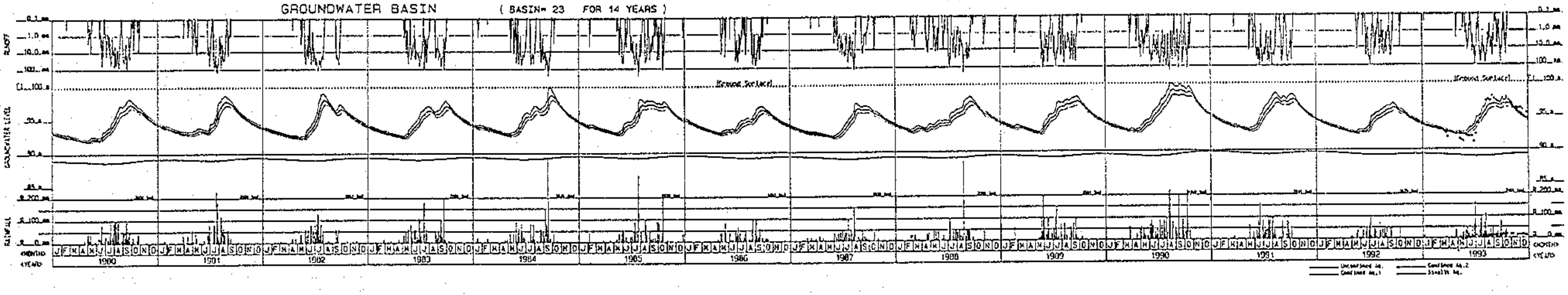
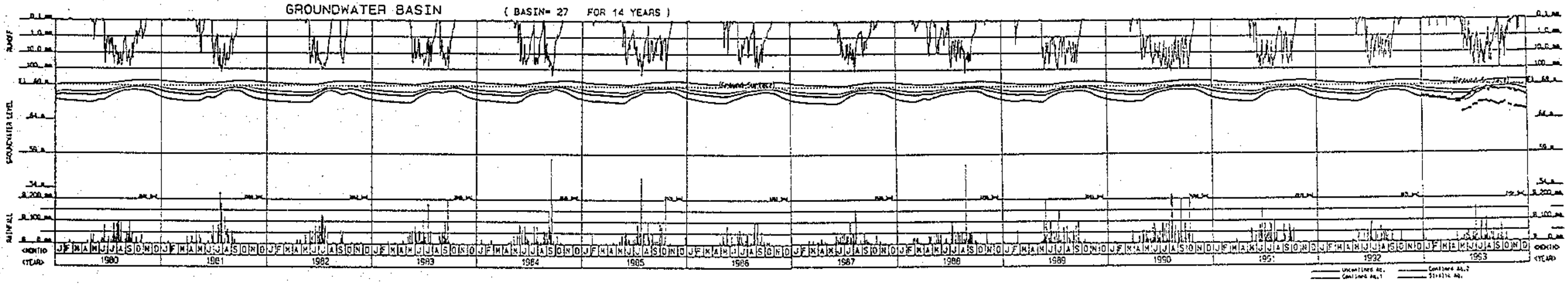


Figure 3.4.1. (b) GROUNDWATER BALANCE

GROUNDWATER BASIN (BASIN= 23 FOR 14 YEARS)



GROUNDWATER BASIN (BASIN= 27 FOR 14 YEARS)



For sub-basin No.1, which is the largest surface basin in the area, the total rainfall is 3,750 MCM/a (3,173 mm) as 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 out to the downstream sub-basin (No. 8). The runoff coefficient in this valley is calculated as 74.3%.

The yearly rainfall varies widely through the 14 years, from 6,182 MCM (5,232 mm) during the wettest year to 2,381 MCM (2,015 mm) during the driest year. This means that the difference between the driest year and the wettest year is approximately 2.6 times. The runoff coefficient is influenced by the rainfall and varies from 80.4% during the wet year to 68.5% during the dry year. Some of the rain water is retained in the system during the wet years, but is consumed during the dry years.

In the other small basins, the average yearly runoff coefficient is approximately 715, ranging from 78% during the wet year to 60% during the dry year. In the Deoniya and Bhakbitta rivers, 17.7% and 8.5% of the rainfall recharges the groundwater, and almost all of the volume flows out.

Table 3.4.2 shows an average monthly surface water balance on pure surface sub-basins for over 14 years. As the table indicates, the surface outflow drastically increases from May, at the beginning of the rainy season. It reaches a maximum in July, and rapidly decreases in volume in October. Although the small sub-basins No. 2 to No. 4 have a small amount of surface outflow during the dry season, as the table shows, this is only because of the average. In these sub-basins, there is no surface outflow through the dry season during usual years, and they have rather large amount of surface flow only during some wet years.

(3) Groundwater Balance

The groundwater balance on a monthly basis as well as the surface water balance are attached in the Appendix and summarized in Table 3.4.3.

Table 3.4.3 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

As shown in the table, the evapotranspiration rate ranges from 640 mm (460.1 MCM, 1992) to 939 mm (646.7 MCM, 1990), with a 771.5 mm average. Recharge volumes from the surface system to the subsurface system vary widely from 205.4 to 384.3 MCM/ year and range from 17.0% to 12.3%, with a 13.94% average as a coefficient. Since the surface runoff is very high during the wet years, the recharge coefficient is in 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 large recharge amount in the area smoothly flows out, the outflow coefficient is approximately 97.5% in the present condition.

Table 3.4.2. AVERAGED MONTHLY SURFACE WATER BALANCE

(1980-1993)

Sub-basin No.1														
Month	1	2	3	4	5	6	7	8	9	10	11	12	Total	Amount
(unit)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(MCM)	(MCM)
Rainfall	10.8	23.3	27.9	64.1	266.4	505.0	900.2	589.5	637.2	137.1	9.1	5.7	3,176	3,752.8
Surface inflow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Evapotranspiration	11.1	15.9	26.0	45.2	105.4	119.3	113.7	119.7	113.8	85.6	43.6	17.1	816	963.3
Surface outflow	27.4	20.5	18.9	16.6	62.1	256.0	692.8	498.1	512.7	172.9	49.9	34.4	2,362	2,791.1
Groundwater recharge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0

Sub-basin No.2														
Month	1	2	3	4	5	6	7	8	9	10	11	12	Total	Amount
(unit)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(MCM)	(MCM)
Rainfall	9.0	19.4	23.2	53.4	221.9	420.9	750.1	491.2	531.1	114.3	7.6	4.8	2,647	13.8
Surface inflow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Evapotranspiration	7.5	10.8	19.2	33.8	90.6	109.4	112.6	111.1	108.2	58.6	8.6	2.4	673	3.5
Surface outflow	1.3	5.7	5.9	13.8	115.6	290.8	630.2	397.4	432.4	78.3	1.4	1.0	1,974	10.3
Groundwater recharge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0

Sub-basin No.3														
Month	1	2	3	4	5	6	7	8	9	10	11	12	Total	Amount
(unit)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(MCM)	(MCM)
Rainfall	9.9	21.3	25.6	58.9	244.2	463.0	825.2	540.4	584.1	125.9	8.4	5.4	2,912	467.0
Surface inflow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Evapotranspiration	7.8	11.6	20.3	36.9	95.0	111.4	112.9	112.4	109.1	59.1	8.2	2.4	687	110.2
Surface outflow	3.4	6.9	8.0	15.1	128.0	324.5	699.4	450.3	485.4	95.0	4.1	2.8	2,223	356.5
Groundwater recharge	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.1	1.85	0.30

Sub-basin No.4														
Month	1	2	3	4	5	6	7	8	9	10	11	12	Total	Amount
(unit)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(MCM)	(MCM)
Rainfall	9.9	21.3	25.6	58.9	244.2	463.0	825.2	540.4	584.1	125.9	8.4	5.4	2,912	193.7
Surface inflow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Evapotranspiration	7.8	11.6	20.3	36.9	95.0	111.4	112.9	112.4	109.1	59.1	8.2	2.4	687	45.7
Surface outflow	2.5	6.8	6.2	16.9	120.2	297.0	646.3	383.9	443.2	74.9	4.4	1.3	2,004	148.0
Groundwater recharge	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.2	0.2	0.1	0.0	1.18	0.10

Not including the yearly average, the hydrologic balance of each groundwater sub-basin (average 14 years) is shown in Table 3.4.4.

Table 3.4.4 Hydrologic Balance of Groundwater Basins

Groundwater Sub-basin	Area (km2)	Rainfall	Evapotrns-piration	Surface Water		Groundwater		
				Inflow	Outflow	Recharge	Outflow	Draft
Sub-basin 9	56.51	149.6	44.3	460.0	553.4	12.0	11.9	0.0
Sub-basin 10	41.32	109.4	30.4	0.0	69.1	9.8	9.8	0.0
Sub-basin 11	28.76	76.1	21.4	27.6	76.4	5.9	6.0	0.0
Sub-basin 12	48.81	129.2	39.2	313.7	401.8	2.0	1.9	0.1
Sub-basin 14	37.8	100.1	30.0	553.4	612.8	10.7	10.4	0.0
Sub-basin 15	37.41	99.0	27.8	69.1	134.6	5.7	5.3	0.1
Sub-basin 16	66.74	176.7	53.7	76.4	190.0	9.1	8.5	0.5
Sub-basin 17	51.77	137.0	39.6	401.8	462.6	36.7	36.3	0.0
Sub-basin 19	28.02	74.2	22.6	612.8	659.7	4.7	1.8	0.1
Sub-basin 20	38.75	102.6	29.6	134.6	193.2	14.4	14.1	0.3
Sub-basin 21	59.65	157.9	49.7	190.0	242.9	56.2	54.9	0.8
Sub-basin 22	16.94	44.8	11.6	0.0	30.4	2.9	2.9	0.0
Sub-basin 23	40.31	106.7	27.0	0.0	67.1	12.6	12.6	0.1
Sub-basin 25	39.3	104.0	31.7	659.8	722.2	9.9	9.9	0.0
Sub-basin 26	72.15	191.0	54.5	223.6	296.3	63.8	63.6	0.2
Sub-basin 27	54.65	144.7	41.7	67.1	161.3	8.8	8.6	0.1
total (MCM)	718.89	1,902.75	554.59	3,789.86	4,873.72	265.23	258.60	2.30
(mm)		2,646.79	771.46	5,271.82	6,779.51	368.94	359.72	3.20

In almost all of these sub-basins, the recharge volumes smoothly flow out and are retained only in a few sub-basins. In the current situation, a total nine sub-basins have drafts for domestic use and water supply; however, the volume is almost negligible (total about 2.3 MCM/year) compare with the irrigation requirements, which are discussed in the following sections.

3.4.2. Simulation of Pumping Conditions

(1) Introduction

After completion of the water balance simulation in the current situation, a forecasting water balance simulation under pumping conditions is conducted. The irrigation water demand is outlined in Chapter 6. Irrigation Plan and the monthly data is shown in Table 3.4.5. The water requirement shown in the table includes all requirements for main paddy, spring paddy, wheat, and spring maize. The amount of water required is further revised by the irrigation coefficient of 0.7 for main/spring paddy and 0.6 for wheat in the course of the calculations.

Table 3.4.5 Monthly 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

The sub-basin division does not conform to the boundary of the irrigable area, as shown in the Figure 3.4.2, therefore, the net irrigable area is divided into a total of seven sub-basins by the ratio shown in Table 3.4.6.

Table 3.4.6 Sharing of Net Irrigable Area

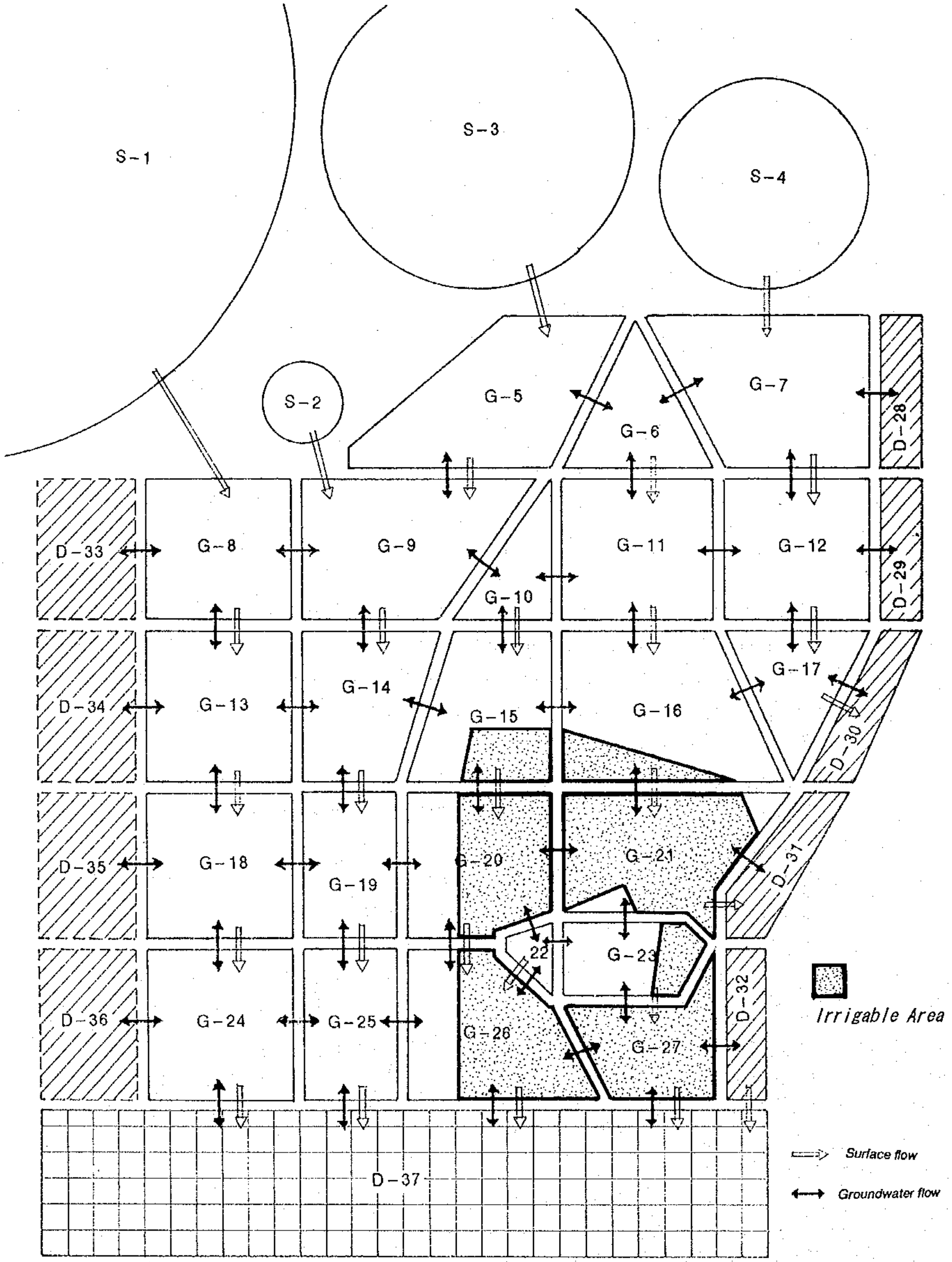
Sub-basin	Total Area	Ratio	Net Area
B15	37.410	0.25	9.353
B16	66.742	0.20	13.348
B20	38.750	0.50	19.375
B21	59.647	0.65	38.771
B23	40.312	0.25	10.078
B26	72.152	0.50	36.076
B27	54.652	0.80	43.722
Total	369.665		170.722

Effective rainfall is more than 5.0 mm and a ceiling of 80.0 mm of rainfall is set, and 80% of this rainfall is treated as the actual effective rainfall reduced from the water requirement. This means that rainfall of more than 80 mm runs out needlessly for irrigation. However, in the case of heavy rain, the rainfall is carried over to the next day though in only half the amount.

The target aquifers to be withdrawn are confined aquifer -1 (AQ1) and aquifer -2 (AQ2), as the depth of the planed production well is from 100 m to 150 m, which usually cannot reach the Churia aquifer (B2). Volumes to be withdrawn from each aquifer are fifty to fifty; however, in some sub-basins the volumes are divided based on the thickness of each aquifer when the thicknesses are recognizably different.

The control level of the drawdown is set at 30 m below the ground surface, since the planned production well has at least 40 m of pump housing. The drawdown is measured by the average water level of aquifer-1 and aquifer-2. Pumping is restricted when the drawdown reaches the control level and is resumed when the water level recovers to the control level.

Fig 3.4.2. THE IRRIGABLE AREA



(2) Result of the Simulation

Simulated hydrographs under pumping condition are attached in the Appendix, and the results of No. 21 and No. 23 sub-basins, which are the most critical sub-basins among seven objective basins, are shown in Figure 3.4.3. Hydrologic balances under pumping are summarized in Table 3.4.7.

Table 3.4.7 Summary of Water Balance Under Pumping

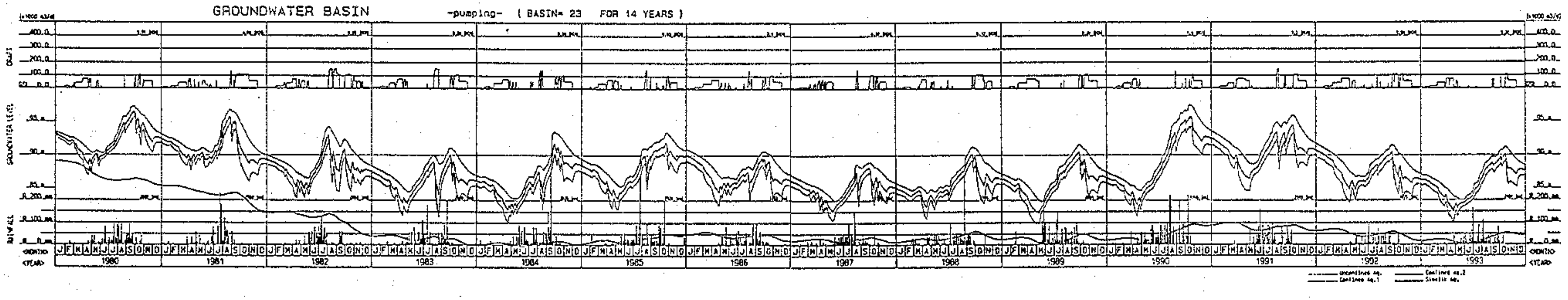
Groundwater Sub-basin	Area (km2)	Rainfall 0	Evapotrns-piration	Surface Water Inflow	Surface Water Outflow	Groundwater Recharge	Groundwater Outflow	Groundwater Draft
Sub-basin 9	56.51	149.6	44.3	460.0	553.4	12.0	11.9	0.0
Sub-basin 10	41.32	109.4	30.4	0.0	69.1	9.8	9.8	0.0
Sub-basin 11	28.76	76.1	21.4	27.6	76.4	5.9	6.0	0.0
Sub-basin 12	48.81	129.2	39.2	313.7	401.8	2.0	1.9	0.1
Sub-basin 14	37.8	100.1	30.0	553.4	612.8	10.7	10.4	0.0
Sub-basin 15	37.41	99.0	27.8	69.1	134.6	5.7	-1.6	7.3
Sub-basin 16	66.74	176.7	53.7	76.4	190.0	9.1	-1.1	10.6
Sub-basin 17	51.77	137.0	39.6	401.8	462.6	36.7	36.3	0.0
Sub-basin 19	28.02	74.2	22.6	612.8	659.7	4.7	1.5	0.1
Sub-basin 20	38.75	102.6	29.6	134.6	193.2	14.4	-2.0	16.6
Sub-basin 21	59.65	157.9	49.7	190.0	242.9	56.2	23.0	34.6
Sub-basin 22	16.94	44.8	11.6	0.0	30.4	2.9	3.0	0.0
Sub-basin 23	40.31	106.7	27.0	0.0	67.1	12.6	5.6	7.9
Sub-basin 25	39.3	104.0	31.7	659.8	722.2	9.9	9.9	0.0
Sub-basin 26	72.15	191.0	54.5	223.6	296.3	63.8	33.7	30.5
Sub-basin 27	54.65	144.7	41.7	67.1	161.3	8.8	-30.2	39.4
total (MCM)	718.89	1,902.75	554.59	3,789.86	4,873.72	265.23	118.26	147.06
(mm)		2,646.79	771.46	5,271.82	6,779.51	368.94	164.50	204.56

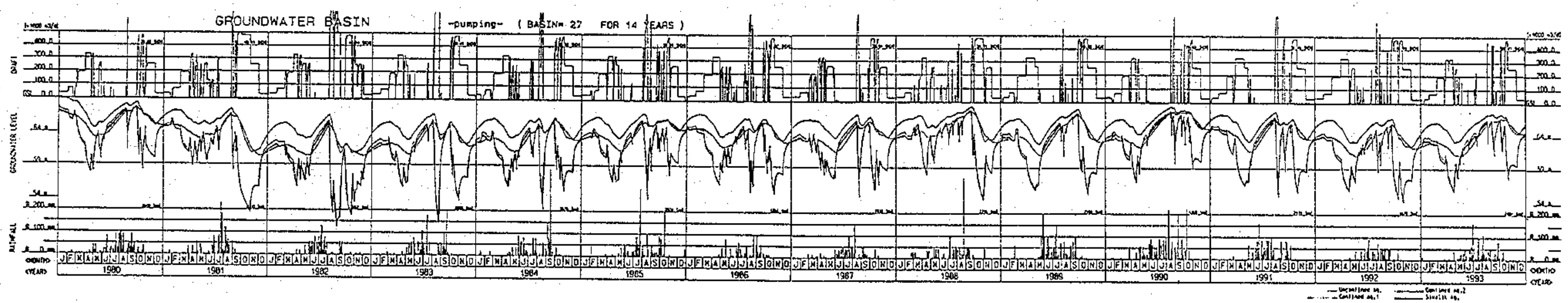
In this condition, the total draft amount is approximately 147 MCM/a on average, and the maximum drawdown in the most critical sub-basin (No. 23) is approximately 23 m below the ground surface. For the water balance, the recharge amount is same as the normal conditions, but the groundwater outflow decreases to compensate the increased draft. In some sub-basins, the outflow indicates a minus value and this means that the groundwater is not flowing out but rather flowing in from neighboring sub-basins. As an extreme case, the No. 27 sub-basin is believed to be drawing groundwater from the Ganges Plain.
At any rate, as the figure and the table suggests, there is practically no problems in withdrawing groundwater from the target aquifers when the pumping rate is same as the irrigation water demand.

(3) Groundwater Volume to be Withdraw

The above table shows that the total volume withdraw is about 147.1 MCM/annum, while the total water requirement derived from Irrigation Plan is approximately 130 MCM/

Figure 3.4.3. GROUNDWATER BALANCE UNDER PUMPING CONDITION





annum in a standard year.

Table 3.4.8 shows the general hydrologic balance of groundwater sub-basins for each year from 1980 to 1993. The table indicates the maximum volume to be withdrawn is more than 193 MCM/annum, and the minimum is nearly 100 MCM/annum.

The table shows that the minimum draft year is 1990, which is also the year with the most rainfall. The maximum draft year is 1982, and this year experienced 2,057 MCM of rainfall, which is more than the average annual rainfall. As a reference, the rainy days in 1990 were 111 days but only 81 days in 1982, which is low but not the lowest (71 days in 1992). This suggests that the annual draft amount is generally determined according to the annual rainfall amount, dependent on the interval of effective rainfall.

Table 3.4.8 Yearly Hydrologic Balance

(Fullscale Development)

Year	Total Area	Rainfall	Evapotrns-piration	Surface Water		Groundwater		
				Inflow	Outflow	Recharge	Outflow	Draft
1980	718.89	1,870.5	578.2	3,614.3	4,648.7	272.9	183.1	121.0
1981	718.89	1,833.2	522.9	3,767.6	4,869.5	211.4	81.1	177.6
1982	718.89	2,057.6	495.9	4,480.5	5,798.2	242.9	52.2	193.3
1983	718.89	1,800.8	539.4	3,540.6	4,532.8	265.6	92.6	164.5
1984	718.89	2,570.9	564.7	5,704.4	7,409.7	302.9	119.9	156.2
1985	718.89	2,104.9	592.7	4,165.7	5,354.5	300.5	140.8	132.8
1986	718.89	1,260.3	521.1	2,085.0	2,632.3	216.5	81.3	158.8
1987	718.89	1,387.5	533.5	2,344.0	2,987.9	210.1	69.5	138.1
1988	718.89	1,722.4	632.6	3,026.7	3,841.8	274.3	142.4	127.5
1989	718.89	1,862.4	549.7	3,678.9	4,717.6	273.9	127.2	146.5
1990	718.89	3,134.4	674.7	6,958.9	9,029.7	384.3	235.3	103.4
1991	718.89	2,098.3	530.2	4,420.8	5,702.8	288.9	148.3	152.9
1992	718.89	1,207.1	460.1	2,062.8	2,606.3	205.4	63.1	165.8
1993	718.89	1,728.2	568.6	3,207.8	4,100.3	263.6	118.8	120.4
Average	(MCM/a)	1,902.8	554.6	3,789.9	4,873.7	265.2	118.3	147.1
	(mm/a)	2,646.8	771.5	5,271.8	6,779.5	368.9	164.5	204.6

3.5. Evaluation of Groundwater Resources

3.5.1. Introduction

Stated simply, the groundwater potential is almost the same as the yearly recharge volume as the volume is recovered every year, even though most of it is extracted. However, the recharge system is not simple or homogeneous, and the total amount of rainfall varies year to year. Furthermore, groundwater movement changes according to the artificial draft. As a result, a careful simulation study under pumping conditions is required to evaluate the groundwater potential.

For the purpose of evaluating groundwater resources, water balance simulations in the following pumping conditions are carried out:

case-1) under pumping conditions with irrigation water demand
case-2) x1.25 times of irrigation water demand
case-3) x1.5 times of irrigation water demand
case-4) x1.75 times of irrigation water demand
case-5) x2.0 times of required amount

The other conditions for simulations such as effective rainfall, target aquifers, and control levels are the same as the ones explained in the previous paragraph.

3.5.2. Evaluation of Groundwater Resources

(1) Results of the Simulation

Results of the simulation are attached in the Appendix, and the simulated hydrographs of several critical sub-basins are shown in Figure 3.5.1.

(2) Evaluation of Groundwater Potential

The results of the simulation are conceptually summarized in Table 3.5.1.

Table 3.5.1 Summarized Groundwater Potential

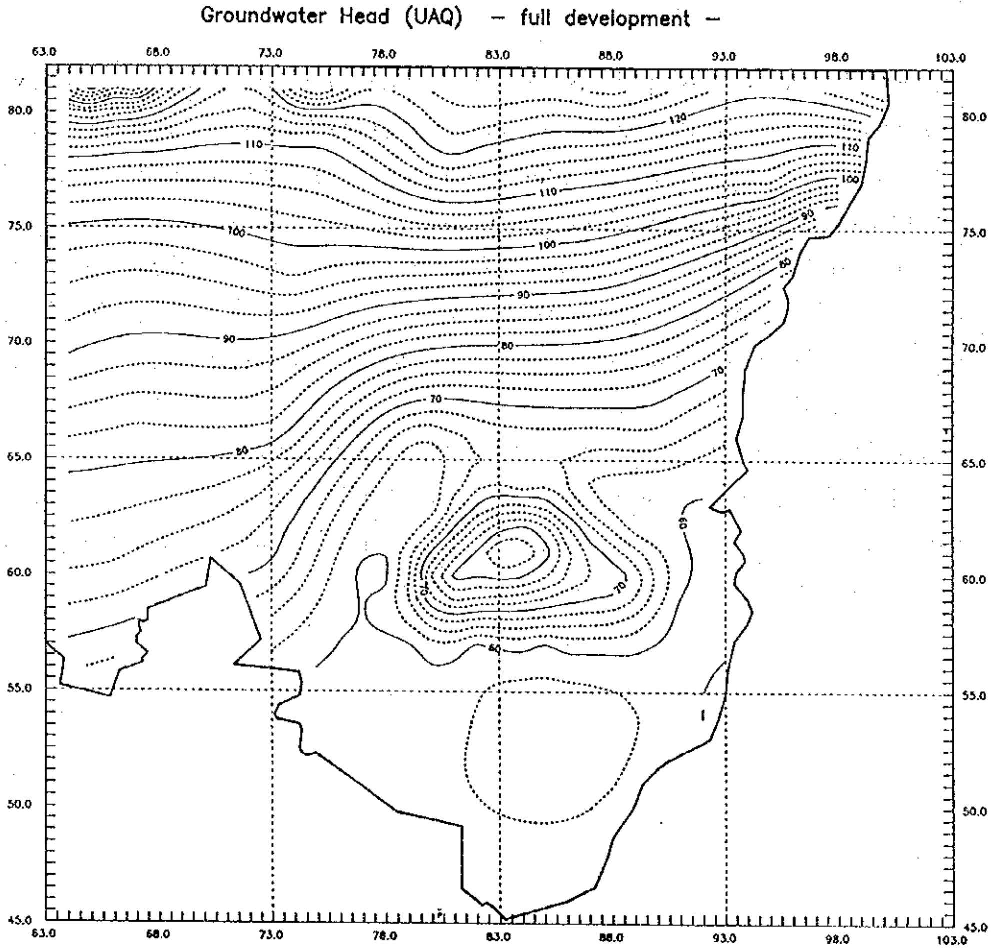
Sub-basin	Case-1	Case-2	Case-3	Case-4	Case-5
No.15	O (16m)	O (16m)	O (22m)	O (24m)	O (30m)
No.16	O (10m)	O (13m)	O (16m)	O (19m)	O (23m)
No.20	O (17m)	O (26m)	▲	X	X
No.21	O (22m)	O (26m)	O (30m)	X	X
No.23	O (23m)	O (28m)	▲	X	X
No.26	O (14m)	O (18m)	O (22m)	O (26m)	O (30m)
No.27	O (19m)	O (24m)	O (30m)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

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

As shown in Table 3.5.1, or calculated in the Figure 3.5.1, there is no shortage year throughout the 14 year simulation for pumping the irrigation water demand as well as the current groundwater use (case-1). In case-2, the situation is almost the same as case-1, but the maximum drawdown is deeper. However, a draft of 1.5 times water demand is hard for the area (case-3). In this case, there are five or six sporadic shortage years only for No. 20 and No. 23 sub-basins. In the other cases, when drafting more than 1.5 times of water demand, the central part of the irrigable area experiences a shortage of irrigation water in almost all years, except in the outer zone. When the pumping up is approximately 1.35 times the water demand, no shortage years are detected throughout the 14 year simulation. Therefore, the groundwater potential of the target irrigable area is 1.35 times the formulated irrigation water demand, or approximately 206 MCM/annum on average, and it can be said that the groundwater potential of the area is sufficient for the planned groundwater irrigation. Furthermore, extensions are possible in the future because the planned pumping conditions exclude the Churia aquifer, which is the strongest aquifer in the area.

Table 3.5.2 shows the water balances under 1.35 times of draft throughout the 14 year simulation. Figure 3.5.2 to Figure 3.5.5 show the groundwater heads of the unconfined aquifer (UAQ), confined aquifer-1 (AQ1), aquifer-2 (AQ2), and the Churia aquifer, at the most critical days under pumping conditions (May 31, 1987), contrasted with the difference from the normal water head at the same date.

Figure 3.5.2. (a) Groundwater Head on Unconfined Aquifer (UAQ)



(b) Drawdown from the normal condition

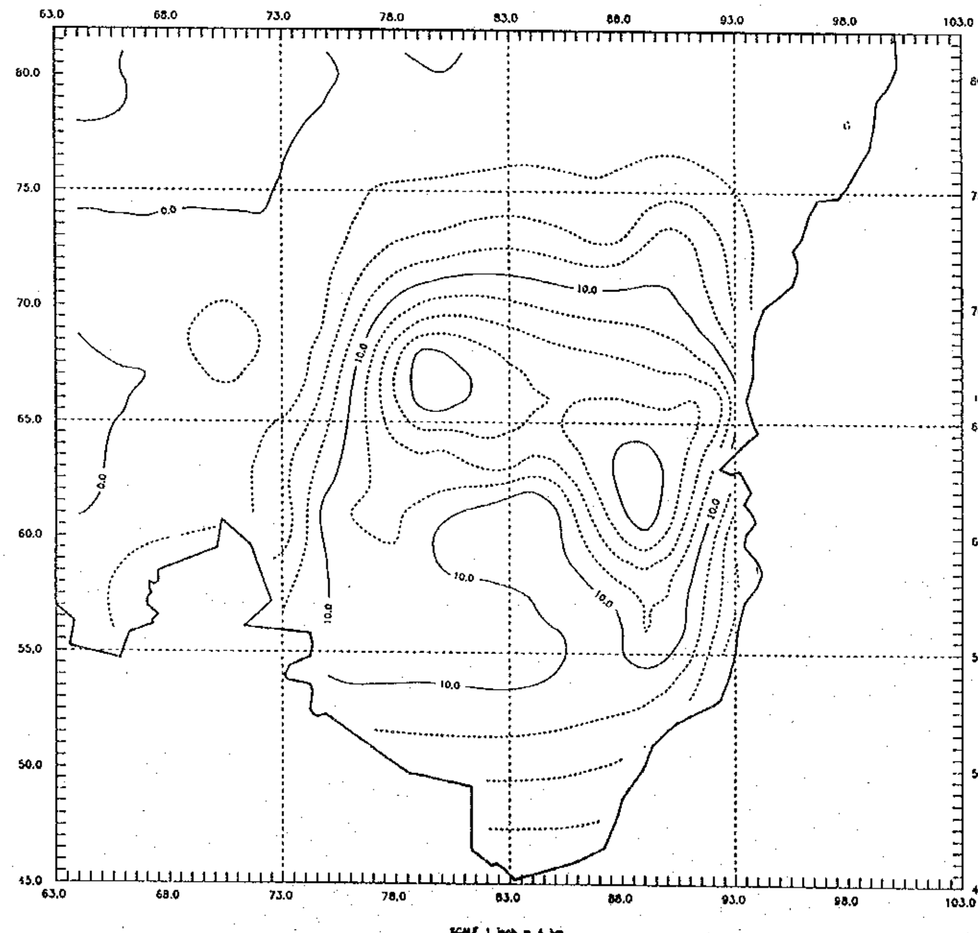
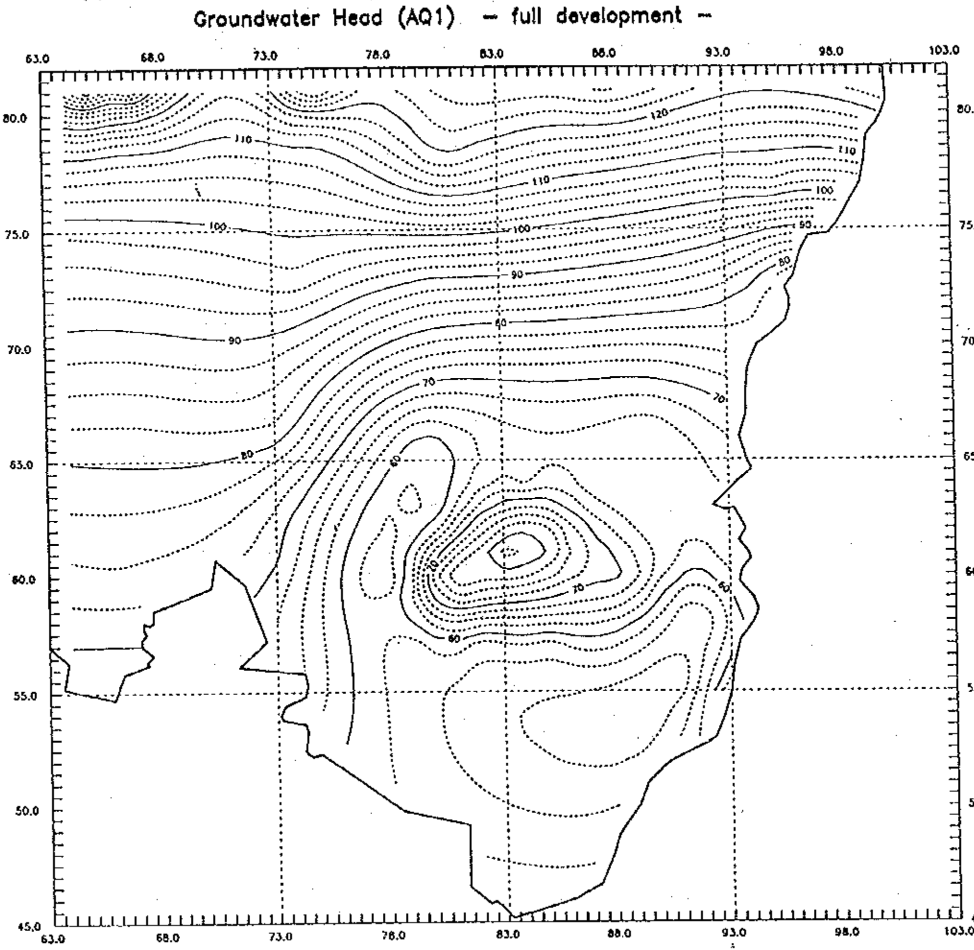


Figure 3.5.3. (a) Groundwater Head on Confined Aquifer-1 (AQ1)



(b) Drawdown from the normal condition

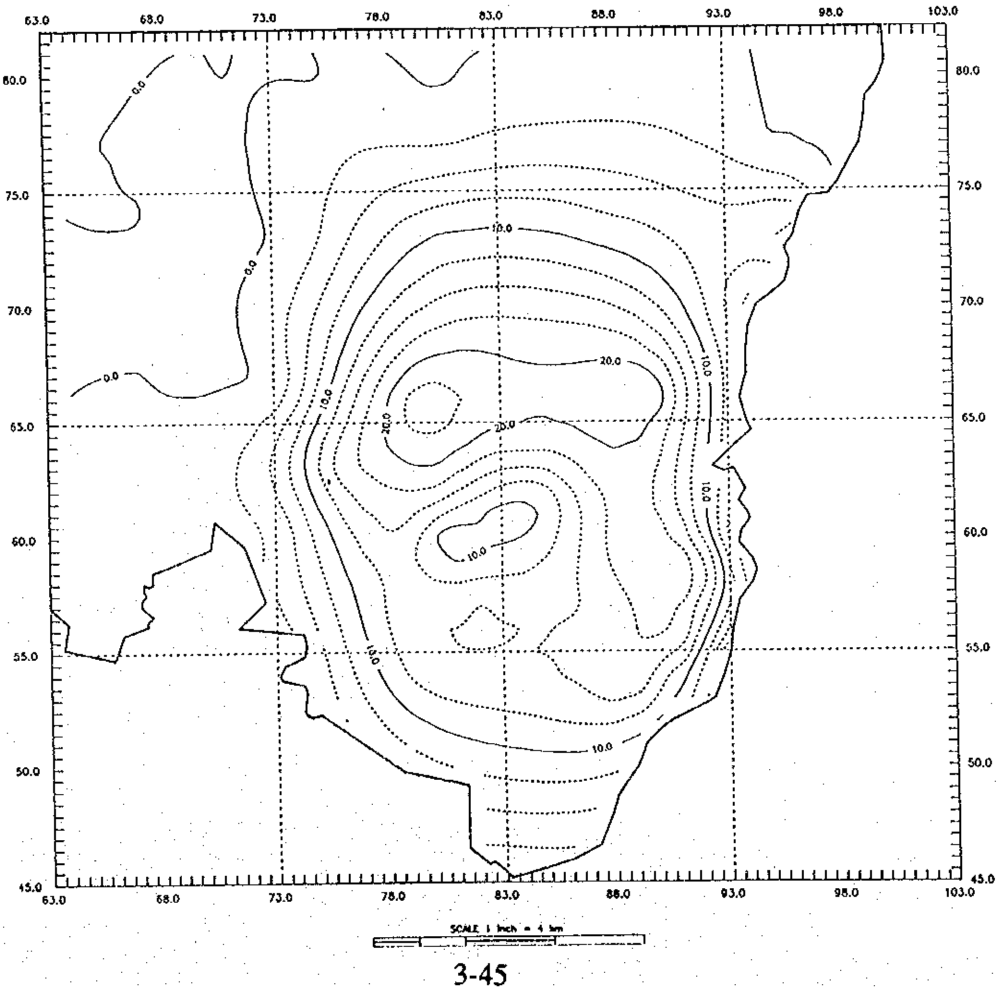
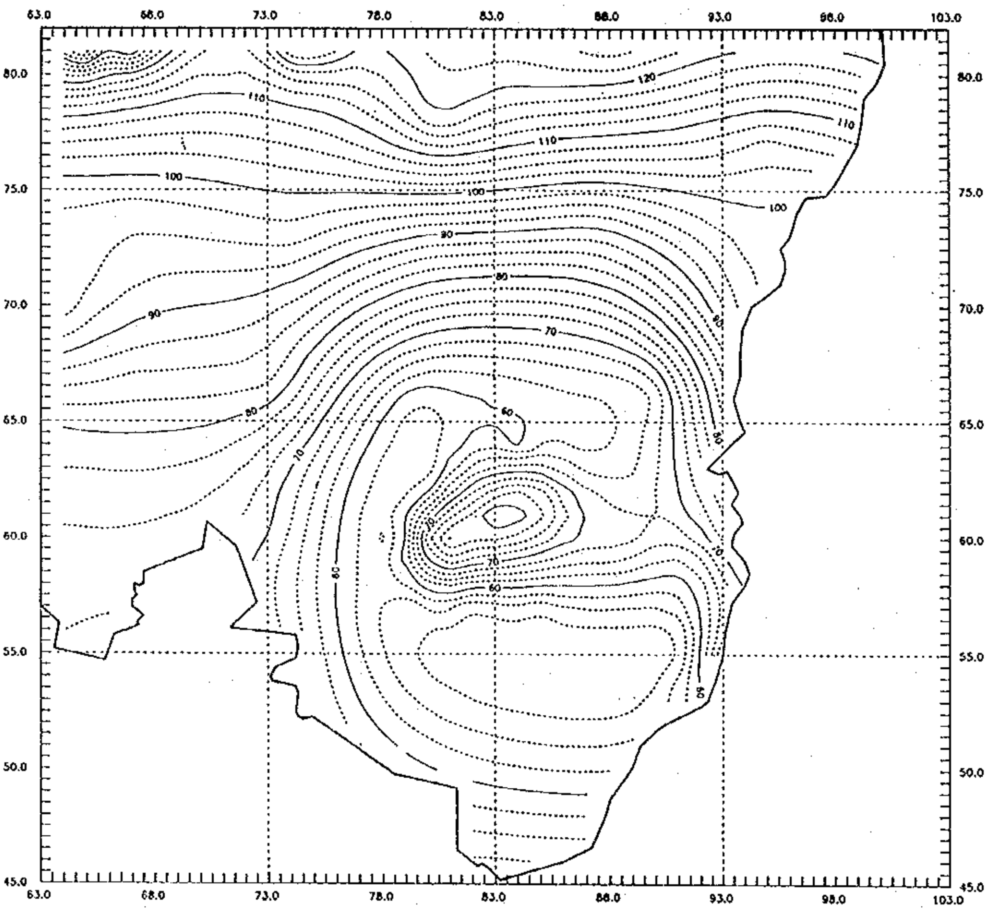
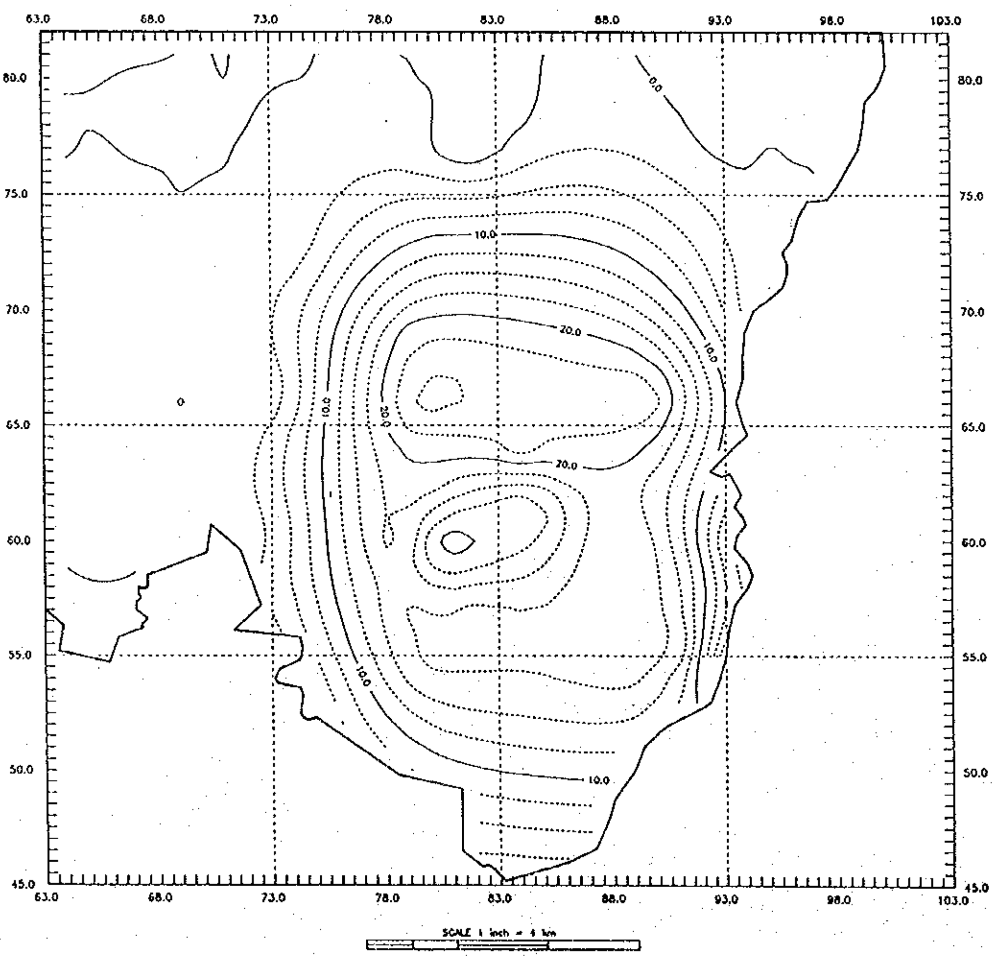


Figure 3.5.4. (a) Groundwater Head on Confined Aquifer-2 (AQ2)

Groundwater Head (AQ2) – full development –

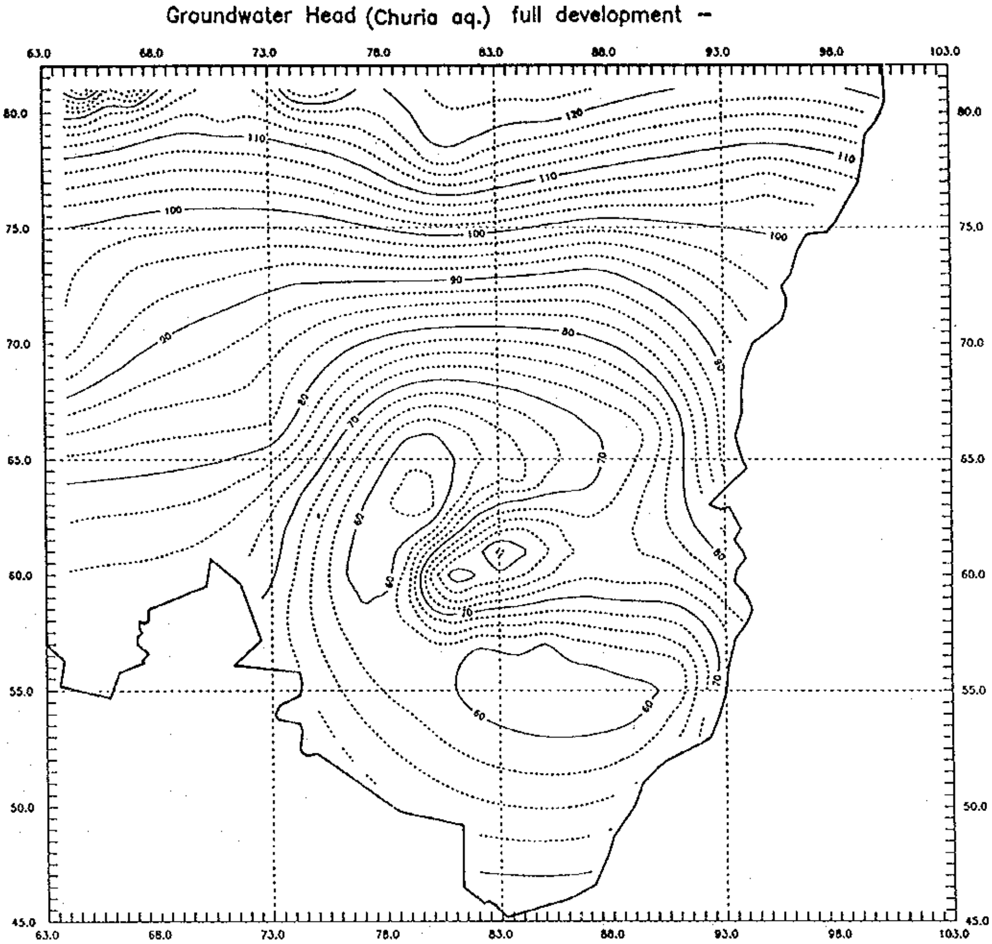


(b) Drawdown from the normal condition



SCALE 1 inch = 4 km

Figure 3.5.5. (a) Groundwater Head on Churia Aquifer (Churia)



(b) Drawdown from the normal condition

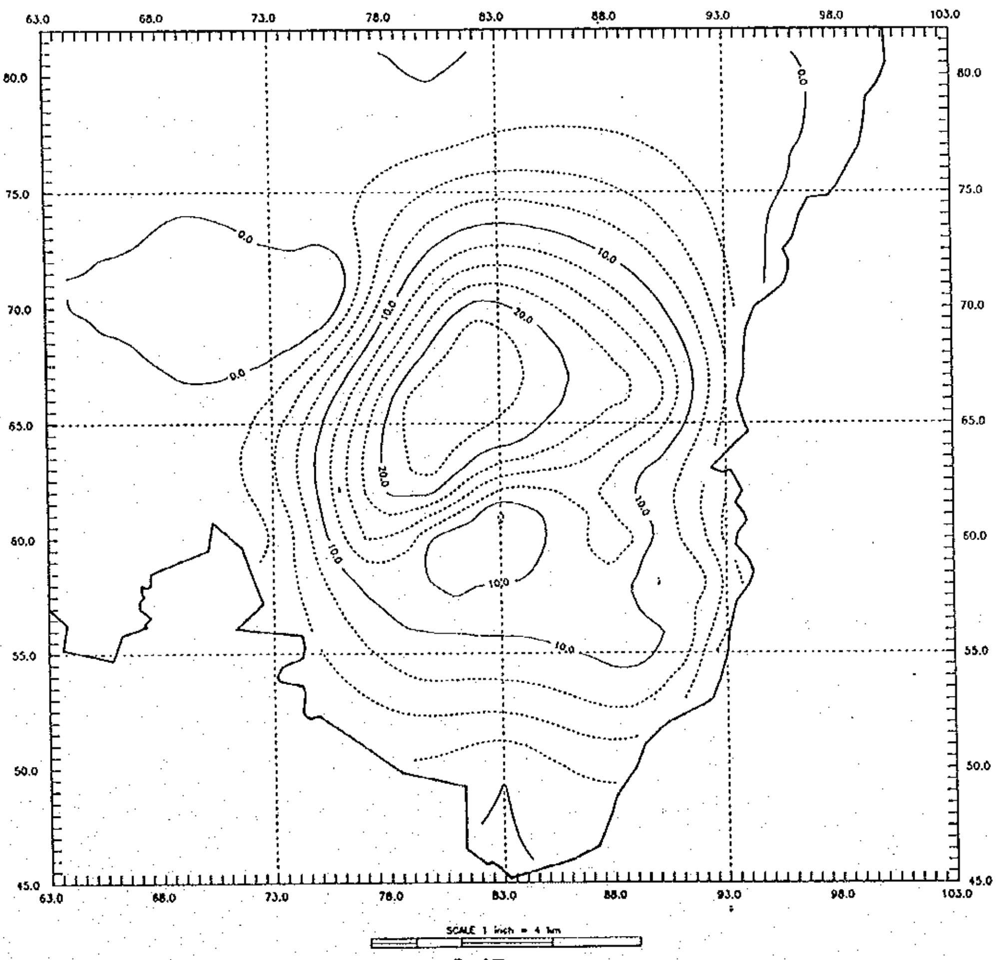


Table 3.5.2 Groundwater Balance under Maximum Draft

(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)

3.5.3. Groundwater Potential on Shallow Aquifers

(1) Outline

The outer zone surrounding the formulated irrigable area (in the Study Area of Jhapa District) is classified into an area where shallow groundwater irrigation is possible.
At the end of simulation study, the potential of the shallow aquifers in the outer groundwater sub-basins is studied. The target sub-basins are No. 14 to No. 27, which is all of the groundwater sub-basins exclusive of the Kankai Valley and the Bhabar Zone.
The pumping condition is set the same as for deep aquifer irrigation, and the net irrigable area is 80% of the gross area. The control level is 30 m below the ground surface but measured by the water level of the unconfined aquifer. During pumping from the shallow aquifer, full development of the deep aquifers in the deep aquifer irrigation area is being conducted.

(2) Groundwater Potential on Shallow Aquifer

In the Study, the groundwater potential of the shallow aquifers is defined as the maximum draft which does not result in pumping shortages of pumping in any year throughout the 14 year simulation in the sub-basin. Results of the Study are summarized in Table 5.3.3.

Table 3.5.3 Groundwater Potential on Shallow Aquifers

(Unit: MCM/a)

Year	B14	B-15	B16	B17	B19	B-20	B21	B23	B25	B26	B27	Total
1980	22.3	7.7	13.8	30.5	11.9	1.3	0.0	0.0	23.2	20.6	0.0	131.3
81	32.5	11.2	20.4	44.6	17.5	2.0	0.0	0.0	33.8	29.4	0.0	191.4
82	35.4	12.2	22.3	48.5	19.1	2.2	0.0	0.0	36.8	31.9	0.0	208.4
83	30.0	10.3	18.8	41.1	16.2	1.8	-0.0	0.0	31.2	27.1	0.0	176.5
84	29.0	10.0	18.3	39.7	15.5	1.8	-0.0	0.0	30.2	26.8	0.0	171.3
85	25.4	8.8	15.7	34.8	13.2	1.6	-0.0	0.0	26.4	24.9	0.0	150.8
86	29.8	10.3	18.7	40.8	15.8	1.9	0.0	0.0	31.0	28.6	0.0	176.9
87	25.9	8.9	16.0	35.5	13.7	1.6	0.0	0.0	27.0	24.6	0.0	153.2
88	23.7	8.1	14.6	32.4	12.6	1.5	-0.0	-0.0	24.6	22.1	0.0	139.6
89	26.5	8.9	16.3	36.4	14.3	1.6	0.0	0.0	27.6	23.8	0.0	155.4
1990	19.3	6.6	11.8	26.5	10.2	1.2	-0.0	0.0	20.1	18.3	0.0	114.0
91	27.6	9.3	17.0	37.8	15.0	1.6	0.0	-0.0	28.7	24.4	0.0	161.4
92	30.7	10.5	19.1	42.0	16.4	1.9	-0.0	0.0	31.9	28.3	0.0	180.8
93	22.6	7.8	13.9	31.0	11.9	1.4	-0.0	-0.0	23.5	21.7	0.0	133.8
Average	27.2	9.3	16.9	37.3	14.5	1.7	-0.0	-0.0	28.3	25.2	0.0	160.3

(Unit: km2)

All Area	37.8	37.41	66.74	51.77	28.02	38.75	59.65	40.31	39.3	72.15	54.65	526.55
area ratio	0.8	0.4	0.4	0.8	0.8	0.2	0	0	0.8	0.2	0	
Net area	30.24	14.96	26.7	41.41	22.42	7.75	0	0	31.44	14.43	0	189.35

As shown in the table, the total groundwater potential of the shallow aquifer is estimated at 160 MCM/a in a net irrigable area of approximately 19,000 ha. The groundwater head of the unconfined aquifer on the most critical day (May 31, 1987) under pumping conditions is illustrated in Figure 3.5.6, and the drawdown at the same time is shown in Figure 3.5.7.

3.5.4. Groundwater Potential on Other Districts

(1) General

As described above, the groundwater potential of the representative area in Jhapa District is sufficient for groundwater irrigation formulated in this Project, and the area has a 35% excess potential without developing the Churia aquifer. In digital, it is possible to develop approximately 206 MCM/annum of groundwater in the total irrigable area (17,000 ha). The hydrogeological conditions of the other two districts, Mahottari and Banke, are not very different from those in Jhapa District as all of these districts are located in the Terai Plain. In this section, the groundwater potential of the two districts is estimated roughly based on the results of the Study in Jhapa District, and the following procedures for groundwater development are explained.

Figure 3.5.6. Groundwater Head on Unconfined Aquifer under Shallow Aquifer Draft

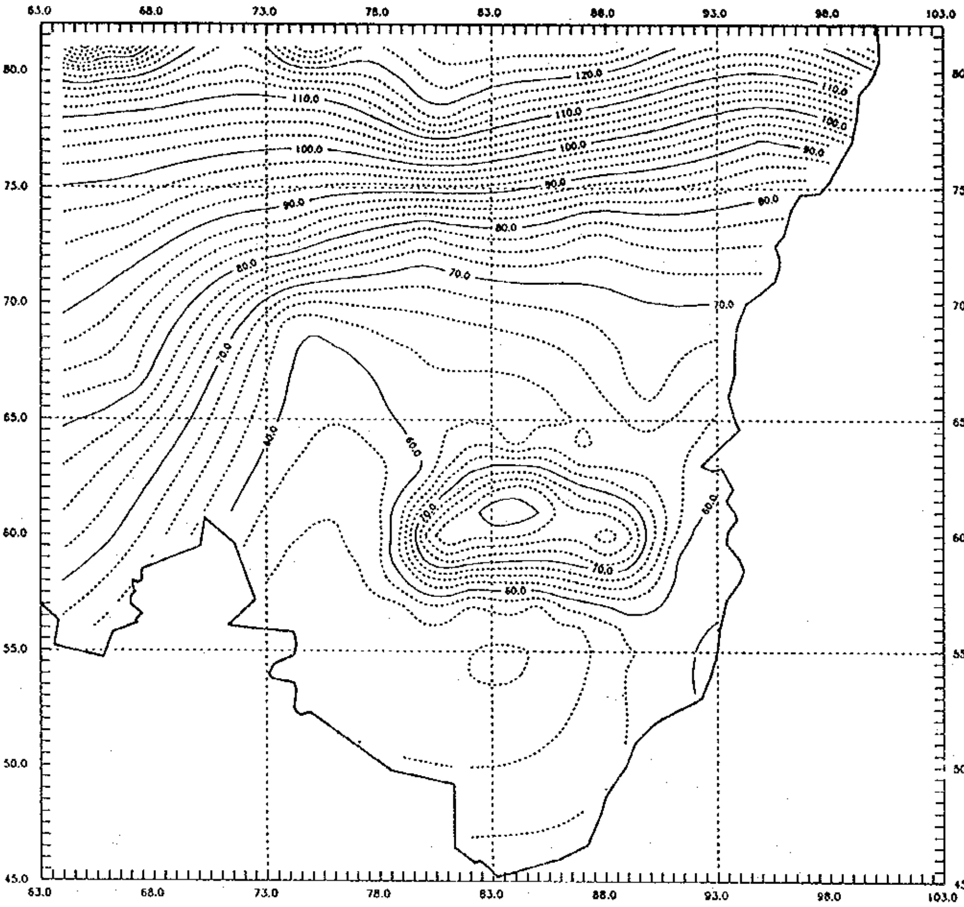
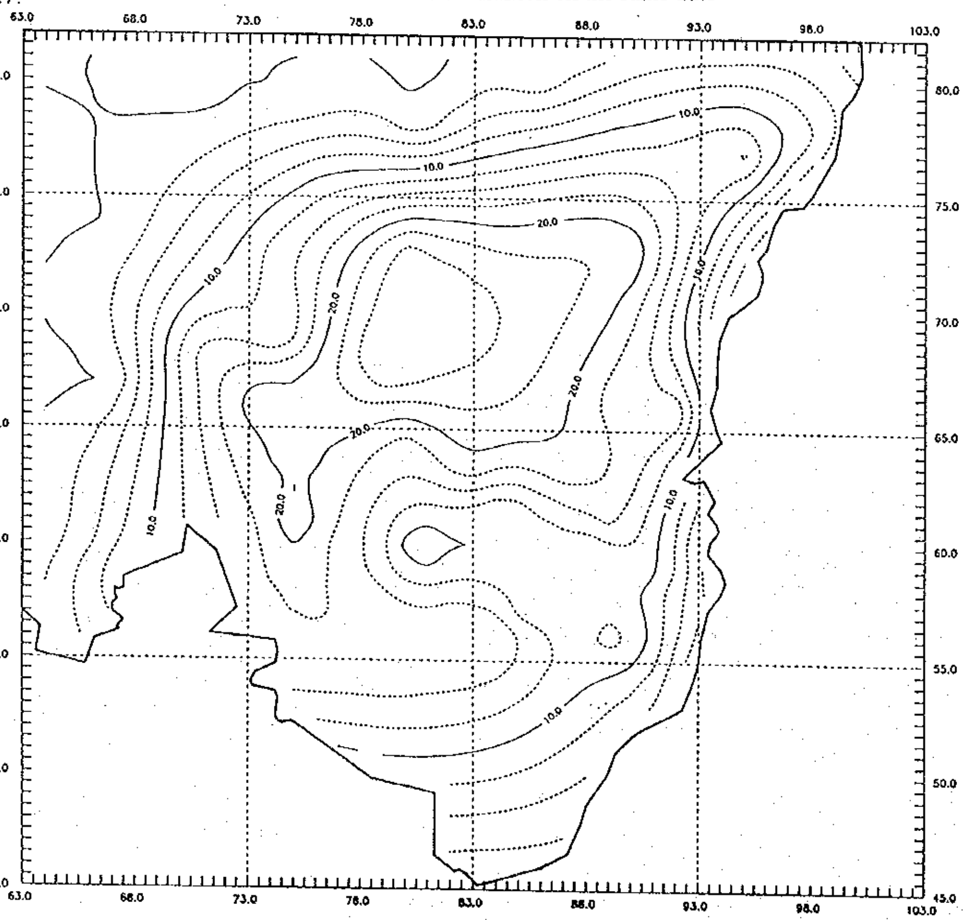


Figure 3.5.7. Drawdown from the normal condition on the same date



(2) Mahottari District

The hydrogeological conditions of the district are similar to those in Jhapa District, which gradually changes from the Bhabar zone, Midlands, and Gangetic Plain (southern Terai). Aquifer conditions represented by transmissivity in the target area in Mahottari are slightly weaker than the ones for Jhapa; however, the rainfall conditions which control the recharge of groundwater are almost the same as those in Jhapa District. This situation suggests that the groundwater potential of the area is almost the same as Jhapa District, which means that the same irrigation plan is applicable for Mahottari District.

For the evaluation of groundwater potential in this area, the same methodology applied in Jhapa Districts can be used. Aquifer classifications and the target aquifers can be copied from the ones in Jhapa District. However, the target groundwater basin must involve the neighboring Dhanusha District, as both surface and subsurface systems of the target area connect to/from Dhanusha District.

(3) Banke District

Although the basic hydrogeological conditions, consisting of the Bhabar Zone, Midlands, and the Gangetic Plain, are almost same as the other two districts, the details of the structure are a little different from the other two. That is, the Churia Basement lies at very shallow level in the current farmland area, with outcrops as mountains or terraces in the north and eastern parts of the district.
As a result of this condition, thick, dominant Quaternary aquifers are expected only along the southern edge of the area. In the central part of the area, Quaternary aquifers including unconfined aquifer are mostly thin and rather complicated. Under the situation, the same irrigation system as the one in Jhapa District is hardly 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 of the best aquifers in the Terai Plain. This situation suggests that the Gangetic aquifer should be the target aquifer in the southern belt, and the Churia aquifer should be developed in the central part of the area.

Along with the hydrogeological conditions, the annual rainfall in the district is smaller than the other two districts, therefore, a careful groundwater balance study including the Churia aquifer is requested for future groundwater irrigation in this district.

3.6. Management of Groundwater and the Monitoring System

3.6.1. Groundwater Management

(1) Concept for Groundwater Conservation Management

As mentioned in the Chapter 5.1 of the Main Report, 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 required

(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 a stochastic maximum value within an allowable environmental range.

Basin-wide groundwater behavior is far more elastic in terms of development than is generally believed as an aquifer can be considered as a type of reservoir. It is unnecessary to always replenish its storage level to that of the previous year. The concept of "secular storage," that is, water should be consumed as much as possible during the dry cycle based on a unit of several years can be applied, with water level replenishment during the following wet cycle. With the development of the "water leakage recharging theory," it is understood that the basin-wide recharge potential excels where aquicludes run in a vertical direction, rather than in the horizontal direction of aquifers. The recharging potential is low when the degree of development is also low. As development of the lower confined aquifer progresses, the groundwater head difference with the upper unconfined aquifer increases and the overall recharge potential increases. The recharging potential has a certain limit which is revealed only after development has advanced.

Using a simulation model is convenient to continuously monitor basin-wide groundwater resources and their behavior, as mentioned above. The model must be capable of handling time-series and fluctuations in the hydrological cycle, including precipitation, evapotranspiration, surface run off, groundwater recharge, storage, flow, and pumping; and it must easy to alter the model parameters. The "synthetic storage model" constructed for Jhapa

District possesses the above conditions and can be used for conservation maintenance simulations for groundwater resources.

However, as this model is identified through the verification data collected in a very short period of time, it must be fine-tuned based on future hydrographs which include precipitation, river discharge, pumping usage volume, and the groundwater head based on sub-basins and layers. As mentioned above, the basin-wide recharging 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 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 managed groundwater head is the average groundwater head of the first and second confined aquifers and is set at a subsurface of 30 m. The actual managed groundwater head, however, should be determined 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 Plain.

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 Plain.

3.6.2. Monitoring of Groundwater Resources

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

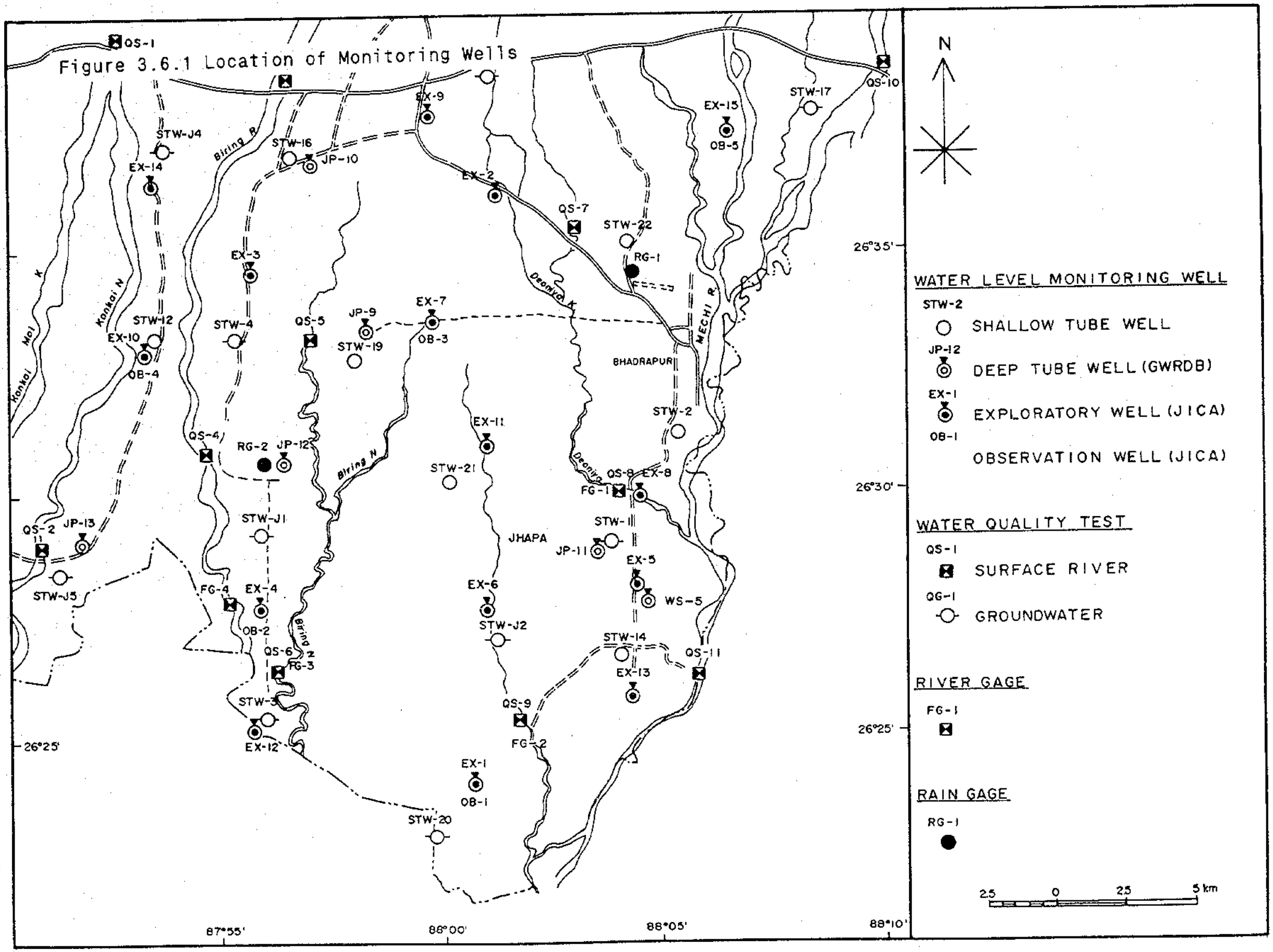
- Precipitation (representative points in the districts, daily)
- River runoff (representative rivers in the district, daily)

- Groundwater head (representative sub-basin, daily, based on aquifer)
- Pump discharge (purpose, sub-basin, monthly, aquifer: measurements by an integrating 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 Department of Irrigation maintain the observation network established by the Study Team and continue these observations (refer to Figure 3.6.1).

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 3.6.1 Location of Monitoring Wells



CHAPTER FOUR

AGRONOMY AND AGRO-ECONOMY

CHAPTER-FOUR: AGRONOMY AND AGRO-ECONOMY

4.1. General

4.1.1. Agriculture in Nepal

Agriculture is the backbone of the Nepalese economy, contributing 53% to the GDP in 1989/90, and supplying raw materials to agro-based industries. Of the economically active population of 7.34 million people (1991), some 81% are working in the agricultural sector, which is the largest supplier of employment opportunities in Nepal.

Major crops in Nepal include paddy, maize, wheat, barley, millet, and pulses; and sugarcane, tobacco, jute, potatoes, and so on, are also planted. As shown in the table, cereal production in 1982/83, 1986/87, and 1989/90 did not meet Nepal's domestic demand because of the dependency on annual climatic conditions, especially the monsoon.

Irrigated areas in Nepal have increased gradually, with about 943,000 ha at present; however, the ratio of irrigated area is only 36% of the total farmland.

Though the number of livestock has also increased, except for cattle, livestock has not been commercialized. Cattle and buffalo are important animals for cultivation, transportation, and milking. Cattle graze on wild grasslands, but overgrazing has been observed because of the imbalance of grass production and the number of livestock. In the mountainous regions, animal feed is fetched by young females.

In spite of the contributions to the national economy, most farmers continue to live on incomes which are below the poverty line. According to the World Bank, some 71% of the nation - 74% of the rural population and 42% of the urban people - live below the poverty line, therefore, the alleviation of poverty is one of the most important policies of the Eighth National Development Plan (1992-1997).

4.1.2. Agriculture in the Terai Plain

The Terai Plain occupies 14.3% of the national land, 41.6% of the farmland, and is divided into 20 districts. Some 45% (1991) of Nepal's total population live in the Terai Plain; and this population is growing annually at a rate of 2.8%, which is higher than the national average of 2.1%.

As shown below, the Terai Plain plays an important role as the granary in Nepal.

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

Some 36% of the cattle and 32% of the buffalo are distributed in the Terai Plain, which also produces 32% of the national milk output. Overgrazing is commonly observed even in the Terai Plain.

Of the total farmland of 1.36 million ha, 53% or 720,000 ha are irrigated, which is higher than the national average of 35%.

4.2. Existing Agriculture and Irrigation in the Districts

4.2.1. Area and Soils

The total land area in the three districts are as follows: 156,500 ha in Jhapa; 75,323 ha in Mahottari; 225,836 ha in Banke. Land categories and their acreage can be summarized as follows:

(ha)

	Jhapa	Mahottari	Banke
Total Land	156,500	101,238	225,836
Cultivated Area	105,121	63,754	49,072
Irrigated Area	47,854	17,313	3,317
Study Area (gross)	29,700	9,800	12,100
Study Area (net)	17,000	7,000	8,000

Soil types in the three districts are classified as Type(I), which is observed in the Terai Plain. Soil textures are sandy loam to silty loam, and soil reactions are weak-acid to neutral.

4.2.2. Population and Farm Households

According to the Statistical Yearbook, the current population in the three districts is as

Table 4.1.1 Gross Domestic Product (GDP)

1. At 1974/75 Prices (constant prices) (Million Rs)

	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90	1990/91	1991/92	1992/93
Agriculture	13668	13990	14705	14789	15993	17234	18513	19026	18805	18579
Non-Agriculture	8594	9640	9940	10828	11522	11514	12521	13422	14310	15496
Total	22262	23630	24645	25617	27515	28748	31034	32448	33115	34075

2. At Current Price (Million Rs, %)

	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90	1990/91	1991/92
Agriculture	22570	23927	26555	30448	35477	40889	47251	52047	61486
(%)	57.3	53.9	52.7	51.4	51.4	52.6	51.9	50.1	48.7
Mining & Quarrying	111	140	120	100	93	101	116	131	162
(%)	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Manufacturing	1816	1998	2622	3065	3761	3799	4775	6333	9330
(%)	4.6	4.5	5.2	5.2	5.5	4.9	5.2	6.1	7.4
Electricity, Gas, Water	158	196	342	415	467	513	537	652	994
(%)	0.4	0.4	0.7	0.7	0.7	0.7	0.6	0.6	0.8
Construction	2576	3583	3989	5040	5396	6074	7042	8155	10193
(%)	6.5	8.1	7.9	8.5	7.8	7.8	7.7	7.8	8.1
Trade, Restaurant, Hotels	1520	1837	2207	2905	3365	3911	4521	5901	7536
(%)	3.9	4.1	4.4	4.9	4.9	5.0	5.0	5.7	6.0
Transport, Communication	2468	2764	3123	3594	3686	3572	4751	5894	7652
& Storage (%)	6.3	6.2	6.2	6.1	5.3	4.6	5.2	5.7	6.1
Financial, Real Eastate	2937	3420	3942	4715	5599	6727	8394	9517	11372
(%)	7.5	7.7	7.8	8.0	8.1	8.7	9.2	9.2	9.0
Community, Social Serv-	2848	3691	4164	5076	5871	6717	7385	8314	9196
ices (%)	7.2	8.3	8.3	8.6	8.5	8.6	8.1	8.0	7.3
Sub-Total	37004	41556	47064	55358	63715	72303	84772	96944	117921
Indirect Taxes	2386	2861	3364	3888	5258	5437	6245	7004	8265
	6.1	6.4	6.7	6.6	7.6	7.0	6.9	6.7	6.5
GDP at Market Price	39390	44417	50428	59246	68973	77740	91017	103948	126186
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: Statistical Yearbook, 1993

Table 4.1.2 (1) Area, Production & Yiels of Principal Cereal Crops

(Unit:ha, ton, ton/ha)

	Food Crops	1985/86	1986/87	1987/88	1988/89	1989/90	1990/91	1991/92	1992/93*	%Change in 1992/93 Over 1991/92
Paddy	Area	1,391	1,333	1,423	1,450	1,433	1,455	1,412	1,262	-10.6
	Production	2,804	2,372	2,982	3,283	3,390	3,502	3,223	2,585	-19.8
	Yield	2.02	1.78	2.09	2.26	2.37	2.41	2.28	2.04	-10.5
Maize	Area	615	627	674	722	751	758	754	775	2.8
	Production	874	868	902	1,072	1,201	1,231	1,205	1,290	7.1
	Yield	1.42	1.38	1.34	1.48	1.60	1.62	1.59	1.66	4.4
Wheat	Area	483	536	597	599	604	593	571	628	10.0
	Production	598	701	745	830	855	836	779	765	-1.8
	Yield	1.24	1.31	1.25	1.39	1.41	1.41	1.36	1.22	-10.3
Barley	Area	29	29	29	29	30	30	30	30	0.0
	Production	23	25	25	27	27	28	28	28	0.0
	Yield	0.79	0.86	0.86	0.93	0.90	0.93	0.93	0.93	0.0
Millet	Area	151	151	165	183	193	199	198	202	2.0
	Production	138	138	150	183	225	232	229	237	3.5
	Yield	0.91	0.91	0.91	1.00	1.17	1.17	1.15	1.17	1.7
	Total Area	**2,669**	**2,676**	**2,888**	**2,983**	**3,011**	**3,035**	**2,965**	**2,897**	-2.3
	Total Production	**4,437**	**4,104**	**4,804**	**5,395**	**5,698**	**5,829**	**5,464**	**4,905**	-10.2
	Index of Cash Crops (1974/75 = 100)									
	Area	124.60	124.93	134.83	139.26	140.57	141.69	138.42	135.24	-2.3
	Production	117.44	108.63	127.16	142.80	150.82	154.29	144.62	129.83	-10.2
	Yield	94.25	97.73	94.32	102.54	107.29	108.89	104.47	96.00	-8.1

*Preliminary

Source:Central Bureau of Statistics and Department of Food and Agricultural Marketing Service.

Table 4.1.2 (2) Area, Production & Yiels of Principal Cash Crops

(Unit:ha, ton, ton/ha)

	Cash Crops	1985/86	1986/87	1987/88	1988/89	1989/90	1990/91	1991/92	1992/93*	%Change in 1989/90 Over 1991/92
Sugarcane	Area	23	25	30	30	32	33	37	39	5.4
	Production	558	617	814	903	988	1,106	1,291	1,366	5.8
	Yield	24.27	24.68	27.2	30.1	30.95	33.52	34.89	35.02	0.4
Oil Seeds	Area	138	143	151	155	154	156	155	166	7.1
	Production	79	83	94	99	98	92	88	94	6.8
	Yield	0.57	0.58	0.62	0.64	0.64	0.59	0.56	0.57	1.8
Tobacco	Area	9	9	6	7	8	7	7	7	0.0
	Production	5	5	4	5	7	7	6	6	0.0
	Yield	0.54	0.56	0.69	0.71	0.88	1.00	0.85	0.85	0.0
Potato	Area	70	74	80	82	83	84	85	87	2.4
	Production	357	395	567	641	671	738	733	733	0.0
	Yield	5.1	5.34	7.07	7.82	8.08	8.79	8.62	8.42	-2.3
Jute	Area	47	20	14	14	13	14	15	9	-40.0
	Production	61	23	15	18	16	16	19	10	-47.4
	Yield	1.29	1.18	1.04	1.29	1.23	1.14	1.26	1.11	-11.9
	Total Area	**287**	**271**	**281**	**288**	**290**	**294**	**299**	**308**	3.0
	Total Production	**1060**	**1123**	**1494**	**1666**	**1780**	**1959**	**2137**	**2209**	3.4
	Index of Cash Crops (1974/75 = 100)									
	Area	129.86	144.15	127.15	130.32	131.22	133.03	135.29	139.36	3.0
	Production	158.21	178.54	222.99	248.66	265.67	292.39	319.00	329.70	3.4
	Yield	121.83	123.58	175.58	190.81	202.46	219.79	235.79	236.58	0.3

*Preliminary

Source:Central Bureau of Statistics and Department of Food and Agricultural Marketing Service.

Table 4.1.3 Food Balance of Nepal

(Unit:ton)

Crops		1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90	1990/91
Rice	P	1,323,777	637,764	1,474,981	14,455,478	1,498,576	1,256,383	1,606,965	1,771,671	1,831,713	1,892,105
	R	1,095,874	1,124,364	1,173,434	1,363,838	1,374,214	1,402,380	1,435,892	1,426,697	-	-
	B	227,903	-186,600	+301,547	+81,640	+124,362	-145,994	+171,073	+344,974	-	-
Maize	P	641,296	612,022	649,095	627,704	669,016	664,595	689,576	835,600	857,846	877,075
	R	712,503	731,023	779,010	623,036	667,092	663,840	663,381	789,229	-	-
	B	-71,207	-119,001	-129,915	+4,668	+1,924	+755	+26,195	+46,371	-	-
Wheat	P	419,985	525,686	501,689	413,568	465,618	548,744	580,184	653,038	667,972	651,956
	R	272,654	280,153	365,367	404,880	418,534	467,150	497,727	548,028	-	-
	B	147,331	+245,533	+136,322	+8,688	+47,084	+81,594	+82,457	+105,010	-	-
Millet	P	104,121	103,439	98,154	101,648	112,646	112,356	122,592	149,851	184,546	190,177
	R	133,555	137,029	144,437	101,648	112,646	112,356	122,592	149,851	-	-
	B	-29,434	-33,590	-46,283	-	-	-	-	-	-	-
Barley	P	19,414	17,615	18,572	6,455	6,373	6,742	6,622	7,409	7,510	7,642
	R	33,038	34,899	37,087	6,455	6,373	6,742	6,622	7,409	-	-
	B	-13,624	-17,284	-18,515	-	-	-	-	-	-	-
Total	P	2,508,593	2,196,526	2,742,491	2,594,853	2,752,229	2,588,823	3,005,939	3,417,569	3,549,587	3,618,955
	R	2,247,624	2,307,468	2,499,335	2,499,857	2,578,859	2,652,468	2,726,214	2,921,214	3,559,011	3,486,776
	B	+260,969	-110,942	+243,156	+94,996	+173,370	-63,645	+279,725	+496,355	-9,424	+132,179

Note: P = Production. R = Requirement, B = Balance
Source: Marketing Services Division. Dept. of Agriculture.

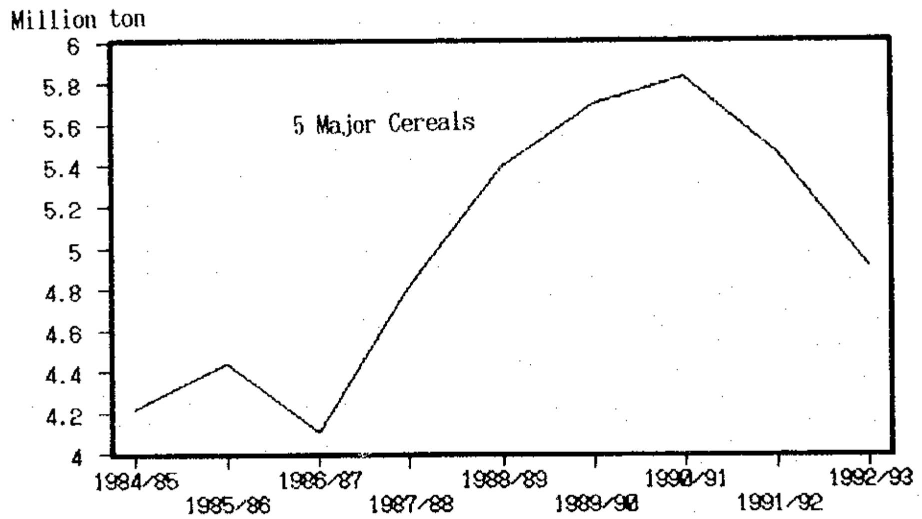
Table 4.1.4(1) Number of Livestock (1992/93)

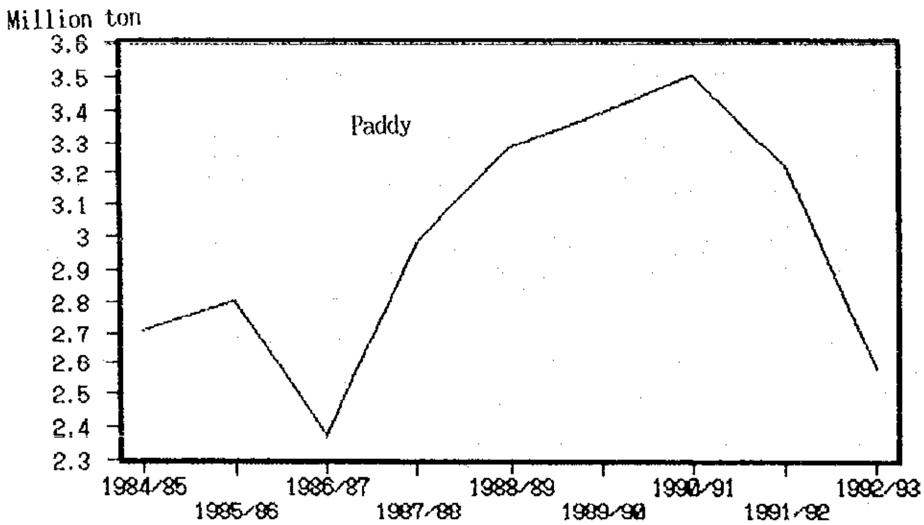
	Cattle	Buffaloe	Sheep	Goat	Pig	Fowl	Duck
Nepal	6,237,231	3,072,682	911,279	5,451,710	604,902	13,600,807	391,718
E. Terai	686,794	268,294	15,102	463,400	55,680	766,297	147,719
C. Terai	592,282	275,589	6,084	588,774	17,897	984,458	101,375
W. Terai	457,870	178,274	11,990	195,305	12,149	464,517	51,304
MW. Terai	353,170	174,273	83,337	211,944	53,683	775,138	10,115
FW. Terai	166,544	76,529	25,893	85,747	30,815	395,787	23,953
Total	2,256,660	972,959	142,406	1,545,170	170,224	3,386,197	334,466
%	36.2	31.7	15.6	28.3	28.1	24.9	85.4

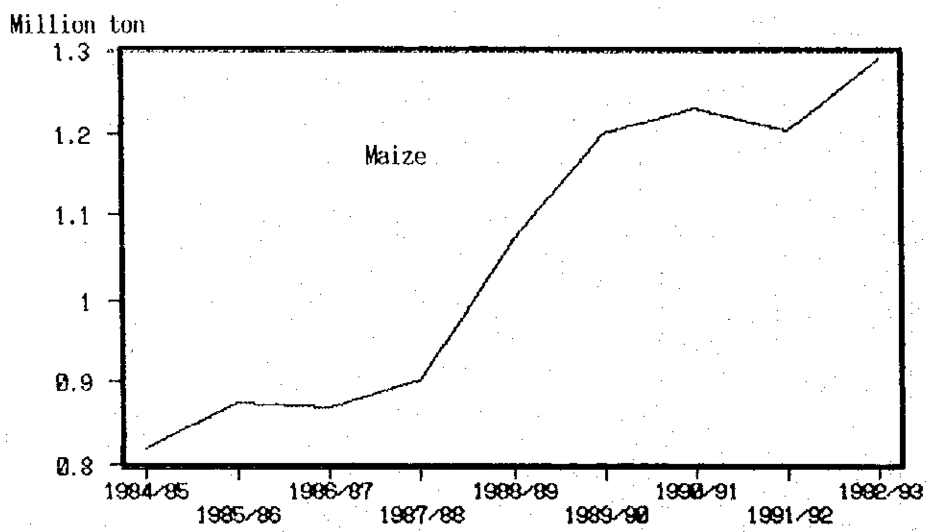
Table 4.1.4(2) Milk Production(1992/93)

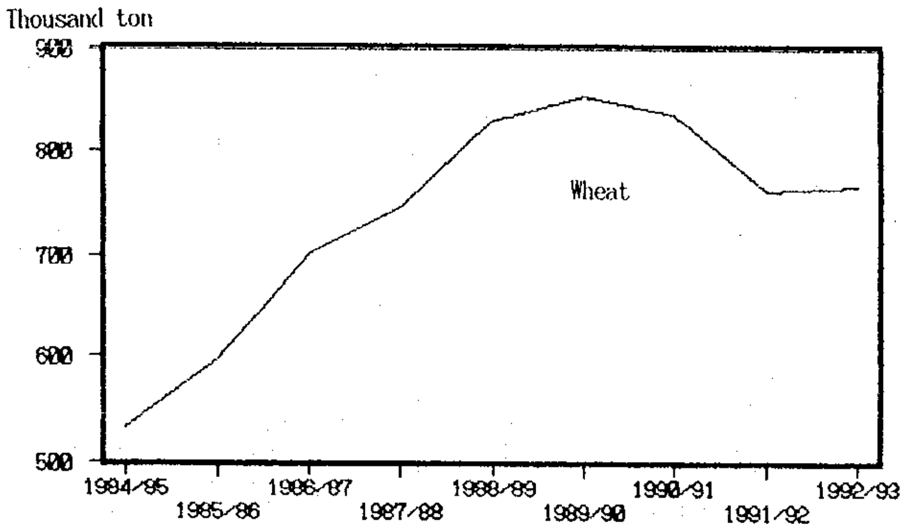
	No. Milk Cow	No. of Milk Buffaloe	Cow Milk	Buffaloe Milk	Total Milk
Nepal	698,931	755,996	260,786	615,808	876,594
E. Terai	75,490	54,174	33,835	55,628	89,463
C. Terai	4,758	63,882	28,352	62,947	91,299
W. Terai	26,032	39,734	11,393	36,175	48,108
MW. Terai	32,825	22,391	10,107	22,299	32,406
FW. Terai	20,022	12,867	6,939	11,848	18,787
Total	159,127	193,048	90,626	188,897	280,063
%	22.8	25.5	34.8	30.7	31.9

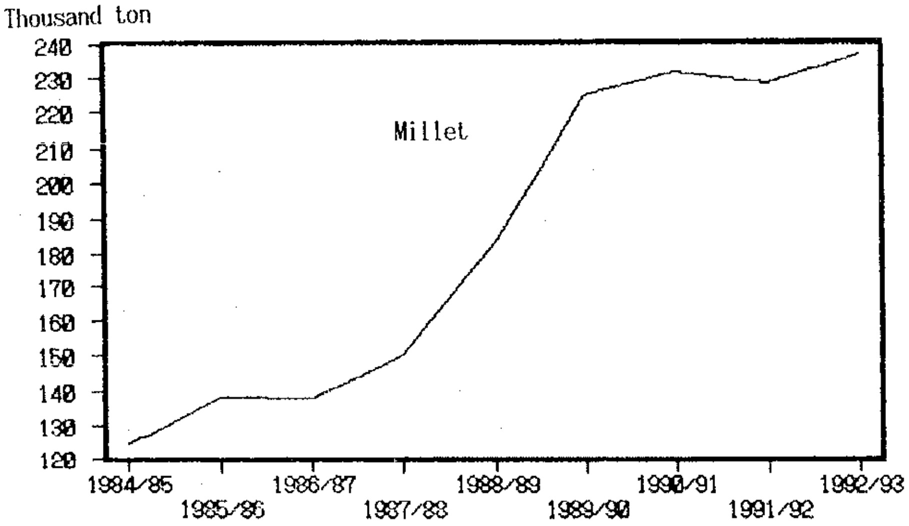
Figure 4.1.1 Agricultural Production (National)

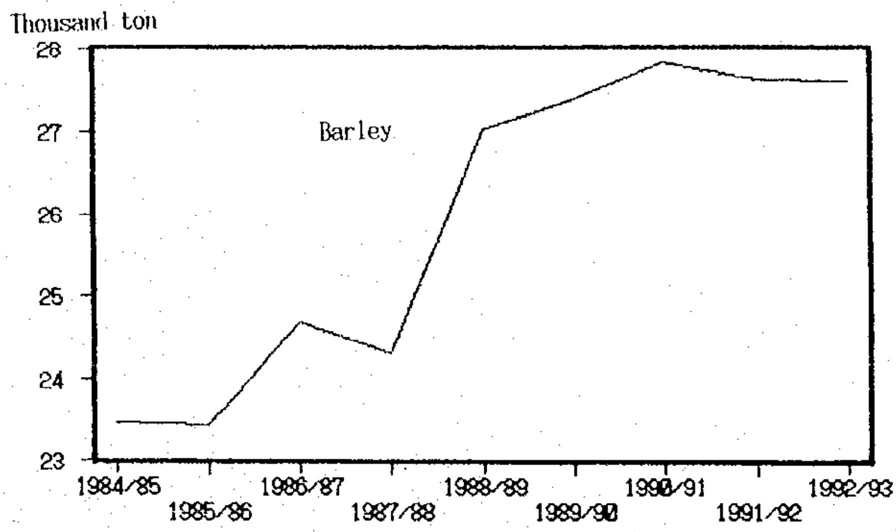







Thousand ton
900
800
700
600
500
Wheat
1984/85
1985/86
1986/87
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93


Thousand ton
240
230
220
210
200
190
180
170
160
150
140
130
120
Millet
1984/85
1985/86
1986/87
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93


Thousand ton
28
27
26
25
24
23
Barley
1984/85
1985/86
1986/87
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93

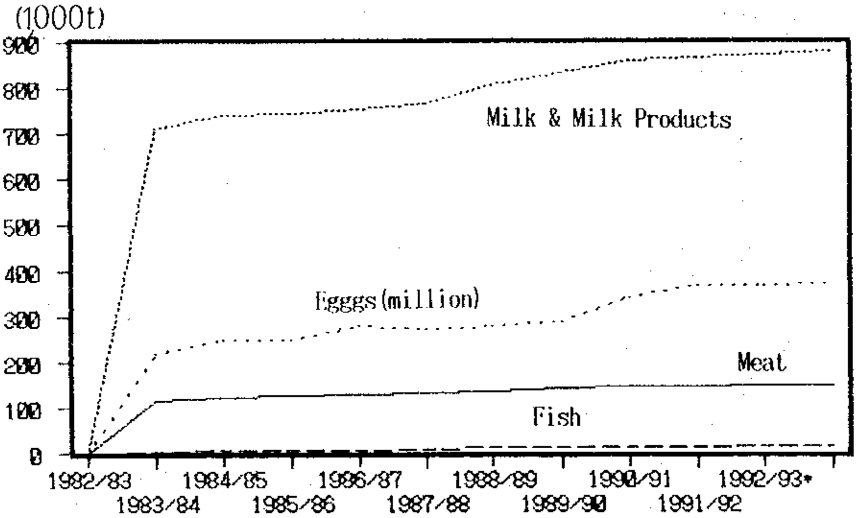

(1000t)
900
800
700
600
500
400
300
200
100
0
Milk & Milk Products
Egggs(million)
Meat
Fish
1982/83
1983/84
1984/85
1985/86
1986/87
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93*

Figure 4.1.2 Major Irrigated Areas

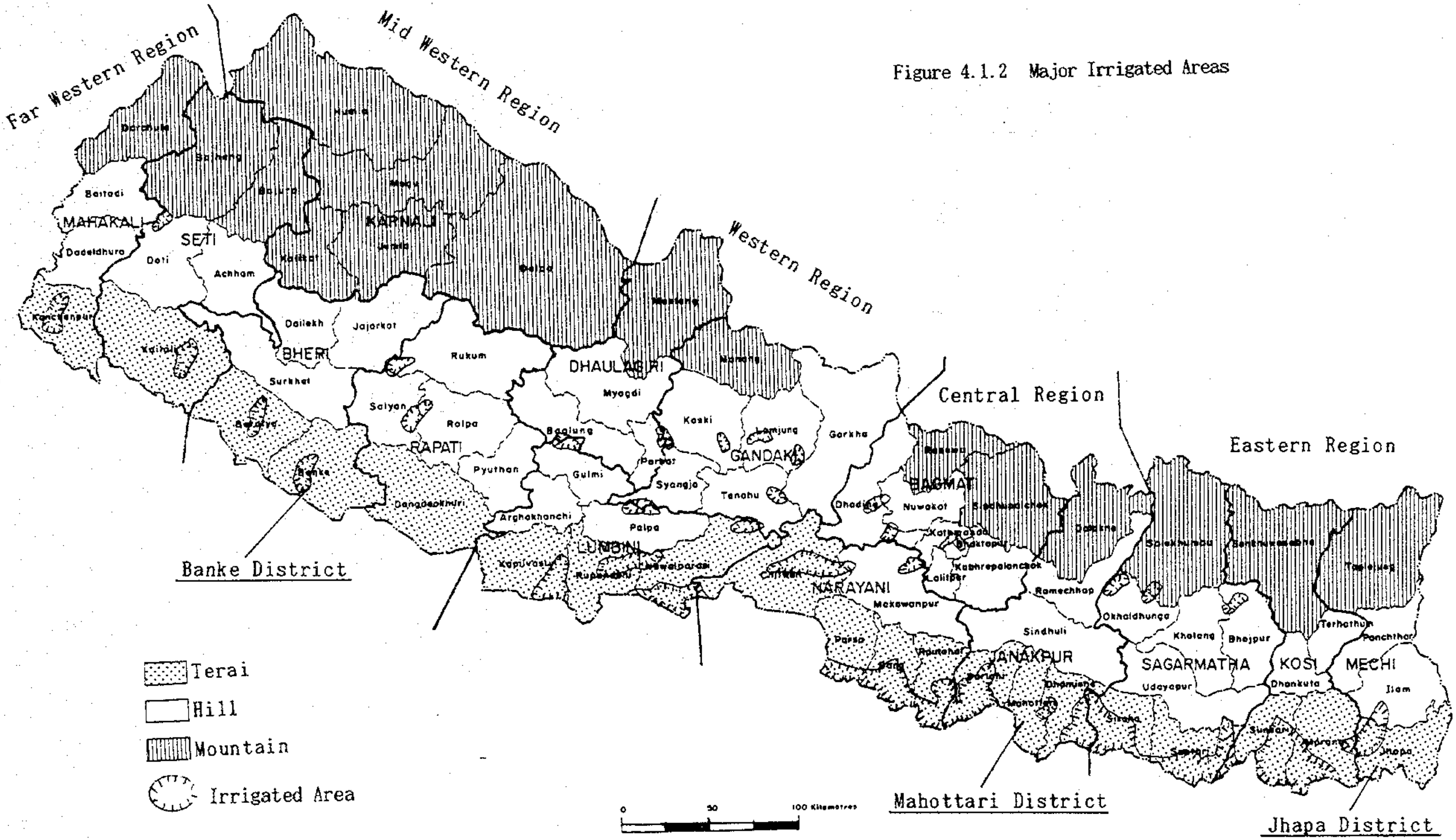


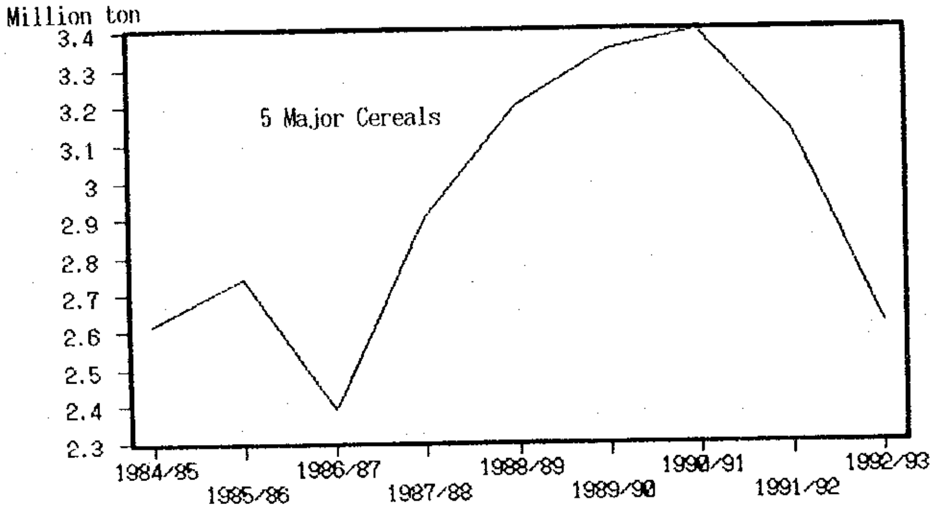
Table 4.1.5 Number of Livestock in Terai (1992/93)

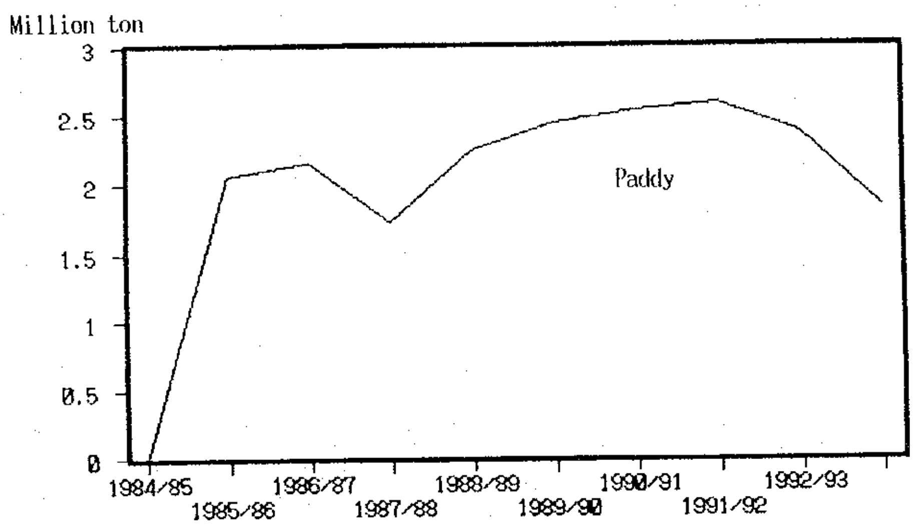
	Cattle	Buffaloe	Sheep	Goat	Pig	Fowl	Duck
Nepal	6237231	3072682	911279	5451710	604902	13600807	391718
E.Terai	686794	268294	15102	463400	55680	766297	147719
C.Terai	592282	275589	6084	588774	17897	984458	101375
W.Terai	457870	178274	11990	195305	12149	464517	51304
MW.Terai	353170	174273	83337	211944	53683	775138	10115
FW.Terai	166544	76529	25893	85747	30815	395787	23953
Total	2256660	972959	142406	1545170	170224	3386197	334466
%	36.2	31.7	15.6	28.3	28.1	24.9	85.4

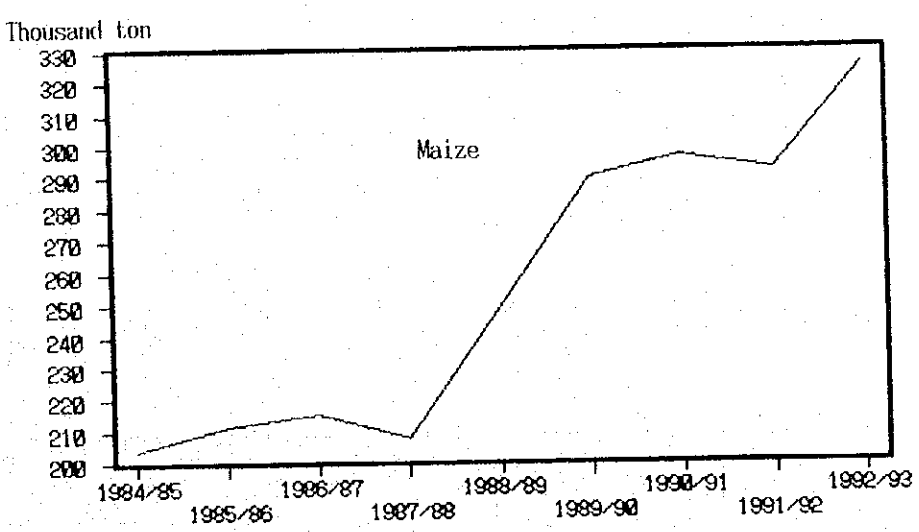
Table 4.1.6 Milk Production in Terai (1992/93)

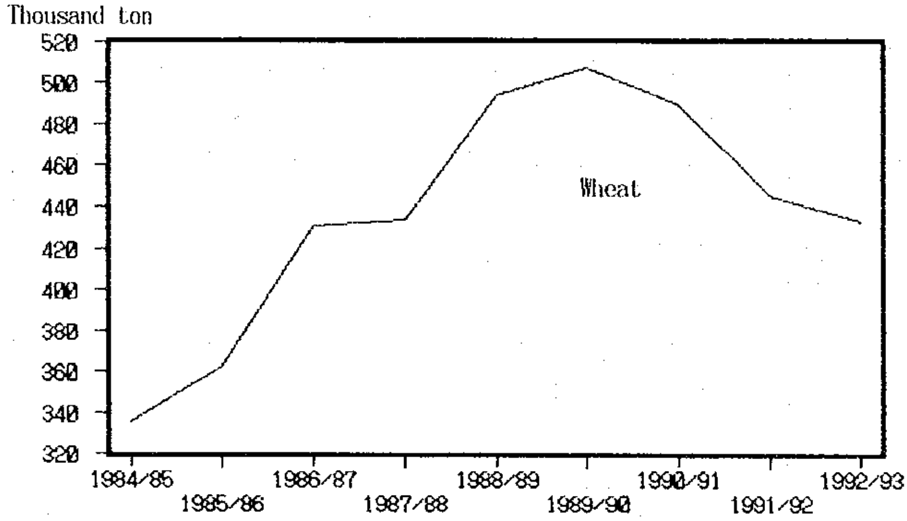
	No. Milk Cow	No. of Milk Buffaloe	Cow Milk	Buffaloe Milk	Total Milk
Nepal	698931	755996	260786	615808	876594
E.Terai	75490	54174	33835	55628	89463
C.Terai	4758	63882	28352	62947	91299
W.Terai	26032	39734	11393	36175	48108
MW.Terai	32825	22391	10107	22299	32406
FW.Terai	20022	12867	6939	11848	18787
Total	159127	193048	90626	188897	280063
%	22.8	25.5	34.8	30.7	31.9

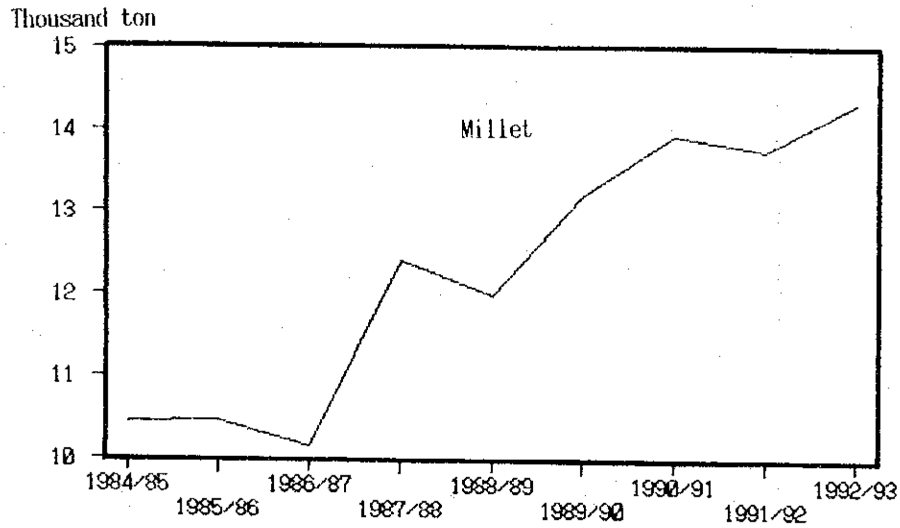
Figure 4.1.3 Agricultural Production(Terai Plain)

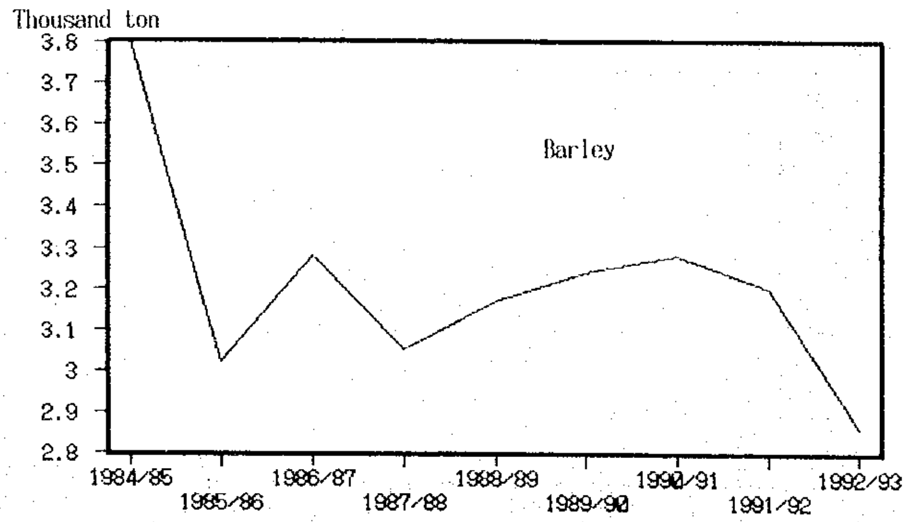







Thousand ton
520
500
480
460
440
420
400
380
360
340
320
Wheat
1984/85
1985/86
1986/87
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93


Thousand ton
15
14
13
12
11
10
Millet
1984/85
1985/86
1986/87
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93


Thousand ton
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
Barley
1984/85
1985/86
1986/87
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93

follows. Among three districts the average annual population growth in Banke District is the highest at 3.36 %, which is higher than all districts in the nation.

This is believed to be caused by the recent transmigration to the district from hilly and mountainous areas.

	Nepal	Jhapa	Mahottari	Banke
1981	15,022,839	479,743	361,054	205,323
1991	18,491,097	593,737	440,146	285,604
Ratio (%)	2.10	2.15	2.00	3.36

The National Sample Census of Agriculture (1991/92) reports the number of farm household by farm size. The total number of farm households, including landless farmers, in Jhapa is 74,727; 58,559 in Mahottari; and 35,912 in Banke. The average farm size in Jhapa is 1.41 ha, which is the largest among the three districts. The percentage of small-scale farmers, that is, farms less than 0.5 ha, is the largest in Mahottari at 41%, while 32% in Jhapa and 24% in Banke.

	Jhapa	Mahottari	Banke
Landless	1104	485	694
Under 0.1 ha	9326	3516	2372
0.1~0.2	4663	7002	1369
0.2~0.5	10062	13611	4899
0.5~1.0	13620	13605	8718
1.0~2.0	18324	11398	9701
2.0~3.0	9898	4365	4899
3.0~4.0	2986	2031	1659
4.0~5.0	2004	1364	675
5.0~10	2413	1000	810
Above 10 ha	327	182	116
Total	74727	58559	35912
Cultivated Land (ha)	105121	63754	49072
Average Farm Size (ha)	1.41	1.09	1.37

The number of farm households is estimated at approximately 12,080 in Jhapa; 6,420 in Mahottari; and 5,850 in Banke.

4.2.3. Farming Practices and Agricultural Production

(1) Farming Practices

1) Paddy

a) Plowing and Harrowing

The operations of plowing, harrowing, and puddling are performed two or three times by a pair of bullock or buffalo with traditional tools. The timing of these land preparations fluctuates depending on availability of rainfall, animal labor, and other inputs; and hired animals are sometimes used.

b) Nursery

The ratio of nursery beds is generally 6% to 7% of the paddy field. The growing period for seeds is about one month, and the height of the nursery is approximately 25 cm to 30 cm. At present both HYV and local varieties are planted in the districts.

c) Transplanting

Transplanting, which can save water compared with the method of direct seeding, is popular in the districts. Men and women are hired for transplanting, but children are not used because of the necessity for experienced labor in this type of work.

d) Weeding

The days for weeding vary in the districts, with approximately six to 20 days per hectare.

e) Harvesting

Since a laborer can harvest 500 m2 of paddy per day, approximately 20 man/days are necessary for harvesting one hectare by manual labor. Hired labor of men, women, and children are also used.

f) Drying on Paddy Field

Harvested paddies are temporarily dried for five to six days on the paddy field to reduce grain moisture.

g) Transportation

After the paddy is dried on the field, it is then transported to the farmer's house for threshing. Hired labor is used for manual transportation, along with a pair of bullock. The lack of farm roads presents problems in terms of transportation.

h) Threshing

There are two traditional threshing methods: manual threshing and animal threshing. Two to four cattle are generally used for animal threshing.

i) Drying of Paddy

Paddy after threshing is dried in the yard or sometimes on roads before milling.

j) Storage of Grains

Crops are transported home or the threshing shed after harvesting. After cleaning and drying, grain is stored in different storage facilities, including bins, pots, sacks, and so forth. The average duration of storage for grain ranges from 3.5 months to five months, and it is estimated that approximately 10% to 25% of the food grain are lost during storage.

2) Upland Crops

After harvesting monsoon paddy, also called main paddy, some type of upland crop is planted on the fields. However, the availability of second crops depends on soil moisture. When soil moisture is low, paddy land is left fallow. Wheat, mustard, and other winter vegetables are commonly planted as a second crops after plowing the land two or three times. Pulses such as lentils and pigeon peas are also commonly observed in fields.

(2) Agricultural Production and Cropping Intensity

The production of major crops in the three districts as of 1992/93 is estimated based on agricultural statistics.

Agriculture in the three districts can be characterized as Jhapa District as the largest producer of paddy in the entire country, with Mahottari and Banke districts having a larger share in the production of pulses.

(ton)

	Nepal	Jhapa	Mahottari	Banke
Paddy	2584900	202630	52140	36120
	(100)	(7.8)	(2.0)	(1.4)
Maize	1290500	18630	8200	20710
	(100)	(1.4)	(0.6)	(1.6)
Millet	236750	2190	1960	-
	(100)	(0.9)	(0.8)	
Wheat	765000	13090	26510	10400
	(100)	(1.7)	(3.5)	(1.4)
Barley	27610	20	220	20
	(100)	(0.1)	(0.8)	(0.1)
Oilseeds	93690	1790	2360	2430
	(100)	(1.9)	(2.5)	(2.6)
Potato	733300	12960	8140	4600
	(100)	(1.8)	(1.1)	(0.6)
Tobacco	6020	730	1200	40
	(100)	(12.1)	(19.9)	(0.7)
Sugarcane	1365870	5500	43610	4270
	(100)	(0.4)	(3.2)	(0.3)
Pulses	203560	890	9540	8580
	(100)	(0.4)	(4.7)	(4.2)

Source: Agricultural Statistics of Nepal, 1992/93

The present cropping intensity is estimated based on the National Sample Census of Agriculture: 151% in Jhapa; 171% in Mahottari; 142% in Banke. The ratio of planted areas with paddy is 83.2% in Jhapa, 71.3% in Mahottari, and 74.3% in Banke. As stated above, Jhapa District can be characterized as a paddy producing area.

4.2.4. Number of Livestock

Livestock, particularly cattle and buffalo plays very important role in both farming operations and farm economy. Since farm practices such as plowing and harrowing are not mechanized, farmers generally have several cattle and buffaloes. Milk produced is sold to the local markets and consumed domestically.

The following represents the number of livestock in 1992/93.

(head/birds)

	Jhapa	Mahottari	Banke
Cattle	191,340	97,854	81,342
Buffalo	75,986	39,882	53,326
Sheep	51	1,258	10,274
Goats	105,788	106,065	81,120
Pigs	22,357	1,970	11,197
Chickens	178,031	85,016	109,476
Ducks	25,183	6,671	1,505

Source: Agricultural Statistics of Nepal, 1992/93

Major feed sources for cattle and buffalo are rice, straw, and wild grass which can be provided by grazing. However, the feed balance for the Total Digestible Nutrients (TDN) in Terai shows a shortage according to the National Farm Management Study (1986) by DFAMS.

4.2.5. Farm Input and Labor Use

The use of chemical fertilizers in Nepal is still the lowest among the countries in the region as Nepal relies on imported chemical fertilizers, which can be costly. As well, the actual use of chemical fertilizers in the three districts is very low due to higher unit costs: Farmers do not want to use chemical fertilizers in order to save on production costs, and some farmers do not use chemical fertilizers at all. The major source of fertilizer is barn yard manure/compost produced at their farm. This is common to all three districts, which results in lower crop yields. Insecticides and other plant protection chemicals are also not commonly used.

Hired labor and hired animals are commonly used for paddy at a rate of 35 Rs/man/day and 60 to 100 Rs/animal/day. One pair of bullock is used for land preparation and two or four cattle are used for threshing. Women and children are also important sources of farm labor during harvesting, transportation, and threshing work.

4.2.6. Crop Yield and Productivity

Crop yields over the last five years (1988/89 to 1992/93) have been compared in order to clarify the productivity of major crops in the three districts.

(ton/ha)

	Paddy	Maize	Wheat	Millet	Barley	Oilseeds
Jhapa	2.45	1.31	1.59	1.01	0.91	0.61
Mahottari	2.12	1.95	1.48	1.04	0.87	0.54
Banke	1.94	1.61	1.40	-	1.00	0.55

	Potato	Pulses
Jhapa	9.09	0.65
Mahottari	10.08	0.57
Banke	11.98	0.68

It can be said that paddy yields are higher in the eastern region than the western as a result of the difference in annual precipitation. Unlike cereal crops, the yield of potatoes in the western region is higher than that of the eastern region.

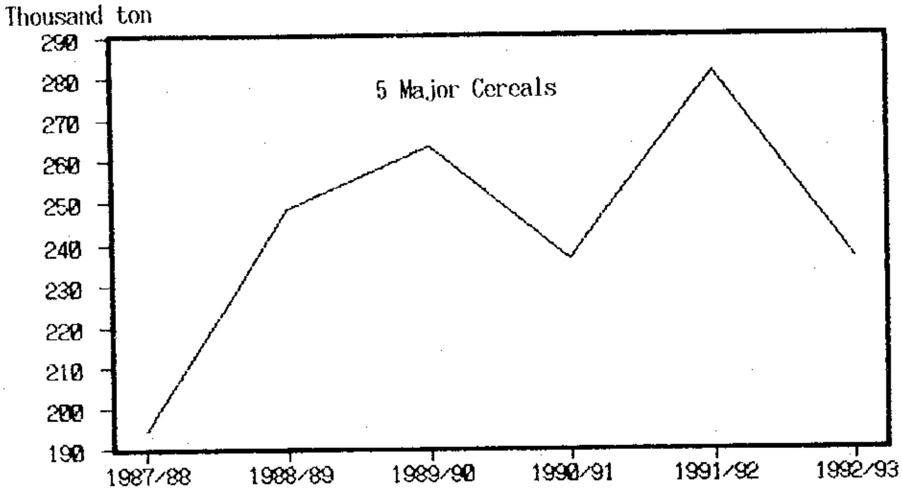
4.2.7. Crop Budgets and Irrigation Benefit

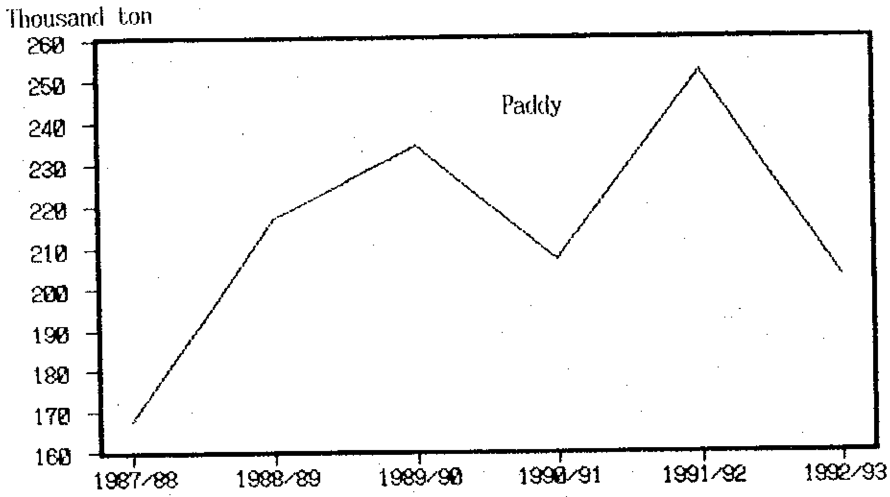
Crop budgets vary with the yield, cost of production, and farmgate prices in each district. Yields also vary with improved seeds or local seeds, and with and without irrigation. The cost of production per hectare varies with the use of fertilizer and labor. Taking the risk of rainfall and cost savings in terms of production into consideration, farmers do not input the appropriate amount of chemical fertilizers and agricultural chemicals.

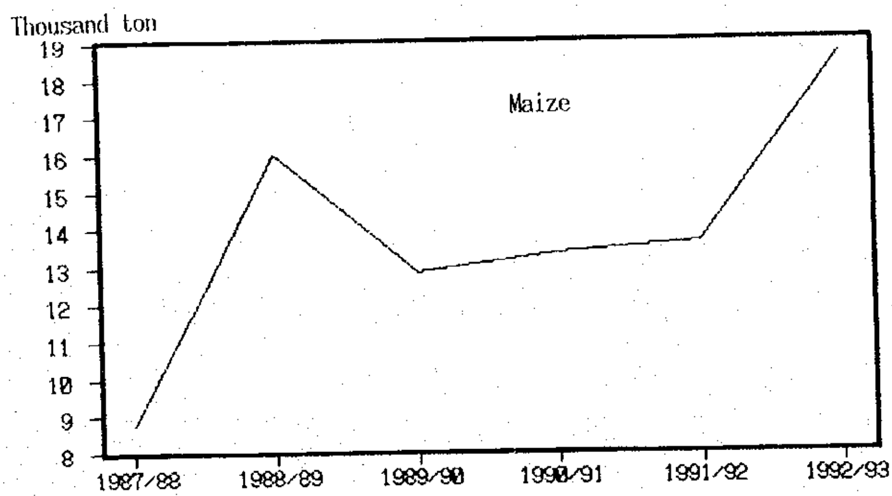
The following chart shows the paddy budgets and the impact of irrigation in three districts:

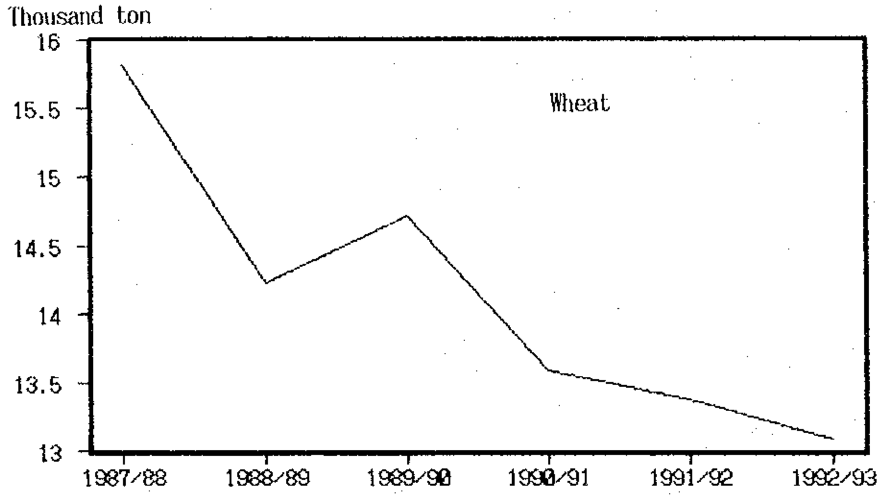
	Yield (kg/ha)	Gross Income (Rs/ha)	Cost (Rs/ha)	Net Income (Rs/ha)
Unirrigated Local Paddy				
Jhapa	2050	11090	7269	3821
Mahottari	1800	9980	6910	3070
Banke	1430	8678	6157	2521
Unirrigated Improved Paddy				
Jhapa	2330	12510	7383	5127
Mahottari	2285	12575	6988	5587
Banke	1945	11748	6614	5134

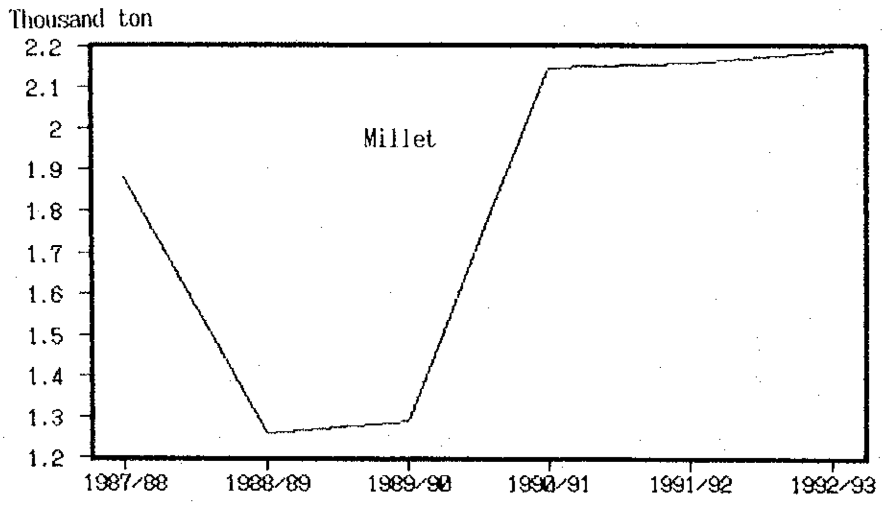
Figure 4.2.1 Agricultural Production(Jhapa)








Thousand ton
16
15.5
15
14.5
14
13.5
13
Wheat
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93


Thousand ton
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
Millet
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93

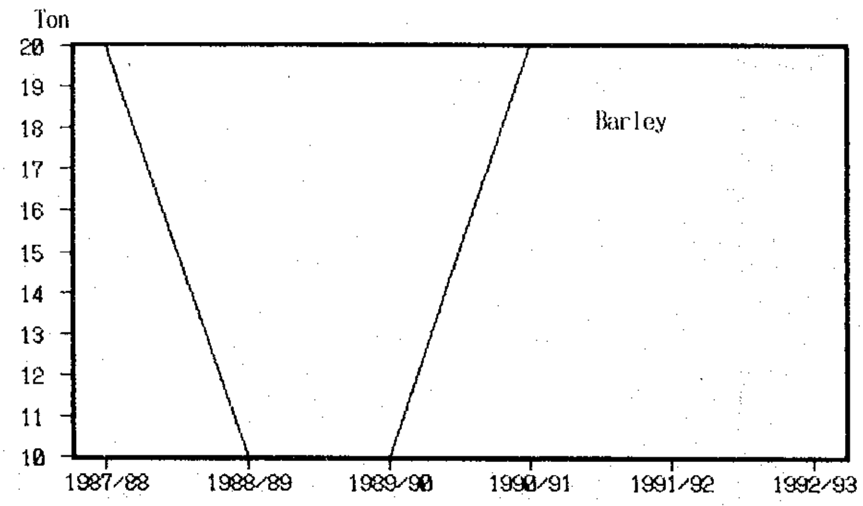
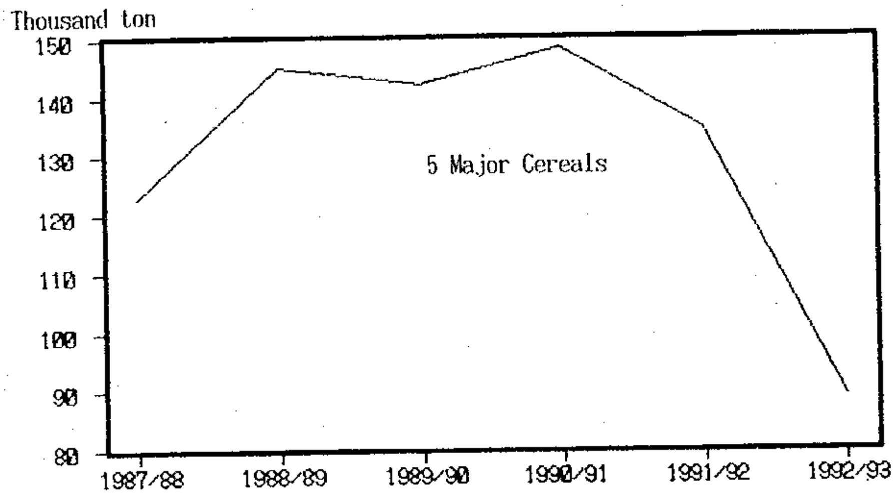
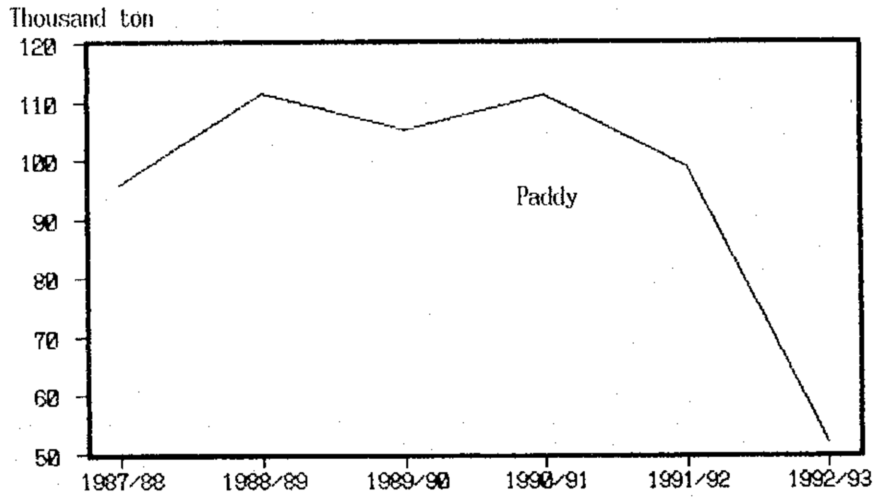
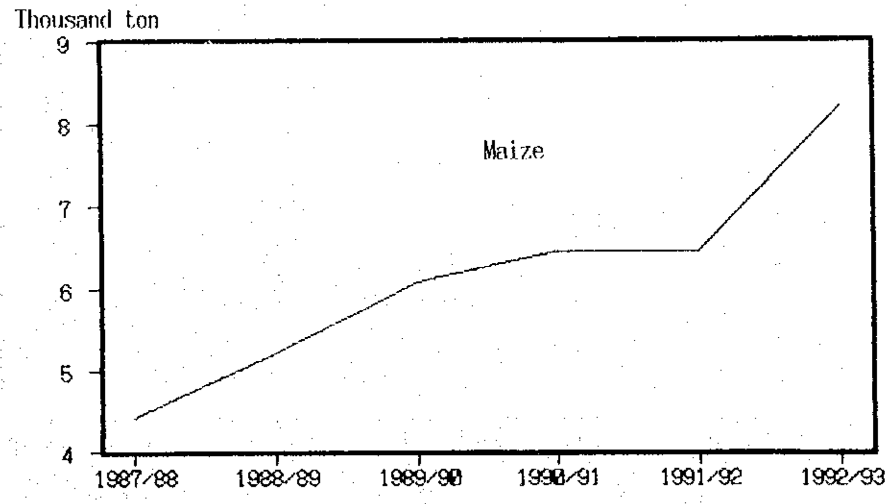
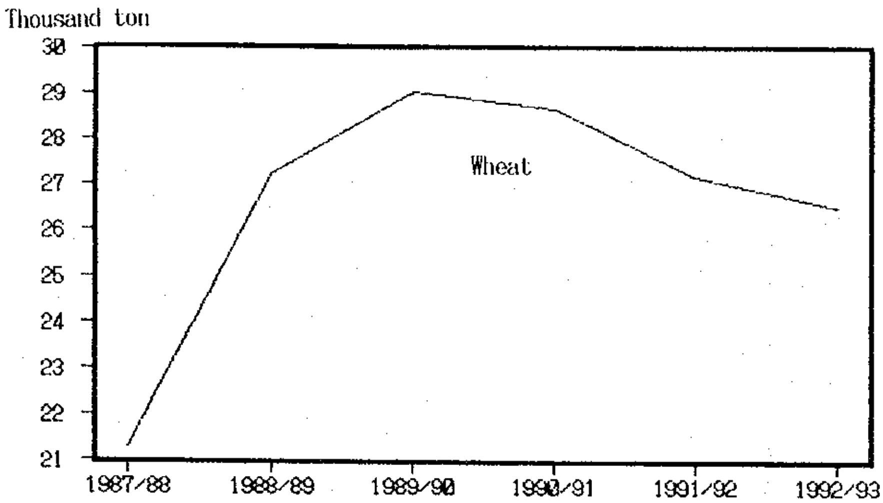

Ton
20
19
18
17
16
15
14
13
12
11
10
Barley
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93

Figure 4.2.2 Agricultural Production (Mahottari)

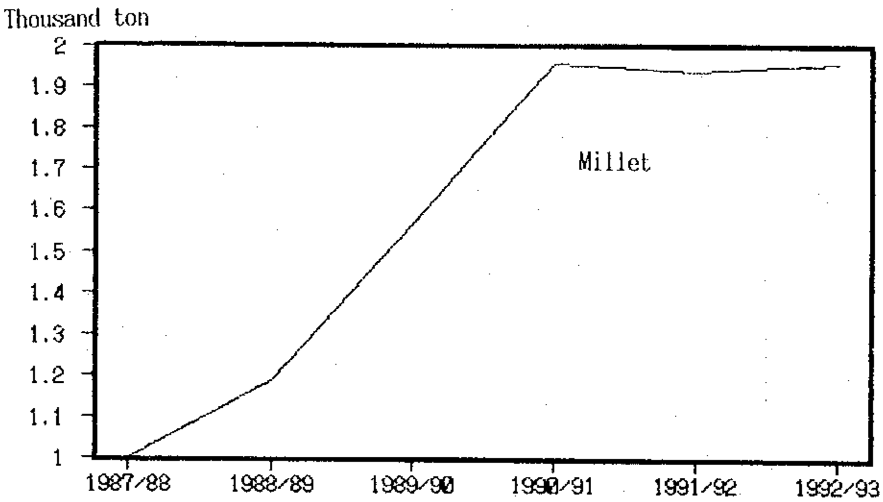




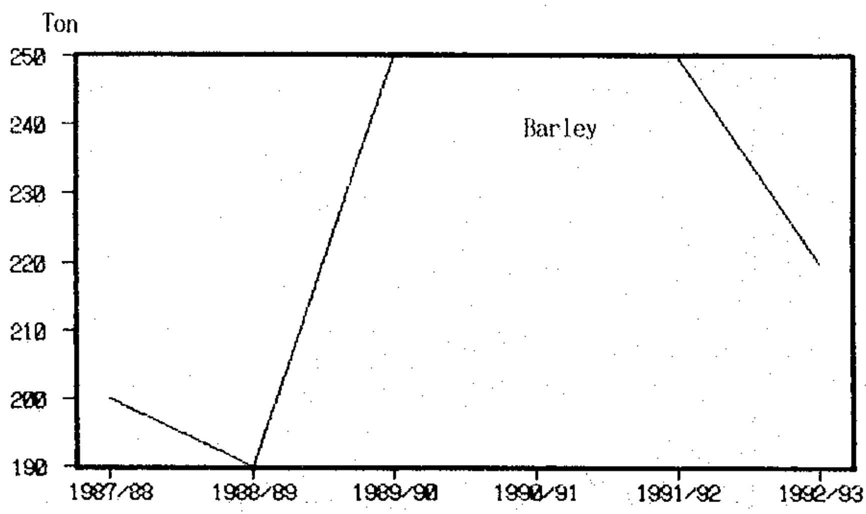




Thousand ton
30
29
28
27
26
25
24
23
22
21
Wheat
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93

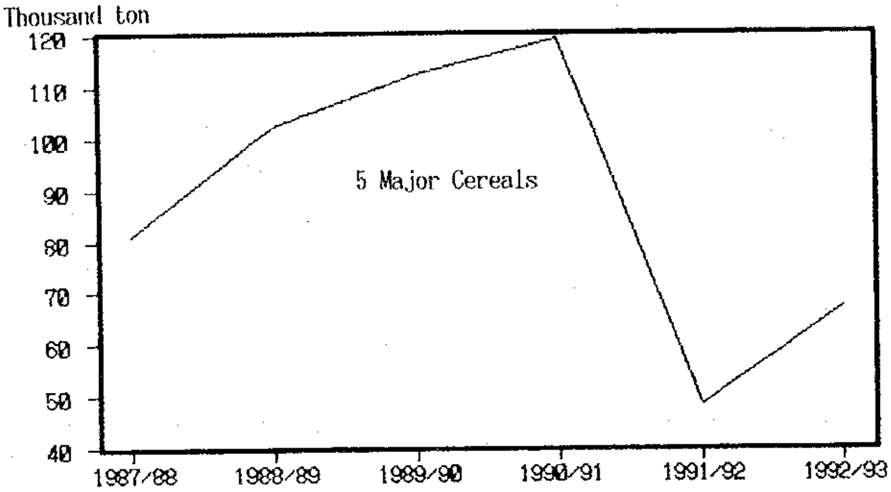


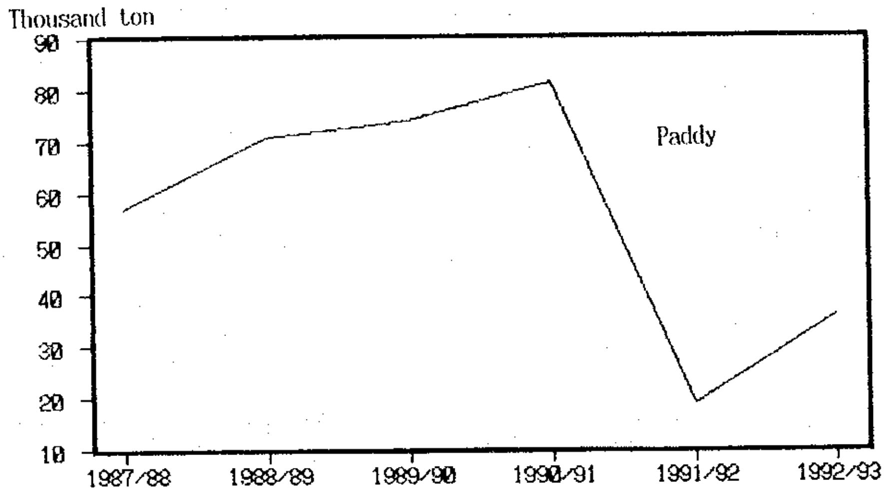
Thousand ton
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
Millet
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93

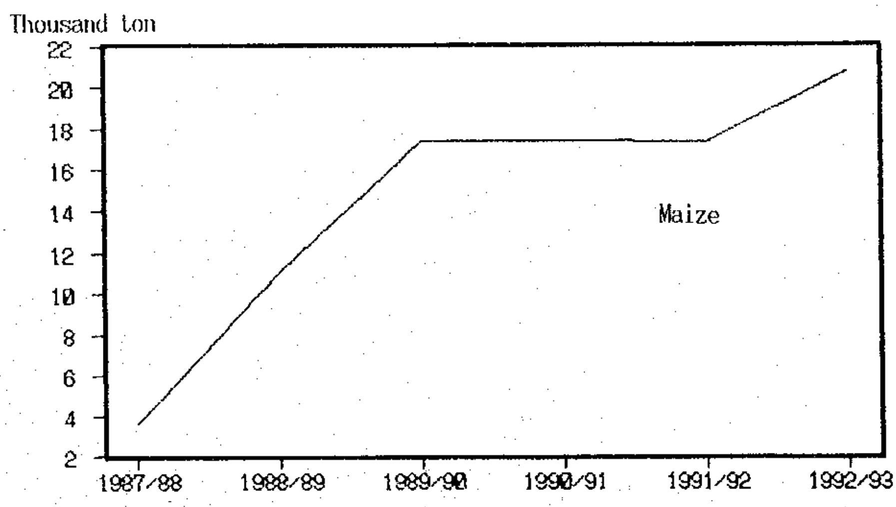


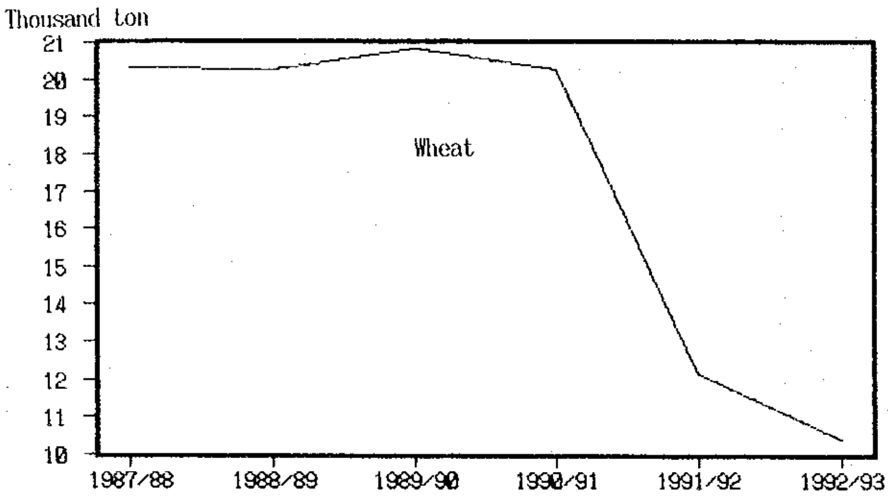
Ton
250
240
230
220
210
200
190
Barley
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93

Figure 4.2.3 Agricultural Production (Banke)

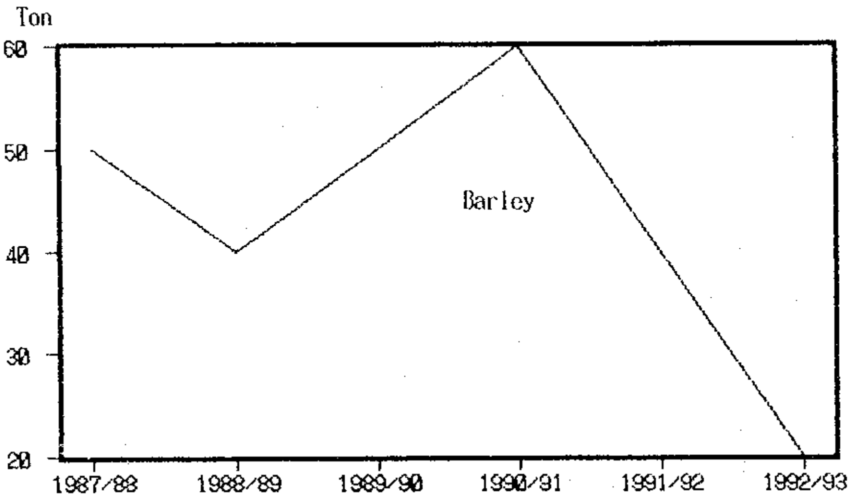








Thousand ton
21
20
19
18
17
16
15
14
13
12
11
10
Wheat
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93



Ton
60
50
40
30
20
Barley
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93

Irrigated Improved Paddy				
Jhapa	2650	14150	7834	6316
Mahottari	2704	14840	7748	7090
Banke	2120	12670	6900	5770

The impact of irrigation is very strong; however, the irrigated land in each district has been limited despite the efforts to improve the irrigation sector. The following shows crop yields for irrigated and unirrigated fields, and local varieties and improved varieties in the Terai Plain in 1986/87.

	Rainfed		Irrigated	
	LV	HYV	LV	HYV
Paddy	1789	2019	2074	2565
Maize	1427	1652	1550	1699
Wheat	-	1423	-	1653

Source: Cost of Production for Major Crops in Nepal, DFAMS

4.2.8. Marketing and Prices

(1) Marketing

Marketing channels for agricultural products are common in all three districts, as shown below.

Paddy: Farmer-Middleman-Wholesaler/Miller-Retailer-Consumer

Vegetable: Farmer-Retailer-Consumer
Farmer-Marketed by farmers themselves - Consumer

Milk: Farmer-Consumer
Farmer-Chilling Center-Dairy Factory
(processing)-Retailer-Consumer

Livestock: Animal market is held once in a week

Transportation of agricultural products to market is done manually or by bullock cart or by bicycle.

(2) Farmgate Prices

A considerable difference in farmgate prices for crops and inputs is observed in the three districts. The price of local paddy is higher than that of improved varieties because of the quality and the preferences of Nepalese people.

			(Rs/kg)
	Jhapa	Mahottari	Banke
Paddy (HYV)	4.79	6.07	5.27
Wheat	4.25	6.01	6.31
Maize	4.59	4.92	5.57
Mustard (seed)	23.11	23.48	20.33
Lentil	14.94	13.94	21.60
Potato	3.88	4.53	3.60
Cauliflower	7.69	6.00	7.00

Note: Average prices from 1988 to 1993

(3) Storage and Mill

AIC, NFC, and the Cooperative Society have their own warehouses (Godown) to store cereal grains and agricultural inputs, but the total capacity in 1989 was small at 15,800 tons in Jhapa, 1,600 tons in Mahottari,s and 3,700 tons in Banke.

There is a considerable number of rice mills in each district which provide milling services to farm households. There are also oil processing units and flour mills.

4.2.9. Farm Economy

Farmers with less than 0.5 ha are classified as small farmers in Nepal.

According to the National Sample Census of Agriculture (1991/92), the number of farm households defined as small farmers with a farm size less than 0.5 ha is estimated at 32% in Jhapa, 41% in Mahottari, and 24% in Banke. In addition, there is a considerable number of landless farmers.

The poverty line to meet the minimum caloric requirement per capita per year is estimated at US$93 by NPC. This rate is applicable even in 1993, which is often discussed with ADO and ADBN.

The average family size in 1991 is 5.4 in Jhapa, 5.5 in Mahottari, 5.9 in Banke (Statistical Yearbook, 1993); therefore, minimum incomes can be estimated as Rs 21,400 in Jhapa, Rs 21,800 in Mahottari, and Rs 23,200 in Banke.

Results of the farm economic survey in Jhapa District carried out by the Study Team for 35 farm households show that family incomes vary from Rs 13,200 to 60,000 according to farm sizes. It can be said in general that the agricultural system is subsistence oriented, particularly for the case of small farmers. Some products are sold by farmers after the harvest in order to meet their cash requirements. It is estimated that a farm of at least two hectares and several animals is necessary to manage a family in Jhapa at the present time.

4.2.10. Farmers' Organization and Governmental Supporting Services

(1) Cooperative Society

The representative farmer's organization is the cooperative society, and district cooperative offices are provided in each district.

The major functions of the cooperative societies include,

- fertilizer supply
- seed supply
- insecticides supply
- machinery supply
- shelling services
- purchasing paddy from farmers.

Cooperative societies include,

- tea cooperative society
- loan cooperative society
- women development cooperative society,
- consumer society,
- agricultural consumer cooperative society

However, some cooperative societies are restricted in their activities, as mentioned above, due to a lack of capital and a lack of quality management and so forth.

(2) Water Users Association (WUA)

There are two types of irrigation systems in Nepal: the farmer-managed irrigation system (FMIS) and the agency-managed irrigation system (AMIS).

FMIS is mainly constructed, operated, maintained, and managed by farmers through the mobilization of their local organization. They have their own local water users' organization, with certain policies, rules, and regulations.

AMIS is constructed, operated, and managed by one of the governmental agencies. In a beneficiary area of AMIS, a water users' association (WUA) is formed to aim at improved water management and crop production. In general WUA is composed of the following staff:

Chairman	1
Vice-Chairman	1
Secretary	1
Joint Secretary	1
Treasurer	1

The duties of a WUA are as follows:

- to maintain harmony and cooperation between various WUAs included in the area;
- to recommend water distribution methods and volumes to the irrigation officer;
- in the case where two or more WUGs may be concerned in maintenance works, WUA shall coordinate and acquire technical personnel if so required from the irrigation office and organize voluntary labor from the WUGs;
- to maintain close contact with the irrigation office about various works required for efficient water distribution;
- to arrange for checks and audits of income/expenditures of concerned WUGs; and
- to instruct and advise WUGs within its area about water use, which shall be the duty of the WUGs to follow.

WUAs are expected to function well in maintaining irrigation facilities and distributing irrigation water equitably, with harmony among WUA members. DOI is promoting the transfer of the maintenance of irrigation facilities to WUAs. For this purpose, continuous training and education for farmers as well as the development of competent leaders will be necessary over the long term. Therefore, DOI is requested to take the initiative in these aspects while maintaining contacts with MOA.

(3) Agricultural Development Bank (ADBN)

The Agricultural Development Bank (ADBN) is the main agency responsible for the supply of institutional credit in the districts. Some branch offices are provided in each district. However, institutional credit is more likely to be borrowed by larger farmers, contrary to the non-institutional loans to small farmers.

(4) Agricultural Input Corporation (AIC)

The Agricultural Input Corporation (AIC) is responsible for supplying agricultural inputs such as chemical fertilizers and agri-chemicals. AIC supplies these agricultural inputs to cooperative societies, and the cooperative societies are responsible for distributing inputs to farmers.

(5) Agricultural Development Office (ADO)

The Agricultural Development Office (ADO) is responsible for agricultural extension services. Some agricultural service centers and agricultural sub-service centers are provided at the village development committee level under ADO. Junior technicians (JT), junior technical assistants (JTA), and some selected farm leaders are working for agricultural extension services at the farm level.

(6) Small Farmers' Development Program (SFDP)

The Small Farmers' Development Program (SFDP) has been implemented by ADBN since 1975 and aims at improving the socio-economic status of the rural poor using a group dynamics approach. The program has worked on functional literacy, leadership creation among the poor, creation of community assets (roads, irrigation schemes, community forests, and so on), individual assets (animals, housing, and so on), training, group savings, and has increased the income of the poor.

4.3. Existing Groundwater Irrigation

4.3.1. Bhailawa-Lumbini Groundwater Irrigation Project (BLGIP)

The Bhairawa-Lumbini Groundwater Project (BLGIP) covers Rupandehi District in Western Terai to irrigate some 21,000 ha by deep tubewells (DTW). The project has been implemented by DOI in three stages: the first stage from 1977 to 1982; the second stage from 1983 to 1990; and the third stage from 1992 to 1999, and is financed by the World Bank. The third stage of the project is shown below.

	No. of DTW	Irrigation Area	Area/DTW
1st Stage	64	7680 ha	120 ha
2nd Stage	38	4560	120
3rd Stage	73	8720	120

Average farm size is 1.3 ha.

Irrigation water is supplied to field through buried pipelines. Water users' associations (WUA) have been established to improve water distribution and to maintain irrigation facilities, and the transfer of facility operation and maintenance (O & M) to WUAs is being promoted. WUAs collect Rs 400/ha/year from members for O & M of irrigation facilities such as DTW and pumps. The energy source for pumps is electricity.

Major crops are monsoon paddy, wheat, oilseeds, and pulses. The areas for spring paddy are estimated at less than 25% of the command area. According to the staff of agricultural sub-centers which are provided at three locations in the area, pulses and vegetables are more profitable crops than paddy. As per paddy, HYV is dominant in the area. The following shows the procedure of yield increase of HYV, before and after the project.

(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 cannot be seen in other districts have also been constructed, and as a result, the transportation of crops as well as general transportation conditions have improved.

Regarding the extension services, three agricultural sub-center DOIs are provided to the area to give farmers guidance on new agricultural technology and training on water use and so forth.

4.3.2. Feasibility Study on Groundwater Irrigation in Birganj

The project area is located in the Terai Plain in the Central Development Region, covering 32,900 ha, as well as the districts of Bara and Parsa. Though the irrigable area is 13,840 ha of the gross area, results of the Study show that it is most economical to apply a 185% cropping intensity in the irrigation acreage of 7,2350 ha. Combined irrigation methods using groundwater and surface water are applied to FMISI for 1,200 ha and SDIS for 970 ha; and a rainfed area of 5,080 is planned to be irrigated by groundwater. The project also includes the construction of 90 km of farm roads. Groundwater is projected to be pumped up from 200 shallow wells and 70 DTWs to irrigate monsoon paddy, wheat, sugarcane, maize, and vegetables.

The total project cost is estimated at 1.587 billion Rs (US $31 million), and an eight year construction period is projected including design and planning. EIRR is estimated at 20.5%.

CHAPTER FIVE

AGRICULTURAL DEVELOPMENT

CHAPTER-FIVE: AGRICULTURAL DEVELOPMENT

5.1 Basic Concept for Development

5.1.1. Governmental Policy for Agricultural Development

HMGN formulated the Program for Fulfillment of Basic Needs (1985-2000) (BNP). Food constitutes the most essential component among the basic needs and is highlighted herein. The food programs in BNP are based on estimates of the minimum caloric requirement at 2,250 calories/capita/day at the national level. BNP emphasizes increasing access to the required level of caloric intake through the consumption of cheaper food sources, such as rice, maize, wheat, millet, barley, pulses, and potatoes.

5.1.2. Strategy for BNP

The strategy is set forth in irrigation management and agricultural support programs, in low-cost demand-driven assistance to FMIS, development of new small schemes, and the construction of shallow tubewells. Because of the emphasis within the food production targets of BNP, investment options in the master plan are evaluated based on food grain-dominated cropping patterns and related assumptions. In ascending order of unit investment cost, evaluated investment options include the following:

(a) irrigation management improvements for existing projects,
(b) groundwater irrigation in the Terai,
(c) small- and medium-surface projects in the Terai, both new and rehabilitated,
(d) small-surface projects in the hills and mountain districts, both new and rehabilitated,
(e) large projects in the Terai

- single-purpose projects, generally river runoff
- multipurpose projects, generally incorporating upstream storage.

5.1.3. Basic Approach

Giving due consideration to the preceding projects in the Terai Plain, three representative districts have been selected as follows:

Region	Representative District
Eastern R	Jhapa D
Central R	Mahottari D
Mid-Western R	Banke-Bardiya D

Next, the priority sub-areas determined in the above districts are based on the following perspectives.

(a)Expected yields of groundwater by DTWs.
(b)Land capability for agricultural production.
(c)Existence of preceding projects.
(d)Present situation of flood damage.
(e)Development conditions of the social infrastructure.
(f) Volition of beneficiaries for development.

(Refer to Figure 5.1.1 to Figure 5.1.3)

5.1.4. Target and Scope of Development

Cropping intensity should be introduced to maintain 200% throughout the year as well as to promote profitable cash cropping during the dry season. As for cropping yields, the main crops proposed shall be required to double their yields based on proper farm management, including irrigation. Furthermore, WUGs are necessary to sustain reasonable operation and maintenance after completion of the project.

5.2. Crops and Cropping Patterns

5.2.1. Priority Sub-Areas in Jhapa District

(1) Proposed Main Crops

The main cereal crops proposed in this area are paddy, wheat, maize, and millet. Jute was an important cash crop in the district, however, international market prices are dropping because of the development of synthetic fibers. Potato is the main vegetable carbohydrate crop and can be consumed or marketed. Jhapa District has a long history as being a very popular high-quality rice production area in Nepal, and weather conditions and soil characteristics of the paddy fields are adapted to high-quality rice production. Considering this situation and the establishment of an irrigation system in future, spring paddy is introduced as a main crop. The proposed main crops in the priority sub-area in Jhapa District area are as follows:

Main paddy (monsoon season)
Spring paddy (dry season)
Main wheat (dry season)
Spring maize (dry season)
Miscellaneous (dry season), potatoes, other kinds of vegetables

(2) Cropping Pattern

The proposed cropping patterns have been determined based on the following conditions.

(a) Rainfall pattern depending on meteorological data
(b) Land system prepared by DOI
(c) Growing stage of main crops
(d) Balance of water requirements
(e) Cropping intensity kept with 200%
(f) Avoiding the duration of intensive farm labor

Details of the proposed cropping patterns are outlined in Figure 5.2.1.

5.2.2. Priority Sub-Area in Mahottari District

(1) Proposed Main Crops

Paddy, wheat, and lentil are the major food crops grown in this district, though potatoes and onions have recently been cultivated as cash crops. Potatoes are mostly exported as a cash crop to India. Oilseed and sugarcane are cultivated by surrounding households and are mostly consumed domestically through local markets. The proposed main crops in this priority sub-area are as follows:

Main paddy (monsoon season)
Spring Paddy (dry season)
Main wheat (dry season)
Potatoes (dry season)
Onions (dry season)

(2) Cropping Pattern

The proposed cropping patterns have been recommended based on the same perspectives as outline for Jhapa District Details are shown in Figure (5.2.2).

5.2.3. Priority Sub-Area in Banke District

(1) Proposed Main Crops

The main crops in this area are paddy, wheat, and maize, as well as grams and pulses. Among the cash crops, mustard, potatoes, sugarcane, and tobacco can be mentioned to some degree, though they barely meet home consumption needs. Based on the establishment of an irrigation system and the increase of cash incomes for the beneficiaries, the proposed main crops for this sub-area are as follows:

Main paddy	(monsoon season)
Main wheat	(dry season)
Spring maize	(dry season)
Pulses	(dry season)
Mustard	(dry season)
Potatoes	(dry season)
Miscellaneous	(dry season), vegetables and others

(2) Cropping Pattern

As mentioned in the previous section, the cropping pattern is decided based on the following points:

- to minimize the water requirement throughout the year
- to minimize the labor requirements for the proposed crops

Details of the proposed cropping patterns are shown in Figure 5.2.3.

5.3. Extent of Beneficial Area by Irrigation

5.3.1. Priority Sub-Area in Jhapa District

(1) Selection of Area

Lifting tests of existing wells as well as additional well testing well have been carried out in the southern part of Jhapa District, which covers the area between Biring and Mechi rivers, except for the northern part of the E-W Highway. A map of safe yields with a scale 1: 50,000 is placed on a map of the land system, while the boundary of the commendable area with irrigation is delineated on a map of the land system. According to results of the lifting test, an average safe yield of groundwater is estimated at approximately 120 l/sec for one deep tubewell within the commendable area (refer to the attached general map).

(2) Irrigable Area

The commendable area is divided into arable land and non-arable land based on the map of the land system, which measures the acreage with a planimeter. As a result of the measurement, the net arable land is estimated at approximately 17,000 ha, within a gross area of 29,700 ha considered to be irrigable (refer to Table 5.3.1).

5.3.2. Priority Sub-Area in Mahottari District

(1) Selection of Area

The proposed sub-area has been selected based on the map of safe yields, which is divided into two sub-areas. The priority 1 area is located near Jaleswar and the other is located in the northern part, 20 km from Jaleswar, as mentioned in the attached general map. According to map of safe yields, the priority 1 area is estimated to have an average yield of 66 l/sec, while the other sub-area is expected to have an average yield of 97 l/sec.

(2) Irrigable Area

The arable land of the priority 1 and 2 sub-areas is estimated at approximately 4,000 ha and 3,000 ha, respectively, through the same approach as in Jhapa District. This land is considered to be irrigable. The details of land classification are shown in Table 5.3.1.

5.3.3. Priority Sub-Area in Banke District

(1) Selection of Area

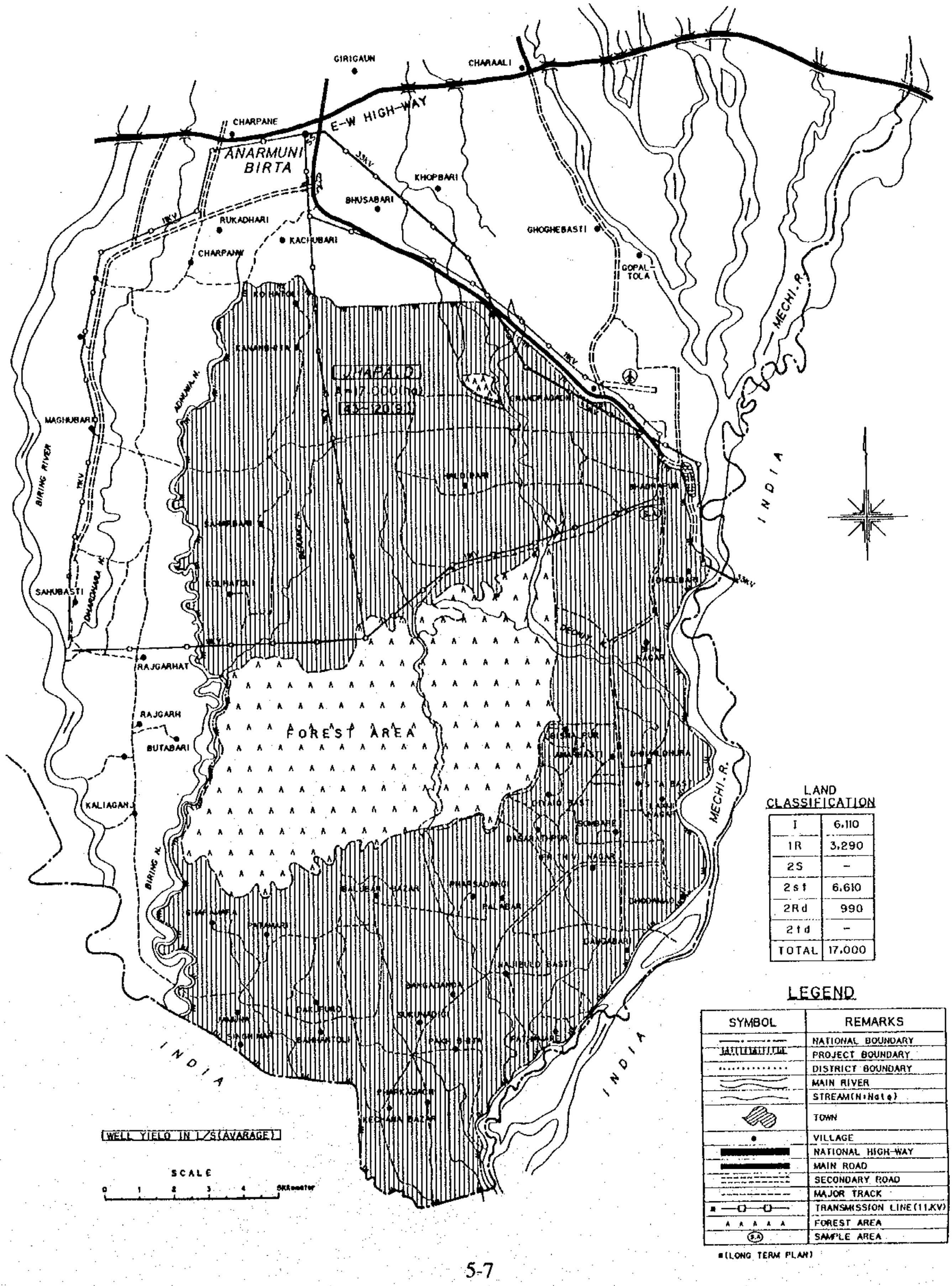
The development area in this district - thin (5 km x 24 km) and directly connected to India in the southern part - is located on the western side of Nepalgunj. A portion of the western side in the commendable area is located in the Bardiya District. As for the safe yield of the DTWs, a production yield of 110 l/s is expected, which is higher than the other districts' sub-areas.

(2) Irrigable Area

The arable land in this sub-area has been estimated based on the same procedure as in Jhapa and Mahottari districts. The arable land is estimated at 8,000 ha, which is equivalent to the irrigable area. Details of land classification are shown in Table 5.3.1.

Figure 5.1.1

GENERAL MAP OF REPRESENTATIVE AREA FOR D.T.W PROJECT IN JHAPA DISTRICT

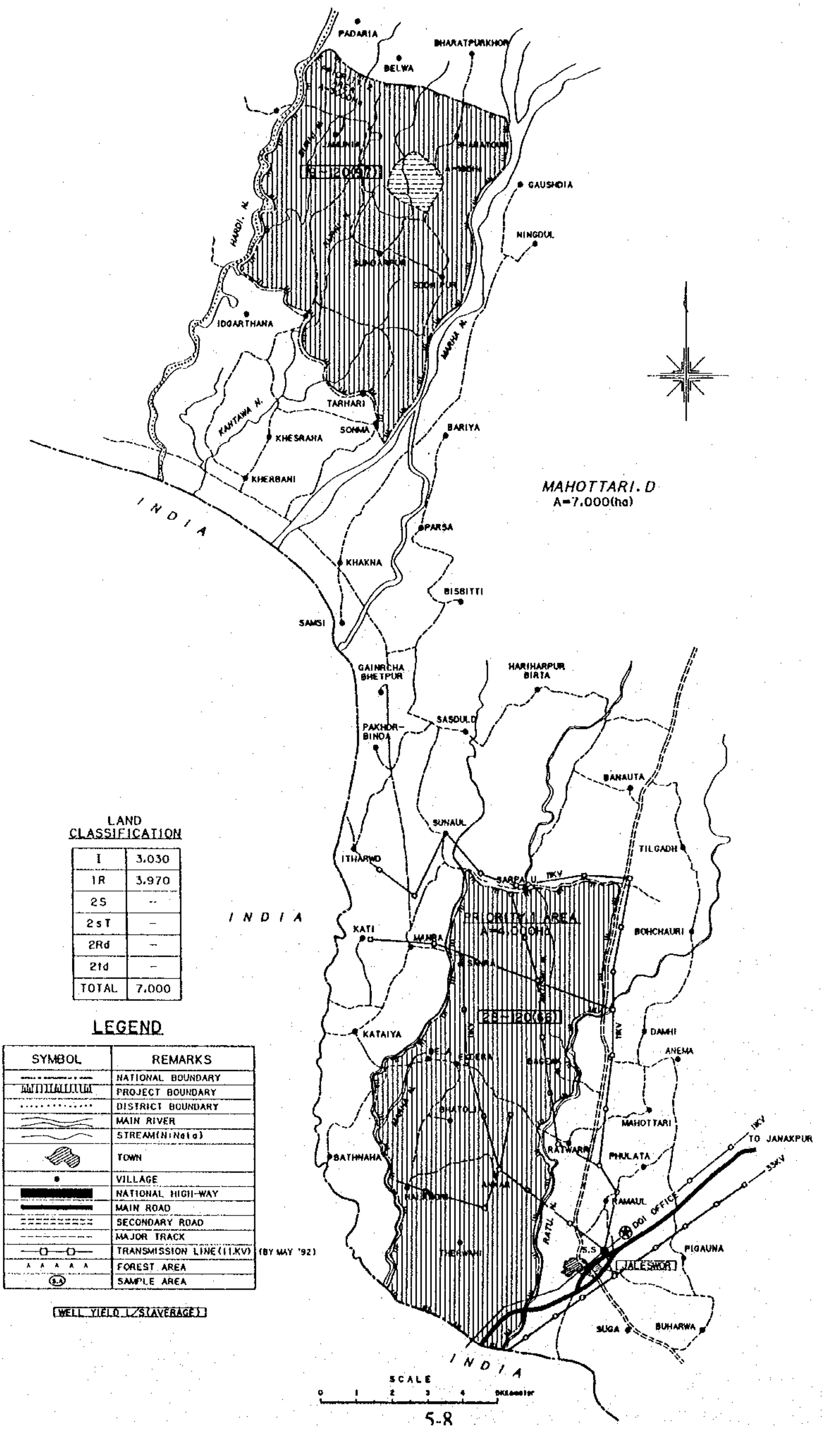


LAND CLASSIFICATION

I	6,110
1R	3,290
2S	-
2st	6,610
2Rd	990
2td	-
TOTAL	17,000

Figure 5.1.2

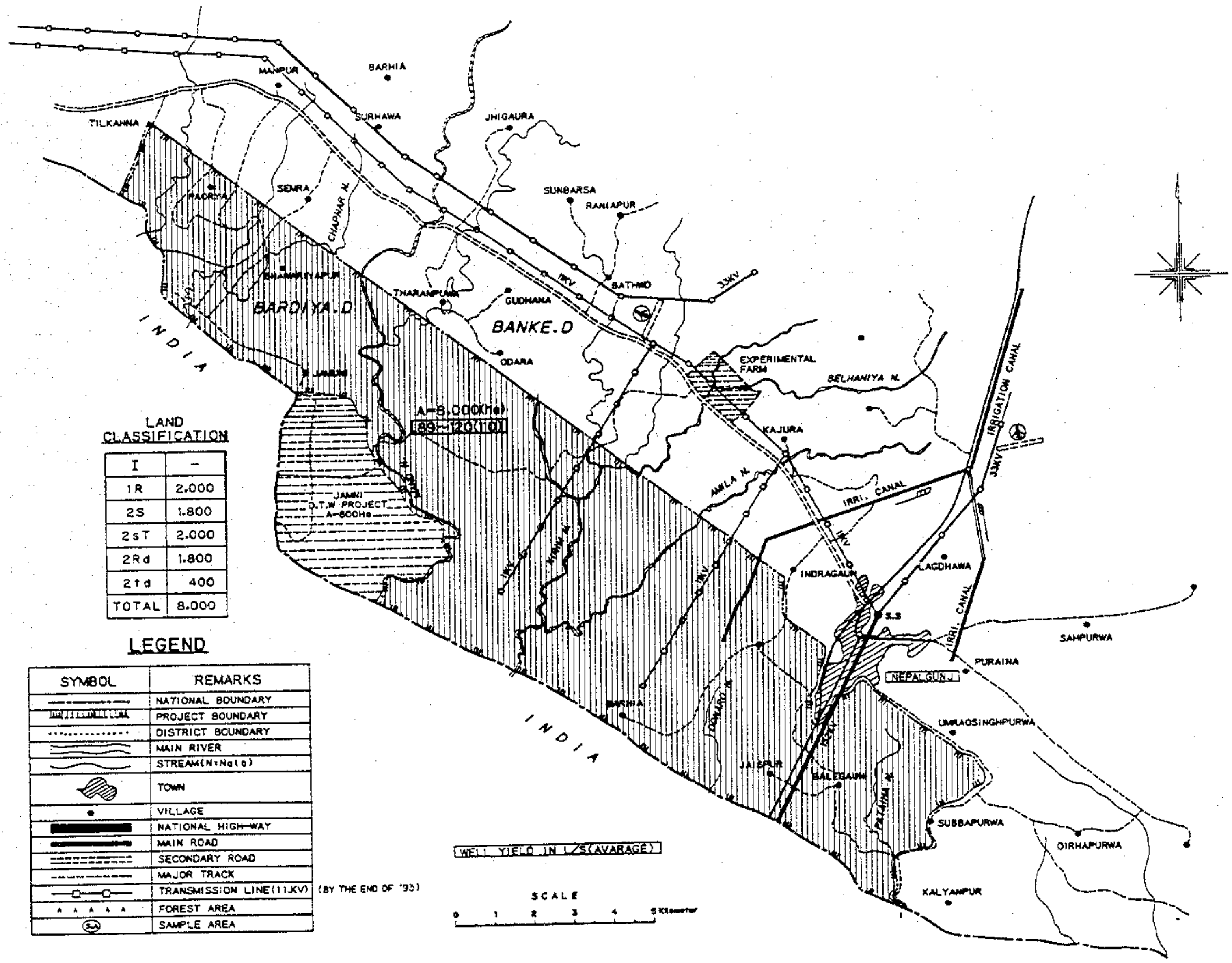
GENERAL MAP OF REPRESENTATIVE AREA FOR D.T.W PROJECT IN MAHOTTARI DISTRICT



LAND CLASSIFICATION

I	3.030
1R	3.970
2S	--
2sT	-
2Rd	-
2td	-
TOTAL	7.000

Figure 5.1.3 GENERAL MAP OF REPRESENTATIVE AREA FOR D.T.W PROJECT IN BANKE-BARDIYA DISTRICT



LAND CLASSIFICATION

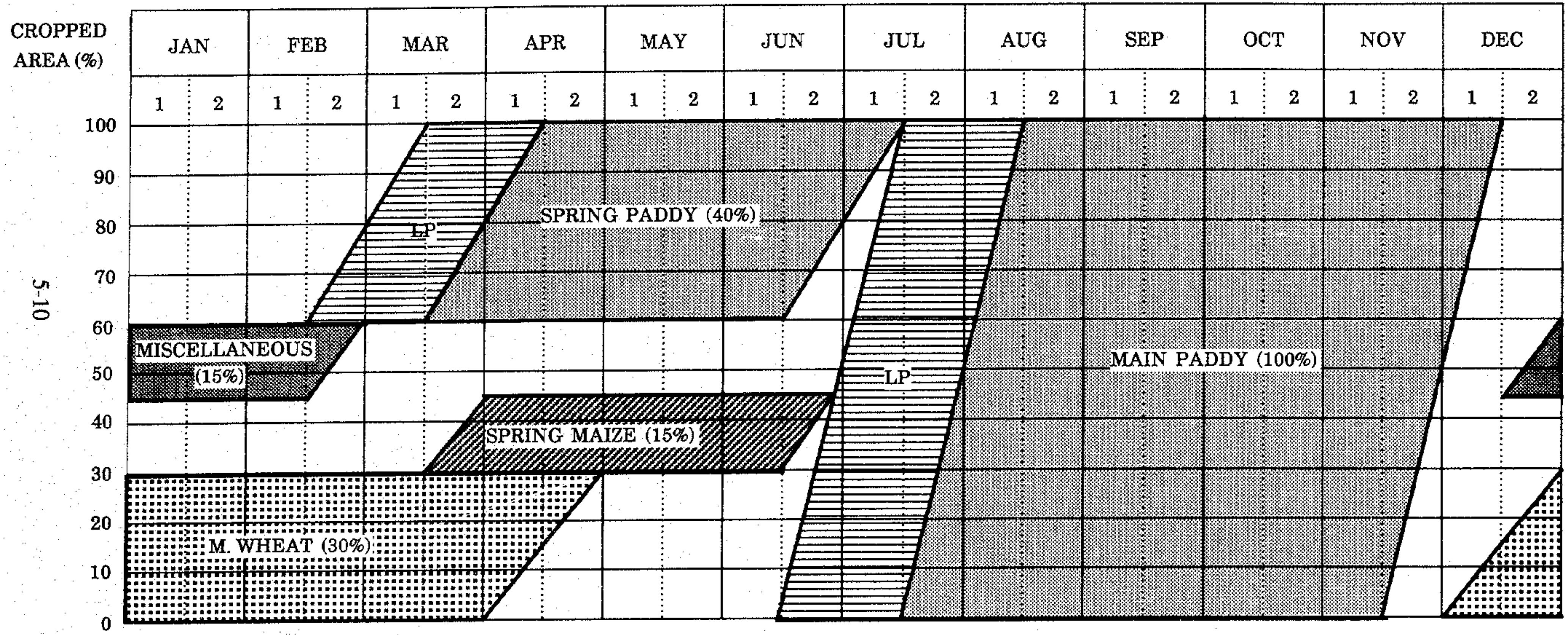
I	-
1R	2.000
2S	1.800
2sT	2.000
2Rd	1.800
2td	400
TOTAL	8.000

LEGEND

SYMBOL	REMARKS
	NATIONAL BOUNDARY
	PROJECT BOUNDARY
	DISTRICT BOUNDARY
	MAIN RIVER
	STREAM(N:Nala)
	TOWN
	VILLAGE
	NATIONAL HIGH-WAY
	MAIN ROAD
	SECONDARY ROAD
	MAJOR TRACK
	TRANSMISSION LINE(11KV) (BY THE END OF '93)
	FOREST AREA
SA	SAMPLE AREA

PROPOSED CROPPING PATTERN

FIGURE 5.2.1 Cropping Intensity = 200% (JHAPA DISTRICT)



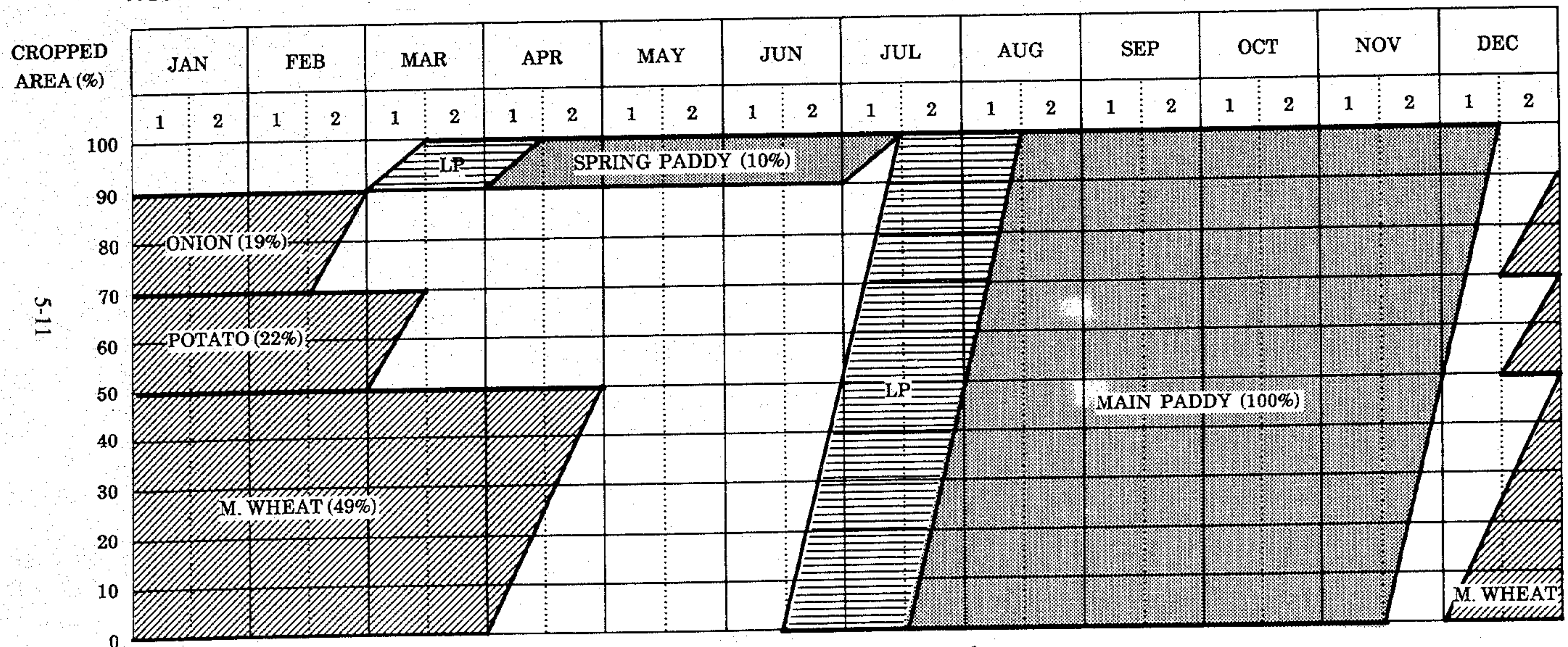
Note ; L.P ; Land Preparation M.WHEAT ; Main wheat Calender Periods ;1/2 month intervals

FIGURE 5.2.2

PROPOSED CROPPING PATTERN

Cropping Intensity = 200%

(MAHOTTARI DISTRICT)



Calendar Periods ; 1/2 month intervals

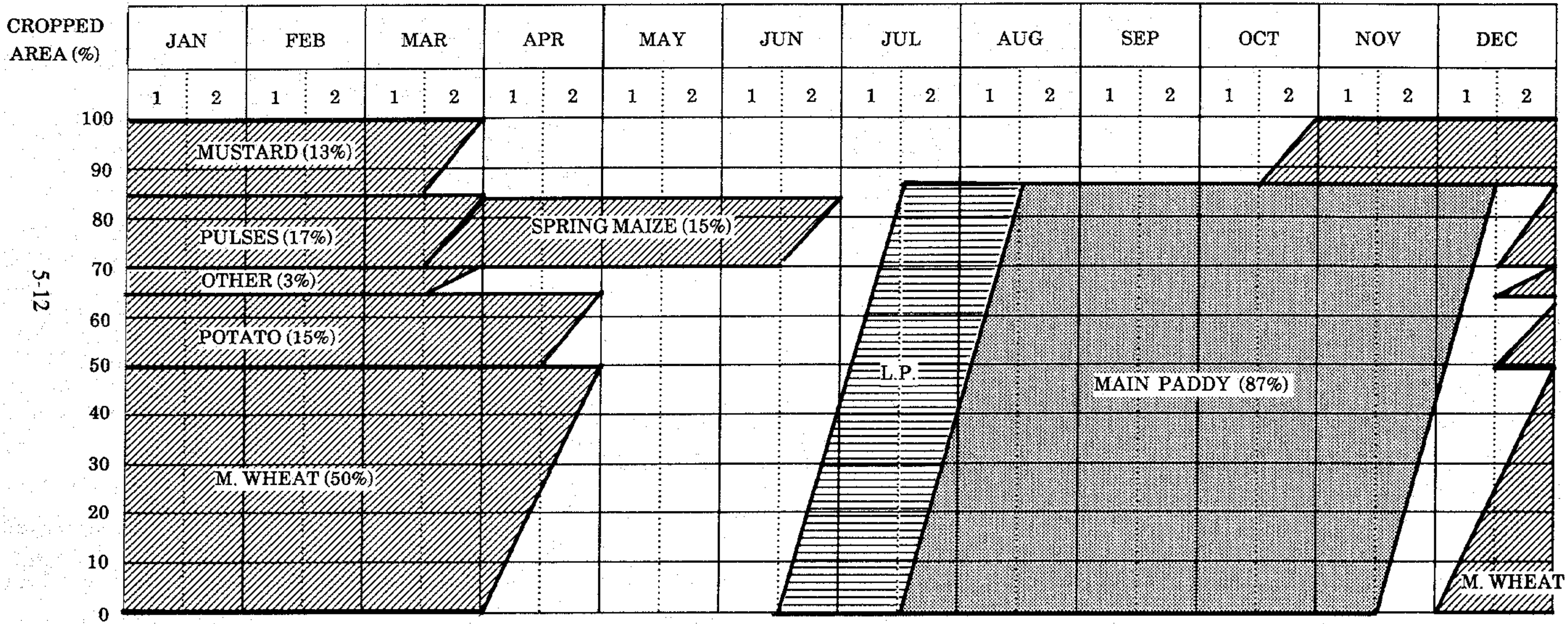
Note : L. P ; Land Preparation ; M. WHEAT = Main Wheat

FIGURE 5.2.3

PROPOSED CROPPING PATTERN

Cropping Intensity = 200%

(BANKE DISTRICT)



Calendar Periods ; 1/2 month intervals

Note : L. P ; Land Preparation ; M. WHEAT = Main Wheat ; S. Wheat = Secondary Wheat

TABLE 5.3.1 LAND CLASSIFICATION OF SUB-AREA IN DISTRICT

(Unit; ha)

Items \ District	JHAPA	MAHOTTARI	BANK - BARDIYA	TOTAL	Remarks
(1) Gross - Area	29,700	9,800	12,100	51,600	
(2) Non - Arable Land	12,700	2,800	3,300	18,800	
(3) Net Arable Land	17,000	7,000	8,000	32,000	
(4) Land Classification					
I	6,110	3,030	-	9,140	
1R	3,290	3,970	2,000	9,260	
2S	-	-	1,800	1,800	
2st	6,610	-	2,000	8,610	
2Rd	990	-	1,800	2,790	
2td	-	-	400	400	
TOTAL	17,000	7,000	8,000	32,000	

5.4. Crop Yield and Production

It is necessary to supply irrigation water stably at required periods and at required amounts, in order to generate irrigation benefits. Agricultural inputs of farmers will be increased by the stable supply of irrigation water, which will remove risks to the water supply. As a result, cropping intensity and crop yields are expected to increase; however, sustainable supporting services of agricultural extensions and WUAs are indispensable.

The target yields in the three districts are determined based on the present yields and the results of trial yields in the agricultural research station, as well as the results of existing irrigation projects such as BLGIP and the data collected by the district ADOs. Based on these studies, present and projected agricultural production are calculated as shown in Table 5.4.1.

Table 5.4.1 Projected Crop Production

1. Jhapa

	Planted Area (ha)	Yield (ton/ha)	Production (ton)
Without Project			
M.Paddy, Rainfed	15,300	2.33	35,649
Maize	1,700	1.31	2,227
Wheat	4,420	1.59	7,028
Total	21,420		
With Project			
M.Paddy, Irrigated	17,000	4.00	68,000
S.Paddy, Irrigated	6,800	3.80	25,840
Maize	2,550	2.70	6,885
Wheat	5,100	2.70	13,770
Miscellaneous	2,550	0.80	2,040
Total	34,000		

2. Mahottari

	Planted Area (ha)	Yield (ton/ha)	Production (ton)
Without Project			
M.Paddy, Rainfed	6,300	2.29	14,427
Wheat	1,400	1.48	2,072
Pulses	1,400	0.60	840
Others	700	0.54	378
Total	9,800		
With Project			
M.Paddy, Irrigated	7,000	3.40	23,800
S.Paddy, Irrigated	700	3.60	2,520
Wheat	3,430	2.60	8,918
Onion	1,330	13.00	17,290
Potato	1,540	12.00	18,480
Total	14,000		

3. Banke

	Planted Area (ha)	Yield (ton/ha)	Production (ton)
Without Project			
M.Paddy, Rainfed	6,400	1.95	12,480
Maize	800	1.61	1,288
Mustard	800	0.55	440
Wheat	2,400	1.40	3,360
Pulses	800	0.68	544
Total	11,200		
With Project			
M.Paddy, Irrigated	6,960	3.50	24,360
Maize	1,200	2.60	3,120
Mustard	1,040	0.80	832
Wheat	4,000	2.10	8,400
Pulses	1,360	1.00	1,360
Potato	1,200	14.00	16,800
Others	240	11.00	2,640
Total	16,000		

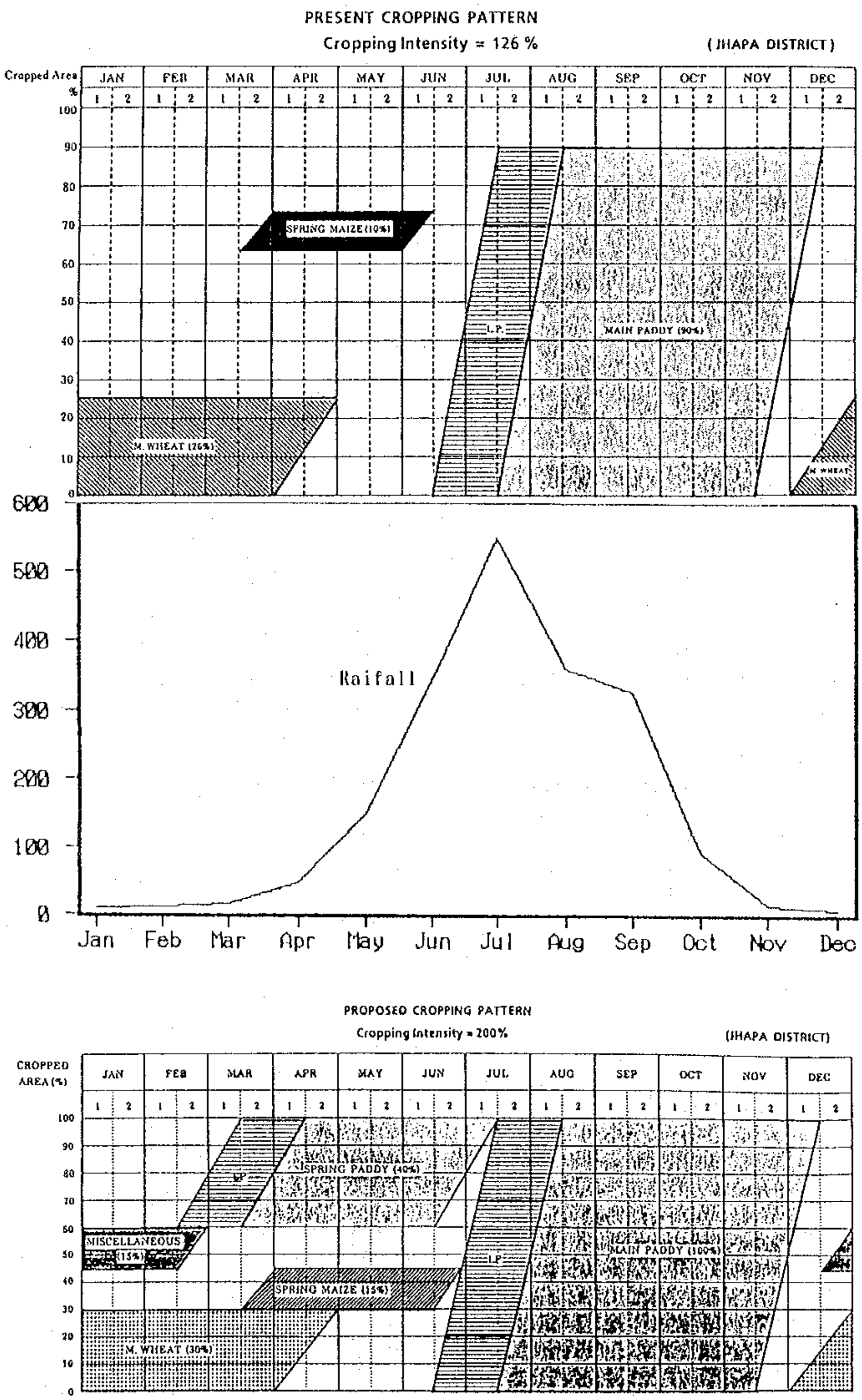


Figure 5.4.1 Present and Proposed Cropping Pattrens in Jhapa District

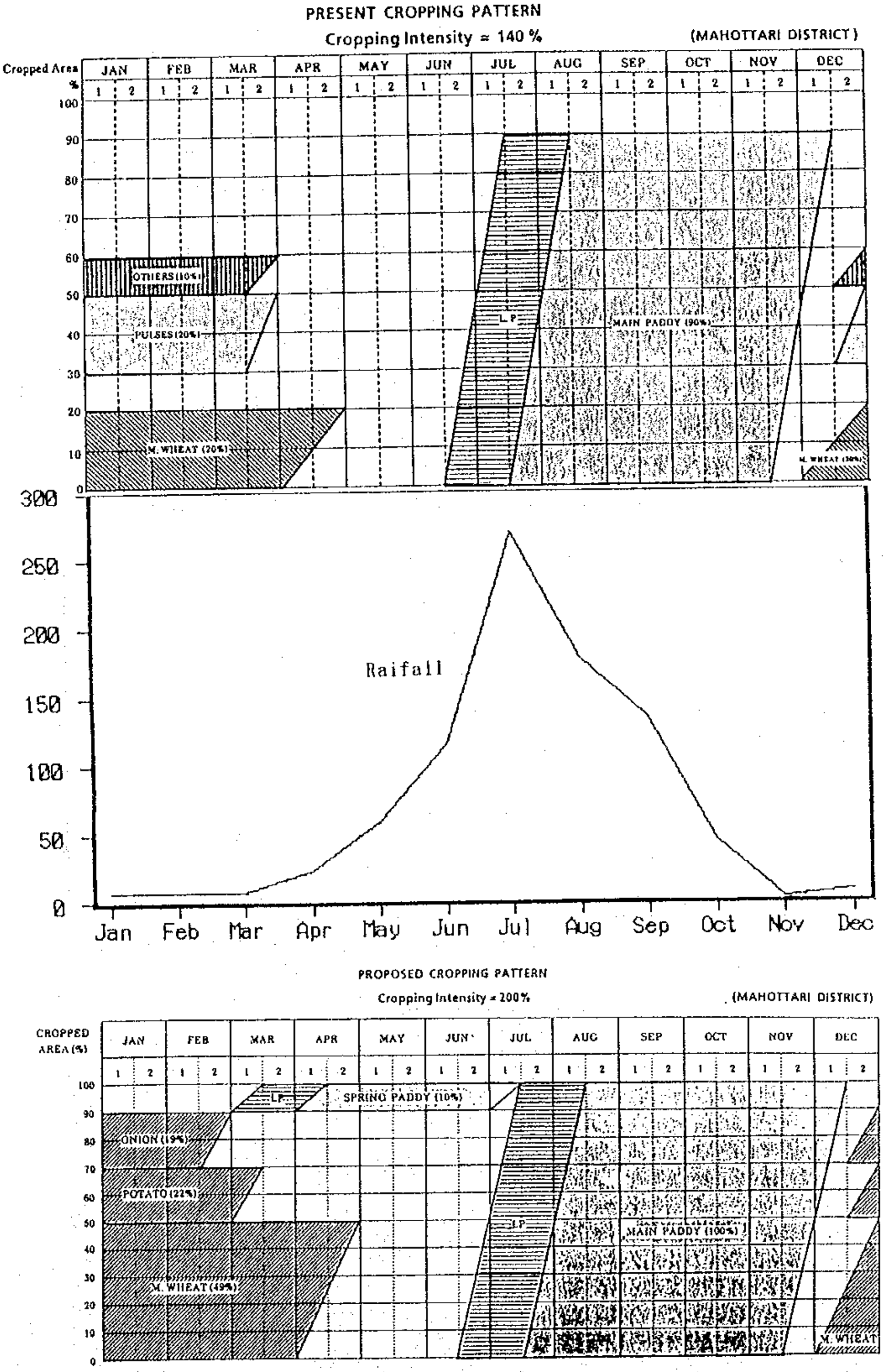


Figure 5.4.2 Present and Proposed Cropping Pattrens in Mahottari District

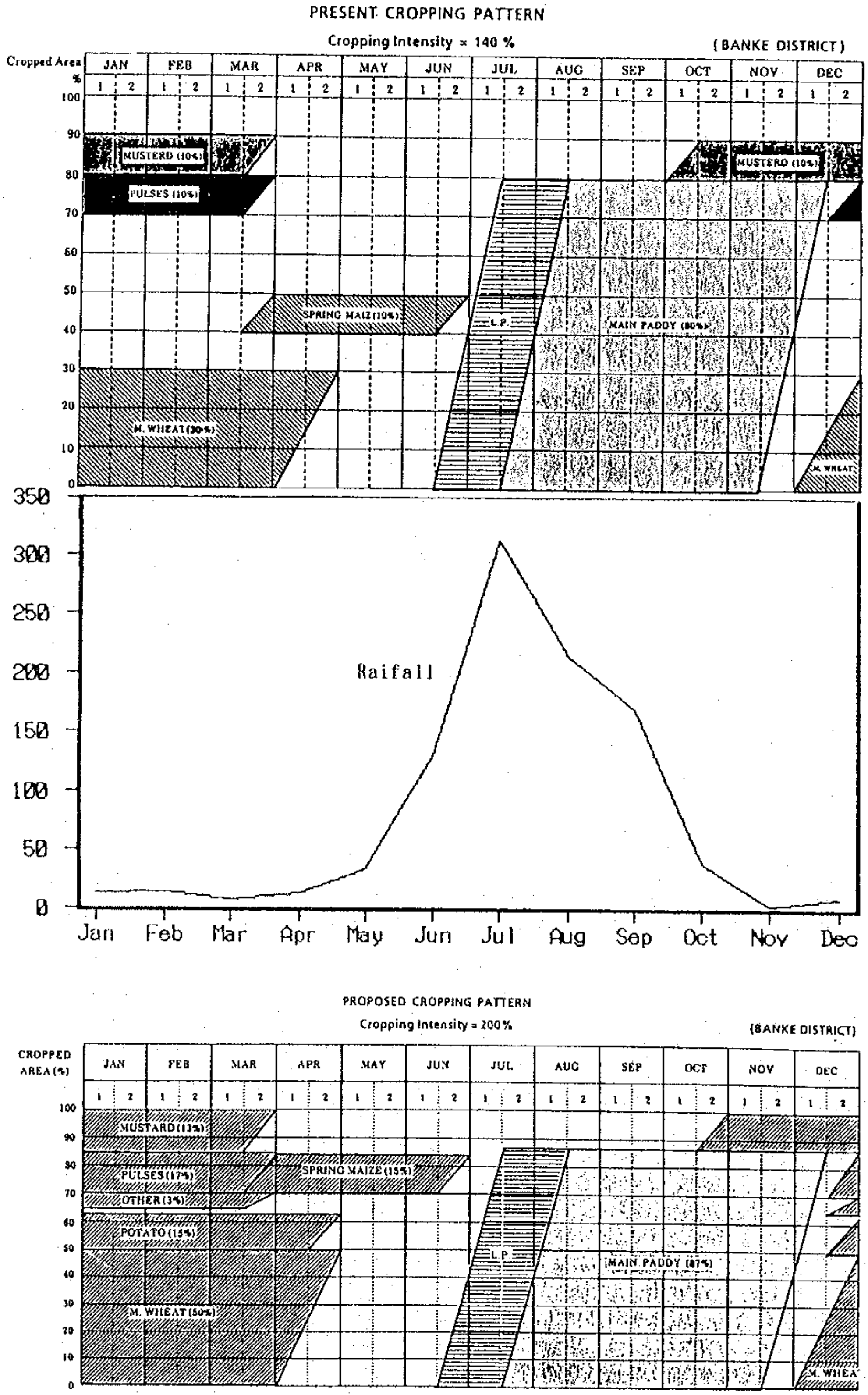


Figure 5.4.3 Present and Proposed Cropping Pattrens in Banke District

5.5. Marketing

Cropping will be possible not only during the monsoon season but also during the dry season as a result of the implementation of irrigation projects in the three sub-area. This will also result in an increase in crop production. As a result, the amount of crops sent to market will also increase; however, marketing should be organized through cooperatives, rather than by individuals in order to deal with wholesalers and middlemen.

5.6. Organization and Supporting Services

The groundwater irrigation project will make it possible to increase agricultural production, but the effects will be small if the supporting services, such as WUA, agricultural extension services, and agricultural credits, are not implemented.

5.6.1. WUAs and WUGs

Irrigation dominates agricultural production and farm incomes. Irrigation facilities therefore are indispensable to sustainable agricultural production, but this requires proper operation and maintenance by farmers, the collection of irrigation charges, and equitable water distribution. WUAs and WUGs will function effectively for these purposes and a request will be made for their establishment before the completion of the irrigation facilities. It is important to have the farmers understand the role of the WUAs and WUGs, the necessity for irrigation fee collection, and so forth. The Farmers' Organization Division in the proposed Project Offices shall be function to training and to educate the farmers.

5.6.2. Agricultural Extension Services

JTs and JTAs under the agricultural sub-centers shall be assigned to contact farm leaders and farmers in their fields. Water management appropriate to the growing stages of crops and crops arrangement will be required to generate higher irrigation benefits. JTs and JTAs are also requested to advise farmers regarding to use of certified seeds, improvements in farm management, and new farm techniques. To accomplish this purpose, a sufficient number of competent JTs and JTAs will be dispatched in the areas.

5.6.3. Agricultural Credit Services

Despite providing institutional credit services, such as ADBN, most farmers use private credit at higher interest from relatives, neighbors, and money-lenders because of the complicated procedures for applying for institutional credit. Taking into consideration that some 74% of the rural population are poor, as estimated by the World Bank, credit at lower interest rates and simpler application procedures should be introduced for small-scale farmers.

5.6.4. Cooperatives

Cooperatives at the present time function only in distributing agricultural inputs supplied from AIC to farmers. In order to sell crops profitably, cooperatives rather than farmers should function to sell crops to middlemen and wholesalers. Originally cooperatives were established to deal with crops as an organized activity, but they no longer function in this manner. Cooperatives should be strengthened to deal not only with agricultural inputs but also crops in an organization way in order to increase the profit for farmers.

CHAPTER SIX

PLAN OF IRRIGATION

CHAPTER-SIX: PLAN OF IRRIGATION

6.1. Basic Strategy

6.1.1. Objective of Irrigation

As mentioned in the cropping pattern, the main crops include main paddy, wheat, and spring paddy; cash crops have been proposed during the dry season in the three priority sub-areas as paddy requires much more water compared with other crops. Fortunately, monsoon paddy receives valuable rainfall in its growing stage; but the rainfall pattern does tend to fluctuate year by year, and favorable rainfall for crops cannot be expected during the dry season. Based on the above, the objectives of irrigation for the proposed area are as follows:

- to stabilize the water supply for fluctuating water demand in the monsoon season (supplementary water supply).
- to make incremental production during the dry season.

6.1.2. Viable Crops for Irrigation

As mentioned in agricultural development, cereal crops are very important for the beneficiary, therefore, main paddy and spring paddy have been given first priority as a viable crop. Consideration however is being given to supply irrigation water to spring maize in dry season; and if the pump capacity exceeds the allowance during operation in a normal year, another cash crop can receive irrigation water within this capacity.

6.1.3. Irrigation System and Method

The irrigation system is composed of a pumping station with a deep tubewell, and a canal network to distribute the irrigation water throughout the beneficiary area.

One pumping station will be able to control a beneficiary area of approximately 70 ha to 150 ha based on the yield of the deep tubewell. A gravity irrigation method is applied after the water is lifted up to the storage tank, and the required capacity of the storage tank is approximately 20 CM, as an average capacity at a pump station.

The canal system in the project area is divided into two canal systems: the pipeline system and the open canal system. The pipeline system is adopted for main canals and secondary canals, while the open canal system (terminal canal) is applied to irrigation blocks of 4 ha to 5 ha, and the outlets of the pipeline are connected to the open canals by alfalfa valves,

therefore they should be installed at highest point in the irrigation block. Furthermore, the effective hydrographical head should be kept more than 1.0 m at the valve.
On-farm canal after the terminal canal is to be constructed by the beneficial farmer himself and excluded from the project component.

There are two kinds of pipeline system: an arborescent pipeline system, and a pipeline network system. The arborescent pipeline system has been applied to the priority sub-area in each district, taking into consideration the topographical conditions and simplification of water management.

6.2. Water Requirement for Irrigation

6.2.1. Basic Concept

(1) Meteorological Data

In connection with crop water requirement estimations, meteorological data is required as a basic element. Three meteorological stations have been selected as representative stations for the three priority sub-areas.

Jhapa Area .... Kankai (795)
Chandragadhi (1412)
Mahottari Area .... Janakpur (1111)
Banke Area .... Khajura (0409)

These stations are recording monthly rainfall, air temperature, relative humidity, wind speed, and sunshine hours. Records of the monthly data are presented in Appendix 4.1 and 4.4.

Calculation of 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) Calculation of Evapotranspiration

There are many methods in which to estimate crop evapotranspiration. The modified Penman Method has been proposed for this study because it is most likely to provide satisfactory results, and it is utilized for many projects which require the estimation of reference crop evapotranspiration. This method has also been recommended for recent studies in Nepal. The modified Penman equation is given below.

$$ETo = c[\underbrace{W \cdot Rn}_{\text{Radiation term}} + \underbrace{(1-W) \cdot f(u) \cdot (ea-ed)}_{\text{Aerodynamic term}}]$$

Where,
- ETo : Reference crop evapotranspiration in mm/day
- W : Temperature-related weighing factor
- Rn : Net radiation in equivalent evaporation in mm/day
- f (u) : Wind-related factor
- (ea-ed) : Difference between the saturation vapor pressure at the mean air temperature and the mean actual vapor pressure of the air, both in m-bar
- c : Adjustment factor to compensate for the effects of daytime and night-time weather conditions

Details are described in FAO Irrigation and Drainage Paper No. 24. By applying the above equation, the reference crop evapotranspiration (ETo) is calculated for the meteorological data at each station, as shown in Appendix 4.4 and summarized below.

(3) Consumptive Use of Crops

The consumptive use of water by crops is obtained by multiplying the reference crop evapotranspiration (ETo) by crop coefficients (Kc) at a given stage. The Kc values of the respective crops other than paddy are determined with reference to the above mentioned FAO Paper No. 24.

(4) Percolation Losses

Based on the data and information of proceeding project and the field investigation, the percolation rate in the paddy field is applied at 2.0 mm/day in both seasons.

(5) Puddling Water Requirement for Paddy Fields

There are many proceeding irrigation projects in Terai; they have examined and proposed 150 mm as the puddling water requirement for paddy fields, based on soil type, soil moisture content, the groundwater table below the ground surface, and so on. Based on this data and information, the puddling water requirement for this projects is set at 150 mm.

(6) Pre-Irrigation Requirement for Crops in the Dry Season

Wheat, lentils, mustard, and so on, are planted during the onset of the dry season, therefore, pre-irrigation is not needed in the field as residual moisture remains in the soil. However, spring maize and spring vegetable are planted during the middle of dry season, therefore, pre-irrigation is required. The water depth required for this pre-irrigation is estimated at 60 mm.

(7) Effective Rainfall

The effective rainfall for paddy fields is calculated based on the following rules.

a) Calculation of Probable Yearly Rainfall
Based on yearly rainfall data at each station, the probable amount of yearly rainfall is estimated using the Gumbel Method.

b) Distribution of Probable Yearly Rainfall to Monthly Rainfall
According to the long-term daily rainfall data, the average rainfall pattern is delineated on a monthly basis, and the percentage of the monthly rainfall in relation to the yearly rainfall is estimated..

c) Estimation of Effective Rainfall on a Monthly Basis
The basic data for effective rainfall is calculated based on daily rainfall data by following rule.

$R<5$ mm/day	$Re=0$
5 mm $<R<$ 80 mm	$Re=R\times0.8$
$80<R$	$Re=80$ mm $\times0.8$

Re: Effective rainfall R: Observed rainfall

The ratio of discount is estimated between the observed rainfall and the effective rainfall on a monthly basis.

d) Distribution of Probable Yearly Rainfall

Probable yearly rainfall is distributed based on the ratio or percentage on a monthly basis. Calculation results based on the above rules are shown in the attached table.

(8) Irrigation Efficiency

According to the information of the preceding projects in Terai, total irrigation efficiency of the paddy field is applied at 0.7 and reduced to 0.6 for upland crops; therefore, the same efficiency is used at 0.7 for paddy fields and 0.6 for upland crops.

6.2.2. Water Demand and Design Discharge

Taking into account the factors mentioned in the above sub-chapter 6.2.1, irrigation demands for the project are calculated on a half month basis based on the proposed cropping pattern. Results of the calculation are tabulated in Table 6.2.1. The unit design discharge on design years (10 year return periods) is estimated based on the proposed cropping pattern; results are compiled in Table 6.2.2.

(1) Priority Sub-area in Jhapa District

As mentioned in Chapter 5.3 and Chapter 6.1.2, crops are selected for irrigation among the four proposed crops: main paddy, spring paddy, wheat, and spring maize. The total water demand and design discharge for the pump facility are summarized below.

Crops	Acreage (ha)	Total Demand (10^3 m^3/year)
Spring Maize	2,550	12,853 (540 mm)
Spring Paddy	6,800	47,579 (700 mm)
Main Paddy	17,000	52,938 (311 mm)
Wheat	5,100	17,398 (341 mm)
Total	31,450	130,768

Design discharge for the facility: 0.8 l/s/ha

(2) Priority Sub-area in Mahottari District

The same procedure mentioned above is adopted for this priority sub-area; the total water demand and design discharge are determined as follows.

Crops	Acreage (ha)	Total Demand (10^3 m^3/year)
Spring Paddy	700	7,198 (1,028 mm)
Main Paddy	7,000	51,037 (729 mm)
Wheat	3,430	14,116 (412 mm)
Total	11,130	72,351

Design discharge for the facility: 1.0 l/s/ha

(3) Priority Sub-area in Banke District

According to proposed cropping pattern, seven crops are recommended for the project area. Main paddy, spring maize, and wheat have been selected among these crops to be irrigated in the project area. The total water demand and design discharge are summarized below.

Crops	Acreage (ha)	Total Demand (10^3 m^3/year)
Spring Paddy	1,200	10,776 (898 mm)
Main Paddy	6,960	42,216 (592 mm)
Wheat	4,000	13,676 (342 mm)
Total	12,160	65,668

Design discharge for the facility: 0.7 l/s/ha

6.3. Facility Planning

6.3.1. Basic Approach

(1) Selection of Sample Area

In regard to the master plan study and the feasibility study, it is very difficult to create a detailed study to cover the whole area. Therefore, a sample area has been selected for a detailed study of the facilities near Bhadrapur in Jhapa District.

(2) Detailed Topo-Survey

A detailed topo-survey has been carried out with direct field survey work under the following specifications: