His Majesty's Government of Nepal
Department of Irrigation
Groundwater Resources Development Project

Reassessment of the Groundwater Development Strategy for Irrigation in the Terai

Volume 4
Engineering

April 1994

Groundwater Development Consultants Ltd
Cambridge, United Kingdom

in association with

Hunting Technical Services Ltd
Hemel Hempstead, United Kingdom
EAST Consult (P) Ltd
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The Report

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CHAPTER 1

INTRODUCTION

1.1 Scope

This volume addresses the engineering aspects of the Study, with particular reference to climate and the setting of tubewell irrigation design duties, irrigation and drainage, power engineering, and associated cost estimates.

The work is based on field investigations carried out in 1993, ongoing groundwater irrigation development--notably for the Bhairahwa Lumbini Groundwater Development Project (BLGWP), the groundwater component of the Irrigation Line of Credit (ILC) programme, and the shallow tubewell sales programme being funded through Agricultural Development Bank of Nepal (ADBN). The continuity in irrigation and sociological specialists on our team also enabled us to compare 1993 conditions with field results from the 1987 Strategy Study and associated conclusions.

We have also drawn on knowledge gained from visits to buried pipe distribution systems in Uttar Pradesh in 1987 and in Bangladesh in June 1993; also on the experience of both our team members and colleagues of very extensive diesel powered deep tubewell development in Bangladesh in the intervening period.

The topic of land drainage is not commonly associated with groundwater irrigation in monsoon climates, and is not covered in our Terms of Reference. However it became clear during the inception phase of the Study that drainage is perceived as problematic in some parts of the Terai and it was agreed to add a brief study to focus specifically on this area. The results of this ten day study are presented in Section 4.4.

1.2 Field Studies

Engineering field work was carried out in the following stages:

- a reconnaissance survey in February/March which covered three deep tubewells (DTWs) and 18 shallow tubewells (STWs), as listed and located in Table 1.1;
- an extensive field survey throughout April and May which covered one DTW, 52 individually owned STWs, three group owned STWs and five dug wells, as listed and located in Table 1.2;
- a visit to Bhairahwa and Birganj in June aimed specifically at tubewell electrification needs; and

- a visit to Bhairahwa in September aimed both at drainage aspects and updating our knowledge of strategy, physical works and costs at BLGWP, and progress with turning over the Stage I wells to the farmers.

The field work was based on a series of questionnaires, the agricultural and sociological aspects of which are addressed in Volume 2. The irrigation aspects are covered in Chapter 4. A particularly important feature of the STW work was the mapping of channel lines, irrigated areas and command areas at 74 STWs and dug wells. The survey sites are mapped on Figure 1.1.

TABLE 1.1

Scope of Initial Tubewell Irrigation Surveys (February/March 1993)

Date	Site Nr	District	Village	Well type	Agency/ Project	Owner -ship	Survey scope			Comments
							I	A	S	
16-2	S1	Chitwan	Ratnanagar	STW	ADBN	Priv.	Y	Y*	Y	*next farmer
16-2	S2	Chitwan	Santichowk	STW	ADBN	Group	Y	X	Y	
17-2	S3	Chitwan	Keshar Bagu	Dug well	ADBN	Priv.	Y	Y	Y	
18-2	D1	R'dehi	Karaniya	DTW	BLGWP#I	DOI	X	Y	Y	TW11
19-2	D2	R'dehi	Tiperigad	DTW	BLGWP#I	DOI	Y	Y	Y	TW20
20-2	S4	R'dehi	Banka Shia	STW	Private	Priv.	Y	Y	Y	+ 2nd STW
21-2	S5	K'vastu	Jinwa	STW	DOI/ILC	Group	Y	Y	Y	ILC
22-2	D3	N'parasi	Asnaiya	DTW	DOI/ILC	Group	Y	X	Y	ILC
1-3	S6	K'vastu	Baniyabar	STW	DOI/ILC	Group	Y	X	Y	ILC#3
2-3	S7	Dang	Banghushar	STW	DOI/ILC	Group	Y	Y	Y	Deukhuri
2-3	S8	Dang	Satbariya	STW	ADBN	Priv.	Y	Y	Y	Deukhuri
4-3	S9	Dang	Malwar	STW	ADBN	Priv.	Y	X	Y	Dang
4-3	S10	Dang	Hariparangna Naga	STW	ADBN	Priv.	Y	Y	Y	Dang
5-3	S11	Dang	Baibang	STW	ADBN	Priv.	Y	Y	Y	Dang
7-3	S12	Banke	Not recorded	Dug well	Priv.	Priv.	Y	X	X	Shadoof well
7-3	S13	Banke	Bankhatiya	STW	ADBN	Priv.	Y	Y	Y	
8-3	S14	Banke	Buchapur	STW	ADBN	Group	Y	Y	Y	SFDP
9-3	S15-S18	Surkhet	Various	Dug well	ADBN	Priv.	Y	X	X	Hand pumps /buckets

Notes:
I = field irrigation survey;
A = agricultural questionnaire;
S = social questionnaire;
Y = interview/ field survey carried out;
X = topic omitted.

Source: First Quarterly Report, GDC, April 1993

Figure 1.1

Study Area

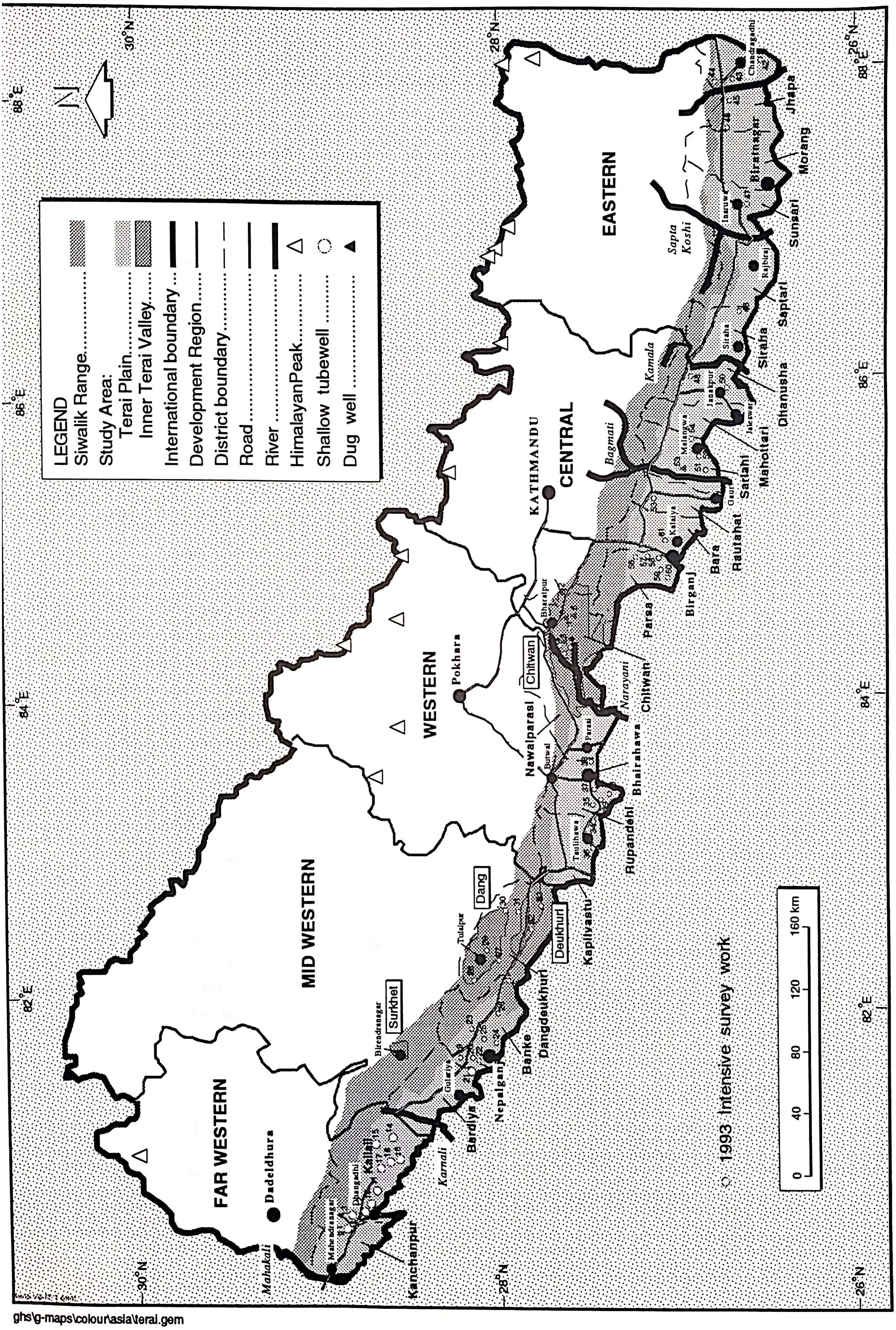

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TABLE 1.2

Scope of Extensive Tubewells Survey (April/May 1993)

Development region/district	Shallow tubewells		Dug wells	Deep tubewells
	Individual	Group	Individual	
Far West				
Kailali	9	1		
Total	9	1	0	0
Mid West				
Bardia	1			
Banke	5	2		
Dang/Deukhuri	6			1
Total	12	2	0	1
West				
Kapilvastu	3			
Rupandehi	4			
Total	7	0	0	0
Central				
Chitwan	5		3	
Parsa	5			
Bara	1			
Rautahat	1			
Sarlahi	3		1	
Dhanusha	2			
Total	16	0	4	0
East				
Siraha	1			
Sunsari	1			
Jhapa	4		1	
Total	6	0	1	0
Grand Total	52	3	5	1

Source: 1993 GDC Field Survey.

CHAPTER 2

IRRIGATION WATER REQUIREMENTS

2.1 General

Crop water requirements have been estimated according to the method set out by Doorenbos and Pruitt (1977) in FAO Irrigation and Drainage Paper 24 and incorporating the guidelines for its application in the Terai set out in Planning and Design Strengthening Project (PDSP) Manual M3 (Hydrology and Agro-Meteorology), (MMG/HMGN) 1990.

Manual M3 provides estimates of reference crop evapotranspiration (ETo) for 12 meteorological stations using the corrected Penman method described in Paper 24. Of the 12 stations, four were selected on the basis of their geographical location along the length of the Terai, in order to estimate the variation in crop water requirements, if any. The stations selected were Khajura, Bhairahwa, Rampur and Tarahara, and their locations and elevations are shown in Table 2.1. Khajura, Bhairahwa and Tarahara were chosen to represent the 'West', 'Central' and 'East' analysis strata, respectively, described in Volume 2, Part B, Chapter 4. Rampur was selected to represent the 'Inner Terai' stratum.

TABLE 2.1

Location of Study Meteorological Stations

Name	Station Nr	Latitude (N)	Longitude (E)	Elevation (m asl)
Khajura	0409	28 09'	81 36'	215
Rampur	0902	27 32'	84 17'	93
Bhairahwa	0707	27 28'	83 24'	115
Tarahara	1320	26 42'	87 16'	200

Source: DIHM.

2.2 Rainfall

2.2.1 Regional Variations

To examine the variation in rainfall along the Terai, the data for 17 stations were collected for the period 1971 to 1990 and analysed to determine mean, median and 1-in-5 dry year conditions, together with seasonal totals. The results are summarised in Table 2.2.

TABLE 2.2

Summary of Rainfall Data for Some Terai Stations (mm)

Region/ station	Analysis period (years)	Mean annual	Median annual	Mean total Nov - Mar	Mean total Apr - May	Mean total Jun - Oct	October mean
Far West							
Balauri	20	1 706	1 654	101	73	1 533	46
Dhangadhi	18	1 776	1 718	81	97	1 597	52
Mid West							
Surkhet*	20	1 613	1 577	137	119	1 356	49
Kusum	17	1 286	1 264	79	88	950	61
Gularia	20	1 487	1 495	76	87	1 326	74
Tulsipur*	20	1 730	1 769	88	102	1 540	75
West							
Butwal	20	2 497	2 437	70	132	2 297	143
Girwani	20	2 597	2 652	83	211	2 304	121
Taulihawa	20	1 651	1 609	66	88	1 496	58
Central							
Jhawani*	20	1 963	1 971	80	195	1 689	85
Simara	20	1 798	1 793	59	183	1 556	86
Ramoli	20	1 747	1 868	59	177	1 511	91
Birganj	17	1 493	1 388	50	128	1 306	65
Patharkot	20	2 057	2 100	56	199	1 802	115
Hardinath	13	1 269	1 287	45	136	1 088	70
East							
Siraha	20	1 468	1 385	59	155	1 253	64
Rajbiraj	18	1 571	1 332	55	1 501	1 288	69

Note: * Inner Terai.

Source: GDC analysis of DHM daily records.

Of these, four were selected to represent the four analysis strata and analysed according to the procedure set out in Chapter 4 of PDSP Manual M3 to determine the 80% reliable rainfall distribution. The calculations for one station - Dhangadhi - are set out in Table 2.3. Detailed mean and 1-in-5 year results for all four stations; Dhangadhi, Tulsipur, Simara and Rajbiraj; are given in Tables 2.4 and 2.5, respectively.

TABLE 2.3

Computation of 80% Exceedence Rainfall for Cumulative Months: Dhangadhi

Year	Cumulative monthly rainfall by months* (mm)												
	11	11-12	11-1	11-2	11-3	11-4	10-4	10-5	10-6	9-6	8-6	8-7	
(a) Basic data													
1971/72	10	10	10	42	42	42	73	73	161	677	1 013	1 377	
1972/73	0	0	1	13	28	28	252	267	415	1 106	1 281	1 482	
1973/74	0	0	18	38	38	38	66	82	681	713	1 014	2 056	
1974/75	12	50	59	71	85	85	120	120	644	991	1 396	1 970	
1975/76	0	0	0	7	9	14	47	80	270	488	837	1 301	
1976/77	0	0	0	0	0	9	51	113	207	398	798	1 131	
1977/78	0	19	28	63	114	147	155	161	375	548	1 165	1 594	
1980/81	0	0	0	0	0	16	16	106	494	721	1 113	1 768	
1981/82	24	46	117	123	135	159	164	187	340	563	1 275	1 614	
1982/83	0	14	86	88	116	184	338	418	697	1 360	1 789	2 301	
1983/84	0	21	84	125	125	139	150	205	832	970	1 313	2 387	
1984/85	0	9	19	19	19	27	241	330	447	885	1 344	1 740	
1985/86	0	46	51	90	93	156	192	269	501	728	925	1 422	
1986/87	15	67	74	90	93	109	109	178	332	525	807	1 455	
1987/88	0	6	14	17	52	77	77	142	349	556	906	1 635	
1988/89	0	30	104	119	151	151	159	171	419	654	1 247	1 817	
1989/90	16	36	36	166	194	195	195	460	663	993	1 403	2 263	
1990/91													
Mean	5	21	41	63	76	92	141	198	460	757	1 154	1 724	
St Dev	8	21	38	50	56	64	83	112	182	249	258	356	
80% exceedence	0	3	9	21	29	39	72	103	307	547	938	1 425	
(b) Typical distribution	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean	20	22	13	16	56	263	570	397	297	49	0	16	1 720
1 in 5 dry year	6	12	8	10	31	204	487	390	241	33	0	3	1 425
(c) Effective rainfall :**													
Mean year													
70%						184	399	278	208				} 1 233 mm**
85%	17	19	11	14	48					42	0	14 }	
1 in 5 dry year													
70%						143	341	273	168				} 1 010 mm**
85%	5	10	7	8	27					28	0	0 }	

Notes:

1 Data for 1987/79 and 1979/80 incomplete;
2 * Months: 1 = Jan, 2 = Feb etc.
3 ** 70% of totals > 100 mm; 85% of totals 5 to 100 mm; totals < 5 mm ignored.

Source: GDC analysis of raw DHM data

TABLE 2.4

Mean Year Half-monthly Total and Effective Rainfall (mm)

Period	Station							
	Dhangadhi West		Tulsipur Inner Terai		Simara Central		Rajbiraj East	
	P*	Pe**	P*	Pe**	P*	Pe**	P*	Pe**
Jan 1	10	8	13	11	6	5	2	0
Jan 2	10	9	14	11	7	6	3	0
Feb 1	11	9	11	9	7	6	7	6
Feb 2	11	9	11	9	8	7	7	6
Mar 1	6	5	7	6	8	7	7	6
Mar 2	7	6	8	7	9	8	8	7
Apr 1	8	7	6	5	32	27	20	17
Apr 2	8	7	7	6	32	27	20	17
May 1	28	24	41	35	64	45	55	38
May 2	28	24	41	35	64	45	55	39
Jun 1	131	92	143	100	126	88	124	86
Jun 2	132	92	144	101	126	88	124	87
Jul 1	285	199	238	167	307	197	214	149
Jul 2	285	200	239	167	308	197	214	150
Aug 1	199	139	202	142	161	131	140	98
Aug 2	198	139	202	143	161	131	140	98
Sep 1	149	104	147	103	152	106	134	94
Sep 2	148	104	146	102	152	106	133	93
Oct 1	25	21	36	31	40	35	33	28
Oct 2	24	21	36	30	40	34	32	27
Nov 1	0	0	0	0	0	0	0	0
Nov 2	0	0	0	0	0	0	0	0
Dec 1	8	7	8	6	6	5	4	4
Dec 2	8	7	8	5	6	5	5	4
Total	1 719	1 233	1 708	1 231	1 822	1 305	1 481	1 054

Note: P* = Total rainfall
Pe** = Effective rainfall

Source: GDC analysis of data from DHM.

TABLE 2.5

One-in-Five Dry Year Half-monthly Total and Effective Rainfall (mm)

Period	Station							
	Dhangadhi West		Tulsipur Inner Terai		Simara Central		Rajbiraj East	
	P*	Pe**	P*	Pe**	P*	Pe**	P*	Pe**
Jan 1	3	2	7	6	4	4	1	0
Jan 2	3	3	7	6	5	4	2	0
Feb 1	6	5	7	6	6	5	6	5
Feb 2	6	5	8	7	7	6	7	6
Mar 1	4	3	4	3	7	6	5	4
Mar 2	4	3	4	3	7	6	5	5
Apr 1	5	4	9	7	13	11	9	8
Apr 2	5	4	9	8	13	11	9	8
May 1	15	13	35	30	59	42	44	37
May 2	16	14	36	30	59	43	44	38
Jun 1	101	71	107	75	89	62	32	68
Jun 2	102	72	108	75	88	62	33	68
Jul 1	243	170	296	172	272	158	187	131
Jul 2	244	171	296	172	273	159	187	131
Aug 1	195	136	202	141	118	114	163	69
Aug 2	195	137	201	141	117	114	163	68
Sep 1	121	84	108	76	99	69	95	66
Sep 2	120	84	108	75	99	70	94	66
Oct 1	17	15	19	16	40	34	27	23
Oct 2	16	14	18	15	39	33	27	23
Nov 1	0	0	0	0	0	0	0	0
Nov 2	0	0	0	0	0	0	0	0
Dec 1	1	0	3	3	0	0	0	0
Dec 2	2	0	4	4	0	0	0	0
Total	1 425	1 010	1 497	1 071	1 416	1 011	1 140	824

Note: P* = Total rainfall
Pe** = Effective rainfall

Source: GDC analysis of data from DHM.

These data indicate that total median rainfall is greater in the Western half of the Terai, with minima occurring in the East between Siraha and Rajbiraj. However, these differences might result more from north-south differences (areas closer to the Siwaliks receiving higher rainfall) as the three inner Terai stations do exhibit higher totals.

The extent of the onset of the monsoon is shown by the sum of the means for April to May which shows much higher rainfalls during this period in the East than the West: the lag between East and West being about one month. Similarly the data for October demonstrate that the monsoon still continues later in the East. This variation in the timing of the monsoon has considerable impact on the timing and equality of irrigation water requirements.

Conversely, the rainfall in the period November to March tends to be higher in the Far West, though only about 25 to 30 mm; this has some significance in winter irrigation reduction terms. More importantly the three inner Terai stations all demonstrate higher winter rainfall and a corresponding drop in winter irrigation needs.

2.2.2 Effective Rainfall

Not all rainfall can be effectively used by crops, due to losses by evaporation or runoff. The effective proportion of total rainfall (Pe) has been calculated, broadly according to WEC Technical Guideline Number 1 (1986) for half-monthly periods at the four chosen rainfall stations. The results are shown in Tables 2.4 and 2.5 for the mean and 1-in-5 dry year cases, respectively (all rainfall less than 5 mm is ignored, 85% of quantities from 5 mm up to 100 mm is taken as effective, as is 70% of quantities greater than 100 mm).

2.3 Consumptive Use

2.3.1 Reference Crop Evapotranspiration

Estimated average monthly reference crop evapotranspiration (ETo) for the four selected stations is shown in Table 2.6.

TABLE 2.6

Estimated Monthly Average Reference Crop Evapotranspiration (mm)

Month	Station			
	Khajura	Rampur	Bhairahwa	Tarahara
January	62.0	58.9	62.9	72.5
February	84.8	54.9	81.8	94.9
March	144.2	142.3	141.9	160.3
April	198.3	190.2	199.2	200.7
May	239.3	201.5	229.1	208.3
June	212.7	164.4	194.1	174.6
July	157.8	133.0	163.4	156.2
August	152.5	143.8	159.7	160.9
September	135.0	124.5	131.4	135.3
October	123.1	117.2	123.4	123.1
November	82.5	80.4	90.0	87.6
December	58.6	58.0	64.2	70.0
Total	1 651.0	1 469.0	1 641.0	1 644.0

Source: PDSP Manual M3, Appendix D (1990).

Evapotranspiration is at a minimum in December, rising to a maximum in May, then falling with the onset of the monsoon. Total annual estimated ETo ranges from about 1 470 mm at Rampur (in the Chitwan Valley) to about 1 650 mm at three main Terai stations, where the total variation is relatively small. The range of monthly ETo along the main Terai shows little general variation although Khajura has the lowest monthly ETo over the period from July to March, but then shows the highest figures during April to June. The July to October figures were not considered credible, and the average value for the other three stations was substituted for this period. Winter evapotranspiration at Tarahara appears to be slightly higher.

2.3.2 Crop Water Requirements

Consumptive use is calculated according to the formula:

ETc = ETo x Kc

Where ETc = consumptive use
ETo = reference crop evapotranspiration
Kc = crop coefficient

Values of Kc for the typical Terai crops are listed in Table 2.7. These have been processed with ETo data for Khajura, Rampur, Bhairahwa and Tarahara (taken as representative of West, Inner Terai, Central and East analysis strata, as defined in Volume 2, Part B, Chapter 4) to produce four sets of crop consumptive use data for half monthly periods. Examples of the calculations for rice and wheat are included in Tables 2.8 and 2.9, respectively, which present the complete irrigation water requirements calculation cycle and summarise the various assumptions used for the ponded water/soil moisture balance. These calculations have been carried out for both mean and 1-in-5 year (80%) rainfall conditions; the former for estimating average annual pumping requirements and the latter for system design purposes (as discussed in Chapter 4).

2.4 Field Irrigation Requirements

As indicated in Volume 2, Part A, Chapter 4, soils physics data for the Terai are very sparse. For the purpose of calculating field irrigation requirements, the following generalised assumptions have been made:

(a) applications for rice land preparation total 150 mm at the field;

(b) deep percolation on puddled rice soil occurs at 100 mm/month;

(c) total available moisture in the Land System 2 soils averages 120 mm/m of which 70% is readily available; and

(d) up to 150 mm of water can be stored in a bunded field before spilling.

The assumption about deep percolation rates is at variance with the PDSP (1990) and WECS (1986) recommendations, which recommend a reduction in infiltration rates as the monsoon proceeds and as the watertable rises.

The more conservative estimate has been used to reflect the overall Terai-wide picture except when considering early rice, which can be reasonably expected to be limited to the heavier, depressional soils which are less permeable.

The gross irrigated demand calculations for individual crops were based on system efficiencies assumed to relate to well built and maintained distribution units. These efficiencies and those assumed for less well managed systems are summarised in Table 2.10. The lower efficiencies for STWs result from the fact that losses from smaller discharges are proportionally larger, and that surface irrigation methods are less efficient when streams of water available at the field head are significantly smaller.

TABLE 2.7

Crop Coefficients for Typical Terai Conditions

	Jan* 1	Jan 2	Feb 1	Feb 2	Mar 1	Mar 2	Apr 1	Apr 2	May 1	May 2	Jun 1	Jun 2	Jul 1	Jul 2	Aug 1	Aug 2	Sep 1	Sep 2	Oct 1	Oct 2	Nov 1	Nov 2	Dec 1	Dec 2
Early rice (100 days)						1.08	1.08	1.10	1.12	1.05	0.95	0.92												
Main rice (150 days)												1.07	1.10	1.11	1.10	1.09	1.07	1.04	0.99	0.96	0.94			
Late rice (114 days)														1.06	1.08	1.11	1.13	1.07	1.01	0.95	0.91			
Summer maize (95 days)												0.27	0.40	0.72	0.95	1.05	1.05	0.95						
Millet (100 - 120 days)													0.30	0.57	0.88	1.00	1.00	0.84	0.44					
Sugar cane (perennial)	0.45	0.53	0.70	0.85	0.96	1.05	1.05	1.08	1.15	1.13	1.06	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.00	0.92	0.80	0.70	0.60
Wheat I (120 days)	1.20	1.20	1.10	0.85	0.45																	0.33	0.65	1.10
Wheat II (100 days)	1.15	0.80	0.40																	0.33	0.45	0.75	1.10	1.22
Wheat III (150 days)	0.82	1.00	1.06	1.07	1.02	0.81	0.41															0.33	0.38	0.53
Winter maize I (130 days)	1.05	1.05	1.00	0.85	0.58																0.33	0.44	0.73	0.97
Winter maize II (130 days)	1.10	1.04	0.83	0.58															0.33	0.35	0.58	0.83	1.05	1.10
Potatoes (100-110 days)	1.10	0.95	0.73																	0.32	0.40	0.63	0.90	1.05
Mung bean/Pulse I (90 days)				0.32	0.43	0.70	1.05	1.10	0.80															
Pulse II (90-100 days)	1.07	1.10	1.07	1.05																	0.30	0.37	0.63	0.93
Winter vegetables (90-100 days)	0.35	0.44	0.62	0.84	0.97	1.00	0.85													0.33	0.43	0.90	1.00	1.00
Winter legumes (90 days)	0.70	0.90	0.95	9.00																			0.32	0.45
Jute (95 days)**					0.5	0.65	0.95	1.05	1.1	0.9														

Note: (1) * Jan 1 adn Jan 2, etc, refer to the first and second half of the month
(2) ** GDC estimate

Source: WEC Technical Guideline Nr 1

TABLE 2.8

Annual Irrigation Requirements for HYV Main Rice: Rampur/ Tulsipur (Inner Terai)

	Item		May 1	May2	Jun 1	Jun 2	Jul 1	Jul 2	Aug 1	Aug 2	Sep 1	Sep 2	Oct 1	Oct 2	Nov 1	Nov 2	Totals
(a)	**80% rain**																
	Initial ponded water	(mm)	0	0	0	42	39	90	136	150	150	109	73	0	0	0	
	Inital SMD*	(mm)	0	1	2	0	0	0	0	0	0	0	0	14	116	211	
	Days in month	(d)	16	15	15	15	15	16	15	16	15	15	15	16	15	15	
	Time planted	(d)	0	0	0	15	15	16	15	16	15	15	15	0	0	0	122
	ETo	(mm/d)	6.5	6.5	5.5	5.5	4.3	4.3	4.6	4.6	4.2	4.2	3.8	3.8	2.7	2.7	
	Kc					1.07	1.10	1.11	1.10	1.09	1.07	0.96	0.94				
	ET free surface	(mm)	11.4	80.4	90.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	66.9	44.6	44.6	
	ET crop	(mm)	0.0	0.0	0.0	88.3	71.0	76.4	75.9	80.2	67.4	60.5	53.6	0.0	0.0	0.0	573
	Deep percolation	(mm)	20	50	50	50	50	50	50	50	50	50	50	50	50	50	50
	Effective rainfall	(mm)	30	30	75	75	172	172	141	141	76	75	16	15	0	0	
	Land preparation depth	(mm)	0	100	50												
	Net irrigation depth	(mm)	60	60	60	60	60	60	60	60	60	60	60	60	60	60	
	Number of applications	(Nr)	0	0	1	1	0	0	0	0	0	0	0	0	0	0	2
	Total water applied	(mm)	0	100	110	60	0	0	0	0	0	0	0	0	0	0	270
	Final ponded water	(mm)	0	0	42	39	90	136	151	161	109	73	0	0	0	0	
	Final SMD	(mm)	1	2	0	0	0	0	0	0	0	0	14	116	211	305	
	Conveyance efficiency	(%)	85	85	85	85	85	85	85	85	85	85	85	85	85	85	
	Monthly requirement	(mm)	0	118	129	71	0	0	0	0	0	0	0	0	0	0	318

	Item		May 1	May2	Jun 1	Jun 2	Jul 1	Jul 2	Aug 1	Aug 2	Sep 1	Sep 2	Oct 1	Oct 2	Nov 1	Nov 2	Totals
(b)	**Mean rain**																
	Initial ponded water	(mm)	0	0	28	62	50	121	150	150	150	150	150	102	41	0	
	Inital SMD*	(mm)	0	1	0	0	0	0	0	0	0	0	0	0	0	29	
	Days in month	(d)	16	15	15	15	15	16	15	16	15	15	15	16	15	15	
	Time planted	(d)	0	0	0	15	15	16	15	16	15	15	15	0	0	0	122
	ETo	(mm/d)	6.5	6.5	5.5	5.5	4.3	4.3	4.6	4.6	4.2	4.2	3.8	3.8	2.7	2.7	
	Kc					1.07	1.10	1.11	1.10	1.09	1.07	0.96	0.94				
	ET free surface	(mm)	11.4	80.4	90.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	66.9	44.6	44.6	
	ET crop	(mm)	0.0	0.0	0.0	88.3	71.0	76.4	75.9	80.2	67.4	60.5	53.6	0.0	0.0	0.0	573
	Deep percolation	(mm)	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
	Effective rainfall	(mm)	35	35	100	101	167	167	142	143	103	102	31	30	0	0	
	Land preparation depth	(mm)	0	100	50												
	Net irrigation depth	(mm)	60	60	60	60	60	60	60	60	60	60	60	60	60	60	
	Number of applications	(Nr)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total water applied	(mm)	0	100	50	0	0	0	0	0	0	0	0	0	0	0	150
	Final ponded water	(mm)	0	28	62	50	121	187	191	188	161	167	102	41	0	0	
	Final SMD	(mm)	1	0	0	0	0	0	0	0	0	0	0	0	29	99	
	Conveyance efficiency	(%)	85	85	85	85	85	85	85	85	85	85	85	85	85	85	
	Monthly requirement	(mm)	0	118	59	0	0	0	0	0	0	0	0	0	0	0	176

Source: GDC

TABLE 2.9

Annual Irrigation Requirements for Wheat (120 days) (Tarahara - East)

Item		Nov		Dec		Jan		Feb		Mar		Apr		Totals
		1	2	1	2	1	2	1	2	1	2	1	2	
(a) 80% rainfall (1 in 5 year dry)														
Initial available SM*	(mm)	75.0	75.0	80.0	57.6	17.1	25.7	31.5	34.2	-0.3	-31.4	-26.4	-18.4	
Days in month	(d)	0	15	15	16	15	16	14	14	15	16	31	28	
Time planted	(d)	0	15	15	16	15	16	14	14	15	0			120
ETo	(mm/d)	2.9	2.9	2.3	2.3	2.3	2.3	3.4	3.4	5.2	5.2	6.7	6.7	
Kc		0	0.3	0.6	1.1	1.2	1.2	1.1	0.8	0.4	0			
ET bare surface	(mm)	0	0	0	0	0	0	0	0	0	0	0	0	
ET crop	(mm)	0.0	14.4	22.4	40.5	41.4	44.2	52.4	40.5	35.1	0.0	0.0	0.0	291
Effective rainfall	(mm)	0	0	0	0	0	0	5	6	4	5	8	8	
Net irrigation depth	(mm)	50	50	50	50	50	50	50	50	50	50	50	50	
Number of application	(Nr)	0	1	0	0	1	1	1	0	0	0	0	0	4
Total water applied	(mm)	0	50	0	0	50	50	50	0	0	0	0	0	200
Final available SM	(mm)	75.0	80.0	57.6	17.1	25.7	31.5	34.2	-0.3	-31.4	-26.4	-18.4	-10.4	
Field efficiency	(%)	60	60	60	60	60	60	60	60	60	60	60	60	
Gross field requiremen	(mm)	0	83	0	0	83	83	83	0	0	0	0	0	
Conveyance efficiency	(%)	85	85	85	85	85	85	85	85	85	85	85	85	
Monthly requirement	(mm)	0	98	0	0	98	98	98	0	0	0	0	0	392

Item		Nov		Dec		Jan		Feb		Mar		Apr		Totals
		1	2	1	2	1	2	1	2	1	2	1	2	
(b) Mean rainfall														
Initial available SM*	(mm)	75.0	75.0	80.0	61.6	25.1	33.7	39.5	-6.8	-41.3	-70.4	-63.4	-46.4	
Days in month	(d)	0	15	15	16	15	16	14	14	15	16	31	28	
Time planted	(d)	0	15	15	16	15	16	14	14	15	0			120
ETo	(mm/d)	2.9	2.9	2.3	2.3	2.3	2.3	3.4	3.4	5.2	5.2	6.7	6.7	
Kc		0	0.3	0.6	1.1	1.2	1.2	1.1	0.8	0.4	0			
ET bare surface	(mm)	0	0	0	0	0	0	0	0	0	0	0	0	
ET crop	(mm)	0.0	14.4	22.4	40.5	41.4	44.2	52.4	40.5	35.1	0.0	0.0	0.0	291
Effective rainfall	(mm)	0	0	4	4	0	0	6	6	6	7	17	17	
Net irrigation depth	(mm)	50	50	50	50	50	50	50	50	50	50	50	50	
Number of application	(Nr)	0	1	0	0	1	1	0	0	0	0	0	0	3
Total water applied	(mm)	0	50	0	0	50	50	0	0	0	0	0	0	150
Final available SM	(mm)	75.0	80.0	61.6	25.1	33.7	39.5	-6.8	-41.3	-70.4	-63.4	-46.4	-29.4	
Field efficiency	(%)	60	60	60	60	60	60	60	60	60	60	60	60	
Gross field requiremen	(mm)	0	83	0	0	83	83	0	0	0	0	0	0	
Conveyance efficiency	(%)	85	85	85	85	85	85	85	85	85	85	85	85	
Monthly requirement	(mm)	0	98	0	0	98	98	0	0	0	0	0	0	294

Source: GDC

TABLE 2.10

Summary of Irrigation Efficiency Assumptions

Parameter	Deep/medium tubewells			Shallow tubewells**
	Buried pipes	Lined channels*	Unlined channels	
Initial development (Base case)				
Channel efficiency (E_C)	0.80	0.65	0.50	0.50
Field efficnecy (E_a)	0.50	0.50	0.50	0.40
Overall efficiency (E_W)	0.40	0.33	0.25	0.20
Improved case (average)				
Channel efficiency (E_C)	0.85	0.70	0.55	0.60
Field efficiency (E_a)***	0.55	0.55	0.55	0.45
Overall efficiency (E_W)	0.47	0.39	0.30	0.27
Improved case (best)				
Channel efficiency (E_C)	0.90	0.75	0.60	0.70
Field efficiency (E_a)***	0.60	0.60	0.60	0.50
Overall efficiency (E_W)	0.54	0.45	0.36	0.35

Note: * Lined feeder channels only; all three systems have unlined earth field/plot channels.
** Unlined earth channels throughout.
*** Dry root crops.

Source: GDC.

The analyses in Tables 2.8 and 2.9 are based on a progressive balancing of the ponded water level in the case of rice, and soil moisture availability in the case of winter crops. The general assumption is that the soils are at almost 90% of field capacity at the time of planting winter crops and that there is a significant soil moisture deficit to replenish before land preparation for rice can proceed. Irrigation for winter crops is assumed to be in 50 mm increments net of application losses, and it is also assumed that the maximum depletion of total available moisture during the growing stages of the crop shall not exceed 50%, though this level of depletion is exceeded in the ripening stage, when yields are not affected.

Agronomists recommend a specific pre-germination irrigation for wheat to ensure that the soil is brought up to field capacity at planting. This irrigation has been included in the calculations for wheat.

The examples show the total number of irrigations required having allowed for effective rainfall, and the gross monthly demand at the well having allowed for application and conveyance inefficiencies.

The results of all the analyses are summarised for mean and 1-in-5 dry year conditions in Tables 2.11 and 2.12 respectively.

These demonstrate clearly the additional pumping required to plant early monsoon rice in the Far West (and potential advantage which groundwater irrigators therefore have over rainfed or surface irrigation farmers); also the lower winter crop irrigation requirements in the Inner Terai - typically one fewer irrigation per crop. The results also show the relatively enormous quantities of water required to support the truly hot season early rice crop. Not surprisingly this practice is only likely in those low lying areas which suffer drainage problems and are not therefore available for successful winter cropping (in which case early summer season cropping is the only means of obtaining intensities of the order of 200%).

The relatively high main rice pumping requirement in Table 2.11 for the East results from consistently low total monsoon rainfall recorded at the two stations studied and is regarded with some suspicion.

To indicate the impact of ranging system efficiencies, specific crop irrigation requirements at the pump for deep and shallow tubewells are listed in Table 2.13 for crops on good medium rice soils.

TABLE 2.11

Comparison between Irrigation Water Requirements: West, Inner Terai, Central, East Strata - Average Rainfall Year

Crop	Growth period (days)	Plant date	Average (mean) rainfall year											
			West(1)			Inner Terai(2)			Central(3)			East(4)		
			ETc (mm)	App* (Nr)	Total net** (mm)	ETc (mm)	App* (Nr)	Total net** (mm)	ETc (mm)	App* (Nr)	Total net** (mm)	ETc (mm)	App* (mm)	Total net** (mm)
Rice														
HYV early	107	16/3	754	12	870	657	10	750	725	10	750	695	10	750
HYV main monsoon 1	107	1/6	625	4	390	531	2	270	620	2	270	588	3	330
HYV main monsoon 2	122	16/6	648	2	270	573	0	150	653	1	210	634	3	330
HYV main monsoon 3	122	1/7	599	1	210	547	0	150	613	1	210	606	1	210
HYV late monsoon	122	1/8	521	2	170	491	1	60	533	2	170	533	3	230
LV main monsoon	153	16/6	758	2	270	678	1	210	765	2	270	745	3	390
Field Crops														
Wheat	120	16/11	254	3	150	222	2	100	257	3	150	291	3	150
Oilseed	107	1/11	165	1	50	153	1	50	172	2	100	189	2	100
Pulse	120	1/11	231	1	50	197	1	50	235	1	50	263	2	100
Potato	107	1/11	184	1	50	166	1	50	190	2	100	211	2	100
Winter maize	135	1/11	266	2	100	235	1	50	350	3	150	303	3	150
Summer maize	107	16/3	405	0	0	306	0	0	413	0	0	408	0	0

Notes:
(1) Khajura ETo; Dhangadhi rainfall;
(2) Rampur ETo; Tulsipur rainfall;
(3) Bhairahwa ETo; Simara rainfall;
(4) Tarahara ETo; Rajbiraj rainfall.

* App = total irrigation application (exclusive of land preparation for rice);
** Total application depth at field (inclusive of land preparation/ deep percolation losses for rice but exclusive of field application losses in field crops).

Source: GDC

TABLE 2.12

Comparison between Irrigation Water Requirements: West, Inner Terai, Central, East Strata 1-in-5 Dry Rainfall Year

Crop	Growth period (days)	Plant date	Average (mean) rainfall year											
			West(1)			Inner Terai(2)			Central(3)			East(4)		
			ETc (mm)	App* (Nr)	Total net** (mm)	ETc (mm)	App* (Nr)	Total net** (mm)	ETc (mm)	App* (Nr)	Total net** (mm)	ETc (mm)	App* (mm)	Total net** (mm)
Rice														
HYV early	107	16/3	754	13	930	657	11	810	725	11	810	695	11	810
HYV main monsoon 1	107	1/6	625	5	450	531	3	330	620	4	390	588	4	390
HYV main monsoon 2	122	16/6	648	3	330	573	2	270	653	4	390	634	5	450
HYV main monsoon 3	122	1/7	599	1	210	547	1	210	613	3	330	606	4	390
HYV late monsoon	122	1/8	521	4	290	491	2	170	533	4	290	533	6	410
LV main monsoon	153	16/6	758	5	450	678	3	330	765	6	510	745	7	570
Field Crops														
Wheat	120	16/11	254	3	150	222	2	100	257	3	150	291	4	200
Oilseed	107	1/11	165	2	100	153	2	100	172	2	100	189	2	100
Pulse	120	1/11	231	2	100	197	1	50	235	2	100	263	3	150
Potato	107	1/11	184	2	100	166	2	100	190	2	100	211	2	100
Winter maize	135	1/11	266	3	150	235	2	100	270	3	150	303	3	150
Summer maize	107	16/3	405	0	0	366	0	0	413	0	0	408	0	0

Notes:
(1) Khajura ETo; Dhangadhi rainfall;
(2) Rampur ETo; Tulsipur rainfall;
(3) Bhairahwa ETo; Simara rainfall;
(4) Tarahara ETo; Rajbiraj rainfall.

* App = total irrigation application (**exclusive** of land preparation for rice);
** Total application depth at field (**inclusive** of land preparation/ deep percolation losses for rice but **exclusive** of field application losses in field crops).

Source: GDC

TABLE 2.13

Indicative Variations in Full Tubewell Irrigation Pumping Requirements: Average Year

Crop	Planting date	Total pumped water depth (mm)*			
		West	Inner Terai	Central	East
(a) Deep Tubewells					
Rice					
Early HYV (107 days)	16.3	1 020	880	880	880
Main monsoon HYV	16.6	320	180	250	390
Main monsoon LV	16.6	320	250	320	460
Late monsoon HYV	1.8	200	70	200	270
Wheat (120 days)	16.11	290	200	290	290
Oilseeds (107)	1.11	100	100	200	200
Winter maize (135)	1.11	200	100	290	290
Summer maize (107)	16.6	0	0	0	0
Potatoes (107)	1.11	100	100	200	200
(b) Shallow Tubewells					
Main monsoon HYV	16.6	470	260	360	570
Main monsoon LV	16.6	470	360	470	670
Wheat (120 days)	16.11	420	290	420	420
Summer maize (107)	16.6	0	0	0	0
Potatoes (107)	1.11	150	150	300	300

Note: * Assuming net irrigation depths of 60 mm for rice and 50 mm for other crops, channel efficiency of 85% for DTWs and 70% for STWs; field efficiency 60% for DTWs and 50% for STWs.

Source: GDC

CHAPTER 3

TUBEWELL IRRIGATION DESIGN DUTIES

3.1 Definitions and Approach

Tubewell irrigation duties are defined as the ratio of installed pump capacity to irrigated command area; the irrigation design duty as the pump capacity required per hectare irrigated for design purposes. These are determined on the basis of peak demand periods for selected cropping patterns under 1-in-5 dry year rainfall conditions.

The analysis is based on the half-monthly pumped water requirement streams described in Section 2.4 and the simplified DTW cropping patterns introduced in Volume 2, Part B, Chapter 4, and illustrated in Figure 3.1.

The most common case is based on a DTW on good Land System 2 soils, taken to command an area typically consisting of 90% medium land (suitable for rice) and 10% high land (suitable for maize based cropping). This is described as the 'Land System 2 Mixed' case, and has been assumed to apply to most suitably sized DTWs (which because of their extent cannot be assumed to command land of uniform topography).

Two other cases are shown: a wholly maize based pattern for upland areas and a wholly rice based pattern for lowlands which remain saturated too long to permit wheat cropping and which therefore require summer cropping to enable reasonable irrigation intensities. These are included for comparison purposes only and not as recommended alternatives.

Design calculations have been made for the mixed and lowland cropping patterns as illustrated in Tables 3.1 to 3.4. These demonstrate analyses for each of the three chosen stations, and the beneficial effect of staggering the rice planting dates (which smooths down the peak demand by distributing it over a longer period.)

3.2 Results and Design Duty Selection

The mixed topography analysis is based on the following simplified irrigated cropping pattern assuming 100% irrigation intensity:

(a) monsoon - 77% High Yielding Variety (HYV) and 13% Local Variety (LV) rice (on medium land only); and

(b) winter - 70% wheat/maize and 25% potato/mustard/vegetables (on medium and high land).

TABLE 3.1

Tubewell Design Duty Calculation : Tarahara/ Rajbiraj East (Land System 2 Mixed)

Item		Jan 1	Jan 2	Feb 1	Feb 2	Mar 1	Mar2	Apr 1	Apr 2	May 1	May 2	Jun 1	Jun 2	Jul 1	Jul 2	Aug 1	Aug 2	Sep 1	Sep 2	Oct 1	Oct 2	Nov 1	Nov 2	Dec 1	Dec 2	Totals
Total water applied (mm):																										
Early HYV rice						210	120	120	120	120	120															810
Main HYV 1										100	110	60	60	60												390
Main HYV 2											100	110	60			60	120									450
Main HYV 3												100	50	60			60	60	60							390
Main LV											100	110	60			60	60	60	60	60						570
Late HYV															50	60	60	60	60	60	60					410
Wheat/ maize		50	50	50																			50.0			200
Potato/ oil seed			50																						50	100
Cropped area (% of total CA):		Total irrigation depth per hectare command area (mm)																								
Early HYV rice	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
Main HYV 1	30	0	0	0	0	0	0	0	0	30	33	18	18	0	0	0	0	0	0	0	0	0	0	0	0	99
Main HYV 2	30	0	0	0	0	0	0	0	0	0	30	33	18	0	0	18	36	0	0	0	0	0	0	0	0	135
Main HYV 3	17	0	0	0	0	0	0	0	0	0	0	17	9	0	0	0	10	10	10	0	0	0	0	0	0	
Main LV	13	0	0	0	0	0	0	0	0	0	13	14	8	0	0	8	8	8	8	8	0	0	0	0	0	74
Late HYV		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-total rice	90	0	0	0	0	0	0	0	0	30	76	82	52	0	0	26	54	18	18	8	0	0	0	0	0	308
Wheat/ maize	70	35	35	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	0	0	140
Potato/ oil seed	25	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	25
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sub-total field crops	95	35	48	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	0	13	165
Days		16	15	14	14	16	15	15	15	16	15	15	15	16	15	16	15	15	15	16	15	15	15	16	15	365
Pump duty 18 hr day (l/s/ha)																										
Crops	Ec																									
Rices	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.78	0.85	0.54	0.00	0.00	0.25	0.56	0.19	0.19	0.08	0.00	0.00	0.00	0.00	0.00	
	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.87	0.94	0.60	0.00	0.00	0.28	0.62	0.21	0.21	0.08	0.00	0.00	0.00	0.00	0.00	
	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.39	1.04	1.13	0.72	0.00	0.00	0.33	0.74	0.25	0.25	0.10	0.00	0.00	0.00	0.00	0.00	
	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	1.30	1.41	0.90	0.00	0.00	0.41	0.93	0.31	0.31	0.13	0.00	0.00	0.00	0.00	0.00	
	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58	1.56	1.69	1.08	0.00	0.00	0.50	1.11	0.37	0.37	0.15	0.00	0.00	0.00	0.00	0.00	
Field crops (Ea = .6)	Ec																									
	1.00	0.56	0.81	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.21	
	0.90	0.63	0.90	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.24	
	0.75	0.75	1.09	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.29	
	0.60	0.94	1.36	1.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.36	
	0.50	1.13	1.63	1.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20	0.00	0.43	
Field crops (Ea = .5)	Ec																									
	1.00	0.68	0.98	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.26	
	0.90	0.75	1.09	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.29	
	0.75	0.90	1.30	1.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.96	0.00	0.34	
	0.70	0.96	1.40	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.03	0.00	0.37	
	0.50	1.35	1.95	1.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.44	0.00	0.51	
Whole farm:	Ec																									
Piped DTW	0.90	0.63	0.90	0.71	0.00	0.00	0.00	0.00	0.00	0.32	0.87	0.94	0.60	0.00	0.00	0.28	0.62	0.21	0.21	0.08	0.00	0.00	0.67	0.00	0.24	
Lined DTW	0.75	0.75	1.09	0.86	0.00	0.00	0.00	0.00	0.00	0.39	1.04	1.13	0.72	0.00	0.00	0.33	0.74	0.25	0.25	0.10	0.00	0.00	0.80	0.00	0.29	
Unlined DTW	0.60	0.94	1.36	1.07	0.00	0.00	0.00	0.00	0.00	0.48	1.30	1.41	0.90	0.00	0.00	0.41	0.93	0.31	0.31	0.13	0.00	0.00	1.00	0.00	0.36	
Optimistic STW	0.70	0.96	1.40	1.10	0.00	0.00	0.00	0.00	0.00	0.48	1.30	1.41	0.90	0.00	0.00	0.41	0.93	0.31	0.31	0.13	0.00	0.00	1.03	0.00	0.37	
Likely STW	0.50	1.35	1.95	1.54	0.00	0.00	0.00	0.00	0.00	0.58	1.56	1.69	1.08	0.00	0.00	0.50	1.11	0.37	0.37	0.15	0.00	0.00	1.44	0.00	0.51	

Source: GDC

Figure 3.1

Representative Main Cropping Patterns - Deep Tubewells

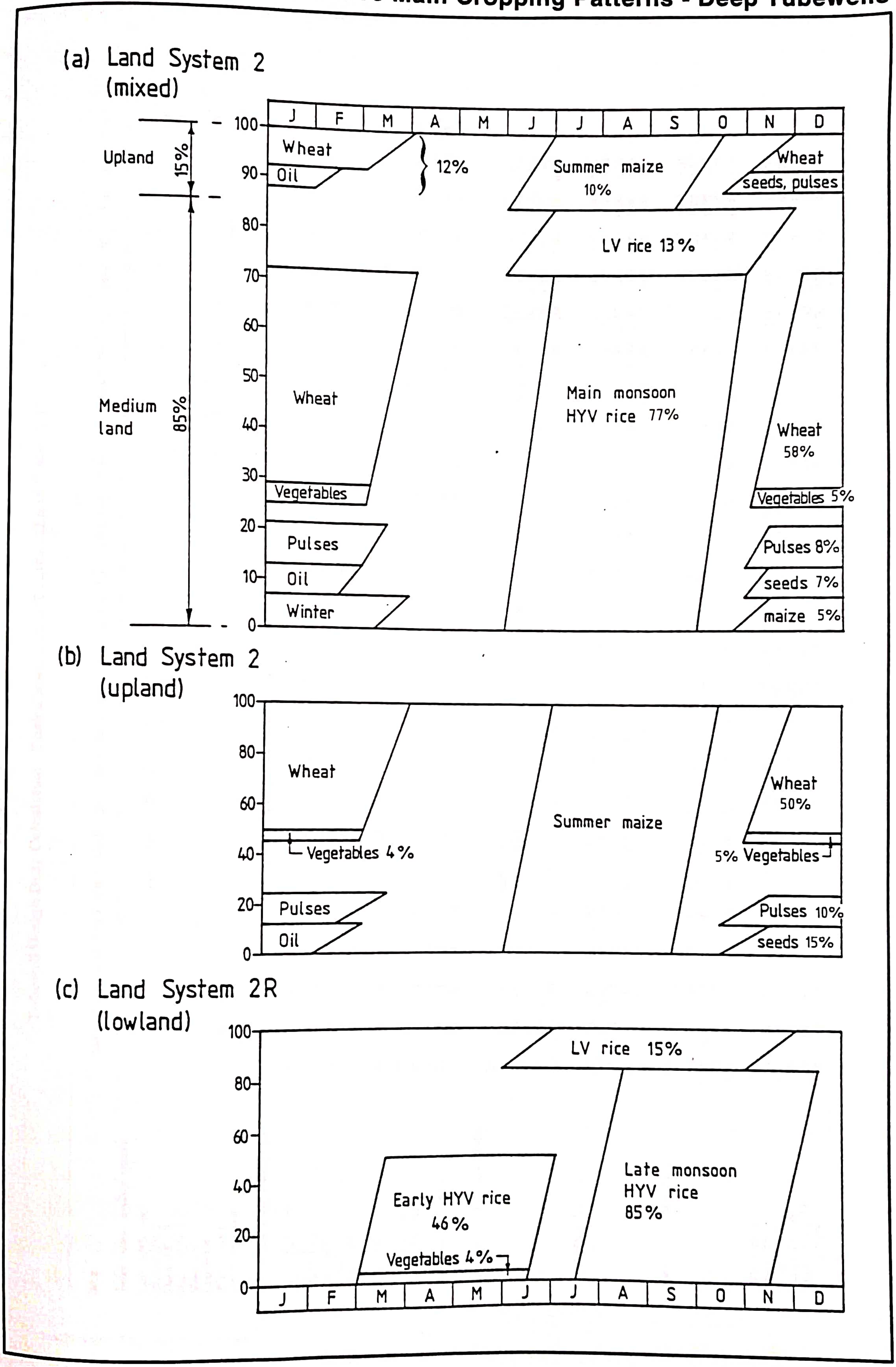


TABLE 3.2

Tubewell Design Duty Calculation : Bhairahawa/Simra (Central) (Land System 2 Mixed)

Item		Jan 1	Jan 2	Feb 1	Feb 2	Mar 1	Mar2	Apr 1	Apr 2	May 1	May 2	Jun 1	Jun 2	Jul 1	Jul 2	Aug 1	Aug 2	Sep 1	Sep 2	Oct 1	Oct 2	Nov 1	Nov 2	Dec 1	Dec 2	Totals
Total water applied (mm):																										
Early HYV rice						210	120	120	120	120	120	0														810
Main HYV 1										100	110	60	60	60												390
Main HYV 2											100	110	120			60	0									390
Main HYV 3												100	50					60	60	60						330
Main LV											100	110	60			60	0	60	60	60						510
Late HYV															50	60	0	60	0	60	60					290
Wheat/ maize		50	50																				50.0			150
Potato/ oil seed			50																						50	100
Cropped area (% of total CA):		Total irrigation depth per hectare command area (mm)																								
Early HYV rice	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
Main HYV 1	25	0	0	0	0	0	0	0	0	25	28	15	15	0	0	0	0	0	0	0	0	0	0	0	0	83
Main HYV 2	34	0	0	0	0	0	0	0	0	0	34	37	41	0	0	20	0	0	0	0	0	0	0	0	0	133
Main HYV 3	18	0	0	0	0	0	0	0	0	0	0	18	9	0	0	0	0	11	11	11	0	0	0	0	0	
Main LV	13	0	0	0	0	0	0	0	0	0	13	14	8	0	0	8	0	8	8	8	0	0	0	0	0	66
Late HYV	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-total rice	90	0	0	0	0	0	0	0	0	25	75	85	73	0	0	28	0	19	19	19	0	0	0	0	0	281
Wheat/ maize	70	35	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	0	0	105
Potato/ oil seed	25	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	25
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sub-total field crops	95	35	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	0	13	130
Days		16	15	14	14	16	15	15	15	16	15	15	15	16	15	16	15	15	15	16	15	15	15	16	15	365
Pump duty 18 hr day (l/s/ha)																										
Crops	Ec																									
Rices	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.77	0.87	0.75	0.00	0.00	0.27	0.00	0.19	0.19	0.18	0.00	0.00	0.00	0.00	0.00	
	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.85	0.97	0.83	0.00	0.00	0.30	0.00	0.21	0.21	0.20	0.00	0.00	0.00	0.00	0.00	
	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	1.02	1.16	1.00	0.00	0.00	0.36	0.00	0.26	0.26	0.24	0.00	0.00	0.00	0.00	0.00	
	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	1.28	1.45	1.24	0.00	0.00	0.45	0.00	0.32	0.32	0.30	0.00	0.00	0.00	0.00	0.00	
	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	1.53	1.74	1.49	0.00	0.00	0.54	0.00	0.38	0.38	0.36	0.00	0.00	0.00	0.00	0.00	
Field crops (Ea = .6)	Ec																									
	1.00	0.56	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.21	
	0.90	0.63	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.24	
	0.75	0.75	1.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.29	
	0.60	0.94	1.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.36	
	0.50	1.13	1.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20	0.00	0.43	
Field crops (Ea = .5)	Ec																									
	1.00	0.68	0.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.26	
	0.90	0.75	1.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.29	
	0.75	0.90	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.96	0.00	0.34	
	0.70	0.96	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.03	0.00	0.37	
	0.50	1.35	1.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.44	0.00	0.51	
Whole farm:	Ec																									
Piped DTW	0.90	0.63	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.85	0.97	0.83	0.00	0.00	0.30	0.00	0.21	0.21	0.20	0.00	0.00	0.67	0.00	0.24	
Lined DTW	0.75	0.75	1.09	0.00	0.00	0.00	0.00	0.00	0.00	0.32	1.02	1.16	1.00	0.00	0.00	0.36	0.00	0.26	0.26	0.24	0.00	0.00	0.80	0.00	0.29	
Unlined DTW	0.60	0.94	1.36	0.00	0.00	0.00	0.00	0.00	0.00	0.40	1.28	1.45	1.24	0.00	0.00	0.45	0.00	0.32	0.32	0.30	0.00	0.00	1.00	0.00	0.36	
Optimistic STW	0.70	0.96	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.40	1.28	1.45	1.24	0.00	0.00	0.45	0.00	0.32	0.32	0.30	0.00	0.00	1.03	0.00	0.37	
Likely STW	0.50	1.35	1.95	0.00	0.00	0.00	0.00	0.00	0.00	0.48	1.53	1.74	1.49	0.00	0.00	0.54	0.00	0.38	0.38	0.36	0.00	0.00	1.44	0.00	0.51	

Source: GDC

TABLE 3.3

Tubewell Design Duty Calculation : Rampur/Tulsipur (Inner Terai) (Land System 2 Mixed)

Item		Jan 1	Jan 2	Feb 1	Feb 2	Mar 1	Mar2	Apr 1	Apr 2	May 1	May 2	Jun 1	Jun 2	Jul 1	Jul 2	Aug 1	Aug 2	Sep 1	Sep 2	Oct 1	Oct 2	Nov 1	Nov 2	Dec 1	Dec 2	Totals
Total water applied (mm):																										
Early HYV rice						210	120	120	120	120	120															810
Main HYV 1										100	110	60	60	0												330
Main HYV 2											100	110	60													270
Main HYV 3												100	50						60							210
Main LV											100	110	60							60						330
Late HYV														50						60	60					170
Wheat/ maize		50																					50.0			100
Potato/ oil seed			50																						50	100
Cropped area (% of total CA):		Total irrigation depth per hectare command area (mm)																								
Early HYV rice	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
Main HYV 1	23	0	0	0	0	0	0	0	0	23	25	14	14	0	0	0	0	0	0	0	0	0	0	0	0	76
Main HYV 2	34	0	0	0	0	0	0	0	0	0	34	37	20	0	0	0	0	0	0	0	0	0	0	0	0	92
Main HYV 3	18	0	0	0	0	0	0	0	0	0	0	18	9	0	0	0	0	0	11	0	0	0	0	0	0	
Main LV	13	0	0	0	0	0	0	0	0	0	13	14	8	0	0	0	0	0	0	8	0	0	0	0	0	43
Late HYV		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-total rice	88	0	0	0	0	0	0	0	0	23	72	84	51	0	0	0	0	0	11	8	0	0	0	0	0	211
Wheat/ maize	66	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0	0	66
Potato/ oil seed	29	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	29
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sub-total field crops	95	33	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0	15	95
Days		16	15	14	14	16	15	15	15	16	15	15	15	16	15	16	15	15	15	16	15	15	15	16	15	365
Pump duty 18 hr day (l/s/ha)																										
Crops	Ec																									
Rices	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.74	0.86	0.52	0.00	0.00	0.00	0.00	0.00	0.11	0.08	0.00	0.00	0.00	0.00	0.00	
	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.83	0.95	0.58	0.00	0.00	0.00	0.00	0.00	0.12	0.08	0.00	0.00	0.00	0.00	0.00	
	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.99	1.15	0.70	0.00	0.00	0.00	0.00	0.00	0.15	0.10	0.00	0.00	0.00	0.00	0.00	
	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	1.24	1.43	0.87	0.00	0.00	0.00	0.00	0.00	0.19	0.13	0.00	0.00	0.00	0.00	0.00	
	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	1.49	1.72	1.05	0.00	0.00	0.00	0.00	0.00	0.22	0.15	0.00	0.00	0.00	0.00	0.00	
Field crops (Ea = .6)	Ec																									
	1.00	0.53	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.00	0.25	
	0.90	0.59	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.00	0.28	
	0.75	0.71	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.00	0.33	
	0.60	0.88	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.00	0.41	
	0.50	1.06	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.13	0.00	0.50	
Field crops (Ea = .5)	Ec																									
	1.00	0.64	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.00	0.30	
	0.90	0.71	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.00	0.33	
	0.75	0.85	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.91	0.00	0.40	
	0.70	0.91	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.97	0.00	0.43	
	0.50	1.27	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.36	0.00	0.60	
Whole farm:	Ec																									
Piped DTW	0.90	0.59	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.83	0.95	0.58	0.00	0.00	0.00	0.00	0.00	0.12	0.08	0.00	0.00	0.63	0.00	0.28	
Lined DTW	0.75	0.71	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.99	1.15	0.70	0.00	0.00	0.00	0.00	0.00	0.15	0.10	0.00	0.00	0.75	0.00	0.33	
Unlined DTW	0.60	0.88	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.37	1.24	1.43	0.87	0.00	0.00	0.00	0.00	0.00	0.19	0.13	0.00	0.00	0.94	0.00	0.41	
Optimistic STW	0.70	0.91	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.37	1.24	1.43	0.87	0.00	0.00	0.00	0.00	0.00	0.19	0.13	0.00	0.00	0.97	0.00	0.43	
Likely STW	0.50	1.27	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.44	1.49	1.72	1.05	0.00	0.00	0.00	0.00	0.00	0.22	0.15	0.00	0.00	1.36	0.00	0.60	

Source: GDC

TABLE 3.4

Tubewell Design Duty Calculation : Khajura/Dhangadhi (West) (Land System 2 Mixed)

Item		Jan 1	Jan 2	Feb 1	Feb 2	Mar 1	Mar2	Apr 1	Apr 2	May 1	May 2	Jun 1	Jun 2	Jul 1	Jul 2	Aug 1	Aug 2	Sep 1	Sep 2	Oct 1	Oct 2	Nov 1	Nov 2	Dec 1	Dec 2	Totals
Total water applied (mm):																										
Early HYV rice						210	120	120	120	180	180															930
Main HYV 1										100	170	120	60													450
Main HYV 2											100	110	120													330
Main HYV 3												100	50						60							210
Main LV											100	110	120						60	60						450
Late HYV															50				60	60	120					290
Wheat/ maize		50	50																				50.0			150
Potato/ oil seed			50																						50	100
Cropped area (% of total CA):				Total irrigation depth per hectare command area (mm)																						
Early HYV rice	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
Main HYV 1	20	0	0	0	0	0	0	0	0	20	34	24	12	0	0	0	0	0	0	0	0	0	0	0	0	90
Main HYV 2	35	0	0	0	0	0	0	0	0	0	35	39	42	0	0	0	0	0	0	0	0	0	0	0	0	116
Main HYV 3	22	0	0	0	0	0	0	0	0	0	0	22	11	0	0	0	0	0	13	0	0	0	0	0	0	
Main LV	13	0	0	0	0	0	0	0	0	0	13	14	16	0	0	0	0	0	8	8	0	0	0	0	0	59
Late HYV		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-total rice	90	0	0	0	0	0	0	0	0	20	82	99	81	0	0	0	0	0	21	8	0	0	0	0	0	264
Wheat/ maize	70	35	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	0	0	105
Potato/ oil seed	25	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	25
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sub-total field crops	95	35	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	0	13	130
Days		16	15	14	14	16	15	15	15	16	15	15	15	16	15	16	15	15	15	16	15	15	15	16	15	365
Pump duty 18 hr day (l/s/ha)																										
Crops	Ec																									
Rices	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.84	1.02	0.83	0.00	0.00	0.00	0.00	0.00	0.22	0.08	0.00	0.00	0.00	0.00	0.00	
	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.94	1.13	0.92	0.00	0.00	0.00	0.00	0.00	0.24	0.08	0.00	0.00	0.00	0.00	0.00	
	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	1.12	1.36	1.11	0.00	0.00	0.00	0.00	0.00	0.29	0.10	0.00	0.00	0.00	0.00	0.00	
	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	1.41	1.69	1.38	0.00	0.00	0.00	0.00	0.00	0.36	0.13	0.00	0.00	0.00	0.00	0.00	
	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.39	1.69	2.03	1.66	0.00	0.00	0.00	0.00	0.00	0.43	0.15	0.00	0.00	0.00	0.00	0.00	
Field crops (Ea = .6)	Ec																									
	1.00	0.56	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.21	
	0.90	0.63	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.24	
	0.75	0.75	1.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.29	
	0.60	0.94	1.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.36	
	0.50	1.13	1.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20	0.00	0.43	
Field crops (Ea = .5)	Ec																									
	1.00	0.68	0.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.26	
	0.90	0.75	1.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.29	
	0.75	0.90	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.96	0.00	0.34	
	0.70	0.96	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.03	0.00	0.37	
	0.50	1.35	1.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.44	0.00	0.51	
Whole farm:	Ec																									
Piped DTW	0.90	0.63	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.94	1.13	0.92	0.00	0.00	0.00	0.00	0.00	0.24	0.08	0.00	0.00	0.67	0.00	0.24	
Lined DTW	0.75	0.75	1.09	0.00	0.00	0.00	0.00	0.00	0.00	0.26	1.12	1.36	1.11	0.00	0.00	0.00	0.00	0.00	0.29	0.10	0.00	0.00	0.80	0.00	0.29	
Unlined DTW	0.60	0.94	1.36	0.00	0.00	0.00	0.00	0.00	0.00	0.32	1.41	1.69	1.38	0.00	0.00	0.00	0.00	0.00	0.36	0.13	0.00	0.00	1.00	0.00	0.36	
Optimistic STW	0.70	0.96	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.32	1.41	1.69	1.38	0.00	0.00	0.00	0.00	0.00	0.36	0.13	0.00	0.00	1.03	0.00	0.37	
Likely STW	0.50	1.35	1.95	0.00	0.00	0.00	0.00	0.00	0.00	0.39	1.69	2.03	1.66	0.00	0.00	0.00	0.00	0.00	0.43	0.15	0.00	0.00	1.44	0.00	0.51	

Source: GDC

These produce peaks in early June and late December/late January in the East and early June and late December in the Far West.

Allowing for the system efficiencies listed in Section 2.4 and assuming 18 hours daily pumping at peak periods (seven days a week), Table 3.5 shows the total calculated irrigation requirements at the well.

TABLE 3.5

Summary of Pump Design Duty Calculations
(1-in-5 dry year rainfall)

Distribution system/analysis stratum	Pre-monsoon peak (1) (l/s per hectare)	Winter peak (2) (l/s per hectare)	(2)/(1) (%)	Adopted duty (l/s per hectare)
Buried pipes				
West*	1.13	0.90	80	1.00
Inner Terai**	0.95	0.59	62	1.00
Central*	0.97	0.90	93	1.00
East*	0.94	0.90	96	1.00
Average	1.00	0.82	82	
Lined open channels 18				
West	1.36	1.09	80	1.25
Inner Terai	1.15	0.80	70	1.25
Central	1.16	1.09	94	1.25
East	1.13	1.09	96	1.25
***Unlined open channels 185% intensity**				
West	1.69	1.36	80	1.50
Inner Terai	1.43	1.00	70	1.50
Central	1.45	1.36	94	1.50
East	1.41	1.36	96	1.50
Shallow tubewells (earth channels)	***	***		***
West	2.03 (1.56)	1.95 (1.39)	96	2.00 (1.35)
Inner Terai	1.72 (1.36)	1.27 (1.03)	84	1.90 (1.35)
Central	1.74 (1.36)	1.95 (1.39)	112	1.90 (1.35)
East	1.69 (1.30)	1.95 (1.39)	115	1.90 (1.35)

Notes:		
	*	Land System 2 (mixed)
	**	Land System
	***	Equivalent figures for lined feeder channels

Source: GDC (Tables 3.1, 3.3 and 3.4)

Also included is an estimate for less efficient STWs (assuming 50% overall channel losses) which are probably equivalent to the better existing systems. The results illustrate the advantage of the earlier monsoon in the East, where about 85% of the Far West requirement is needed. This has the effect of raising the calculated pump duty from about 1.05 l/s per hectare to 1.2 l/s per hectare, but this is not a major difference in view of the range of assumptions involved in the calculation.

At these levels the absolute values can be changed in theory by varying the amount of stagger in the rice planting programme, but this would push the analysis beyond its limits, particularly as it assumes relatively sophisticated crop and water management practices on the part of the farmers which have yet to be demonstrated in practice.

The more important conclusion is that the pre-monsoon peak is far more dominant than the winter season peak. Groundwater irrigation clearly provides a unique opportunity to achieve timely seed bed and rice land preparation and transplanting, with benefits which are clearly perceived by groundwater irrigators; not simply a case of being able to plant rice nurseries on time (not requiring much water). Groundwater irrigation provides the means for adopting a radically different approach to rice cultivation, both at transplanting time and during dry spells in between the monsoon rains. The farmers' awareness of this is reflected by the high daily pumping hours observed in projects such as BLGWP in May/June.

Having established that there is not enormous range in peak monsoon season pumping requirments across the whole Terai and the inner Terai valleys, there does appear to be a greater range in winter irrigation needs. Whilst relatively constant in the main Terai, the inner Terai valleys do exhibit more reliable winter rainfall, with a corresponding 25% reduction in calculated peak needs.

In average rainfall years, the inner Terai and Far Western districts all benefit from more dependable winter rainfall, and this is reflected in lower winter pumping hours as described in Section 3.3.

The impact of varying irrigation system efficiencies on pump requirements is also demonstrated in Table 3.5: 0.94 l/s per hectare for a DTW with an efficient piped distribution system irrigating rice in the East compared with 1.7 l/s per hectare for a typical STW in the same area.

These results lead to the question of which peak demand period (pre-monsoon or winter) to select for design purposes? The ratios between the winter and pre-monsoon peaks are given for buried pipes DTWs in Table 3.5.

For broad planning purposes, it is not considered that the calculated differences between the pre-monsoon peaks are significant enough to justify the adoption of different values; any extensive investment in DTWs will be preceeded by site specific feasibility studies which will permit more localised and rigorous review of the main assumptions made. For this reason it is proposed to adopt a uniform 1.0 l/s per hectare to meet the pre-monsoon needs in buried pipe DTW systems.

The more thorny question is which peak should dominate; the winter or pre-monsoon? A duty of 1.0 l/s per hectare would result in over-capacity of 49% in the inner Terai valleys (but only 10% in the main Terai).

More fundamentally, we believe that inadequate water supplies are responsible for many of the water management problems demonstrated by tubewell irrigators. Moreover, since timely monsoon cropping is seen as the key to realising major tubewell irrigation benefits, should pumps not be sized to meet this most crucial demand period? It certainly appears to interest the farmers more. An approach which leaves DTWs in the inner Terai with about 45% over capacity in the winter peak time still implies a winter peak pumping rate of 12 hours per day).

In this case it could be very tempting to design for the winter peaks and assume that farmers can be persuaded, either amongst themselves or institutionally, not to irrigate all their land. (This is precisely what the Warubundi system in India is about, as well as the theory of allocating limiting surface water resources in India and Nepal.) Moreover, it means including more farmers for a given well size and to a certain extent reduces the installed cost per hectare.

Our estimates do include a safety margin of six hours pumping a day, but this should be kept in reserve in case of breakdown and to cope with the threat of load shedding in the case of electric wells. Moreover, the 18 hour operating day will require at least six hours of pumping at night; this is far less efficient and farmers will avoid this if they can. Also, the calculated pump duties assume water management standards at assumed design efficiencies, which is something that may take five years to develop at a particular well.

Taking these aspects into consideration, as well as our belief that many of the classic water management problems, such as illegal abstractions, are exacerbated by water shortage, we recommend that wells should be sized as far as possible according to whichever watering peak applies. Those indicated in Table 3.5 can most probably be reduced by spreading out planting dates and this should be studied (although it implies very sophisticated application by the farmers themselves).

We also believe that the argument that it is unfair to provide tubewell irrigators with more water than surface irrigators is not valid since it is unlikely that surface irrigators will have to pay remotely as much for their water in the foreseeable future.

Using these data, a 14 l/s STW will command about 7 ha with improved distribution channels (comfortably exceeding the 4 ha target chosen for standard ADBN STWs). This is based on an overall channel efficiency of 50%. Providing lined feeder channel systems for STWs enables the target area to be raised to about 10 ha, assuming a design duty of 1.35 l/s per hectare.

These calculations are very sensitive to localised data for rainfall and percolation rates; the latter are not at all well documented and would need to be studied in detail at feasibility study level. The inner Terai and Far West cases in particular need further thought; the imbalance between winter and pre-monsoon peaks could possibly be reduced by modifying the cropping pattern. North-south variations in rainfall across the Terai are also significant.

These calculations are based on applying the full Penman water requirements, and for design purposes it is recommended that DTW pumps should be sized accordingly.

3.3 Pumping Hours Calculations

Having determined the well design duties, average annual pumping hours can be calculated on the basis of the irrigated area, requirements for the individual crops concerned, and associated irrigation intensities. An example is shown on Table 3.6 which is based on buried pipe distribution systems in the Central and East strata. In order to relate the analysis to the three cases on which the economic and financial analysis presented in Volume 5, Economics are based, assumptions have been made regarding the build-up in irrigation water use and corresponding water use efficiency which can be expected as the water management learning process develops. The improved case will not be achieved without serious water management extension efforts and applied field research to determine the extension messages.

These calculated hours can be taken as representative of DTWs with different distribution systems; reductions in efficiencies are offset by the increase in well design duty and correspondingly smaller command area for a given size of well.

The situation for shallow tubewells is different, being directly related to area. Pump capacity should only become a limitation when attempting larger areas than the 4 ha taken for ‘improved’ planning purposes; this would occur in the case of trying to expand irrigation through lined channel systems (such as being developed under ILC) or more sophisticated means of distribution. It is not likely to influence the standard ADBN approach.

An example calculation is given in Table 3.7, while considering a 4 ha ‘improved’ STW and a nominal 7 ha ‘improved’ STW with lined feeder channels. The overall calculations are summarised on Tables 3.8 and 3.9.

TABLE 3.6

Deep Tubewell Annual Pump Hour Calculations (60 l/s well)

								60	
Item	Fraction applied (%)	Central stratum				East stratum			
		1.00 l/s/ha Application		60.0 ha CA		1.00 l/s/ha Application		60.0 ha CA	
		Full (mm)	Actual (mm)	Irrigation intensity (%)	Pump hours	Full (mm)	Actual (mm)	Irrigation intensity (%)	Pump hours
(a) Improved Case (best)									
Rice:									
Early HYV	100%	750	750	0%	0	750	750	0%	0
Main HYV 1	100%	270	270	20%	150	330	330	30%	275
Main HYV 2	100%	210	210	40%	233	330	330	33%	303
Main HYV 3	100%	210	210	27%	158	210	210	24%	140
Main LV	100%	270	270	13%	98	230	230	13%	83
Late HYV	100%	170	170	0%	0	390	390	0%	0
Sub-total (net demand)				100%	638			100%	801
Efficiency (Ec)					90%				90%
Sub-total (gross demand)					709				890
Field crops (Ea = 60%)									
Wheat/ maize	100%	150	150	70%	292	150	150	70%	292
Potato/ oil seed	100%	100	100	25%	69	100	100	25%	69
Sub-total (net demand)				95%	361			95%	361
Efficiency (Ec*Ea)					54%				54%
Sub-total (gross demand)					669				669
Total pump hours:				195%	1 378			195%	1 558
(b) Improved Case (average)									
Rice:									
Early HYV	85%	750	638	0%	0	750	638	0%	0
Main HYV 1	85%	270	230	20%	128	330	281	30%	234
Main HYV 2	85%	210	179	40%	198	330	281	33%	257
Main HYV 3	85%	210	179	27%	134	210	179	24%	119
Main LV	85%	270	230	13%	83	230	196	13%	71
Late HYV	85%	170	145	0%	0	390	332	0%	0
Sub-total (net demand)				100%	543			100%	681
Efficiency (Ec)					85%				85%
Sub-total (gross demand)					638				801
Field crops (Ea = 55%)									
Wheat/ maize	85%	150	128	70%	248	150	128	70%	248
Potato/ oil seed	85%	100	85	25%	59	100	85	25%	59
Sub-total (net demand)				95%	307			95%	307
Efficiency (Ec*Ea)					47%				47%
Sub-total (gross demand)					653				653
Total pump hours:				195%	1 292			195%	1 454
(c) Basic Case (average)									
Rice:									
Early HYV	65%	750	488	0%	0	750	488	0%	0
Main HYV 1	65%	270	176	20%	98	330	215	30%	179
Main HYV 2	65%	210	137	40%	152	330	215	33%	197
Main HYV 3	65%	210	137	27%	102	210	137	24%	91
Main LV	65%	270	176	13%	63	230	150	13%	54
Late HYV	65%	170	111	0%	0	390	254	0%	0
Sub-total (net demand)				100%	415			100%	520
Efficiency (Ec)					80%				80%
Sub-total (gross demand)					519				651
Field crops (Ea = 50%)									
Wheat/ maize	65%	150	98	70%	190	150	98	70%	190
Potato/ oil seed	40%	100	40	25%	28	100	40	25%	28
Sub-total (net demand)				95%	217			95%	217
Efficiency (Ec*Ea)					40%				40%
Sub-total (gross demand)					543				543
Total pump hours:				195%	1 062			195%	1 194

Source: GDC

TABLE 3.7

Shallow Tubewell Annual Pump Hour Calculations (14 l/s well)

Item	Fraction applied (%)	West stratum (Unlined)				Inner Terai stratum (lined)			
		3.50 l/s/ha		4.0 ha CA		2.00 l/s/ha		7.0 ha CA	
		Application Full (mm)	Application Actual (mm)	Irrigation intensity (%)	Pump hours	Application Full (mm)	Application Actual (mm)	Irrigation intensity (%)	Pump hours
(a) Improved Case (best)									
Rice:									
Early HYV	100%	870	870	0%	0	750	750	0%	0
Main HYV 1	100%	390	390	20%	62	270	270	30%	113
Main HYV 2	100%	270	270	40%	86	150	150	34%	71
Main HYV 3	100%	210	210	27%	45	150	150	23%	48
Main LV	100%	270	270	13%	28	210	210	13%	38
Late HYV	100%	170	170	0%	0	60	60	0%	0
Sub-total (net demand)				100%	220			100%	269
Efficiency (Ec)					70%				75%
Sub-total (gross demand)					315				359
Field crops (Ea = 50%)									
Wheat/ maize	100%	150	150	70%	83	100	100	66%	92
Potato/ oil seed	100%	50	50	25%	10	50	50	29%	20
Sub-total (net demand)				95%	93			95%	112
Efficiency (Ec*Ea)					35%				32%
Sub-total (gross demand)					266				349
Total pump hours:				195%	581			195%	708
(b) Improved Case (average): area =		2.5 ha				4.0 ha			
Rice:									
Early HYV	85%	870	740	0%	0	750	638	0%	0
Main HYV 1	85%	390	332	20%	33	270	230	30%	55
Main HYV 2	85%	270	230	40%	46	150	128	34%	34
Main HYV 3	85%	210	179	27%	24	150	128	23%	23
Main LV	85%	270	230	13%	15	210	179	13%	18
Late HYV	85%	170	145	0%	0	60	51	0%	0
Sub-total (net demand)				100%	117			100%	131
Efficiency (Ec)					60%				70%
Sub-total (gross demand)					195				187
Field crops (Ea = 45%)									
Wheat/ maize	85%	150	128	70%	44	100	85	66%	45
Potato/ oil seed	85%	50	43	25%	5	50	43	29%	10
Sub-total (net demand)				95%	50			95%	54
Efficiency (Ec*Ea)					27%				32%
Sub-total (gross demand)					184				170
Total pump hours:				195%	379			195%	357
(c) Basic Case (average)		2.5 ha				4.0 ha			
Rice:									
Early HYV	65%	870	566	0%	0	750	488	0%	0
Main HYV 1	65%	390	254	20%	25	270	176	30%	42
Main HYV 2	65%	270	176	40%	35	150	98	34%	26
Main HYV 3	65%	210	137	27%	18	150	98	23%	18
Main LV	65%	270	176	13%	11	210	137	13%	14
Late HYV	65%	170	111	0%	0	60	39	0%	0
Sub-total (net demand)	65%			100%	90			100%	100
Efficiency (Ec)					50%				65%
Sub-total (gross demand)					179				154
Field crops (Ea = 40%)									
Wheat/ maize	65%	150	98	70%	34	100	65	66%	34
Potato/ oil seed	40%	50	20	25%	2	50	20	29%	5
Sub-total (net demand)				95%	36			95%	39
Efficiency (Ec*Ea)					20%				26%
Sub-total (gross demand)					182				149
Total pump hours:				195%	361			195%	302

TABLE 3.8

Summary of Annual Pumping Hour Calculations
(Land System 2, Mixed)

Well type/ analysis case	Far/Mid West (hours)	Inner Terai (hours)	West/ Central (hours)	East (hours)	Average l/hectare	
					Main Terai	Inner Terai
DTWs/MTWs*						
Improved case	1 300	930	1 280	1 480	23	16
Average case	1 300	870	1 240	1 390	22	15
Basic case	1 080	720	1 020	1 140	18	12
STWs						
(a) Lined open channels:						
- Improved case (7 ha)	960	710	900	1 040	138	101
- Average case (4 ha)	520	360	500	560	132	90
- Basic case (4 ha)	440	300	430	470	112	75
(b) Earth channels:						
- Improved case (4 ha)	580	400	550	630	147	100
- Average case (2.5 ha)	380	260	370	410	154	104
- Basic case (2.5 ha)	360	250	350	390	147	100

Note: * Based on 60 l/s DTW with buried pipes - 60 ha; applicable to open channel systems with correspondingly lower areas.

Source: GDC (Volume 4, Chapters 2 and 3).

TABLE 3.9

Summary of Unit Area Pumping Requirements: Land System 2, Mixed (hours/hectare per year)

Well type	Pump size (l/s)	Status*	Main Terai			Inner Terai		
			Piped system	Lined feeder	Earth feeder	Piped system	Lined feeder	Earth feeder
DTWs/MTW	90	Imp	15	19	23	10	13	16
		Bas	12	15	18	8	10	12
	60	Imp	23	29	35	16	19	23
		Bas	18	23	27	12	15	18
	45	Imp	31	39	47	21	26	31
		Bas	24	30	36	16	20	24
	30	Imp	46	58	69	31	39	47
		Bas	36	45	54	24	30	36
	15	Imp	92	115	138	62	78	93
		Bas	72	90	108	48	60	72
STWs	14	HU		138	147		101	100
		Imp		132	154		90	104
		Bas		112	147		75	100

Notes: * Status:
HU High Utilisation (STWs only)
Imp Improved Utilisation
Bas Basic analysis case

Source: GDC (from Table 3.8)

CHAPTER 4

IRRIGATION AND LAND DRAINAGE STUDIES

4.1 Deep Tubewells

4.1.1 Current Systems

Having evolved from a series of exploration boreholes started in 1969, deep tubewell irrigation development activities in the Terai have progressed as follows:

(a) IDA assisted Birganj Project under Narayani Zone Irrigation Development Project (NZIDP);

(b) IDA assisted Bhairahwa Lumbini Groundwater Project (BLGWP) under GWRDB;

(c) HMGN financed investigation/production programmes under GWRDB;

(d) HMGN financed conversion of GWRDB investigation boreholes to production wells under the Former Irrigation and Water Utilisation Division (FIWUD) of the Directorate of Agriculture (DOA) - now the Irrigation Management and Water Utilisation Division of the DOI;

(e) ADBN assisted Sagarmatha Integrated Rural Development Project (SIRDP) under GWRDB;

(f) Japanese assisted Janakpur Agriculture Development Programme (JADP) under DOA;

(g) IDA assisted production well development under the groundwater component of the Irrigation Line of Credit (ILC) Programme.

These activities are discussed in greater detail in Volume 1, Chapter 3, and their overall scope is summarised in Table 4.1 together with an estimate of the area operating under DTWs in mid-1993, based on the unit areas stated in Table 4.2. The Kailali Kanchanpur DTW Project under GWRDB handed over 32 DTWs to FIWUD in 1986, at least 28 of which are complete with distribution systems (eigth also with pumps). Some of these wells are probably being used informally with free flowing artesian water, and since the end of FIWUD's operations, these wells are understood to be under operation by the irrigation component of the Seti Integrated Rural Development Project through GWRDB's office in Dhangadhi.

TABLE 4.1

Extent of Deep Tubewell Facilities (Mid 1993)

Development Region and District	Operator	DTWs selected for irrigation	DTWs commissioned for irrigation	Approximate area in command by 1993 (ha)
Far West				
Kanchanpur	GWRDB	21	14	560
Kailali	GWRDB	95	27	1 080
Sub-total		116	41	1 640
Mid West				
Banke	GWRDB	6	6	240
Dangdeukhuri	ILC	4	0	0
	GWRDB	4	4	160
Sub-total		14	10	400
West				
Kapilvastu	GWRDB	50	20	800
	ILC	7	6	240
Rupandehi	BLGWP I	64	64	4 800
	BLGWP II	38	16	500
	BLGWP III	18	0	0
	GWRDB	46	28	1 100
Nawalparasi	ILC	6	4	160
Sub-total		229	138	7 600
Central				
Chitwan	JADP	4	0	0
Parsa	GWRDB	9	1	40
Parsa/Bara	NZIDP	29	19	1 020
Sarlahi	GWRDB	13	0	0
	JADP	15	4	160
Mahottari	GWRDB	32	18	570
	JADP	8	3	120
Dhanusha	JADP	78	15	600
Sub-total		188	60	2 510
East				
Siraha	SIRDP	14	12	460
Saptari	SIRDP	5	3	110
Sub-total		19	15	570
Total Terai		568	264	12 720

Source: GDC

TABLE 4.2

Typical Deep Tubewell Irrigation Design Features

Project/development	Representative			Distribution system type*
	Well capacity (l/s)	Command area (ha)	Design duty (l/s per hectare)	
Kailali/Kanchanpur	40	60	0.67	L/E
Bhairahwa/Lumbini:				
Stage I	110	120	0.92	L/E
Stage II	83	116	0.72	B/E
Stage III**	42-83	54-108	0.77	B/E
Birganj:				
Earlier wells	50-70	57-100	0.7-0.9	L/E
Later wells	80	120	0.67	L/E
Sarlahi (FIWUD)	45	50	0.90	E/E
Mahottari (GWRDB)	10-57	14-57	1.00	E/E
JADP	35	40	0.88	L/E
SIRDP	35	50	0.70	L/E
ILC (force mode	25-45	25-45	1.00	L/E
ILC (suction mode)	14	10	1.40	L/E

Notes: * Feeder/field channels: L= lined, E = earth, B = buried pipe
** Under construction

Source: Data from GWRDB, NZIDP, FIWUD, JADP, ILC.

Nevertheless, only about 55% of the existing DTWs selected for irrigation (as opposed to some investigation wells without development potential) are operational; this is mainly because of lack of pumps and distribution facilities - a few others are different for one reason or another.

The main features of the various DTW irrigation systems are summarised in Table 4.2. This indicates that most DTWs have been designed on the basis of between 0.7 and 1.0 l/s per hectare; most of the systems use lined open channels for the main feeder channels; that is significantly less than the 1.25 l/s per hectare recommended in Section 3.2. This limitation is clearly noted at BLGWP Stage I, where the **effective** irrigation duty - 64 wells averaging 110 l/s and currently irrigating some 4 800 ha - is closer to 1.45 l/s. This should improve when the channel lining programme is completed (see Section 4.1.2).

4.1.2 DTW Utilisation and Farmer Participation

The Bhairahwa Lumbini Groundwater Irrigation Project (BLGWP) has provided a valuable model against which to track the transition from technically, top-driven project orientated DTW irrigation to a farmer demand driven approach. Development has taken place in three stages, the key features of which are summarised in Table 4.3.

TABLE 4.3

Irrigation Planning and Management Features; BLGWP Wells

Item	Project Stage		
	I	II	III
Construction Period	1978-84	1985-93	1991-98
Numbers of wells (Nr)	64	16+22*	79**
Average pump size (l/s)	110	83	42-83
Target command area (ha)	120	120	108
Feeder system (initial)	Partial lined earth	Buried pipe	Buried pipe
Farmers participation in well siting/system design	Very little	Some	Extensive
WUOs set up in advance?	No	No	Yes
Initial water charging policy	Water tax	Water tax	Pay fuel
Current water charging policy	Farmers pay	Farmers pay	Farmers pay
Number of WUOs paying bills	52	7	n/a
Number of WUOs paying operator	5	0	n/a
Current effective area (ha)	4 800	No data	n/a
Gross command area (ha)	7 650	1 850	8 600

Notes: * Stage II, Phase 2 wells, now complete but for pump sets

** Stage III wells, 18 drilled to date.

Source: BLGWP, September 1993

At each stage the level of farmer involvement at the planning and design stage has increased, to the extent that the Stage III wells are now being sited on the basis of negotiations stemming from an initial technical assessment/identification of contiguous irrigable land within the overall Stage III boundaries.

The approach is to:

- meet the farmers concerned and introduce the well concept and area under consideration;
- discuss the proposal and assume its workability from both organisational and technical aspects;
- revise the concept as necessary;
- ensure that the farmers understand the ownership and operational requirements to receive a well and clarify the obligations and long term maintenance responsibilities of the government; and
- leave the farmers to form a Water Users Organisation (WUO) and to apply for a well; assist as necessary.

In this way, the WUO applies for a well, undertakes to provide free labour for all earthworks involved in the distribution system (particularly for pipe trenching and farm channels), agrees to take over management responsibility and to pay all operation and maintenance costs.

The move towards turnover of the Stage I wells from the project to the farmers has not been easy. Farmers, rightly, wanted to be confident that they were to take over management of wells which would function properly and were manageable. Aware that they were in a position of strength, the farmers embarked on a negotiation procedure with a mixture of fair and excessive demands. One result has been the recognition that the open channel feeder systems needed to be fully lined as far as the 4 ha irrigation unit outlet. This means 147 km of lining in addition to the 107 km already provided. A second result has been the recognition that some farmers, or even whole well groups, will not cooperate, and that there are areas which are not available for winter cropping due to waterlogging.

As a result, the Stage I operations are now focused on some 4 800 ha at 52 of the original 64 wells, and a programme of completing the feeder channel lining is under way. This operation is a key transition point in the turnover process: by accepting an improved lining system, the farmers commit themselves to taking over management of the well, paying for direct pumping costs and the operator and (after one year) maintenance costs. It is expected that the remaining 12 wells will be de-commissioned and the well facility taken from the farmers concerned.

BLGWP now believes that it has the confidence of the farmers; the product of 10 years operational experience and much mutual learning, and an increasing dependence on the wells by the farmers. Feeder channels at a further 15 priority wells will be lined in 1993/94.

All the first 16 Stage II wells, with buried pipe systems, have now been operated for either three or four years. There, only seven WUOs have established themselves as reliable electricity bill payers and the consolidation/confidence building process is still in process.

Accurate data on actual irrigated areas are not available, but about half the potential area is currently irrigated. Experience of operating the buried pipe systems is growing, but there are clear concerns about water theft (which has discouraged farmers from night irrigation) and overall hydraulic management of the systems.

The approach to the Stage III wells has gone one stage further, in that the WUOs have to agree to contribute labour for all earthworks (particularly pipe line trenching) as well as to take over and operate the well. This has met with some resistance (all the Stage I and Stage II works were 'free' as far as the farmers were concerned) and a complementary flexibility on the part of the project in terms of determining the size of command area, location of irrigation outlets, and so forth has evolved.

Even in the Stage III area the project's negotiating position is weakened because, having determined the boundary and the number of wells to be contained within it, there is relatively little choice over where the wells are sited. The farmers know this, and so the concept of demand driven siting is limited.

Nevertheless, there has been significant progress in the development of farmer involvement from Stage I to II and then to III. This has required give and take on both sides, but at least the principles of turnover are being established, along with the accountabilities of each party - the project and the farmers. However, at least one thorny and confusing issue remains: how can the farmer reasonably be expected to accept maintenance of the mechanical and electrical plant, and where are the responsibility boundaries?

'Handover' to the WUOs should not be seen as a means of relinquishing responsibility for complex items such as the 11 kV/440 V step down motor starter circuitry and the motor/pump assembly itself: these are beyond the farmers' current understanding and financial reach.

One predictable result of the farmers taking over responsibility for pump operation is that they clearly look for economies. BLGWP expects that analysis of 1992/93 pumping season electrical consumption costs (largely paid by the farmers) will show significant savings (perhaps 40%) on the 1991/92 figures. The farmers are also much quicker to complain to the project about leaking distribution system structures, and three of the five WUOs now responsible for paying the pump operators salary have elected to release the project trained operator and employ their own (cheaper) candidate.

Attempts to assess the overall utilisation of DTWs have only been partially successful as records of actual pumping hours tend to be spasmodic and there is a tendency to quote target areas rather than actual irrigation areas. Target areas too can be misleading; these are often stated **without** regard to the area that can actually be served by gravity from a given point.

Pump operation data provided by BLGWP and NZIDP are given in Tables 4.4 and 4.5 respectively. The BLGWP data are interesting as they demonstrate considerable variation between wells, a few of which are used very heavily. However, the average pump hours are probably distorted by unrecorded periods of free artesian flow which may account for some of the apparently very low utilisations. The FIWUD data indicate fairly consistent operations in the range of 500 to 800 hours per year except in the Far West where the annual total is much lower at 150 to 200 hours (and probably related to the fact that there is a reluctance to pump when artesian water can be used at rates between Rs 1 and Rs 4 per hour compared with Rs 16 per hour for pumped water). The great problem with this is that the irrigated area is much reduced (the available area typically falling to one-quarter when the pump is not run).

TABLE 4.4

Average Annual Pumping Time: BLGWP Stage I Wells
1989/90 to 1991/92

Operation parameter	Manpakadi sub-centre	Bhalwari sub-centre
Number of wells operating	37*	27**
(a) Ranking by hours per year		
>2 000	1	0
1 500 - 2 000	6	3
1 001 - 1 500	15	5
500 - 1 000	11	11
1 - 500	4	8
(b) Ranking by hours/hectare***		
>15	2	0
11 - 15	12	5
6 - 10	18	8
1 - 5	5	14
Annual maximum	2 211	1 714
Medium	1 015	673
Annual minimum	35	21

Notes:
* 36 only in 1991/92
** 26 only in 1989/90 and 1991/92
*** design command area

Source: BLGWP data

The BLGWP data have also been analysed on a monthly basis as shown in Table 4.6. This demonstrates the May/June peak anticipated in Chapter 3, but the high September/October use is surprising **unless** the farmers prefer to drain their fields during the monsoon period rather than trying to maintain standing water up to say 150 mm and only spilling the rest; this needs further study.

TABLE 4.5

Pump Utilisation - Birganj DTWs

Year	Pumps operated (Nr)	Irrigated area		Annual operation (hours/pump)		
		(ha)	(%)	Maximum	Minimum	Average
1980	20	911	33	1 250	295	692
1981	19	776	28	1 330	20	680
1982	25	1 535	55	1 909	138	1 140
1983	28	1 760	63	1 652	201	1 041
1984	21	1 130	41	1 643	280	824
1985	22	1 037	37	1 400	200	620
1986	21	1 106	40	989	242	545
1987	20	1 094	39	1 237	177	783
1988	17	1 019	37	1 601	475	1 075
1989	25	ND	ND	1 715	10	780
1990	23	ND	73	1 433	158	798
1991	19	ND	ND	1 366	201	760
1992	19	ND	ND	1 407	114	722

Source: Analysis of NZIDP Data Presented by Nippon Koei (1993)

During the 1987 study, useful data were gained for six wells studied closely during the fieldwork. These were effectively elements of subgroups, each installed, operated and managed according to separate sets of rules and timescales. This work was very useful in studying different agency or project approaches to DTW irrigation and associated farmers' reactions, whilst clearly limited by the recognition that the wells visited were not representative of their subgroups. The salient features of the DTWs studied are summarised in Table 4.7. At the time they were not encouraging in view of the low actual irrigated areas.

Our 1993 Field Study (less focused on DTWs) indicate that this picture has not changed much for DTWs not operated more closely (such as BLGWP and NZIDP). Use at JADP and SIRDP is very poor.

TABLE 4.6

Monthly Variations in BLGWP Stage I Monthly Pump Operation

Period	1989/90		1990/91		1991/92	
	M*	B*	M	B	M	B
Number of wells	37	27				
Command area (ha)	4 409	3 309				
Jul/aug	123	106	172	107	277	219
aug/Sep	156	129	277	195	95	72
Sep/Oct	88	56	95	57	193	138
Oct/Nov	108	46	48	16	90	34
Nov/Dec	62	38	53	25	57	36
Dec/Jan	35	28	36	37	16	12
Jan/Feb	94	37	77	45	2	2
Feb/Mar	14	8	56	28	31	23
Mar/Apr	63	41	76	47	58	43
Apr/May	39	31	72	55	55	54
May/Jun	38	35	74	56	78	72
Jun/Jul	128	87	150	153	172	194
year	944	642	1 187	821	1 125	900
Average (ha)	119	123				

Notes: (1) M = Manpakadi sub-centre
(2) B = Bhalwari sub-centre

Source: BLGWP

GWRDB at Mahottari has been very diligent, and the operational results for 17 diesel drive DTWs are summarised in Table 4.8. There, the relatively low usage (32 to 756 hours/year) demonstrates the extent of the work to be done to increase utilisation up to the 35 to 2 211 h/year at BLGWP and 20 to 1 909 h/year at NZIDP. It may also demonstrate the farmers' preferences for (cheaper) electricity.

Some of the difficulties are believed to result from the fact that it is not uncommon to experience problems converting test wells installed for hydrogeological exploration purposes to irrigation use unless unusually high attention has been paid to well siting in the first place, and that the well really produces enough water (external pressures to commission marginal wells yielding half or less than the required amount or which are poorly sited are common in many Asian countries).

TABLE 4.7

Main Utilisation Features of Surveyed Deep Tubewells

District	Well	Pump start	Installed pump capacity (l/s)	Command area (ha)			Feeder channels (m)			Pumping 1985/86 (hours)	Operator
				Stated	Available	Irrigated winter 1987	Built	Lined	Required		
1. Birganj	DTW7	1972	58	53	53	12(+4?)**	12,000	800	1,700	705+	NZIDP
2. Mahottari	MH10	1986	57	54	20?	8	800	0	1,100	450	MGWP
3. Siraha	DTW3	1986	35	44	>50	4(+1.5?)	1,500	1,500	1,700	123++	SIRDP
4. Kailali	(Rajpur)	1987	40*	40	>20	5.8(+6.5?)	800	640	1,000	0	KKGWP
5. Kailali	(Manayhara)	1977	35	32	>20	1.3(+12?)	930	930	930	150	FIWUD
6. Rupandehi	TW9 (Mudiyari)	1982	100	101	?	13.8++	2,850	***	2,850	449	BLGWP

Notes:
* Free artesian flow about 10 l/s
** Areas shown in brackets were cropped with poor looking wheat which was almost certainly rainfed only
*** Extensive channel lining now under construction.
\+ Reported average for 1978/79, 1979/80 and 1980/81
++ Taken from hours run meter
+++ Area of wheat, maize, vegetables and potatoes taken from BLGWP records (total winter crop area = 20.7 ha)

(1) All pump sets diesel driven except wells 1 and 6 (electric)
(2) The command areas at wells 2 and 6 not fully mapped, but a detailed command areaa map was available for Well 6

Source: 1987, GDC

TABLE 4.8

Annual Pump Utilisation in GWRDB DTWs

Location	Well No	1987 (hours)	1988 (hours)	1989 (hours)	1990 (hours)	1991 (hours)	1992 (hours)	Year	Total Hours	(h/y)
Laxminiya	11	429	300	418	441	598	439	5	2625	525
Ramnagar	19	546	310	495	917	883	630	5	3781	756
Vagarwasar	18	22	39	9	94	155	63	5	382	76
Bhijalpura	21	161	153	77			130	3	521	174
Bhijalpura	34	155	96	136	184	325	179	5	1075	215
Hathilet	12	111	216	154	120	376	195	5	1172	234
Belgachhi	29		68	138	18	117	85	5	426	85
Laxminiya	33	102	506	384	257	422	334	5	2005	401
Phulhatta	35				108	409	258	3	775	258
Mahottari	17		22			42	32	3	96	32
Pasupatinagar	31		190	225	7	90	128	5	640	128
Bharatpur	36		130	159	249	261	199	5	998	200
Bhijalpur	42			278	324	454	352	4	1408	352
Laxminiya	41			311	384	305	333	4	1333	333
Gaushala	37				56		56	2	112	56
Jalaswore	1				82	106	94	3	282	94
Ramnagar	20								0	0
Auraha	7								0	0
Hathilet	26								0	0
Bhangaha	9				20	213	116	3	349	116
Number of wells operated		7	12	12	15	16	17		79	
Average hours pumped / yr		218	169	232	216	284	206		1325	

Source: GWRDB Mahottari, 1993

It is therefore unfair to judge the performance of such wells as being representative of the DTW irrigation sector as a whole (and credit should be given to GWRDB in those cases where success has been achieved). Excluding the DTWs at SIRDP (now understood to be defunct), there are really only five developments against which to judge DTW irrigation achievement: Bhairahwa Lumbini, Birganj, Mohattari, JADP and ILC. As already stated, JADP and SIRDP are extremely disappointing. In this context, it will be very important to monitor the performance of the ILC DTWs and MTWs.

Nevertheless, current utilisation levels for DTWs are disappointing, not least because of past lack of reliability (often due to electricity supply failure). We believe that this has severely damaged farmers' confidence and therefore willingness to take risks using the wells (and making associated investments). Other significant constraints are believed to result from:

(a) lack of farmer involvement at the well site selection and distribution system design stage;

(b) consequent low farmer identification with the wells and their distribution systems and the attitude that they belong to the government which should therefore operate and maintain them at its own expense;

(c) long delays between drilling and commissioning wells;

(d) inadequate irrigation pump duties (particularly at Birganj);

(e) difficulties with managing command areas greater than, say, 40 ha with open channel distribution;

(f) lack of detailed command area planning maps to define irrigated area, distribution system layout and water management strategy;

(g) inadequate distribution systems in many cases, with high losses in unlined channels and inclusion of low-lying areas subject to waterlogging and so unsuitable for winter crops;

(h) availability of partial monsoon surface water supplies in some cases;

(i) unwillingness to pay for using pumps on DTWs with some artesian flow, when artesian use is virtually free; and

(j) difficulties with project-appointed operators.

All these factors further result in a slow build-up to reasonable yields and cropping intensities and reduce the present value of future benefits. Current HMGN policy is now firmly aimed at dealing with items (a) and (b) but the remaining points commonly remain to be addressed in a systematic way. The ILC programme is seriously attempting to bridge the gap.

4.1.3 Open Channel Distribution Systems

Water from most of the currently operating DTWs in the Terai is distributed to the fields via open channel systems. These systems consist of feeder channels which convey water to the head of an irrigation block, usually controlled by a feeder outlet, from which it flows to individual fields through a series of field and plot channels. Flow from the well into the feeder channel(s) is normally controlled by a discharge box which decelerates the pump discharge ready for the channel to receive it. The junctions of two or more feeder channels are controlled by feeder channel boxes. The components are summarised on Figure 4.1.

Whereas physical seepage losses do occur in channels, it has become clear that these are frequently insignificant when compared with the extent of losses through rat and snake holes which are a feature of many earth channel embankments, particularly those which are poorly compacted. To counter these losses, and to deter farmers cutting directly into feeder channel supplies, the lining of feeder channels is becoming widespread. Designs vary between brickwork thicknesses and choice of channel invert material (brick, soling or concrete), but all are based on a rectangular channel section. As demonstrated by ILC, the single brick width option is significantly cheaper; examples of channels built in this way appeared to perform well.

One limitation of the channel systems seen during the 1987 fieldwork was that the feeder channels were too short, and not enough attention had been paid to building field channels. As noted in Section 4.1.2, BLGWP is now addressing this by extending the lined sections. As a result, the irrigated area tends to develop in ribbons around the channel system. The objective of a feeder channel is to deliver a large quantity of water (possibly the whole pump discharge) to the irrigation area at the extremities of the command area; this cannot occur if the splitting process starts too close to the well.

Other physical limitations noted in some of the feeder channel systems visited in 1987 and 1993 included:

(a) channels built unnecessarily high thus requiring greater falls at outlets and unnecessarily wide strips of land lost in embankments;

(b) inadequate gates or other sealing devices at feeder division boxes or outlets; these account for considerable losses down channels not scheduled for irrigation at that particular time;

(c) feeder channel outlets sited without regard to field boundaries (which field channels should normally follow).

In addition, we have received frequent comment from the farmers that they had not been adequately consulted during the horizontal channel alignment selection, and had generally not been involved in the construction process. Some had, however, responded well regarding field channels.

The matter of gates needs real emphasis. We strongly recommend that trails are carried out with prefabricated steel gates (similar to that shown in Figure 4.2 - a successful Indonesian design). The feeder channel structures have been costed in Chapter 5 assuming that all diversion boxed and outlets are some equipped. These cost a fraction of the lining.

A variety of the feeder channel structures were noted; culverts, falls, low pressure siphons, aqueducts, cattle crossings, etc. Generally these were straightforward except in those low lying areas which are prone to waterlogging and those cases where difficult topography had to be dealt with to achieve very large command areas (in which case the number of cross drainage structures rise considerably). Since the cost of providing drainage is generally very high, it is concluded that DTWs are best kept away from low lying areas and that open channel systems should not exceed a notional 60 ha size. The need to limit farmer cooperation problems (exacerbated by larger areas) further strengthens this view. The influence of topography on DTW siting is further illustrated in Figure 4.3.

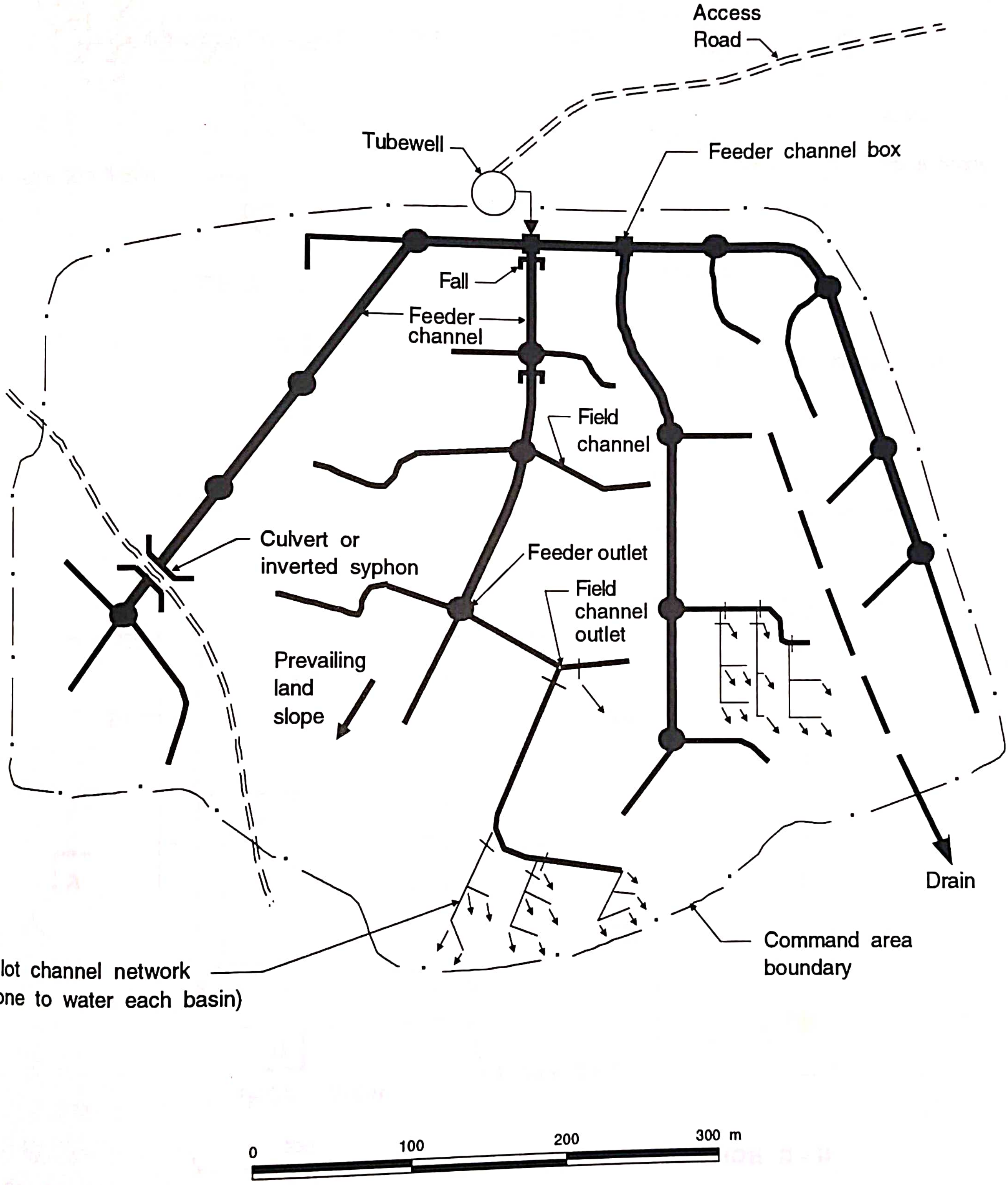
4.1.4 Buried Pipe Distribution Systems

The successful implementation and management of open channel distribution systems have long been constrained by the reluctance to give up land for channels, the difficulty in preventing illegal abstractions and the time taken for water to reach the fields for its service; farmers lower down the system, who are most affected by illegal abstractions and channels upstream, are most particularly vulnerable. In addition, feeder channels require careful design and setting out in more complicated terrain, and may themselves cause cross drainage problems when sited across depressions.

These difficulties can be alleviated by using buried pipes to convey the water; this has been practised successfully in many parts of the world in the course of high pressure application for overhead irrigation and low pressure uses for surface irrigation, many of which have involved tubewell sources. Specifically, the approach has been adopted successfully in Uttar Pradesh State (UP) in India, where some 900 DTWs are currently operating with buried pipe distribution systems through the IDA assisted 2nd UP Tubewell Project. Sixteen similar units are not operational for the Stage II BLGWP wells. A typical unit consists of a DTW with electric submersible pump energised via dedicated 11 kV power supply. The pump lifts water up to an elevated header tank adjacent to the pump house which has about 10 minutes storage. The tank is linked via 200 mm uPVC pipes to a system of 150 mm diameter uPVC buried pipes laid in two or more rings, as illustrated in Figure 4.4. Water is released from the buried pipe rings through alfalfa valves located at the head of irrigation blocks, and is then fed to the fields via earth field channels. Each ring is designed to take about 22 l/s and the system is operated such that only one valve is open in a particular ring at one time; thus the system delivers the whole discharge to the head of each irrigation block (typically 3.5 ha), for a specified period (typically one day). The required pump capacity is determined by the number of rings; systems with one, two, three and four rings have been analysed in this report. Most of the UP wells have two rings and those constructed at BLGWP generally have four.

Figure 4.1

Schematic Open Channel / Structure Layout



Note :
Other occasional structures, such as aqueducts, cattle crossings not shown.
Source : Modified from PDSP Manual M 6, MMP (1990)

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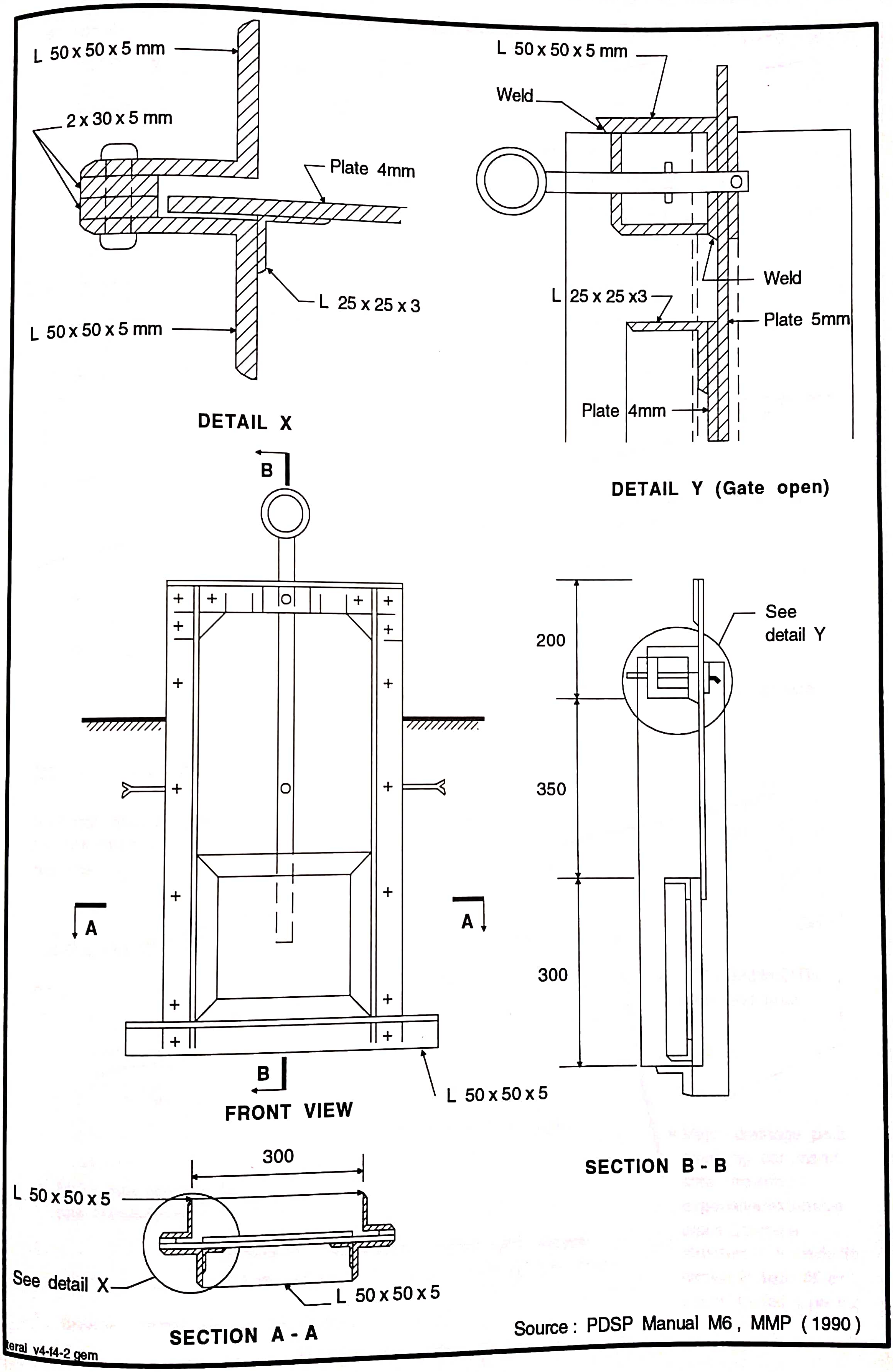
Figure 4.2

Prefabricated Steel Gate

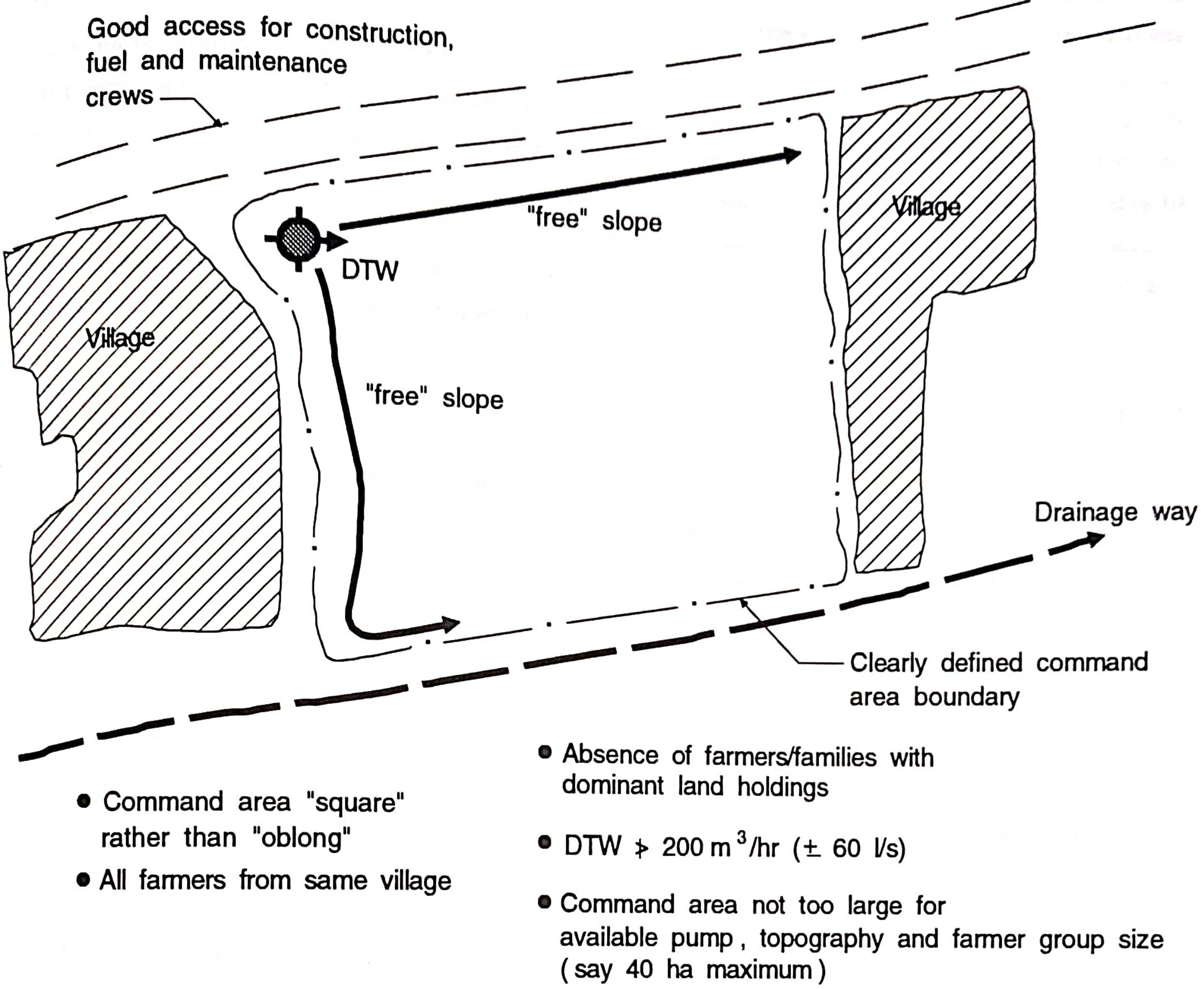


Source : PDSP Manual M6 , MMP (1990)

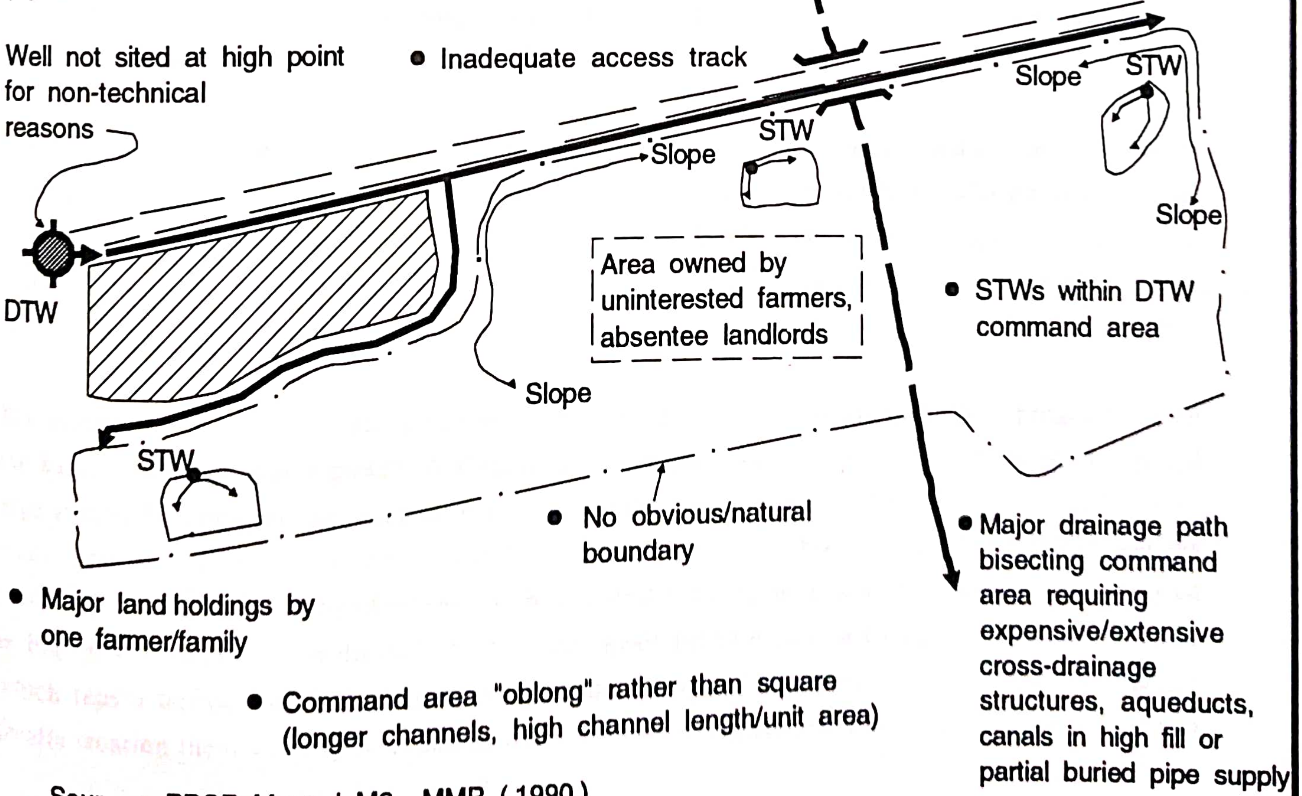
Figure 4.3

Typical Tubewell Command Area Layout Features

(a) Ideal



(b) Less Desirable



Source : PDSP Manual M6, MMP (1990)

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An important feature of these systems is that they are operated purely according to demand. Pump operation is automatically controlled by water level probes in the elevated tank; the pump switches on when the water level drops in response to an alfalfa valve being opened and switches off as the tank water level rises following closures of the alfalfa valves. Since the ring mains are kept full at all times, water flows from an alfalfa valve as soon as it is opened, regardless of location. The valves are designed to be 'tamper-proof' and to be opened only with a special key, thus making it easy to police irrigation water releases: nevertheless vandalism has been a problem with the UP alfalfa valves, and considerable effort has been directed at developing the 'tamper-proof' concept and educating the farmers to be more responsible.

The UP wells are designed on the basis of between 0.4 and 0.5 l/s per hectare, fully recognising that 100% irrigation intensity is not possible. This is compatible with the 'Warubundi' water distribution system which is practised in parts of India, and relies on the willingness of farmers to irrigate only a part of their land. It is believed that this may cause some farmers to abuse the system in order to get more water. Considering this and lower landholding sizes of many Terai farmers, it has been concluded in Section 3.2 that pumps should be sized to provide for 100% water irrigation intensity in order to maximise unit area production and to minimise the risk of water management disputes.

Other advantages of these systems are that they are quicker to install than channel systems, the joints (solvent welded into collars) are quick, permanent conveyance losses are limited to the field channels system, the most direct pipe alignments can be used, and the uPVC pipes used are moderately flexible.

It has to be said however, that buried pipes are harder to police than open channels, and results from the Stage II BLGWP wells so far indicate that there is some way to go until all these (real) advantages are realised. This needs further study. It is also important to ensure that the alfalfa valves are sited at high points to permit easy gravity supply to the fields: this requires a high standard of design and supervision.

The fully automatic operation can only be achieved with electrified pumps, and to keep the cost of dedicated power lines within reasonable limits, the wells have to be relatively close and a measure of project orientated control is inevitable; this must be kept within the limit required to maintain active farmer participation and competition in the well siting process and to restrict wells to high demand areas. This is discussed further in Section 6.8.

The discussion in Chapter 6 casts serious doubt on the wisdom of designing DTW programmes on the basis of electric motor power. A shift to diesel engines would require a re-think on the buried pipe approaches, and reliance on automatic electrically-driven control. Diesel pumpsets are not very compatible with ring main systems, and for this reason we have briefly considered radial systems (such as successfully developed recently in Bangladesh). The salient technical features are compared in Figure 4.5. Radial pipes do lack the 'instant' availability provided by opening an alfalfa valve which taps a buried ring main kept full and under pressure. However, they are easier to manage (really treating them as an open channel) with pumping arrangements which do not require frequent pump starting and stopping. The need for storage at the well is removed, and the simpler works required to maintain enough head to drive the pipe system hydraulically are far cheaper. Figure 4.6 shows the works required to drive two radial pipe arms.

Typical quantities and cost of buried pipe systems are discussed in Section 5.3.

4.2 Shallow Tubewells

Fifty STWs and five dug wells were studied in detail during April/May 1993. The areas under irrigation were measured together with the extent of rainfed cropping and the possibilities for expanding irrigation coverage.

The irrigation achievements of the wells are summarised in Table 4.9 together with results for 17 STWs surveyed in January/February 1987 for comparison.

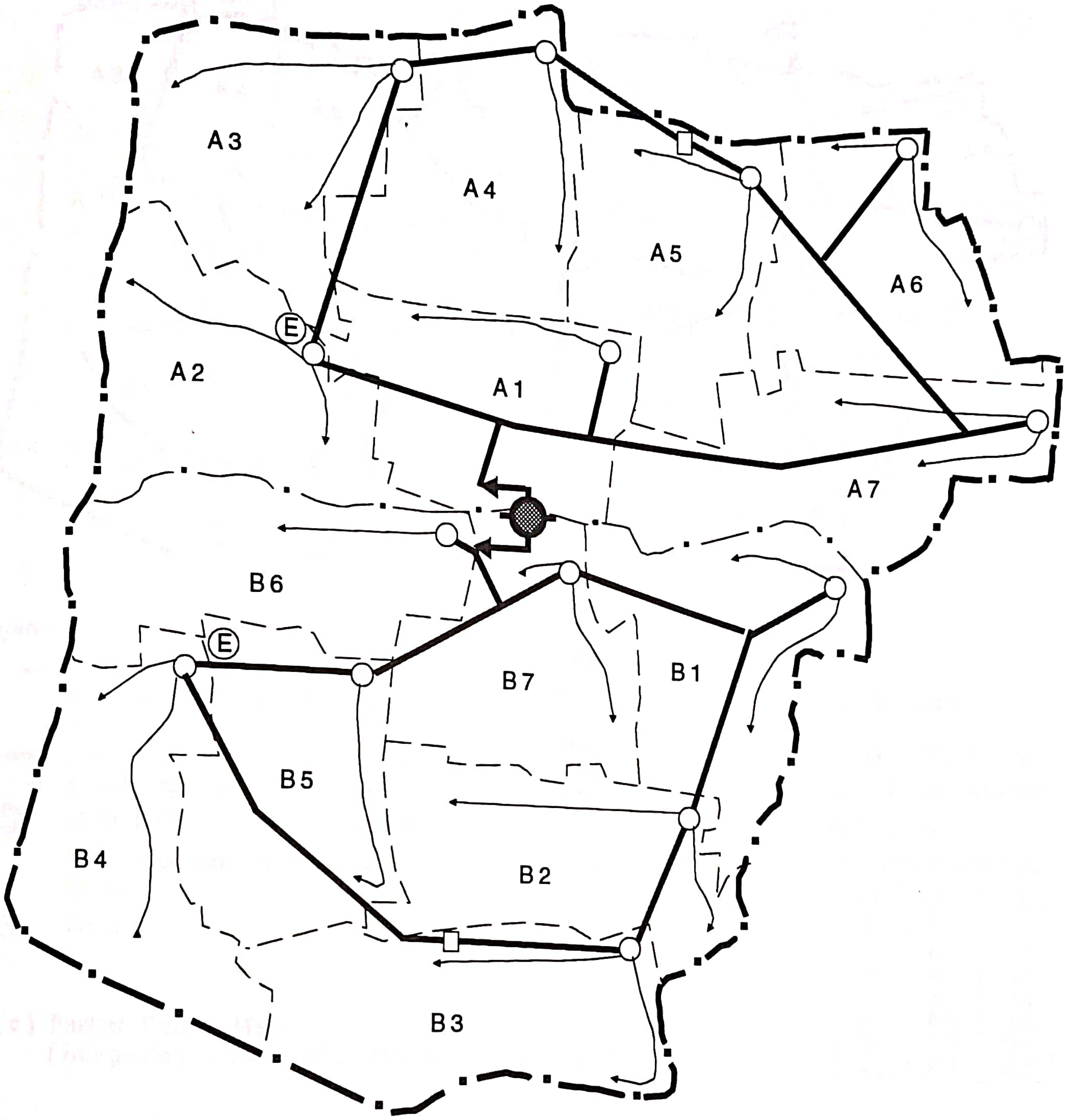
The general conclusions in 1987 were that the average STW irrigates 1.9 ha in the winter, 0.1 ha of which belongs to water buyers. By selling water or growing irrigated rather than rainfed crops within the current irrigated boundaries, the average STW could cover 3.4 ha, and by extending channel systems to adjacent farmers' land this could increase the area to 4 ha with ease, if a good water selling service was provided. The 1993 data indicate a slight improvement from 1.9 ha to 2.4 ha overall, and support the premise that target areas of 4 ha are attainable. The absolute averages should be treated with caution as the sample sizes are small, but the general findings between the two surveys are compatible.

Most of the earth channels within STW areas need to be improved considerably to do this. This is demonstrated for an 'average irrigated' STW on Figure 4.6, where the scope for expansion, provided neighbouring land owners could be interested, was considerable.

In comparison with DTWs, the STWs are relatively easy to assess; an STW area can be mapped in two or three hours. Dug wells were found to be more successful than expected, but the sample size was small. Difficulties with sustainable well yield were anticipated, but not found. Some of the dug wells in Chitwan district yielded about 20 l/s.

Figure 4.4

Schematic Layout for Ring Main Type Buried Pipe Distribution System (Deep Tubewells)



Notional rotation plan

Day	Rotation Unit	
M	A1	B1
T	A2	B2
W	A3	B3
T	A4	B4
F	A5	B5
S	A6	B6
S	A7	B7

Legend

DTW command area boundary	━ ▪ ━
Ring main command boundary	— · —
Rotation unit boundary	– – – –
Buried feeder main (200 mm dia.)	━━━
Buried ring main (150 mm dia.)	───
45 l/s DTW and elevated distribution chamber	⊕
Field outlet with Alfalfa valve	○
Air vent	□
Escape	Ⓔ

Note: Actual rotation block time allocations dependent on areas commanded from each field outlet.

Source: PDSP Manual M6, MMP (1990)

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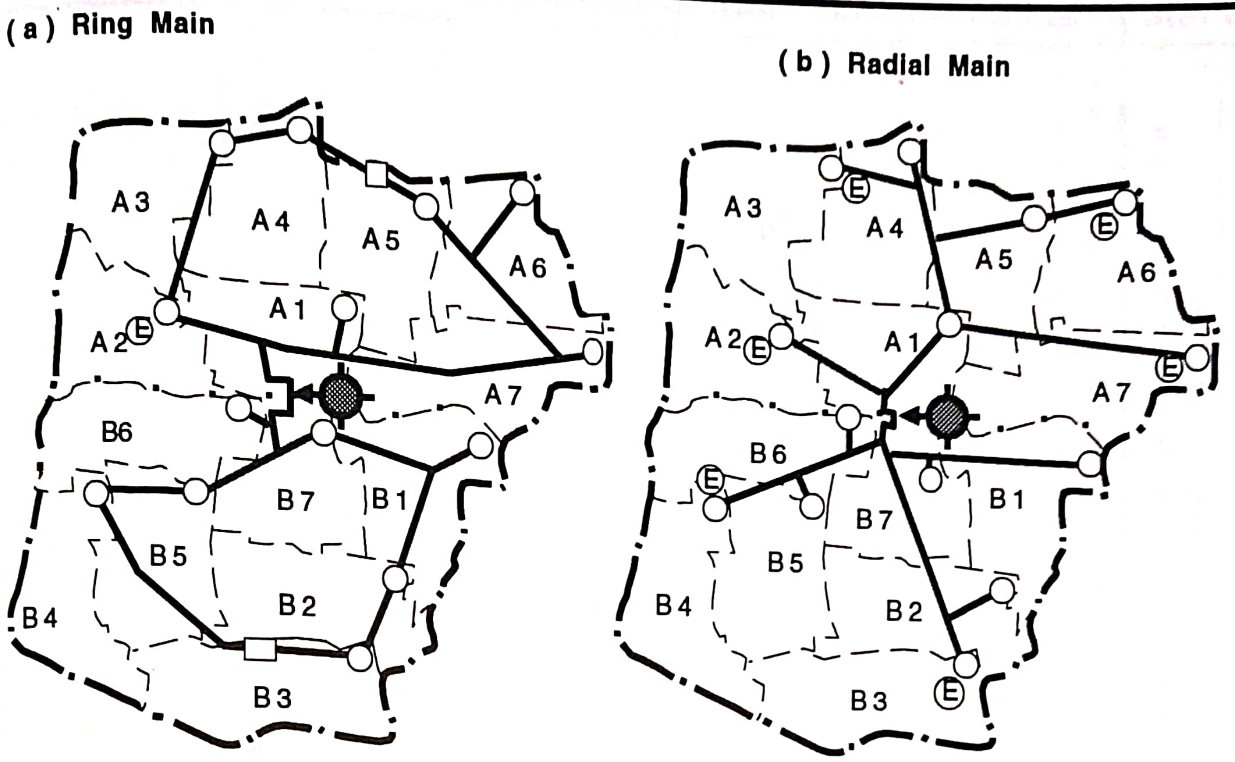
Figure 4.5

Alternative Buried Pipe Configurations


(a) Ring Main

(b) Radial Main

Legend

- ▬ · ▬ DTW command area boundary
- — · — Ring main command boundary
- — — — Rotation unit boundary
- ▬ Buried radial feeder main (200 mm dia.)
- — Buried ring main (150 mm dia.)
- ● 45 l/s DTW and main division structure
- ○ Field outlet with Alfalfa valve
- □ Air vent
- Ⓔ Escape

Legend

- ▬ • • DTW command area boundary
- — — — Rotation unit boundary
- ▬ Buried radial feeder main (200 mm dia.)
- ● 45 l/s DTW and main division structure
- ○ Field outlet with Alfalfa valve
- Ⓔ Escape

Notional rotation plan

Day	Rotation Unit	
M	A 1	B 1
T	A 2	B 2
W	A 3	B 3
T	A 4	B 4
F	A 5	B 5
S	A 6	B 6
S	A 7	B 7

(c) Partial Radial Main
(integrated pipe / earth feeder channel use)

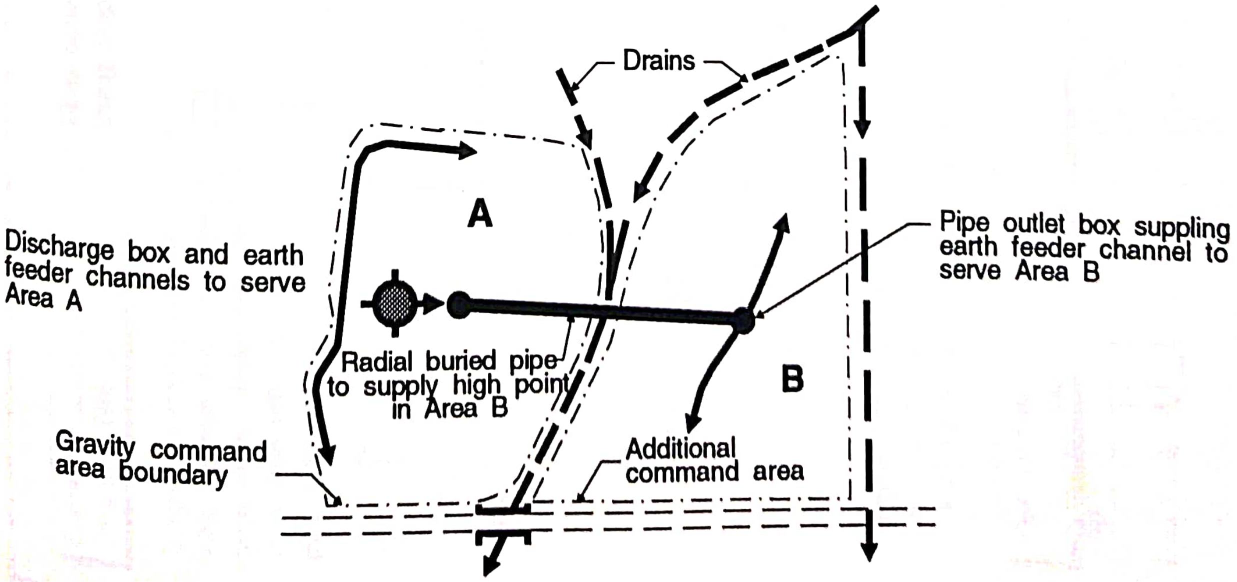
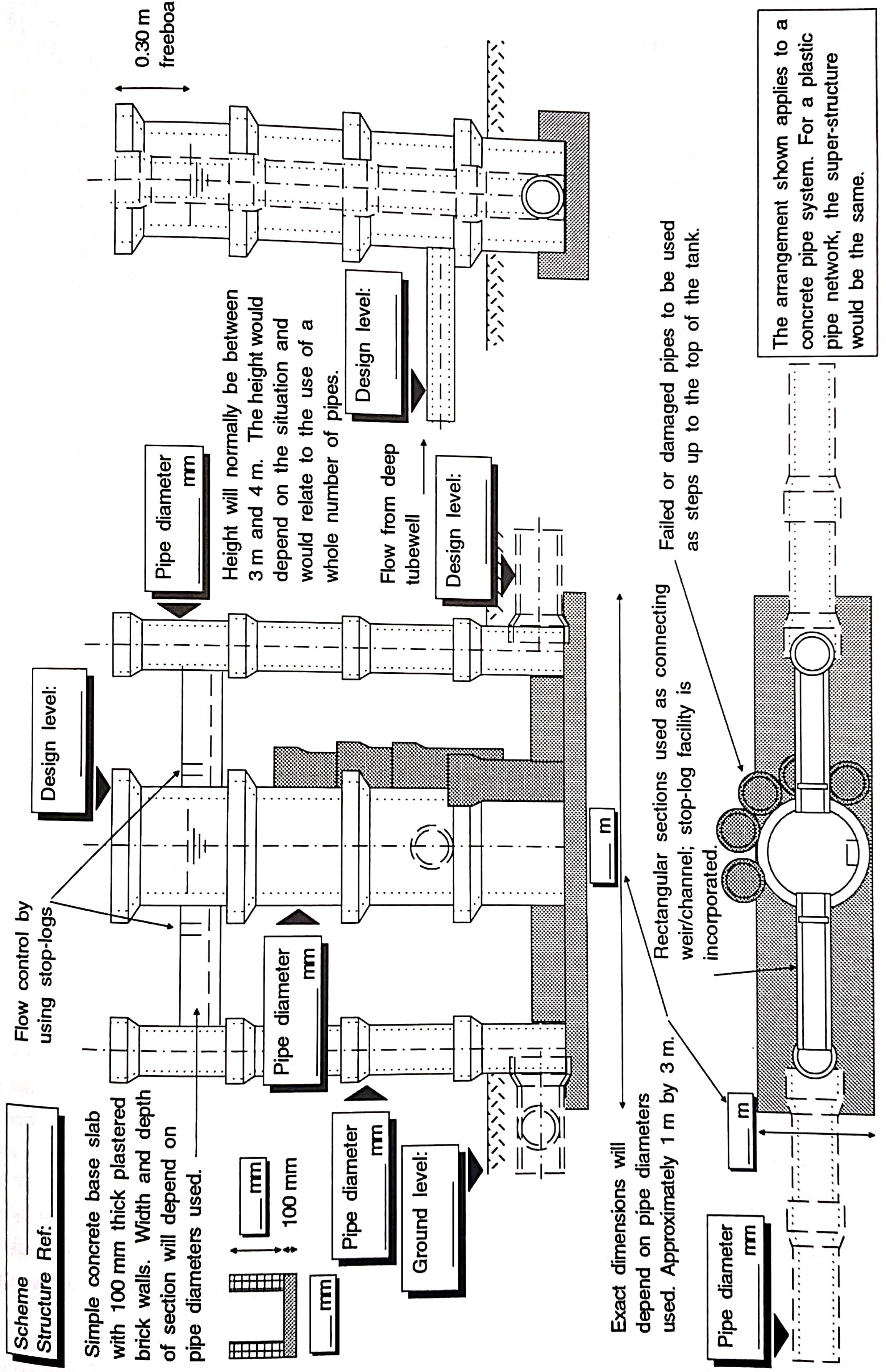


Figure 4.6

Radial Type Buried Pipe Distribution System Main Division Structure - Using Satellite Upstands



Scheme ____
Structure Ref: ____

Simple concrete base slab with 100 mm thick plastered brick walls. Width and depth of section will depend on pipe diameters used.

Flow control by using stop-logs

Height will normally be between 3 m and 4 m. The height would depend on the situation and would relate to the use of a whole number of pipes.

0.30 m freeboard

Flow from deep tubewell

Exact dimensions will depend on pipe diameters used. Approximately 1 m by 3 m.

Rectangular sections used as connecting weir/channel; stop-log facility is incorporated.

Failed or damaged pipes to be used as steps up to the top of the tank.

The arrangement shown applies to a concrete pipe system. For a plastic pipe network, the super-structure would be the same.

Source : IDA Tubewell , II Project , Bangladesh (MMP 1992)

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TABLE 4.9

Salient Irrigation Features of Shallow Tubewell Surveys

Item	Areas per well command (ha)			Potential expansion (ha)	Channel length (m)
	Irrigated	Rainfed	Total		
(a) 1987 Survey (17 STWs)					
Maximum	4.3	4.1	9.2	>2	1 150
Minimum	0.3	0	0.4	0	230
Mean	1.9	1.5	3.4	>1	520
Median	1.8	1.4	2.9	-	410
(b) 1993 Survey* (50 STWs)**					
Maximum	9.0	0	9.0	0	900
Minimum	0.6	4.0	4.6	4.0	100
Mean	2.4	1.8	4.2	1.8	350
Median	2.3	3.5	5.5	3.5	300
(c) 1993 Survey* (5 dug wells)					
Maximum	5.5	0.0	5.5	0.0	350
Minimum	0.7	4.0	4.7	4.0	100
Mean	2.6	1.4	4.2	1.4	354
Median	2.8	1.5	4.3	1.5	450

Notes: * average discharge for 48 STWs/dug wells measured (crudely) as 13.5 l/s.
** omitting four STWs not in use and one for which area not measured.

Source: GDC 1987, 1993

The main problems with STW distribution systems were that the channels were too small, with poorly constructed banks. As a result, the flows reaching the perimeter of an STW command area tend to be small which, not surprisingly, does not encourage would-be water buyers. Topography at the majority of the STWs studied did not present distribution problems, most of the land being of even slope, and many of the field boundaries set out roughly on a rectangular grid following a north-south axis. The problems noted were difficulties coping with the transition from high land fields around the well to medium level land surrounding them (which required simple fall arrangements) and a long embankment channel required to feed a high area away from the well; this was leaking badly and needed much improved compaction.

In spite of the widely held view that STW irrigation commands are kept small because of extensive land fragmentation, only two of the STW farmers interviewed seemed seriously constrained by this (both in the 1987 survey). One had three boreholes and one pump (which he appeared to use very inefficiently) and the other had built very long channel lengths to link his three separate plots. Data on STW utilisation are very suspect, with most estimates of current use being between 200 and 300 hours/year; there is considerable scope for increasing irrigated areas and overall crop production. There is undoubted scope for reducing water losses with channel lining, simple buried pipes or lay flat hose, which costs about Rs 70/m in Europe and could be made (more cheaply) in Nepal.

For costing and economic analysis purposes it has been assumed that one STW and one pump are required to irrigate 4 ha (taken as the target for future irrigation coverage). Expansion to 4 ha per single borehole is easily possible through water sales and group operation.

In the absence of any hard data, we have assumed that the ILC STWs (all of which are served with some lined channel) currently irrigate 4 ha and will expand, with the proper water management extension) to a conservative 7 ha. For comparisions's sake we have looked at the costs of simple radial buried pipe system for STWs and MTWs at ILC type STWs in Chapter 5.

4.3 Artesian Shallow Tubewells

None of the 1993 Survey STWs were artesian, but four free-flowing artesian STWs were studied briefly during February and April 1987, and their general features are summarised in Table 4.10. Installation costs (1987) varied between Rs 12 000 paid for a drilled 4 inch well in Kanchanpur to Rs 1 500 for a manually installed well in Rupandehi completed with second-hand pipe. Yields (measured by bucket filling times) varied between 1.9 l/s for a 2 inch well and 2.6 l/s for the single 4 inch well. All wells were freely flowing (without valves to control waste).

TABLE 4.10

Flowing Artesian Shallow Tubewells

Number	District	Diameter (in)	Q (l/s)	year	Cost (Rs)	Channel length (m)	Irrigated area (ha)
1	Kanchanpur	4	2.6	1985	12 000	140	*
2	Rupandehi	2	2.0	1986	1 000	45	0.04
3	Rupandehi	2	1.9	1983	5 000	190	*
4	Rupandehi	2	?	1981	1 500	100	0.15

Note: * Flowing to waste.

Source GDC, 1987.

For one reason or another, generally related to labour shortage within the families concerned, two of the wells were effectively redundant, although each commanded about 0.5 ha. Only one of the four farmers appeared to exploit his well effectively; he used it to top up about 1 ha of monsoon rice, to irrigate about 0.2 ha of wheat, vegetables, maize and mustard and for rice nursery preparation.

The overall conclusion at the time was that these wells were not making any significant impact on crop production and were an unwanted cause of water loss. Their benefit as potable water sources was more apparent. We see no reason to change this view now.

4.4 Drainage

4.4.1 Introduction

Drainage has not usually been provided for groundwater irrigation projects in the Terai, and it was not recommended in the 1987 study. However, there was a hint in the field work in 1987 that drainage problems were emerging in the Bhairahwa Lumbini Groundwater Development Project area (BLGWP), and some drainage has now been constructed. It therefore is necessary to consider:

- whether there is a real problem of drainage;
- if deep tubewell irrigation does or can make the problem worse;
- the appropriateness of the solutions being applied at BLGWP; and
- whether the BLGWP area is typical of the Terai.

The issue should not arise with shallow tubewells. It is unlikely that farmers would want to construct such wells in poorly drained lands, but if they did do so the wells should improve the situation by lowering the watertable. The following discussion of these problem is based on LRMP (Kenting, 1986) data and discussions with BLGWP staff.

(a) The Problem

Some land dries out slowly after the end of the monsoon, and thus winter crops are sown late or not at all. This situation has been observed in BLGWP and can be inferred from the LRMP data: Land Unit 2a is depressional land (which covers about 8% of the Terai) and is regarded as of moderate suitability for rice (2Rd) because of drainage limitations. Existing land use is rice followed by a variety of winter crops with part of the area remaining fallow.

More detailed studies in BLGWP confirm the problem. Agricultural staff on that project have classified tubewell commands into three categories - upland, midland and lowland - on the basis of topography and crops. The distinction in topography is quite subtle - a few centimetres can separate different classes - but the cropping is quite distinct. This also reflects soil types.

Poor drainage limits the suitability of these lands for irrigation. If they are to be irrigated, then the need for drainage must be considered, but an alternative might be to exclude them from the irrigation development plan.

(b) Does Irrigation Exacerbate Poor Drainage?

There are clearly some problems of drainage in the Terai. Poorly managed surface irrigation can make these worse, but groundwater irrigation should not have this effect. As noted above, STWs in an unconfined aquifer should lower the watertable and thereby provide drainage. However, surplus water from deep tubewells in a confined aquifer could in theory pond on the surface in depressions.

This does not seem likely since farmers are unlikely to pump more water than they need, which would cause a surplus that might flow on to low-lying land and delay drying-out. Unavoidable seepage losses would be too small to have a significant impact. The water which causes the problem is more due to late monsoon rainfall - farmers do not irrigate rice at the end of the season. They are equally unlikely to allow expensively pumped water to flow to waste once they start irrigating dry season crops. This is very different from the situation with surface irrigation, where water management is more difficult and dependent on larger scale management of the whole system.

Some farmers in BLGWP have complained that there has been deterioration in some low-lying lands, but this appears to be mainly a problem of water management. Since farmers have not been directly liable for the amount of water used, wells have apparently been pumped or allowed to flow uncontrolled for much longer than is required for irrigation. These lands are not well-suited to irrigation development (mainly Class 2Rd), but their condition should not deteriorate if good standards of water management are maintained. It is true that drainage combined with better agricultural techniques (without the need for irrigation) could help improve these lands, but that is a separate issue.

The main risk with deep tubewells is from uncontrolled artesian flows, but it would be more sensible to prevent such misuse of water rather than provide drainage to reduce its impact.

Farmers are also concerned about the monsoon crop, since heavy rain can damage this. Irrigation during the monsoon could make this worse by reducing the field storage available for rainfall, but tubewells are unlikely to be (and should not be) operated in a way that would affect this. Thus there seems little justification for thinking that irrigation without drainage could make the situation worse.

(c) Bhairahwa Lumbini Groundwater Development Project (BLGWP)

The Bhairahwa Lumbini Groundwater Development Project favours inclusion of drainage works. There are three main reasons for this:

- the project area was defined in advance, so the option of excluding certain areas from development was not really open;
- there are some large and numerous small areas where there is poor drainage, and it was considered that the additional benefits would be considerable; and
- tubewell commands are large (around 120 ha) and are therefore likely to include pockets of low-lying land (as well as requiring extensive cross-drainage works)

In these circumstances, the works proposed by BLGWP are entirely logical and evidently beneficial. On their land classification, about 30% of the land suffers from poor drainage and there is one large area of about 500 ha in Stage II Phase 2 which is particularly seriously affected. Only a single crop per year is possible on many of these lands. They have constructed short drains (1 to 4 km) to adjacent watercourses where possible. The large area required a larger solution: a 10 km drain with up to 20 m^3/s capacity.

They have not been able to implement all that was planned (12 out of 64 units in Stage I, and 13 km out of 24 in Stage II which mostly involved enlarging existing watercourses), largely because of farmer opposition. This opposition is interesting because the drainage is supposed to benefit the farmers. There are several factors involved in this:

- inadequate understanding of the purpose and benefits;
- opposition by downstream farmers, who give up land but receive none of the benefits;
- impact on irrigation, since the drains would typically be enlarged *kulos* which would then be less suitable for surface irrigation;
- recognition that drainage is only one factor limiting crop production and that soils may still be critical; or
- disbelief in the feasibility of drainage.

Some farmers have subsequently relaxed their opposition and drainage has been provided in some places: for example nine tubewell commands out of 37 wells in Stage I/Manpakadi have now been drained. It is interesting that only seven of these wells are in Unit 2a land but three of these (45%) have been drained; only six out of the remaining 30 wells (20%) have been drained. There are clearly many factors involved, but this suggests that detailed farm-level knowledge supports the LRMP conclusion that drainage is an important requirement if Unit 2a land is to be irrigated.

There is also a suggestion that some Stage II farmers are relaxing their opposition to drainage, following this year's heavy monsoon rain. This is a rather different situation, but the drainage should be able to reduce the damage (it is in fact designed to reduce the submergence of rice to a depth of no more than 150 mm) from a 1 in 10 year three-day flood to a maximum of seven days. This would not be sufficient to prevent yield loss in a heavy storm, such as occurred in July 1993, but it would help. The question of maintenance has not been fully resolved. It is assumed that farmers will undertake this work (essentially cutting grass/reeds and removing earth), but this is not yet happening adequately.

(d) Other Areas

The BLGWP approach is sound, but may not be necessary in other areas. The main reason for this is that the BLGWP area is unusually badly drained. This is apparent from the LRMP data which shows that 20% of all Class 2a land with potential for deep tubewells is in BLGWP and almost 50% is in Rupandehi District (Section 4.4.6). This is not conclusive since the LRMP did not map areas smaller than 25 ha, and many of the depressions in BLGWP are smaller than this. However, comparison of detailed data from BLGWP with the national planning data from LRMP suggests a fair correlation (Section 4.4.2).

4.4.2 The Extent of the Problem

The drainage problem in BLGWP has been well documented, lowland areas have been identified and mapped, and remedial measures planned. Such detailed information is not available for other areas. The main source of information on land resources - LRMP - is at a much smaller scale and may not identify all the problem areas. However, despite the smallness of the scale, LRMP does appear to be useful in this context.

The detailed maps which identify upland, midland and lowlands for Stage II Phase 1 (1 850 ha) have been examined and superimposed on LRMP land systems and land capability maps. These categories do not correspond directly to LRMP classes, but LRMP regards its Land System 2a as being of limited suitability for irrigation because of drainage constraints (Class 2Rd) and thus analogous to BLGWP lowlands. This is discussed further in Volume 2, Part A, Chapter 4.

This area is almost equally divided between Units 2c and 2a, with only a very small amount of Unit 2b. Seventy per cent of the lowlands are in Unit 2a, with the remainder in Unit 2c (Table 4.11). It is not surprising that there should be some low lands in Unit 2c since this is undulating land. The lowlands in Unit 2c are all very small (averaging 5 ha if units which are part of larger lowlands in Unit 2a are excluded or 9 ha if they are included).

This is an encouraging correlation: it suggests that if Unit 2a land is excluded from development plans, all large contiguous areas of poorly drained land will be excluded. Any remaining problematic land will be scattered in small parcels (mostly less than 10 ha) totalling 10 to 15% of the area.

TABLE 4.11

Comparison of BLGWP and LRMP Land Classification
(Stage II, Phase 1 area)

TW	Total area	BLGWP Class			LRMP Class. Land unit capability			BLGWP Lowlands in LRMP units			
								Total area (ha)		Avg area per low spot *	
	(ha)	Upland	Midland	Lowland	2c 1	2b 1R	2a 2Rd	LRMP 2a	LRMP 2c	LRMP 2a	LRMP 2c
1	136	8	101	27	0	0	136	27	0	9	
2	129	25	88	16	39	0	90	16	0	16	
3	123	8	73	42	0	12	98	42	0	14	
4	133	24	85	24	133	0	0	0	24		3
5	112	13	52	47	45	0	67	38	9	38	9
6	128	21	49	58	0	26	102	58	0	6	
7	126	10	99	17	101	0	25	9	9	9	9
8	117	23	78	16	35	12	70	10	6	2	2
9	119	15	3	101	48	0	71	81	20	101	
10	104	14	48	42	73	0	31	17	25	42	
11	137	38	36	63	110	0	27	25	38	63	
12	124	12	73	39	74	25	25	23	16	23	16
13	119	36	58	25	83	0	36	25	0	25	
14	123	42	50	31	123	0	0	0	31		4
16	131	11	46	74	13	0	118	74	0	74	
Total	1,861	300	939	622	876	74	898	445 50%	177 20%	18	5

Notes: * Where individual low spots are spread over both unit 2a and 2c lands (TW 9,10 and 11), these are shown under 2a

Source: GDC

The Unit 2a land classification is slightly broader than the BLGWP lowland category; only 50% of Unit 2a land is lowland. Blanket exclusion of Unit 2a land would exclude some suitable areas. However, much of this would be in small pockets of midland within lowland areas and thus not well suited to deep tubewell development.

4.4.3 The Effectiveness of Drainage

(a) Technical Feasibility

There are low-lying lands which could be upgraded if drainage was available. However, these are, by definition, difficult lands to drain. Pumped drainage is prohibitive and river levels may preclude gravity surface drainage. The Stage I drains in BLGWP are very shallow and constrained by outfall levels, so they are unable to drain all of the lowlands. Probably 50% can be drained (thus converting them to midlands), but the remainder are too low for this. Thus in round terms, 15% of BLGWP can be drained and 15% will remain badly drained.

In some cases the rivers are more deeply incised; for example, the Kothi River is so low that it is 5 m below the design bed level of the BLGWP main drain at the outfall. This makes drainage possible, but only at a high cost, since the drain had to be excavated for 6.6 km beyond the area to be drained in order to reach this outfall site. Rivers are generally at a high level, since sediment loads brought down from the hills during floods exceed the channel carrying capacities once the river reaches the Terai. Excess sediment is deposited, thus raising the river bed and floodplain above the level of the surrounding land. This mainly occurs in the fans where rivers cut through the Siwaliks (such as the Tinau River in the case of BLGWP). The Kothi River rises at a lower altitude south of the Siwaliks and does not deposit sufficient sediment to raise its bed level and constrain drainage.

(b) Problems of Implementation

Even where the problem of outfall does not make drainage impossible, careful quality control during survey design and construction is essential since there is little leeway for errors in drain levels. Poor maintenance after completion can soon impede drainage.

A second category of problems arises from farmer attitudes. The drains often need to pass through well drained land. In fact the natural channels which would be used as drains are often used as irrigation canals for these higher lands. If these channels are enlarged and deepened, irrigation from them becomes more difficult. Irrigation is still possible if weirs (of local brushwood type rather than permanent structures) are built, but this is an added complexity that these farmers (who gain no benefit) have to cope with. Such irrigation may impede the drainage which the channel is enlarged to provide, but there is not usually any conflict since this irrigation is mainly needed at the start of the rice season and drainage at the end: there is insufficient surface water for irrigation of winter crops from these canals (deep tubewells would not be needed if there were). Even if there is no theoretical conflict, farmers may be doubtful; much depends on the relations between the two groups of farmers. This is an important reason for the failure of BLGWP to build all the drains that were planned.

4.4.4 Benefits

The purpose of drainage is, in BLGWP terms, to convert lowlands to midlands or, in LRMP terms, to convert Class 2Rd land to Class 1R, and thus enable higher cropping intensities. Since there is a relatively limited demand for wheat, more diverse crops such as oil seeds and pulses might then be grown on the original midlands.

Three crops per year can be grown on uplands and midlands in BLGWP area. Some lowlands can support two crops, but about half is too wet for even a late wheat crop. BLGWP are developing some new agricultural techniques which will improve this land, for example growing *Sesbania* as a green manure before rice which should increase rice yields, but drainage is necessary before there can be much change in the cropping pattern. Conversely, soil improvements are needed before the benefits of drainage can be realised. Where winter cultivation is possible on lowlands, the yields are relatively low and should be increased as a result of drainage.

The present cropping intensity in BLGWP Stage II Phase 2 was about 162% in 1992/93 (99% in the monsoon, 57% in winter, and 5% in spring). This is a substantial increase on the 122% cropping intensity achieved in 1988/89, but still less than in Stage I (187% in 1992/93). It is anticipated (by BLGWP) that the crop area would increase by about 15% (mainly wheat), as a direct consequence of drainage. Yields on about half of the remaining lowland (about 10% of the total area) should increase by about 25%. The rice yield over the lowland area (about 40%) would also increase slightly. The drainage is designed to protect rice against a 1-in-10 year storm. Thus a generous estimate of average annual yield increase over the whole area due to prevention of flood damage would be 5%. The benefit in this particularly badly drained area would thus be:

- 18% increase in wheat production; and
- 5% increase in rice production.

This is a particularly bad area, and the benefits in other parts of Stages I and II would be less. About 30% of the BLGWP area is lowland, and about half of this produces a winter crop. With drainage, this lowland winter crop would be improved and half of the remaining land would become cultivable in winter. Thus the benefits in BLGWP resulting from inclusion of drainage would be an increase in crop area of about 7%, and an increase of 25% in wheat yields on about 15% of the area.

This would initially be an increase in wheat area, but might later be an increase (by substitution) in pulse or oil seed area. Further increases in crop area may be possible if a third crop is grown on newly drained lowlands, but this is less likely since there is already a large area of midlands on which only two crops are grown. Drainage is not the only or even the main reason limiting third season cropping:

Thus the benefits can be summarised as:

- 10% increase in wheat production; and
- 3% increase in rice production.

4.4.5 Costs

Data from BLGWP provides a useful basis for estimating costs. These will only be approximate estimates for drainage in other parts of the country, since a large part of the cost depends on the location of the outfall. Stage II of BLGWP is fortunate in having a deeply incised river for the outfall, even though it is some distance from the areas to be drained. Other areas, even some within BLGWP, are not so well served. Drainage of these would be either very expensive or impossible by gravity.

Two sets of estimates have been prepared (Table 4.12):

- based on Stage II, where a main drainage system has been constructed by enlarging a natural drain; and

- based on Stage I, where relatively short drains (with an average total length of 2 km per 120 ha tubewell) have been built and linked to existing drains or streams.

Allowing for inflation, the costs of the physical drainage works are estimated as some Rs 15 000 per ha, with an additional Rs 15 500 to cover engineering and administration (25%) and contingencies (10%).

4.4.6 Selection of an Appropriate Strategy

(a) Alternatives

There are three options for poorly drained land:

- to irrigate it, without providing drainage;
- to improve drainage as well as irrigation; or
- to exclude it from irrigation development.

TABLE 4.12

Costs of Drainage Derived from BLGWP

	Item		Cost (Rs)	Basis
Minor Drains				
Stage I Costs	Earthworks/km		99,585	Rs 2 400 000 for 24.1 km
	Stuctures/km		30,000	
	km/ha		0.017	24.1 km for 1 389 ha
	Sub-total	Rs	2,239 per hectare	
Allow inflation		12%		4 years since construction
Sub-total (construction)			3,523	
Allow engineering/admin		25%	881	
Contingencies		10%	352	
TOTAL		Rs	4,800 per hectare	Cost for Minor Drains
Main Drains				
Stage II costs	Earthworks/km		230,769	Rs 3 000 000 for 13 km
	Stuctures/km		53,846	Rs 700 000
	km/ha		0.026	Area drained 500 ha
	Sub-total	Rs	7,400 per hectare	
Allow inflation		12%		
Sub-total (main construction)			11,644	
allow minor drains			3,523	Assume same as Stage I
Sub-total (all construction)			15,167	
Allow engineering/admin		25%	3,792	
Contingencies		10%	1,517	
TOTAL		Rs	20,500 per hectare	Cost for all drains

A fourth option of improving the land without irrigation is not relevant in the present context, although it may sometimes be possible.

Choosing among these can be made on a number of criteria, such as technical feasibility of drainage (particularly the existence of an outfall), cost, sustainability (drain maintenance is notoriously difficult), farmer attitudes, and the sustainability and long term impact of irrigation without drainage.

Irrigation without drainage is not a sensible option on these lands since winter crops cannot be grown or only give low yields. If farmer demand is, as recommended, a major factor in siting wells, it is unlikely that wells would be sited on such land. Irrigation with drainage is rational, but it is only economically viable in places where local drainage is possible and not where long main drains are needed Section (c) below.

(b) Extent of Poorly Drained Land

Land Unit 2a is a useful proxy for the amount of land with poor drainage. Small areas within this will be adequately drained, and small areas of land in System 2c will be badly drained. These are likely to be isolated small pockets (much less than a typical tubewell command).

The total area of Unit 2a is about 8% of the total cultivable area of the main Terai. Part of this has already been developed with deep tubewells, a large part is covered by surface irrigation, and not all of the remainder has a suitable aquifer for groundwater development. Details of the area of Unit 2a land, existing development and aquifer conditions are presented in Table 4.13. This indicates that almost half of the Unit 2a land is located in three districts (Saptari, Kapilvastu and Rupandehi), almost half of this has already been developed for irrigation (Kosi Pump and BLGWP), and little of the remainder has a suitable deep aquifer for tubewell development.

TABLE 4.13

Aquifer Quality in Land System Unit 2a

District	Area (ha)	Aquifer quality		Comments
		Deep	Shallow	
Kanchanpur	3 788	Marginal	Good	
Kailali	1 732	Fair	Marginal	Flowing
Bardia	3 790	Marginal	Good/marginal	
Banke	11 750	Marginal	Good	
Kapilvastu	27 970	Marginal	Marginal/good	
Rupandehi	25 399	Good	Good	40% in BLGWP
Nawalparasi	7 980		Good	25% in Gandak W
Parsa, Bara	5 940	Good	Good	30% in Birganj TP, 20% in NZIDP
Rautahat	7 160	Good	Good/marginal	40% in NZIDP/Jhajh
Sarlahi	5 848	Good	Marginal	25% in the Bagmati E
Mahottari	5 998	Good		
Dhanusha	11 280	Good		10% in Kamala W
Siraha	8 866	Marginal	Marginal	30% in Kamala E
Saptari	35 008	Marginal	Good/marginal	80% in Kosi pump
Sunsari	4 262	Good	Good	100% in SMIP
Morang	7 002	Marginal	Good	50% in SMIP
Jhapa	7 128	Marginal	Good	
Total	180 902			

Thus although there is 180 000 ha of Unit 2a land in total, only about 54 000 ha of this has both a good aquifer and is not already irrigated from surface sources (Table 4.14). 10 000 ha is included in BLGWP Stages I to III, leaving a potential for future development of only 44 000 ha. Although the fact that there is an existing surface irrigation scheme does not necessarily mean than farmers would not want tubewells for conjunctive use, it is reasonable to discount this land for planning purposes. Water management is so much more difficult in surface irrigation schemes that drainage problems would already be much worse than on new lands that it is very unlikely that farmers would want tubewells.

TABLE 4.14

Area of Unit 2a Land with Good Deep Aquifer and No Surface Irrigation

District	Area (ha)	Comments
Rupandehi	25 000	10 000 ha BLGWP I-III
Bara	6 000	2 000 ha Birganj TP (prop), 1 000 ha NZIDP
Rautahat	4 000	
Sarlahi	4 000	
Mahottari	6 000	
dhanusha	10 000	
Total	54 000	20% in BLGWP

It is possible to take this analysis one step further and exclude lands with a good shallow aquifer; it would be far better to use shallow tubewells in this poorly drained land, since these will actively improve drainage. The remaining land which has a good deep aquifer, poor shallow aquifer and no surface irrigation is only 22 000 ha, almost entirely around Janakpur (Table 4.15). This is just 1% of the total area of the Terai, or perhaps 5% of the area recommended for groundwater development.

TABLE 4.15

Area of Unit 2a Land with Good Deep Aquifer, Poor Shallow Aquifer and No Surface Irrigation

District	Area (ha)
Rautahat	2 000
Sarlahi	4 000
Mahottari	6 000
Dhanusha	10 000
Total	22 000

(c) Technical Feasibility and Sustainability

There is thus a small area of land which is suitable for deep tubewell development, apart from drainage constraints. The remaining question is whether it is technically feasible to drain this land in a sustainable manner. There are two main considerations in deciding this:

- the location of a suitable outfall; and
- the cost of maintenance and the willingness of farmers to undertake this task.

These can only be decided by local surveys. It is possible that some rivers in the Janakpur area are sufficiently incised to provide an outfall, since they rise south of the Siwaliks. Even if this were the case, there is little reason to be optimistic for sustained maintenance by farmers.

(d) Cost-Benefit Analysis

The discussion so far suggests that drainage is not a serious issue; it causes some problems in certain areas, but these are difficult to solve. There are also non-technical constraints and concerns for maintenance arrangements. A simple economic analysis has also been done which in general confirms this pessimistic assessment of drainage. There are, however, some places where local drainage of small pockets of low-lying land can give significant benefit at a relatively low cost.

This analysis is based on the following assumptions:

- costs as given in Section 4.4.4, plus annual operation and maintenance costs equal to 2% of the initial cost;

- benefits as given in Section 4.4.5, converted to economic values by using the following economic crop gross margins (Rs/ha):

Crop	High yield	Low yield
Wheat	8 800	4 225
Rice	15 200	9 500

- benefits build up over a three year period (50%, 80%, 100%).

The resulting rates of return are given in Table 4.16.

TABLE 4.16

Economic Internal Rate of Return for Drainage

	Local drainage possible	Main drainage needed
Low yield	9%	0%
High yield	21%	8%

This suggests that local drainage is useful if farmers are able to get good yields, but the benefits are more marginal in the more usual case of relatively low yields on this land. Such local drainage might be favoured by farmers where they are able to undertake the work themselves at little more than the cost of their labour, which would be less than the costs quoted above.

However, local drainage is not usually possible, and it is doubtful whether large scale drainage can be justified.

(e) Conclusions

In the context of this strategy, it would be more appropriate to exclude the large contiguous areas of badly drained land. Drainage of these would be expensive, hard to justify and difficult to sustain. However, there will inevitably be some small badly drained areas in deep tubewell commands. Where possible these should be drained; especially if it is just a question of a short ditch which farmers can implement themselves with a little technical assistance. If this is not possible, because there is no gravity outfall, then the poor drainage should be accepted.

It might be considered that this is avoiding the issue of how to develop poor lands, but any such development should not involve deep tubewells. It may be possible to combine drainage and irrigation with shallow tubewells in such areas, and there may be scope for improved agricultural practices (such as are also being investigated in BLGWP). Completely different solutions - such as fish farming - may be more sensible in some of these places.

There are some difficulties in identifying the areas which are poorly drained. The LRMP irrigation suitability classes are a useful basis, but they are too crude to identify all unsuitable lands and may misclassify some suitable lands. This is not an important consideration since there is a fairly good correlation and there is no intention of siting individual tubewells on the basis of LRMP data. That would only be done by detailed studies, following a specific request by farmers.

Thus a sensible policy to adopt is that:

- Land System 2a lands (irrigation suitability 2Rd) should be excluded from the development plan for deep tubewells;
- implementation of the plan should be flexible and highly responsive to farmer requests; extension efforts to stimulate farmer interest should concentrate on the most suitable areas, but requests for tubewells in adjacent Unit 2a areas should not be automatically dismissed;
- drainage problems should be assessed when reviewing specific farmer requests for deep tubewells (although it may be considered unlikely that farmers will wish to contribute to the cost of wells in land which they would know is unsuitable); this may lead to some Unit 2a lands being included or some Unit 2c lands excluded;
- technical assistance should be given to help farmers resolve any small local drainage problems (design of drains, liaison between farmers' groups, agricultural techniques to improves soil condition, etc);
- there should be no HMGN commitment to maintenance of drains - all operation and maintenance must be the responsibility of farmers, and thus large scale drainage is unlikely to be sustainable;
- deep tubewells should not be sited in places where there are large scale drainage problems; and
- tubewell commands should not be too large - preferably no more than 60 ha, and ideally no more than 40 ha - this makes management easier and hence more efficient, and reduces problems of cross-drainage in open channel systems in areas of undulating topography (such as Land Unit 2c).

CHAPTER 5

CIVIL WORKS COSTS

5.1 Unit Rates

Unit rates have been derived from the standard rates for estimating civil works applied at Dhangadhi, Dang, Bhairahwa, Parsa and Biratnagar. These five locations (one in each of the development regions) are all bases for DOI construction activities. The unit material and labour costs taken for the whole of the Terai are listed in Table 5.1. Individual construction rates from the five locations are presented in Table 5.2, together with the average of the five taken as the overall Terai value. There are local variations in costs and these will have to be considered when planning specific projects. For completeness' sake the average rates are compared with those tendered for recent ILC groundwater work at Butwal.

The costs shown for uPVC pipes and fittings are based on those tendered for the Stage II Bhairahwa Lumbini wells in late 1992.

The breakdown of costs into unskilled labour, skilled labour and other local costs, and foreign exchange are shown in Table 5.3. These are based on Bhairahwa figures and have been adopted universally for economic pricing. The elements described as 'Local/Foreign' refer to goods, such as cement, which are made in Nepal but are occasionally imported from India.

5.2 Structure Costs

Quantities were calculated for a variety of well headworks and irrigation distribution system channels and structures. The designs are based broadly on those used for ILC groundwater works or given in the PDSP design manuals. In 1987, alternatives were costed to examine the difference between 10 inch and 5 inch brickwork channel lining sections and to compare concrete with traditional brick soling inverts for lined channels and distribution structures. As a result, the current estimates are based on 5 inch brick work channel lining wall sections and on structures built on concrete bases

Structures have been costed to include prefabricated metal gates. Ring main buried pipe system components have been costed according to drawings for 45 l/s systems built in India, including the elevated control tank.

TABLE 5.1

Unit Labour and Material Costs: Civil Works

	Item	Unit cost
(a)	**Labour**	
	Head mason/carpenter/blacksmith (80-120)	Rs 100/day
	Mason (range 75-110)	Rs 88/day
	Skilled labourer (45-75)	Rs 62/day
	Labourer (male) (38-50)	Rs 43/day
	(female) (38-50)	Rs 43/day
(b)	**Materials**	
	First class bricks (per thousand)	Rs 1 240-1 820
	Cement (Nepalese price; Indian 208)	Rs 215/50 kg
	Sand	Rs 175-370/m^3
	Stone chips	Rs 350-620/m^3
	400 mm (ID) PCC pipe	Rs 460/m
	Jointing collar for above	Rs 46 each
	200 mm (ID) uPVC pipe (2.5 kg/cm)	Rs 210/m
	160 mm uPVC pipes	Rs 150/m
	Supply and fix fabricated steel control gate	Rs 2 650 each
	Alfalfa valve	Rs 1 780 each
	Mild steel bar 10 to 20 mm	Rs 26/kg

Source: DOI field officers in the Terai and inner Terai

Quantities calculated for these works have been costed with a series of standard spreadsheets such as that shown for the elevated control tank in Table 5.4. The overall results are summarised in Table 5.5 which includes costs for channels and structures with flows in the range 30 to 90 l/s.

5.3 Deep Tubewell System Costs

5.3.1 Open Channel Systems

Quantities for lined and unlined open channels systems have been estimated on the basis of a limited sample of six DTWs surveyed in 1987, systems built at BLGWP visited during the 1993 field work, and experience in Bangladesh and Indonesia. They are summarised in Table 5.6. The density of field channels is based on the average of 280 m/ha measured in the surveyed STWs. Table 5.6 address applications for DTWs, MTWs and STWs including the lined systems built for STWs by the ILC programme.

TABLE 5.2

Comparison between Calculated Civil Works Rates for Selected Terai Stations Rates (Rs)

Item	Unit	Dhangadhi (Far West)	Dang (Mid West)	Bhairahwa (West)	Parsa (Central)	B'nagar (East)	Average	Tendered rates Bhutwal (Rs)	Change (%)
Earthwork:									
Excavation	(m3)	34.8	39.2	34.8	35.0	34.8	35.7	28.0	-22%
Fill	(m3)	24.1	27.2	24.0	24.1	24.1	24.7	25.0	1%
Brickwork									
1:4	(m3)	2 113	2 442	2 200	2 172	2 447	2 275	2 500	10%
1:6	(m3)	1 965	2 299	2 053	2 026	2 300	2 129		
Mud mortar	(m3)	1 398	1 784	1 528	1 526	1 758	1 599		
Soling on edge	(m2)	204	246	216	212	248	225		
Flat soling	(m2)	124	143	128	124	145	133	140	5%
OPC plaster 1:3	(m2)	69	67	65	62	68	66	76	15%
OPC plaster 1:6	(m2)	57	56	53	50	56	54		
Concrete									
1:2:4	(m3)	2 701	2 649	2 703	2 657	2 693	2 681	2 905	8%
1:3:6	(m3)	2 197	2 169	2 214	2 163	2 198	2 188		
ms bar	(kg)	37	36	35	34	35	35	42	19%
Shuttering	(m2)	172	112	171	230	204	178	60	-66%
Woodwork									
Frames	(m3)	32 910	22 690	32 118	41 550	37 569	33 367		
Shutters	(m2)	1 754	1 387	1 638	2 052	1 877	1 742		
Miscellaneous									
Sand fill	(m3)	523	403	428	362	457	435		
Whitewash	(m2)	9	9	7	7	7	8		
Aluminium paint	(m2)	59	63	54	57	56	58		
Snocem paint	(m2)	25	35	30	35	29	31		
Enamel paint	(m2)	59	64	64	56	57	60		
DPC 1:1.5:3	(m3)	3 263	3 230	3 266	3 271	3 265	3 259		
Site clearance	(m2)	2.9	3.3	2.9	2.8	2.9	3.0	2.0	-32%
Turfing	(m2)	2.4	2.7	2.4	2.3	2.4	2.4		
PCC pipe (400 mm)	(m)	1 100	1 165	1 082	1 000	1 125	1 094		
Pipe collar	(Nr)	110	117	110	100	113	110		
MS pipe (150 mm)	(m)	1 200	1 350	1 200	1 300	1 175	1 245 *		
MS bent pipe	(m)	1 300	1 450	1 300	1 400	1 280	1 346 *		
Gravel fill	(m3)	388	358	308	326	515	379		
Boulder pitching	(m3)	724	717	665	647	672	685	250	-64%

* Estimate

Note : based on 20 km average haul; rates for 1992/93
Source: Calculated according to standard analysis/ norms using GWRDP field office prices

TABLE 5.3

Civil Works Unit Rate Estimates: Breakdown into Labour, Materials, Profit and Taxes (Based on Bhairahwa Rates)

Item	Unit	Rate (Rs)	Unskilled labour		Skilled labour		Other local		Economic costs breakdown "Local/ Foreign"		OH/ Profit		Tax	
			Costs	(%)	Costs	(%)	Costs	(%)	Costs	(%)	Costs	(%)	Costs	(%)
Earthwork:														
Excavation	(m3)	35	28.0	80%	0.0	0%	0.8	2%	0.0	0%	4.3	12%	1.7	5%
Fill	(m3)	24	20.0	83%	0.0	0%	0.0	0%	0.0	0%	3.0	12%	1.2	5%
Brickwork														
1:4	(m3)	2 200	168	8%	120	5%	1 100	50%	433	20%	273	12%	105	5%
1:6	(m3)	2 053	168	8%	120	6%	1 109	54%	303	15%	255	12%	98	5%
Mud mortar	(m3)	1 528	140	9%	80	5%	1 045	68%	0	0%	190	12%	73	5%
Soling on edge	(m2)	216	13	6%	8	4%	158	73%	0	0%	27	12%	10	5%
Flat soling	(m2)	128	4	3%	4	3%	98	77%	0	0%	16	12%	6	5%
OPC plaster 1:3	(m2)	65	8	12%	15	23%	4	6%	27	42%	8	12%	3	5%
OPC plaster 1:6	(m2)	53	8	14%	15	29%	5	9%	17	31%	7	12%	3	5%
1:2:4	(m3)	2 704	200	7%	80	3%	573	21%	1 386	51%	336	12%	129	5%
1:3:6	(m3)	2 215	200	9%	80	4%	601	27%	953	43%	275	12%	105	5%
ms bar	(kg)	35	0	1%	1	2%	0	0%	28	80%	4	12%	2	5%
Shuttering	(m2)	171	3	2%	1	1%	137	80%	1	1%	21	12%	8	5%
Frames	(m3)	32 118	136	0%	3 060	10%	22 897	71%	506	2%	3 990	12%	1 529	5%
Shutters	(m2)	1 638	19	1%	424	26%	824	50%	89	5%	204	12%	78	5%
Sand fill	(m3)	428	26	6%	0	0%	328	77%	0	0%	53	12%	20	5%
Whitewash	(m2)	7	0	6%	3	48%	0	0%	2	29%	1	12%	0	5%
Aluminium paint	(m2)	54	4	8%	10	18%	0	0%	31	57%	7	12%	3	5%
Snocem paint	(m2)	30	0	1%	5	17%	0	0%	19	65%	4	12%	1	5%
Enamel paint	(m2)	64	3	5%	7	11%	0	0%	42	66%	8	12%	3	5%
DPC 1:1.5:3	(m3)	3 266	280	9%	120	4%	572	18%	1 733	53%	406	12%	156	5%
Site clearance	(m2)	3	2	83%	0	0%	0	0%	0	0%	0	12%	0	5%
Turfing	(m2)	2	2	83%	0	0%	0	0%	0	0%	0	12%	0	5%
PCC pipe (400 mm)	(m)	1 082	40	4%	31	3%	398	37%	427	40%	134	12%	52	5%
Pipe collar	(Nr)	110	4	4%	3	3%	41	37%	43	39%	14	12%	5	5%
MS pipe (150 mm)	(m)	1 200	30	3%	0	0%	40	3%	924	77%	149	12%	57	5%
MS bent pipe	(m)	1 300	30	2%	0	0%	45	3%	1 002	77%	161	12%	62	5%
Gravel fill		308.3	24.0	8%	0.0	0%	231	75%	0	0%	38	12%	15	5%
Boulder pitching		665.3	28.4	4%	169.6	25%	353	53%		0%	83	12%	32	5%

Source : DoI Offices

TABLE 5.4

Structure Costs Estimation Spreadsheet

Type: Elevated tank

Discharge : 45 l/s

Item	Unit	Rate	Qty	Cost	Unskilled labour		Skilled labour		Economic costs breakdown Other local		"Local/ Foreign"		OH/ Profit		Tax	
		(Rs)		(Rs)	(%)	(Rs)	(%)	(Rs)	(%)	(Rs)	(%)	(Rs)	(%)	(Rs)	(%)	Costs
Earthwork:																
Excavation	(m3)	36	5.0	179	80%	143	0%	0	3%	5	0%	0	12%	21	5%	9
Fill	(m3)	25	0.7	17	83%	14	0%	0	0%	0	0%	0	12%	2	5%	1
Brickwork:																
1:4	(m3)	2 275	12.0	27 300	8%	2 184	5%	1 365	50%	13 650	20%	5 460	12%	3 276	5%	1 365
1:6	(m3)	2 129	0.0	0	8%	0	6%	0	54%	0	15%	0	12%	0	5%	0
Mud mortar	(m3)	1 599	0.0	0	9%	0	5%	0	69%	0	0%	0	12%	0	5%	0
Soling on edge	(m2)	225	0.0	0	6%	0	4%	0	73%	0	0%	0	12%	0	5%	0
Flat soling	(m2)	133	4.0	532	3%	16	3%	16	77%	410	0%	0	12%	64	5%	27
OPC plaster 1:3	(m2)	66	63.0	4 158	12%	499	23%	956	6%	249	42%	1 746	12%	499	5%	208
OPC plaster 1:6	(m2)	54	16.8	907	14%	127	29%	263	9%	82	31%	281	12%	109	5%	45
Concrete:																
1:2:4	(m3)	2 681	5.0	13 405	7%	938	4%	536	21%	2 815	51%	6 837	12%	1 609	5%	670
1:3:6	(m3)	2 188	1.0	2 188	9%	197	4%	88	27%	591	43%	941	12%	263	5%	109
ms bar	(kg)	35	906.0	31 710	1%	317	2%	634	0%	0	80%	25 368	12%	3 805	5%	1 586
Shuttering	(m2)	178	25.0	4 450	2%	89	1%	45	79%	3 516	1%	45	12%	534	5%	223
Frames	(m3)	33 367	0.0	0	0%	0	10%	0	71%	0	2%	0	12%	0	5%	0
Shutters	(m2)	1 742	0.0	0	2%	0	26%	0	50%	0	5%	0	12%	0	5%	0
Sand fill	(m3)	435	0.0	0	6%	0	0%	0	77%	0	0%	0	12%	0	5%	0
Whitewash	(m2)	8	0.0	0	6%	0	48%	0	0%	0	29%	0	12%	0	5%	0
Aluminium paint	(m2)	58	0.0	0	8%	0	18%	0	0%	0	57%	0	12%	0	5%	0
Snocem paint	(m2)	31	0.0	0	1%	0	17%	0	0%	0	65%	0	12%	0	5%	0
Enamel paint	(m2)	60	0.0	0	5%	0	11%	0	0%	0	67%	0	12%	0	5%	0
DPC 1:1.5:3	(m3)	3 259	0.0	0	8%	0	4%	0	18%	0	53%	0	12%	0	5%	0
Site clearance	(m2)	3.00	0.0	0	83%	0	0%	0	0%	0	0%	0	12%	0	5%	0
Turfing	(m2)	2.40	0.0	0	83%	0	0%	0	0%	0	0%	0	12%	0	5%	0
PCC pipe (400 mm)	(m)	1 094	0.0	0	4%	0	3%	0	36%	0	40%	0	12%	0	5%	0
Pipe collar	(Nr)	110	0.0	0	4%	0	3%	0	37%	0	39%	0	12%	0	5%	0
MS pipe (150 mm)	(m)	1 245	0.0	0	3%	0	0%	0	3%	0	77%	0	12%	0	5%	0
MS bent pipe	(m)	1 346	0.0	0	2%	0	0%	0	3%	0	78%	0	12%	0	5%	0
Gravel fill	(m3)	379	0.0	0	8%	0	0%	0	75%	0	0%	0	12%	0	5%	0
Boulder pitching	(m3)	685	0.0	0	5%	0	25%	0	53%	0	0%	0	12%	0	5%	0
Pipework and incidentals		17 500	1.0	17 500	3%	525	10%	1 750	20%	3 500	50%	8 750	12%	2 100	5%	875
Extra 2............	...	....	0.0	0	3%	0	10%	0	20%	0	50%	0	12%	0	5%	0
Extra 3............	...	....	0.0	0	3%	0	10%	0	20%	0	50%	0	12%	0	5%	0
Sub-total				102 346	5%	5 049	6%	5 653	24%	24 817	48%	49 427	12%	12 282	5%	5 117
Miscellaneous small items			3%	3 070	3%	92	10%	307	30%	921	40%	1 228	12%	368	5%	154
Totals				105 416	5%	5 142	6%	5 960	24%	25 739	48%	50 656	12%	12 650	5%	5 271

Source: GDC

TABLE 5.5

Summary of DTW/ MTW Component Civil Works Cost Estimates

Item	Q (l/s)	Unit	Cost (Rs)	Economic pricing breakdown (%)					
				Unskilled labour	Skilled labour	Other local	Foreign exchange	OH/ profit	Tax
(a) Open channels									
Half brick lined	90	m	850	13%	7%	38%	25%	12%	5%
Half brick lined	60	m	800	13%	7%	38%	25%	12%	5%
Half brick lined	45	m	725	13%	7%	38%	25%	12%	5%
Half brick lined	30	m	660	13%	7%	38%	25%	12%	5%
Earth (bal cut/fill)	90	m	48	83%	0%	0%	0%	12%	5%
Earth (bal cut/fill)	60	m	37	83%	0%	0%	0%	12%	5%
Earth (bal cut/fill)	45	m	34	83%	0%	0%	0%	12%	5%
Earth (bal cut/fill)	30	m	27	83%	0%	0%	0%	12%	5%
Earth (in cut)	90	m	33	83%	0%	0%	0%	12%	5%
Earth (in cut)	60	m	24	83%	0%	0%	0%	12%	5%
Earth (in cut)	45	m	19	83%	0%	0%	0%	12%	5%
Earth (in cut)	30	m	16	83%	0%	0%	0%	12%	5%
Earth (in fill)	90	m	89	83%	0%	0%	0%	12%	5%
Earth (in fill)	60	m	80	83%	0%	0%	0%	12%	5%
Earth (in fill)	45	m	69	83%	0%	0%	0%	12%	5%
Earth (in fill)	30	m	49	83%	0%	0%	0%	12%	5%
Field channels	30	100m	250	83%	0%	0%	0%	12%	5%
(b) uPVC buried pipes									
Elevated tank	90	Nr	125 000	5%	6%	25%	47%	12%	5%
Elevated tank	45	Nr	105 000	5%	6%	25%	47%	12%	5%
200 mm pipe	45-90	m	240	1%	2%	0%	80%	12%	5%
160 mm pipe	22	m	180	1%	2%	0%	80%	12%	5%
Pipe outlets	22	Nr	6 500	8%	7%	36%	32%	12%	5%
(c) Structures (open channels)									
3 way lined feeder box	90	Nr	11 900	11%	13%	46%	13%	12%	5%
3 way lined feeder box	60	Nr	11 500	11%	13%	46%	13%	12%	5%
3 way lined feeder box	45	Nr	11 100	11%	13%	46%	13%	12%	5%
3 way lined feeder box	30	Nr	10 700	11%	13%	46%	13%	12%	5%
2 way lined feeder box	90	Nr	8 250	11%	13%	46%	13%	12%	5%
2 way lined feeder box	60	Nr	8 000	11%	13%	46%	13%	12%	5%
2 way lined feeder box	45	Nr	7 750	11%	13%	46%	13%	12%	5%
2 way lined feeder box	30	Nr	7 500	11%	13%	46%	13%	12%	5%
3 way earth feeder outlet	90	Nr	17 250	11%	13%	46%	13%	12%	5%
3 way earth feeder outlet	60	Nr	16 500	11%	13%	46%	13%	12%	5%
3 way earth feeder outlet	45	Nr	15 750	11%	13%	46%	13%	12%	5%
3 way earth feeder outlet	30	Nr	15 000	11%	13%	46%	13%	12%	5%
2 way earth feeder outlet	90	Nr	13 000	11%	13%	46%	13%	12%	5%
2 way earth feeder outlet	60	Nr	12 500	11%	13%	46%	13%	12%	5%
2 way earth feeder outlet	45	Nr	12 000	11%	13%	46%	13%	12%	5%
2 way earth feeder outlet	30	Nr	11 500	11%	13%	46%	13%	12%	5%
Culvert	45	Nr	4 200	9%	7%	43%	24%	12%	5%
Low head syphon	45	Nr	20 000	13%	6%	32%	32%	12%	5%
Fall	45	Nr	5 000	12%	11%	47%	13%	12%	5%
Aqueduct	n/a	Nr	35 000	9%	7%	41%	27%	12%	5%
Cattle ramp	n/a	Nr	3 000	9%	7%	38%	31%	12%	5%
(d) Well head works									
Pump house (diesel)	>=45	Nr	126 000	5%	9%	38%	31%	12%	5%
Discharge box	45	Nr	10 500	8%	11%	40%	24%	12%	5%

Source: GDC

TABLE 5.6

Salient Quantities for Open Channel Distribution Systems

Item	Pump size (l/s)	Design duty (l/s/ha)	Command area (ha)	Feeder channels (m)	Field/ farm channels (m)	Feeder boxes/ outlets (Nr)	Other structures (Nr)	Land take (feeders) (m2)
(a) Unit quantities per 10 ha				35	280		1.4 to 1.8	
(b) Lined feeders	90	1.25	72	2,520	20,160	21	10	7,560
	60	1.25	48	1,680	13,440	14	8	4,704
	45	1.25	36	1,260	10,080	14	6	3,150
	30	1.25	24	840	6,720	7	5	1,890
ILC type STW	14	2.00	7	245	1,960	7	3	490
(c) Unlined feeders	90	1.5	60	2,100	16,800	21	8	7,350
	60	1.5	40	1,400	11,200	14	6	4,480
	45	1.5	30	1,050	8,400	14	5	2,940
	30	1.5	20	700	5,600	7	4	1,750
ADBN type STW	14	3.5	4	140	1,120	7	2	308

* for 45 to 90 l/s wells

Source: GDC

The quantities of outlets are based broadly on a seven day rotation system. A typical distribution system calculation is shown in Table 5.7. Quantities for site-specific structures such as inverted siphons (at road crossings), falls and aqueducts have been 'allocated' on a broad basis. The costs for all the systems analysed are summarised in Table 5.8.

5.3.2 Buried Pipe Systems

Quantities of pipes for buried distribution systems are based on those designed for the 38 BLGWP Stage II DTWs, as shown in Table 5.9 and, assuming that these are designed with 14 outlets per loop only, two for each daily rotation unit. These quantities have been developed to produce total quantities for 90, 60, 45 and 30 l/s wells as shown in Table 5.10.

These quantities have been costed in a series of spreadsheets as shown for a 45 l/s ring main buried pipe system in Table 5.11.

The buried pipe analysis also includes a crude estimate for radial pipe systems, which might, for operational reasons, prove more suitable in areas where diesel drive pumps are unavoidable. This practice has been successfully developed in Bangladesh with 60 l/s DTWs (Sir M MacDonald & Partners, 1993). It is particularly useful, in partial piped systems, for dealing with topographic constraints which would otherwise limit the size of a gravity fed command area; particularly for crossing depressions.

TABLE 5.7

DTW/ MTW Distribution System Cost Estimates: 90 l/s Well with Lined Feeder Channels 72 ha net (Rs @ 1993 financial prices)

Area : 72 ha

Lined : 90 l/s

Item	Q	Unit	Qty	Rate	Total	Economic pricing breakdown (%)						
	(l/s)			(Rs)	(Rs)	Unskill labour	Skilled labour	Other local	Foreign exchange	OH/ profit	Tax	Total
(a) Open channels												
Half brick lined	90	m	2000	850	1 700 000	13%	7%	38%	25%	12%	5%	100%
Half brick lined	60	m	520	800	416 000	13%	7%	38%	25%	12%	5%	100%
Half brick lined	45	m	0	725	0	13%	7%	38%	25%	12%	5%	100%
Half brick lined	30	m	0	660	0	13%	7%	38%	25%	12%	5%	100%
Earth (bal cut/fill)	90	m	0	48	0	83%	0%	0%	0%	12%	5%	100%
Earth (bal cut/fill)	60	m	0	37	0	83%	0%	0%	0%	12%	5%	100%
Earth (bal cut/fill)	45	m	0	34	0	83%	0%	0%	0%	12%	5%	100%
Earth (bal cut/fill)	30	m	0	27	0	83%	0%	0%	0%	12%	5%	100%
Earth (in cut)	90	m	0	33	0	83%	0%	0%	0%	12%	5%	100%
Earth (in cut)	60	m	0	24	0	83%	0%	0%	0%	12%	5%	100%
Earth (in cut)	45	m	0	19	0	83%	0%	0%	0%	12%	5%	100%
Earth (in cut)	30	m	0	16	0	83%	0%	0%	0%	12%	5%	100%
Earth (in fill)	90	m	0	89	0	83%	0%	0%	0%	12%	5%	100%
Earth (in fill)	60	m	0	54	0	83%	0%	0%	0%	12%	5%	100%
Earth (in fill)	45	m	0	69	0	83%	0%	0%	0%	12%	5%	100%
Earth (in fill)	30	m	0	49	0	83%	0%	0%	0%	12%	5%	100%
Field channels	30	100m	202	1 000	202 000	83%	0%	0%	0%	12%	5%	100%
Sub-total (Rs)					2 318 000	442 740	148 120	804 080	529 000	278 160	115 900	2 318 000
(b) uPVC buried pipes												
Elevated tank	90	Nr	0	125 000	0	5%	6%	25%	47%	12%	5%	100%
Elevated tank	45	Nr	0	105 000	0	5%	6%	25%	47%	12%	5%	100%
200 mm pipe	45-90	m	0	240	0	1%	2%	0%	80%	12%	5%	100%
160 mm pipe	22	m	0	180	0	1%	2%	0%	80%	12%	5%	100%
Pipe outlets	22	Nr	0	6 500	0	8%	7%	36%	32%	12%	5%	100%
Sub-total (Rs)					0	0	0	0	0	0	0	0
(c) Structures (open channels)												
3 way lined feeder box	90	Nr	6	11 900	71 400	11%	13%	46%	13%	12%	5%	100%
3 way lined feeder box	60	Nr	0	11 500	0	11%	13%	46%	13%	12%	5%	100%
3 way lined feeder box	45	Nr	0	11 100	0	11%	13%	46%	13%	12%	5%	100%
3 way lined feeder box	30	Nr	0	10 700	0	11%	13%	46%	13%	12%	5%	100%
2 way lined feeder box	90	Nr	12	8 250	99 000	11%	13%	46%	13%	12%	5%	100%
2 way lined feeder box	60	Nr	3	8 000	24 000	11%	13%	46%	13%	12%	5%	100%
2 way lined feeder box	45	Nr	0	7 750	0	11%	13%	46%	13%	12%	5%	100%
2 way lined feeder box	30	Nr	0	7 500	0	11%	13%	46%	13%	12%	5%	100%
3 way earth feeder outlet	90	Nr	0	17 250	0	11%	13%	46%	13%	12%	5%	100%
3 way earth feeder outlet	60	Nr	0	16 500	0	11%	13%	46%	13%	12%	5%	100%
3 way earth feeder outlet	45	Nr	0	15 750	0	11%	13%	46%	13%	12%	5%	100%
3 way earth feeder outlet	30	Nr	0	15 000	0	11%	13%	46%	13%	12%	5%	100%
2 way earth feeder outlet	90	Nr	0	13 000	0	11%	13%	46%	13%	12%	5%	100%
2 way earth feeder outlet	60	Nr	0	12 500	0	11%	13%	46%	13%	12%	5%	100%
2 way earth feeder outlet	45	Nr	0	12 000	0	11%	13%	46%	13%	12%	5%	100%
2 way earth feeder outlet	30	Nr	0	11 500	0	11%	13%	46%	13%	12%	5%	100%
Culvert	45	Nr	5	20 000	100 000	9%	7%	43%	24%	12%	5%	100%
Low head syphon	45	Nr	2	20 000	40 000	13%	6%	32%	32%	12%	5%	100%
Fall	45	Nr	2	5 000	10 000	12%	11%	47%	13%	12%	5%	100%
Aqueduct	n/a	Nr	1	35 000	35 000	9%	6%	41%	27%	12%	5%	100%
Cattle ramp	n/a	Nr	3	3 000	9 000	9%	5%	38%	31%	12%	5%	100%
Sub-total (Rs)					388 400	40 744	38 322	167 694	75 612	46 608	19 420	388 400
Totals (a) + (b) + (c)					2 706 400	483 484	186 442	971 774	604 612	324 768	135 320	2 706 400
Land purchase	na	100m2	75	750	56 250				56 250			56 250
Overall total					2 762 650	483 484	186 442	971 774	660 862	324 768	135 320	2 762 650
Total unit financial cost (Rs/ha)					38 370	0	0	0	0	0	0	1

Source: GDC

TABLE 5.8

Summary of Open Channel Distribution System Costs

Feeder channel type		Pump size (l/s)	Command area (ha)	Component costs (Rs '000)				Cost/ha (Rs)	Unskilled labour (%)
				Channels	Structures	Land	Total		
(a)	**Lined** (1.25 l/s/ha)	90	72	2 318	388	56	2 762	38 370	18
		60	48	1 411	279	35	1 725	35 930	18
		45	36	998	247	23	1 268	35 280	18
		30	24	621	153	14	788	32 850	18
ILC type STW		15	7	144	103	4	251	35 850	17
Average								35 660	18
(b)	**Unlined** (1.5 l/s/ha)	90	60	270	466	55	791	13 200	37
		60	40	162	294	58	514	12 850	33
		45	30	122	273	22	417	13 690	31
		30	20	75	162	13	250	12 520	32
Average								13 070	33
ADBN STW		14	4	13	0	2	15	3 870	100

Source: GDC.

TABLE 5.9

Main Design Features of BLGWP Buried Pipe Systems

Feature	Stage			GDC Planning target
	II/1	II/2	III	
Numbers of systems	16*	22**	16***	
Average area served (ha)	115.6	125.2	106.9	
Number of loops	4	4	3.6	
Area served per loop (ha)	28.9	31.3	29.5	30
Number of irrigation blocks	24	88	ND	
Number of outlets	52	59	ND	
Number of outlets/loop	13	14.8	?	
Area served per outlet (ha)	2.2	2.1	?	2.14
Length of 200 mm pipe (m)				
- average per system	494	995	?	200
- per loop	123	249	?	6.7
- per hectare	3.9	8.0	?	
Lengths of 160 mm pipe (m)				
- average per system	7 966	7 856	?	2 000
- per loop	1 992	1 964	?	65
- per hectare	69	63	?	

Notes: (1) * These wells were commissioned in 1989/89 to 1989/90; data collected in 1987 prior to installation; all nominally 300 m^3/h

(2) ** These systems are all installed but awaiting pumps; pumps in range 225 to 300 m^3/h - average 273 m^3/h

(3) *** These systems being designed; installation to start in 1993/94; command areas vary between 67 and 126 ha; number of loops vary between 2 (1 Nr), 3 (4 Nr) and 4 (11 Nr)

(4) ND = not yet designed

Source: GDC interpretation of BLGWP data.

TABLE 5.10

Salient Quantities for Buried Pipe Distribution Systems

Item	Pump size (l/s)	Command area (ha)	Nr of loops/ radii	Area/ loop (ha)	Length of pipe (m)			Outlet valves (Nr)*	Field/ farm channels (m)
					200 mm	150 mm	100 mm		
Quantity/hectare					6.7**	66**			280
(a) Ring main system	90	90	3	30	600	5 940	0	42	25 200
	60	60	2	30	400	3 960	0	28	16 800
	45	45	2	22.5	300	2 970	0	21	12 600
	30	30	1	30	200	1 980	0	14	8 400
(b) Radial system* **	45	45	3	15	3 000	0	0	21	12 600
	30	30	2	15	0	2 500	0	14	8 400
	15	15	1	15	0	0	2 000	7	4 200

Notes:
- * 1 outlet per 2.14 ha and 2 daily blocks per outlet
- ** ring main system only
- *** guideline estimates only

Source: GDC

TABLE 5.11

DTW/ MTW Distribution System Cost Estimates: Ring Main Piped System: 45 l/s Well (@ 1993 financial prices)

Item	Q	Unit	Qty	Rate	Total	Economic pricing breakdown (%)						
				(Rs)	(Rs)	Unskill labour	Skilled labour	Other local	Foreign exchange	OH/ profit	Tax	Total
	(l/s)											
(a) Open channels												
Half brick lined	90	m	0	850	0	13%	7%	38%	25%	12%	5%	100%
Half brick lined	60	m	0	800	0	13%	7%	38%	25%	12%	5%	100%
Half brick lined	45	m	0	725	0	13%	7%	38%	25%	12%	5%	100%
Half brick lined	30	m	0	660	0	13%	7%	38%	25%	12%	5%	100%
Earth (bal cut/fill)	90	m	0	48	0	83%	0%	0%	0%	12%	5%	100%
Earth (bal cut/fill)	60	m	0	37	0	83%	0%	0%	0%	12%	5%	100%
Earth (bal cut/fill)	45	m	0	34	0	83%	0%	0%	0%	12%	5%	100%
Earth (bal cut/fill)	30	m	0	27	0	83%	0%	0%	0%	12%	5%	100%
Earth (in cut)	90	m	0	33	0	83%	0%	0%	0%	12%	5%	100%
Earth (in cut)	60	m	0	24	0	83%	0%	0%	0%	12%	5%	100%
Earth (in cut)	45	m	0	19	0	83%	0%	0%	0%	12%	5%	100%
Earth (in cut)	30	m	0	16	0	83%	0%	0%	0%	12%	5%	100%
Earth (in fill)	90	m	0	89	0	83%	0%	0%	0%	12%	5%	100%
Earth (in fill)	60	m	0	54	0	83%	0%	0%	0%	12%	5%	100%
Earth (in fill)	45	m	0	69	0	83%	0%	0%	0%	12%	5%	100%
Earth (in fill)	30	m	0	49	0	83%	0%	0%	0%	12%	5%	100%
Field channels	30	100m	126	1 000	126 000	83%	0%	0%	0%	12%	5%	100%
Sub-total (Rs)					126 000	104 580	0	0	0	15 120	6 300	126 000
(b) uPVC buried pipes												
Elevated tank	60	Nr	0	138 000	0	5%	6%	25%	47%	12%	5%	100%
Elevated tank	45	Nr	1	105 000	105 000	5%	6%	25%	47%	12%	5%	100%
200 mm pipe	45-90	m	300	240	72 000	1%	2%	0%	80%	12%	5%	100%
160 mm pipe	22	m	2970	180	534 600	1%	2%	0%	80%	12%	5%	100%
Pipe outlets	22	Nr	21	6 500	136 500	8%	7%	36%	32%	12%	5%	100%
Sub-total (Rs)					848 100	22 236	27 987	75 390	578 310	101 772	42 405	848 100
(c) Structures (open channels)												
3 way lined feeder box	90	Nr	0	11 900	0	11%	13%	46%	13%	12%	5%	100%
3 way lined feeder box	60	Nr	0	11 500	0	11%	13%	46%	13%	12%	5%	100%
3 way lined feeder box	45	Nr	0	11 100	0	11%	13%	46%	13%	12%	5%	100%
3 way lined feeder box	30	Nr	0	10 700	0	11%	13%	46%	13%	12%	5%	100%
2 way lined feeder box	90	Nr	0	8 250	0	11%	13%	46%	13%	12%	5%	100%
2 way lined feeder box	60	Nr	0	8 000	0	11%	13%	46%	13%	12%	5%	100%
2 way lined feeder box	45	Nr	0	7 750	0	11%	13%	46%	13%	12%	5%	100%
2 way lined feeder box	30	Nr	0	7 500	0	11%	13%	46%	13%	12%	5%	100%
3 way earth feeder outl	90	Nr	0	17 250	0	11%	13%	46%	13%	12%	5%	100%
3 way earth feeder outl	60	Nr	0	16 500	0	11%	13%	46%	13%	12%	5%	100%
3 way earth feeder outl	45	Nr	0	15 750	0	11%	13%	46%	13%	12%	5%	100%
3 way earth feeder outl	30	Nr	0	15 000	0	11%	13%	46%	13%	12%	5%	100%
2 way earth feeder outl	90	Nr	0	13 000	0	11%	13%	46%	13%	12%	5%	100%
2 way earth feeder outl	60	Nr	0	12 500	0	11%	13%	46%	13%	12%	5%	100%
2 way earth feeder outl	45	Nr	0	12 000	0	11%	13%	46%	13%	12%	5%	100%
2 way earth feeder outl	30	Nr	0	11 500	0	11%	13%	46%	13%	12%	5%	100%
Culvert	45	Nr	0	20 000	0	9%	7%	43%	24%	12%	5%	100%
Low head syphon	45	Nr	0	20 000	0	13%	6%	32%	32%	12%	5%	100%
Fall	45	Nr	0	5 000	0	12%	11%	47%	13%	12%	5%	100%
Aqueduct	n/a	Nr	0	35 000	0	9%	6%	41%	27%	12%	5%	100%
Cattle ramp	n/a	Nr	0	3 000	0	9%	5%	38%	31%	12%	5%	100%
Sub-total (Rs)					0	0	0	0	0	0	0	0
Totals (a) + (b) + (c)					974 100	126 816	27 987	75 390	578 310	116 892	48 705	974 100
Land purchase	na	100m2	4	750	3 000				3 000			3 000
Overall total					977 100	126 816	27 987	75 390	581 310	116 892	48 705	977 100
Total unit financial cost (Rs/ha)	45				21 713	13%	3%	8%	59%	12%	5%	100%

Source: GDC

Radial systems may also have useful applications will better yielding STWs. They are relatively easy to construct and do not require elaborate high level head/control tanks. Adequate head to drive radial pipe distribution systems can be obtained by making ground-based towers using large diameter concrete rings sealed one upon the other as shown in Figure 4.6. This is much cheaper, and quite appropriate for operation with diesel drive pumps. The buried pipe cost estimates are summarised in Table 5.12.

The results indicate overall average costs of about Rs 36 000/ha for open channel systems with lined feeders, Rs 4 000/ha for unlined systems, Rs 22 000/ha for ring main systems and Rs 23 000/ha for radial pipe systems. This demonstrates the relative expensiveness of lined channel systems. Considering too the great advantages of buried pipe systems (discussed in Section 4.1), it is clear that buried pipes are also to be preferred to unlined earth channels (which are marginally more expensive in cost per hectare terms when including the well costs).

5.3.3 Wellhead Works

The costs of wellhead works (pump houses and discharge boxes/pipe control tanks) are summarised for a range of well sizes and pump prime mover types in Table 5.13. These include a nominal allowance for the simple shelters built at many STW sites and a basic discharge box at each STW (to avoid the extensive erosion and water wastage noted at several sites). All the electrically-driven STWs we have seen (including ADBN supplied wells) have more substantial shelters and these have been costed accordingly.

TABLE 5.12

Summary of Buried Piped Distribution System Costs

Pipe system type	Pump size (l/s)	Command area (ha)	Component costs (Rs '000)					Cost/ hectare (Rs)	Unskilled labour (%)
			Headwork*	Pipes	Outlets	Channel	Total		
(a) **Ring main (primarily electric systems)**	90	90	161	1 213	273	252	1 899	21 100	13
	60	60	141	809	182	168	1 300	21 700	13
	45	45	108	606	137	126	977	21 700	13
	30	30	88	404	91	84	667	22 200	13
Average								21 700	13
(b) **Radial** (primarily diesel systems)**	45	45	43	720	137	126	1 026	22 800	12
	30	30	33	450	91	84	658	22 000	13
	15	15	28	240	42	42	352	23 500	12
Average								22 700	12

Notes:
- * including Rs 3 000 for land
- ** guideline estimates only
- *** engineering costs not included

Source: GDC

TABLE 5.13

Summary of Wellhead Works Costs (Rs '000 at 1993 Financial Costs)

Distribution system	Pump size (l/s)	Pump houses		Discharge box	Control tank	Land (400 m²)	Totals	
		Diesel	Electric				Diesel	Electric
(a) Open channel systems	90	126	69	14	0	3	143	86
	60	126	69	11.5	0	2.5	140	83
	45	126	69	10.5	0	2.5	139	82
	30	100	55	9.5	0	2.5	112	67
	15*	75	40	6	0	2	84	49
	15**	35	20	6		-	41	26
(b) Ring main buried pipe system	90	126	69	0	158	3	287	230
	60	126	69	0	130	3	259	202
	45	126	69	0	105	3	231	177
	30	100	55	0	85	3	188	143
(c) Radial buried pipe systems	60	126	n/a	0	50	3	179	n/a
	45	126	n/a	0	40	3	169	n/a
	30	100	n/a	0	30	3	133	n/a
	15	75	40	0	25	3	103	68
(d) ADBN STWs	10-15	2	20	5	0	-	7	25

Notes: * VT pump
** Centrifugal pump: ILC model.

Source: GDC.

CHAPTER 6

POWER ENGINEERING

6.1 Introduction

6.1.1 Government Strategy on Power Subsector Development

HMGN's strategy for the Power Subsector addresses the supply, the development of the agricultural and industrial economies, and amelioration of the condition of the poor.

On the supply side, participation of the private sector is being actively encouraged, especially in the field of hydro-electric construction and operation. An Act of Parliament has been passed authorising the licensing of generating stations and transmission lines for periods up to 50 years with a guarantee that they will not be nationalised during the currency of the licence, except in the case of an isolated plant of less than 1 000 kW capacity, which can be taken over but only to incorporate it within a larger power system.

The supply authority, the NEA, is being encouraged to become commercially viable, while, as a longer term objective, the government has entertained the concept of the privatisation of all the NEA's facilities except for the main transmission system, leaving the Authority to control and dispatch the privately owned generating plants to serve the electrical distribution networks.

To assist the development of the agricultural sector, cheap electricity is provided by financially assisting rural electrification and by offering an especially low electricity tariff for small pumps.

6.1.2 Tubewell Pump Electrification Schemes: Technological Options

To date, the technological options that have been available in Nepal for tubewell electrification are the conventional 3 phase high voltage distribution and the Single Wire Earth Return System (SWER). The SWER system provides electricity over a single wire and is evidently cheaper than conventional distribution which requires the use of at least two wires, and most often three.

The appropriateness of the SWER system has yet to be proved. A pilot scheme is under study at Sudal Village in Bhaktapur District. Field studies undertaken in New Zealand and Australia have not shown conclusively that the SWER system is appropriate for widespread application in Nepal. The disadvantage of the scheme is that while it serves a lightly populated area very economically, once electric load density increases beyond a very low figure, it must be replaced by the conventional type of distribution. It has been employed in Australia where population density is minimal. In rural Nepal, load density is low because of the low economic level of the people, not because the people are not there. It is confidently expected that the response of the rural population to electrification will be to increase consumption rapidly, so the provision of a higher capacity system from the outset will prove economical. To encourage this growth, the NEA has established tariffs in which the basic demand charge is low. This is economically justifiable because the nature of the hydro-power sites in Nepal results in relatively low-cost capacity so the system will normally be constrained by its ability to generate energy. Given the availability of the water for generation, there should be no difficulty in supplying the peak load.

6.1.3 Power Options for Groundwater Pumping

The two options currently available for driving pumps are diesel engines and electric motors. The prevalent practice in the Terai is to use diesel engines. In fact, of the approximately 45 000 groundwater pumps listed in Nepal in 1993, only 455 were irrigation customers of the NEA.

All diesel fuel must be imported, however, whereas most of Nepal's electricity is generated by indigenous hydro-power plants. Thus it is government policy to replace as many of the diesel drives as soon as possible. The NEA's Seventh Power Project which is in the early stages of initiation, includes provision of electricity to 4 500 irrigation pumps in 10 districts by the end of 1995.

6.2 Power Generation

6.2.1 Existing Power Generating Plants

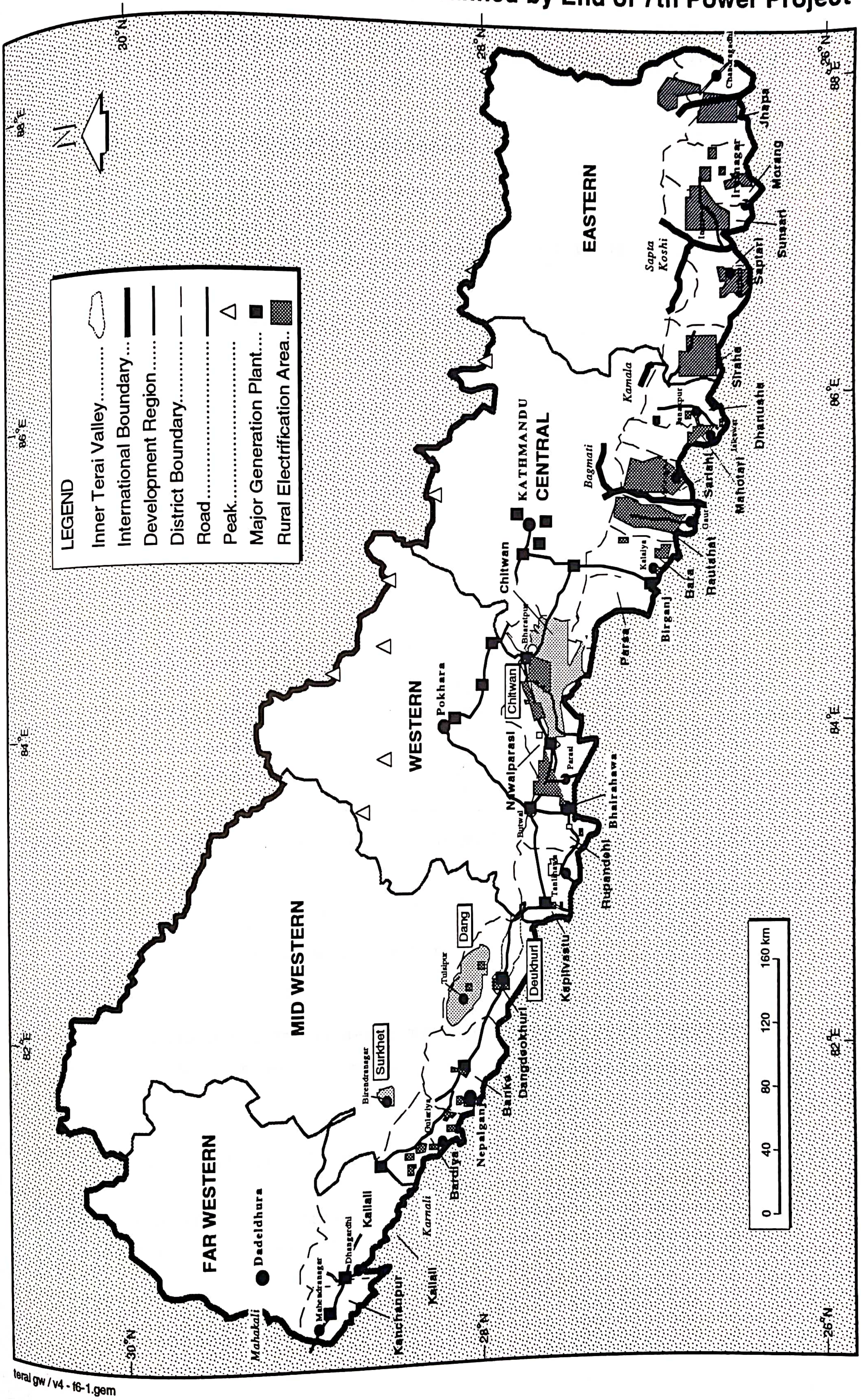
The seven major and two minor hydro-power plants currently in operation have a total capacity of almost 230 MW and a 'firm' annual energy capability of 1 200 GWh. The firm energy is the production that can be expected in a low water year provided the power system can use the energy when it is available.

Six of these plants are located in the Central Region, two are in the West Region, and all within 150 km of Kathmandu. These are shown on Figure 6.1.

There is seasonal storage on only one river on which there are two plants with a combined capacity of 92 MW. The rest are all 'run-of-river', meaning that the energy must be used the day the water is available; production can vary within the day to accommodate the peak and light loads, but little can be carried forward from one day to the next. The river gradients in the Himalayas are extremely steep, providing good sites for high-head plants but little storage behind the dams. The high heads result in high-speed, low-cost generators, hence the cheap capacity referred to at the end of Section 6.1.2. The rapidly flowing rivers carry large quantities of sand and silt, even gravel at times, so the plants must be shut down frequently for maintenance and to remove accumulated silt from the headponds.

Figure 6.1

Rural Electrification Areas Planned by End of 7th Power Project



terai gw / v4 - f6-1.gem

Two major diesel plants contain a total of 40 MW of generators. The newest one, at Dhuabi in south-eastern Nepal, with 24 MW has not been performing satisfactorily. At the Hetauda plant, 40 km south of Kathmandu, only 7 MW out of 14.4 MW is operational.

More precise details of the major plants are given in Table 6.1.

TABLE 6.1

Existing and Committed Generating Plants on the Integrated Nepal Power System

Plant	Year of commission	Installed capacity (MW)	Annual energy (GWh)
(a) Existing Hydro-electric Schemes			
Panauti*		2.4	-
Trisuli and Devighat	1962, 1983	35.1	269.3
Sunkosi	1973	10.5	71.5
Marsyangdi	1989	69.0	500.0
Kulekhani I and II	1982, 1986	92.0	230.0
Gandaki	1979	15.0	87.5
Andi Khola	1991	5.1	44.4
Small Hydro		7.0	23.2
Sub-total		233.7	1 225.9
(b) Committed Hydro-electric schemes			
Jhimruk	1995	12.0	81.0
Khimiti	1997	60.0	-
(c) Thermal Power Stations			
Hetauda Diesel	1983	14.4	
Multifuel	1991	26.0	

Note: * Plant inoperative because water discharge is less and is being diverted for irrigation purposes.

Source: (i) World Bank Staff Appraisal Report Nr 9077-NEP, Power Sector Efficiency Project, Feb 27, 1992.
(ii) NEA (Personal communications to World Bank Staff).

There are several very small generating stations, mini-hydros and isolated diesels. None is capable of contributing to the power supply to tubewells.

6.2.2 Generating Plants under Construction

Two plants are currently under construction. A 12.5 MW run-of-river hydro-power station at Jhimruk near the Mid West/West Region boundary is expected to be commissioned by NEA by the end of this year.

The private sector has a 60 MW plant under construction by the Butwal Power Company on the Khimti River, about 165 km east of Kathmandu, which it expects to commission to supply the Integrated Nepal Power System (INPS) in 1997. This is actually the third hydro-power station to be built by this company which entered the electric supply business in 1966 with a mini-hydro plant at Butwal from which it distributed power to the town of Butwal. Recently the company built a second plant of 5 MW capacity, which now supplies the INPS. The original mini-hydro and the distribution business in Butwal were handed over to the NEA when the town was connected to the INPS.

6.2.3 Planned Power Generation

Plans for the future expansion of the generation to supply the INPS are less than satisfactory.

In spite of completion of a 132 kV line from east to west extending the INPS from end to end of the country, only 11% of Nepalis now have access to electricity. The development of the electric supply is in so early a stage that the existing customers have been increasing their use of electricity at an annual rate of 8%. Extensions of the existing distribution facilities and the creation of new rural electrification have been adding consumers so rapidly that the total number of consumers has been increasing at a rate of 10% yearly. The new consumers start at very low consumption levels so the combined effect of growing demands of existing consumers and the growth in consumer numbers results in an overall increase of 12 to 13% annually.

Currently the load has reached 225 MW, and it would be even higher in the absence of load shedding, so, were it not for the limitations imposed by the generating facilities, the INPS load would be increasing by about 25 to 30 MW annually.

Clearly the current construction programme will not keep up with demand.

A 201 MW run-of-river plant in the Eastern Region, Arun III, is in the early stages of implementation. The necessary foreign funds have almost been assured by the World Bank and other donors. However, it cannot be operational until 2002 at the earliest. By that time, load growth in Nepal, supplied by ever-increasing thermal generation, is expected to absorb its entire capacity to displace fuel consumption at the thermal plants. This reasonable expectation has led the NEA to embark on another run-of-river hydro-power project, Kali Gandaki 'A'. That project would provide about 140 MW a few years after Arun III is commissioned. However, the Bank believes that essentially all the financial and managerial resources of NEA will be required to implement the Arun III project and has threatened to withdraw its support of that project if NEA raises any money for Kali Gandaki 'A'. Hence the desire for the participation of the private sector.

To provide the generation that is immediately needed, the NEA has recently decided to add about 40 MW of thermal capacity at or near the existing Hetauda diesel station, and the government has published requests for indications of interest in the private sector. To this end an 'Investment Forum' was held recently in Kathmandu which attracted the interest of private entrepreneurs in a 10 to 15 MW hydro plant on the Modi Khola in the Mid-West Region.

6.2.4 Conclusion as to the Availability of Supply

It appears evident that the rotating power cuts to which the people of Nepal have become accustomed during the last two years will continue for several more years and at greater severity. Power cuts have to be planned and kept reasonably short, three hours at most to avoid spoilage of refrigerated products. Since the objective is to reduce energy production while minimising the duration of the cuts, they will be carried out around the periods of peak consumption, that is starting shortly after dark. If they are to become a regular feature a schedule of cuts will have to be publicly announced. Circuit breakers will be operated to drop the load, and it is desirable that a significant amount of load be shed for each operation. The circuits in the Bagmati area, where 60% of the electricity is consumed, are the most heavily loaded so there will be a tendency to subject them to somewhat longer cuts than in the lightly loaded rural areas. However the NEA will have to be seen to treat all consumers alike so, even though they don't shed much load, circuit-breakers in rural areas will have to take their turn, and there might be a temptation to over deprive the rural areas in favour of the urban demand. Planned cuts may only have little effect on tubewell operations as even in the driest periods they seldom need to operate around the clock. However, cuts would complicate the scheduling of water deliveries by pump operators, and it remains to be seen how much cuts are perceived as inconveniences rather than as a threat to farm production.

It is important to recognise that the current shortages as well as the uncertainty in the plans for the future need not seriously inhibit plans for the development of groundwater resources using electric drives. Electricity consumption for irrigation is now less than 3% of the total energy sales of the NEA, and no practical expansion in groundwater development is going to increase that percentage significantly. The NEA could be expected to accommodate the requirements of so small a sector if the economic benefits justify the diversion of resources from less productive activities. In view of the analysis in Section 6.7, this may marginally be the case for large capacity wells.

6.3 Power Exchanges with India

At about a dozen points along the Nepali-Indian border, 11 kV lines cross to serve villages on both sides of the border that were once isolated from the main power systems in their respective countries. The amounts of energy involved are not significant for the purposes of this study, although it may be possible that some wells in Nepal are receiving Indian electricity.

At four border points, interconnections have been extended at 33 kV. The Katiya 33 kV substation in the Indian state of Bihar has lines to both Biratnagar and Rajbiraj, in Morang and Saptari districts, respectively, Eastern Development Region, where up to 6.8 MW has been imported. Power has been exported at 132 kV from Gandak hydro-power plant on the Narayani River, the border between the Central and Western Regions, very close to the Indian border over a line provided by India. Export is limited to about 5 MW. Power is also exported at 33 kV at Raxaul, near Birganj, Central Region.

These power exchanges are made by isolating local parts of the importing power systems and connecting them to the cross-border exporting lines since the electrical system in Nepal cannot be synchronised to either of the electric systems of the adjacent State Electricity Boards.

The Mahakali River forms the border between the Far Western Region of Nepal and the Indian State of Uttar Pradesh (UP). The UP Electricity Board is constructing the Tanakpur hydro-power plant on the Mahakali River. The reservoir will flood into Nepal. To compensate Nepal for the loss of land by flooding, the Indian government has agreed to export annually to Nepal 20 GWh (20 million kWh) at nearby Mahendranagar as soon as the Indian plant is commissioned. Twenty GWh represents the supply of 4.5 MW at the NEA system load factor, not very significant in the overall supply picture.

A new 132 kV line is being considered from the Duhabi 132 kV substation to Bhantabari in the Eastern Region with a view to contracting for the purchase of about 50 MW from the Katiya thermal generating station of the Bihar State Electricity Board.

6.4 Transmission and Sub-transmission

6.4.1 Existing and Planned Transmission

All the major generating stations are interconnected by the INPS, which consists of 1 191 km of lines operating at 132 kV and 222 km of 66 kV construction. The INPS extends from Anarmani, Jhapa District, in the Eastern Region to Mahendranagar, in the Far Western Region. In the Bagmati area surrounding Kathmandu, 66 kV lines, originally constructed to bring hydro-power from Trisuli hydro station to the city, connect to substations that step the voltage down to 11 kV for distribution in the towns and villages. Further south, in the Birganj area, the same system delivers power to that part of the Terai.

Starting with the NEA's Sixth Power Project sponsored by the Asian Development Bank (ADB), 33 kV lines supplied by substations tapped into the 132 kV lines have been constructed in parts of the Terai as well as the hill country to the north of the 132 kV lines. These 33 kV lines in turn supply 11 kV distribution lines that carry the electricity to the towns and villages within about 15 km of the 33 kV circuits. By 1995, on completion of the Seventh Power Project, most of the Terai in the Eastern, Central, and Western Regions will be within the 15 km reach of an 11 kV extension fed from a 33 kV line.

Figure 6.1 also shows the locations of the main generating and transmission system that constitute the INPS, as well as highlighting the 1 386 km of existing 33 kV lines and those included in the Seventh Power Project, so that the geographical availability of electricity for pumping in the Terai is emphasised.

6.4.2 Existing and Planned Distribution Systems

Rural electrification lines operating at 11 kV extend from substations fed by the 33 kV lines shown in Figure 6.1.

The recently completed Sixth Power Project provided rural electrification to 26 villages in Morang and Sunsari Districts, Eastern Region; 11 villages in Parsa and Kalaiya Districts, Central Region; and 42 villages in Nawalparasi District, Western Region. Under the Seventh Power Project service will be extended to eight districts in the Terai: 49 villages in Jhapa and 111 villages in Siraha, Eastern Region; 38 villages in Chitwan and 101 villages in Rautahat, both in the Central Region; and 77 villages in Nawalparasi, Western Region. The area to be covered by the end of Seventh Power Project is also sketched on Figure 6.1.

Although the needs of groundwater development are mentioned in both power projects, all the 11 kV rural lines follow existing roads and tracks as far as possible. This not only facilitates their construction but also brings them close to as many villages and dwellings as possible, thus maximising the availability of electricity to people, as opposed to farms. However this means that there are extensive areas of open farmland in the Terai where pumped irrigation is already or could be implemented that are not sufficiently close to the existing distribution lines to make affordable the necessary connections.

No discussion of the distribution system would be complete without some reference to the reliability of the long rural supply lines. The Terai is an area of intense electrical storms and the distribution lines are often the highest objects in the landscape. Protection of the lines themselves is impossible but often the fault induced by the lightning takes the form of a breakdown of the air around an insulator which if the power-voltage is removed rapidly suffers no damage and the line can be re-energised immediately and the supply suffers only a flicker. Distribution 'reclosers', using both oil and vacuum as the interrupting medium, have had a long record of success in this special operation. The oil type is cheaper but requires more maintenance, so only vacuum reclosers should be used in Nepal.

The transformers connected to the distribution lines are everywhere protected against lightning by surge diverters connected to the lines in front of the fuses that protect the transformer from faults on the 400 V lines they feed.

In view of the high incidence of electrical storms in Nepal, an adequate supply of spare surge diverters is essential as they protect the transformer insulation essentially by being the weakest part of the system insulation. They contain elements that allow them to absorb the energy in most lightning strikes, but there is a limit to their ability to do so without being destroyed in the process, hence the need for a good stock of replacements. On a recent visit to DTWs in the Terai, having located no STWs with electric drives, not a single pump site visited had a complete set of three surge diverters connected as required. At some sites, at least one was missing altogether. In many, apparently defective units had simply been disconnected (an example of destructive maintenance), in spite of which, irrigation requirements somehow continue to be met. In such an environment it is difficult to discuss the reliability of the supply. One thing is certain, Nepal needs to establish schools for training in the electrical trades if full advantage is to be taken of its hydro-electric potential.

6.5 The Cost of Electricity for Groundwater Irrigation

6.5.1 NEA Tariffs

In spite of an increase in NEA tariffs during the year 1991/1992, the unaudited annual statement shows revenues of Rs 2.01/kWh against costs of Rs 2.36/kWh. In a press release on 18 January 1993, another increase in tariffs was announced. The tariffs for irrigation supply are:

400 V:	up to 10 kVA,	Rs 10 per kVA per month plus Rs 1.15 per kWh
	over 10 kVA,	Rs 15 per kVA per month plus Rs 1.50 per kWh
11 kV		Rs 20 per kVA per month plus Rs 1.40 per kWh

Only pumps operating less than about 50 hours per month will pay enough through the demand charge to cover the cost of supply. While this may be applicable in some STW operations, the tariff contains a subsidy for most DTWs and some STWs.

6.5.2 Estimated Long-range Costs

No estimate of the long range marginal cost (LRMC) was obtainable from NEA. Indeed it is difficult to see how it could provide one as its expansion plans for the additional generation required before Arun III comes on-line in 2002 or 2003 are too vague to establish their likely costs.

An analysis was made in 1992 by the Electricity Sub-sector Management Assistance Programme of the World Bank (ESMAP) in which the installation of 25 MW gas turbine generators was proposed as a stop-gap measure which ESMAP preferred to diesels in view of the earlier unsatisfactory performance of such machines in the service of NEA. ESMAP figures for the LRMC of energy at the various supply voltages were US$ 70/MWh at 33 kV, US$ 87/MWh at 11 kV, and US$ 120/MWh at 400 V. The US dollar figures are calculated from the ESMAP data using an exchange rate of Rs 49. The US$ 120/MWh for 400 V supply includes a substantial allowance for the so-called non-technical losses, a euphemism for theft, and should be substantially reduced as it is not the fault of the paying customers that the NEA is unable to collect the revenue due on all the electricity delivered. Theft should not be sloughed off as "part of the business".

For economic analysis, the figure of US$ 87/MWh, Rs 4.263/kWh, is recommended as all DTWs will be connected directly to a transformer for the exclusive use of the well operator. In the economic analysis of supply to STWs, allowance should be made for some capital outlay, perhaps in the form of a contribution in aid to the supplier, to reinforce the 400 V lines and, possibly, to replace the transformer with a larger one. Cost at the 11 kV level should therefore be used to evaluate the energy consumption.

As explained in Section 6.1.2, above, energy costs are suitable for analysis as the electricity supply will be limited by the ability of the system to produce energy rather than to deliver capacity.

6.6 Technical Requirements for Electrical Supply

6.6.1 Deep Tubewells

(a) Electrical Drives

Probably the most fundamental decision is the choice of pump-set, submersible pump-motor, or a surface-mounted motor with a drive shaft to the submerged pump. The groundwater project staff at Birganj were very positive in their preference for submersible units they said had given trouble-free service for 20 years. Judging by the condition of the electrical switchgear at the wells visited, which was very poor, these must have been 20 years of neglect, or, worse still, of ‘adverse’ maintenance. The head of the Birganj unit spent 10 years in the Bhairahwa unit where surface-mounted motors had been used.

The staff at Bhairahwa did not comment on the choice of motors but all the motors there are grossly oversized for the job, which was said to have been a deliberate choice in order to minimize stress. Facilities existed at one Bhairahwa site to permit measurement of the actual power being drawn from the supply. A 75 kW rated motor was taking 12.5 kW from the mains. This oversizing has been accepted by the NEA’s commercial staff, who bill for a demand of 40 kW for 75 kW motors, and 34 kW for the smaller standard 55 kW unit at this project. In the case of the submersible pumps, oversizing could not be checked; it is safe to assume that it is practised with these pumps too, though there may be less opportunity owing to the restrictions on the outside diameter of the machine which must fit within the well casing. The pump performance characteristics as offered by Worthington for the surface motor, KSB Pumps for the submersibles, indicate that submersibles provide for a much wider range of operating head. In spite of this, surface mounted hollow shaft electric motors are preferred on the grounds of easier and less risky maintenance.

It is expected that the power required for pumping from a DTW will exceed 10 kW and could well reach 50 kW. When a motor is energised, there is a very large inrush of current, almost six times that required for rated full load once operating speed has been reached. This inrush causes a severe voltage drop in the 400 V supply line and may well cause other motors on the same line to disconnect. It is normal practice to reduce the inrush to a little more than three times full load current by using a star/delta starter that reduces the voltage initially applied to the motor windings to 57% of normal. Since pumping load only builds up slowly as the motor speeds up, this is an ideal application for the reduced-voltage starter since the reduced torque delivered by the motor, only one-third of that at full voltage, still suffices for rapid acceleration during the early part of the run-up.

In rural areas the 400 V supply conductors are light, and even for as little as 10 kW, it is preferable to install an 11 kV transformer near the pump house to provide exclusively for the well. The transformer is mounted on a double pole structure to keep the 11 kV live parts well out of reach. Lightning arresters and fuse cut-outs are provided in the incoming 11 kV line to protect the transformer. The 400 V cables are taken from the transformer directly into the pump house where they enter a fused isolator to protect the utility's system from errors or accidents on the customer's premises.

To minimise stress on the motor it is current practice in Nepal to install a pump oversized by about 50% for the expected maximum load. While this practice minimises motor failures, it presents the system with a power factor well below optimum so in all cases a capacitor of the maximum size permitted by the pump manufacturer should be connected on the motor side of the pump starter to ensure that it is in service when the pump is on and out when the pump is off. It is understood that this 'power-factor correction' will be applied in the next major irrigation project in the Birganj area.

The switchgear for protection and control of the motor as well as metering the load is contained in a dust-proof steel cabinet, normally wall-mounted. It contains an isolator interlocked with the door access to ensure that the apparatus is isolated from the supply before the door is opened; this is in the obvious interest of safety. In addition to the star/delta starter, the panel must contain a circuit-breaker with thermal and instantaneous overload protections, the former for the motor, the latter for the cable. Since prolonged interruption of one of the three phases can cause motor failure, 'single-phasing' protection is also normally included in the starter circuit.

A voltmeter, an ammeter, and start and stop buttons are also required. If the pump supplies water to an elevated tank for distribution through buried plastic piping, the pump may be controlled automatically by water level detectors in the tank. In that case the switchgear panel should contain a front-mounted switch to select auto or manual control. An overflow detector should also be fitted to shut down the pump should the upper water-level detector fail to stop the pump. The Worthington surface-mounted motor was provided with a mechanical ratchet to prevent rotation in the wrong direction should the phases be accidentally reversed, as can easily happen during repairs to the 11 kV and 400 V lines. No such provision was offered for the submersible units so an electrical device should be included in the control panel in spite of the fact that the operator should notice that when restarting the pump after a power failure, no water was delivered.

(b) Diesel Drives

Diesel engines for tubewell service are water-cooled with an air-cooled radiator. They are equipped with a power take-off clutch and a right-angle gear drive which can provide any change of speed required to drive the pump.

Starting is electric for all engines with three or more cylinders. The engine should be protected by a shut-down system in the event of low lubricating oil pressure or high cooling-water temperature. A tachometer is required so that the governor is correctly adjusted to provide the required speed. An hours-run counter must be provided to show when routine maintenance should be carried out and to provide a check on annual pump operation.

6.6.2 Shallow Tubewells

(a) Electric Drives

The standard pump for STWs delivers 13 to 15 l/s against a head of seven to 12 m. Currently farmers can borrow from the Agricultural Development Bank of Nepal (ADBN) to purchase a complete standard 6kw/8hp diesel-driven unit for Rs 24 000 (Rs 20 000 for a 4kw/5.5 hp unit).

These pumps are favoured by the ADBN because spare parts and the mechanics to use them properly are readily available in most small towns. It appears to be the opinion of the ADBN that skilled electricians are very difficult to find, and the condition of the switchgear at Birganj, commented on in the preceding sub-section, bears this out.

Some doubt as to the quality of diesel driven pumps appeared during a visit to an STW development 70 km west of Butwal. A member of the project management team insisted that the use of electric drives was made hopelessly uneconomical by the high initial cost of the electrical connection for an application that was only required to operate for about 200 hours/year. Confidence in the ability to maintain the diesel-driven pumps was shaken when three pump-sites had to be visited before finding a pump that would work.

If the policy of oversizing the electric motors is accepted, the electric motor required for the standard STW duty should be 3.5 to 5 kW. The installation would require a fused isolator on the incoming to 400 V, three wire supply from the supply authority. If this unit is sealed by the utility as it precedes the meter in the supply connection, another isolator should be provided under the control of the well owner so that access to the motor controls can safely be provided.

The only other switchgear needed is a combination star/delta starter with thermal overload and single-phasing protection.

(b) Diesel Drives

The standard diesel-driven pumpset for STWs is a compact portable device that can be started by hand and moved as required with a minimum of labour. It is a comparatively slow-speed engine with a built-in speed increaser for the pump. The engine is cooled by water taken from the pump outlet and discharged to waste.

6.7 Cost Estimates and Economic Analysis

6.7.1 Deep Tubewell Pumps

The prices of DTW equipment used for the economic and financial comparisons in Section 6.7.4 are based on quotations from reputable manufacturers. For the various size ranges the prices for motor/engine sets with shaft drive vertical turbine pumps are shown as follow:

kW	Electric (US$)			Diesel
	Pump	Control	Total	(US$)
3.7	1 400	200	1 600	1 800
4.5	1 500	300	1 800	2 000
11	2 300	500	2 800	3 200
30	3 800	1 200	5 000	6 000
40	4 500	1 600	6 100	7 300
50	5 000	2 000	7 000	8 500

Installation cost (pump house and fittings) is estimated to be 50% of the capital cost.

For the electrical installation the annual operating and maintenance cost is assumed to be about 1% of the installed cost.

For the diesel installation, the annual operation and maintenance costs are estimated to be Rs 1 500 (US$ 30) per kW per year plus the Rs 450 (US$ 9) for the energy output equivalent to 1 MWh.

6.7.2 Shallow Tubewells

The cost of a standard electrically driven 5 hp/3.7 kW STW centrifugal pump manufactured in India is estimated to be Rs 23 200 (US$ 470) for the pumpset plus some Rs 4 000 (US$ 80) for the isolator and starter. Installation is again estimated at 50% of the capital. Chinese manufactured 3.7 kW electric pump sets are quoted in Kathmandu at about Rs 12 000 ($240) per set.

Operation and maintenance are estimated as for the DTWs.

6.7.3 Electrical Supply

The current NEA practice is that the cost of providing electrical distribution lines and connection to the 11 kV system for both STWs and DTWs should be borne by the consumer (or project authority where this exists).

It is assumed that all 11 kV lines will be three phase circuits; the SWER system has not been considered appropriate. A 100 mm^2 aluminium core, steel reinforced (ACSR) conductor is assumed in the belief that this is a standard used by the NEA who would ultimately take over operation and maintenance of all the 11 kV equipment. In the case of dedicated 11 kV lines for DTWs it can be argued that the restriction to 100 m^2 ACSR is unnecessarily costly for lower power MTWs and that smaller section, lightweight conductor could be used. This needs further study.

Reclosers are provided as considered appropriate in the interest of service continuity.

For the STW 400 V lines, 100, 50 and 30 mm^2 are used; two conductors should a pump below 1 kW be considered, otherwise four conductors; three phases and a neutral. The STW connection costs discussed in Section 6.7.5 are based on 30 mm^2 ACSR conductor strung on wooden poles. This is common practice in the Terai and is considerably cheaper than the 100 mm^2 variant strung on tubular or concrete poles.

6.7.4 Economic Analysis

In order to compare the relative economics of electrical and diesel drives for DTWs a generalised and simplified approach to the electrical supply was developed. This was based on the investment required to supply electricity to a 10 km^2 area. Obviously this depends on the arrangement of the wells so a square network was assumed with a set spacing between the pumps. A spreadsheet was used so that the size of the square could be varied as well as the spacing between the wells. The length of 11 kV lines to supply all the wells was determined. A pump discharge was then selected which would irrigate an area around the well calculated on a broad basis of 1.0 l/s per hectare (estimated in Chapter 3 to be adequate for buried pipe distribution systems). For DTWs this pump discharge was varied and the area irrigated by the well varied accordingly. As the area served by each well expanded, allowance was made for the difficulty anticipated in getting the required number of the neighbouring farmers to participate in the scheme and for physical construction, such as topography, which might limit the number of suitably sized land parcels for large well sizes.

Once the number of wells was calculated, the cost of both electrical and diesel drives was estimated and the total capital cost calculated.

For annual costs, it was considered that the capital will be recovered by a mortgage earning 10% amortised over 20 years for DTWs with electric drives, 10 years for the diesels since they are 1 500 rpm, and five years for STWs.

For financial analysis, the cost of electricity was estimated according to the relevant current tariff. The LRMC of US$ 87 (Rs 4 350)/MWh for electricity was used for economic analysis and the capital costs and diesel fuel costs were multiplied by a shadow pricing factor calculated as 83% and 106% respectively.

The total annual costs per well (capital plus recurrent) were then computed as the final figure of interest, for comparison between electric and diesel prime movers.

The spreadsheet operates on a range of pump discharges and well spacings. Other variables such as the average head at which the pump is to operate, the number of hours per year for which pumping will be needed for irrigation, and the size of the square are also considered.

The result for 60 l/s wells at a 1.0 km nominal grid as shown on Table 6.2.

These results indicate that, for the well density assumptions discussed in Section 6.8, electrification is generally competitive with diesel in financial terms, but generally at least 25% more expensive in economic terms. The sensitivity of the analysis to changes in pumping hours and 11 kW line costs is summarised on Table 6.3. These do little to shift the view that, economically, electrification is more costly that diesel.

Of course these calculations do not alter the view that electrification remains very attractive to the farmers at the current electrical tariffs and also has major operational attractions.

6.8 Well Density and Impact on Electrification Costs

While interpreting the results, it is important to remember that the cost of supplying new 11 kV distribution works to serve irrigation wells is very largely determined by the density of the wells to be energised; the closer the wells, the lower the cost.

If it is assumed that DTW electrification can only normally be undertaken on a project-financed basis, then it is necessary to take a view on the well density which can be realised in practice. Previous projects, such as BLGWP and the Birganj wells, have been designed on the basis of fitting wells within a prescribed boundary and assuming that the majority of the land concerned can be served: this is illustrated in Figure 6.2.

Experience at the BLGWP Stage III area has shown clearly that such a constraint - the need to fit in a prescribed number of wells within an area which is too ‘tight’ - imposes severe restrictions on those involved in siting new wells. The concept of locating wells on the basis of farmers’ demand becomes futile if the area available is too small to ensure competition among farmers for the number of wells on offer.

TABLE 6.2

Comparison of Modelled Electrified and Diesel Driven Pumpsets (60 l/s) (US$ '000 at 1993 financial and economic prices)

Exchange Rate US$ 1	= 50 NRs			
Shadow Price Multiplier =	0.83 (1 for Financial analysis)			
Area	= 10 km^2			
Maximum water requirement	= 1 l/s/ha			
Pump flow	60 l/s		60 l/s	
Maximum pumping head	21 m		21 m	
Irrigable area/well	60 ha		60 ha	
Well spacing	1 km		1 km	
Nr of pumps	82		82	
Pump oversizing Factor	1.5		1.5	
Overall pumping efficiency	65%		65%	
Average pump size	30 kW		30 kW	
	Financial prices		Economic prices	
Electric system	Electric	Diesel	Electric	Diesel
11 kV line length	115 km		115 km	
11 kV line cost	1 035 k$		859 k$	
Nr of reclosers	10		10	
substation cost	308 k$		294 k$	
Pump and control cost	615 k$	738 k$	414 k$	654 k$
Total electricity capital	2 079 k$	738 k$	1 677 k$	654 k$
Annual costs				
Capital recovery	Electric	Diesel	Electric	Diesel
Amortisation period	20 years	10 years	20 years	10 years
Interest rate	10%		10%	
Mortgage	244 k$/y	120 k$/y	212 k$/y	106 k$/y
Average pumping hours/year	1 300 h/y		1 300 h/y	
Total annual energy	2.1 GWh/y		2.1 GW/y	
NEA bills	3 378 kRs/y		3 378 kRs/y	
Cost of energy	68 k$/y	175 k$/y	185 k$/y	186 k4/y
O&M cost (1% of capital)	21 k$/y	20 k$/y	18 k$/y	20 k$/y
Total annual cost per pump	4 055 $/y	3 848 $/y	5 072 $/y	3 810 $/y
Electric/diesel	1.05		1.33	

TABLE 6.2 (cont)

Comparison of Modelled Electrified and Diesel Driven Pumpsets (60 l/s) (US$ '000 at 1993 financial and economic prices)

(a) Relative tubewell costs per well - electric/diesel: (Financial)

Pump (l/s)	Well spacing (km)						
	0.50	0.75	1.00	1.25	1.50	2.00	2.50
30	1.05	1.24	1.47	1.71	1.87	2.53	3.10
60	0.81	0.92	1.05	1.20	1.28	1.67	2.00
90	0.72	0.79	0.89	0.98	1.04	1.31	1.54
120	0.67	0.73	0.81	0.89	0.94	1.16	1.35

(b) Relative tubewell costs per well - electric/diesel: (Economic)

Pump (l/s)	Well spacing (km)						
	0.50	0.75	1.00	1.25	0.50	2.00	2.50
30	1.29	1.46	1.66	1.86	1.99	2.56	3.05
60	1.12	1.22	1.33	1.45	1.52	1.85	2.12
90	1.05	1.12	1.20	1.28	1.33	1.55	1.74
120	1.02	1.07	1.14	1.20	1.25	1.43	1.59

(c) Calculated well numbers (in 10 km x 10 km square)

Pump (l/s)	Well spacing (km)						
	0.50	0.75	1.00	1.25	1.50	2.00	2.50
30	328	145	82	52	36	20	13
60	328	145	82	52	36	20	13
90	328	145	82	52	36	20	13
120	328	145	82	52	36	20	13

TABLE 6.3

Summary of Sensitivity Tests on 60 l/s DTW Electrification Costs on Nominal 1.0 km Grid

Item	Cost of 11 kV line ($/km)	Ratio of total annualised pump costs -electric/diesel for selected annual pumping hours		
Annual pumping (hr)		800	1 300	1 800
(a) Financial	11 000	1.41	1.15	0.99
	9 000	1.29	1.05	0.91
	7 000	1.16	0.96	0.84
(b) Economic	11 000	1.58	1.41	1.31
	9 000	1.48	1.33	1.25
	7 000	1.37	1.25	1.18

Note: Ratios shown underlined denote the base case for this analysis (1 300 h/year and $9 000/km).

Source: Table 6.2 and related analyses.

For this reason, the following assumptions have been made concerning the portion of a given development area which could be expected to be taken up by active competing farmer groups in say, a 10 km x 10 km square:

Well size (l/s)	Gross area (ha)	Net area (%)	Farmer interest (%)	Overall density (%)	Overall area (ha)	Number of wells
120	10 000	75	45	34	3 400	28
90	10 000	75	55	41	4 100	46
60	10 000	75	65	49	4 900	82
45	10 000	75	70	53	5 300	118
30	10 000	75	75	56	5 600	188

These well densities have been taken as limiting in an overall planning sense. A more pessimistic view on the level of active farmer interest and response, particularly for the larger wells might reduce these well numbers by a further 25%. The impact of these limitations is summarised in Table 6.4 where 'densest' refers to the tabulated maxima and 'less dense' refers to the more pessimistic farmer interest assumptions.

Whilst readily accepting that these analyses result from an attempt to simplify an altogether complex set of conditions (way out of the scope of this assignment), the answer does enable us to take a view on adopting electrification costs for planning purposes. To put it into local context, BLGWP (1993) reports an actual tubewell cost of US$ 295 920 for 27.2 km of 11 kV line (US$ 10 880/km) to energise 22 wells in the Stage II/Phase 2 areas: equivalent to 1.24 km/well and US$ 13 450 (Rs 673 000) per 83 l/s wells. Targets for the Stage III area allow for 108 km of 11 kV line for 79 wells, or 1.37 km per well. The cost of 33 kV/11 kV sub-stations (one of which is to be built for the Stage II/Phase 2 area) has not been included in our analysis on the assumption that this would normally have been provided through NEA's routine power infrastructure.

TABLE 6.4

Comparison of DTW/MTW Electrical Supply Installation Cost Estimates (US$ '000 @ 1993 financial prices)

Well size (l/s)	Grid spacing (km)	Number of wells	Length (km)	Cost* ($ '000)	Cost ($ '000)		Length/ well (km)
					/km*	/well	
(a) densest ***							
30	1.0	188	115	1 599	13.9 (659)**	8.5 (425)*	0.61
60	1.0	82	115	1 343	11.7 (584)	16.4 (818)	1.40
90	1.0	46	115	1 257	10.9 (544)	27.2 (1 360)	2.50
120	1.0	28	115	1 063	9.2	38.0 (1 898)	4.10
(b) less dense***							
30	1.0	140	115	1 455	12.7 (632)	10.4 (520)	0.80
60	1.0	60	115	1 260	11.0 (550)	21.0 (1 050)	1.90
90	1.0	35	115	1 200	10.4 (522)	34.3 (1 714)	3.30
120	1.0	20	115	1 129	9.8 (490)	56.4 (2 823)	5.80

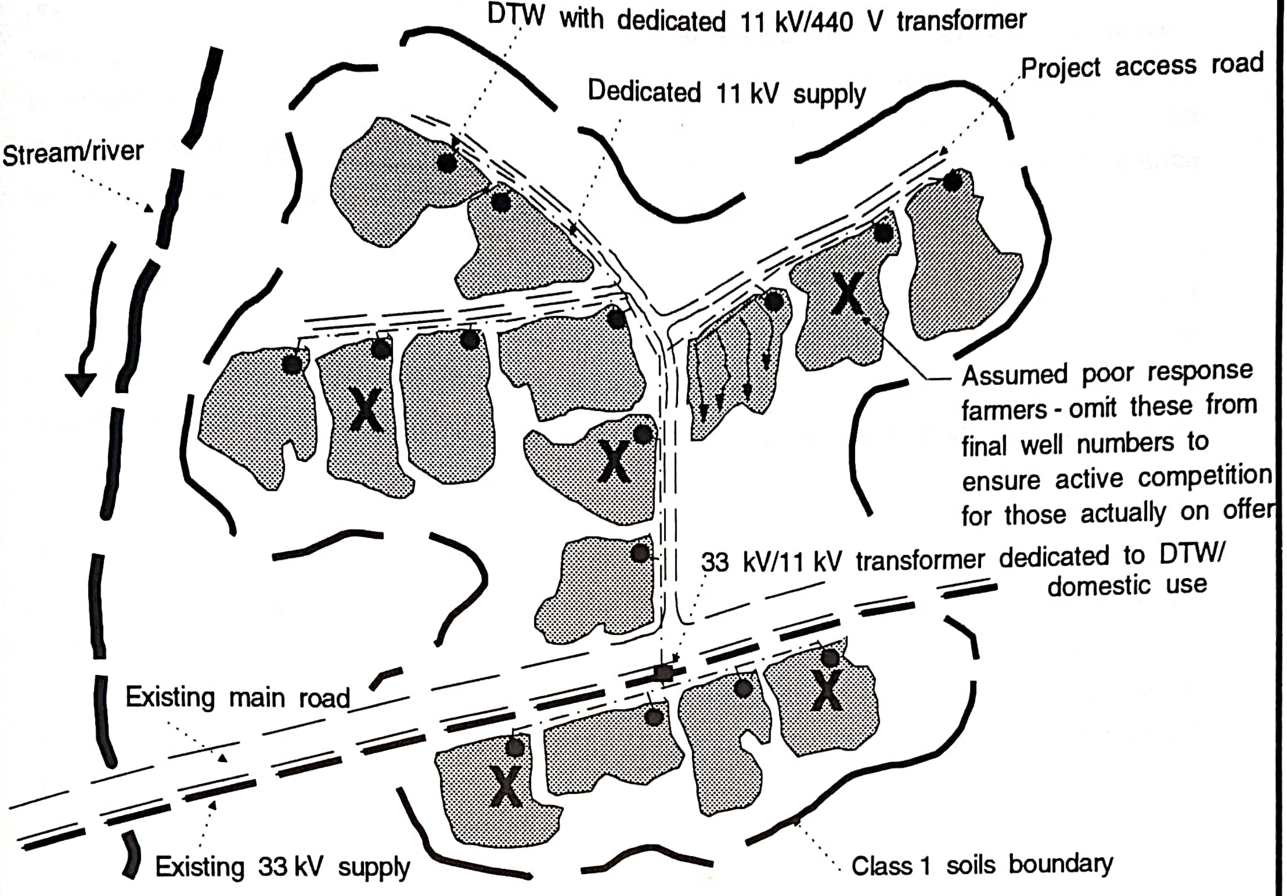
Notes:· * 11 kV line plus substations, assuming 100 mm^2 conductor for all pump sizes.
** numbers in brackets denotes equivalent in Rs '000.
*** See text.

Source: Table 6.2 (for 60 l/s well) and related analyses.

Figure 6.2

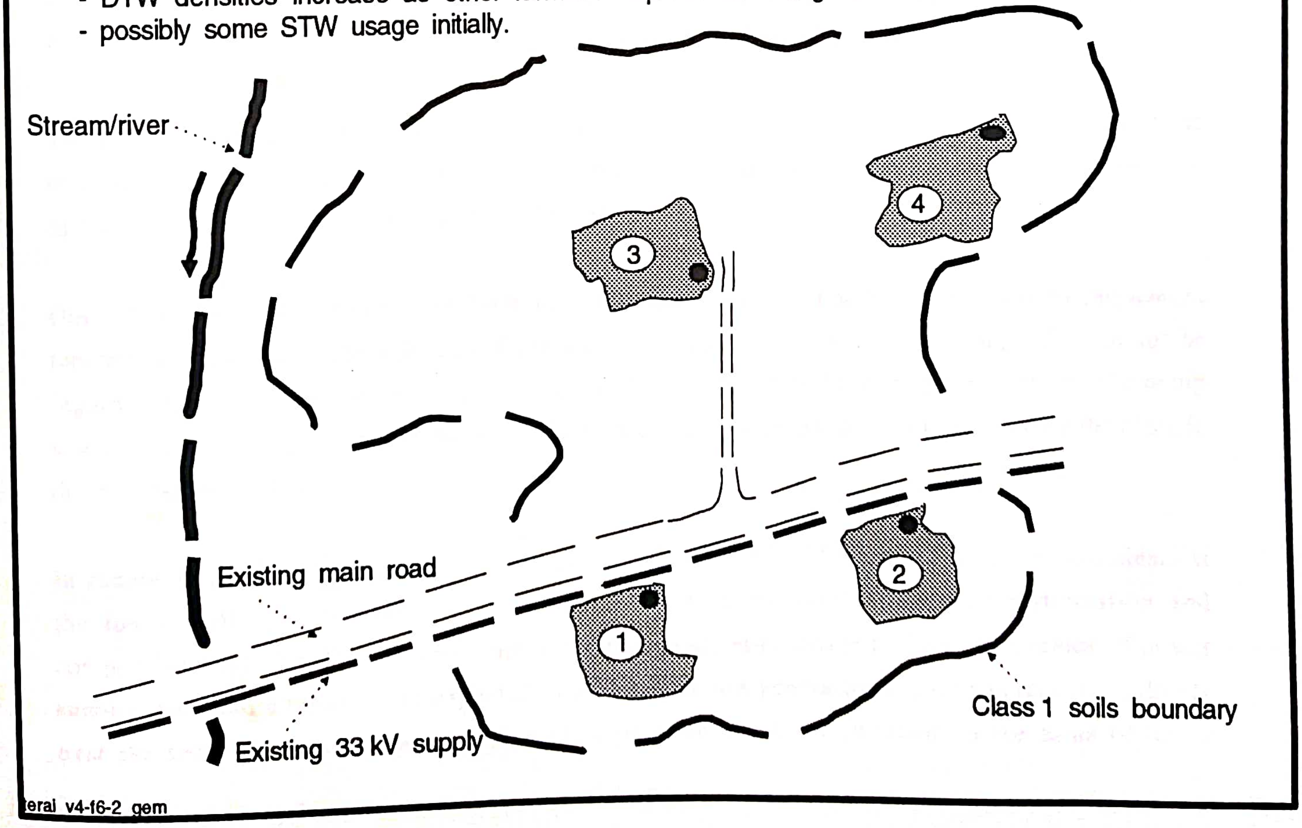
Deep Tubewell Siting Strategies

(a) Project Orientated Approach



(b) Farmer Request Approach

- initial wells close to existing access;
- commissioned with diesel engine drive and converted to electric motors when DTW density large enough or routine electrification programme close enough to individual wells;
- DTW densities increase as other farmers respond and village road networks increase;
- possibly some STW usage initially.



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Taking the US$ 13 450 per well and doubling it to allow for increasing the well spacing to accommodate real farmer competition for wells would result in a unit cost of say US$ 27 000 (Rs 1.3 million) per well. This compares with Rs 1.36 million for 90 l/s wells in the 'densest' category in Table 6.4 and Rs 1.7 million for the 'less dense' case (both inclusive of the cost of the 11 kV/400 V step down transformer at the well, costed as Rs 0.1 million). The only other comparison available to us is Nippon Koei's 1993 draft electrification at Birganj which amount to Rs 69 million for 231 km of 11 kV line to energise 70 DTWs of 80 l/s capacity.

This amounts to Rs 1.0 million (US$ 19 700) per well or Rs 299 000 (US$ 5 980) per kilometre and 3.3 km of 11 kV line per well. The two sources are not very compatible, the Nippon Koei estimates being based on extensive use (82%) of 70 mm^2 ACSR lightweight conductor as opposed to the standard 100 mm^2 generally adopted in the Terai. The overall costs per well are comparable if the concept of spreading wells out is accepted.

As a result, we have adopted a planning price of Rs 1.3 million to energise one 90 l/s DTW based on a value between the two density conditions in Table 6.4 having deducted Rs 0.1 million for the 11 kV/400 V step down at the wells. The prices adopted for overall planning purposes (deliberately on the conservative side) are summarised in Table 6.5 which also includes the LV connections to STWs and low capacity MTWs. Clearly the cost of electrical connections, particularly for 11 kV work, needs to be studied very carefully at feasibility level.

6.9 Conclusions

Although it may be fair to describe the future prospects of the power supply situation in Nepal as confused, it is reasonable to suggest that electricity for groundwater irrigation will be made available if the social and/or economic conditions demand it. The more pertinent question to ask is how much faith will farmers have in a system liable to be plagued by load shedding?

The reliability of the electricity distribution is difficult to assess in view of the poor quality of the maintenance of the 11 kV and 400 V systems, but there is no reason to believe that the maintenance of large diesel driven DTW pumps would be any better.

Our relatively crude financial analysis indicates that it would not be economical to implement electrically supplied DTW schemes if the wells are more than 1 km apart, though this cannot be regarded as a precise determination as it is dependent on the annual pumping hours and on the pump size required to pump against higher head. Increases in either annual hours or head favour the electric drive at larger well spacing.

In economic terms it appears that electrification will always be 15% more expensive than diesel at the lower well densities believed to be necessary to encourage true farmer participation and competition for wells. This assumes that benefits are only attributable to the well operator. If power supplies were more reliable (the expected availability of new generation capacity makes this unlikely over the next 10 years at least), such a price premium might be justified on the basis of better

TABLE 6.5

Forced-Mode Tubewell Electrical Connection Costs (Rs '000 @ 1993 Financial Prices)

Item	STWs/MTWs			MTWs/DTWs				Economic Pricing			
								Labour			
	Distance (m)	3.5 kW (4.4 kVA)	6.5 kW (8.5 kVA)	Distance (km)	10 kW (13 kVA)	15 kW (20 kVA)	27 kW (34 kVA)	Unsk.	Skill.	Local	FE
Pump Capacity (l/s)		15	30		45	60	90				
(a) 11 kV 400 V transformer		25	25		25	50	50				
equipt (transformer)		35	35		35	50	50			100%	
installation											
- poles		20	20	neg	20	20	20				100%
- hardware		6	6		6	6	6				100%
- fuses,earthing		11	11		11	11	11				100%
- labour		13	13		13	13	13	50%	50%		
Sub-total (Rs '000)		85	85		85	100	100				
(b) 11 kV line to well **		0	0	1-3	600	800	1 300	3%	3%	29%	65%
(c) 400 V connection to well *											
- poles & conductor	500	31	31	0	0	0	0			50%	50%
- cable & cable head	25	3	3	25	5	7	7			50%	50%
- pole mounted MCB		5	5		5	6	6				100%
- labour		7	7		2	2	2	50%	50%		
Sub-total (Rs '000)		45	45		12	15	15				
(d) connection at well (25 m)											
- control equipt		10	15		32	42	42				100%
- starter panel											
- meter		3	3		3	3	3				100%
- labour		2	2		5	5	5	40%	60%		
Sub-total (Rs '000)		15	20		40	50	50				
Total Connection Cost ((a)+(b)+(c)+(d))		145	150		737	965	1 465	48.5	49.5	430.5	936.5
Total less 11 kV/400V transformer		60	65			not applicable		3%	3%	30%	64%
Total plus 25% share of 11 kV/400V transformer		81	86								

Note: (1) * 500 m with 300mm2 conductor strung on wooden poles

(2) ** 1 to 3 km priced at US$ 9000 (Rs 450 000) per kilometre

Source: GDC estimates

management and operation and maintenance performance (clearly perceived as an advantage of electric power) and implied financial support to the farmers. For the time being, our conclusion has to be that new projects should be planned on the basis of diesel wells with a view to conversion to electricity when the power generation and distribution position becomes more settled. In the meantime it is likely that several of the wells sited close to the existing distribution infrastructure will be energised.

It may also be worth examining the point of view that the provision of electricity, like the construction of roads, is a social service only the running cost of which should be charged to the immediate users. If the capital recovery of the 11 kV system is omitted, or at least partially offset against other consumers, the electric drive is to be preferred for all likely DTW pumping once the power availability position settles down.