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 3
Groundwater

April 1994

Groundwater Development Consultants Ltd
Cambridge, United Kingdom

in association with

Hunting Technical Services Ltd
Hemel Hempstead, United Kingdom
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The Report

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CHAPTER 1

TERAI GROUNDWATER RESOURCES AND DEVELOPMENT

1.1 Introduction (and objectives of the studies)

The present groundwater studies are part of a reappraisal of groundwater development for irrigation in the Terai. They include a review of the aquifer systems, aquifer development potential, the methods currently being used to exploit these aquifers by tubewell irrigation, and the possibility that existing tubewells may be better designed and constructed at sizes and costs appropriate to the Terai irrigator.

The area considered, shown by Figure 1.1, includes the main Terai together with the inner Terai valleys of Chitwan, Dang/Deukhuri and Surkhet.

1.2 The Aquifer System

Main Terai

The main Terai is underlain by detrital, alluvial and eluvial sediments which wedge out northwards upon the consolidated folded rocks of the Siwaliks and thicken southwards towards the Indo-Gangetic plain. Fold and thrust faulting within the Siwaliks and rocks of the Himalayan foothills have produced structurally controlled valleys of the interior Terai: Chitwan, Dang, Deukhuri and Surkhet.

The main Terai comprises the following hydrogeologically significant lithological-depositional units: the Bhabar zone, the inner Terai valleys, and the Indo-Gangetic plains.

The **Bhabar zone** consists of coarse eluvial and alluvial sediments deposited as outwash fans at the mountain front where the rivers enter the Terai plain. The width and geometry of the Bhabar zone sediments seem to have been controlled by the flow regime, energy and catchment size of the rivers entering the Terai plain; the zone is not everywhere present in Nepal, in particular where Siwalik sediments occur close to the Indian border.

The distribution of the Bhabar zone fan deposits (coarse sand, gravel and sometimes cobble deposits) and the deposition of the parent river exert a strong control on occurrence and lithology of the Terai aquifers. The best aquifer conditions can be related directly to major river systems which have historically deposited coarse materials in which is developed a very permeable, unconfined aquifer.

The Bhabar zone is the major intake area to the aquifers of the main Terai. It is recharged direct from rainfall and from infiltration from the river beds, particularly those debouching from the neighbouring hills.

The **interior Terai valleys** are structural basins filled with coarse eluvial and alluvial sediments. In Dang, at least, the valley fill is highly variable and contains several terrace surfaces developed in older, part cemented alluvium; below these terraces are alluvial tracts of the present river systems.

Locally, at least, these valley sediments are moderately permeable and have some considerable aquifer potential. In Surkhet, the valley fill alluvium and eluvium are very thin and cementation appears to have reduced porosity.

Sediments typical of the **Indo-Gangetic** floodplain underlie the major part of the Terai and comprise alluvial clays and silts with important but subordinate sand and gravel layers. These appear to be products of historical deposition from the braided, high energy rivers which cross the Terai. These rivers contain a coarse bedload material of sands and gravels and are characterised by constant lateral channel shifts.

Northwards and at depth, the sediments of Gangetic type appear to merge with Bhabar type deposits while towards the Indian border, fine grained sediments predominate (Figure 1.2).

The total thickness of the sediment pile under the Terai is not known, but exploitable aquifer material is unlikely below 500 m. Analysis of deep exploration boreholes drilled under United States Geological Survey (USGS) technical control in Bheri, Lumbini and Mahakali Zones suggests that no significant permeable material occurs below 250 m (Table 1.1), while in the interval 0 to 200 m, between 10 to 25% of the section is described as screenable. For recent drilling in the Jhapa District, Japan International Cooperation Agency (JICA) and Groundwater Resources Development Board (GWRDB) give much higher estimates (53 to 65%) for the interval 0 to 300 m, but these are thought to reflect a different basis for field sample description rather than a major aquifer quality.

The system is regarded as leaky aquifer pile, with vertical exchange between shallow and deep confined aquifers, dependent upon thickness and lateral persistence of the low permeability beds.

Screenable aquifer material can invariably be cut throughout the profile, with a well defined shallow zone about 50 to 60 m thick (in which locally small artesian heads are developed) and a generally confined deeper zone in which large pressure heads are developed sufficient to give flowing artesian boreholes. Subdivision of the deep confined zone, on the basis of depth and head, has been attempted in the Bhairahwa zone, but regionally, such a division is most difficult to maintain.

In the shallow zone, sand and gravel layers, although they cannot be correlated over distance, are generally common enough to support productive, unconfined shallow aquifers which can be found in most areas. Typically, between 20% and 50% of screenable sand-gravel is encountered to 46 m (46 m is used as a convenient classification limit for tubewells which exploit the shallow zone) and such material may exhibit high permeabilities, with a range of 20 to 150 m/d.

Locally, this shallow aquifer is confined, allowing seasonal free flow artesian discharge from some shallow domestic tubewells.

Figure 1.1

Study Area

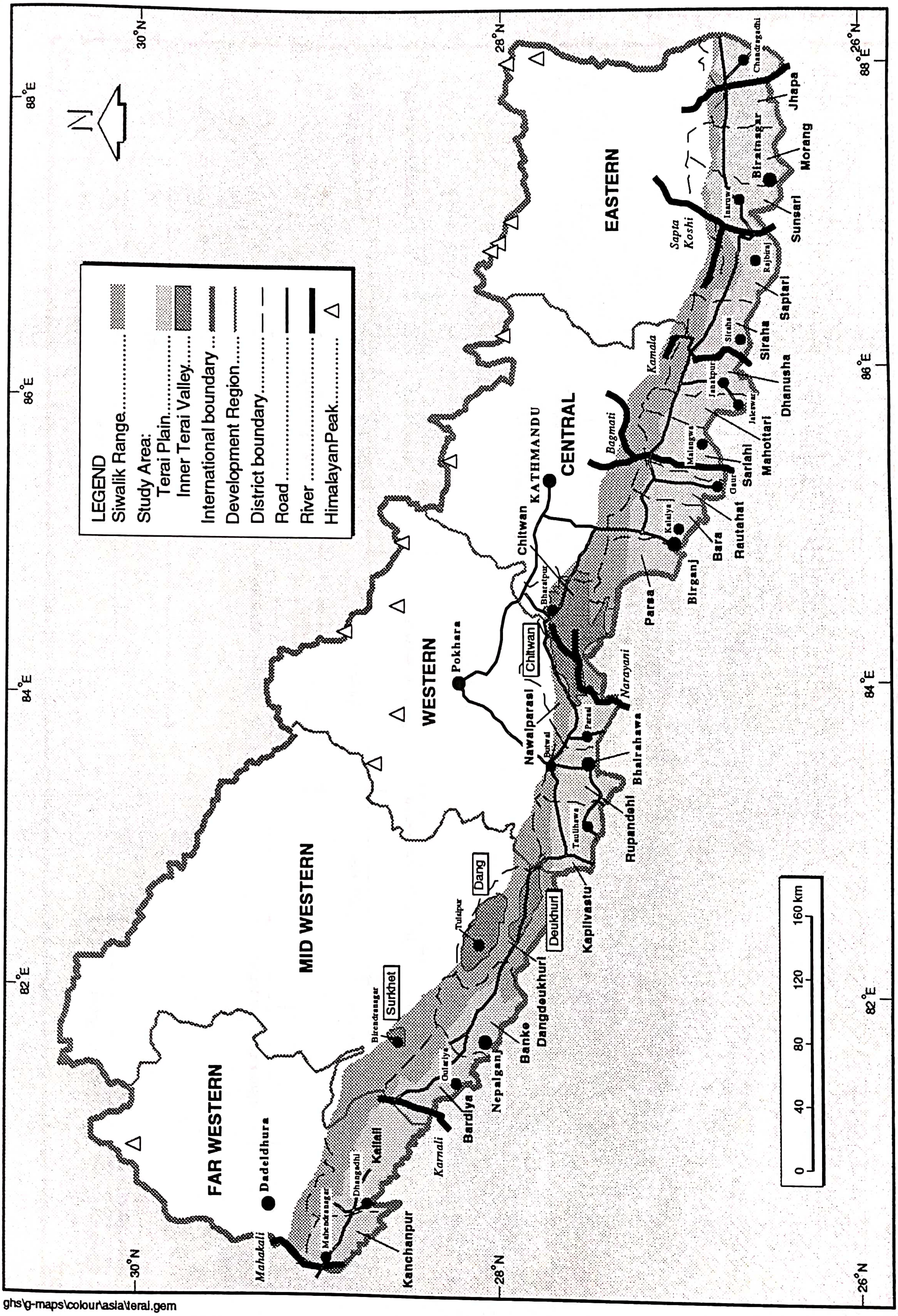

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Figure 1.2

Schematic Section Through Main Terai Aquifers

(Vertical exaggeration 20:1)

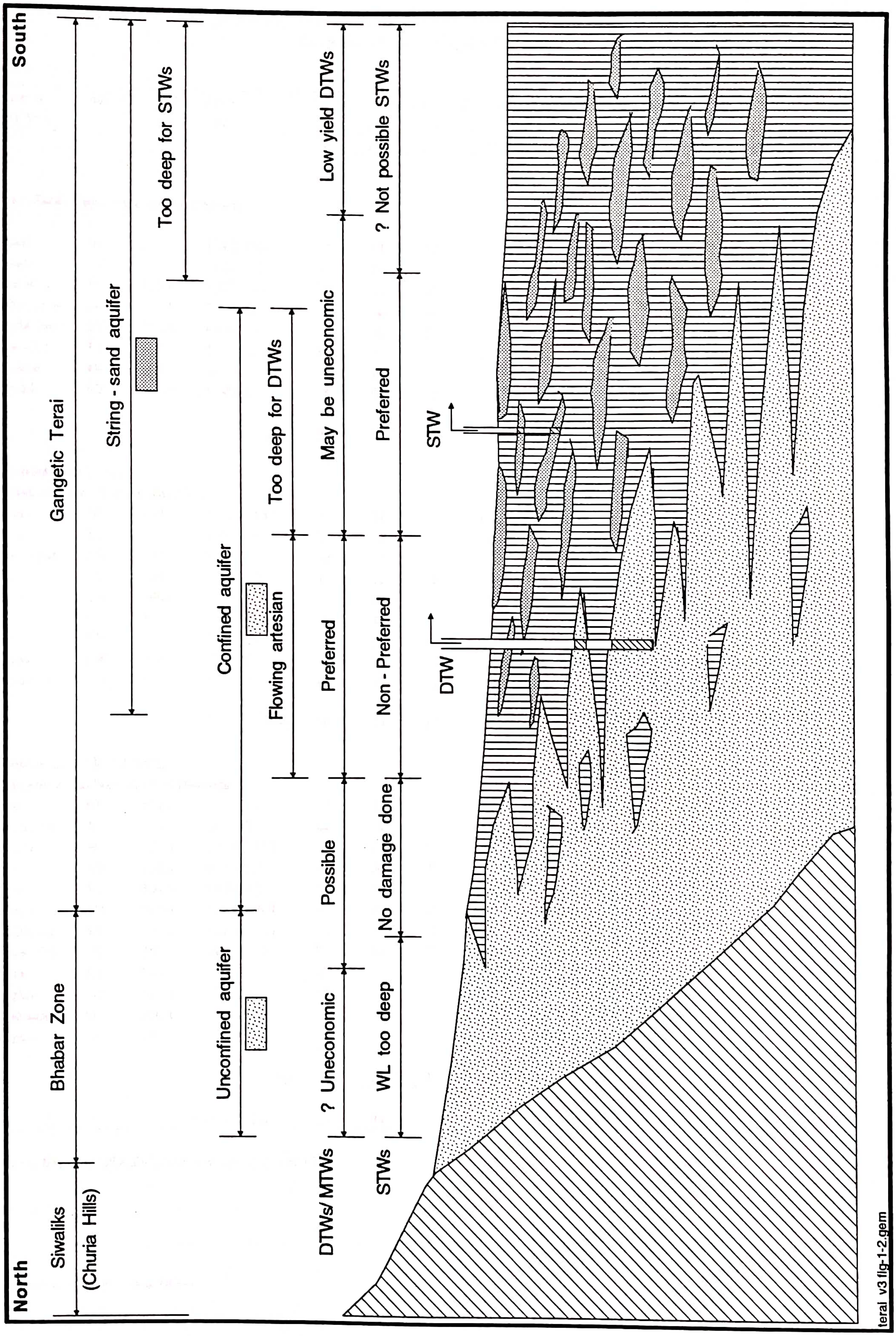


TABLE 1.1

Deep Aquifer Lithological Data

Name of Test Bore	No	TD (m)	Screen (m)	Percentage of screenable material within interval (m)								
				0-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400	400-450
Bheri Zone: Bardia and Banke Districts												
Kamdi	1/5	217.0	114.3-120	32	27	12	2					
Mauda	1/7	207.6	71.6-77.7	6.7	12	6	24					
Jamunaha	2/1	305.8	124.7-132.6	31	63	62	18	7	38			
Kohalpurwa	2/11	457.3	210-216.5	5	0	10	1	18	4	8	0	4
Sainik Gaon	3/1	304.8	43.3-52.4	15	40	54	24	9	0			
Odarapur	3/3	457.3	58.2-64.3	25	25	12	11	18	29	4	9	0
Dhakela	4/4	369.0	38.1-44.2	30	16	21	0	0	7	12		
Taratal	6/2	339.0	82-86.6	55	54	0	6	0	0			
			Average	24	30	22	11	9	13	8	4	2
Seti-Mahakali Zones: Kailali and Kanchanpur Districts												
Basanta	3/1	457.3	47.25-55.35	13	24	15	12	5	2	2	0	0
Sisaiya	3/5	353.0	175.3-181.4	15	2	4	31	6	8	0		
Ganeshpur	3/8	122.2	80.2-85.1	38	14							
Phulverria	4/1	304.8	77.7-85.3	17	21	0	0	0	0			
Dhabai	4/5	196.0	90-96	4	34	7	0					
Dangari	5/3	127.1	108.8-114.8	20	46							
Geta	5/7	304.8	85.3-88.4	14	18	42	6	1	0			
Kaspa	6/4	304.8	67.7-70.7	9	16	0	4	14	1			
Bichhuwa	7/6	304.8	87.5-93.7	47	37	1	5	1	5			
			Average	20	23	10	8	5	3	1	0	0
Lumbini Zone: Kapilvastu, Rupandehi and Nawalparasi Districts												
Semri	6/6	461.0		32	23	11	6	20	26	1	8	18
Harakpura	2/1	271.3	63.7-69	62	12	0	12	11				
Swathi	3/5	304.9	191.4-197.5	2	13	11	21	9	1			
Sunwal	3/7	152.4	42.6-45.7	41	38	31						
Sunwal	3/8	304.9	86.2-89.3	37	40	1	1	9	18			
Sitlapur	4/2	243.9	100.6-106.7	12	25	20	7					
Paklihawa	5/1	304.9	149.4-152.4	26	17	1	35	15	1			
Driver Tole	5/17	250.0	94.5-106.7	73	64	77	59	59				
Jigna	6/1	289.6		27	9	0	1	1				
Hughla	8/2	300.9	154-156.1	31	5	14	31	9	6			
Chakacouda	9/1	300.3		6	6	12	1	1	0			
Ajigara	12/1	284.5		7	0	1	3	0				
			Average	30	21	15	16	13	9	1	8	18
			Average all zones:	25	24	16	12	10	8	5	4	5

Source: Based on USAID-USGS investigations, 1969-73

The GWRDB/UNDP (United Nations Development Programme) shallow aquifer investigation, carried out in all Terai districts between 1987 and 1992, has allowed a much better definition of the shallow aquifer, in terms of thickness and permeability of screenable aquifer, and water level behaviour of the shallow zone.

The deeper profile of Terai alluvium, in the interval down to 150 m, contains an average of between 15 and 25% of screenable sand and gravel material within clay-silt layers. Locally, over 60% is screenable. These deeper sands and gravels support productive aquifers typically with 20 to 60 m/d permeabilities. Locally, in the coarser sediments, very high permeabilities exceeding 100 to 150 m/d are known. Many deep exploration bores (such as those drilled under United States Geological Survey (USGS) technical control in 1969 to 1974) and deep irrigation tubewells drilled by the Bhairahwa Lumbini Groundwater Project (BLGWP) had original artesian heads up to 20 m above ground level; despite subsequent head decline, many wells are still free flowing at ground level.

Inner Terai

The inner Terai valleys of Surkhet, Dang and Deukhuri are discrete, bounded valleys formed by fold structures and faulting within older, consolidated rocks, while Chitwan valley is an extensive alluvial tract, formed by the coalescence of the braided channels of the Rapti and Narayani Rivers as these enter the main Terai.

The Dang valley is crossed by the Babai River: this flows in a wide alluvial plain which merges northwards into a terraced surface dissected by Babai tributaries. Dang appears generally to be underlain by bouldery eluvial-alluvial sediments at least 120 m thick, in which both shallow and deep aquifers have been proved by drilling; the section contains bouldery layers which make drilling difficult, and impossible by manual methods. Locally at least, there is a clear separation of these aquifers seen in terms of hydraulic head difference; and in the southeastern part of the valley, a distinct difference can be observed between the deep aquifer watertables (over 30 m deep) and the shallow aquifer water level.

Well tests have indicated a generally high transmissivity aquifer in the shallow zone within the Babai alluvial plain and the east-centre part of the valley, in coarse sands and gravels, although locally, cementation may reduce transmissivities. In interfluve areas and towards the north valley margin, shallow zone water levels deepen to over 10 m, and it becomes impossible to construct suction mode Shallow Tubewells (STWs).

The deep zone contains very permeable sands and gravels which form a productive aquifer occurring at least down to 100 m depth. However, water levels in the aquifer are deep, often below 30 m, and show large annual fluctuations in response to recharge.

The Deukhuri valley lies about the Rapti River, and much of the area consists of flat, alluvial valley bottom lands with a shallow watertable except at the valley margins. The shallow zone generally contains a high percentage of coarse permeable material in which is developed a productive phreatic aquifer with high or very high transmissivities and test permeabilities up to 150 to 200 m/d; potentially, it can support productive STWs, except in the Lamahi district where silt, fine sand and clay reduce aquifer potential. Most of the area has water levels of less than 6 m depth, particularly in the Rapti riverline belt where water levels are shallow. Test drilling to below 100 m has indicated a substantial thickness of permeable aquifer material, particularly gravel, although this deep aquifer is untested.

The Surkhet valley is bounded by folded and faulted older rocks which partly control drainage and may focus spring discharge; a major spring (25 l/s) discharges in the valley centre and spring flows are used for irrigation. There are no irrigation STWs and no DTWs. The rock section under Surkhet valley seems to contain no substantial aquifer material, but rather a very thin alluvial-eluvial fill which mantles the older rocks. The evidence suggests three layers, below which is evidence of very low permeability Siwalik rock:

- a superficial layer (perhaps less than 10 m thick) of low permeability, recent alluvial;

- colluvial material, which is rather argillaceous; and

- below, a sequence of up to 100 m of old alluvium-colluvium, comprising gravel, sand and clay beds; the sequence is generally argillaceous, cemented, and appears also to have low permeability.

The recent and cemented alluvial-colluvial deposits seem to have insufficient permeability to support pumped wells and although they may support low discharge dug wells, they are very poor aquifers. Siwalik strata are likewise of low mass permeability; they cannot be classed as aquifer material, although fracture storage may be developed.

Aquifer occurrence in the Chitwan area has been controlled by alluvial sedimentation from the Rapti and Narayani Rivers. The shallow alluvial section commonly contains 70% of coarse sand-gravel which supports a highly transmissive aquifer (some permeabilities exceed 200 m/d) which is exploited by dug wells. However, there is widespread occurrence, at about 9 to 10 m, of a hard, cemented boulder conglomerate, while locally, fine sands occur in shallow section. Both lithologies cause drilling difficulty. The watertable in Chitwan is shallow and generally lies at less than 5 m below ground. Similar aquifer conditions are anticipated in the deep zone since a 100 m deep but untested well at Bharatpur showed over 70% of the section to be screenable material.

1.3 System Recharge

Main Terai

Recharge to the main Terai aquifer systems principally occurs direct from rainfall to the Bhabar zone and by infiltration from the beds of rivers crossing the Bhabar zone. Southward, less significant recharge occurs directly into the shallow zone sediments and through river bed infiltration. Recharge is transferred laterally into the confined deep zone aquifers, whose driving artesian head is maintained by higher level recharge to the Bhabar zone. Artesian aquifer response to annual recharge has been noticed in the BLGWP tubewells, some of which start to flow freely after June, and until November when the artesian head falls below the casing top.

Some authors (Jenkins, 1983), on the basis of some C14 isotope studies in the region between the Siwaliks, Bhutwal and the border, have suggested some boundary recharge from subsurface Siwalik sediments into the Terai alluvium. This Study considers such a recharge path most unlikely to provide a significant contribution to the flow balance. It is unsupported by any piezometric data, while typical Siwalik sandstones are argillaceous and of very low porosity.

Natural discharge from the system takes place by the following mechanisms:

- leakage to the shallow aquifer layers, across leaky aquitards of clay-silt; leakage is "driven" by the head difference between deep confined layers and the shallow zone;

- local, lateral discharge from the shallow aquifer to incised river channels;

- spring discharge at the slope break between the Bhabar zone and the Terai proper;

- subsurface outflow across the Indian border; and

- evapotranspiration and evaporation from the shallow watertable (which, in some districts with a widespread shallow watertable, maybe substantial).

Abstraction, either pumped or by artesian free flow, is now locally a major element in the discharge from the aquifer systems; consequent head reductions in the deep artesian aquifer are thought likely to reduce leakage to the shallow zone.

Some tentative quantification of recharge is useful for estimation of the possible upper limit of aquifer development. This upper limit might involve the widespread intensive development of STWs in areas of suitable land without surface water for irrigation in conjunction with significant DTW development in appropriate deep aquifer areas.

Theoretically, there exists an upper development limit where recharge availability will start to constrain STW development, through declining dry season water levels which lead to discharge-suction problems. It must be stressed however, that intensive STW development may in some areas have a function in drainage and watertable control; i.e., intensive development will reduce evaporative losses and thus make a further contribution to water availability.

Concurrently, development of the deeper aquifer zone by means of medium and deep tubewells (MTWs and DTWs) is likely to reduce piezometric heads in the system. As a consequence of this, leakance recharge from the deep to the shallow aquifer will be reduced.

Recharge estimation involves several unquantified elements, principally the definition of recharge intake areas and the value and variation of effective infiltration rates across the recharge intake areas.

Actual and potential recharge have been estimated by various studies, notably by Duba in 1982, and in the reports of the GRWDB/UNDP shallow groundwater investigations. These estimates involve both infiltration estimates and the calculation of throughflow estimates using piezometric gradient and transmissivities.

The Bhabar zone receives the highest rainfall in the Terai and has the greatest infiltration capacity. Estimates of potential recharge to this zone, generally based only on rainfall recharge (ignoring river bed infiltration and upwards leakance), vary from 465 mm (Electrowatt, 1984) to very high estimates given by Tahal who, in modelling work (BLGWP/Tahal, 1992), presents a groundwater balance for the Bhabar zone which allows that about 42% of rainfall (over 1 100 mm) reaches the aquifer; this study also considers recharge input from streams which cross the Bhabar zone, in addition to rainfall recharge.

Duba (1982) studied recharge on a zonal basis; he separately considered recharge to the Bhabar zone and to the shallow aquifer to the south of the Bhabar.

The precise distribution of the Bhabar zone is difficult to establish; in some areas it is indistinct but elsewhere, clearly coincident with coarse fan deposits. Nevertheless, the Duba estimate of 4 014 km^2 for the Bhabar area looks sound. Using this, Duba derives a mean annual recharge to Bhabar of 685 mm, an average of zonal values, with a range between 329 mm and 1 089 mm (the minimum being in the Rapti zone) equivalent to a mean recharge of 33.5% of annual rainfall.

Since well hydrographs in the Bhabar zone strongly suggest that soon after the onset of the monsoon, the aquifer becomes full and rejects recharge, potential recharge estimates cannot be verified. The rapidity of the watertable rise does however confirm the high infiltration capacity of the system.

Estimates of direct rainfall recharge to the shallow aquifers south of the Bhabar zone have been made by several authors: 124 mm (Kenting 1984) to 370 mm with an average of zonal values of between 215 and 644 mm (Duba 1982). Such variations appear inconsistent with rainfall which shows little variation from west to east across the Terai.

Further, on the basis of Groundwater Development Consultants (GDC) work in Bangladesh, where well calibrated groundwater modelling has demonstrated vertical recharge through Gangetic type soils of 420 to 500 mm, we would be sceptical about the lower recharge estimates given above. It is also pertinent that the consumptive use of the former 100% sal forest cover in the Terai is estimated as 600 mm, all of which was consumed from the shallow aquifer.

The lower recharge estimates are thought more applicable to very heavy soils or to dense vegetation cover, neither of which is widespread in the Terai.

To improve on the various estimates quoted above, some more detailed fieldwork, with appropriate field instrumentation, linked to some modelling of the groundwater/surface water system, would be required. However, recharge appears unlikely to be a resource constraint in the foreseeable future and a much more intensive degree of development may be needed before the likely limit can be deduced with any certainty.

Because of the continuing uncertainties in recharge estimation and the lack of any detailed field studies, we propose to follow the 1987 work of GDC, and adopt an overall recharge value of 600 mm which is to include 460 mm rainfall recharge and 140 mm leakance from the deep aquifer to the shallow zone. (This value is conservative since the shallow aquifer, which rejects recharge through much of the monsoon period, would actually accept more recharge where the shallow aquifer is developed and the watertable lowered). Further, a safety factor is applied to this figure to give a recoverable or developable recharge of 450 mm.

We consider this a credible but conservative value for planning purposes. It would for example allow a development level in the shallow aquifer of 16 STWs/km^2 (13 l/s discharge, 590 h/y operation). This is equivalent to one STW per 6.25 ha gross; a level quite unlikely to be practically realised. If irrigation losses are considered available for pumping, the STW density could reach saturation levels. Further points are as follows:

- intensive STW development is only likely in Class S1/S2 areas (good-average lithologies with shallow watertables); areas classified poor-marginal will inevitably be less developed, as the deep aquifers will be used in preference to the shallow zone;

- on the evidence of STW development and build up in the last 10 years, the pace of future STW development will be steady, unspectacular, and phased; this will allow observation through the GWRDB/UNDP monitoring network of the effects of progressive development; and

- local over-development of the shallow aquifer has few cost penalties; STW well life is short (five to eight years) and well capital cost is small; damaging effects could therefore be quickly reversed by allowing STWs to go out of production.

Inner Terai

In the inner Terai valleys of Chitwan, Surkhet, Dang and Deukhuri, there are considerable variations in rainfall, soil and topography, and it is anticipated that recharge conditions will differ from those in the main Terai. No specific recharge studies have been carried out, however, and only a qualitative appraisal is possible. In none of Chitwan, Dang nor Deukhuri is recharge thought to be a constraint to irrigation development; such constraints will come rather from soil permeability, deep water levels with high irrigation pumping lifts, and practical difficulties in drilling and well completion. In Surkhet, a lack of aquifer material rather than recharge will constrain any development.

The Chitwan valley is an extensive alluvial tract, formed by the coalescence of the braided channels of the Rapti and Narayani Rivers. There is active recharge through highly permeable superficial alluvium to the shallow aquifer; recharge input is direct from rainfall and from river bed infiltration.

The Dang valley consists of two morphological components:

- the alluvial plain of the Babai River, with coarse alluvial bed material overlying an alluvial shallow aquifer; and

- an elevated highly dissected terraced interfluve area, developed on bouldery alluvial and eluvial sediments and characterised by deep water levels.

Well hydrographs suggest that active river recharge to the shallow aquifer occurs along the Babai River channel; at the time of the monsoon, large and rapid rises in the watertable (up to 30 m) in wells in the interfluves indicate rapid recharge through permeable boulder deposits.

Much of the Deukhuri area consists of a flat, alluvial tract about the Rapti River and the riverine plain. Recharge is through highly permeable alluvial surface deposits to the shallow aquifer which itself then discharges to Rapti base flow, which is perennial. River gauging of the Rapti River at its entry and exit points to the valley established a credible estimate of flow accretion due to the groundwater contribution to base flow (UNDP/HMGN (His Majesty's Government of Nepal) 1989; Deukhuri Valley: Technical Report 9 (NEP/86/025): this led to an estimate of annual recharge to the groundwater system of 181 million m^3/y.

The Surkhet valley, an area of about 150 km^2, is underlain by Siwalik formation consisting of quartzitic sandstones, siltstones, shales and brecciated limestone. No major drainage lines cross the area. The valley fill consists of deposits of alluvium, fan talus, and colluvium which mantle the older Siwalik rocks, but these are very thin, of low permeability and do not support a useful shallow aquifer. While potential recharge may be high, actual recharge is extremely limited because there is little available storage in the thin alluvial-eluvial layer.

1.4 Present Development and the Hydrogeological Database

1.4.1 General

Three well designations are in current use in the Terai, defined as follows:

- deep tubewell (DTW), typically drilled to depths of 120 to 160 m by direct circulation (DC) and equipped with 20 to 45 m of screen and a gravel pack; designs are configured for production discharges up to 80 to 100 l/s, using force mode pumps (lineshaft or electric submersible turbine);

- Medium tubewell (MTW; generally the Irrigation Line of Credit (ILC) terminology), typically drilled to depths of 60 to 80 m by direct circulation (DC) and equipped with 20 m of screen and a gravel pack; designs are configured for production discharges around 25 l/s; force mode pumps are used, although in some ILC areas with shallow watertables, suction pumps are used; and

- Shallow tubewell (STW), typically drilled to depths of 20 m by manual drilling methods (*thokuwa* or *bogi*), and equipped with 3 to 5 m of screen; designs generally use 100 mm production casing to allow production discharges up to 15 l/s and are equipped with suction pumps; in some areas with watertables too marginal for suction pumps, the STW may be set in a pit.

A machine drilled STW is used by ILC of maximum depth 60 m and with 10 to 15 m of screen; suction pumps are used but in some ILC areas with deep watertables, force mode pumps are used.

These typical designs are shown in Figure 1.3.

1.4.2 The DTW Database

The DTW database consists of records for over 800 wells drilled since 1969. Initial work was concentrated on basic deep aquifer exploration and carried out by USGS/HMGN between 1969 and 1971 in the Terai portions of Bheri, Mahakali and Lumbini zones. This programme constructed numerous investigation DTWs; some exhibit free artesian flow and some have been converted for irrigation use.

Since then, exploration drilling has been carried out in many Terai districts by GWRDB. The work has involved basic resource investigations by drilling, logging and pump testing, while in some areas, the tubewells have been converted and handed over to other agencies, for example the then Farm Irrigation Water Utilisation Division (FIWUD) for irrigation use.

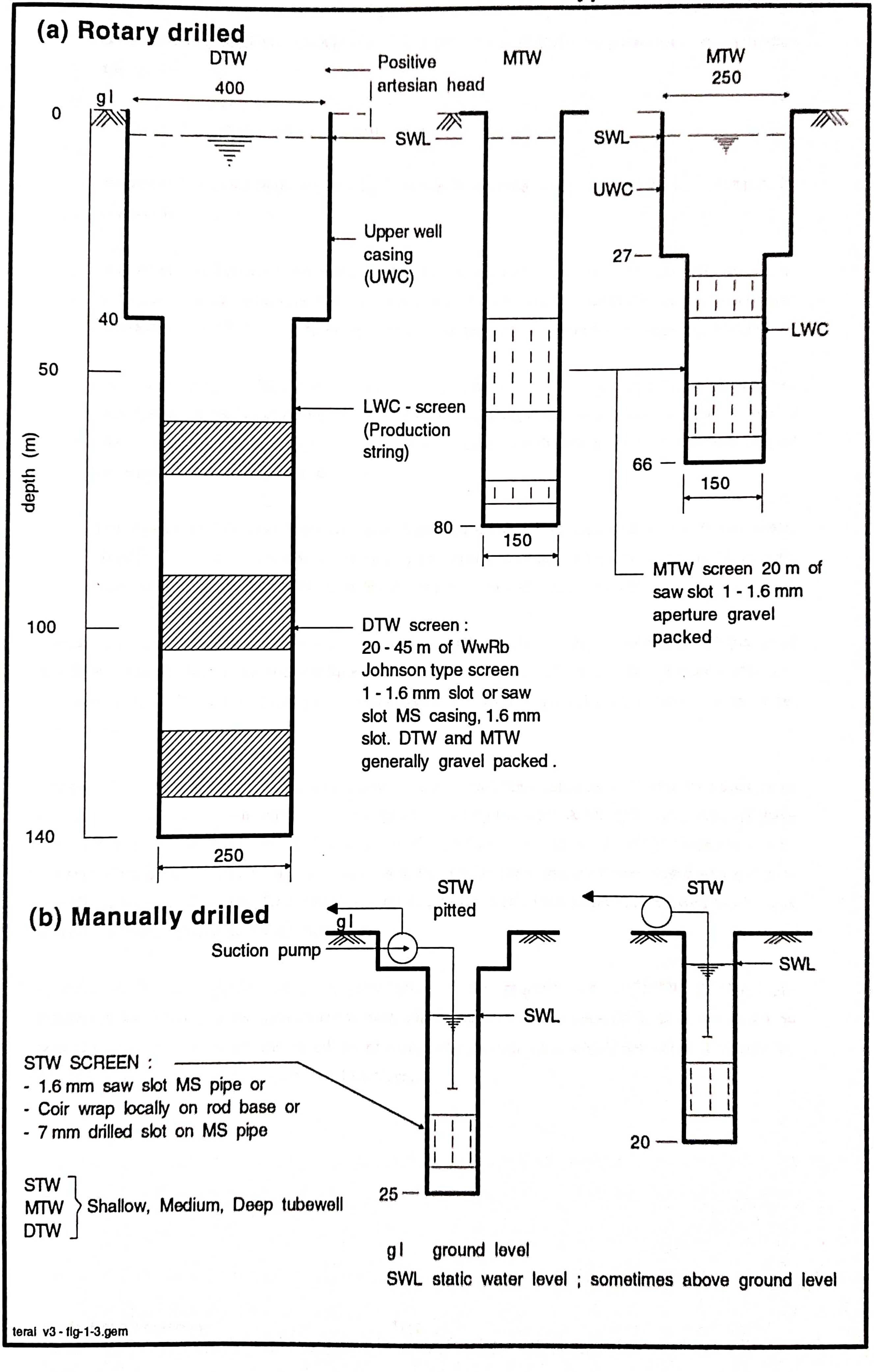
In addition, both investigation and production DTW drilling has been carried out within feasibility studies and specific projects aimed at irrigation and agricultural development and small town/urban water supplies and some factories. Particular sources of information are as follows:

- the Bhairahwa Lumbini Groundwater Project (BLGWP) in Rupandehi District, which has since 1979 has constructed over 140 irrigation DTWs by DC methods; well depths are between 150 and 300 m;

- the Narayani Zone Irrigation Development Project (NZIDP) in the Birganj area, the Janakpur Agricultural Development Programme (JADP) in the eastern Central Region, and the Kapilvastu Tubewell Project (KTIP) in the Kapilvastu/Nawalparasi area;

Figure 1.3

Typical Tubewell Designs



- GWRDB completed 91 DTWs in the period 1975/76 to 1988/89 for purposes of investigation and production;

- GWRDP has constructed investigation DTWs in Birganj;

- the irrigation component of the Sagarmatha Integrated Development Project (SIRDP) by GWRDB;

- the current well installation works under the groundwater component of the Irrigation Line of Credit (ILC) programme. ILC is constructing STWs, MTWs and DTWs in Kapilvastu and Nawalparasi with designs to meet specific farmer group demand for irrigation water;

- current work by GWRDB with Japan International Cooperation Agency (JICA) funding and assistance on the evaluation of groundwater resources and associated irrigation master planning activities for Jhapa District where exploration DTWs have recently been drilled to depths of over 300 m; and

- twenty-one DTWs have been drilled to depths of up to 200 m, on behalf of the Nepal Water Supply Corporation (NWSC), for supply to Terai towns and a further 80 wells of varying size drilled by the Department of Water Supply and Sanitation (DWSS).

Evidence is discussed elsewhere in Chapters 3 and 4 that the design, completion and development of some DTWs and MTWs, and some machine drilled STWs, may conspire to produce rather inefficient wells with partly blocked screens, particularly where the well is gravel packed or the screens set deep.

Evidence of this process is provided where well test performance (stated as well specific capacity or transmissivity) is inconsistent with the lithology screened by the well. A likely consequence of these DTW (and machine drilled STW) design and completion faults is depressed well performance; well test parameters derived from single well tests will be considerable underestimates and will not give any realistic picture of the aquifer formation screened by the well. The matter is discussed later, since it directly affects aquifer potential mapping.

The main design and performance characteristics of the majority of the DTW database are summarised by district or by development authority/programme in Appendix I. It is necessary to repeat the caution that these are based on existing completion data which are often distorted by dubious construction and/or supervision practices.

1.4.3 The Shallow Tubewells Database

Most STWs in the Terai have been drilled by private contractors, using manual drilling methods, for farmers assisted by loan or subsidy arrangements from the Agriculture Development Bank of Nepal (ADBN). These wells are not logged or tested and no well records are made; they are therefore of little use in shallow aquifer classification beyond giving a general view of current development densities and associated trends.

Between 1987 and 1991, the UNDP assisted GWRDB with carrying out a major investigation of the Terai shallow aquifers. This work included the drilling, logging and pump testing of exploratory STWs throughout the Terai, including the Dang and Chitwan valleys.

Subsequently, selected STWs have been incorporated into a Terai-wide monitoring network, to track fluctuations in the shallow watertable and to allow mapping of areas with end of dry season watertables shallow enough to allow suction mode (centrifugal) tubewell pumps.

The GWRDB/UNDP work has been presented in a series of basic data reports for each district of the Terai. Regrettably, many of these suffer from poor well completion and performance testing with the particular result that much of the data on aquifer parameters is misleading.

Summaries of some of these data are listed in Appendix II, Tables II.1 to II.5, which also include data for 63 community STWs in the Birganj area.

Other agencies who have drilled STWs, and who keep records of STW position, construction and performance include:

- the GWRDP/ILC Programme: since 1992, GWRDP has been involved in the Kapilvastu Tubewell Irrigation Project (KTIP), financed under the ILC groundwater component. The project is drilling both STWs and medium/deep tubewells in Nawalparasi, Kapilvastu and Dang districts;

- GWRDB: which has constructed STWs in several districts including Birganj and then handed them over to farmers groups;

- SIRDP and JADP;

- the Japanese Red Cross Society (JRCS) which has constructed 25 mm to 100 mm diameter wells in Rupandehi District for rural water supply; and

- other small town and rural water supply programmes, including the Finnish International Development Agency (FINNIDA), HMGN rural water supply project.

The great majority of the STWs installed in the Terai are completed by manual drilling contractors for farmers; the work is either funded privately or under the ADBN subsidy scheme. Almost no information is collected during the drilling and completion of these wells, and they cannot be regarded as making a useful contribution to the STW database. Evidently, the drillers do retain field information on drilling conditions and shallow zone productivity and watertables, but this is nowhere recorded.

1.4.4 The GWRDB/UNDP Shallow Aquifer Survey

The GWRDB/UNDP work has been a valuable aid in assessing the shallow aquifers of the main Terai and their potential for STW development. It has provided basic information in terms of transmissivity on shallow aquifer material and thickness, water levels and aquifer productivity.

The data collected from this programme are not, however, always of high reliability. The programme was ambitious and involved a large number of exploratory drillings throughout the Terai, with consequent logistical, supervisory and contractual problems. In some areas, the programme does not appear to have been adequately supervised, with adverse consequences for well construction and testing. The following problems are noted by the GWRDB personnel who did the data analysis and produced the basic data reports:

- STW construction faults: failure to reach target well depth, screen misplacement, use of incorrect screen aperture, or screen blockage through lack of any well development;

- frequent use of test pumping times of sometimes only 30 to 40 minutes, which is quite inadequate, particularly in those cases where well development was occurring during a pump test;

- the quite inappropriate use of suction pumps for pump testing; many wells could not be tested because of the rapid fall of the pumping water level below the suction limit of the pump; and

- unreliable or unavailable instruments for measurement of water levels and test discharge.

The main consequences were that many wells were not completed to specification; many were not tested while others were incorrectly tested with very dubious results. The GWRDB hydrogeologists have noted the common situation where the test results, either in terms of transmissivity or specific capacity, are quite inconsistent with the lithology of the material screened. In many cases, testing has taken place with a partially blocked and undeveloped well screen; this has resulted in high well drawdowns, caused by high head losses in the well, and consequent gross underestimation of well transmissivity. The situation was made evident where GWRDB personnel carried out a few well tests with a piezometer; the latter records formation parameters (transmissivity) more characteristic than those obtained from the blocked well.

This frequent underestimation of formation characteristics poses problems in the classification of the Terai aquifers; these are discussed in Section 1.5 which follows.

1.5 Aquifer Development Classification

1.5.1 Lithological Classification

Although there are many data from both deep and shallow tubewells, drilled both for investigation and for production purposes, there exists a constant suspicion that aquifer parameters derived from single well tests, permeability or transmissivity, may be depressed by faulty well design and completion.

In reports on the GWRDB/UNDP shallow aquifer study, GWRDB quotes numerous examples of well tests which give parameters quite inconsistent with the lithology of the screen zone. In cases where gross screen misplacement can be ruled out, this behaviour has to be a consequence of screen blockage by drilling mud or drill cuttings.

Similar evidence comes from the ILC programme where, in some MTW and DTW cluster areas, the indicated well specific capacity and transmissivity are consistently low and inconsistent with formation screened; subsequently, such wells have developed continuously during step discharge tests to give well parameters more representative of the screened zone.

In BLGWP Stage II-2, problems with gravel pack design and placement, rather than formation deterioration, clearly depressed the specific capacity and indicated transmissivity of the Stage II-2 DTWs.

These matters must be considered when applying the aquifer lithological classification discussed below.

The classification method, which generally follows that developed for the 1987 GDC Study, is based on the use of mappable indicative values for the aquifer permeability and clay percentage for the deep and shallow aquifer. The GWRDB/UNDP shallow aquifer investigations have provided data for the whole Terai, not available in 1987, on screenable aquifer percentage and aquifer transmissivity. Although the STW classification is primarily based on aquifer percentage, field transmissivity values have been used to test for consistency between reported lithological section and well performance.

The DTW data contain rather intermittent information on clay percentage (or percentage screenable material) in the deep profile; such information is complete only for the exploration DTWs built by USGS and for exploration bores recently constructed in Jhapa District.

Perhaps 70% of DTWs have been tested to give well transmissivity (but usually from single well tests, without the preferred piezometer) or at least a well specific capacity index. These well parameters have to be used with some caution since, as explained elsewhere, poor well construction and development may give a depressed and unrepresentative parameter value.

Classification limits have been set up to group shallow aquifers lithologically into three classes (good, marginal, poor); and three deep aquifer classes (good, fair, marginal) as shown in Table 1.2.

In practice, it has not proven possible to apply the threefold classification effectively because of the difficulty of applying the original class limits to STWs whose depth varied much, from 8 to 35 m by district and by drilling method. As a result, the "marginal" and "poor" classes for STWs have been lumped together for classification and subsequent mapping purposes. Where the aquifer is judged "poor" and incapable of supporting an irrigation tubewell, the area has been classified S0.

TABLE 1.2

Aquifer Lithological Classification

Shallow tubewells (0 to 46 m)		Deep tubewells (46 to 120 m)	
Classification	Percentage of aquifer	Classification	Transmissivity of 100 m section (m^2/d)
Good	> 40%	Good	> 2 000
Marginal*	20 - 40	Fair	1 000 - 2 000
Poor*	< 20	Marginal	< 1 000

Note: * For mapping purposes, "marginal" and "poor" STW areas have been lumped together as "marginal" except for areas classed as S0 for excessively deep watertable or drilling difficulty reasons.

Source: GDC

The cut-off point between a shallow aquifer and a deep aquifer is maintained at 46 m.

The classification is based upon percentage of aquifer within a section, as shown in Table 1.2, but where possible, well transmissivity data are used to confirm the classification.

For STWs, a rule of thumb was used, that an STW screened in a good aquifer would support a transmissivity value of about 600 to 800 m^2/d, sufficient to support a 15 l/s STW with a 2 m maximum drawdown; UNDP test data were evaluated against this informal criterion.

For DTWs, there is generally little reliable information on the permeable section and so the transmissivity values from well tests are used for classification as shown. In both STWs and DTWs, the use of transmissivity data is complicated by the problem of possibly depressed transmissivity values in ill-constructed tubewells.

In some cases, where there is evidence of well construction problems, the field transmissivity has been adjusted upwards to better reflect real aquifer conditions.

One of the most important products of the GWRDB/UNDP shallow aquifer study was the setting up of a Terai-wide monitoring network based on observation STWs. The network is read monthly, allowing the watertable to be monitored into the critical end of the dry season period from May to June when the watertable is at its lowest.

Most importantly, the network allows us to map the position of the 5 m depth to water level contour, which is considered the practical limit for suction pump operation and hence is crucial to planning groundwater development and pump type. The watertable mapping for May 1991 has generally been adopted in aquifer classification. It shows the deep watertable zones of the northern Terai margin; it also shows limited but significant areas, particularly in the border region, where the watertable may reach 5 to 7 m in the dry season. In such an area (an ILC cluster at Jahada in Kapilvastu), suction pump operation has only been made possible by installing pumps in pits between 1 and 3 m below ground level.

Such mapping was included in the 1987 GDC Study, but was based on a single survey of dug wells, several of which represented shallower perched watertables rather than the more extensive shallow aquifer available at typical STW depths. As a result, the extent of the system with watertables greater than 5 m is now thought to be significantly smaller than as mapped in 1987. This in turn has reduced the extent of shallow aquifer down-graded in terms of development potential because it exceeds suction pump limits. The 1993 lithological and water level mapping is shown in Volume 6, Plates 1 to 8.

1.5.2 Development Classification

Piezometric and aquifer lithological information have been combined to develop an aquifer development classification specific to Terai conditions as defined in Table 1.3.

The classifications are roughly in order of development priority, but since water levels are more significant than aquifer quality for STWs, while the reverse is true for DTWs, the sense of the classification is not immediately obvious. The rationale is that while a marginal classification for STWs would at worst result in a few (rather inexpensive) failures during drilling, completion in deep watertable areas, even in a good aquifer, can result in extra pumping costs which may make DTWs uneconomic.

The STW classification takes a water level of 5 m below ground, as this is thought to reflect a practical limit for operation of suction pumps within STWs. The DTW cut-off point has been set at a static water level of 10 m below ground level, since economic calculations suggest questionable benefits at greater depths.

TABLE 1.3

Aquifer Development Classification

Shallow tubewells			Deep tubewells		
Class	Lithology	Watertable	Class	Lithology	Piezometry
S1	Good	< 5 m	D1+	Good	Artesian
			D1	Good	< 10 m
S2	Marginal	< 5 m	D2+	Fair	Artesian
			D2	Fair	< 10 m
S3	Good	> 5 m	D3	Marginal Good	< 10 m > 10 m
S4	Marginal	> 5 m	D4	Marginal	> 10 m
S0	Poor	Any	D0	Poor	Any
	Any	North of 5 m limit (drilling difficulty)			

Source: GDC

1.6 Mapping

Hydrogeological data for the shallow and deep aquifer zones of the main Terai and inner Terai valleys have been mapped at 1:250 000 scale and classified in terms of development classes. The mapping is given in Volume 6, whilst a hydrogeological discussion of all Study Area districts is given in Chapter 2.

Several practical issues arise in the classification and mapping process, for example:

- There are areas between proven expanses of "good" deep tubewell lithology for which there are few or no data, and which have therefore been classed lithologically as "fair"; notable examples occur in Rautahat and Sarlahi districts. Applying the principles of depositional continuity, it might be considered reasonable to upgrade such areas, as was done in some cases in 1987. This approach has not been repeated in this exercise because, generally, the availability of data is better. However, for planning purposes, these areas should not be ignored, particularly those classed as D2; rather they should be viewed as priority for future exploratory programmes.

- Some areas have been classed as D2/"Fair" deliberately, confidently supported by deep bores; examples occur, for example, in Kailali and Kanchanpur districts, and in eastern Morang/Jhapa. It is important to remember that the purpose of the classification is to compare different aquifer conditions in relative terms and then to rank them in priority terms. The relative merits of the different class aquifers are addressed in Chapters 3 and 4, where unit water production costs are compared for a range of well sizes and construction methods.

- In areas where there are no DTW data and depositional pattern "bracketing" cannot be considered, then a marginal lithological class has been used: this invariably leads to down-grading to classes D3, D4 or D0. Yet a D4, and certainly a D0 class, implies that no DTW development is possible in the area. (The S0 shallow tubewell classification generally means that it is impossible to construct STWs, either because there is insufficient shallow screenable lithology, or because of drilling difficulties and deep water levels.)

- In the case of the DTW development classification, the D0 class cannot fairly be equated with the STW S0 class. In the main Terai, there are no areas known where an irrigation tubewell cannot be constructed (although in the less favourable areas, the tubewell designer may have to use excessive drilling depth and screen to achieve a reasonable production discharge, and then have to contend with very slow drilling due to boulders and cobbles; this could not be justified for irrigation purposes, but might result in a very acceptable source for a town water supply).

- Where the DTW classification system encounters cases where good and fair lithologies are coincident with deep (>10 m) water levels, the areas have been effectively downgraded for development by the use of the following modifications:

    - "good" lithology/deep water level: use class D3; and
    - "fair" lithology/deep water level: use class D4.

- Finally, the problem remains of how to fairly classify areas where defective well construction may have depressed aquifer parameters. A typical problem arises when a group of DTW tests gives average (probably depressed) transmissivities in the range of 300 to 750 m^2/d and sporadic transmissivity values of 1 000 to 2 000 m^2/d. Yet in these areas, descriptions of strata cut indicate that perhaps 25 to 30 m of gravel or very coarse sand have been screened. The formal classification will class these areas marginal and generally D4, or even D0, for development; the occurrence of transmissivities outside the reference range (and any suspicion that well construction faults have occurred) justifies moving the area into a higher class.

CHAPTER 2

REGIONAL HYDROGEOLOGY

2.1 Far Western Region

2.1.1 General

Sedimentation in the region has been dominated by deposition at the mountain front of alluvial fan deposits by the Karnali River in the west and the Mahakali River in the east. This has had the effect of extending Bhabar zone deposits across the Terai. Such areas are rated good for both STWs and DTWs, although the area near the Karnali River has been down-rated for STWs because of drilling difficulty which may require powered rigs.

Throughout both districts, there is a productive artesian aquifer between the major rivers. When USGS test drilled the area in 1969 to 1972, it generally established fairly widespread permeable aquifer material and artesian flowing heads of 6 to 12 m.

Subsequent DTW drilling confirms generally permeable lithology that will support productive DTWs. Unfortunately, the artesian head has not been regularly monitored and we do not know if any significant head declines have occurred since 1972.

2.1.2 Kanchanpur

Shallow Aquifer

The GWRDB/UNDP shallow aquifer programme drilled 15 STWs to an average depth of 32.3 m and established that 44% of the cut section is useful aquifer material. Their test data indicated high transmissivity values in the east, adjacent to the Mohana River and in the south to southeast border region, in general agreement with reported coarse gravel lithology with a small fraction of clay and fine sand. Although this area is classed good on lithological grounds, part of the area is downgraded to Class S3 for development because of deep water levels in the shallow zone.

There are insufficient data in the west-southwest, and so the area is not classified.

In the centre-northwest region, there appears to be some lithological deterioration, with significant clay-medium sand in the section (UN 7, UN13, UN6); test transmissivity values from this area are low, suggesting that there is a real lithological deterioration compared to the far east to southeast. The area is classed as marginal in lithological terms.

Gravel and boulders were reported during drilling in the far north-west, in Bhabar fan deposits, and along the riverine plain of the Mahakali River. Such deposits are laterally variable, and highly permeable. Although they would be classed as good on lithological grounds alone, they are re-classed marginal because of the difficulty of drilling and well completion in these sediments.There are no shallow data in the southwest forest, but we would expect lithology to be derived from the Mahakali fan, and hence to be permeable and productive.

Water level mapping for May 1991 (GWRDB) indicates generally shallow watertables, but in the north and in a zone stretching from the highway to the Indian border, dry season depths to water level exceed 5 m; these areas are reclassified to reflect anticipated pump suction problems.

Deep Aquifer

There are few consistent data available on the deep aquifer since the USGS work, so it is used as a reference. Later data are incomplete and in some cases, it is impossible to distinguish aquifer characteristics from well construction faults. The riverine deposits associated with the Mahakali River form permeable deep aquifers and the area is lithologically good for DTWs; however, boulder-gravels in this zone may make drilling difficult while river bed shift and flooding would make well construction difficult.

An east-west flowing artesian zone extends through central Kanchanpur; positive heads up to 10 m were recorded by the USGS drilling programme in 1971 although these may have since declined. However, GWRDB-FIWUD production wells drilled 10 years later recorded free flows with heads of +6 to +18 m.

The USGS exploration wells, all south of the highway, gave transmissivities in the range 80 to 2 495 m^2/d and in a sample of 11, four exceeded 1 000 m^2/d and two exceeded 2 000 m^2/d. In view of the head losses ascribed to the mode of well construction (a casing-screen string of only 100 mm diameter), we have uprated these data and classified the lithology of the whole area south of the highway as fair.

North of the highway, there are no data and the area is classed as marginal for DTWs.

2.1.3 Kailali

Shallow Aquifer

The major hydrogeological features of the district mirror those of Kanchanpur; these are a flowing artesian zone in the west-centre area, and coarse permeable fan deposits in the east associated with the Karnali River.

The UNDP drilled 33 wells, of average depth 26 m (range 10 to 56 m) in the shallow zone, and 32 were successful. Sixteen out of 19 had a discharge greater than 8 l/s, and 13 out of 19 had a discharge greater than 12 l/s, indicating a generally productive shallow aquifer with excellent potential. Analysis of the UNDP lithological logs and test data suggests:

- marginal areas for STWs in the central and southern border region, probably connected with an increase in clay-fine sand in the shallow section, and showing transmissivity values consistently less than 1 000 m^2/d; and

- otherwise, a widespread occurrence of coarse, permeable material in the shallow section in the west between the Khutiya and Mohana Rivers; these areas are classified fair on the basis of lithology and test results.

In the southeast, in the area of Karnali River fan deposits, gravel-coarse sand lithologies are associated with the highest transmissivity values. These areas are classed as good.

The area north of the highway is problematic as it contains gravel lithologies which support locally highly productive STWs (UN30 in the northeast, UN17 in the northwest), but also several wells with non Bhabar argillaceous/sand lithology. Because of the lithological variability, the area is classed marginal.

The May 1991 GWRDB/UNDP water level map (based on STWs) shows that no deep water levels occur and much of the area appears ideal for suction mode pumps. Only locally, near the southern border and in the central north area around the Kanara River, do water levels at the end of the dry season exceed 5 m. In the north border strip of Kailali, water levels exceed 5 m below ground (this zone is classed S) to indicate that STW operation with suction pumps is impossible.

Deep Aquifer

The deep aquifer classification is made on the basis of the USGS exploration well data (from 100 mm test bores) and from subsequent GWRDB exploration wells, some of which have been converted to irrigation use by FIWUD.

The USGS data for 23 tests show average transmissivities of 672 m^2/d with a range of 30 m^2/d to 2 892 m^2/d. It is significant that the highest transmissivity values are from the east, in the zone between the Pathariya River and the Karnali; this zone is classed good for DTWs, with a D1 development classification.

On the basis of the USGS and GWRDB data, the remainder of the area, the centre west, is classed as fair (D2 development class) on the basis of high well specific capacities, and local occurrence of well tests reporting transmissivities exceeding 1 000 m^2/d; in the flowing zone, such areas receive the D2+ classification.

There are no specific test data for the northern fringe; coarse lithologies, deep water levels and drilling difficulties justify a marginal classification (D3, D4 development classification).

2.2 Mid Western Region

2.2.1 General

In general, much of Bardia appears highly suitable for STWs. The Banke shallow zone is generally marginal, except in the south-east; in central Banke, there are areas with deep, pre-monsoon shallow watertables and these have little STW development potential (classed S4).

Deep aquifer appraisal is based largely on USGS data. In general, the sedimentary sequence is dominated by alluvial deposition from the Karnali River in west Bardia, and the Rapti River in east Banke; these rivers have deposited a thick sequence of coarse, permeable sediments in the deep profile while areas between these two sources of coarse sedimentation tend to have deep aquifer material of lower, marginal quality.

Over an extensive area of central and south Bardia and Banke, the deep aquifer has deep water levels which result in low D4 rating for development.

2.2.2 Bardia

Shallow Aquifer

The May 1991 GWRDB/UNDP watertable mapping shows that overall, water table levels in Bardia are extremely shallow; only in the extreme north of the district do levels exceed 5 m, with potential dry season STW pump suction problems.

The UNDP investigations drilled 19 STWs, of average depth 39.6 m; these bores showed an average permeable thickness of 39.6% in the shallow section. The UNDP experienced well completion problems and only four STWs were pump tested because of field technical reasons. Consequently, the results of this work give a most incomplete cover of the district.

A re-analysis of STW lithological logs indicates that in much of central and west Bardia, lithology and permeable thickness allow STWs to be installed; in the zone adjacent to the River Karnali, lithology is coarse and correlates with transmissivity values between 380 and 550 m^2/d quoted by the UNDP. Similar materials and potential seem to exist in east Bardia, about the Man River. All these areas are generally suitable for STW development, being classed S1 and S2.

Data are missing for the Bhabar zone in the northwest; on the assumption of good lithology but deep water levels, the area is classed S3.

In the south of the district, boreholes indicate lithologies dominated by clay, silt, fine sands or at best thin coarse sands, and gravels. Here, it is difficult for a STW driller to find 6 m of suitable screenable material. The area is classed, at best, marginal (S2).

Deep Aquifer

Data on the deep aquifer are entirely from the USGS exploration programme of 1969-72, although this programme constructed no boreholes in west Bardia. In the Far West, about the Karnali riverine plain, there are no data, but by analogy with the Kanchanpur area, it is likely that this zone has thick, permeable materials in the deep section. It is accordingly classed good for DTWs and D1 for development; however, there may be other practical constraints to DTW construction here, such as flooding, well protection and drilling difficulty. In west Bardia, USGS well 6/3 confirms very high transmissivity values in thick permeable sediments, possibly associated with continuing sedimentation about the Karnali River fan.

The high classification of these areas is modified to D3, in the south-centre of Bardia, to reflect the depressed water levels found in the deep aquifer here.

In east and central Bardia, fine lithology restricts transmissivities (confirmed by USGS transmissivity data in the low range 180 to 510 m^2/d) and the area is classified marginal at best for DTWs (D3 for development); in areas where this marginal class coincides with deep water levels, a very low D4 development class results.

2.2.3 Banke

Deep Aquifer

All DTW data for Banke is from USGS exploration work in 1969 to 1972.

In the south-east region, adjacent to the major southwards shift in the Rapti, a group of USGS exploratory DTWs gave transmissivity values between 470 and 3 050 m^3/d. Despite construction techniques which may have reduced recorded transmissivity (100 mm casing diameter, 3 m screen), these data suggest that the area be classed good to fair for DTWs. Elsewhere through Banke, the wells show rather low transmissivities, in the range of 20 to 400 m^2/d, and the area is classed as marginal only. There are no data in the extreme southeast, south of the Rapti; the area is classed marginal (D3) only to reflect a lack of data.

It is noted that the deep water level zone in Bardia extends through Banke almost to the Rapti River area; water levels in DTWs often exceed 14 m. In areas judged of fair or marginal lithology, such deep water levels lead to poor development classes of D3 and D4 respectively. In north Banke, artesian surface flows were recorded by the USGS work in 1969 to 1972. Until present head values are known, the classification does not account for these artesian conditions.

Shallow Aquifer

The 1987 mapping of STW potential classed all of Banke as good for STWs, except for a narrow belt in the west-central region.

More recent data from the GWRDB/UNDP shallow aquifer survey allows more subdivision of the shallow zone. The survey drilled 24 bores, of average depth 43 m and with a rather low (24%) aquifer percentage in the section. However, the UNDP identified well construction problems with gravel pack, poor development and screen blockage. Only seven project wells were tested (five reliably), because of major field problems with equipment and logistics. Five ADBN wells were also tested. Despite the doubts about some of their transmissivity data, UNDP constructed a map which broadly showed higher transmissivities at the periphery of the district, reducing towards the centre.

An analysis was made of the lithology of these project wells and of the shallow section data from USGS wells. Classification was confirmed where possible by test transmissivity results, although these are ambiguous because of poor construction and because development has almost certainly depressed these values.

The analysis shows:

- shallow, permeable gravel and sands occur in the northwest, along the Man River; this area is classed good for STWs;

- bores in the east and southeast near the Rapti River, with 90% permeable screenable material (UN wells 10, 24, 23, USAID wells 1/5); thick sections of permeable sands and gravels occur here, distributed about the curve of the Rapti River; these materials are in the lithological class good and in S1 for development;

- in central Banke, bores occur with no screenable material (UN wells 6, 17, 18, 4); sections are dominated by finer sands and clays and bores; the area is classed, at best, marginal with development Class S4; and

- in the northern margin of Banke, Bhabar zone material is discontinuous, often with thin gravel horizons and some clays and fine sands. The area is classed marginal for lithology, S4, locally S2 for development.

The May 1991 watertable mapping, based on UNDP STW observation, shows that overall, watertables in Banke shallow zone are extremely shallow; in one area, northwest of the Rapti in north-central Banke, water levels will exceed 5 m below ground level (bgl) and will hence potentially cause STW suction problems. In these areas, STW development classifications are reduced to S4.

2.3 Inner Terai

2.3.1 General

The inner Terai valleys of Surkhet, Dang and Deukhuri were formed by fold structures and faulting within older, consolidated rocks.

The Dang valley, which consists of a highly dissected surface with terraces, is filled with bouldery alluvial and eluvial sediments. It is characterised by deep water levels except in the Babai River plain, and by difficult drilling conditions. Deukhuri is formed almost symmetrically about the Rapti River, and much of the area consists of flat, alluvial valley bottom lands.

The Surkhet valley is bounded by folded and faulted older rocks. No major drainage lines cross Surkhet, and the valley seems to contain only a very thin alluvial-eluvial fill.

Although Chitwan is classed as an interior Terai valley, its form is different. It is an extensive alluvial tract formed by the coalescence of the braided channels of the Rapti and Narayani Rivers. The area contains a shallow watertable and has thick, but locally cemented, alluvial deposits.

2.3.2 Dang Valley

Introduction

The groundwater system has the Babai River as a local base level; recharge input to the north of the valley results in large water level fluctuations with subsequent falls as the sediments drain to the river at high gradients. A deep water level zone in the north is coincident with large water level fluctuations.

Recharge is mainly on the north edge of the valley through very permeable surface deposits; the system discharges to the Babai and much of Babai base flow is from groundwater discharge.

The strata contains several permeable layers, locally separated by clay layers. In the north, the deep aquifer watertable is generally deep (up to 30 m) sometimes with a 20 m annual fluctuation. In the southeast of the valley, a distinct difference can be observed between the deep aquifer watertables (apparently 50 to 70 m deep) and the shallow aquifer water level, indicating clear aquifer separation.

Shallow Aquifer

In Dang, older alluvial-colluvial terrace deposits are deeply dissected by tributary rivers running south to the Babai River; typically there are rapid topographical changes between elevated interfluve areas and the river channel. These landforms will control groundwater development, as follows:

- the flat interfluve area, invariably with deep water levels: force mode pumps are needed; and
- the river channels and adjacent lands, with shallow water levels: suction pump operation is possible.

Hence topography changes over short distances with rapid changes in water level depth. The May 1991 UNDP watertable map is based on observation points of insufficient number to reflect the rapid topographical changes and their effects on permissible pump type. The mapping has other anomalies; chiefly the inclusion of piezometry from distinct aquifers.

To improve the mapping of areas where STWs could be used, GDC made a detailed survey of water points in May 1993 to better define in detail the water level pattern and to isolate areas where only dug wells and force mode pumps are feasible.

The GWRDB/UNDP drilled 10 STWs in the Dang valley, of average depth 29.9 m (although the UNDP did recognise these well depths were inadequate to define the shallow zone since in northern Dang, water levels were greater than 30 m); drilling was often very difficult because of boulders and cobbles. Upper section data from DTWs and STW lithological data showed that 48% of an average STW would consist of screenable sand/gravel. Nine well tests were completed, while others suffered from problems with the use of suction mode test pumps, poor measurement devices, and short test times. Tests indicated generally high transmissivities from 18 to 5 670 m^2/d, from lithology described as gravel and sand. Some of the low transmissivity (T) values were quite inconsistent with supposed lithology and some wells may have been poorly constructed; alternatively, some of the low transmissivity values may reflect cemented or conglomeratic gravels.

The transmissivity data and analysis of lithological logs suggest that much of the Babai plain and centre-east Dang has adequate coarse sand-gravel lithology and will support STWs. The area is classed good for STWs on lithological grounds.

While the Babai valley lands are classed S1 for STW development, it is inevitable that in deep water level areas away from the valley and in the interfluves, it will be difficult or impossible anywhere to construct suction mode STWs, even though shallow zone lithologies in Dang are classed good to fair. Deep watertable areas are classed S0 (development not recommended) and locally S3/S4 development class.

For much of the western area, data are lacking, although some low capacity STWs were constructed near Bainsa. The area is classed marginal for STWs.

Deep Aquifer

GWRDB drilled 17 DTWs in the valley, to average depths of 92.7 m, with screen set as deep as 108 m and typically set in the interval 40 to 95 m. Water levels in these wells are generally deep, up to 35 m, apparently through the entire area and this will prove to be a constraint to DTW development. Six of the DTWs were pump tested, and the UNDP reports transmissivity values in the range 18 to 5 670 m^2/d. The low T values are inconsistent with position and lithology, and must represent major construction-test faults. We consider the more credible values to be those in the range 1 035 to 5 670 m^2/d and conclude that very permeable sands and gravels form a productive aquifer which occurs at least down to 100 m depth. Conservatively, transmissivities over 1 000 m^2/d should be widespread and hence, the central area is all classed as fair on lithological grounds; the north fringe is classed marginal at best because of deep water levels; large annual fluctuations, and hard drilling conditions.

These lithology - based classes are downgraded because of the excessively deep water levels and hence the DTW development class generally becomes D4.

2.3.3 Deukhuri

Shallow Aquifer

The GWRDB/UNDP study drilled six STWs of average depth 29 m, and established that 53% of the average shallow section consists of permeable sand and gravel; drilling was much less difficult than in Dang, and manual methods are possible along the Rapti River plain. Ten STWs were tested (UNDP and ADBN STWs), but testing was constrained by test pump suction and measurement problems.

While Pliocene-Pleistocene cemented conglomerate, sandstone and clays occur in the rocks of the valley rim, the valley alluvium and colluvial deposits are of main interest.

Recharge is through highly permeable surface deposits to the shallow aquifer which then discharges to Rapti base flow, which is perennial. The groundwater gradient is from east to west, as the river flows.

In April 1989, most areas had water levels of less than 6 m depth, particularly in the Rapti riverine belt where water levels are shallow. This picture is confirmed by water level observation maps for May 1991 which show shallow water level regime along the Rapti River plain; deeper levels (6 to 8 m) occur southwest of the river.

However, the test data indicate generally very high transmissivity values as follows:

- project STWs T range 990 to 9 925 m^2/d
- ADBN STWs T range 700 to 4 928 m^2/d

The transmissivity data are consistent with a lithological analysis which indicates that the shallow zone invariably contains permeable coarse sand and gravel, except in the Lamahi district where silt, fine sand and clay are important in the shallow section. The conclusion is that on lithological grounds, the shallow zone around the Rapti should be classed as good for STWs, S1 for development; marginal areas occur in poor lithology near Lamahi. There are no data for the north and south valley margins which are classed marginal on lithological grounds.

Deep Aquifer

An analysis of seven GWRDB DTWs was done. These have an average depth of 71 m, with screens usually set in the interval 30 to 55 m but occasionally deeper, below 100 m. All bores cut a substantial thickness of permeable aquifer material, particularly gravel, but no test data were available. Nevertheless, it is concluded that the potential of the deep aquifer is fair; test drilling is needed to confirm this.

2.3.4 Surkhet

The Surkhet valley, an area of about 150 km^2, is underlain by the Siwalik formation consisting of quartzitic sandstones, siltstones, shales and brecciated limestone; rocks of this type also form a hill in the centre of the valley. The valley fill apparently consists of deposits of alluvium, fan talus, and colluvium which mantle the older Siwalik rocks.

The watertable in the valley is generally very shallow, and this shallow groundwater is exploited by dug wells, for domestic and garden use, and by springs. A major spring (25 l/s) discharges in the valley centre. Springs and river flow are used for irrigation. There are no irrigation STWs and no DTWs.

A geological sketch map (after GWRDB (Uprety), 1985) is given which shows drainage, rock outcrop and dip information; an interpretation of deep structure is given in an east-west geological cross section.

The area is seen as a bedrock valley developed in folded Siwalik sediments, faulted along northwest-southeast and northeast-southwest lines. The drainage pattern in the area is probably controlled by these fault lines; they may also be responsible for convergence of groundwater flow at major spring sites.

Several field investigations have been made as follows:

- geophysical (electrical resistivity and shallow seismic) survey in 1986: the results were somewhat difficult to interpret in terms of aquifer occurrence, as no correlation borehole was available; they did however suggest that generally, some high resistivity material occurs below 50 to 60 m depth; the recommendation was to drill deep exploratory bores to look at the deep section;

- GWRDB exploratory shallow well drilling in 1986/87: four bores were drilled to the south and southeast of the town, at Chilan Tal (69 m), Dayuti (55 m), and Tilpur (50 m); very thin layers of permeable material were cut, but apparently, these could not be developed, and aquifer potential was too low to justify casing and testing of the bores; the bore at Mangal Gadhi (44 m) was screened in an apparently good aquifer layer, but excessive, rapid drawdown in the bore caused the test to be abandoned; it was concluded that STWs were not feasible; and

- Nedrill drilled three 200 m deep exploration bores in the valley in 1991, generally south of the town, at Bulbule, Budbude and Latikoili; the drilling was by the DC method, using drilling mud weighted by barytes. The contractor noted very hard drilling in brecciated material in some sections. Nedrill conclusions were:

    - Bulbule: multiple water bearing formations between 66 to 135 m;
    - Budbude: a shallow aquifer only, at 30 to 34 m; and
    - Latikoiali: water bearing formation at 102 to 112 m.

Significantly, the Nedrill strata description mentions "crushed quartzitic sand associated with brown shale". This may be Siwalik strata, and not alluvial-colluvial deposits. The bore was screened 102 to 112 m, gravel packed and developed sand free by air lift at 2 l/s. None of the bores were pump tested, possibly because of equipment constraint or because of perceived low formation permeability.

Our interpretation of the log of the deep exploration boreholes gives the following sequence:

- thin, recent alluvial-colluvial sediments (<10m);

- older, cemented and low permeability alluvium and colluvium, possibly ancient valley fill-fan material (up to 100 m); and

- folded Siwalik sediments.

Siwalik rocks generally lack significant primary permeability, although fractures in the quartzite members may locally enhance permeability; in general, these rocks do not support good aquifers. The alluvial-colluvial materials in the valley floor may contain permeable sand and gravel but are extremely thin. A simplified geological section is given on Figure 2.1.

Our conclusions are as follows:

- the evidence suggests a superficial layer (perhaps less than 10 m) of low permeability, recent alluvial-colluvial material (A in the cross section) which is rather argillaceous;

- below that is a sequence of up to 100 m of old alluvium-colluvium (Ac in the cross section) comprising gravel, sand and clay beds; the sequence is generally argillaceous, and is cemented and appears also to have low permeability;

- below this, there is evidence of low permeability Siwalik rock (SSiSh-Fes); in the Nedrill bore at Budbude, black shales are logged at 114 m and phyllitic? shales at 190 m. At Bulbule, similar black shale is reported at 106 m depth;

- likewise, the lithology reported in the screened zone at 102 to 110 m at Latikoiali, "crushed quartzitic sand associated with brown shale", is likely to be low permeability Siwalik strata;

- The recent and cemented alluvial-colluvial deposits seem to have insufficient permeability to support pumped wells, but low discharge dug wells can be sustained; Siwalik strata are likewise of low permeability and are unlikely to support DTWs;

- although there is unlikely to be any significant groundwater potential in this valley, drilling, well completion and testing have not been adequately carried out and there is no clear reason why the DTWs were untested;

- some supervised test work is needed to confirm the low potential; and

- on present information, Surkhet has a zero classification; it is considered that no meaningful STW or DTW potential exists.

2.3.5 Chitwan

Shallow Aquifer

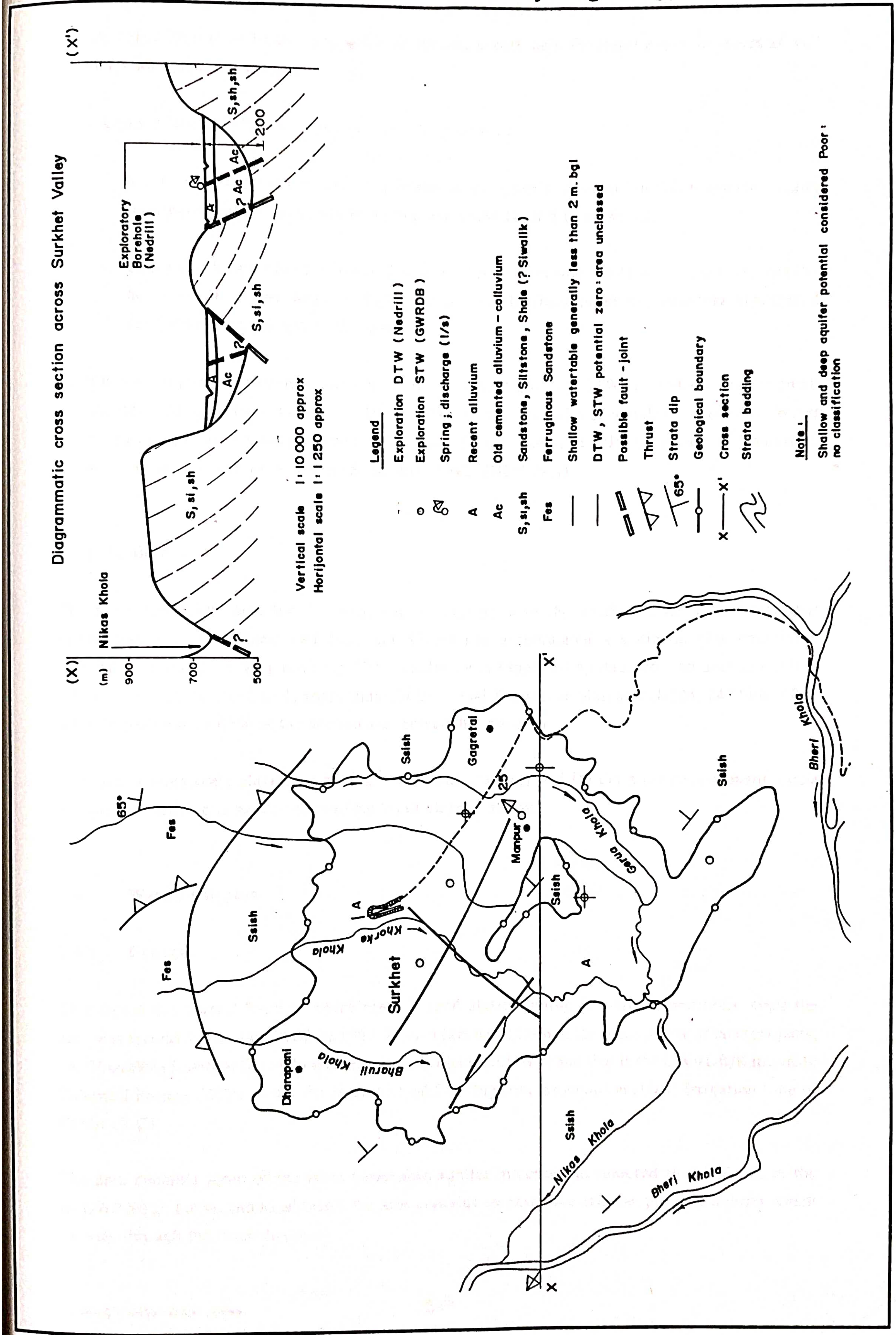
In the Chitwan area, there is widespread occurrence, at about 9 to 10 m, of a hard, cemented conglomerate which cannot be penetrated by manual methods. Consequently, there are almost no manually drilled STWs in Chitwan. Instead, many caisson lined, shallow dug wells have been constructed in the layer above 10 m. In some cases, penetration into the saturated zone is insufficient to maintain production discharge in May-June. Locally, fine sands in the shallow section may impede drilling and well digging.

The UNDP shallow groundwater project drilled 17 investigation STWs in Chitwan, in the area between the Rapti and Narayani Rivers. Since most STWs were manually drilled, they were necessarily very shallow, of average depth only 10.2 m, certainly too shallow for investigation purposes. The wells proved that 70% of the section consisted of screenable material.

Six wells were pump tested, at yields between 5 and 22 l/s. Testing, defective because of problems with field measurement equipment and lack of supervision, nevertheless indicated a widespread zone of high transmissivities in the range 767 to 6 423 m^2/d. These can be correlated with the coarse

Figure 2.1

Hydrogeology of Surkhet Valley



gravels cut in typical STWs and dug wells. In the south-east, near the Rapti River, boulders as well as finer sand material were cut.

Re-analysis of the lithological logs indicated the following:

- a very typical profile is 2 to 3 m of clay upon gravels; boulders in this sequence usually terminate drilling, particularly by manual methods, at 8 to 10 m; and

- in the south-east near the Rapti, 2 to 3 m clay overlie fine sands which pass into gravel-boulders. These fine sands could give screening difficulties; otherwise, lithological potential for STWs is as the rest of the area.

On lithological grounds therefore, the whole area is classed good for STWs and S1 for development; the quoted transmissivity values allow 15 l/s STWs to function with acceptable drawdowns. Water tables appear shallow almost everywhere, less than 5 m. In one area only, southwest of Bharatpur, depths to water seem to exceed 6 m (September 1992 UNDP data).

Deep Aquifer

There are few DTW data for the area, but by analogy with the shallow zone, it is likely that sedimentation by the Rapti and Narayani Rivers has accumulated a sediment pile containing permeable materials in deep sections. This conclusion is supported by data from an untested 100 m tubewell at Bharatpur (NCD01; approximately Universal Transverse Mercator (UTM) 247 000, 3 065 500), in which over 85% of the section was screenable material.

The area is tentatively classed as having a marginal lithology and D3 class for development; some exploratory drilling is needed to confirm these classifications.

2.4 Western Region

2.4.1 General

This region has several features which allow a good understanding of aquifer conditions, since the area was test drilled by the USGS in 1969-72, and this work formed the basis of major later projects, the Bhairahwa Lumbini Groundwater Irrigation Project (BLGWP) and that is the GWRDB/Kapilvastu Tubewell Project (KTP), under the International Development Association (IDA) Irrigation Line of Credit (ILC).

The area contains some of the most permeable aquifer material encountered in the Terai, in the BLGWP Stage I area, and in addition, the area contains an extensive artesian pressure aquifer which extends through the three districts.

The present piezometric map of the deep aquifer, shown on the map, is controlled by an extensive well head levelling programme. Closely spaced piezometric contours are interpreted to mean poor, low permeability aquifers, while wider spacings are thought to mean aquifers of higher permeability. The reasoning indicates a band of poor aquifer material in the southwest, south of the BLGWP area; this is further interpreted as "shutting in" the artesian heads to the north. This restricted down-slope outflow has allowed artesian heads to develop in an east-west zone extending through the three districts.

Initial heads in this artesian zone exceeded 13 to 15 m (around 1969-72) but since then, there has been up to 10 years of increasing groundwater discharge from the system, by pumping and by uncontrolled artesian flow. Head monitoring by BLGWP suggests that locally, there has been a 7 m decline in head.

The groundwater system has been studied by Tahal for BLGWP; Tahal has modelled the aquifer system as two aquifer layers separated by an aquitard.

2.4.2 Kapilvastu

Shallow Aquifer

In Kapilvastu, the GWRDB/UNDP shallow aquifer study drilled 23 STWs of average depth 50 m. Thirty-two per cent of the average section consisted of coarse sand and gravel. The UNDP mentions that some of the STWs had construction faults, including screen design, poor well development and screen blockage. It also experienced problems with its well test programme; some test results were unusable. It concluded that the shallow aquifer in the west was marginal (and had no deep aquifer).

Analysis of the transmissivity and lithology results from the UNDP and from the ILC work suggests that higher transmissivities occur in the northwest and northeast but lower transmissivities occur in the south and centre. Data from the ILC Shivagarhi cluster in the northwest indicate moderate specific capacities and average transmissivities around 513 m^2/d. STWs have generally been successful here, despite construction faults. Likewise in the Valwad cluster in the northeast, tests indicate moderate specific capacities and average transmissivities of 518 m^2/d. Water level mapping indicates that dry season water table levels exceed 5 m only in the northern fringe of Kapilvastu.

The centre-south has therefore been classified as marginal lithology (S2 for development), and the northeast and northwest as generally good (development classes S1, or S3 in deeper watertable areas).

These areas are therefore classified fair for DTWs. In the development classification, such areas, where coincident with the artesian zone, are classified D2+.

Deep Aquifer

The USGS data and the GWRDB K series boreholes indicate that no useful deep aquifer exists in the west of Kapilvastu; the K series DTWs indicate that transmissivities are generally below 500 m^2/d and sand percentages are apparently around 10 to 23% in the 0 to 150 m range. This would be mapped marginal at best (In the 1987 work, no DTW potential was ascribed to this area. Transmissivities were indeed low, but this is thought partly due to poor construction and development). However, results from the ILC work at Shivagarhi suggest that the northwest should be reclassified fair for DTWs; and the west-southwest as marginal.

In the northeast-east of the area, we have some ILC data for MTWs and DTWs in the Valwad and Kopwa clusters. This indicates that Valwad has a moderately productive deep aquifer, with average transmissivities of 970 m^2/d; however, the DTWs at Valwad may have construction faults which have depressed the transmissivity values. At Kopwa, MTWs indicate an average transmissivity of 654 m^2/d (range 300 to 1 000 m^2/d). Small head artesian flows occur in both the Valwad and Kopwa clusters.

On the basis of the ILC data from Valwad and Kopwa and USGS mapping, northeast and east Kapilvastu is classed fair for DTWs.

2.4.3 Rupandehi

Shallow Aquifer

The UNDP STW study drilled 26 STWs of average depth 47 m and proved 38% permeable material in the average well. The UNDP transmissivity results are consistent with reported lithology and suggest the following classifications:

- in the west-southwest about the Kothi River, low formation transmissivities are coincident with an area of low STW density (picked from mapping/census done by the consultants, United Designers); the area also has a lithology with a high clay-fine sand content; the area is classed marginal for STWs; and

- the central north area is classed good (S1 for development), as it contains coarse materials with high permeabilities and has shallow watertables; it encompasses Stage I BLGWP area and the Butwal area in the Bhabar zone; peripheral transmissivity reduces.

Deep Aquifer

Drilling and construction of production wells in the BLGWP allow us to classify the majority of the Rupandehi area.

South of the Bhairahwa-Lumbini development areas, there is an arcuate zone stretching from the west of Rupandehi to the south of Lumbini to the Indian border, and extending to the northeast, to the south of the extreme east section of BLGWP Stage III area; the northwest margin of the zone is defined by Stage III west DTWs. This zone typically has between 20 and 30% screenable material in the producing interval 50 to 150 m and moderate permeabilities which appear to reduce southwards to the border. These reducing permeabilities may be responsible for shutting in and creating the high artesian heads to the north.

In the north of this zone, 300 m³/h DTWs are generally possible. It is classed lithologically fair (D2 or D2+ development classes), but towards the Indian border, lithology seems to become marginal for DTWs.

The major part of the BLGWP project area is classed as good (D1 for development) on the basis of Stage 1, II-1 DTWs. Where such areas are coincident with artesian flow zones, then these areas have the highest DTW development class, D1+.

2.4.4 Nawalparasi

Shallow Aquifer

During the UNDP field studies, 17 STWs of average depth 33.7 m were drilled; they proved that 48% of the average borehole section was permeable material. Subsequent pump testing of eight wells was unsatisfactory because of screen development problems, and difficulties with the centrifugal suction test pump, which may have depressed field transmissivity results. Analysis of the UNDP field results and reported lithology shows that the area southeast of Nawalparasi, towards the Narayani River, is good for STWs; in the Narayani riverine plain, however, drilling is likely to be difficult in bouldery conditions. Similar conditions occur in the adjacent area of the ILC Jahada cluster, which indicates coarse screenable sediments, with average transmissivities of 500 m^2/d and average STW yields, of 10 l/s. This area is also, on lithological grounds, good for STWs, although deeper pre-monsoon water levels about Jahada lower the development classification to S3.

The north-northwest is generally marginal for STWs and locally deep water levels cause low development classes. In the extreme northern fringe, beyond the 5 m watertable line, conditions for STWs are poor and the area is classed S0.

The UNDP water level mapping for May 1991 does not easily define the northern edge; water levels exceeding 5 m in the northwest are assumed on the basis of other reports. The deep water level area (5 to 6 m) in central Nawalparasi indicated on water level maps can be confirmed since it is coincident with the Jahada ILC cluster area where we know that average water levels are about 6 m and that 14 out of 23 STWs are pitted to 0.5 to 3.5 m. Such deep water levels are clearly a constraint on development since, in this case, the farmer has to bear the cost of deep pit construction and maintenance in addition to the well and pumpset cost.

Deep Aquifer

Information is available from GWRDB and from the ILC programme. In the Jahada cluster, MTWs (of 56 m average depth) have been built; specific capacities are rather low (about 2.6 l/s per metre) and transmissivities around 300 m^2/d. DTWs at Sunwal (average depth 121 m) are more indicative with specific capacities of 6.8 l/s per metre and average transmissivities of 780 m^2/d. Conversely, the USGS data does however indicate a rather low percentage of permeable material: 15 to 23% for the section 0 to 150 m.

The area is therefore classed as all above marginal for DTWs except in the northwest where Sunwal data suggest good to fair potential for DTWs (development class D1+ and D2).

2.5 Central Region

2.5.1 Parsa

Shallow Aquifer

Information on the shallow zone is available from STWs drilled by the UNDP shallow aquifer programme, by NZIDP, and by JRCS. In addition, Biswakarma carried out a STW inventory.

Data for the 25 UNDP STWs is unreliable; most have extremely low specific capacities, inconsistent with the stated thickness of permeable material in the well (UN 2; 6 m screen, 11.8 m permeable thickness, SC 1.63/UN10; 7.6 m screen, 19.2 m permeable thickness, SC 1.57). The exceptions are in the north-centre area where STWs have high specific capacities. These results must be controlled by construction faults/development and test form, and do not give mappable numbers. Nevertheless, an attempt was made to classify using specific capacity and lithology.

On this basis, the south-southeast is classed as, at best, marginal since drillers might have difficulty in finding sufficient sand or else the formation is generally of fine medium sand and difficult to screen.

The central zone is all classed good on lithological grounds, but towards the northern margin of the district, there are reports of increasing (hard) drilling difficulties, and the area is classed marginal.

Watertable mapping is available for May 1990/91. It shows that no deep water levels were recorded over most of Parsa; only in the extreme northeast and in the forest are pre-monsoon watertable levels likely to exceed 5 m.

Deep Aquifer

DTW data are available for an east-west zone across central Parsa; they consist of test data from six GWRDB wells and three NZIDP wells which are of depths between 100 to 150 m. Although we have no lithological data for the cut section, DTW specific capacities and transmissivity values are generally high (transmissivities in the range 1 500 to 2 400 m^2/d); reported test yields are high (all over 60 l/s).

In view of these data, the east-west zone across central Parsa is classed good on lithological grounds (D1/D1+ development classes); elsewhere, there are no data and the areas are classed fair (i.e., the southwest corner). We lack data to fix the northern boundary, but the approximate limit of Bhabar sediments was established on drilling evidence. Any DTW lithology north of this is classed marginal (and hence D3/D4 development class) because of drilling difficulty and low aquifer saturation rather than on strict lithological evidence.

2.5.2 Bara

Shallow Aquifer

The UNDP shallow aquifer study of Bara proved that about 40% of aquifer material can generally be expected. They also showed a lithological deterioration to the southwest (Balrampur UN19) where the section is very argillaceous suggesting a poor to marginal lithology. Pump test data indicate that moderately high transmissivities occur in permeable Bhabar sediments, in wells close to the highway, and fairly high transmissivities in coarse alluvial sediments derived from the Pasada Nadi River. Conversely, low capacity wells at the southwest border region reflect poor lithology.

Watertable maps are available for May 1991. The network is sparse in the north-northeast, making contouring difficult. However, two other points, at Simara in the northwest and Nizagarh in the northeast-east indicate very deep water levels (about 15 m); these are consistent with the Biswakarma census which describes no STWs in the area. Other reports indicate severe drilling problems in this area, including very hard drilling and very deep water levels. The northern area is classed poor in lithological terms, at best marginal; the deep water levels suggest development class S0.

In summary, the central zone of Bara has good potential for DTWs and an S1 development class (although locally, deep water level areas occur and reduce development class). The shallow aquifer deteriorates to the southwest, towards the Birganj-border region, where it is at best marginal (D3 for development, D4 where the watertable exceeds 5m). Conditions in the northern, Bhabar zone, are marginal for both STWs and DTWs. Certainly, machine rigs would be needed to drill in this area.

Deep Aquifer

Both GWRDB and NZIDP-Birganj DTWs have been drilled in the area. The NZIDP data shows that typically 53% (range 39 to 74%) of the section 50 to 150 m is screenable and test transmissivities average 1 474 m^2/d. On the basis of T values and lithology, most of the area is classed good (locally fair in the southeast). The northern boundary of good DTW conditions is drawn just north of Pathlaiya near the King Mahendra (East-West) Highway, where there is a successful 95 m DTW. Northwards, the area is classed marginal and this class, with deep water levels, leads to a D4 development class.

There is a significant area in southeast and south Bara with depressed water levels in the deep aquifer; on the grounds of a pumping cost penalty, this leads to the reclassification of otherwise good DTW areas there to D3 and D4 development categories.

Piezometric levels in the DTWs are generally in the range 4 to 6 m bgl but locally, in the area southeast of Kalaiya, water levels just exceed 10 m bgl. Artesian flows are uncommon but a flow was recorded at Phattepur, north of Kalaiya; this is marked on the map as a small flow zone.

2.5.3 Rautahat

Shallow Aquifer

Lithology and well test data derived from the UNDP shallow aquifer study indicate the following:

- 39% of the average STW is screenable (an average well is 29.2 m deep);

- rather thick sand-gravels occur in the southeast border region and adjacent to the Bagmati River: associated with high transmissivities and classed good for STWs (S1 for development);

- clay rich shallow section in the southwest area: classed lithologically marginal, and S2 for development; and

- coarse but variable lithology north of the highway, in Bhabar zone and to the Siwalik-Terai boundary; with locally high transmissivities; classed as marginal only (and deep water levels and drilling difficulty (difficult with machines and impossible with manual rigs) suggest S0 development class).

Watertable levels for May 1991 are almost everywhere less than 5 m in Rautahat, except in the northern fringe where water levels may exceed 10 m in May.

Deep Aquifer

There is very little deep aquifer data, except for six GWRDB wells. These DTWs, with depths between 123 to 160 m, have between 29 to 59% screenable material in producing section. Unfortunately, there is no performance data for these wells, but since contiguous areas in Bara and Sarlahi are classified as good to fair, it seem reasonable to classify the majority of the area as fair (development class D2) except in the southwest, where depressed water levels lead to class D4. Clearly, there is a need for some controlled pump tests in the area.

2.5.4 Sarlahi

Shallow Aquifer

The UNDP shallow aquifer survey drilled 20 STWs (average depth 31.4 m) in Sarlahi and established that over 50% of the shallow section consists of screenable aquifer material. Unfortunately, few reliable tests were carried out to confirm the lithological data. Analysis of the test data and STW lithology generally allows the following subdivision of the shallow aquifer:

- finer lithology and lower transmissivity values in the southeast towards the border and Hardinath River: classed as lithologically marginal and S2 for development;

- in much of the centre-west of Sarlahi, higher transmissivities are consistent with high aquifer percentage (locally less than 65%): classed as good lithology for STWs and S1 for development; and

- in the region of the highway and north, the shallow aquifer lithology is classed marginal as the area is difficult to drill and is bouldery, although there seems to be a high aquifer percentage; here, the shallow aquifer has a low development class (S0) to reflect pre-monsoon water levels greater than 5 m and the difficulty of well completion.

The shallow watertable configuration, derived from May 1991 data, indicates generally shallow water levels, except in the north-centre.

Deep Aquifer

DTWs built along the Mahendra Highway to depths of 70 to 110 m, exhibited low transmissivities (<350 m^2/d) and a deep static water level (SWL) which exceeded 15 m everywhere. This zone can therefore be classed marginal for DTWs and D3 class for development.

There are also 13 DTWs in the south-southeast; these have water levels below 10 m but have high transmissivity, usually exceeding 2 000 m^2/d. The whole area is classified as lithologically good and D1 for development.

In central-west Sarlahi, there is an absence of data; the area is classed fair on the basis of the lithology of contiguous areas.

There are no artesian flows reported in the district, but it is likely that a westwards extension of the Mahottari artesian zone occurs in the extreme southeast.

2.5.5 Mahottari

Shallow Aquifer

The UNDP drilled 15 STWs, of average depth 38 m, and established that between 30 and 40% of permeable material existed in the shallow zone. Transmissivities from nine STW tests were low and ranged from 130 to 320 m^2/d. Analysis of shallow zone lithology shows thick, permeable material in a central zone and towards the northwest; this is classed as good for STWs.

Northwards, boulders are encountered and the area is downgraded to marginal for STWs (S2 for development); further north, dry season watertable levels exceed 5 m and STWs are not possible; the area is graded S0 for development planning.

In the southeast (into Dhanusha) and southwest, there is a significant lithological change, to fine sands and clay section with little gravel or coarse sand. This zone has only between 5 and 15 m of aquifer in the top 40 m and must be classified as having marginal lithology; however, conditions for manual tubewell construction are reported to be good.

Deep Aquifer

A zone of deep water levels in the deep aquifer extends through north Mahottari into north Dhanusha while an artesian flow zone exists in central Mahottari, and extends through Dhanusha into south Siraha.

There are data from DTWs (JADP M series wells) in the north-centre coincident with the zone of deep water levels. This group of wells shows generally high transmissivities, which average over 2 000 m^2/d (range 570 to 4 750 m^2/d) for discharges between 20 to 50 l/s. These data indicate good potential for DTWs. For purposes of development, these areas are variously classed D1, D1+, D2 and D3 to reflect variations in water level and the position of the artesian zone.

The rest of the centre-south, much of which is coincident with the artesian zone, is classed as fair, and D2+ for development; although transmissivities are less than 500 m^2/d (only exceptionally reaching 1 000) there is thought to be some underestimation of formation parameters by poor construction.

Northwards, marginal deep lithology (the Bhabar zone may be absent here) coincides with deep water levels and increasing drilling difficulty. These areas are classed D4 for development, a recognition that even with marginally suitable lithologies, drilling and saturation problems will make successful DTW completion difficult.

2.5.6 Dhanusha

Shallow Aquifer

Lithological and well transmissivity data from the GWRDB/UNDP shallow aquifer survey indicate that most of Dhanusha has excellent shallow zone lithology, except for an ill-defined area in the south centre.

Well tests by the UNDP showed a wide range in transmissivity from 200 to 8 000 m²/d and well yields between 5 to 15 l/s. While faulty well construction is probably responsible for some of the low transmissivity values, the data are taken to generally indicate a permeable shallow zone classed S1 for development.

In the north, many sections show gravel and coarse sand, yet at some points, non Bhabar material (clay, fine sand) dominates the section; these areas are classed as having marginal lithology.

A change to fine sand-clay lithologies with much lower transmissivities can be seen in the south-centre zone. The area is classed marginal for STWs (and S2 for development).

The UNDP development map classes the whole of Dhanusha as "probable area of shallow irrigation wells". However, they seem to define a well adequate for irrigation if it produces "3 to 5 l/s or more". This definition is too broad and would lead to classification of almost every part of the Terai as a "probable area of shallow irrigation wells".

The watertable in Dhanusha is everywhere shallow.

Deep Aquifer

The DTW data generally indicate well transmissivities less than 1 000 m²/d which would normally demand a marginal classification. However, because well performance may often be reduced by construction faults, the centre-southwest has accordingly been classed fair and D2+ for development. Marginal areas are:

- the southeast where there is evidence of lithological deterioration from data in Siraha; classed as marginal lithology and D3 for development; and

- a zone of deep water levels (greater than 30 m bgl) which occurs in the northern area centred on the King Mahendra East-West Highway and extends to Mahottari, in Dhanusha, this belt of deep water levels seems to coincide with marginal lithology for DTWs, which leads to a poor development classification of D4.

An extensive zone of flowing artesian conditions can be traced through Mahottari to south central Dhanusha and into the southwest of Siraha.

2.6 Eastern Region

2.6.1 Siraha

Shallow Aquifer

The UNDP tested 16 STWs and established a transmissivity average of 670 m^2/d (possibly depressed by defective well construction). Higher values occurred in the areas judged good on lithological grounds. Values greater than 500 m^2/d are generally found only in the area judged lithologically good.

An analysis of lithological and pump test data derived from the UNDP shallow aquifer study, showed that the majority of north and central Siraha contains coarse permeable sediments which would support STWs and would be classified good (and S1 for development in shallow watertable areas). Some of this coarse material seems to be a fan deposit of the Kamala River.

On the south border region, there is a distinct deterioration in formation quality to sections rich in clay and/or fine sand. This area is classed as marginal on the basis of lithology and either S2 for development or S4 in the deep watertable area on the border.

A STW census by East Consult indicates generally low STW densities north of the highway and the change to generally low STW numbers is taken as the northern boundary of good conditions; beyond, STW drillers will encounter deeper water levels and boulders, and the area must be considered marginal.

May-June water levels reported in May 1991 are generally less than 4 m bgl, but locally exceed this along the northern boundary, north of the road. On the southeast margin, adjacent to the Indian border, there are other areas which commonly record water levels greater than 5 to 6 m bgl.

Deep Aquifer

The following conclusions were made on DTW potential:

- much of the area north of the highway is a difficult drilling area for any rig type; fine sands in section, and thin permeable layer in section, make DTW completion difficult; and there are some failed wells here; to the immediate south, Sagarmatha Integrated Rural Development Project (SIRDP) wells 9 to 14 indicate useful transmissivities (range 320 to 1 500 m^2/d) in a belt north of the highway; this small area is classed fair, although increasingly deep water levels (23 to 34 m) lead to a poor development classification of D3;

- southwards, transmissivity information is scarce and we can only classify, at best, as marginal; and

- in the southeast around Bhagwanpur, five SIRDP wells indicate that DTWs can be completed with moderate specific capacities (2.5 to 5) and with transmissivity values around 300 to 500 m^2/d; since lithological descriptions suggest that transmissivities are being depressed by well construction faults, the area is classed as fair for DTWs (D2 for development).

2.6.2 Saptari

Shallow Aquifer

The fan sedimentation of the Sapti Kosi River, and to a lesser extent, the Bhatiwaian River, dominates the hydrogeological system. Coarse fan sediments dominate both the shallow and deep aquifer zone.

UNDP field work established lithological sections in 31 STWs of average depth 39.2 m. For all the UNDP wells (plus some shallow section data in DTWs), a high proportion, 46%, was screenable. Sixteen STWs were tested to give a transmissivity range of 100 to 8 000 m^2/d and well yields of 5.0 to 15 l/s. Almost all transmissivity values greater than 500 m^2/d were from STWs in areas of coarse sands and gravels. Correlation between well log descriptions and test results was good.

Analysis indicates the following:

- coarse sand-gravels in the southeast margin area and in the west are of lithological class good;

- rather mixed, fine lithologies with gravel strings in the north suggesting Bhabar type is absent; and

- elsewhere, lithology is marginal for STWs.

These coarse permeable materials in the southeast and west are riverine fan deposits of Sapta Koshi, which have excellent lithologies, but there may be other constraints in the riverine tract to STW development; e.g. land and flooding. Development class is S1, or S3 in deep watertable areas.

Water level data for May 1991 indicates that pre-monsoon water levels reach 5 m bgl along the northern fringe and in one area south of the district.

Deep Aquifer

Deep aquifer data are scarce but we know that much of the area north of the highway is a difficult drilling area; fine sands in the section make DTW completion difficult. There are several failed wells here. Some of the wells report a small aquifer percentage. Water levels are generally deep (18 to 30 m bgl). Since transmissivity information is absent, we must classify, at best, as marginal. Development class is D3 at best, possibly D4 as water levels deepen towards the north. In the east, along the Sapta Koshi and to the southeast, there are wells locally with high aquifer percentages and high specific capacities. Neglecting values which cannot be reconciled with lithology (ER3, 5, 6), transmissivities are in the range 350 to 1 077 m^2/d. Optimistically, the area is classed fair, D2 for development.

There are no data in the southwest but by analogy with adjacent wells in southwest Siraha (T values 300 to 550 m^2/d, Sc 2.5 to 5). The area is classed marginal only.

2.6.3 Sunsari

Shallow Aquifer

As in Siraha, coarse alluvial fan deposition of the Sapta Koshi dominates aquifer occurrence here and in the southwest of Morang. This thick alluvial section contains a high percentage of coarse screenable material (UNDP established 56% from its STWs) which gives high transmissivities to STWs.

Lithological analysis of 17 UNDP STWs indicates widespread occurrence through Sunsari, of coarse screenable material in the shallow zone. Gravel and coarse sand lithologies are common. These areas all have good lithologies for STWs. Test results in the shallow zone indicate that very high transmissivities are common. For 10 tests, average transmissivity exceeded 2 000 m^2/d, while the range was 313 to 4 300 m^2/d. In the case of lower transmissivities, UNDP implicates formation damage and incomplete well development as the cause of these low values in the well. These areas of good lithology have a S1 development class except in the centre-north where dry season watertables exceed 5 m and lead to a S3 classification. Some practical constraints exist however. In the riverine plain of the Sapta Koshi, bouldery conditions make drilling by any method difficult; locally, measures would have to be taken to protect well heads from flood.

In the centre-east of Sunsari, about Khanar, these coarse fan deposits are reduced and the percentage of clay and medium-fine sand in section increases significantly. Either no tests were carried out or low discharge prevented any test (Shimariya); the lithological deterioration here is almost certainly reflected in low T values and indicates a zone of poor potential, marginal at best, leading to S2 development class, or S4 in deep water level areas.

In fact, water levels (May 1991 reference) exceed 5 m in several areas:

- in the east along the Budhi River where depressed water levels may indicate local drainage of the shallow aquifer to the river base flow; water level gradient mapping also indicates some groundwater flows westwards to the Sapta Koshi River; and

- through a part of the centre of Sunsari, particularly around Jhumka (where the deep water level prevented testing with a suction pump); locally, pre-monsoon water levels may exceed 8 m bgl.

In these areas where water level exceeds 5 m bgl, the lithological classification is downrated.

In the northeast, artesian flow is recorded, even from a bore of shallow depth (44 m). This is an extension of the artesian zone of Morang.

Deep Aquifer

Data from 14 GWRDB DTWs indicate generally moderate transmissivities (average 688 m^2/d in the range 105 to 1 000). Some of these low transmissivities are probably depressed by construction problems. Because of the influence of Sun Koshi fan sedimentation, lithology in DTWs seems generally to mirror the shallow zone, and the whole area is classed as fair for DTWs. This generally leads to D2 development class.

There are no DTW data for the east fringe area, but by analogy with the shallow sedimentary section, we assume some deterioration in lithology, and class the area marginal and D4 for development.

2.6.4 Morang

Shallow Aquifer

An assessment of lithology and transmissivity values from the UNDP test STW programme indicates that there is invariably 6 m of screenable coarse sand-gravel in the 0 to 25 m shallow zone, although some lithological deterioration may occur in the centre-west around Pothiyahi.

Allowing for screen/construction problems which certainly depress transmissivity (T) values (at Salakpur, the project well T of 261 m^2/d is near an ADBN well with T of 2 793 m^2/d, in similar lithology), there seems to be a moderately high transmissivity overall. For a 19 well sample,

- 6 have T < 1 000;
- 8 have T of 1 000 to 2 000; and
- 5 have T > 2 000.

It can be concluded that almost the entire shallow zone south of the highway is classed good on grounds of lithology and transmissivity, and S1 for development.

There are no data north of the highway except for a STW census mapping by United Designers, 1989; their work indicates that there are almost no STWs north of the highway. Accordingly, the area has to be classed as marginal for STWs, and D4 for development generally.

For May 1991, the UNDP monitoring established shallow water levels everywhere; no stations exceeded 3.5 m bgl; in many areas, large evaporative losses must occur from the very shallow watertable (and hence STW intensive development might have a benefit in watertable control). May 1988/89 water level data however show a small area where depth to water is greater than 5 m in the west-northwest.

Deep Aquifer

The deep aquifer database is from 16 GWRDB drilled DTWs and five other DTWs, some of which may have been drilled by the Koshi project. These wells were all drilled south of the highway.

In the northwest and centre, several DTWs have small positive heads which allow delineation of a flowing artesian zone (possibly continuous with the artesian zone in Sunsari). In this area, heads are small and may rapidly fall as wells are discharged.

It appears that the area is not well connected to recharge areas in the Bhabar zone and is of local, rather than regional importance.

The data indicate that, over much of the district, a high percentage (52%) of the deep section is screenable material, while higher aquifer percentages seem to occur in the west and southwest, where the Sapta Koshi has contributed coarse fan material to the section, and in the northeast where coarse fan material from the Ratuwa River, has entered the section.

Generally, transmissivities are in the range 10 to 900 m^2/d, while locally these may exceed 1 000 m^2/d. However, there are insufficient data to precisely class the area, so the district is therefore classed marginal for DTWs (hence D3 for development), except for areas of possible fan material, which are classed as fair.

2.6.5 Jhapa

Shallow Aquifer

Except for northern fringe areas, the whole of Jhapa is classed in lithological terms as good for STWs.

The UNDP generally established that there was 58.9% of permeable material in the shallow sections cut by the 21 project STWs, the highest recorded in Terai. They carried out pumping tests on project STWs and some ADBN STWs and established that the shallow zone has generally permeable sediments with sufficient transmissivities (average 600, range 211 to 1 140 m^2/d), although some lower end transmissivities are ascribed by the UNDP to construction faults, screen blockage or screen misplacement.

Water levels in the district are generally shallow pre-monsoon, and do not exceed 5 m, except in the far north in the Bhabar zone; annual water level fluctuation are invariably less than 3 m.

In development terms, almost the entire area has good lithology and shallow watertables, and is therefore classed as S1 for development purposes. It is only in the extreme north of Jhapa, in the Bhabar zone, that deeper water levels and possible drilling difficulties reduce the development class to S2/S0.

Deep Aquifer

Information on the deep aquifer zone is derived from 16 GWRDB DTWs scattered over the district, and also from recent data from 15 exploration boreholes drilled by JICA in southeast Jhapa.

The GWRDP bores, which were up to 130 m deep, indicated only moderate transmissivities (average 660 m^2/d, range 45 to 1 750 m^2/d, at test discharges around 40 l/s; these data would indicate marginal conditions for DTWs. The JICA data are more complete although restricted to the south-southeast of Jhapa. It tells us that there is apparently an exceptionally high percentage of screenable material in the section (quite atypical for the Terai and possibly affected by sampling bias), even down to 250 m, as follows:

- interval 0 to 50 m, average 65%;
- interval 50 to 100 m, average 59%;
- interval 100 to 150 m, average 53%;
- interval 150 to 200 m, average 56%; and
- interval 200 to 250 m average 69%.

The JICA boreholes were screened in this section at different depth intervals, between 57 m and 248 m, and there is a clear trend of decreasing permeability with screen setting depth. However, average permeabilities are around 25 m/d, range 10 to 66 m/d and average transmissivities are

930 m²/d (range 300 to 2 700 m²/d). These data indicate a deep aquifer of moderate productivity which is classed fair on transmissivity grounds.

The apparent discrepancy between the GWRDB and JICA data sets may be due to different construction practices. In this respect, the JICA results are considered more reliable.

Accordingly, the aquifer is classed fair (D2 for development), except in the north margin where data are lacking (lithology classed marginal, hence D3 or D4 in deep water level areas) and in the west about the Kankai River, where the data are also poor (lithology classed marginal, D3 for development).

There are no data on heads in the deep aquifer, although some artesian flows are reported.

2.7 Artesian Aquifer Head Decline

Artesian head monitoring has been carried out by the BLGWP in Rupandehi and in eastern Kapilvastu since 1975/76 at observation points on the margin of, and within, the BLGWP tubewell irrigation areas. The records from 12 boreholes are shown in Figures 2.2 and 2.3. These are distributed as follows:

- seven from the BLGWP Stage I area (W/38, W/34, W/42, W/63, W/57, W/40, W/39); since this area is in production, all piezometers may be affected by pumping; W/38 in particular appears to be a production well used for piezometric observations;
- two from Stage II-2 areas (R1/2, R2/1); and
- three from south of the BLGWP area (R2/9, 5/2, 5/5).

The detailed abstraction history of the area cannot be reconstructed from the available records. Pumped abstractions have progressively increased, but there is no usable record of abstractions since the start of production while uncontrolled free flows are not measured. Abstraction history cannot therefore be reliably correlated with the piezometric record.

The piezometers 5/2 and 5/5, since they are most distant from the production area and have the longest record, are thought to be most representative of the behaviour of the system. They generally show a head decline of 9 to 10 m since 1971, when observations started following the USGS drilling programme. The decline consists of an initial rapid but exponentially decreasing head decline in the period 1971 to 1981, possibly reaching a near equilibrium state (roughly corresponding to free flow discharge from an increasing number of DTWs). An increase in pumped abstractions through 1983 to 1993 has probably been responsible for a further decline to a new equilibrium level, and for the last 3 years, heads have stabilised at 0.5 to 1.7 m above ground level (agl).

In the Stage I and II areas, the majority of monitoring points have lost several metres of head since measurements started, but now appear to be near to a stable level, at around 1 to 3 m agl. Heads in the piezometers in the Stage II area, where production build up is currently occurring (R1/2, R2/1), continue to lose head.

These trends suggest that over a 10 to 15 year period, the confined system head about the BLGWP has stabilised at around 1 to 3 m agl. The initial or steady state condition of the system was not observed, but the 1971 head data shown for 5/2 and 5/5 (where 9 to 10 m of head have been lost from an initial 10 to 11 m head) are thought to be close to an initial condition.

It is important that the pressure system continues to be observed as Stage II and Stage III tubewells are brought into production to determine if there exists a new equilibrium at the final, full development production rate.

On present evidence, it is likely that initial heads exceeding 5 m agl will now be rare in the BLGWP area, and that initial heads will invariably decline to 1 to 3 m agl. This suggests that high weight drilling fluids may not now be needed to control high artesian pressures in Kapilvastu and Rupandehi. It further suggests that free flow DTW designs cannot be considered; as at present, pumped DTW designs should be designed with an upper well casing sized for heads close to surface datum.

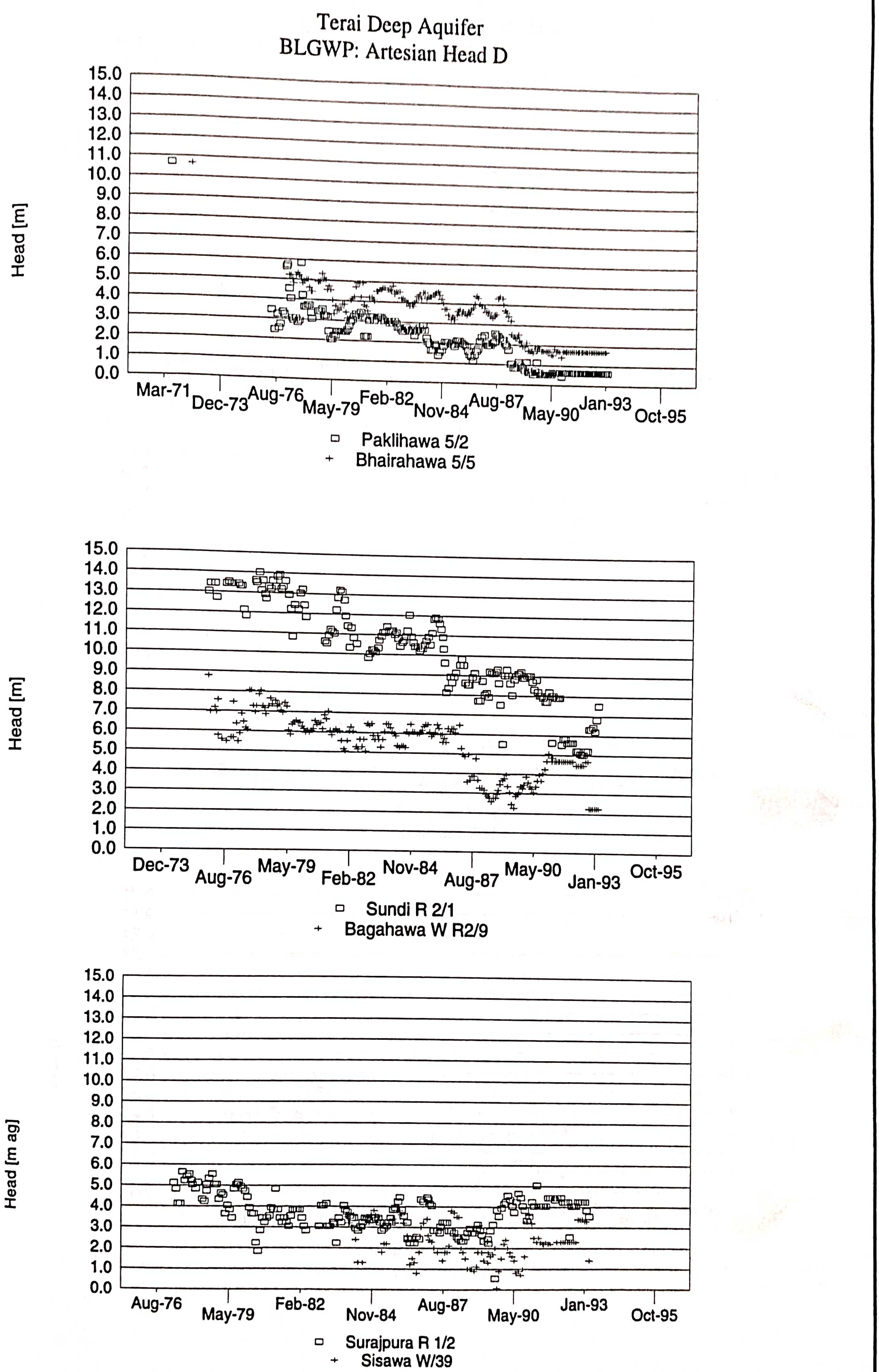
2.8 Water Quality

It appears that little routine water sample collection and analysis has taken place since the USGS work in 1969 to 1971 and the early production drilling work of the BLGWP. The main body of data is from these sources (Table 2.1). Samples are generally from the deep aquifer zone. All were apparently laboratory analyses and no well head analysis, for unstable ions and dissolved gases was done.

These analyses consistently indicate a mildly alkaline groundwater, rich in bicarbonate and calcium/magnesium. Average salinity is low (320 mg/l) and conductivity 470 micromhos. The data show no consistent chemical variation with screen depth, or from north to south across the Terai.

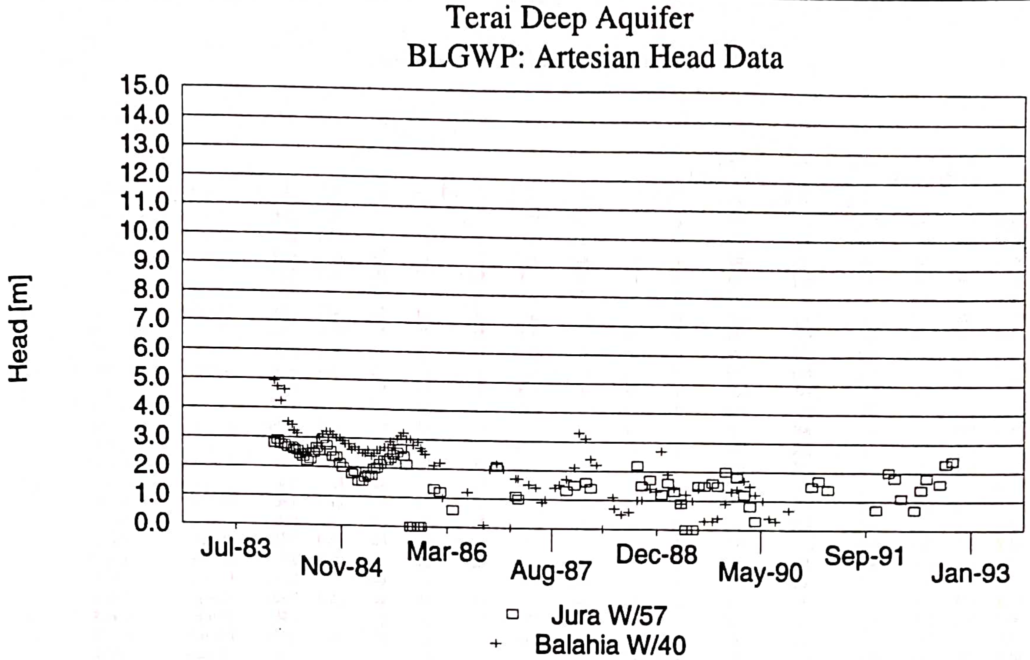
The alkalinity hazard index of sodium adsorption ratio (SAR) of these waters is generally very low (less than 2), and much below the 7.5 threshold where alkalinity is considered in problems in soil management. A few analyses (Bheri 3/3, 3/4) apparently show a deteriorating quality through elevated sodium and high SAR (but chloride is not high). Although these are not from the deep aquifer zones, they certainly do not conform to the general conclusion that all these waters are of excellent irrigation quality. Although there are few analyses from the shallow aquifer, this zone is in a direct recharge path and is likely to contain groundwaters somewhat less salinised than those of the deeper aquifer layers.

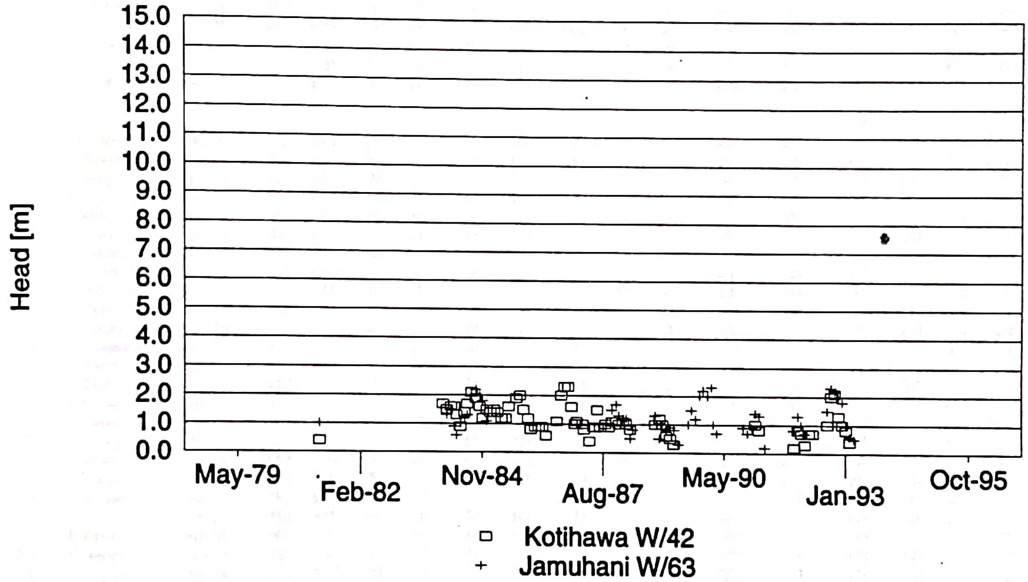
Terai Deep Aquifer BLGWP : Head Data



afig-2-2.gem

Terai Deep Aquifer BLGWP : Head Data





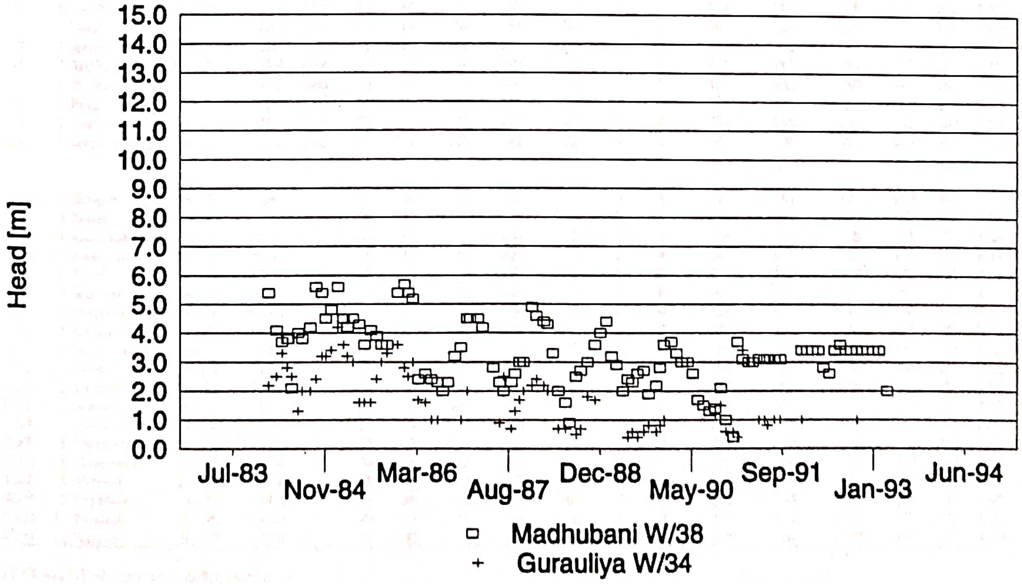


TABLE 2.1

Terai Aquifers : Chemical Analysis

(ions, mg/lit)

Zone	Well Nr	Location	Date	Depth to Aquifer (m)	Fe	Ca	Mg	(calc) Na + K	HCO3	So4	Cl	CO3	Total Dissolved Solids	Total Hardness CaCO3	Calc Hardness CaCO3	Alkality	EC (25 C)	pH	SAR	HCO3 Hazard
Bheri	1/1	1 Piprahawa	Feb-73	34.1	0.01	107	1	-	192	NIL	8	0	316	269	271	157	271	7.90	-	-
Bheri	1/2	2 Daspurwa	Mar-73	12.5	0.01	68	18	3	296	NIL	6	0	552	224	244	243	466	8.10	0.06	-
Bheri	1/4	4 Halbaldoli	Jan-73	62.8	0.00	97	1	5	296	NIL	6	11	406	244	246	261	426	8.50	0.08	0.30
Bheri	1/5	5 Kamdi	Mar-73	114.3	0.04	20	41	22	316	NIL	5	0	322	218	219	269	488	7.30	0.34	0.81
Bheri	1/7	7 Manda	Apr-73	71.6		40	30	60	422	NIL	6	0	398	222	223	346	683	8.00	1.59	2.46
Bheri	1/8	8 Udai	Mar-73	63.7	0.00	22	12	21	160	6	3	0	208	106	104	141	255	8.50	0.60	0.74
Bheri	2/1	1 Jamunaha	Dec-72	124.7	0.00	8	41	99	402	26	38	26	642	187	189	372	918	8.90	3.95	3.69
Bheri	2/3	3 Pan. Trn. Cr.	Jul-73	43.0	0.80	8	31	64	326	NIL	5	8	340	148	148	267	569	8.60	0.26	2.66
Bheri	2/6	6 Police Trn Cr.	Jan-73	99.4	0.00	67	1	124	458	28	24	2	872	168	171	444	979	8.00	4.85	5.48
Bheri	2/8	8 Ranjha		107.3		7	26	119	414	18	18	10	504	196	124	339	598	8.50	1.12	4.63
Bheri	2/9	9 Army Camp Ranjha		46.6		40	30	137	614	4	7	0	646	222	223	503	738	7.20	1.49	5.59
Bheri	2/11	11 Kohalpurwa	Feb-73	210.3	0.00	12	21	91	314	29	11	0	324	104	116	257	488	8.20	2.36	2.82
Bheri	2/12	12 Thukali	Dec-73	128.0		78	29	6	388.0	4	4	0	384	316	314	318	523	7.10	-	0.02
Bheri	3/1	1 Sanik Gaon	Nov-73	43.3		36	27	132	576	NIL	15	0	704	202	201	472	837	7.50	1.42	5.42
Bheri	3/3	3 Odarapur	Apr-73	58.2	0.00	29	22	186	604	58	6	0	596	162	163	495	1025	8.10	5.46	6.64
Bheri	3/4	4 Agri Farm	Feb-73	30.5	0.10	8	21	216	656	33	9	56	722	108	106	630	1175	9.00	9.34	8.62
Bheri	3/5	5 Agri Farm	Feb-73	93.0		20	27	70	372	NIL	6	0	368	161	161	305	513	8.30	1.27	2.88
Bheri	3/8	8 Modaha	Mar-73	57.9	0.01	88	0	-	216	NIL	5	8	230	220	220	190	326	8.50	0.01	-
Bheri	3/10	10 Amohia	Mar-73	7.0	0.04	15	22	60	304	NIL	5	0	430	126	128	249	513	7.90	2.27	2.42
Bheri	4/1	1 Kanthpur	Apr-73	115.8		68	18	3	296	NIL	6	0	552	244	244	243	466	8.10	0.06	
Bheri	4/2	2 Daurah	Apr-73	108.5	0.00	40	20	86	440	NIL	8	0	616	182	182	361	609	8.10	1.81	3.57
Bheri	4/5	5 Dhakela	Apr-73	38.1		23	32	38	320	NIL	6	0	352	188	189	262	569	7.60	1.39	1.47
Bheri	5/1	1 Ubdraoyr	May-73	125.0	0.01	75	40	-	400	NIL	6	0	386	354	352	354	539	7.80	0.01	-
Bheri	5/2	2 Belbhar	May-73	79.2		13	79		194	162	8	14	220	143	358	143	293	8.60	0.01	0.62
Bheri	5/4	4 Belbhar	Jun-73	69.5	0.60	76	0	36	242	11	6	0	280	190	190	190	367	8.20	0.01	0.18
Bheri	5/5	5 Jabdahawa	Jun-73	82.3	0.00	23	28	95	450	NIL	8	0	466	174	173	316	603	7.80	1.97	3.93
Bheri	6/1	1 Taratal	Jun-73	81.4	0.00	22	21	46	270	NIL	9	6		138	141		243	8.50	0.92	0.37
Bheri	6/3	3 Beluwa	May-73	78.9	0.05	49	22	76	238	168	8	0	304	214	213	214	478	7.90	0.35	-
Bheri	6/5	5 Bhurkia	May-73	68.3	0.08	29	22	19	204	22	6	4	220	264	163	264	331	8.40	0.01	0.16
															0					
Set/Mah	1/1	1 Durganli	May-74	15.2	0.00	81	2	45	340	10	15	0	298	210	210	279	533	7.50	0.78	1.37
Set/Mah	2/1	1 Bhanjani	May-74	72.8	0.01	36	24	75	364	43	6	0	286	190	189	298	533	8.00	1.14	2.20
Set/Mah	2/2	2 Joshipur	May-74	41.8	0.04	69	1	62	386	29	10	0	244	178	176	267	436	7.70	0.63	1.82
Set/Mah	2/3	3 Semri	May-74	67.1	0.00	64	26	53	410	37	8	0	308	270	267	336	600	7.50	0.41	1.39
Set/Mah	2/4	4 Semri	May-74	18.0	0.00	101	24	37	454	43	8	0	500	350	351	372	738	7.80	4.42	4.97
Set/Mah	2/6	6 Semri	May-74	40.2	0.01	88	14	58	446	27	9	0	336	280	277	366	600	7.50	0.28	1.77
Set/Mah	3/1	1 Basante	Jun-74	47.2	0.01	42	15	93	394	32	8	0	196	166	167	323	505	7.50	1.33	3.13
Set/Mah	3/2	2 Katanipur	Apr-74	39.6	0.02	44	6	74	314	24	10	0	240	136	135	257	400	7.80	1.13	2.46
Set/Mah	3/3	3 Bijayapur	May-74	83.8	0.00	59	0	76	334	20	13	0	248	148	147	274	480	7.70	1.53	2.53
Set/Mah	3/5	5 Sisaiya	Apr-74	175.3	0.01	57	2	79	340	24	9	0	254	150	151	284	487	7.50	1.29	2.57
Set/Mah	3/7	7 Sisaiya	May-74	17.1	0.00	44	20	39	298	18	9	0	270	190	192	244	384	7.90	-	1.03
Set/Mah	3/8	8 Ganashpur	Apr-74	80.2	0.04	48	13	28	248	21	9	0	210	176	173	203	343	7.90	-	0.59
Set/Mah	4/1	1 Phulverria	Apr-74	77.7	0.02	59	18	102	432	70	10	0	334	220	221	354	565	7.80	0.83	2.66
Set/Mah	4/2	2 Gadriya	Apr-74	66.8	0.22	56	10	60	366	5	4	0	250	180	181	300	544	7.20	1.36	2.39
Set/Mah	4/3	3 Banda	Apr-74	86.0	0.00	70	1	82	356	44	12	0	258	178	179	292	457	7.80	0.75	2.27
Set/Mah	4/5	5 Dhabai	Apr-74	89.9	0.02	62	7	53	302	38	9	0	244	184	184	248	436	7.80	0.52	1.29
Set/Mah	5/1	1 Dhangarhi city	Feb-74	36.0	0.01	57	7	55	324	18	5	0	248	172	171	266	469	7.40	0.97	1.89
Set/Mah	5/3	3 Dhangari W T	Feb-74	108.8	0.04	60	10	41	334	0	4	0	228	190	191	274	492	7.40	0.80	1.66
Set/Mah	5/4	4 Dhangari W T	Jun-74	92.0	0.04	59	3	37	286	0	5	0	232	160	160	234	544	7.30	1.78	1.50
Set/Mah	5/5	5 M Camp	Jun-74	78.3	0.02	41	16	40	264	24	10	0	182	170	168	216	384	7.70	0.36	0.95
Set/Mah	5/7	7	Feb-74	85.6	0.00	44	1	64	242	43	8	0	342	166	114	198	331	7.70	0.96	1.69
Set/Mah	5/8	8 Autaria	Feb-74	116.4	0.00	21	10	38	158	32	9	0	106	94	94	129	196	8.20	0.09	0.72
Set/Mah	5/9	9 Teghari	Feb-74	76.2	0.00	45	16	24	240	20	9	0	186	178	178	197	345	7.60	-	0.36
Set/Mah	6/2	2 Cha Goan	Mar-74	82.0	0.04	30	23	44	288	12	14	0	252	172	170	236	369	8.20	0.23	1.35
Set/Mah	6/3	3 Amaraiya	Feb-74	45.7	0.01	42	17	46	316	8	5	0	216	176	175	259	417	7.90	0.51	1.68
Set/Mah	6/4	4 Kaspa	Feb-74	67.7	0.02	89	4	58	418	11	8	0	320	240	239	343	600	7.70	0.80	2.08
Set/Mah	6/5	5 Dekhatbhuli	Mar-74	87.5	0.00	32	14	17	200	5	6	0	116	140	138	164	282	8.10	0.06	0.53
Set/Mah	6/6	6 Bandi	Mar-74	71.6	0.01	24	14	16	168	9	4	0	124	118	118	138	240	8.30	0.05	0.40
Set/Mah	7/1	1 Pachui	Mar-74	88.7	0.01	54	19	54	366	24	5	0	304	216	213	300	565	7.80	0.96	1.75
Set/Mah	7/2	2 Amlia	Mar-74	83.5	0.00	31	24	26	270	9	5	0	190	182	176	221	384	8.20	-	0.06
Set/Mah	7/5	5 Bichhuwa	Mar-74	14.9	0.06	53	5	46	292	0	9	0	232	152	153	139	449	7.50	1.17	1.74
Set/Mah	7/6	6 Bichhuwa Jhal	Mar-74	87.5	0.00	76	36	9	416	8	4	0	320	336	338	341	505	7.50	-	0.07
Set/Mah	7/7	7 Patia	Mar-74	60.0	0.00	46	26	28	312	20	5	0	220	224	222	256	457	8.10	0.09	0.67
Set/Mah	7/8	8 Sudha	Apr-74	36.3	0.04	90	27	36	466	24	5	0	394	336	336	382	689	7.40	0.10	0.95
Set/Mah	8/1	1 Mahendranaga	Apr-74	15.8	0.00	113	1	100	568	25	9	0	482	298	286	466	738	7.30	0.98	3.59
Bhairahawa	4/2	2 Sitlapur	Dec-76	244		31	28	10	246	8	3	0	270	192	193	157	386	8.20	0.31	0.18
Bhairahawa	4/3	3 Belahia	Jun-77	79.3		16	27	15	204	10	5	0	260	152	151	167	250	8.00	0.52	0.30
Bhairahawa	R1/8	8 Ramnagar	Jun-77	93.33		24	31	19	254	2	5	8	200	190	188	215	329	8.50	0.58	0.36
Bhairahawa	R2/10	10 Saphigaon	Jun-77	70.45		14	31	15	206	6	5	8	200	164	163	175	256	8.60	0.49	0.10
Bhairahawa	6/7	7 Semri	Jun-77	153.3		24	24	5	184	NIL	5	8	220	160	159	157	267	8.50	0.18	-
Bhairahawa	8/2	2 Muglaha	Jun-77	301.03		18	15	46	228	13	5	0	260	108	107	187	288	8.10	1.91	1.58
Bhairahawa	8/2	2 Muglaha	Feb-78	301.03		50	15	53	340	13	6	0	298	186	187	279	514	8.20	1.68	1.85
Bhairahawa	8/3	3 Muglaha	Feb-78	164.39		49	15	42	324	2	6	0	302	184	184	266	491	8.10	1.35	1.64
Bhairahawa	8/4	4 Sarahawa	Jun-77	152.5		14	34	8	208	0.8	5	8	200	174	175	177	256	8.60	0.27	-
Bhairahawa	R2/1	1 Sundi	Jun-77	117.9		17	19	11	158	6	5	0	180	120	121	130	205	7.90	0.42	0.20
Bhairahawa	R2/2	2 Bharbalia	Jun-77	71.37		34	28	9	260	NIL	5	0	280	200	200	213	311	8.20	0.28	0.26
Bhairahawa	R2/3	3 Sonbarsi	Jun-77	80.5		14	33	NIL	180	2	5	0	140	170	171	148	230	8.00	-	-
Bhairahawa	R2/4	4 Govrauri	Dec-76	97.6		20	25	27	248	2	3	0	246	151	153	124	289	8.20	1.37	1.01
Bhairahawa	R2/5	5 Chamartola	Dec-76	100.65		26	8	59	265	5	5	0	360	100	98	82	515	8.20	2.59	2.39
Bhairahawa	R2/6	6 Chirpurwa	Jun-77	125.9		34	25	23	258	2	5	10	260	186	188	220	319	8.50	0.45	-
Bhairahawa	R2/8	8 Shihawa	Jun-77	115.8		22	29	6	202	NIL	5	10	200	174	174	174	267	8.60	0.23	
Bhairahawa	R2/9	9 Bagahawa	Jun-77	111.2		11	29	36	188	44	5	12	200	148	147	164	267	8.60	1.30	0.12
Bhairahawa	R2/10	10 Bhujauli	Feb-78	136.64		40	17	65	340	22	6	0	324	168	170	279	471	8.20	2.19	2.21
Bhairahawa	R2/11	11 Nanaulia	Jun-77	125.6		24	33	5	220	NIL	5	20	220	206	196	197	295	9.00	0.14	-

Data from BLGWP and USGS exploratory drilling programme

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However, considerations on the aquifer flow mechanism and the evidence of isotopic studies suggest that groundwater velocities should decrease and residence time increase with depth in the Terai aquifer pile. It is speculated that more saline, chloride-sodium bicarbonate rich groundwaters, possibly with low acid pH and dissolved CO_2, may exist in the deep aquifer. Such groundwater would certainly be corrosive to mild steel, and may be implicated in screen blockage and reducing well specific capacities reported for some Terai DTWs. Some well head chemical analysis of discharge from deep screened wells would allow confirmation of such corrosive deep waters, and allow utilisation of corrosion resistant well screen materials.

CHAPTER 3

DEEP TUBEWELL STUDIES

3.1 Introduction

For groundwater irrigation development in the Terai to be successful, it is essential that the tubewell designer and constructor implement a tubewell of sound design which delivers water at minimum practical cost and lives a long life. Reasonable requirements of the designer and tubewell constructor are that:

- tubewells are reliable and of long life;

- tubewells follow good standard design practice, consistent with local availability of materials and equipment and with contractor capacity;

- tubewell costs should be kept at a minimum, consistent with sound design and the farmers' ability to pay for the well;

- tubewell design and configuration are consistent with natural aquifer water levels and fluctuation; and

- tubewell performance is consistent with local aquifer permeability; defective well design and screen development leads to under-performing wells due to excessive water level drawdowns; although he may not always appreciate it, the farmer (or the project) would therefore be burdened with unnecessary extra pumping costs throughout the life of the tubewell.

In this present strategy review, groundwater engineering studies are used to define a least cost, practicable DTW design or range of designs for the Terai; these studies involve the following:

- design yield;
- pump type;
- well configuration and hydraulic design;
- borehole construction methods;
- operation and maintenance; and
- economic optimisation.

There is generally a range of design solutions, some of which reflect the ideal or possible and some reflect the present experience. A consistent theme in assessing design decisions is whether the choice is a largely reactive one imposed by circumstance or a genuine choice out of a range of options.

The methodology adopted is to develop a series of model type designs, and examine the economics and optimum performance of each design over a range of parameters covering the expected hydrogeological variations in the Terai.

However, there are many aspects of well design where the ultimate choice may be dictated by broader social and economic issues. The choice of diesel or electric power is an example of this, as preferred solutions range from government operated and managed high capacity electric driven wells to small capacity diesel wells where the inherent flexibility and mobility will be more valuable to some farmers than low financial operating costs. The economic comparisons herein are restricted to direct costs.

In this chapter, the present design, construction practice and well performance characteristics of Terai DTWs are discussed, then in Appendix V on groundwater engineering, we give basic well design criteria and completion methods. Tubewell design optimisation is discussed in the following chapter.

3.2 Current Terai Tubewell Design, Construction and Performance

3.2.1 Design and Construction

In current Terai practice by GWRDB and private drilling contractors, deep production tubewells (DTW) for irrigation are drilled to typical depths of 120 to 160 m by direct circulation (DC) and equipped with a single string casing-screen string of mild steel casing and 20 to 45 m of steel screen (generally with 1.6 mm saw slot), with a gravel pack grading 2 to 5 mm or 3 to 8 mm. Casing size is reduced in diameter at the base of the upper or pump chamber casing. Reverse circulation (RC) drilling is also used successfully to drill a few DTWs. Plastics (PVC or ABS) and fibreglass are not currently used.

Designs are configured for production discharges up to 80 to 100 l/s, using force mode pumps (lineshaft or electric submersible turbine). A more shallow variant is the medium tubewell (MTW), typically drilled to depth 60 to 80 m by direct circulation (DC), but sometimes by machine percussion, and equipped with 20 m of screen and a gravel pack. Design is configured for production discharges of about 25 l/s. Force mode pumps are used, although in some ILC areas with shallow watertables, suction pumps are used.

Somewhat different, and often deeper, tubewell designs have been used for investigation purposes, for example the USGS investigation programme in 1969-72, which constructed 100 mm test tubewells to depths up to 305 m, and the current JICA work in Jhapa, where 100 to 300 m tubewells are being installed with successively deeper screen settings.

Some irrigation DTW designs used in the Terai are given in Table 3.1 below and in Figure 1.3. Design and performance data for most Terai districts are tabulated in Appendix I, Tables I-1 to I-16.

Figure 3.1

BLGWP DTW Data

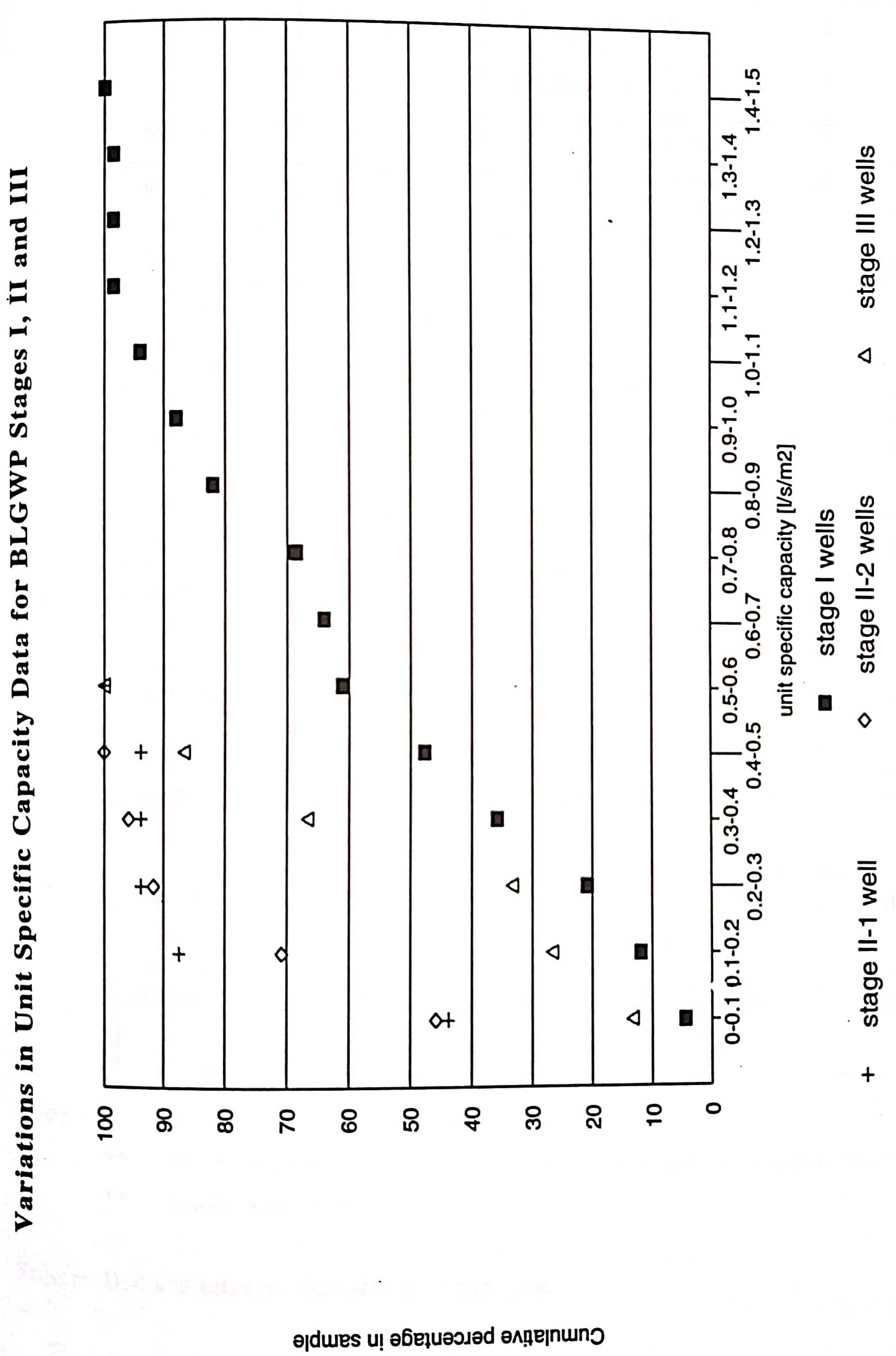

TABLE 3.1

Typical Existing DTW Designs in the Terai

Project	Well depth (m)	UWC (m)	Screen length (m)	Test yield (l/s)	UWC/LWC diameter (mm)	Specific capacity ((l/s)/m))
			(average parameters)			
NZIDP	142	53	41	69	350/250	12.9
Birganj	136	50	37	67	400/250	9.8
BLGWPI	141	43	55	135*	350/200	26.5
BLGWP II-1	177	47	43	109*	400/250	5.4
BLGWP II-2	140	44	29	82	350/200	2.9
BLGWP III	143	42	18	82	350/250 400/250	5.0
ILC-DTW	112	-	34	38	250/150	7.5
JADP***	141	-	35.7	27.6	350/200 300/200	2.3
Mahottari	137	-	21	23.6	250/200 250/150	3.1
Siraha	114	38	18	79	300/200 350/200	5.5
Sarlahi	89	-	23	49	250/225 300/200	10.9
ILC-MTW**	66		18.3	25.2	250/150 150/150	5.3

Notes
* production yields around 80 l/s
** MTW medium tubewell; defined by ILC as a tubewell < 100 m depth, around 25 l/s;
*** Danusha District

Source: DOI and other project offices in the Terai

The current Terai design is invariably drilled with the DC mud method. While sample control is difficult, the driller tries to identify and screen only coarse sands and gravels, and to avoid finer, but potentially screenable material; no formation grain size analysis, on which one might base screen-pack design, is carried out and natural development is not considered. The design is considered conservative. There is certainly scope for more design flexibility, based on good sampling and formation grain size analysis, a wider choice of screen type and aperture, and possibly on the use of RC drilling methods (which, since they are water flush, avoid formation mud damage, offer good sample control, and offer reduced drilling costs). For as conditions vary through the Terai, it is certain that well design should also.

The tubewells drilled by the Bhairahwa Lumbini Groundwater Project (BLGWP), while not typical of general Terai practice, are instructive as project DTW design has been modified several times (Appendix I, Table I-6). The design has changed from naturally developed, two string Stage I and Stage II-1 designs to the present Stage III single string gravel packed wells, screened with stainless Johnson wire wound rod based (WwRb) screen. BLGWP uses DC mud drilling for DTWs. All bores are geophysically logged, but no formation sampling or grain-size analysis is carried out; screen/pack design appears generally fixed. Air lift and pump development is used on the wells. DTWs are constructed in the depth range of 140 to 170 m, with screens installed in the interval 40 to 170 m.

The changes in design over the project life seem to have been prompted by several factors and apprehensions:

- original high artesian pressures, which required two string completions with pressure cementing of the upper well casings, and drilling mud weighted with barytes, to control artesian pressure; such two string completions were also appropriate to (then) perceived rig capacity which was thought incapable of installing the entire casing screen string. The use of high weight drilling mud continues, although in the BLGWP project area, artesian heads seem to have declined to 1 to 3 m agl;

- screen length based on a 80 to 100 l/s design discharge and a fixed screen entrance velocity criterion; screen aperture choice has normally been restricted to 1 and 1.6 mm;

- in Stage II-2 areas, there was frequent well failure because of sand ingress, and consequently, gravel packs were adopted as a safety measure, although their installation was often defective (sand ingress may have been a consequence of using a design appropriate to the coarser formation conditions in Stage I areas in the finer formation in Stage II-2 areas; despite the continued use of gravel packs, several of the Stage III wells have high sand ingress, and pack-screen design may be implicated;

- the current design is a single string completion (apprehension about rig capacity has been overcome), with Johnson type screens with 1.0 mm to 1.6 mm slots opposite a 2 to 8 mm gravel pack; screen-pack design does not seem to be based on any routine formation grain size analysis; and

- subsequent experience has indicated that original well discharges applied to 120 ha command areas gave an irrigation unit too large for good water management by some farmer groups; current Stage III DTWs are designed for 300 m^3/h discharges.

3.2.2 DTW Performance

Performance data for the majority of DTWs in the Terai are given in Appendix I, Tables I-1 to I-16. Performance is generally reported in terms of a well productivity index (specific capacity (SC) or the inverse, specific drawdown) of transmissivity and of permeability. In an attempt to assess the performance of the well screens, two indices are tabulated: specific capacity per unit screen length and discharge per unit screen length.

The data generally show a very large range in well performance, expressed as specific capacity or as transmissivity. In Mahottari District for example (Appendix I, Table I-10), average specific capacity is 8 (l/s)/m but the range is between 0.1 and 39 (l/s)/m; the SC values of less than 2 (l/s)/m (38% of the sample) are not consistent with descriptions of coarse sand/gravels screened by the well. The implication is that either the descriptions are optimistic or the well screens are partially blocked or misplaced.

Data for the Dhanusha District show that for 33 irrigation DTWs, average SC is only 2.3 (l/s)/m with a narrow SC range of 0.2 to 5.7 (l/s)/m (Appendix I, Table I-12); this average value is considered very low and inconsistent with the sands and gravels reportedly screened by an average of 35 m of screen.

It is evident that such specific capacity data and transmissivity estimates for the deep aquifers cannot be adopted uncritically since many values tell us more about defective well construction and consequent head losses through incorrect casing/screen diameters and screen blockage than about the formation screened by the tubewell. Screen blockage can be inferred, for example, where very low well transmissivities occur in tubewells screened opposite clean coarse sands and gravels. A particular difficulty arises where transmissivity estimates are used as the basis of the area lithological classification for tubewells (Chapter 2).

Construction and performance of BLGWP DTWs is well documented; data are given in Appendix I, Table I-6 and in the summary table below (Table 3.2).

It is significant that while average Stage I DTW specific capacities were 27 (l/s)/m, current BLGWP Stage III wells have specific capacities of around 5 (l/s)/m (and only 2.9 (l/s)/m in Stage II-2 wells). A graph of unit specific capacity distribution (SC, specific capacity per unit length of screen, a well productivity index) for wells in each Stage of BLGWP (Figure 3.1), show a decline in the median SC from Stage I through Stage III. Another trend can be detected in the value of discharge per unit screen length, a direct indicator of screen transmission efficiency; this declines from Stage I to Stage II-2, but increases in Stage III wells.

TABLE 3.2

Summary of BLGWP Deep Tubewells Construction Data

Stage/ Phase	Nr of DTWs	Nr failed	Free flow (Nr)	Pumps installed (Nr)	Irrig area (ha)	Design Q (m3/h)	Design type	Comment	Sample size (Nr)	Ave. depth (m)	Depth of UWC (m)	Ave screen (m)	Test yield (m3/h)	Spec cap (l/s/m)	Spec DD (m/l/s)	Kd (m3/d/m)	K screen (m/d)	SC/screen length (l/s/m2)	Q/screen length (l/s/m)
I	69	5	23	62	7 500	400	Natural devt; 2 string; 400/250 mm	Channel systems in commission; seasonal free flow (to Nov) in 42 DTWs.	65	143.9	43.9	54.7	493	27.1	0.1	3 089	64	0.56	2.77
II/2	18	2		16	1 850	300	Natural devt; 2 string; 400/250 mm 400/250	Channel systems in commission; Both slotted MS pipe, galvanised wwrb and stainless Johnson wwrb screen used.	16	177.2	47.0	43.4	395	5.4	0.3	611	13	0.12	2.31
II/2	37	15			4 600	300	Gravel pack, 2 string	Piped systems; 16 DTWs in commission Sand ingress; failures common due to poor pack installation, tremie problems & artificial gravel pack problems; 17 wells redrilled. Apprehension about rig capacity. Few free flowing wells.	23	140.1	43.8	29.5	296	2.9	0.3	331	12	0.09	1.86
III	18	?	?	0		<= 300	11 are gravel packed; 1 string design: 400/250; 300/200; 350/250	79 DTW target in 5 years Design Q according to farmer demand/ agreement; probable range 150 - 400 m3/h). 350/200 OK for 300m3/h, else 350/ 250; 300/200 for 60ha units Screen aperture 1.6mm (1/16in) nominal	19	142.8	41.6	18.0	298	5.0	0.2	568	33	0.23	3.39
Totals	142	22		78															

Source: BLGWP DTW construction data; April 1993

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These performance changes are probably explicable in terms of a combination of factors:

- a change in aquifer material in Stages I, II and III development areas (reported "sand" percentage in the production interval has also declined, from 63% in Stage I to between 27% and 42% in Stage II wells);

- screen-pack design may not be appropriate to Stages II and III formation, while drilling practice and development methods may not fully clean and develop well screens-gravel pack zone, particularly for those deeper set screens; and

- changes in screen type.

The reductions in SC and unit SC essentially indicate declining well productivity, and hence increasing pumping costs. One of the causes is thought to be formation damage and partial blockage of the screen-pack-formation zone, by heavy drilling mud and cuttings; damage may be exacerbated by the long drilling mud residence time (over 12 days in the typical BLGWP DTW) required for mud DC gravel packed designs. Without effective mud breakdown and high energy development at the screen face, blockage of the screen and the pack-screen annulus will cause high head losses and increased well drawdowns. This effect may be in addition to falls in formation permeability caused by a regional deterioration in the permeability of the aquifer formation in the Stage II and III areas. It is difficult to evaluate formation permeability changes since sampling from the DC mud stream is difficult, and no formation grain size analyses are available.

Discharge per unit screen length falls from Stage I to II-1 and II-2 and may reflect screen clogging while the high value in Stage III (3.4 (l/s)/m) probably reflects the use of high open area, stainless steel WwRb screen, together with improved pack emplacement achieved in Stage III work.

As the designer uses more screen, even if as in this case, the use of WwRb type screen has now replaced saw-slot pipe, there should be a trend to reducing drawdown (and a parallel increase in SC). Yet although very different lengths of screen were used in Stage I (55 m), Stage II-2 (30 m) and Stage III (18 m), there is no correlation between screen length and SC (Figure 3.2). This suggests that even in the longer screen strings, blockage has occurred and transmission is only occurring along a limited part of the screen.

There is also some field evidence, from current JICA-GWRDP work in Jhapa, that the specific capacity of deep screened wells is lower than those of designs with shallow set screens; an indication that it may be difficult to fully develop deep screens (Figure 3.2).

Some similar problems seem to be occurring in DTWs and MTWs drilled under the Kapilvastu Tubewell Project (KTP) under Irrigation Line of Credit (ILC); some data are given elsewhere (Appendix I, Table I-5). ILC is completing mud drilled, gravel packed DTWs and MTWs configured to yield 30 to 40 l/s and 20 to 30 l/s, respectively. The tubewells have mild steel casing and saw slotted steel screens typically set in the range of 50 to 112 m depth.

Although average specific capacities of ILC wells are between 5.3 (l/s)/m (for MTWs) and 7.5 (l/s)/m (for DTWs), there is a wide variation in SC which has no obvious explanation in terms of formation sample description or screen material used. Some areas have wells with very low specific capacities (e.g., Jahada MTWs, Valwad DTWs), very low apparent discharges per unit screen length, and screen permeabilities which are not consistent with descriptions of formation screened (by comparison, BLGWP Stage III DTWs typically have SCs of around 7 (l/s)/m). Some ILC data are summarised as follows:

Location	Nr	KS (m/d)	SC ((l/s)/m))	Q/Screen length ((l/s)/m))
MTW:				
all MTWs	28	34	5.3	1.4
Jahada MTWs	10	26	2.6	1.7
Valwad MTWs	9	46	8.5	1.3
Kopwa	7	21	5.7	1.2
Bhal/BAL VDC 8	2	34	5.3	1.4
DTW:				
all DTWs	14	22	7.5	1.1
Sunwal DTWs	4	20	6.9	1.0
Valwad DTWs	3	11	2.8	1.1
Kopwa DTWs	4	32	8.8	1.2
Motipur VDC 1,9	2	-	7.5	1.1

The gravel pack design of these wells is not entirely rational (2 to 5 mm pack grading for 1.6 mm slot size) and may impede effective formation development because no fraction of the pack material can pass the slot.

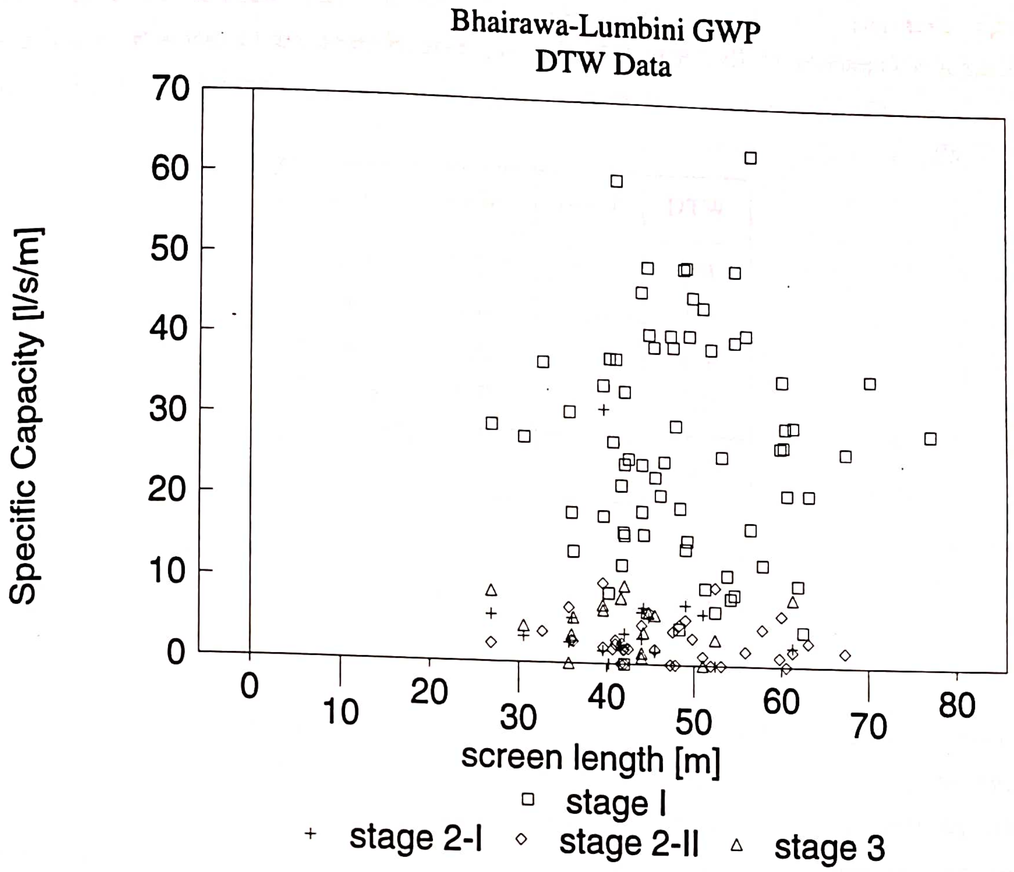
Further, it appears that the development tools available to KTP are of inadequate design or capacity. Some of the air compressors and "jetting" heads used by the KTP are of insufficient capacity to allow working with air below 60 m to 70 m depth; the implication is that no effective air development by compressor is possible at the deeper screen settings used in medium and deep tubewells. To do this, a larger compressor rated 14 to 18 kg/cm^2 pressure and 350 to 600 cubic feet per minute (cfm) volume would be required.

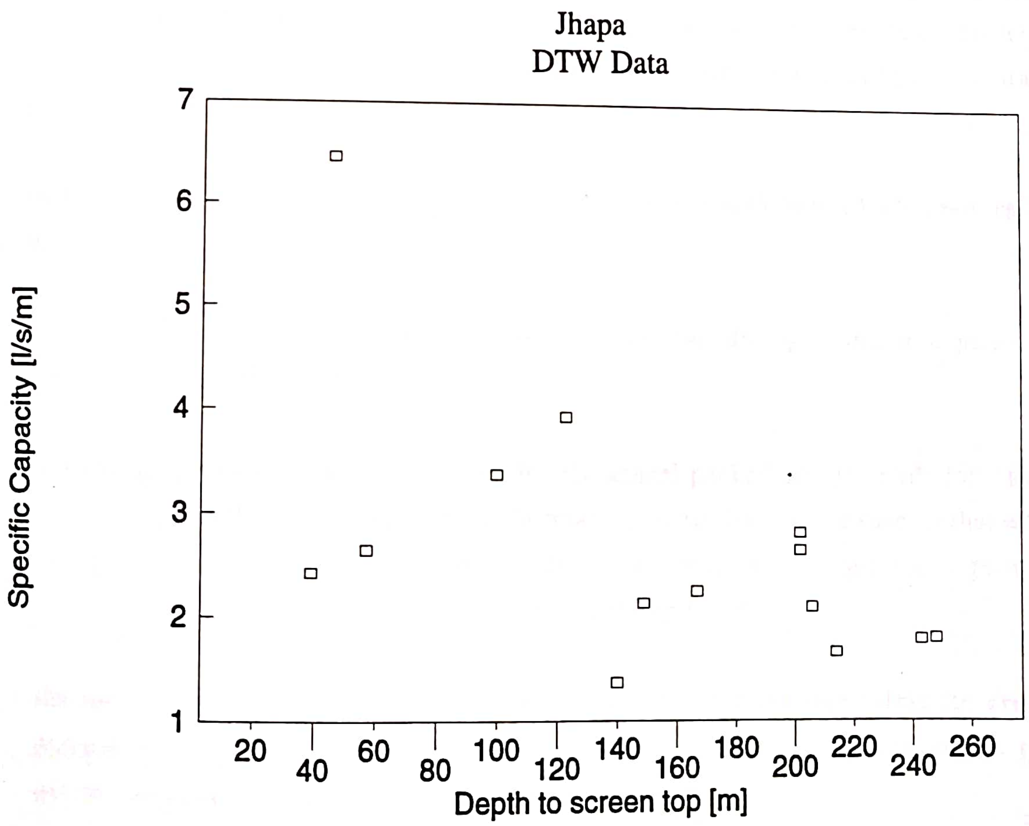
The "jetting tool" in current use, a 50 cm long, 3 inch diameter pipe perforated with many 3 mm holes, used with a rather low capacity pump, is incapable of delivering effective water velocities (up to 50 m/s velocities are required) to the slot-gravel pack zone within the 4 and 6 inch slotted casings used. The tool is better regarded as a low velocity washing tool only.

The possibility that in some ILC wells and in some clusters, well development has been ineffective,

Figure 3.2

DTW Performance





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is supported by step discharge data shown below. In many cases, the test data clearly show some increase in SC as step discharges are increased because the poorly developed well is developing during the test pumping cycle. Such SC behaviour is abnormal, and of the 22 step tests reported in the 1992 ILC KTP work, 12 are unanalysable, precisely because well development is masking well hydraulic effects. As follows:

Cluster	STW	MTW	DTW
Jahada	2*/2**	8/7	1/0
Valwad	0/0	1/0	3/0
Sunwal	0/0	0/0	4/1
Kopwa	0/0	0/0	3/2
Total	2/2	9/7	11/3

Note: * number of step tests

** number not analysable because of well development

It is highly likely therefore that many deeper screens in ILC tubewells are not being cleaned and developed and some may remain blocked by drill debris and mud; this is likely to be one of the causes of low well specific capacities reported at Jahada and Valwad. It is of interest that when step tests were carried out on a series of Jahada MTWs, the tests could not be analysed because well development continued throughout the tests. Clearly, some ILC well development has been defective; wells with screen blockage will have excessive drawdowns and a permanent penalty in pumping costs to the farmer-irrigator.

There are several aspects of current DTW well design and completion which need review or modification:

- the use of drilling mud of excessive weight; this can damage formation permeability, particularly if DTW drilling times are long;

- very large diameter holes are required for the gravel packed designs with 350 mm upper well casings (UWC), needed for 300 m^3/h production discharges; we suspect that where rig mud pump capacity is inadequate for this duty, there may be consequences in poor sample cuttings recovery and excessive drilling and reaming times;

- the use of gravel pack seems to be based on a desire for extreme safety (to avoid sand pumping) rather than rational design; both the current gravel pack design and the possible use of naturally developed designs instead need review;

- some routine formation grain size analysis and a choice of screen aperture size would allow the designer to screen and develop finer formation material, allow some reduction in the length of the production string, and avoid deeper set screen lengths; and

- if a mud drilled DTW is to be completed with gravel pack and deep screens, then effective well development is going to be difficult, particularly in deep screens; equipment depth capacity and lack of correct development tools may be the cause; new equipment may be needed.

3.2.3 DTW Drilling Contractors in Terai

Rig capacity is limited: there are about 45 machine drilling rigs working in Nepal, operated by government agencies and by the private sector. These include direct circulation rotary rigs with 100 m to 300 m depth capacities (sometimes with the capacity to drill with air-foam or bentonite mud), simple machine percussion rigs with 100 m capacity and a single reverse circulation rig. Drilling personnel are also few. Numbers are as follows:

	Government		Private Sector
	DOI	JADP	
Drilling Rigs			
Depth capacity	8	7	3
100 m	6	4	6**
200 m	4	4	3
500 m	18	15	12
total			
Personnel			
Drilling engineers	0	4	10
Drillers	18	0	

Notes: * private sector includes partially HMGN firms such as Nedrill
** includes one reverse circulation (RC) rig

Several important issues are involved in current drilling and well completion practice in the Terai, as follows:

- In the Bhabar zone of the Terai, and in the inner Terai valleys of Dang and Deukhuri, deep watertables and boulder-gravel formations make drilling difficult, by whatever methods. Formation penetration difficulties, casing blockage and failure, and high circulation losses make well completion difficult;

In these areas, both RC and DC rigs work with extreme difficulty (and manual rig contractors generally avoid bouldery areas altogether); the percussion-bailer system, where drilling takes place inside casing and casing is driven, is often successful in these extreme conditions;

- In 1969-71, during the USGS investigation drilling, DC mud drilling successfully handled artesian pressures encountered during drilling; 20 m positive heads were controlled by drilling mud weighted with barytes. In current DTW drilling, it is customary still to use high weight mud, yet, in Kapilvastu and Rupandehi at least, there is monitoring evidence that artesian heads have declined to values close to ground level. Continued use of weighted drilling mud in areas where it is unjustified, contributes to formation damage by deep mud entry into target formation. This can make effective well development most difficult, and almost impossible where the well is gravel packed. A review is needed of the use of high weight drilling mud, particularly in gravel packed wells;

- RC rigs with water flush can only operate satisfactorily in non-artesian zones (although wells have been drilled successfully in mildly artesian areas using RC with mud drilling fluid);

- A single RC rig successfully operates in the Terai where it has drilled over 40 irrigation tubewells to depths of up to 200 m. In optimum conditions (finer formations, watertable below 3 m) drilling times are about twice as fast and drilling costs considerably less than for the DC mudflush method. RC sample control and discrimination allow more precise screen design and placement while the absence of drilling mud makes well development a much easier task, particularly in gravel packed completions. RC methods deserve to be more widely used for tubewell drilling in the Terai;

- Rig ancillary equipment, particularly compressors, jetting and circulating pumps, mud pumps and development tools, may sometimes be inadequate for DTW and MTW designs currently being built in the Terai, particularly where screens are set deep. Suitable jetting tools, capable of high exit velocities, are required and much ancillary equipment, particularly compressors, need upgrading;

- machine percussion rig operators, who are currently working on rural water supply tubewells, appear to lack knowledge of percussion technique, in particular, maintenance of drill bit form or the use of bits appropriate to formation conditions. Some operator training is indicated; and

- currently, mild steel casing with saw cut slots, is in common use for both MTWs and DTWs; use of wirewound rodbased (WwRb) screen, galvanised or stainless, is apparently uncommon. Plastics and composites (GRP, ABS, PVC) are not used for irrigation wells although PVC is being used (in 75 mm and 100 mm diameters) for rural water supply wells: GRP was apparently once used in Birganj, but failed in use, possibly because of mishandling during installation. PVC is locally made (but currently only in 100 mm, 150 mm and

200 mm diameters) and is 50 to 60% cheaper than imported mild steel casing. Introduction of plastic casing and screen into smaller discharge tubewell designs (MTWs) lowers well capital costs; its use needs to be promoted for intermediate depth MTWs.

3.3 Model DTW Designs

3.3.1 General

The preceding discussion of current DTW design practice and resulting performance has indicated where some improvements to DTW design and completion may be needed while in Appendix V, we discuss basic DTW design criteria. These criteria were used together with information on what is currently practicable in the Terai to derive a limited number of standard or model DTW designs.

Chapter 4 examines the economic design of tubewells. The methodology adopted for the study has been to evaluate a wide range of discharges and well configurations using a slight modification of the computer program previously used in the 1987 study (GDC 1987, MMP 1990). The results are expressed as present day cost per cubic metre; i.e., unit cost; and the sensitivity of this cost to the assumed design features then examined. The methodology and results of this sensitivity exercise are described in Chapters 4 and 5.

The standard or model DTW designs have been examined in more detail in Volume 5, Economics, Chapter 7.

3.3.2 DTW Models

For any combination of permeability and percentage screenable aquifer, economic analysis of capital and operating costs for a range of DTW designs and discharges shows that there is an optimum configuration which produces water at least cost. When a range of different discharges are compared, minimum unit water cost is found to be usually derived from tubewells with the maximum possible discharge. However, such discharges may not necessarily be appropriate to farmer needs in the Terai. A desirable practical discharge can depend on other considerations, including available command area and channel losses in the irrigation distribution system. Perhaps most importantly, the discharge has to be easily manageable by a farmers' group as this may have a significant effect on eventual handover. The experience of farmer group organisation and irrigation water management in existing 120 ha commands based on 300 m^3/h DTWs has not been encouraging and certainly suggests that a range of DTWs with much lower discharges, need to be considered as well as the 300 m^3/h DTW design.

Other considerations will affect DTW design in Terai, in particular, the drilling methods used and the design and availability of casing, screen and ancillary equipment. DTWs in the Terai are invariably completed by rotary direct circulation (DC) mud flush drilling, with single string, gravel packed completions; reverse circulation (RC) drilling is uncommon (although there is one working rig which has completed over 40 irrigation tubewells), and natural well development is seldom adopted, although this study has concluded that there are potential advantages to these other drilling methods and design features.

Well designs for detailed analysis were configured around discharges of 90, 60, 45, 30, and 15 l/s. The 90 and 60 l/s discharges correspond generally in Terai terminology to a deep tubewell (DTW), and the 45 and 30 l/s discharges to a medium tubewell (MTW). The 15 l/s discharge model is usually considered a shallow tubewell (STW); the STW, whether drilled manually or by drilling rig, is by definition fitted with a suction pump, although a force mode pump at the same discharge (but termed a MTW) is briefly considered for comparison.

Several basic designs were examined:

- direct circulation (DC) mudflush drilled, gravel pack designs, with a single string completion, mild steel casing and saw cut slotted mild steel screen; it is assumed that the well is built in D2 aquifer development class; this design is close to standard Terai practice and uses easily available steel pipe;

- natural pack designs, DC drilled, in D2 aquifer development class; and

- reverse circulation (RC) drilling, of gravel pack designs (D2 also).

For the lower discharge wells (i.e., the 45 and 30 l/s MTW models), it is considered feasible to install PVC casing-screen strings safely to design depths; at greater depths, practical considerations of casing strength and handling dictate that steel casing must be used. The use of PVC (manufactured in Nepal at diameters of 4 to 8 inches) gives considerable potential savings in capital cost and expected working life as compared to imported mild steel materials. Accordingly, some further optimisation runs were done on MTW designs, using PVC casings and screens.

These designs are summarised in Table 3.3 and also in Figure 3.3.

The DC gravel pack, steel casing-screen model was tested on the assumption that this well design, for all design discharges, would be built in both D1, D2 and D3 aquifer development classes. On the basis of the DTW lithological classification shown earlier in Section 4.2, these classes were set equivalent to percentages of screenable aquifer greater than 0.6, 0.4 and 0.2. For all models, a simplifying restriction was made, and permeability set at 30 m/d.

These models of varying aquifer development class are given Table 3.4.

TABLE 3.3

Standard Well Configurations: Wells in S1/ D2 Aquifer Lithologies

Well type	Completion	Drilling method**	Pump mode*	Screen type***	Design Q (l/s)	Screenable aquifer (%)	Well depth (m)	UWC min ID (mm)	UWC nom. diam. (in)	UWC drilled length (m)	UWC length (m)	LWC/ screen min ID (mm)	LWC/ screen diam (in)	LWC drilled length (m)	LWC length (m)	Screen length (m)	UW drilling diameter (mm)	UW drilling diameter (in)	LW drilling diameter (mm)	LW drilling diameter (in)	Drilling time (days)
DTW	Gravel pack	mud DC	fm: ls	Saw slot	90	40	160	343	14	25	20	260	10	135	87	48	508	20	445	17.5	30
DTW	Natural devt.	mud DC	fm: ls	Saw slot	90	40	160	343	14	20	20	260	10	140	92	48	405	16	305	12	25
DTW	Gravel pack	mud DC	fm: ls	Saw slot	60	40	120	343	14	25	20	206	8	95	59	36	508	20	355	14	27
DTW	Natural devt.	mud DC	fm: ls	Saw slot	60	40	120	343	14	20	20	206	8	100	64	36	355	14	305	12	23
DTW	Gravel pack	water RC	fm: ls	Saw slot	60	60**	120	343	14	25	20	206	8	95	59	36	560	22	405	16	23
MTW	Gravel pack	mud DC/ perc.	fm: ls	Saw slot	45	40	100	311	12	25	20	206	8	75	48	27	457	18	355	14	22
MTW	Natural devt.	mud DC	fm: ls	Saw slot	45	40	100	311	12	20	20	206	8	80	53	27	355	14	255	10	18
MTW	Gravel pack	mud DC/ perc.	fm: ls	Saw slot	30	40	80	260	10	25	20	156	6	55	34	21	457	18	305	12	20
MTW	Natural devt.	mud DC	fm: ls	Saw slot	30	40	80	260	10	20	20	156	6	60	39	21	305	12	255	10	16
MTW	Gravel pack	water RC	fm: ls	Saw slot	30	60**	80	260	10	25	20	156	6	55	34	21	405	16	405	16	18
MTW	Gravel pack	mud DC/ perc.	fm: ls	Saw slot	15	40	60	205	8	25	20	100	4	35	15	15	355	14	255	10	13
MTW	Natural devt.	mud DC	fm: ls	Saw slot	15	40	60	205	8	20	20	100	4	40	15	15	255	10	203	8	12
STW	Gravel pack	mud DC/ perc.	suction	Saw slot	15	40	60	205	8	25	20	100	4	35	15	15	355	14	255	10	13
STW	Gravel pack or natural development	manual	suction	Saw slot/ mesh/ coir	15	40	20	100	4	12	12	100	4	8	6	6	152	6	152	6	7

Notes:

* pump mode: fm forced mode; ls lineshaft pump; suction mode (centrifugal pump).

** DC direct circulation drilling rigs; Perc percussion drilling rigs; RC reverse circulation drilling rigs (RC drilling enables close sample control, so more section potentially screenable).

*** screen type saw slotted MS pipe with 1 to 1.6 mm slots; open area 8%

1 Well depths/screen lengths rounded, near optimum except for manual STW model.

2 Current practice is to avoid medium sand/ fine sand sediments, and only screen coarse sand and gravel; hence full potentially screenable interval often not used

3 These models are generally based on Class D2 aquifers ("Fair", transmissibility > 1 000m2/d; broadly equivalent to specific capacity of 6 to 8 l/s/m.

Source: GDC

TABLE 3.4

Comparison between Gravel Packed Well Designs for Classes D1, D2 and D3 Aquifers

Well Type	Aquif. Devt. Class	Drill method	Pump mode	Design Q (l/s)	Well depth (m)	Equiv T (m2/d)	SC (l/s/m)	Sw (m)	PWL (m bgl)	Total head (m)	UWC min id (mm)	UWC nom. diam. (in)	UW drill length (m)	UWC length# (m)	LWC-screen min id (mm)	LWC-screen nd (in)	LW drill length (m)	LWC length (m)	Screen length (m)	UW drill diam (mm)	UW drill diam (in)	LW drill diam (mm)	LW drill diam [in)
DTW	D1	DC	fm:ls	90	130	2000	18	5.6	10.0	14.0	343	14	25	20	260	10	105	45	60	508	20	445	17.5
	D2	DC	fm:ls	90	160	1500	13	6.9	11.6	15.6	343	14	25	20	260	10	135	87	48	508	20	445	17.5
	D3	DC	fm:ls	90	230	750	6	10.5	16.1	20.1	343	14	25	20	260	10	205	172	33	508	20	445	17.5
DTW	D1	DC	fm:ls	60	100	2000	18	5.0	9.3	13.3	343	14	25	20	206	8	75	30	45	508	20	355	14
	D2	DC	fm:ls	60	120	1500	13	6.2	10.8	14.8	343	14	25	20	206	8	95	59	36	508	20	355	14
	D3	DC	fm:ls	60	180	750	6	9.4	14.8	18.8	343	14	25	20	206	8	155	131	24	508	20	355	14
MTW	D1	DC/perc	fm:ls	45	80	2000	18	4.9	9.1	13.1	311	12	25	20	206	8	55	22	33	457	18	355	14
	D2	DC/perc	fm:ls	45	100	1500	13	6.1	10.6	14.6	311	12	25	20	206	8	75	48	27	457	18	355	14
	D3	DC/perc	fm:ls	45	140	750	6	9.3	14.6	18.6	311	12	25	20	206	8	115	97	18	457	18	355	14
MTW	D1	DC/perc	fm:ls	30	70	2000	18	4.1	8.1	12.1	260	10	25	20	156	6	45	18	27	457	18	305	12
	D2	DC/perc	fm:ls	30	80	1500	13	5.2	9.5	13.5	260	10	25	20	156	6	55	34	21	457	18	305	12
	D3	DC/perc	fm:ls	30	110	750	6	7.9	12.9	16.9	260	10	25	20	156	6	85	70	15	457	18	305	12
MTW	D1	DC/perc	fm:ls	15	50	2000	18	3.1	6.9	10.9	205	8	25	20	100	4	25	7	18	355	14	255	10
	D2	DC/perc	fm:ls	15	60	1500	13	3.9	7.9	11.9	205	8	25	20	100	4	35	20	15	355	14	255	10
	D3	DC/perc	fm:ls	15	80	750	6	5.9	10.4	14.4	205	8	25	20	100	4	55	46	9	355	14	255	10

Notes:

All screen MS saw slot with 1 to 1.6 mm with 1-1.6 mm saw slots - 8% open area.

K=30 m/d for all cases

fm:forcemode
ls:lineshaft pump

Gravel pack designs

Source: GDC

Well depths/ screen lengths rounded, near optimum, except for manual STWs

DC direct circulation mud
RC reverse circulation mud/ water
Perc percussion

Well specific capacity derated over well life by 1.25 safety factor;
- 1 m for delivery head + 1 m for regional decline = 2 m

PWL = SWL + (Sw * 1.25): SWL = 3 m bgl
Total Head = SWL + (Sw * 1.25) + dh + sf + rd

For pack emplacement, upper well (UW) drilled 5 m over UWC length

UWC length fixed

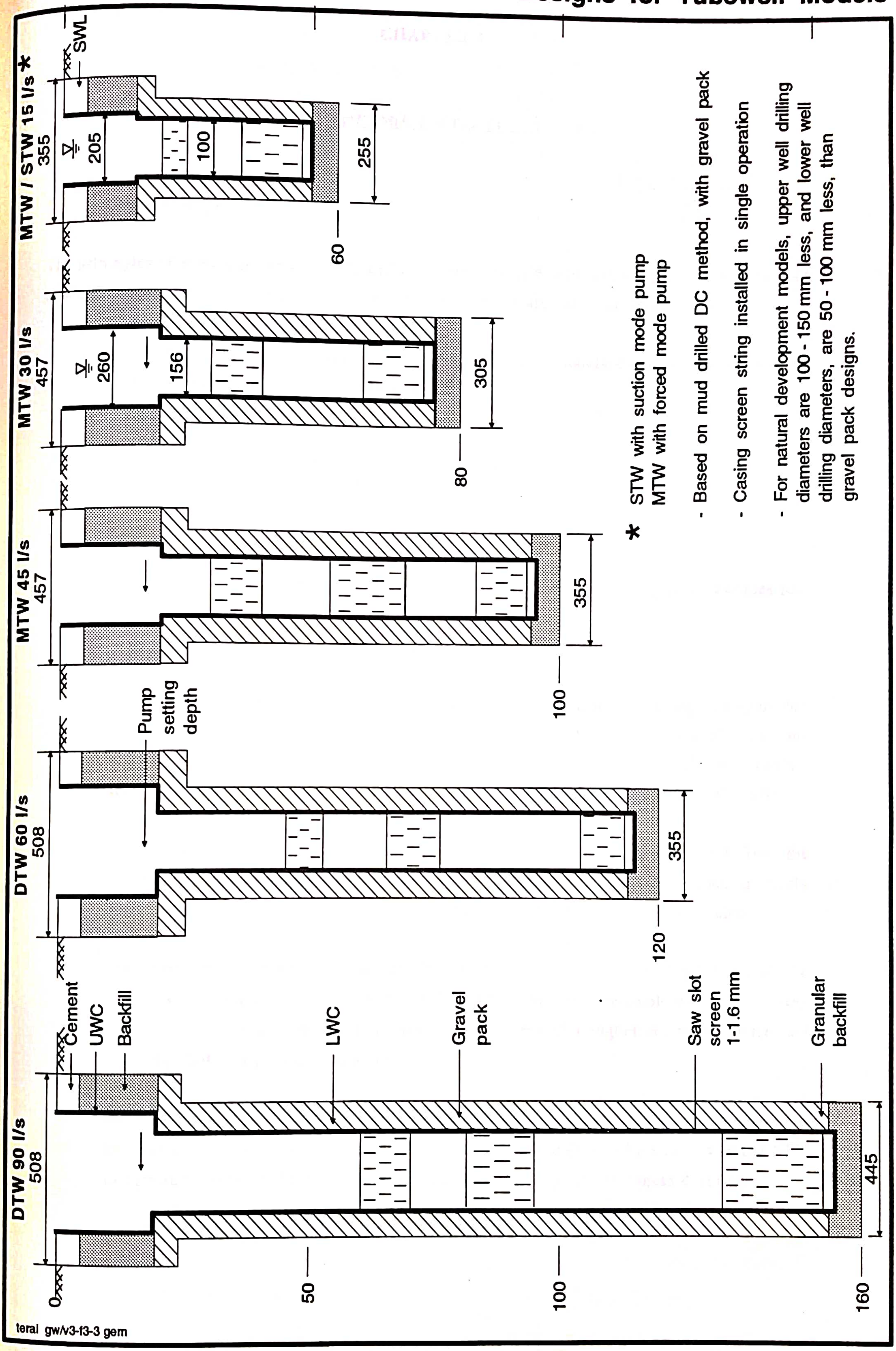
v3-t3-4.wk1

Several points need to be made about these assumptions:

- the standardised designs use well depths and screen lengths which approximate to the optimum for least cost water, rather than to any configurations currently used in the Terai; they therefore do not necessarily represent wells that are practically buildable; for example, the test of 90 l/s DTWs in D3 areas not unexpectedly gave an optimum well depth which is clearly excessive; and

- it may be feasible to use cheaper PVC materials in MTWs and STWs; in the main models, however, steel was used for pricing purposes because of current Terai practice and availability; more exotic or higher cost materials, for example fibreglass casings and stainless steel "Johnson" type screens, were not considered in the detailed analysis because of cost and availability; they were, however, included in the sensitivity study.

Figure 3.3
Designs for Tubewell Models



CHAPTER 4

ECONOMIC DESIGN OF TUBEWELLS

4.1 Methodology

The principles of economic design of tubewells have been described in detail in previous reports such as GDC (1987) and MMP (1990) Volume 6. The main points are summarised as follows:

- the present value (PV) of future costs can be obtained by standard discounting techniques; the formula for n years of an annual cost C_n is:

$$PV = C_n \times \frac{(1+r)^n - 1}{r(1+r)^n}$$

where r is the discount rate. For a 20 year well life and 7% discount rate, this comes to:

$$PV = 10.6 \times C_n;$$

(this more severe than the 12% interest rate adopted for the least cost well comparisons discussed in Volume 5, Chapter 7, where PV = 7.47 × C_n. As a result the analysis in this chapter - intended to focus on graph slope and sensitivity rather than absolute costs - reflects a higher value (from the farmer's perspective) on minimising principal costs).

- the annual costs are largely due to the power requirements for lifting water from the pumping water level to the discharge box; other operation and maintenance costs are fairly small; screen length (L) and drawdown and thus annual costs are directly related;

- the capital costs of construction are attributable to drilling to sufficient depth to install the screen with blank lower well casing (LWC) opposite any un-screenable material, drilling for and provision of upper well casing (UWC), tubewell completion, pump house and discharge box and pumping equipment;

- there is therefore an optimum depth at which the cost of the water produced is a minimum because an increase in screen length; i.e., capital cost is balanced by a saving in the NPV of operation because the drawdown is reduced; this is depicted in Figure 4.1; and

- for each well configuration, a series of optimum screen lengths can be found based on different design discharges; in normal irrigation wells, the overall cost of water reduces as the design discharge is increased.

This last point is of particular importance to the Terai since, as described in Chapter 3, changes in well design and performance are needed dependent on the aquifer properties and method of drilling employed. Therefore, a series of different optimised well configurations can be examined at a maximum discharge for each case, and the resulting cost of water compared. A particular question examined in this Study is whether the expected "economy of scale" is likely to be found for the wide range of tubewells that are possible in the Terai.

A second objective of the optimisation was to identify suitable designs for detailed costing and economic analysis. The lumped parameters in the optimisation model allow a wide range of designs to be easily examined and thus test the sensitivity of the recommended designs.

The derivation of the cost elements, the results obtained and conclusions drawn are presented in the following sections.

4.2 Base Costs

4.2.1 Pumping Equipment

Recently tendered pump and motor costs (excluding spares, control panel, etc.) from the BLGWP project have been compared with data presented from the Minor Irrigation Supplement of the Deep Tubewells project in Bangladesh (MMP 1991). The latter have been upgraded to current prices assuming inflation factors (in US$) of 1.3 (1989) and 1.1 (1991), based on the World Bank index numbers of wholesale prices. In addition, budget quotations have been sought from manufacturers in Bangladesh, India and Pakistan.

The data for electric motors and lineshaft pumps have been graphically fitted to the usual general relationship as shown in the lower half of Figure 4.2 and the following result obtained:

$$PUC = 2000 + 500 \times Q^{0.6} \times H^{0.9}$$

The relatively low sensitivity of pump motor unit cost (PUC) to discharge (Q) relates to the minor changes to pump, column pipe and line shaft diameter, and thus raw material content. The higher sensitivity to operating head (H) is partly due to the proportional effect on power requirements and partly due to the direct effect on pump costs as the number of stages and setting depth increases (as illustrated in the upper half of Figure 4.2).

Figure 4.1

Economic Well Design

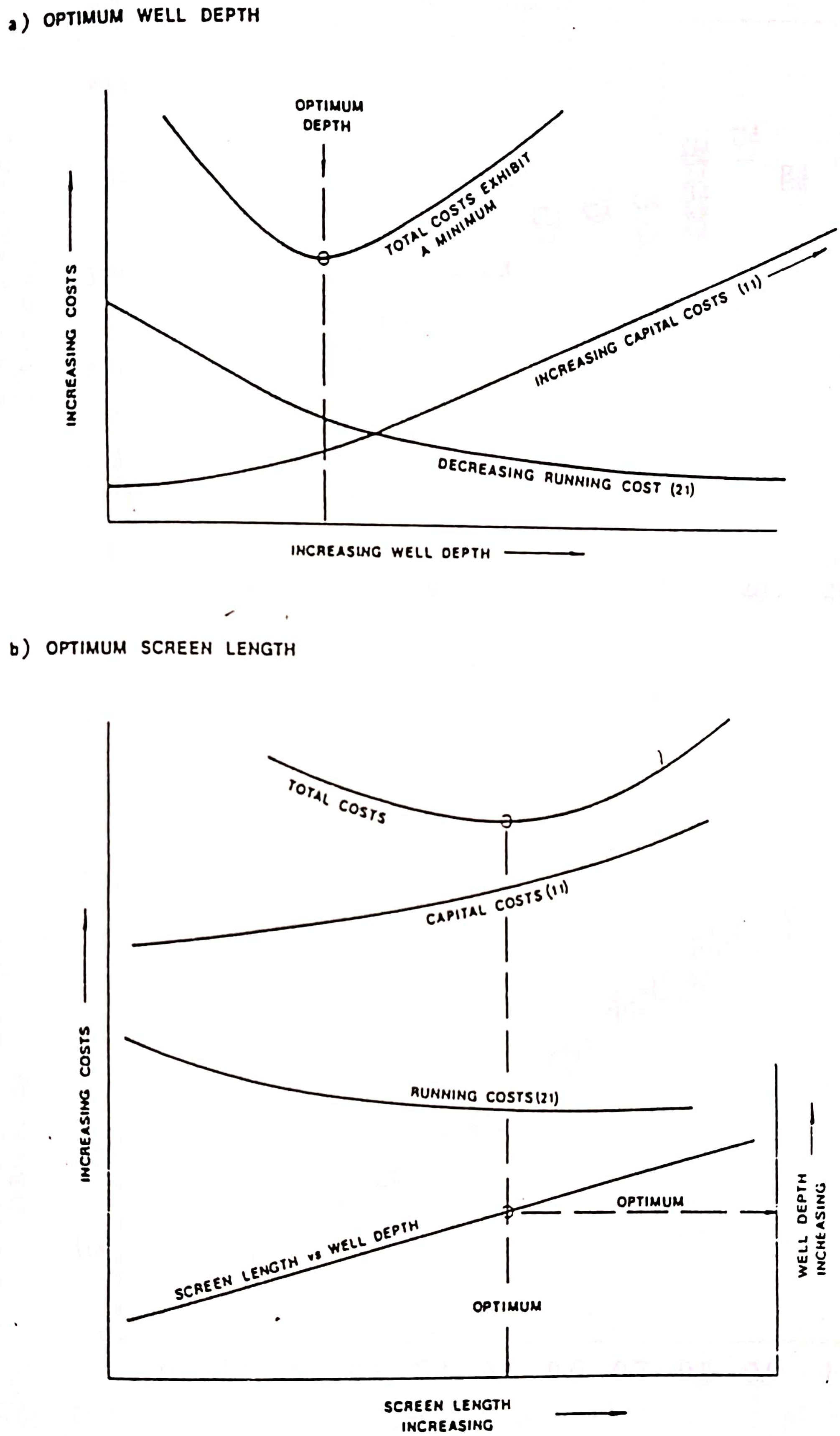
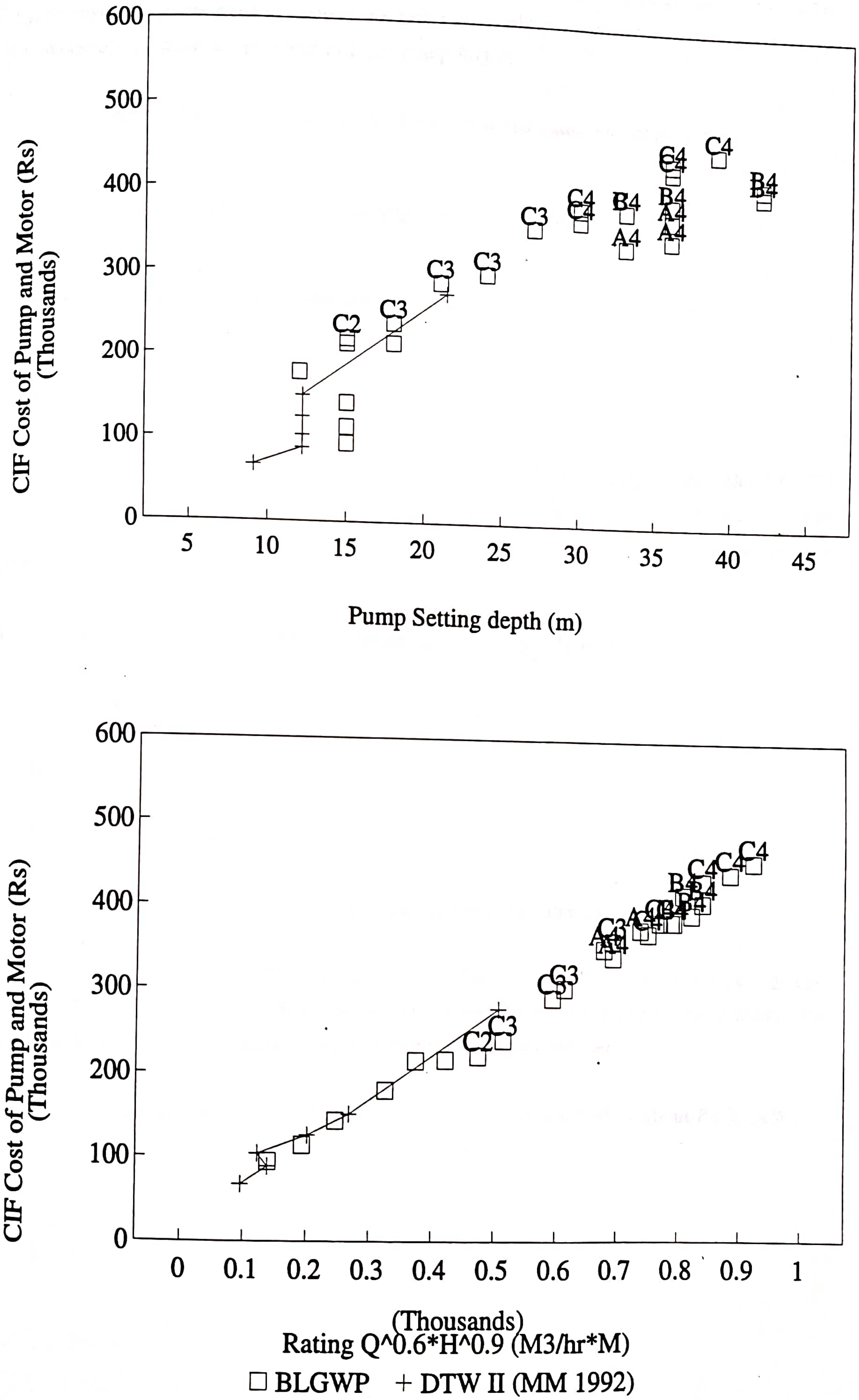


Figure 4.2
DTW Pump and Electric Motor Costs



BLGWP pumps labelled as type (A,B or C) with number of stages

7066B01/terai/pumpcost.wk1

Electric submersible pumps have not been considered since they are rarely competitive at shallow depths, have lower bowl and motor efficiencies because of the reduced diameter and have higher maintenance costs due to the need to remove the entire assembly in case of motor damage. They do have the advantage of much simpler and cheaper pump houses.

The option to use direct drive diesel engines has been examined using the relationship:

$$PUC = 49500 + 289 \times Q^{0.6} \times H^{0.9} + 34 \times Q \times H$$

This assumes a 50% increase in costs over the 1987 Study.

4.2.2 Energy

Electricity costs for economic analysis have been based on the 11 kW marginal rate (Rs 2.6/kW) available at the time of the Inception Report (GDC 1993) plus an allowance of Rs 2 000/kW-year as a fixed cost. One lower and three higher tariffs were also examined. One additional rate of Rs 2 000/kW + Rs 1.4/kWh was checked to represent the present subsidised tariff.

Power requirements have been computed assuming the following efficiencies:

Pump bowl	-	75%
Electric motor	-	95%
Drive shaft/head losses	-	85%
Diesel engine/gear box	-	90% (additional to the above)

These efficiencies give 0.6 and 0.55 "wire to water" efficiencies for electric and diesel drives, respectively. These are quite severe but may reflect the present tendency to operate at lower than design heads, and also a general absence of data to support higher efficiencies.

Diesel fuel has been priced at the prevailing Rs 12/litre thus giving a cost of about Rs 3.7/kWh.

4.2.3 Casing, Screen and Drilling

The following UWC and LWC unit costs have been derived for the limiting discharges examined:

Discharge (m^3/h)	LWC	Price (Rs/m)			
		Plain	$Drilling^{DC}$	UWC^{DC}	UWC^{RC}
50	4"PVC	300	1 200	2 800	3 700
100	6"PVC	600	2 300	4 900	4 100
150	8"Steel	1 500	3 000	5 900	4 500
300	10"Steel	1 900	3 600	7 200	4 900
450	12"Steel	2 300	4 500	8 600	5 300

In the case of UWC costs, this includes an allowance for reaming out to a larger diameter as well as providing steel pipe at an appropriate diameter.

The above data for direct circulation drilling (DC) are referred to in the analyses as parameter set P2. For reverse circulation drilling (RC), a unit rate of Rs 2 200/m was used for all diameters and the UWC costs adjusted as shown. This parameter set is referred to as RC1 or P3. Two additional sets of costs were created to reflect the smaller diameters needed for naturally packed wells (P5) and some special study of 200 m^3/h (56 l/s) tubewells.

Parameter Set P5 - Natural Packed Wells (Rs/m)

Discharge (m^3/h)	Price (Rs/m)		
	LWC	Drilling	UWC
50	300	1 200	2 700
100	600	1 200	4 200
150	1 500	2 000	5 300
300	1 900	2 700	6 300
450	2 300	3 000	7 100

Parameter Set P6 - for 200 m³/h (83 l/s) wells (Rs/m)

Discharge (m³/h)	Price (Rs/m)			
	LWC	Drilling	14" UWC	Remarks
200-1	Steel 1 500	3 600	7 200	DC
200-2	Steel 1 500	1 500	4 200	RC
200-3	Steel 1 500	2 700	6 300	N Pack*
200-4	GW 3 000	2 700	6 300	N Pack*
200-5	GW 3 000	1 500	4 200	RC

Note: * Naturally developed gravel pack.

4.3 Results

The previous studies described in GDC (1987) were based on a fixed UWC cost per metre and a constant rate for drilling. The results show clearly the weak dependence of minimum cost water with annual hours of pumping (± 4 to 7%) for ± 300 hours per year for 1 100 hours. Accordingly, the present study has concentrated on the 1 100 hour case.

The previous study also showed how unit water costs were very sensitive to the static water level (SWL) assumed. This is however "fixed" in the sense that the optimum screen length does not depend on SWL although the net present value (NPV) of the operating costs does. The present study has therefore been carried out using a modification of the original computer program so that a range of different designs could be examined effectively. In the revised program, the unit cost of water at an assumed static water level of 3 m bgl is calculated and presented in the output. The calculated construction cost and net present value of operating costs are also shown. If costs for a different static water level are needed, they can be readily estimated by factoring as follows:

$$NPV_x = \frac{S+x}{S+3} * NPV_3$$

where S is the value listed for drawdown. The choice of a 3 m SWL is intended to be directly comparable with the previous study and allow comparison with shallow tubewells. In practice, a SWL of 3 m in the shallow aquifer would usually preclude use of DTWs. However, because of the frequent tendency for a degree of artesian rise in DTWs, a DTW of about 3 m might occur in areas where STWs were impossible.

The results have been calculated for a range of aquifer percentages (20, 40 and 60%) and permeabilities. The general case of 30, 40 or 60 m/d was run; and a few special high cases of 50, 100 or 200 m/d also. The aquifer percentage figures investigated reflect the range anticipated depending on the gravel packs, slot size and drilling technique to be utilised.

Figure 4.3 shows the unit cost of water for the two parameter sets (P2 and RC1) for electric or diesel (/D) powered pumps.

Figure 4.4 shows the results for high permeability aquifers and Figure 4.5 the effect of different permeability for the standard (P2) configurations. Figure 4.6 shows the results for the standard 40 m/d permeability case but with a wide range of electricity tariffs.

4.4 Conclusions

4.4.1 Operating and Capital Costs

At the discount rate of 7% employed (more severe that the 12% adopted for the analyses in Volume 5, Chapter 7), the NPV of the operating costs is always greater than the capital costs for the optimised well configuration. This weighting is always greater at high discharges, high aquifer proportions and high electricity tariffs. As a result, the optimum screen lengths are such that drawdowns only exceed 10 m in a few unlikely combinations of high discharge, low permeability and low aquifer percentage. With the cheaper flat rate RC drilling costs, the theoretically optimum drawdowns get as low as 1 to 2 m with corresponding inflow rates of around 0.6 (l/s) m to 0.8 (l/s) m of screen.

The overall tendency to higher operating costs, longer screen lengths and low drawdowns also increases the preference for cheap screen and high aquifer percentage if this can be achieved.

4.4.2 Power Source

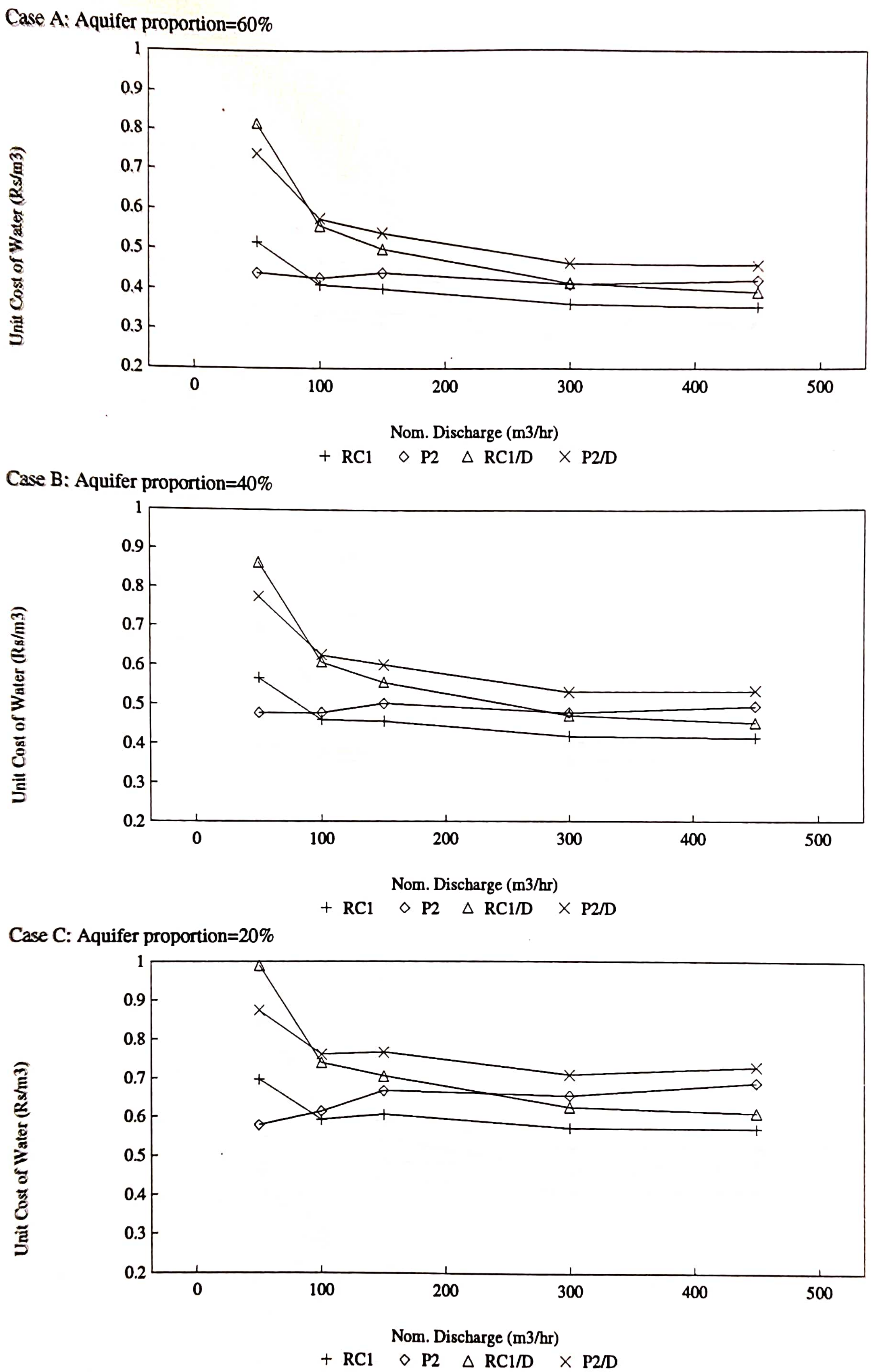
Figures 4.3 and 4.4 show how unit water costs for diesel are always higher in standard low yielding RC or DC drilled tubewells, irrespective of aquifer proportion and permeability, than for electricity priced at Rs 2 000/kW plus Rs 2.6/kW per hour. Comparison with Figure 4.6 suggests that diesel can become cheaper (for K=40 m/d) with DC drilling if the power tariff is Rs 3 000/kW plus Rs 3.0/kW per hour or more. The switch between electricity and diesel moves to progressively lower discharges as the aquifer proportion reduces or the power tariff increases.

In the extreme case, diesel is cheaper for flows greater than around 250 m^3/h at an aquifer percentage of 20% and permeability of 40 m/d.

The results also show how overall water costs for diesel driven tubewells reduce significantly with increasing discharge or with a switch to cheaper (RC) drilling. The apparently high cost of diesel power for wells of less than 100 m^3/h (28 l/s) capacity could warrant some further investigation.

Figure 4.3

Unit DTW/MTW Water Costs and Aquifer Proportions (K=40 m/d)



Annual Operating Hours =1100, Electricity at Rs 2000 & Rs 2.6, Diesel at Rs 12/l, Permeability = 40 m/d

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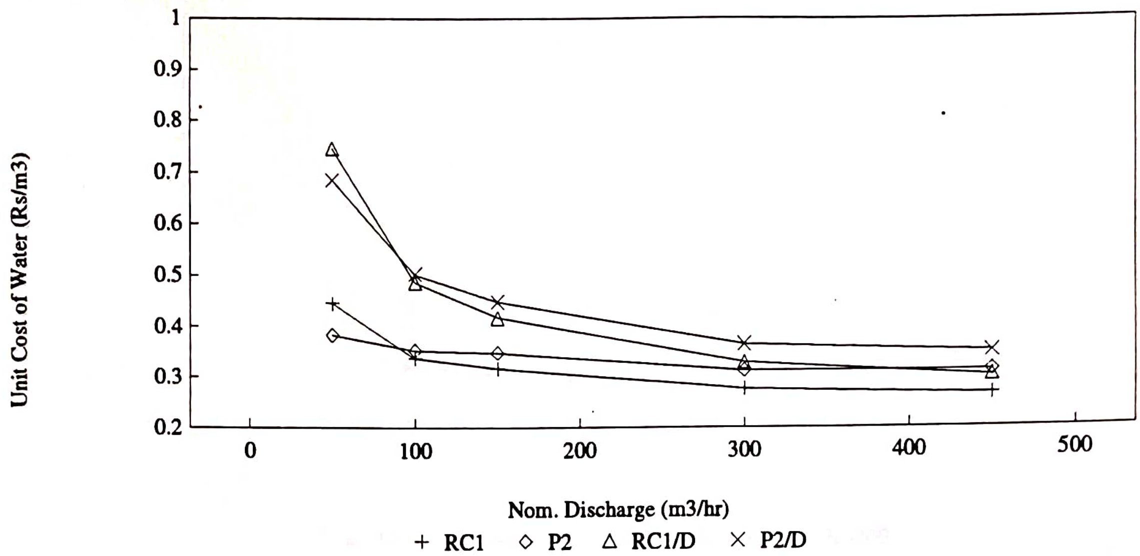
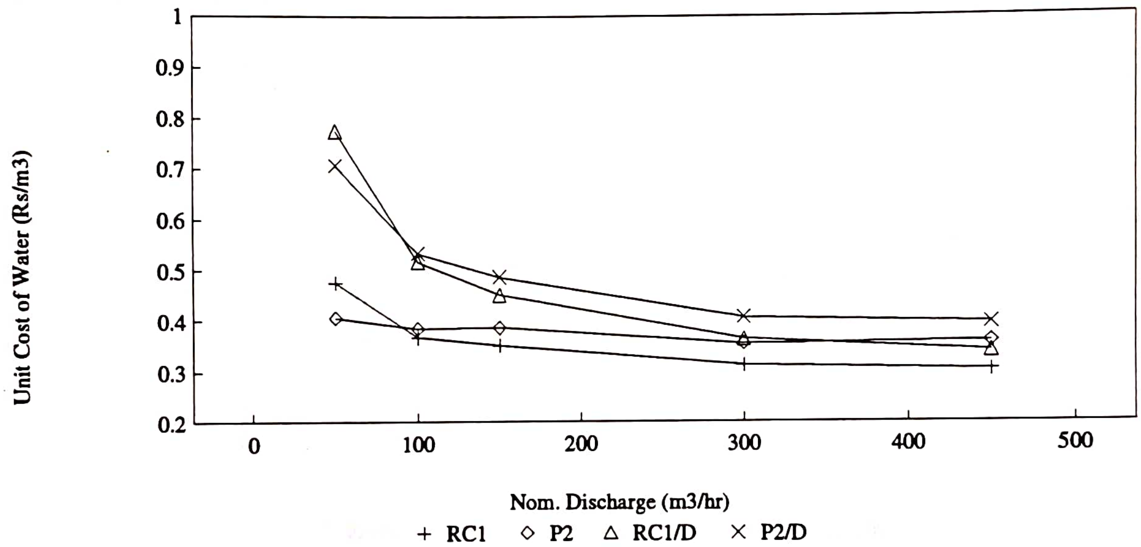
Unit DTW/MTW Water Costs and Aquifer Proportions (K=100 m/d)

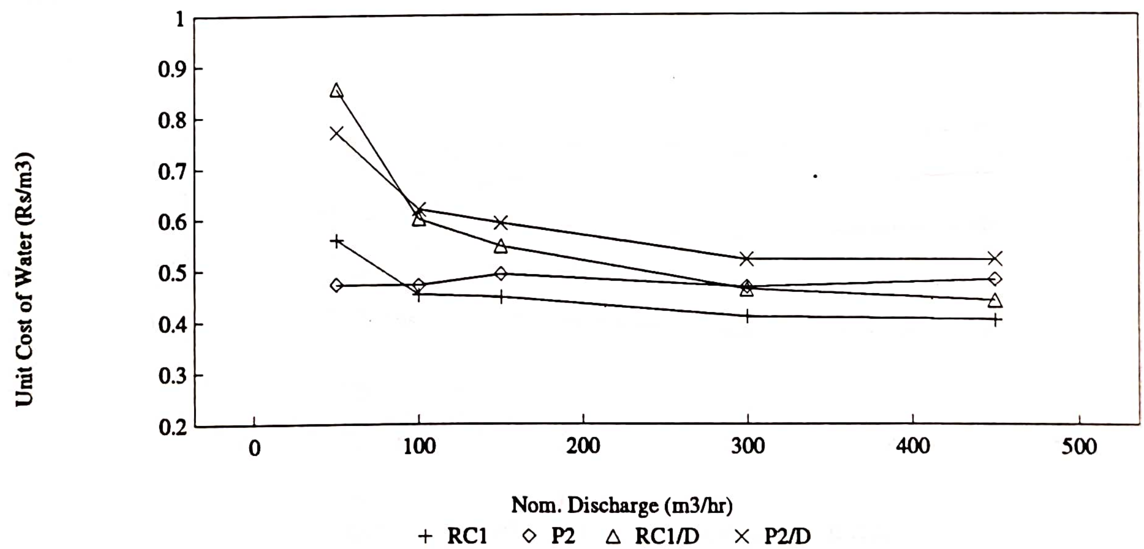
Case A: Aquifer proportion=60%



Case B: Aquifer proportion=40%



Case C: Aquifer proportion=20%



Annual Operating Hours =1100, Electricity at Rs 2000 & Rs 2.6, Diesel at Rs 12/l, Permeability = 40 m/d

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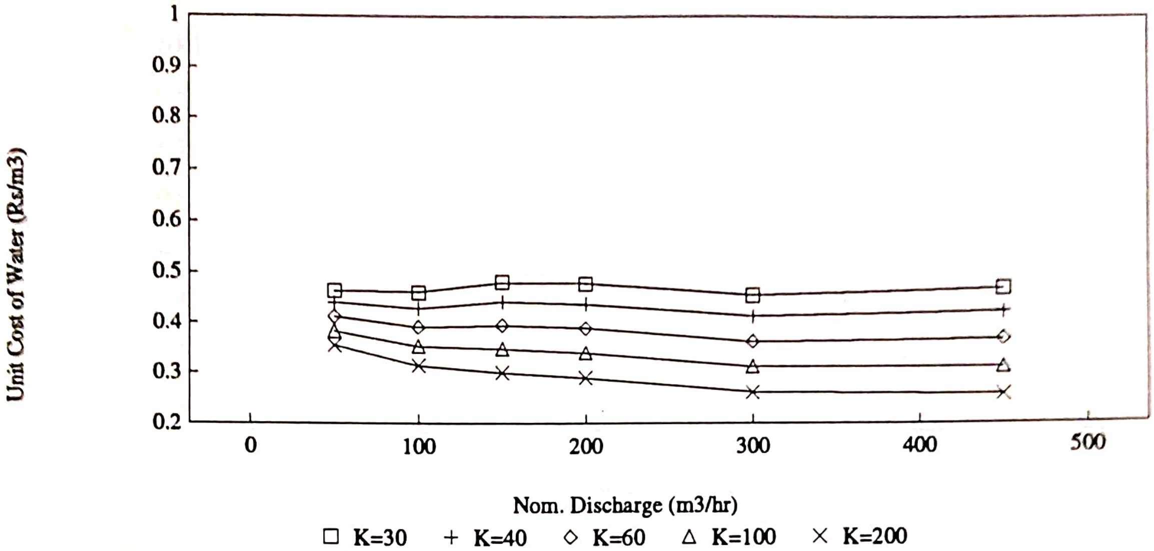
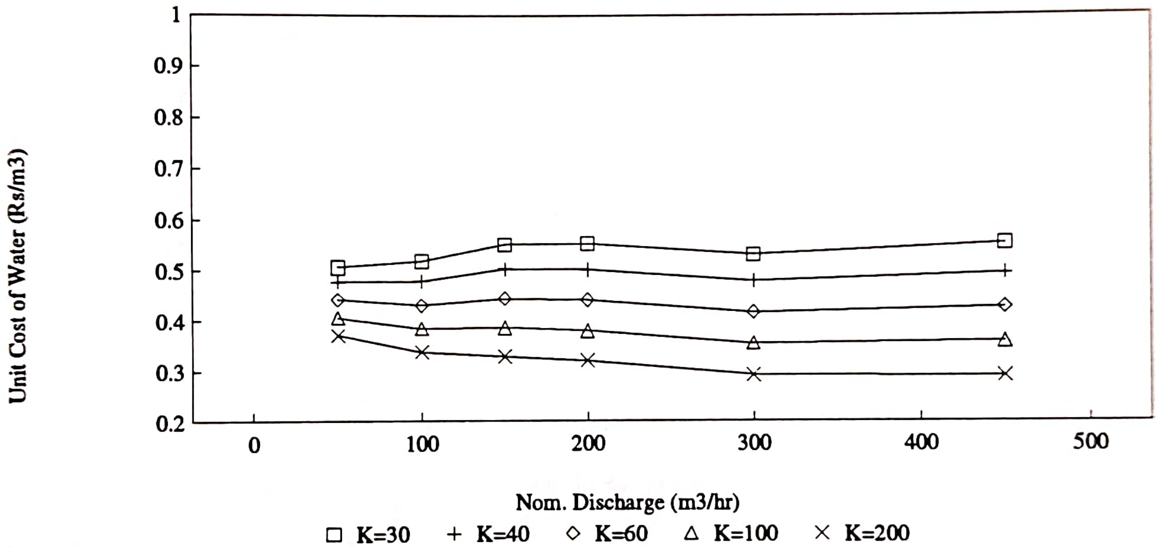
Figure 4.5

Unit DTW/MTW Water Costs and Permeability Ranges

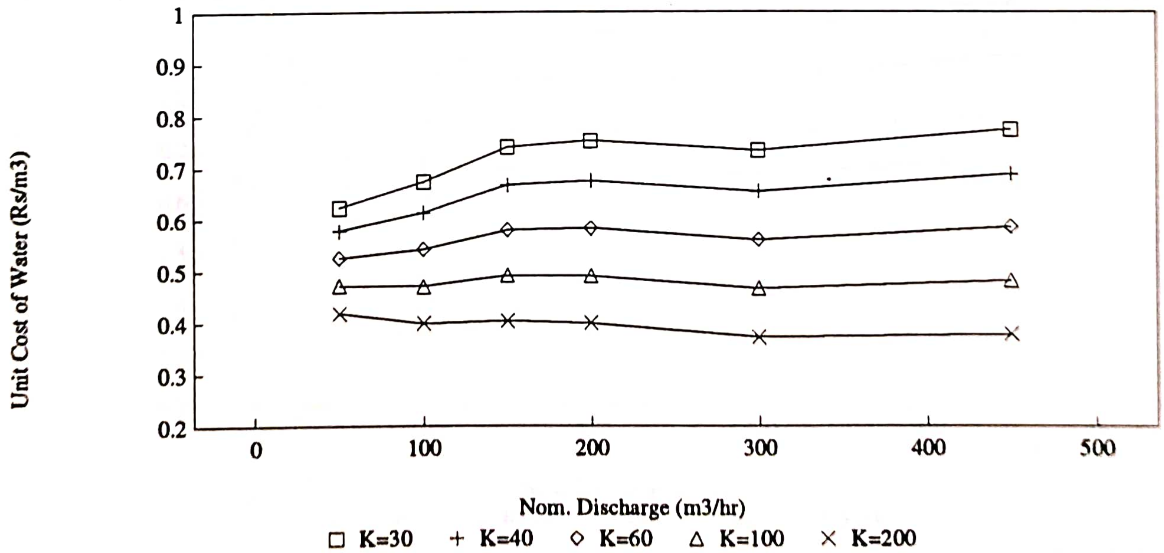
Case A: Aquifer proportion=60%



Case B: Aquifer proportion=40%



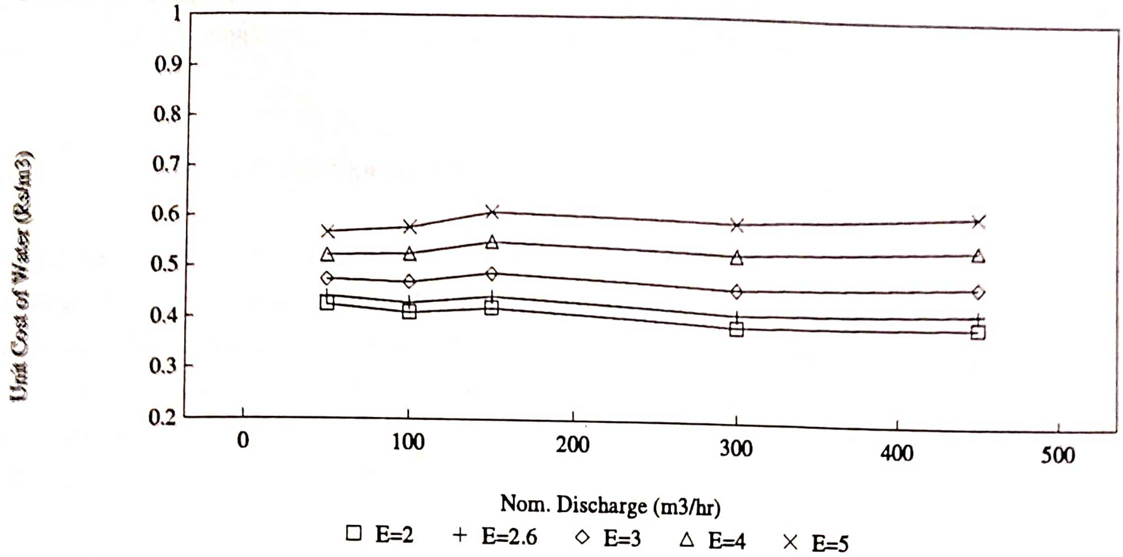
Case C: Aquifer proportion=20%



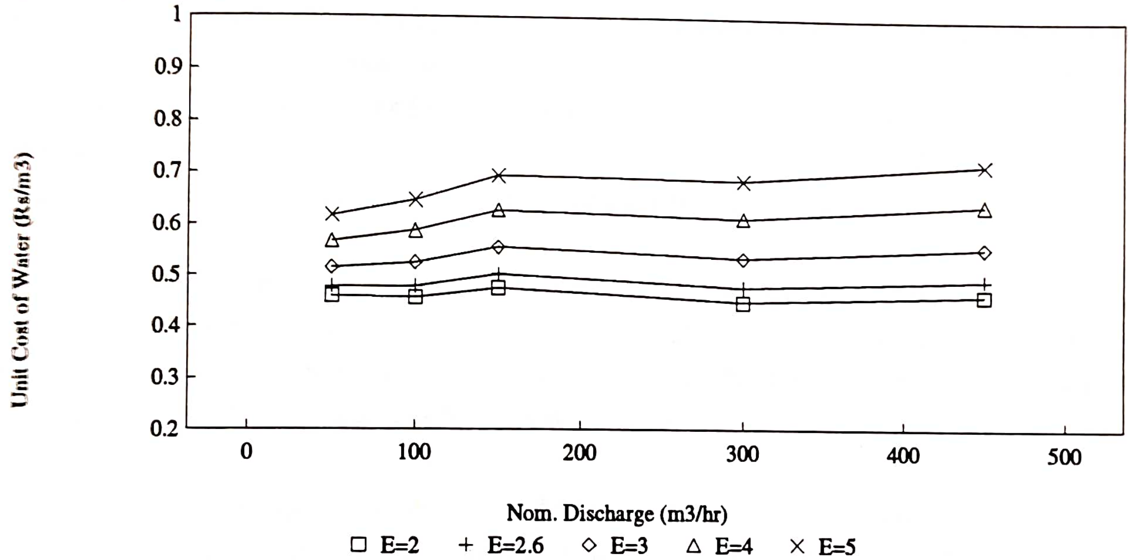
Annual Operating Hours =1100, Electricity at Rs 2000 & Rs 2.6

Unit DTW/MTW Water Costs and Electrical Power Tariff Ranges

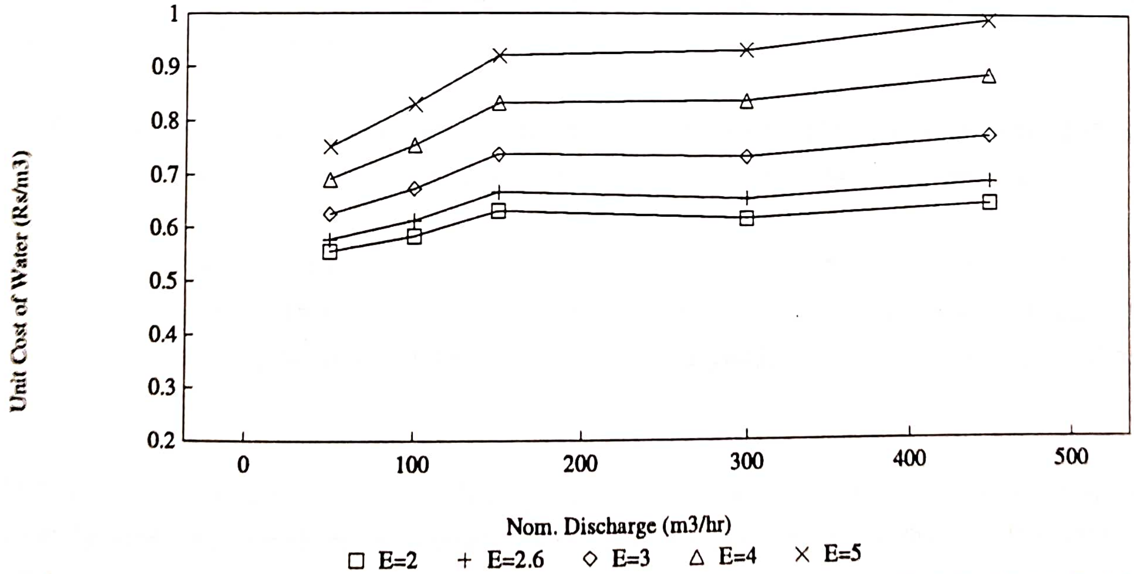
Case A: Aquifer proportion=60%



Case B: Aquifer proportion=40%



Case C: Aquifer proportion=20%



Annual Operating Hours = 1100
K=40 m/d

E=2 Rs 2000 & Rs 2.0
E=2.6, Rs 2000 & Rs 2.6

E=3 Rs 3000 & Rs 3.0
E=4 Rs 4000 & Rs 4.0
E=5 Rs 5000 & Rs 5.0

Previous studies investigated the effect of capital weighting and concluded that diesel's cost disadvantage at standard tariffs increased at yields over 150 m^3/h (42 l/s) as capital costs were factored up to 1.5 times base costs. At lower yields, the cost disadvantage reduced, but remained.

4.4.3 Optimum Well Configurations - Pumped Wells

The present study can be compared to the results in the 1987 report with regard to the optimum discharge. The earlier work consistently showed lower costs for higher discharges whereas the present study only shows this for RC drilled holes. This result follows directly from the comparable assumption of a constant drilling cost irrespective of depth or diameter. The present study allocates increasing costs to larger diameters and this reduces the tendency to a cost advantage with higher discharges.

In addition, the switch from 4 and 6 inch PVC casing and screen to an assumed slotted mild steel at the limiting yield of 100 m^3/h actually results in lower unit water costs for the smaller wells in all DC drilled holes. This cost advantage is increased at high tariff rates, low aquifer percentage and low permeability; i.e., any condition tending to cause higher operating costs. In the event that high cost wire wound screen or corrosion resistant glass reinforced plastic (epoxyresin) (GRP) were employed instead of mild steel, the advantage of smaller discharges would increase.

However, the major purpose of this investigation is to identify the optimum well configuration and resulting unit costs for the anticipated range of conditions rather than determining the minimum cost of water within a given configuration. The results for RC and DC holes are shown in Table 4.1 for the electric tariff of Rs 2 000 kW plus Rs 2.6/kW per hour.

Certain combinations of aquifer properties and drilling method have been excluded. For example, at very high permeabilities, RC drilling is more difficult due to fluid loss and the likely presence of bouldery or artesian conditions. Conversely, a high percentage of low permeability material is unlikely to be drilled using DC.

Table 4.1 also shows clearly that a change in the definition of screenable material from say 20% to 40% or 40% to 60% is always worthwhile, even if the permeability drops by the same ratio.

In certain conditions marked (*) in the table, deeper higher yield tubewells would be cheaper. However, the resulting depth at the optimum is excessive for RC drilling, particularly due to the risk of artesian pressure. Intermediate depths and slightly higher yields of say 200 m^3/h might still be preferred.

A second concern is that the DC drilled, high permeability cases are optimised with screen lengths that can be unrealistically short on hydraulic criteria. This mainly applies to the very low aquifer proportion case.

TABLE 4.1

DTW Drilling Method, Depth and Optimum Unit Water Costing (Rs/m³)

Screenable aquifer (%)	20	40	40	60	60
Drilling method	DC	RC	DC	RC	DC
Permeability (m/d)					
30	0.62 50/87	0.46 300/162 or 450/218*	0.50 50/65	0.40* 300/133 or 450/178*	-
40	0.58 50.79	0.42 300/143 or 450/192*	0.48 50/59 or 300/127	0.36* 300/118 or 450/157	0.41 300/106
50	0.55 50/73	0.39 300/130 or 450/175*	0.44 100/68 or 300/116	0.33 300/108 or 450/143	0.39 450/121 or 300/97
60	0.52 50/69	0.36 300/121 or 450/161	0.42 300/108	0.31 300/101 or 450/132	0.36 300/90
100	0.45 100/72 or 300/124	-	0.36 300/89	-	0.31 300/75 or 450/93
200	0.37 300/95 or 450/118	-	0.29 300/70 or 450/85	-	0.26 300/60 or 450/72

Key: Unit Cost (Rs/m³) / Optimum discharge (m³/h)/Optimum Depth* (m)

Notes:
(a) * See text
(b) Standard Power as Rs 2 000 kW plus Rs 2.6 kW/h, 1 100 hour year.
(c) Costs for standard case with SWL = 3 m, 20 m UWC

Source: GDC

The main purpose of Table 4.1 is to allow aquifer proportion and by implication, drilling methods to be compared. The optimum yields and well design are of secondary importance because as discussed earlier, the unit cost for water may not vary much with alternative yields. In fact, in some cases shown in the table, two different yields give an identical unit cost.

The table shows clearly that high permeability is a major factor in producing cheaper water.

The particular case of the 200 m^3/h tubewell is illustrated in Figure 4.7 for the standard tariff case.

The selection of slotted base pipe or galvanised wire wound screen (GWS) makes little difference to the unit price, as does the shift from natural pack to RC drilling if the latter cause the permeability band to drop by one step. The high relative cost of DC artificially packed holes is clearly shown. The corresponding screen length and specified capacities are shown in Figure 4.8.

This conclusion supports the rationale of switching, for the larger discharges, from DC drilling with medium to coarse sand being defined as screenable, to RC drilling with fine sand and upwards being screened.

4.5 Gravel Packing

The cost of water produced in gravel packed and non-gravel packed wells has been compared for several different power tariffs and the results for the standard tariff are shown in Table 4.2. The benefit of smaller diameters and natural gravel packs results in unit costs lower than for gravel packed DC wells. The savings are comparable to those for RC drilling. If naturally packed wells actually produce any increase in effective permeability compared to normal DC drilling, then there is an additional benefit for the same proportion of screenable aquifer. If, however, there is a reduction in screenable thickness, the effective permeability usually needs to increase by at least one step for natural packing to retain its price advantage.

4.6 Effect of Subsidy

The provision of a subsidy to the farmer through the electricity tariff structure produces distortions in the well designs preferred by the farmer group if they pay a fixed proportion of well costs.

In essence, the farmers may prefer to install cheaper tubewells with less screen than the economic optimum because they are not paying an economic price for electricity.

The optimum tubewell characteristics at standard power tariff are compared with a subsidised tariff of Rs 2 000/kW + Rs 1.4/kWh below:

Discharge 100 m^3/h	k=30 m/d, p=40%	K=60 m/d, p= 40%
Power at 1.4 Rs/kWh	18.5 m screen, total well cost Rs 260 000, water costs 0.47 Rs/m^3	13.3 m screen, total well cost Rs 216 000, water cost 0.39 Rs/m^3
Power at 2.3 Rs/kWh	20.7 m screen, total well cost Rs 277 000, water costs 0.52 Rs/m^3	14.7 m screen, total well costs Rs 227 000, water costs 0.43 Rs/m^3

TABLE 4.2

Natural Pack DTW Completion and Unit Water Costs (Rs/m^3)

	Percentage aquifer (%)		
Permeability (m/d)	20	40	60
30	0.56 100/136	0.44 100/96	0.40 100/81
40	0.56 100/121	0.41 100/87	0.38 100/74 or 450/147
60	0.46 100/103	0.38 100/75 or 450/151	0.33 450/124

Key: Unit Cost (Rs/m^3) / Optimum discharge (m^3/h)/Optimum depth (m)

Assumption: Tariff Rs 2 000 kW + Rs 2.6/kWh, 1 100 hours, drilling and casing costs set as P5.

Source: GDC

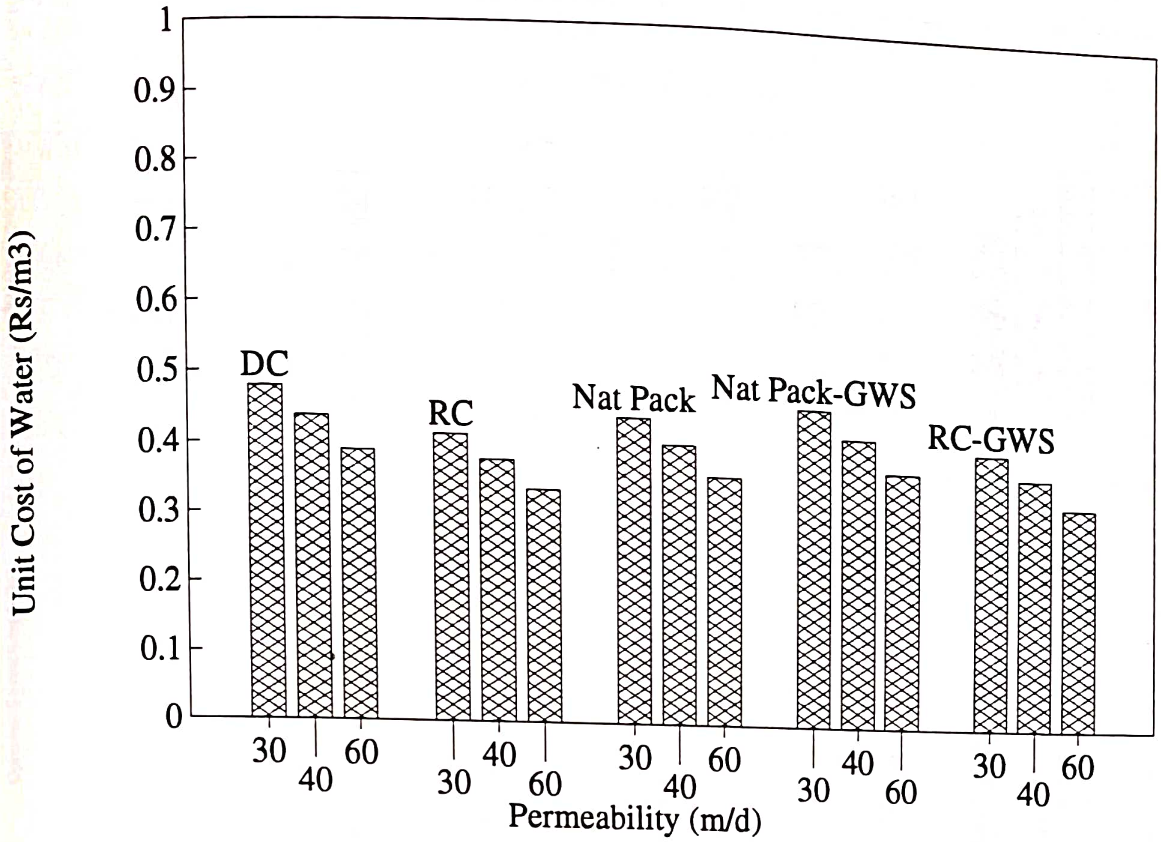
The apparent dilution of the impact of greater subsidies for power to result only in a 10% reduction in the cost of water results from the fixed component of water costs. These are 50% for the capital costs and of the remaining 50% operating costs, 56% of the power charges are based on the fixed annual fee of Rs 2 000 kW.

4.7 Optimum Well Configuration - Artesian Condition

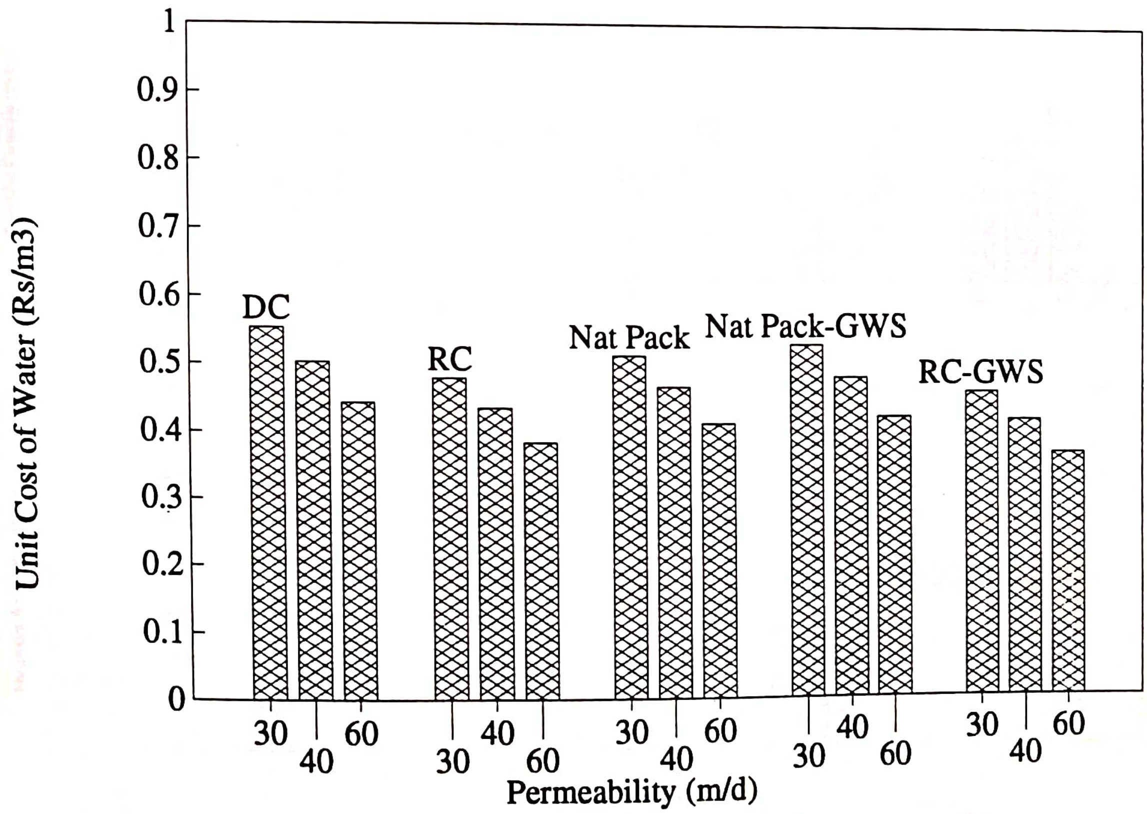
The common existence of artesian conditions outside the Bhabar Zone gives rise to a complex series of conditions:

Figure 4.7
Unit Water Costs for 200 m^3/h Tubewells

Case A: Aquifer proportion=60%



Case C: Aquifer proportion=40%



Alternative 200 m3/hr tubewell designs for 1100 hours operation, tariff Rs 2000 + Rs 2.6 /kWh

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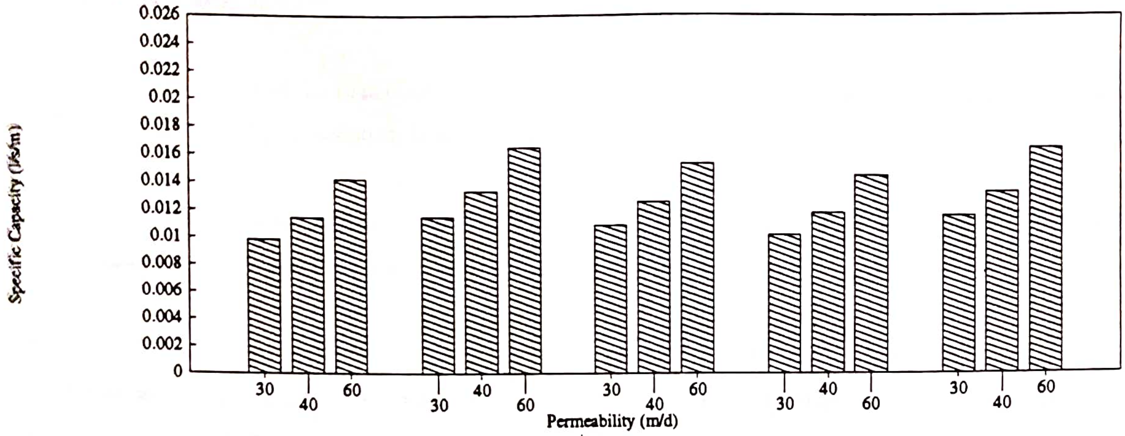
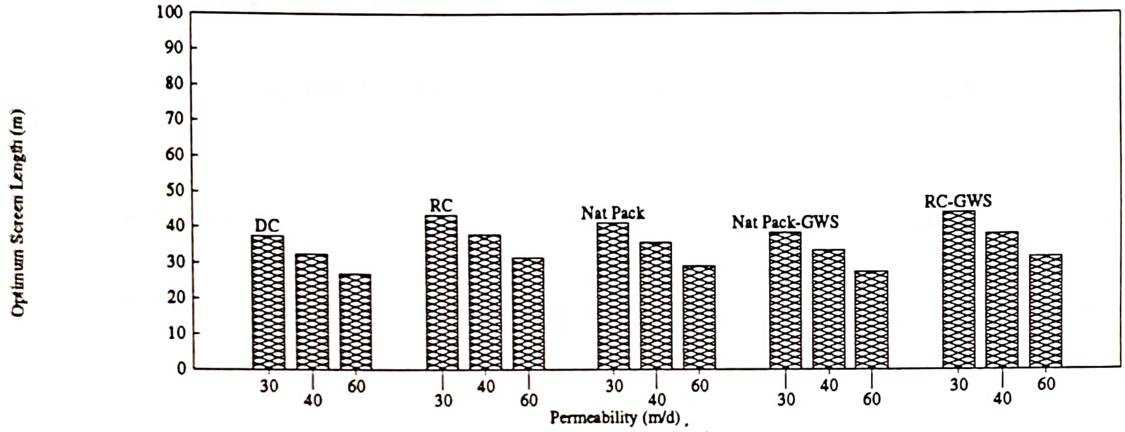
Figure 4.8

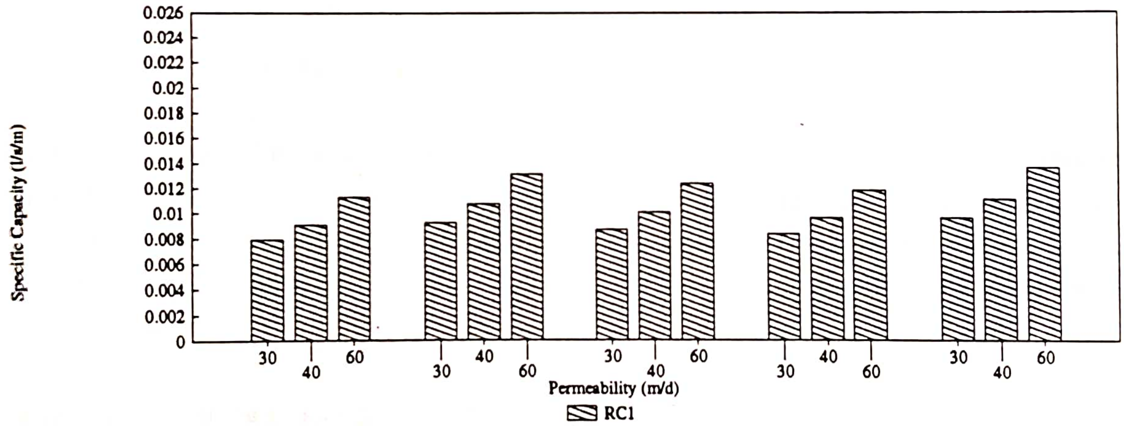
Screen Length & Specific Capacity for 200 m ^{3}/h Tubewells

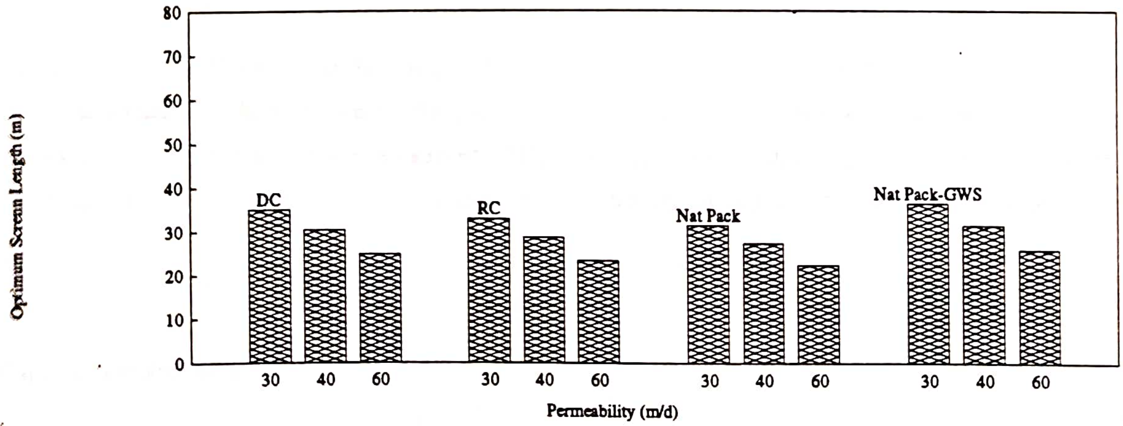
Case A: Aquifer proportion=60%





Case B: Aquifer proportion=40%





Alternative 200 m3/hr tubewell designs for 1100 hours operation, tariff Rs 2000 + Rs 2.6 /kWh

- the available head is sufficient to remove the need for pumping and the well is artesian flowing (AF);

- the available head is insufficient at critical times to produce a useful artesian flow and centrifugal pump assistance is needed (AP); and

- the available head merely causes a rise in the static water level and this sub-artesian assistance to the turbine pump reduces the cost of pumping (SAT).

In addition, the amount of excess pressure may increase with well depth because of the hydrogeological environment. This over pressure rate (OPR) can be expressed as metres of artesian rise per metre of drilling.

A complete economic analysis is beyond the scope of the study because of additional considerations such as:

- artesian heads will decline with aquifer utilisation; the conditions that give high pressure; i.e., elastic (low) coefficient of storage and tight confining condition (low coefficient of vertical permeability) themselves cause drawdown to increase more than experienced in low head aquifers;

- the switch to pumped conditions will happen at some ill-defined time in the future, making NPV calculations inaccurate; and

- the OPR is not well defined in most areas.

The 1987 study considered the interrelation of flow, initial head and various aquifer parameters on optimum flowing well design. It was concluded that heads over 7 m were likely to be better designed as free flowing wells (AF) whereas centrifugal pump assistance (AP) was needed at lower heads. Artesian heads at +5 m always produced much cheaper water than vertical turbine (VT) pumps with a SWL of + 3 m.

There thus appears to be a clear decreasing preference AF>>AP>>SAT.

In the present study, the artesian flowing and pump assisted criteria have not been examined again, but more attention has been given to the SAT case. A rise in static water level of 1 m produces a reduction in NPV of annual power consumed (APC) and the life expectancy of this rise can be taken as NY years. For a discount rate of 7% and a value of NY of 10 years, the saving is given by:

$$\text{Saving} = (APC_1 - APC_2) \times 7.02$$

Drilling to additional depth costs:

$$\text{Cost} = \text{Depth} \times (\text{Drilling Cost} + \text{LWC cost})$$

There is no extra screen cost because the objective is to set the same screen length deeper to get the SAT advantage.

UWC casing costs are likely to increase because of the need to fully cement the UWC to a depth around the first confining layer. Additional grout plugs above the gravel pack may be also needed if the main confining layer is deep. This increase in UWC costs from the normal 20 m case already considered can be calculated as:

$$Cost = 20 \times (UWC_{casing} + UWC_{drilling}) \times 1.1$$

where the 1.1 factor offsets the extra work involved in grouting.

4.8 DTW Costs Summary

The range of cost estimates for gravel packed, mud DC drilled DTWs in the three deep aquifer development units is summarised in Table 4.3. These estimates are based on a standard priced bill of quantities, an example of which is shown for a 60 l/s well with diesel driven vertical turbine pump on Table 4.4.

TABLE 4.3

Comparison of the Cost of Gravel Packed, Mud DC Drilled Tubewells Installed in Aquifer Development Units D1, D2 and D3

Design discharge Q (l/s)	Unit D1 Total depth (m)	Unit D1 Drill costs (Rs)	Unit D1 Pump* costs (Rs)	Unit D1 Total costs (Rs)	Unit D2 Total depth	Unit D2 Drill costs (Rs)	Unit D2 Pump costs (Rs)	Unit D2 Total costs (Rs)	Unit D3 Total depth	Unit D3 Drill costs (Rs)	Unit D3 Pump costs (Rs)	Unit D3 Total costs (Rs)
(a) Absolute costs												
90	130	878 760	442 800	1 321 560	160	1 029 360	471 060	1 500 420	230	1 389 860	542 600	1 932 460
60	100	589 010	361 200	950 210	120	677 860	379 100	1 056 960	180	893 460	431 860	1 325 320
45	80	469 410	323 300	792 710	100	547 010	337 800	884 810	140	700 060	381 470	1 081 530
30	75	363 110	252 300	615 410	80	392 310	262 300	654 610	110	483 510	295 080	778 590
15	50	206 180	178 200	384 380	60	225 300	180 100	405 400	80	263 480	205 290	468 770
(b) Costs relative to Unit D1												
90		100%	100%	100%		117%	106%	114%		158%	123%	146%
60		100%	100%	100%		115%	105%	111%		152%	120%	139%
45		100%	100%	100%		117%	104%	112%		149%	118%	136%
30		100%	100%	100%		108%	104%	106%		133%	117%	127%
15		100%	100%	100%		109%	101%	105%		128%	115%	122%

Note: Costs based on DC mud drilled wells with gravel packs and vertical turbine pumps driven by diesel engines.
* pump costs include installation and pump house but EXCLUDE discharge box/ buried pipe head tank

v3-t4-3.wk1

Source: GDC

v1-t4-5.wk1

TABLE 4.4

Sample Deep Tubewell Costs Estimate (Financial, 1993): 60 l/s Mud Drilled, Gravel Packed Well with Diesel Engine

DTW Model: D2 Gravel Packed:diesel power/VT lineshaft
60 l/s,td 120m:Dc mud drilled :non tele:27 days;drill/test; total head 14.8 m

Item	Unit	Rate (Rs)	Qty	Total (Rs)
Setup on site: shift to next site	LS	15 000	1	15 000
Restore site	LS	5 000	1	5 000
Drill 508 mm min. for UWC	m	4 300	23	98 900
Drill 355 mm for LWC	m	2 600	104	270 400
Geophysically log bore	LS	13 000	1	13 000
Supply 343 mm [14in] UWC ms casing	m	2 600	20	52 000
Supply 206 mm [8in] LWC ms casing	m	1 350	59	79 650
Supply 206 mm [8in] slotted ms casing	m	1 900	36	68 400
Supply reducer 14 - 8in	LS	1 750	1	1 750
Install casing & screen	LS	11 000	1	11 000
Supply & fix well cap	LS	3 000	1	3 000
Supply, install graded gravel pack	m3	1 000	6	6 000
Supply, install backfill; grout upper casing annulus	LS	5 000	1	5 000
Collect lithologic /water samples	LS	1 500	1	1 500
Carry out formation sieve analysis: 5 per bore	Nr	300	5	1 500
Develop well by compressor, air lift pump etc	hr	600	24	14 400
Carry out step & CD pumping test:inc. measurement	hr	570	48	27 360
Supply borehole completion report	LS	4 000	1	4 000
			sub total:	677 860
VT lineshaft pump: 19.8 bhp/14.8kW; diesel power (inc gearbox) [complete inc discharge head,] 60 l/s*14.8m head	LS	239 800	1	239 800
Installation	LS	5 000	1	5 000
Valves etc	LS	8 300	1	8 300
Pump house/ control chamber	LS	126 000	1	126 000
Discharge Box	LS	11 500	0	0
Transformer 11/ 0.4kV: 50kVA	LS	13 000	0	0
[ENERGY COST 3.7 Rs/Kwh :				
Annual running cost = 14.8kw * annual operating hours * 3.7 Rs			sub total:	379 100
Pump Operator: cost as Rs 120/ ha/ year				
			total	**1 056 960**
Replacement:Well 25 years/ Pump + motor 15 years				

Note:
Exclude the following items as in rates:

Item	Unit	Rate	Qty	Total
Driller	man day	300	28	8 400
Day paid labour:27 days/ DTW:				
Supervision	man day	50	28	1 400
sampler/ welder	man day	45	56	2 520
driller helpers [10 Nr]	man day	45	280	12 600
Watchman/ camp worker	man day	40	56	2 240
Rig service (once each 2 DTWs)	LS	5 000	1	5 000

Source: GDC

CHAPTER 5

SHALLOW TUBEWELL STUDIES

5.1 Introduction

Shallow tubewells (STWs) have been consistently identified as the groundwater irrigation technology of choice in the Terai. The predicted rapid increase in number and use still does not appear to be taking place, although there has been steady growth since 1987 in the numbers installed through ADBN, ILC and other government programmes along with those installed by the private sector. It is likely that several factors are impeding a massive expansion in STW development, and these certainly include contractual, technical, economic and social factors. This chapter addresses contractual problems and technical deficiencies in the STW sector. The latter are not always easy to define because the great majority of STWs built in the Terai are unreported: STW performance, lithological and water level data are therefore generally absent, and technical conclusions have to rely on small sample surveys.

Nevertheless, this study has concluded that the preferred development strategy must allow for the maximum use of STWs: to this end, the quality of the product must be technically sound and there must be a range of design and construction methods and materials to suit the range of hydrogeological conditions.

In this chapter, we discuss general criteria for STW design, and then review present design and construction practice in the Terai. The review is based on published data (GRWDB/UNDP, see Appendix II, Tables II.1 to II.5), brief field surveys in early 1993, an extended census of irrigation STWs in April-May 1993 (Appendix III, Tables III.1 and III.2) and interviews with drilling contractors working both manual and machine rigs (Appendix IV, Table IV.1). Finally, model STW designs, generally based on present practice, are given (Section 5.5) as a basis for economic analysis (Chapter 5), together with recommendations for the STW sector, including target criteria for design and construction.

5.2 STW Design Considerations

The overriding consideration in STW design is that the pumping water level does not fall beyond the suction limit of the pumps being used. This means that drawdowns, for a 2 to 2.5 m static water level, must be limited to less than around 4 m, implying typical screen lengths as shown in Table 5.1. Screen lengths for other yields and drawdowns can be easily calculated or prorated from the table.

TABLE 5.1

STW Screen Length for 4 m Drawdown

Coefficient of permeability (m/d)	20	40	60
Minimum screen length for			
Q = 15 l/s	21	10.5	7.1*
Q = 10 l/s	25	7.0*	4.7*

Note: * 10 m minimum recommended, see text.

Source: GDC

Longer screen lengths are automatically needed when the aquifer is finer (lower permeability) or the dry season SWL deeper, although field interview results suggest that longer screen lengths are seldom employed and this implies a failure by the parties concerned to give due weight to the design. This failure, and some of the other problems faced in STW construction, may be a result of the application of the same methods of tubewell construction to irrigation STWs that are applied to hand pump water supply tubewells: these wells only supply one or a few households, so maximum yield is seldom an issue.

The dimensions of the STW must allow water to reach the pump without excessive upflow losses; 4 inch diameter casing and screen is normally adequate for flow of up to 15 l/s. The topmost 9 m or preferably 12 m of the STW should be airtight to prevent loss of suction. If an entry velocity criterion is applied, assuming no screen blockage or open area reduction, and a factor of safety, the desirable inflow rate for 4 inch diameter material with 8% open area, is about 0.8 (l/s)/m. This dictates that screen length for STWs should always be more than 10 m.

A wide range of materials can be used for STW construction since there are few strength limitations at the required installation depths; these include plastics (PVC, HDPE, ABS), glass reinforced epoxy resins (GRP), steel and local materials such as bamboo and mesh.

Terai based manufacturers appear able to produce either PVC blank pipe or higher specification ribbed screen while 4 inch diameter steel pipe is also manufactured in the Terai. PVC materials offer considerable advantages in terms of cost, working life and range of possible slot sizes. They have become the dominant material in Bangladeshi STWs within two years of becoming available. Since they are not suitable for drilling by *thukwa* (drive), their use in Nepal may require active promotion by the government or manufacturers, with concurrent training of some drilling contractors.

Sand control in STWs is problematic. Whereas clear, sand-free water is normally seen by drillers and farmers to be the ultimate aim, the methods available are limited due to the manual technologies employed. Bailing and overpumping are normally possible, but, as for DTWs, a surge block or backwashing and jetting using a suction pump would often be beneficial. The survey has not produced any evidence that STWs are normally sounded after development to check if there is any backfill inside; such backfill, if more than a few metres thick, would significantly reduce the effective screen length.

A typical STW pump and motor combination is the Kirloskar NW4 (182 mm diameter) equipped with a TV1 water cooled medium speed (1 500 rpm) diesel.

The pump is capable of 75% bowl efficiency between 16 and 23 l/s at a total head of 10.2 m down to 8.5 m. In this range, net positive suction head (NPSH) requirements are less than 1 m and power consumption is less than 3.7 brake horse power (BHP). The TV1 engine has a rated output of 7 hp or 14 hp, depending on the number of cylinders. If the tubewell has a specific capacity around 2 to 3.5 (l/s)/m, the pump motor and tubewell will be reasonably well matched so that the whole operation is fairly efficient. For specific capacity less than 1.0 (l/s)/m, the yield drops to 10 l/s and the bowl efficiency drops to 55%, giving a 2.5 bhp power requirement. The 33% deduction from 15 l/s gives rise to only a 17% reduction in power needed, causing a significant rise in the cost of water. The pump would also have more chance of breaking suction if the flow reaches 27 l/s due to the higher NPSH requirements.

The solution is to match the pump to the duty and the motor to the required power. This process is much easier with diesel drive than electric because the farmer may be able to adjust the operating speed to get better overall fuel economy. This fine tuning is more practicable if the mismatch between the tubewell and the pumping equipment is not too severe in the first place. The present list price for STW pumps and engines is around NRs 20 000 for a 5.4 hp pump and engine, NRs 21 000 for the 7 hp system and about NRs 24 000 for a 8 hp system. Farmers are said to prefer engines in the 8 to 10 hp range because they can be used for purposes other than pumping, such as running threshers. There is thus a tendency, supported by the price structure, to get higher rated pumps than are strictly necessary.

Better matching of pump to duty requires that the specific capacity of the well is known, thus reinforcing the case for properly testing the well at the time of construction.

5.3 Present STW Design and Construction Practice

5.3.1 Design and Completion

There are over 35 000 STWs in the Terai, the majority drilled privately or under ADBN auspices by local contractors with manual drilling equipment, although several projects have used machine percussion rigs to drill STWs. Some typical STW specifications are as follow:

Sample	Depth (m)	Casing length (m)	Screen length (m)	Diam (mm)	Drill time (day)	Motor (hp)	SC ((l/s)/m)
GDC 1993 survey: (70 STWs)	17.8	13	5.75	100	7.3	6.1	-
ILC STWs, KTP	45.9	-	11.5	100	-	-	4.3
Birganj *	34.8	29	6	100	-	-	6.5
Birganj **	25.4	14.5	11.2	-	-	-	3.9
GDC 1987 survey: (248 STWs)	21.8	15.3	6.5	100		-	-

Notes: * UNDP: Bara, Parsa and Rautahat Districts
** S wells: Bara, Parsa and Rautahat Districts

Shallow tubewells are being manually constructed throughout the Terai to depths of between 10 and over 50 m. Drilling is generally to a standard design, the contractor is generally unsupervised and there is no systematic sampling/testing. With manual methods, the most typical completion is drilling at 4 to 6 inch diameter, to depths of 20 to 30 m, followed by the installation of 100 mm mild steel casing, with 3 to 5 m of 100 mm screen. Screen material includes locally fabricated coir or nylon mesh wrapped on a pipe base, slotted bamboo, high density polyethylene (HDPE) or steel saw slotted (possibly galvanised) pipe; the slotted mild steel pipe in common use in the Terai can deteriorate in storage to give slot form largely blocked by rust spall. There is little choice of well screen aperture available to the contractor (screen choice may be limited by bulk procurement), and in some cases, screen misplacement or use of inappropriate aperture screen combined with a lack of development, allows sand ingress which causes screen blockage and reduced performance or well failure. Well development is by circulation of water through the well screens but evidence of sand ingress and short STW lifetimes, suggest that development is quite inadequate. However, the manual contractor does not have the resources to deploy standard development tools (such as high velocity jetting heads or compressors) although it should be possible for him to operate surge block devices in the screen zone. The consequences of inadequate development may be excessive well drawdowns and frequent occurrence of sand pumping or sand blocked STWs.

Typical well discharges are around 13 l/s but it is common to find both low discharge wells (around 5 l/s), and wells whose discharge fails in the dry season or over time.

Machine drilled STWs, although of greater average depths, do not always appear to be significantly better in performance terms than manually drilled wells. In the case of DC mud drilled STWs, it appears that development has been inadequate to effectively remove drilling mud. GWRDB hydrogeologists working on the GWRDB/UNDP shallow aquifer drilling comment that the development of STWs drilled with manual methods (water flush or drive) can often be easier and more effective than with wells drilled by mud flush rigs.

STW well performance data are scarce because no data are collected during construction except for a spot discharge estimate, and no formation sampling or drawdown discharge tests are done. Most STWs are built without any survey of water level depth and variation; as a consequence, some STWs have been built in areas where suction operation is not possible without pitting of the well to 1 to 3.5 m (Jahada).

The typical Terai STW operates with a surface mounted suction lift pump powered by a 5 to 7 hp diesel. The installation runs to a suction lift limit of about 7 m and the overriding design consideration is that pumping water levels do not fall below this suction limit and hence the STW must be installed in a shallow watertable area.

Costs for manual drilling are typically around NRs 2 500 to 2 700 per well (while rates for drilling by imported percussion machine percussion are around NRs 2 000 to 2 200/m). A typical 4 inch cased STW drilled under the ADBN subsidy scheme to 15 m costs about NRs 12 000 to 15 000 excluding pump set; the pumpset typically costs NRs 20 000.

5.3.2 Drilling Methods and Contractors

STWs drilled by manual methods such as *thukwa* (manual driving of a slotted casing terminated at a pointed drive spear) are often limited to shallow depths, particularly in cobble-gravel materials; such materials are also slow and difficult to drill with machine percussion rigs drilling inside temporary casings. In cobble free areas, all manual methods are successful. Hand sludging (also called *dhikuli* (Tillson 1985)) can be used to achieve hole diametres of 6 inches to 50 to 60 m; i.e., adequate for natural packed 4 inch diameter casing and screen. Manual percussion (*bogi*) using a simple tripod and temporary casing can give finished diameters of 8 inches but requires a level of capital investment intermediate between other manual methods and the use of imported machine percussion rigs. Wash boring or jetting using a suction pump or hand donkey pump is less frequently used in the Nepal Terai than in northern Bangladesh; costs can be expected to be comparable to manual percussion.

Drilling progress using the above methods can often be improved by use of a two string completion where the STW suction pipe/upper well casing (UWC) is used as a conductor pipe during drilling of the lower well casing (LWC) section. However this configuration increases the costs, not least because of the risk of being unable to retrieve the UWC if drilling in the deeper section cannot be completed.

Machine percussion and rotary rigs have also been used to drill STWs in the Terai, especially for specific projects such as the ILC KTP; the GWRDB/UNDP shallow aquifer investigation programme used both machine and manual methods.

The Agricultural Development Bank of Nepal (ADBN), the principal employer of STW manual drilling contractors, insists on a minimum 6 l/s discharge from the STW, as a contractor payment condition (but it is reported that even this yield stipulation maybe relaxed subject to farmer consent).

However, this criterion of success may often give farmers a low expectation of what could be achieved. It is unfortunate that while the farmer may have little idea of what techniques the driller could employ to improve things, the driller has a disincentive to provide appropriate additional development effort since he is unlikely to be paid extra. Instead he is likely to close up the screen slot size to reduce sand ingress and try and use a minimum screen length so that this can be set against the less troublesome looking formations. Both of these actions will reduce the hydraulic performance of the well, reduce the specific capacity, and ultimately increase the cost of pumped water.

The number of working contractors in the Terai is not known, but on the basis of reported ADBN 1992/93 fiscal year STW completions (4 400 ADBN supported STWs plus 1 300 private STWs in a nine month drilling season at 5 to 7 day completion time per well), there could be over 100 working in the whole Terai.

5.4 STW Surveys

5.4.1 General

Interviews with both STW owners and with drilling contractors (Appendices III and IV; Tables III.1, III.2 and IV.1) have indicated that the following issues need attention:

- much of the Bhabar zone and the interior Terai valleys, contains aquifers within material which can be difficult to drill, particularly for manual methods; in Deukhuri, drilling difficulty (and ADBN rules on the basis of payment for successful and failed STWs) seems to have discouraged contractors from tendering; in 1993 in Dang, where drilling is of particular difficulty, only one drilling contractor remained;

- there is a tendency to adopt insufficient screen length, pipe diameters and airtight blank casing;

- there are numerous reports of STW failure or discharge decline (these exclude drilling failures where the contractor cannot complete and the well is abandoned without casing), a consequence of well or pumpset defects; and

- there is particular evidence of sand ingress to STWs, resulting in clogging of well-slot and reduction of the zone of saturation, and reduction in STW specific capacity and discharge; this suggests either incorrect screen-slot placement, incorrect screen-slot size, use of unstable or mechanically weak screen-slot material, or inadequate or non-existent well development.

5.4.2 The 1993 Shallow Tubewell Survey

An extensive field survey of STWs in the main Terai and Inner Terai valleys was carried out in the period February to May 1993. Concurrently, a survey was conducted of STW drilling contractors in the Terai.

The majority of the wells in the field survey sample were drilled by manual methods. The survey has indicated that while discharge may generally be satisfactory, pump drawdowns may be excessive (possibly blocked screens), the life of the STW may be short, and matters of operation and maintenance are sometimes neglected. The data from these surveys are summarised in Appendices III and IV, respectively.

The sample survey indicated the following pattern of design and usage:

- the sample average STW depth was 17.8 m, with 13 m of 100 mm casing and 5.7 m of screen; the STW was normally drilled and completed in 7.3 days;

- the well is equipped with motors of between 1 to 8 hp, but generally in the range 5 to 8 hp. Motor power appears ill matched to pump size as there is no correlation between pump outlet diameter and horsepower; all sets in the 5 to 8 hp range tended to have 2 to 4 inch outlets;

- 29% of the former sample (72) reported seasonal reduction in the pump discharge, presumably because of an increasing suction depth; 8% reported that yield from the STW decreased significantly after long pumping times;

- 20% reported pumping sand, sand ingress to the STW or well blockage from sand; there were isolated reports of well collapse because of sand entry and collapse around the STW surface casing;

- over 47% of farmers (sample size 75) reported that long times were required for pump priming (defined as greater than 15 minutes); in the worst case, the priming operation needed two hours; and

- discharge was measured for 54 STWs; the average was 13.7 l/s with a range of 2 to 25 l/s.

5.4.3 Other STW Data

To complement the field survey, other STW data were reviewed: data were available from several projects from the UNDP shallow aquifer survey, and from the ILC work in Kapilvastu.

Unlike the manually drilled STWs, there are usually some data available for machine drilled STWs or STWs drilled under project auspices. These data normally include a yield-drawdown test and sometimes step discharge tests which tell us something of well performance. This indicates that powered rigs, with ancillary pumps and compressors, do not always produce better STWs, particularly if drilling mud is used.

The Kapilvastu Tubewell Project under ILC has screened STWs in a formation described as gravel with subordinate coarse sand; in this material (theoretical minimum permeabilities about 70 m/d), a properly constructed 10 l/s STW with 11 m of screen, could be expected to have a specific capacity (SC) of 6 to 7 (l/s)/m. Yet the ILC sample of 59 STWs shows average SC values of 4.3 (l/s)/m, with a wide variation within one cluster area from 1 (l/s)/m to over 15 (l/s)/m as follows:

Cluster	Percentage of STWs with Specific Capacity		
	<1 (l/s)/m	1-2.5 (l/s)/m	>2.5-5 (l/s)/m
Jahada	0.0	26.0	52.0
Shivagarhi	10.5	26.3	21.0
Goberdiha	0.0	9.1	81.8

It is considered that wells with SC of less than 2.5 (l/s)/m (25% of the STW sample in some clusters) have either been drilled in areas of very low permeability formation material, or more likely, have partly blocked, poorly developed screens.

The evidence is similar with some ILC built MTWs with mean SC values of only 2.6 (l/s)/m (Jahada cluster MTWs). Formation damage by drilling mud and poor development is implicated, especially in deeper screened wells.

5.5 Model Shallow Tubewell Designs and Costs

The configurations for STW models considered later in the economic analysis are given below (Table 5.2), together with estimated capital costs of the models. The objective is to compare typical costs of the following:

- improved version of typical current Terai STW: a 20 m STW, constructed manually under ADBN subsidy, cased with mild steel (MS) pipe and equipped with a suction pumpset; the STW has a more serious development effort and a simple test to establish the 6 l/s minimum yield currently required for contractor payment by ADBN;

- a similar design, but one which uses PVC for casing and screen: elsewhere, we advocate the trial use of PVC casing and screen, which is made locally at 4 and 6 inch diameters, and is much cheaper than imported mild steel (MS) casing; although irrigation STWs are seldom completed with PVC (although its use for rural water supply wells is more common), we anticipate that PVC use will become much more common;

- a machine-drilled, 60 m deep, suction pumped STW, similar to those being constructed in the Terai for the ILC programme: this design is fitted with mild steel (MS) casing and saw slot screen, is gravel packed, fully logged, developed and tested, and equipped with a simple pumphouse and discharge box; capital costs of this design are five times that of the manual STW; and

- an additional 15 l/s machine drilled tubewell, similar to the third design above yet equipped with a submerged, diesel powered pump; similar designs (here designated MTWs because a submerged pump rather than a suction pump is sometimes used) have been used in the ILC programme; as for design 3, the capital cost is some eight times greater than the manual STW designs.

Both machine drilled 15 l/s designs demonstrate the very large capital cost difference between manual and machine methods. It is difficult to see how machine drilling of STWs can be competitive with manual drilled STWs under present practice, particularly as the machine drilled mud drilled option (as implemented under ILC) seems to provide wells which are difficult to develop. To make machine drilled STWs affordable would require a major modification in the machine drilling method (different work practice, use of down hole hammer or RC rigs) to give low drilling costs, together with adoption of drilling costs closer to the manual driller, and low cost plastic casing and screen. They do have valid applications in the areas where manual drilling methods are not practicable.

For completeness, Table 4.7 includes the cost of electrified STWs, and dug wells.

All STW and dug well variants have an allowance of RS 2 000 for a simple discharge box (rarely used at present) and a nominal Rs 5 000 to cover the value of the thatched huts usually built by the owners to protect the pump and provide daytime shelter. This addition of Rs 7 000 is not normally included in the typical ADBN STW package.

TABLE 5.2

Well Configurations and Capital Costs Comparisons: STWs and Dug Wells

Item	STW* machine drilled (ILC model)	STW manually drilled: steel casing-screen; improved Terai practice (ADBN model)		STW manually drilled: PVC casing screen	Dug wells	MTW* machine drilled
Depth (m) Discharge (l/s)/engine (hp)	60 15/8	20 10-15/8 Diesel	20 10-15/8 Electric	20 10-15/8	10 7.5/5	60 15
Component:						
Set up/restore site	7 500	-	-	-	-	12 500
Drilling	117 500	2 100	2 100	2 100	10 000	117 500
Geophysical logging/sampling/report	1 500	-	-	-	-	14 400
Casing, screen, reducer/cap	MS 49 750	12 800	MS 12 800	PVC 7 400	5 100	MS 52 000
Installation	4 500					4 500
Gravel pack/grout	3 500		-	-	-	3 500
Develop/test	10 620	2 500	2 500	2 500	1 000	20 900
Sub total	194 870	17 400	17 400	12 000	16 100	225 300
Pump and diesel engine	Su 24 000	Su 24 000	23 000	Su 24 000	Fm 20 000	Fm 100 600
Priming hand pump	-	1 200	1 200	1 200	-	-
Installation/valves	2 000	2 000	2 000	2 000	2 000	5 500
Pump house/discharge box**	41 000	7 000	22 000	7 000	-	81 000
LV connection cost	-		76 000			
Total	261 870	51 600	141 600	46 200	38 100	412 400

Notes: D2/S1 aquifer; * gravel packed

** includes Rs 2 000 for simple STW discharge box and Rs 5 000 for value of typical existing thatched STW houses

MS mild steel; PVC polyvinyl chloride; Su suction pump; Fm force mode

Source: GDC

5.6 Recommendations for the STW Sector

5.6.1 Suggested Target Criteria

The hydrogeological evidence suggests that much of the Terai is underlain by very permeable shallow aquifer material yet the performance and life of many STWs suggests that STW drilling and completion needs improvement. With some flexibility in screen design, and attention to well components and well development and completion, we see no reason why a target acceptance yield of 15 l/s, and a STW life of 15 years minimum, should not be considered realistic. We suggest that the following provisional acceptance criteria and procedures be adopted.

Design Minimum screen length 10 m. Internal diameter 4 inch for 15 l/s target yields or less. Minimum 12 m blank pipe from ground level to top of screen.

Development Minimum activities to comprise bailing, use of a surge block and overpumping. Development considered complete once water is clear (i.e., fingers visible through 18 inches of water in a bucket) and sand free, i.e., no more than 1 gram of sand or half a teaspoonful per 20 l of water at any time during the first 10 minutes of pumping and a negligible amount thereafter).

Yield test Separate criteria for minimum test yield depending on static water (SWL) level at the time of testing.

If SWL <3 m bgl, minimum flow rate to be 12 l/s;

If SWL <6 m bgl, minimum flow rate to be 8 l/s; and

If SWL >6 m bgl, minimum flow rate to be 5 l/s.

Casing and Screen In subsidised STWs, well screen should be 0.8 mm saw slotted smooth or preferably ribbed PVC screen to DIN 4925. Larger slot widths up to 1.5 mm should be considered if the screenable formation is mostly fine gravel or coarser material.

In the possibly unusual circumstance that formations comprising uniform fine to medium sand have to be exploited, a coarse sand to fine gravel pack or wrapped screen could be employed. Base pipe for wrapping should be smooth wall rather than ribbed.

PVC casing set less than 20 m below ground level could have a wall thickness of 3.7 mm absolute minimum; i.e., class 3 to IS 4985. Deeper PVC casing should have an absolute minimum wall thickness of 5 mm (the same as for screen to DIN 4925).

Where *thukwa* drilling is to be employed to install permanent casing and screen directly, steel pipe will have to be used as at present. If *thukwa* can be modified to drive a 5 to 6 inch temporary casing more like a *bogi* or standard percussion technique, then PVC could still be installed.

Reports The driller should provide GWRDB with a simple proforma report stating the location, client, date of construction, depth, materials used, SWL and test yield. Some drillers might be able to provide more detailed information such as a description of the lithology or drawdown during testing. These extra data need not form part of the basic standard.

5.6.2 Manpower and Research Needs

The STW sector requires both some technical-design input and field supervision and experimentation, in addition to some modifications to the contractual system. Technical and supervisory personnel from government and the ADBN would need to be involved at field level in practical well design changes, involving both contractor and farmer. There are several basic requirements:

- practical research into all aspects of STW design criteria, materials (in particular the increased use of Nepali manufactured PVC casing and screen), construction and development techniques;

- investigate the feasibility of modification of existing manual rigs, for example the modification of the *bogi* system by addition of circulation/rotation pump and small rotary drilling bits; this element would also consider adoption of improved development techniques, using surge block and overpumping;

- a need for some limited field experimental work into the development process, to be focused on existing machine drilled ILC boreholes where development appears incomplete, or on newly constructed test wells to allow controlled development, design innovation and the test use of new STW screen materials;

- technical field supervision and reporting on the ADBN STW programme is required on a routine basis; there is a clear need for technical supervision of the design, sampling, development and testing process; hydrogeological technicians, with knowledge of formation sampling, screen design and well development, yield drawdown testing and reporting, and pumpset maintenance, are needed at field level; however, it is unlikely that any organisation such as ADBN could mobilise enough technicians to supervise and monitor STW construction and operation; some of this will have to be done by the farmer, with suitable extension and advice;

- a training element to ensure ADBN technical staff, drillers and GWRDB technical staff understand basic design and construction and well development;

- an extension type approach to help farmers understand what could and should be achieved, what can be done to achieve it and their role in implementation; with appropriate training and explanation, it should be possible for the farmer to monitor the drilling, yield performance and water levels in his own STW; and

- some adjustment to the risk-reward ratio within the contractual system operated by ADBN is needed to more fairly balance the contractual risk to manual contractors who drill in difficult areas, particularly in bouldery or fine sand conditions; at present, there is a tendency for such contractors to refuse to work in marginal or difficult areas; the modifications should include preferential drilling rates for difficult drilling conditions, or possibly an allowance for equivalent pilot hole drilling should the STW have to be abandoned because of adverse drilling conditions.

Although ADBN promotes the majority of STWs in the Terai, the agency is not, as a matter of current policy, involved technically in STW construction supervision (except to certify a limiting well discharge on which contractor payment is based). This leaves a serious technical-supervisory gap which needs to be filled both to protect the farmers and to safeguard the longer term investment.

Because of the involvement of ADBN in the STW sector, it seems logical to suggest that ADBN's current policy should be reversed, and that ADBN, with appropriate technical strengthening, is well placed to provide technical field supervision through mobilisation in the field of suitable groundwater technicians with knowledge of formation sampling, screen design and well development, yield drawdown testing and reporting, and with additional pump-motor training.

The required field research should be implemented by GWRDB hydrogeologists, supported by a consultant hydrogeologist/groundwater engineer and a consultant drilling engineer. These people would not be project specific, but would review well design practice throughout the Terai.

More specific matters of STW design, design change and component materials, and field research on existing underperforming STWs would be addressed by Department of Irrigation (DOI) through the GWRDB research group mentioned above.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 General

For the reasons discussed above, the performance and life of Terai tubewells does not always attain what is practically possible, yet these things can be improved by small changes in the processes of well design, well construction and development. The scope for improvement is discussed broadly in the subsections which follow and is particularly important in the context of improving the quality and cost effectiveness of the tubewell on offer to farmers.

6.2 STW Construction and Contractual Systems

The hydrogeological evidence is that much of the Terai is underlain by very permeable shallow aquifer material, yet the performance and life of many STWs suggest that STW drilling and completion need improvement. With some flexibility in screen design, and attention to well components and well development and completion, we see no reason why a target acceptance yield of 15 l/s and a STW life of 15 years minimum should not be considered realistic. The target acceptance yield and other acceptance criteria are given in Chapter 5. To achieve these targets, several measures are required, as follows:

Drilling Contractors:

The manual well driller needs technical field advice and supervision on matters of formation sampling, screen selection and placement, well development and simple but controlled yield testing. The contractor must be required to carry out effective well development and this may require him to use additional equipment. He should be required to make simple reports.

Contractor training programmes, such as those run in the past by the ADBN, should be restarted.

ADBN should consider making loans to drillers to encourage them to acquire the extra equipment needed for correct STW development.

Contractual System:

The contractual system by which the majority of STWs are built needs review.

Some adjustment to the risk-reward ratio within the contractual system operated by ADBN is needed to balance more fairly the contractual risk to manual contractors who drill in difficult areas, particularly in bouldery or fine sand conditions. Preferential drilling rates for difficult drilling conditions, or possibly an allowance for equivalent pilot hole drilling should the STW have to be abandoned because of adverse drilling conditions, should be considered.

Equipment: Field Experimentation and Modification:

Experimentation in manual drilling practices is indicated. For example, modification of the *bogi* drilling system, with addition of a circulation/rotation pump and small rotary drilling bits could allow the system to drill faster and at larger diameters. Development and specification of simple development equipment and use.

Well Development:

Required field experimental work into the development process should be focused on existing machine drilled ILC boreholes where development appears incomplete, or on newly constructed test wells to allow controlled development, design innovation and the test use of new STW screen materials.

Alternative Casing-Screen Material:

Promotion of the use of plastic casing and screen through DOI (for trials), ADBN and drilling contractors, with concurrent technical design liaison with Nepali PVC manufacturers.

Field Supervision:

Technical field supervision and reporting on the ADBN STW programme is required on a routine basis. There is a clear need for technical supervision of the design, sampling, development and testing process, and for field advice on pumpset installation and maintenance.

6.3 DTW Design and Completion

Well completion and well design practice is somewhat rigid and requires critical review; in some cases, earlier designs are being subsequently applied to different formation-aquifer conditions with unsatisfactory results.

The current Stage III DTW well completion practice in Bhairahwa Lumbini Groundwater Project (BLGWP) is not entirely logical, and is in some respects unduly conservative. Overweighted drilling mud is used to control much diminished artesian heads, with consequent formation mud damage. The logic of the use of a 2 to 8 mm gravel pack opposite stainless steel WwRb screen with 1.6 mm aperture, other than extreme safety, is unclear; it is likely to impede effective development in the screen-pack zone.

Yet these designs are pursued without any formation grain size sampling and analysis. Formation analysis, and a choice of screen sizes, would allow more design flexibility and a reduction in length of production strings and in screen setting depths.

Since well design in Stage I of BLGWP used natural development and produced DTWs with specific capacities five times those of current DTWs, we suspect that current well design is defective while development of the well, particularly opposite deeper screens, is ineffective.

At the Kapilvastu Tubewell Project, the ILC DTWs and MTWs (and machine drilled STWs) show some similar design and completion problems. The wells are mud drilled and completed with 1.5 mm saw cut slots and a 2 to 5 mm gravel pack, a somewhat illogical and conservative design with built-in development problems. Some of the wells are of low specific capacity and show clear evidence that the screens have not been developed. That development is difficult or ineffective is partly confirmed by compressors which are incapable of working below 70 m depth and the lack of proper jetting-development tools.

In view of this evidence of poor well performance and problems with screen development, there seems to be a need for some rethinking of DTW design and completion. A critical review and concurrent pilot field study by people with background in drilling engineering and hydrogeology, is required of the current practices in the Terai, and should include the following topics:

- review the justification for continued use of gravel packs in DC mud drilled wells, screen selection and gravel pack design; review the logic and justification, in terms of safety, for use in BLGWP and ILC of packs grading outside the slot width; review gravel pack grading and placement and the requirement for routine formation sampling and mechanical grain size analyses, to derive grading curves to assist the screen design-placement process; reconsider the current definition of screenable material - should more screen design flexibility be available, and how does this affect the length of the production string required?;

- reassess the applicability and advantages of naturally developed well completions in terms of drilling costs, possible reduction in formation damage, and ease of formation development;

- review current operation of the one reverse circulation rig in the Terai and consider the feasibility of the more widespread use of RC;

- review drilling mud control and weighting materials in context of present reduced artesian heads; examine alternative mud formulations;

- review well development methods, equipment and chemicals used; examine development efficiency, particularly in deep set screens, in terms of well specific capacity; arrange field testing of appropriate isolated section well screen development techniques and possible in-screen flow logging techniques;

- focus on increasing specific capacity/decreasing well pumping costs as integral part of the well design process; and

- implement sequential specific capacity tests for individual wells, to detect performance deterioration; review possible causes, which could include physical sand blockage, bio-fouling or non-organic encrustation.

In view of the apparent advantages of the medium tubewell (MTW), namely reduced drilling depth and diameter, more shallow screen set and hence reduced drilling cost and fewer screen development problems, further work is needed on the design of these tubewells with typical yields in the range 20 to 40 l/s and their application to irrigation use.

Ancillary equipment needs to be upgraded. New development tools need to be provided to allow effective development across deep screens where deep screen settings can be justified; a flow log wireline tool should be acquired to allow investigation of well screen performance where specific capacity appears inconsistent with the grain size of the formation screened.

6.4 Manpower and Research Needs

Implementation of the recommendations given in Sections 6.2 and 6.3 will require involvement of personnel from the Nepali government, the private sector and from external consultant organisations.

The major requirements are:

- a need for practical research, and development, into all aspects of DTW design, construction and development;

- consolidation of DTW and STW data from all Terai districts into a database and mapping to allow basic aquifer resource and planning studies;

- research is required into STW design, construction methods and materials used; this could cover possible upgrading of the manual drilling process, new development techniques and a demonstration of the feasibility of using PVC casing and screens;

- a need for some limited field experimental work into the development process, to be focused on existing ILC boreholes where development appears incomplete; and

- promotion of technical field supervision and reporting on the ADBN STW programme is required on a routine basis; supervision is needed during design, sampling, development and testing process; hydrogeological technicians with knowledge of formation sampling, screen design, well development, yield drawdown testing and reporting are routinely needed at the field level (since farmers at present lack back-up in the operation and maintenance of their pumpsets, it would be desirable if the same technician could assist with the pumpset problems).

Well design and field experimentation in both the DTW and STW sector should be implemented by DOI/GWRDB hydrogeologists, supported by a consultant hydrogeologist/groundwater engineer and a consultant drilling engineer. These people would not be project specific, but would review well design practice, including materials, and carry out practical field tests throughout the Terai. GWRDB would then be in a position to promote incorporation of test results into tubewell production drilling, either by direct field liaison or by incorporation of modifications into standard contract specifications.

The DOI/GWRDB is the repository of the majority of Terai groundwater data, from both the deep and the shallow zone aquifers. It needs to expand this function and develop a comprehensive tubewell data base linked to hydrogeological mapping and mapping for development planning.

Water level mapping is of particular importance to successful STW expansion. The GWRDB maintains a basic but low density water level monitoring network (initiated under the GWRDB/UNDP shallow aquifer survey). A reasonable long term objective would be to increase the level of detail in this network by incorporating routine water level data collected during the ADBN STW programme by rural water supply programmes and by other projects. This would allow GWRDB to compile STW development mapping at a scale suitable for field planning use.

In the STW sector, hydrogeological technicians with knowledge of formation sampling, screen design and well development, yield drawdown testing and reporting are routinely needed at field level to assist farmers and perhaps to train them in basic water level yield measurements. Since farmers at present lack back-up in the operation and maintenance of their pumpsets, it would be desirable if the same technician could assist with the pumpset problems.

It was earlier mentioned that although ADBN promotes the majority of STWs in the Terai, the agency is not, as a matter of current policy, involved technically in STW construction supervision (except to certify a limiting well discharge on which contractor payment is based). This leaves a serious gap which needs to be filled both to protect the farmers and to safeguard the longer term investment.

Because of the involvement of ADBN in the STW sector, then the logical position is to suggest that ADBN's current policy should be reversed and that ADBN should provide technical field supervision through mobilisation of suitable and mobile technical personnel (groundwater technicians with additional pump-motor training, capable of producing full well completion-test reports) within the Terai districts. This is addressed further in Volume 1, Chapter 11.

APPENDIX I

DEEP TUBEWELL CONSTRUCTION DATA

Table I.1 : Deep Tubewell Design and Production Data; Kailali-Kanchanpur Districts, Seti & Mahakali zones; USAID DTWs

File : V3-TI-1.wk1 17-Dec-93

DTW Nr	Location	Elev (m)	Total depth (m)	Screen length (m)	Screen interval (ft)		SWL (m)	Test yield (l/s)		DD (m)	SC (l/s/m)	SD (m/l/s)	Kd (USGS) (usgpd/ft)	Kd (USGS) (m3/d/m)	Kd (Logan) (m3/d/m)	K screen (m/d)	SC/screen length (l/s/m2)	Q/screen length (l/s/m)	UWC/LWC diam (in)	Comment
1/1	Durgauli	166.2	26.2	9.1	50-80		3.37	3.6		0.94	3.8	0.3	232890 (r)	2892	436	48	0.42	0.39	4/4	T Theis
2/1	Bhajani	150.6	184.8	5.8	239-258		3.57	3.5		1.24	2.9	0.4	64280 (r)	798	325	56	0.49	0.61	4/4	r recovery
2/2	Joshipur	158.8	53.4	5.8	137-156		4.04	3.7		1.35	2.8	0.4	92910 (r)	1154	314	54	0.48	0.64	4/4	
2/3	Semri	161.3	156.1	6.1	220-240		1.99	3.6		1.68	2.1	0.5	108040 (r)	1342	243	40	0.35	0.59	4/4	
2/4	Semri	161.3	25.9	3.0	59-69		3.05	3.6		0.35	10.2	0.1	45480 (T)	565	1168	383	3.36	1.18	6/6	
2/6	Semri	161.3	54.9	3.0	132-142		2.39	3.6		2.33	1.5	0.6	100320 (r)	1246	176	58	0.51	1.18	4/4	
3/1	Basanta	159.1	457.3	6.1	155-175		5.22	3.6		3.60	1.0	1.0	11900 (r)	148	114	19	0.16	0.59	4/4	
3/2	Kantipur	161.9	198.5	9.1	130-150		1.29	3.5		6.43	0.5	1.9	9320 (r)	116	61	7	0.06	0.38	4/4	
					275-285														4/4	
3/3	Bijapur	168.3	115.2	3.0	307-317		1.83	3.6		7.38	0.5	2.1	5730 (T)	71	55	18	0.16	1.18		
3/4	Bijapur	168.3	99.7	6.1	275-285		1.83												4/4	
					307-317															
3/5	Sisaiya	166.8	353.0	6.1	575-595	+	13.47	4.0	ff	10.98	0.4	2.8	2380 (r)	30	41	7	0.06	0.65	4/4	
3/6	Sisaiya	166.8	22.0	4.6	53-68		5.79												4/4	
3/7	Sisaiya	166.8	24.4	6.1	56-76		5.88	3.4		1.30	2.6	0.4	21920 (T)	272	299	49	0.43	0.56	8/8	
3/8	Ganeshpur	166.5	122.3	4.9	263-279	+	18.78	10.2	ff	13.39	0.8	1.3	45020 (r)	559	87	18	0.16	2.10	4/4	
	Phulvarriy	164.9	304.9	7.6	255-280		2.93	3.6		0.99	3.6	0.3	66470 (r)	826	412	54	0.47	0.47	4/4	
	Gadriya	166.2	130.5	6.4	219-240	+	4.15	4.7	ff	4.15	1.1	0.9	32560 (r)	404	128	20	0.18	0.73	4/4	
	Bhada	170.7	97.9	6.4	282-303	+	15.55	3.4	ff	0.00								0.53	4/4	
	Bhada	170.7	94.5	6.4	284-305	+	9.46	3.4	ff	0.00			45390 (T)	564				0.53	4/4	
	Dhabai	182.3	196.6	6.1	295-315	+	17.85	3.2	ff	11.59	0.3	3.7	32200 (r)	400	31	5	0.04	0.52	4/4	
	Dhangadhi City	179.9	67.1	20.4	118-185		2.93	15.8		3.70	4.3	0.2	45840 (T)	569	485	24	0.21	0.77	8/8	Municipal
	Dhangadhi Tower	179.9	51.2	6.1	138-158		2.74	9.5		0.00								1.55	4/4	s/b
	Dhangadhi Tower	179.9	127.1	5.8	357-376	+	10.14	6.9	ff	5.23	1.3	0.8	6480 (r)	80	151	26	0.23	1.20	6/6	s/b
	Dhangadhi Tower	179.9	152.4	7.0	302-325	+	6.32	6.3	ff	0.00			38080 (r)	473				0.90	6/6	s/b
	Boradadi	180.8	125.9	9.1	297-307	+	7.08	1.6	ff	0.00			3070 (r)	38				0.17	4/4	
					377-397					0.00										
	Geta	187.8	126.2	4.3	281-295	+	10.32	14.3	ff	10.06	1.4	0.7			162	38	0.33	3.35	6/6	
	Geta	187.8	304.9	3.0	280-290	+	10.06	6.3	ff	0.00			38500 (T)	478				2.07	4/4	
	Autairaya	195.1	132.9	5.5		+	11.69	3.8	ff	3.16	1.2	0.8	29890 (r)	371	137	25	0.22	0.69	4/4	
	Taghariya	210.4	97.0	5.5	252-270		1.62	3.7		1.41	2.6	0.4	165990 (r)	2062	300	55	0.48	0.68	4/4	
	Cha Goan	171.6	138.7	9.5	273-304		13.72	3.0		1.83	1.6	0.6			185	20	0.17	0.31	4/4	
	Cha Goan	171.6	94.5	9.5	269-300		13.69	20.7		9.77	2.1	0.5	34280 (T)	426	242	26	0.22	2.19	6/6	
	Amariya	167.1	157.6	3.0	150-160		3.78	3.5		2.42	1.4	0.7	69990 (r)	869	163	54	0.47	1.14	4/4	
	Kaspa	170.1	304.9	3.0	222-232		0.98	1.9		31.34	0.1	16.6	6350 (r)	79	7	2	0.02	0.62	4/4	Screen dev problem
	Dekhatbuli	178.7	152.4	6.1	287-307	+	10.07	12.6	ff	8.42	1.5	0.7	94290 (r)	1171	171	28	0.25	2.07	4/4	
	Bandi	190.9	145.4	1.5	255-260	+	8.39	0.4	ff	0.00			18740 (r)	233				0.29	4/4	Dev problem
	Pachui(Cal)	165.2	152.7	6.1	291-311		3.79	3.8		1.32	2.9	0.3	197980 (r)	2459	327	54	0.47	0.62	4/4	
7/2	Amlia	169.8	128.0	6.4	274-295		2.32	3.9		1.61	2.4	0.4	28220 (r)	350	277	43	0.38	0.61	4/4	
7/3	Bichhuwa	173.8	19.8	3.4	48-59		1.83	0.0		0.00									4/4	
7/4	Bichhuwa	173.8	19.8	3.0	48-58		1.83	0.0		0.00									4/4	
7/5	Bichhuwa	173.8	19.8	3.4	48-59		1.88	3.8		1.79	2.1	0.5	171590 (T)	2131	240	72	0.63	1.13	6/6	
7/6	Bichhuwa Jhala	174.7	304.9	6.1	287-307		0.83	3.7		1.70	2.2	0.5	73390 (r)	912	249	41	0.36	0.61	4/4	
7/7	Partia	178.4	72.0	6.1	197-217	+	6.88	8.6	ff	6.71	1.3	0.8	34190 (r)	425	146	24	0.21	1.41	4/4	Sand producer
7/8	Sudha	196.3	39.9	3.0	119-129	+	0.61	2.1		25.91	0.1	12.5			9	3	0.03	0.68	4/4	Construction fault
8/1	Mahendranagar	0.0	34.5	16.2	52-105		2.48	15.5		7.65	2.0	0.5	146550 (r)	1820	231	14	0.13	0.96	6/6	
	Average		123.6	5.8							1.5	1.3		612	171	35	0.31	0.84		

Table I.2 : Deep Tubwell Design and Production Data; Bardiya District, USAID DTWs

File : V3-TI-2.wk1 17-Dec-93

DTW Nr	Location	Total depth (m)	Csg (m)	Screen length (m)	Screen interval (m)	Screen top (m)	SWL (m)	Test yield (l/s)	Sw (m)	SC (l/s/m)	SD (m/l/s)	Kd (Usaid) (m2/d)	Kd (Logan) (m2/d)	K screen (m/d)	SC/screen length (l/s/m2)	Q/screen length (l/s/m)	UMC/LWC diam (mm)	
3/8	Madada	305.0	75.6	14.6	57.9-72.5	57.9	+0.51	3.3	4.26	0.8	1.3		89	6	0.05	0.23	150/100	
3/9	Madada	76.3	74.7	6.4	60-63.4, 69.5-72.5	60.0	+0.51					330					100/100	?
3/10	Amohia	217.5	159.1	5.5	151.5-157	151.5	5.18	3.3	1.82	1.8	0.5	80	209	38	0.33	0.61	150/100	
4/1	Kanthapur	305.0	133.5	14.6	115.8-130.4	115.8	10.05	3.0	1.22	2.4	0.4	510	277	19	0.17	0.20	150/100	
4/2	Daurah	217.5	127.4	5.8	108.5-114.3	108.5	14.62	2.8	3.35	0.8	1.2	180	94	16	0.14	0.48	150/100	
4/3	Machhagar	206.8	204.8	11.6	191.7-203.3	191.7	17.67	0.3								0.03	150/100	
4/4	Dhakela	369.1	45.7	6.1	38.1-44.2	38.1	7.31					680					100/100	?
4/5	Dhakela	46.4	44.5	6.1	38.1-44.2	38.1	7.31	22.7	6.70	3.4	0.3	630	386	63	0.55	3.72	250/150	
5/1	Indrapur	157.4	131.7	4.8	125-129.8	125.0	6.40	3.0	1.52	1.9	0.5	1140	222	46	0.41	0.62	150/100	
5/2	Belbhar	149.5	89.9	9.2	79.2-88.4	79.2	7.61	3.0	2.07	1.4	0.7	250	163	18	0.16	0.32	150/100	
5/3	Belbhar	100.7	75.3	4.9	69.5-74.4	69.5	7.31					400					100/100	?
5/4	Belbhar	90.6	76.5	4.9	69.5-74.4	69.5	7.31	19.5	11.58	1.7	0.6	390	192	39	0.34	3.99	250/150	
5/5	Jabdahawa	93.6	87.2	2.8	82.5-85.3	82.5	0.57	3.0	1.82	1.6	0.6	350	185	66	0.58	1.06	150/100	
5/6	Bechaiya	31.7	31.1	7.1	28-35.1	28.0	9.75										200/100	
6/1	Taratal	86.9	86.9	5.5	81.4-86.9	81.4	14.62	2.8	0.45	6.2	0.2	1250	702	128	1.12	0.50	150/100	
6/2	Taratal	339.5	86.9	6.4	75.6-82	75.6	3.35										250/150	
6/3	Belwa	86.9	86.9	5.2	78.9-84.1	78.9	14.93	2.4	0.30	8.0	0.1	2058	909	175	1.53	0.46	150/100	
6/4	Banbirpur	63.1	62.5	4.6	57.9-62.5	57.9	9.84										150/100	
6/5	Bhurkia	101.0	79.5	9.1	68.6-77.7	68.5	6.40	3.0	0.60	4.9	0.2	870	563	62	0.54	0.33	150/100	
	Average			7.1						1.8	0.3	651	200	34	0.30	0.63		

Table I.3 : Deep Tubewell Design and Production Data; Banke District; USAID DTWs File : V3-TI-3.wk1 17-Dec-93

DTW Nr	Location	Total depth (m)	Cased (m)	Screen length (m)	Screen interval (m)	SWL (m)	Test yield (l/s)	Sw (m)	Specific capacity (l/s/m)	Specific drawdown (m/l/s)	Kd (Jica) (m3/d/m)	Kd (Logan) (m3/d/m)	K screen (m/d)	SC/screen length (l/s/m2)	Q/screen length (l/s/m)	UWC/LWC diam (mm)
1/1	Piprahawa	77.2	45.2	8.2	34.1-42.3	2.13	4.0	0.97	4.1	0.2	470	470	57	0.50	0.49	150/150
1/2	Daspurwa	62.5	15.2	2.5	12.5-15	1.17	3.6	0.36	10.0	0.1	3050	1140	456	4.00	1.44	150/150
1/4	Halbaldoli	139.1	66.4	5.9	61.5-67.5	8.53	3.3	8.53	0.4	2.6	35	45	8	0.07	0.57	150/100
1/5	Kamdi	217.5	122.0	5.7	114.3-120	10.36	3.5	0.88	4.0	0.2	580	457	80	0.70	0.62	150/100
1/6	Kamdi	125.4	121.6	5.3	112.7-118	10.36	16.7	11.00	1.5	0.7	620	173	33	0.29	3.15	300/200
1/7	Manda	207.7	79.9	6.2	71.6-77.8	21.03	2.2	0.71	3.1	0.3	330	353	57	0.50	0.35	150/100
1/8	Udain	184.5	71.3	4.3	63.7-68	+10.6	15.8				230				3.66	150/100
2/1	Jamunaha	305.9	134.7	7.4	124.6-132	13.70	2.5	0.36	7.0	0.1	1640	798	108	0.95	0.34	150/100
2/2	Mahendra	140.3	51.5	5.9	43.5-49.4	4.50					400					100/100
2/3	Mahendra	50.6	50.0	5.8	43.0-48.0	3.40	17.0	12.19	1.4	0.7	260	159	27	0.24	2.93	250/250
2/4	Nepalganj	13.7	13.7	5.9	4.8-10.7	14.10										150\150
2/5	Nepalganj	366.0	366.0	39.5	100.4-106.7,	10.98	35.3	18.30	1.9	0.5		220	6	0.05	0.89	350/300
					161.4-167.3,											
					232.1-237.8,											
					255.4-272.4,											
					359.3-363.9											
2/6	Karkando	301.6	108.8	7.0	99.4-106.4	14.30	2.3	4.27	0.5	1.9	100	60	9	0.08	0.32	150/100
2/7	Ranjha	244.9	117.6	3.3	111.0-114.3	14.30										100/100
2/8	Ranjha	120.8	117.6	7.4	107.2-114.6	14.30										200/150
2/9	Army camp	150.1	120.4	9.0	47.5-49.0	14.30	0.2	1.37	0.2	6.2	150	18	2	0.02	0.02	250/150
					77.7-82.3,											
					115.2-119											
2/10	Haldarpurwa	230.6	217.3	7.0	209.7-216.7	5.50	4.1								0.58	100/100
2/11	Kohalpurwa	457.5	222.5	5.7	210.3-216	2.40	0.6	14.32	0.0	22.7	10	5	1	0.01	0.11	150/100
2/12	Thukali	216.9	130.0	3.6	128.0-131.6	+6.70	4.0				330				1.11	100/100
3/1	Sainik Gaon	305.0	55.5	8.8	43.2-52	8.20	2.5	1.67	1.5	0.7	22	171	19	0.17	0.28	150/100
3/2	Sainik Gaon	55.8	53.5	6.1	45.7-51.8	8.20					230					100/100
3/3	Odrapur	457.5	69.2	6.2	58.2-64.6	8.20	2.3	17.37	0.1	7.5	30	15	2	0.02	0.38	150/100
3/4	Agri-farm	305.0	39.3	5.8	30.4-36.2	5.50	2.8	13.41	0.2	4.8	20	24	4	0.04	0.48	150/150
3/5	Agri-farm	132.7	129.2	22.0	93.0-115.0	10.30	20.1	6.77	3.0	0.3		338	15	0.13	0.91	300/200
					122.0-127											
3/6	Agri-farm	122.6	120.4	6.0	102.0-108	10.30					450					100/100
3/7	Dahawa	305.0	103.3	5.2	97.0-102.2											150/100
	Average	203.7		7.9					1.2	2.2	389	222	44	0.39	0.81	

Table I.4 : Deep Tubewell Data, Kapilvastu, Rupandehi and Nawalparasi District (USGS Data - Lumbini Zone)

Well name	Well Nr	Date complete	Elev. (masl)	Total depth (m)	Screen interval (m)	Length screen (m)	Casing depth (m)	Casing diam (in)		SWL/ head* (m)	Sw (m)	Yield Q (l/s)		SC l/s/m	Kd (USg/d/ft2)	Kd [Logan] (m3/d/m)	K Screen (m/d)	SC/m screen (l/s/m2)	S	Comment
Pasauli	2/3	5.71	101.3	152.4	32-39.6	7.6	45	1.5		4.00	13.40	29.8	p	2.2	23 690	254	33	0.29		
Visnupura	4/1	3.71	101.6	72.8	58-62.8	4.8	64	1.5	+	1.10	0.22	0.5	f	2.3	12 820	259	54	0.47		
Sitlapur	4/2	3.71	105.4	243.0	100.6-106.7	6.1	110	1.5	+	12.80	0.34	1.5	f	4.4	21 340	507	83	0.73		
Belahia	4/4	3.71	104.4	80.5	68.6-74.7	6.1	24.7	10				16.5	f		54 000				0.00017-0.0000585	
							18-81.4	6												
Kerwani	4/6	4.71	128.7	152.4	122-128	6.0	24.4	8			1.11	2.5	p	2.3	32 150	259	43	0.38		Sc=11gal/ft dd?
							18.3-131	4												
Paklihawa	5/2	6.71	104.3	83.2	80.8-83.8	3.0	67	6			3.75	3.2	f	0.8	3 420	96	32	0.28		
							85.3	4												
Paklihawa	5/3	6.71	104.3	155.5	144.8-154	9.2	154	6			6.28	14.1	f	2.2	8 400	255	28	0.24		
Bhairawa SP Camp	5/5	6.72	106.7	80.8	73.2-77.1	3.9	78.6	6				12.6	f		48 250				0.0003-0.00068	
Bhairawa Airport	5/6	10.71	105.0		58.5-62.8	4.3	64.3	6			2.04	26.2	f	12.8	105 000	1465	341	2.99		
Ag Res Farm	5/9	5.70	109.0	54.5	48.7-50	1.3	50	8	+	9.15	0.48	26.5	f	55.2	236 000	6296	4843	42.47		
Govt Fish Fm	5/10	5.70	110.6	54.8	48.2-54.3	6.1	54.8	6				30.9	f		192 000					
Manigram	5/14	7.69	128.6	48.2	24.4-47.3	22.9	24.4	14			1.83	76.3	p	41.7		4755	208	1.82	0.00011-0.0000338	Kd from obswell Bhabar
							47.3	8												
Driver Tole	5/17	1.71	135.4	250.0	94.5-106.7	12.2	91.5	10			6.25	20.0	p	3.2	237 000	365	30	0.26		?Bhabar
							79-114	6												
Jogikuti	5/18	4.71	148.4	45.7	23.5-43.3	19.8	23.8	10			1.28	24.6	p	19.2	435 000	2192	111	0.97		Bhabar
							45.7	8												
Bhutwal	5/19	9.71	174.0	90.2	25.3-42m	27.3	24.7	14			3.23	21.1	p	6.5	188 000	744	27	0.24		Bhabar
					58-62.8m		65.8	8												
					75-80.8m															
Bogri	6/4	2.72	95.3	38.1	30.5-36.6	6.1	37.8	8			2.13	3.2	p	1.5	12 000	169	28	0.24	0.00021-0.00039	
Semri	6/7	5.72	100.6	153.3	65.5-73.2	7.7	74.7	4	+	13.31	0.31	5.1	f	16.3	83 000	1858	241	2.12		
Chapia	6/10	12.72	114.8	59.1	52.1-57m	4.9	59.1	8				28.4	f		129 000					
Chapia	6/8	12.71	114.4	147.2	21.3-30.5	9.2	30.5	8			1.31	3.2	p	2.4	28 400	274	30	0.26	0.000062-0.000052	Kd from obswell
Bhujauli	6/12	12.71	119.7	99.1				1.5/3?	+	4.12	0.10	1.4	f	13.8	64 000	1574			0.00016-0.000128	
Mughla	8/3	1.72	101.5	164.0	152.4-158.5	6.1	161.6	6	+	11.90		21.1	f		12 900					
Asnia	8/5	3.72	113.9	122.9	65.5-72.3	6.8	75.6	3	+	8.38	1.04	7.3	f	7.0	27 600	795	117	1.03	0.0011-0.00032	
Rehara	9/5	3.72	109.1	41.2	33.8-36.9	3.1	38.4	8		1.52	3.93	3.2	p	0.8	7 100	91	29	0.26	0.000093	
Motipur	9/8	4.72	120.1	52.4	40-50.9	10.9	52.4	8	+	8.80		39.0	f		59 000				0.0001	
Taulihawa	10/3	5.72	103.5	160.4	152.4-156.7	4.3	29.8	10	+	2.43	17.07	2.3	fp	0.1	2 000	15	4	0.03	0.00012	
							158.5	6												
Champapur	11/5	4.72	115.5	152.4	53.9-57	3.1	58.5	3	+	4.02	1.16	0.8	f	0.7	6 500	81	26	0.23		
Dharamnagar	12/4	5.72	123.7	153.0	60-64	4.0	65.2	3	+	4.87		1.6	f		5 400					
Shivanagar	13/2	5.72	102.8	152.4	64-69.2	5.2	27.4	8		4.80	5.97	2.7	p	0.4	13 000	51	10	0.09		
							69.8	6												
Averge				113.4		8.0						15.19		5.47	80 418	607	173	1.52		

Table I.5 : Data from ILC Groundwater Sub-Project, Kapilvastu Tubewell Project, Progress Report; GWRDB 1992. File : V3-TI-5.wk1 10-May-94

Well name	Pump set	Pump type	TD (m)	SWL (m)	Test time (min)	Q (m3/h)	Q (l/s)	PWL (mbgl)	Measured drawdown (m)	SC (l/s/m)	SC (m3/h/m)	Logan Kd (m3/d/m)	Length screen (m)	K screen (m/d)	Comment	SC/stet (l/s/m2)	Q/stet (l/s/m)	Screen length/Q (m/l/s)
Nawalparasi																		
Jahada STW-1	Su:0.75	S	51.0	6.2	70.0	57.6	16.0	7.54	1.34	11.9	43.0	1361.8	19.2	70.9	all 100mm string	0.62	0.8	1.2
Jahada STW-2			52.5	5.3	45.0	50.4	14.0	6.65	1.34	10.4	37.6	1191.5	14.0	85.1	Coconut string screen	0.75	1.0	1.0
Jahada STW-3			54.5	5.8		50.4	14.0	6.91	1.11	12.6	45.4	1438.4	14.0	102.7		0.90	1.0	1.0
Jahada STW-4	Su:0.5	S	50.5	5.5	50.0	25.2	7.0	8.77	3.26	2.1	7.7	244.9	13.7	17.9		0.16	0.5	2.0
Jahada STW-5	Su:0.75	S	50.8	5.6	50.0	25.2	7.0	7.50	1.90	3.7	13.3	420.2	12.6	33.3		0.29	0.6	1.8
Jahada STW-6	Su:1.0	S	52.3	5.5	60.0	36.0	10.0	7.84	2.34	4.3	15.4	487.4	16.8	29.0	Coconut string screen	0.25	0.6	1.7
Jahada STW-7	Su:0.5	S	51.0	4.9	45.0	50.4	14.0	7.15	2.21	6.3	22.8	722.5	14.0	51.6	part coconut string screen	0.45	1.0	1.0
Jahada STW-8			33.5	6.2		54.0	15.0	8.70	2.50	6.0	21.6	684.3	14.0	48.9	150mm/100mm	0.43	1.1	0.9
Jahada STW-9	Su:3.5	S	55.5	5.1	400.0	37.8	10.5	8.77	3.69	2.8	10.2	324.5	11.0	29.5		0.26	1.0	1.0
Jahada STW-10	Su:2.0	S	31.0	6.5	80.0	43.2	12.0	9.02	2.52	4.8	17.1	543.1	12.0	45.3		0.40	1.0	1.0
Jahada STW-11	Su:5.0	S	60.8	7.4	40.0	25.6	7.1	10.48	3.10	2.3	8.3	261.6	12.2	21.4		0.19	0.6	1.7
Jahada STW-12	Su:2.0	S	57.2	5.6	35.0	34.2	9.5	7.96	2.41	3.9	14.2	449.6	12.2	36.8		0.32	0.8	1.3
Jahada STW-13	Su:3.5	S	54.5	6.3	80.0	30.6	8.5	9.00	2.71	3.1	11.3	357.7	10.0	35.8		0.31	0.9	1.2
Jahada STW-14	Su:4.5	S	54.1	7.0	70.0	25.2	7.0	10.42	3.47	2.0	7.3	230.1	12.0	19.2		0.17	0.6	1.7
Jahada STW-15	Su:3.5	S	51.1	5.5	80.0	28.8	8.0	8.94	3.41	2.3	8.4	267.6	11.0	24.3		0.21	0.7	1.4
Jahada STW-16	Su:3.5	S	50.6	5.7	50.0	28.8	8.0	8.91	3.18	2.5	9.1	286.9	12.0	23.9		0.21	0.7	1.5
Jahada STW-17	Su:3.5	S	51.1	7.0	55.0	22.7	6.3	8.92	1.96	3.2	11.6	366.9	11.0	33.4		0.29	0.6	1.7
Jahada STW-18			56.5	8.4	400.0	37.8	10.5	11.40	3.01	3.5	12.6	397.8	11.2	35.5	step II:150mm/100mm	0.31	0.9	1.1
Jahada STW-19			56.9	8.5	280.0	37.8	10.5	13.79	5.32	2.0	7.1	225.1	12.2	18.5	step II:150mm/100mm	0.16	0.9	1.2
Jahada STW-20			56.9	9.0	800.0	37.8	10.5	12.71	3.71	2.8	10.2	322.8	12.3	26.2	150mm/100mm	0.23	0.9	1.2
Jahada STW-21			53.5	5.1	800.0	36.0	10.0	10.80	5.70	1.8	6.3	200.1	12.1	16.5	150mm/100mm	0.14	0.8	1.2
Jahada STW-22			50.0	5.4	720.0	37.8	10.5	8.20	2.80	3.8	13.5	427.7	12.0	35.6	150mm/100mm	0.31	0.9	1.1
Jahada STW-23			50.1	4.9	720.0	36.0	10.0	8.70	3.80	2.6	9.5	300.1	12.1	24.8	150mm/100mm	0.22	0.8	1.2
Jahada		23	51.5				10.3		avg:	4.4	15.8	500.5	12.8	37.7		0.33	0.8	1.3
Kapilvastu																		
Shivagarhi STW-1	Su		45.8	7.0	55.0	31.0	8.6	7.55	0.55	15.7	56.4	1785.6	12.6	141.7	Shivagarhi STW's are 100mm	1.24	0.7	1.5
Shivagarhi STW-2	Su		45.3	6.0	55.0	32.4	9.0	7.70	1.75	5.1	18.5	586.5	12.0	48.9	casing-screen	0.43	0.8	1.3
Shivagarhi STW-3	Su		44.8	5.0	50.0	37.8	10.5	6.65	1.65	6.4	22.9	725.8	12.0	60.5		0.53	0.9	1.1
Shivagarhi STW-4	Su		47.3	6.1	40.0	25.2	7.0	8.16	2.04	3.4	12.4	391.3	15.0	26.1		0.23	0.5	2.1
Shivagarhi STW-6	Su		59.0	7.7	40.0	16.2	4.5	8.56	0.84	5.4	19.3	611.0	12.0	50.9		0.45	0.4	2.7
Shivagarhi STW-7	Su		57.0	7.0	80.0	32.4	9.0	8.07	1.08	8.3	30.0	950.4	14.0	67.9		0.60	0.6	1.6
Shivagarhi STW-8	abd		65.0	4.9	100.0	22.7	6.3	7.89	3.01	2.1	7.5	238.9	10.0	23.9	Coconut string screen	0.21	0.6	1.6
Shivagarhi STW-9	Su		45.0	5.8	50.0	28.8	8.0	7.26	1.42	5.6	20.3	642.5	13.0	49.4	Local screen	0.43	0.6	1.6
Shivagarhi STW-10	Su		49.0	3.8	110.0	39.6	11.0	5.42	1.61	6.8	24.6	779.2	13.0	59.9		0.53	0.8	1.2
Shivagarhi STW-11			52.5	+art	360.0	46.8	13.0	1.42	1.42	9.2	33.0	1044.1	12.0	87.0		0.76	1.1	0.9
Shivagarhi STW-13			48.0	1.2	200.0	54.0	15.0	5.24	4.06	3.7	13.3	421.4	12.0	35.1		0.31	1.3	0.8
Shivagarhi STW-14			58.0	+art	360.0	32.4	9.0	5.40	6.40	1.4	5.1	160.4	12.0	13.4	1m +head assumed	0.12	0.8	1.3
Shivagarhi STW-15			54.0	+art	420.0	43.2	12.0	6.88	7.88	1.5	5.5	173.7	12.0	14.5	1m +head assumed	0.13	1.0	1.0
Shivagarhi STW-16			51.0	2.4	260.0	22.7	6.3	8.25	5.90	1.1	3.8	121.9	12.0	10.2		0.09	0.5	1.9
Shivagarhi STW-17			56.0	2.8	280.0	43.2	12.0	5.80	3.05	3.9	14.2	448.7	12.0	37.4		0.33	1.0	1.0
Shivagarhi STW-18			51.0	+art	240.0	25.2	7.0	7.82	8.82	0.8	2.9	90.5	15.0	6.0	1m +head assumed	0.05	0.5	2.1
Shivagarhi STW-19			54.5	4.0	320.0	34.2	9.5	7.30	3.35	2.8	10.2	323.4	12.0	27.0		0.24	0.8	1.3
Shivagarhi STW-20			45.0	1.1	140.0	18.0	5.0	8.80	7.75	0.6	2.3	73.6	12.0	6.1		0.05	0.4	2.4
Shivagarhi STW-21			59.0	1.8	60.0	30.6	8.5	7.35	5.55	1.5	5.5	174.7	12.0	14.6		0.13	0.7	1.4
		19	52.0				9.0		avg:	4.5	16.2	512.8	12.5	41.1		0.36	0.7	1.5
Kapilvastu																		
Valwad STW-1			37.5	2.1	100.0	84.5	23.5	6.34	4.29	5.5	19.7	624.0	14.0	44.6		0.39	1.7	0.6
Valwad STW-2			38.0	2.4	560.0	64.8	18.0	5.57	3.17	5.7	20.4	647.6	12.0	54.0		0.47	1.5	0.7
Valwad VDC 4 STW Jenewa				+art		82.8	23.0		9.22	2.5	9.0	284.5						0.0
		3	37.8				21.5		avg:	4.5	16.4	518.7	13.0	49.3		0.29	1.1	0.4

Table I.5 : Data from ILC Groundwater Sub-Project, Kapilvastu Tubewell Project, Progress Report; GWRDB 1992.

File : V3-TI-5.wk1 10-May-94

Well name	Pump set	Pump type	TD (m)	SWL (m)	Test time (min)	Q (m3/h)	Q (l/s)	PWL (mbgl)	Measured drawdown (m)	SC (l/s/m)	SC (m3/h/m)	Logan Kd (m3/d/m)	Length screen (m)	K screen (m/d)	Comment	SC/stet (l/s/m2)	Q/stet (l/s/m)	Screen length/Q (m/l/s)
[STW GB wells not reported by Shah]																		
Gb Goberdiha																		
STW GB-1			28.5	4.3	160.0	43.2	12.0	6.92	2.64	4.5	16.4	518.4	10.7	48.4		0.42	1.1	0.9
STW GB-4	Su		28.7	8.8	210.0	39.6	11.0	11.80	2.99	3.7	13.2	419.6	9.2	45.6		0.40	1.2	0.8
STW GB-5	Su		27.2	6.9	150.0	36.0	10.0	10.10	3.25	3.1	11.1	350.9	6.2	56.6		0.50	1.6	0.6
STW GB-6			27.1	5.9	150.0	28.8	8.0	8.06	2.12	3.8	13.6	430.4	6.2	69.4		0.61	1.3	0.8
STW GB-7			25.9	5.9	210.0	28.8	8.0	8.10	2.19	3.7	13.2	416.6	6.2	67.2		0.59	1.3	0.8
STW GB-8	Su		25.7	8.3	120.0	28.8	8.0	10.08	1.80	4.4	16.0	506.9	6.2	81.8		0.72	1.3	0.8
STW GB-9	Su		26.1	9.3	160.0	21.6	6.0	10.60	1.35	4.4	16.0	506.9	6.1	83.1		0.73	1.0	1.0
STW GB-11	Su		19.2	6.5	180.0	36.0	10.0	8.86	2.41	4.1	14.9	473.2	6.1	77.6		0.68	1.6	0.6
STW GB-12			22.2	4.4	210.0	68.4	19.0	7.97	3.53	5.4	19.4	613.9	6.1	100.6		0.88	3.1	0.3
STW GB-13	Su		28.1	8.8	120.0	36.0	10.0	10.85	2.03	4.9	17.7	561.8	6.0	93.6		0.82	1.7	0.6
STW GB-14			19.8	3.2	150.0	36.0	10.0	8.53	5.31	1.9	6.8	214.8	6.1	35.2		0.31	1.6	0.6
		11	25.3				10.2		avg:	4.0	14.4	455.8	6.8	69.0		0.61	1.5	0.7
Patana VDC 8 STW Balapur				+art		90.0	25.0		6.30	4.0	14.3	452.6						
Patana VDC 8 STW Balapur				+art		82.8	23.0		6.76	3.4	12.2	388.0						
Patna VDC 4 STW Dharmpur				+art		79.2	22.0		7.55	2.9	10.5	332.3						
		3					23.3		avg:	3.4	12.3	391.0						
all STW		59	45.9				10.2			4.3	15.6	495.1	11.5	45.5	all STW	0.38	0.9	1.2
Nawalparasi																		
Jahada MDTW-1			62.0	6.9	245.0	64.8	18.0	10.25	3.33	5.4	19.5	616.5	6.1	101.1	step III:150mm	0.89	3.0	0.3
Jahada MDTW-2			61.5	8.7	240.0	64.8	18.0	12.06	3.40	5.3	19.1	603.8	19.0	31.8	step IV:150mm	0.28	0.9	1.1
Jahada MDTW-3			56.0	8.0	280.0	72.0	20.0	16.07	8.12	2.5	8.9	280.9	19.0	14.8	250mm/150mm	0.13	1.1	1.0
Jahada MDTW-4			54.5	6.3	350.0	86.4	24.0	17.23	10.98	2.2	7.9	249.3	13.0	19.2	step II:250mm/150mm	0.17	1.8	0.5
Jahada MDTW-5			54.0	6.1	270.0	79.2	22.0	17.07	10.99	2.0	7.2	228.3	13.0	17.6	step II:250mm/150mm	0.15	1.7	0.6
Jahada MDTW-6			53.0	6.6	350.0	72.0	20.0	17.07	10.43	1.9	6.9	218.7	13.0	16.8	step II:250mm/150mm	0.15	1.5	0.7
Jahada MDTW-7			56.0	7.3	180.0	86.4	24.0	20.00	12.70	1.9	6.8	215.5	12.5	17.2	250mm/150mm	0.15	1.9	0.5
Jahada MDTW-8			55.0	5.1	880.0	79.2	22.0	19.52	14.43	1.5	5.5	173.9	14.0	12.4	step III:250mm/150mm	0.11	1.6	0.6
Jahada MDTW-9			55.0	6.1	800.0	93.6	26.0	19.97	13.87	1.9	6.7	213.8	13.0	16.4	step III:250mm/150mm	0.14	2.0	0.5
Jahada MDTW-10			53.5	5.9	1340.0	72.0	20.0	19.14	13.29	1.5	5.4	171.6	13.5	12.7	step III:250mm/150mm	0.11	1.5	0.7
		10	56.1				16.8		avg:	2.6	9.4	297.2	13.6	26.0		0.23	1.7	0.6
Kapilvastu																		
Valwad MDTW-1			72.5	+art	100.0	100.8	28.0	4.47	4.47	6.3	22.6	714.4	20.7	34.5	150mm	0.30	1.4	0.7
Valwad MDTW-2			68.0	2.4	180.0	91.8	25.5	5.31	2.96	8.6	31.0	982.5	20.7	47.5	150mm	0.42	1.2	0.8
Valwad MDTW-3			72.0	3.3	70.0	97.2	27.0	5.58	2.25	12.0	43.2	1368.6	19.0	72.0	150mm	0.63	1.4	0.7
Valwad MDTW-4			67.0	2.6	160.0	97.2	27.0	4.48	1.89	14.3	51.4	1629.3	23.0	70.8	150mm	0.62	1.2	0.9
Valwad MDTW-5			68.5	1.2	245.0	140.4	39.0	7.34	6.14	6.4	22.9	724.4	24.0	30.2	250mm/150mm	0.26	1.6	0.6
Valwad MDTW-7			57.0	2.6	45.0	97.2	27.0	6.19	3.56	7.6	27.3	865.0	21.0	41.2	150mm	0.36	1.3	0.8
Valwad MDTW-8			68.5	1.6	160.0	75.6	21.0	7.82	6.23	3.4	12.1	384.4	23.0	16.7	150mm	0.15	0.9	1.1
Valwad MDTW-9			69.5	+art	120.0	101.9	28.3	3.06	3.06	9.2	33.3	1054.8	20.0	52.7	150mm	0.46	1.4	0.7
Valwad MDTW-10			68.5	3.1	200.0	91.8	25.5	6.05	2.94	8.7	31.2	989.2	20.5	48.3	150mm	0.42	1.2	0.8
		9	67.9				27.6		avg:	8.5	30.6	968.1	21.3	46.0		0.40	1.3	0.8

Table I.5 : Data from ILC Groundwater Sub-Project, Kapilvastu Tubewell Project, Progress Report; GWRDB 1992.

File : V3-TI-5.wk1 10-May-94

Well name	Pump set	Pump type	TD (m)	SWL (m)	Test time (min)	Q (m3/h)	Q (l/s)	PWL (mbgl)	Measured drawdown (m)	SC (l/s/m)	SC (m3/h/m)	Logan Kd (m3/d/m)	Length screen (m)	K screen (m/d)	Comment	SC/stet (l/s/m2)	Q/stet (l/s/m)	Screen length/Q (m/l/s)
Kapilvastu																		
Kopwa MDTW-1			74.5	+art	120.0	100.8	28.0	3.18	3.18	8.8	31.7	1004.2	24.8	40.6	Kopwa MDTW's are 150mm	0.36	1.1	0.9
Kopwa MDTW-2			96.0	+art	100.0	79.2	22.0	8.75	8.75	2.5	9.1	286.7	23.2	12.4	casing-screen	0.11	0.9	1.1
Kopwa MDTW-3			87.0	+art	180.0	88.2	24.5	8.67	8.67	2.8	10.2	322.3	19.5	16.5		0.14	1.3	0.8
Kopwa MDTW-4			93.5	+art	140.0	88.9	24.7	2.94	2.94	8.4	30.2	958.2	22.5	42.6		0.37	1.1	0.9
Kopwa MDTW-5			73.0	1.8	80.0	100.8	28.0	4.90	3.06	9.2	32.9	1043.6	20.3	51.4		0.45	1.4	0.7
Kopwa MDTW-6			68.5	0.0	80.0	100.8	28.0	5.19	5.19	5.4	19.4	615.3	22.0	28.0		0.25	1.3	0.8
Kopwa MDTW-7			71.5	+art	180.0	75.6	21.0	6.84	6.84	3.1	11.1	350.1	16.0	21.9		0.19	1.3	0.8
		7	80.6				25.2		avg:	5.7	20.7	654.3	21.2	30.5		0.27	1.2	0.8
Bhalward VDC 8 MDTW Bhardapur				6.9		108.0	30.0	1.52	8.25	3.6	13.1	414.7						0.0
Valwad VDC 8 MDTW Bhartapur				5.0		129.6	36.0	17.12	12.12	3.0	10.7	338.8						0.0
		2					33.0		avg:	3.3	11.9	376.7				0.00	0.0	0.0
all MDTW		28	66.8				25.2			5.3	19.2	607.8	18.3	34.1		0.28	1.3	0.7
Jahada DTW-1			151.5	10.5	720.0	140.4	39.0	16.92	6.42	6.1	21.9	692.8	21.2	32.7	step III:250mm/150mm	0.29	1.8	0.5
		1																
Nawalparasi																		
Sunwal DTW-1			116.0	5.0	560.0	147.6	41.0	12.77	7.73	5.3	19.1	604.9	37.0	16.3	step III:all 250mm/150mm	0.14	1.1	0.9
Sunwal DTW-2			120.5	4.6	480.0	144.0	40.0	9.93	5.38	7.4	26.8	847.9	36.6	23.2	step IV	0.20	1.1	0.9
Sunwal DTW-3			122.0	3.3	480.0	144.0	40.0	8.55	5.22	7.7	27.6	873.9	36.6	23.9	step IV	0.21	1.1	0.9
Sunwal DTW-4			128.8	6.2	720.0	144.0	40.0	11.83	5.63	7.1	25.6	810.3	47.0	17.2	step IV	0.15	0.9	1.2
		4	121.8				40.3			6.9	24.8	784.3	39.3	20.2		0.18	1.0	1.0
Kapilvastu																		
Valwad DTW-1			91.0	4.2	290.0	115.2	32.0	21.98	17.81	1.8	6.5	204.9	30.0	6.8	step III:250mm/150mm	0.06	1.1	0.9
Valwad DTW-2			73.5	6.7	540.0	144.0	34.0	20.15	13.49	2.5	10.7	287.4	26.0	11.1	step IV:250mm/150mm	0.10	1.3	0.8
Valwad DTW-3			90.0	13.6	760.0	100.8	28.0	20.36	6.76	4.1	14.9	472.4	33.0	14.3	step IV:250mm/150mm	0.13	0.8	1.2
		3	84.8				31.3			2.8	10.7	321.6	29.7	10.7		0.09	1.1	1.0
Kapilvastu																		
Kopwa DTW-1			107.6	13.4	260.0	154.8	43.0	20.06	6.71	6.4	23.1	730.9	30.3	24.1	All 250mm/150mm string	0.21	1.4	0.7
Kopwa DTW-2			106.5	8.9	255.0	165.6	46.0	12.79	3.85	11.9	43.0	1362.7	30.0	45.4		0.40	1.5	0.7
Kopwa DTW-3			96.5	17.4	175.0	129.6	36.0	20.26	2.91	12.4	44.5	1410.9	33.0	42.8		0.37	1.1	0.9
Kopwa DTW-4			94.0	24.0	60.0	68.4	19.0	28.10	4.14	4.6	16.5	523.4	33.0	15.9		0.14	0.6	1.7
		4	101.2				36.0			8.8	31.8	1007.0	31.6	32.0		0.28	1.2	1.0
Motipur VDC 1 DTW Ganesh Sabha				8.7		162.0	45.0	12.16	3.45	13.0	47.0	1487.6						0.0
Motipur VDC 9 DTW Morml				7.0		144.0	40.0	9.39	2.36	16.9	61.0	1933.0						0.0
		2					42.5			15.0	54.0	1710.3				0.00	0.0	0.0
all DTW		14	111.6				38.0		avg:	7.5	27.1	854.5	34.4	22.1		0.17	1.0	0.8

file includes final step data only 1/16"(1.6mm)nom. saw slot

Table I.6 : Deep Tubewell Data, Bhairahawa Lumbini Groundwater Irrigation Project, Rupandehi District

File : V3-TI-6.wk1

10-May-94

DTW Nr	Location	Date drilled (finyear)	Elev (m asl)	Total depth (m)	Pump chamber (m)	Screen (m)	Sand screened (m)	Total sand (m)	Prod. string (m)	Sand in prod string	Sand in top 50 m (m)	SWL (m)	Free Flow (m3/h)	Test yield (m3/h)	Sw (m)	SC (l/s/m)	SD (m/l/s)	Kd [logan] (m3/d/m)	K screen (m/d)	SC/screen (l/s/m2)	Q/screen (l/s/m)	UWC/LWC diam (in)	Design: Yield/dd (m3/h:m)	Comments
Stage I:																								
W/1	Farsatikar	76/77	126.6	87.5	46.7	36.0	29	29	63	46	32	6.6		455	6.79	18.6	0.05	2 123	59	0.52	3.51	14/8		All Stage I wells completed with slotted pipe
W/2	Juda II	76/77abd		122.0	46.0	44.0	44	50	76	66	+	3.7		223	2.50	24.8	0.04	2 826	64	0.56	1.41	14/8		
W/3	Bhalwari	77/78	121.1	118.6	42.7	30.6	34	52	76	68	22 +	0.5	<50	563	5.60	27.9	0.04	3 185	104	0.91	5.11	14/8		
W/4	Sekhowani	77/78	119.1	125.7	42.3	52.4	47	47	84	56	14 +	2.0	144	382	15.90	6.7	0.15	761	15	0.13	2.02	14/8		
W/5	Parsawal	77/78	122.7	107.4	37.8	44.2	39	53	69	77	14 +	0.0	<50	495	8.56	16.1	0.06	1 832	41	0.36	3.11	14/8		
W/6	Kotihawa	77/78abd		120.0	37.0	42.0	42	52	86	68														
W/7	Karaunjia	77/78	121.7	113.5	35.4	35.7	36	46	78	59	24 +	1.6		472	4.21	31.1	0.03	3 552	99	0.87	3.67	14/8		
W/8	Pathardanda	77/78abd		111.0	41.0	44.0	43	43	70	61	+	3.3	90	409	6.01	18.9	0.05	2 156	49	0.43	2.58	14/8		
W/9	Muriyari	77/78	121.7	120.2	38.1	51.0	51	56	82	68	9	1.3		587	3.65	44.7	0.02	5 095	100	0.88	3.20	14/8		
W/10	Jahada	77/78	121.1	110.1	32.3	44.8	48	57	78	73	3	1.0		609	4.11	41.1	0.02	4 694	105	0.92	3.77	14/8		
W/11	Karahia	77/78	123.1	116.2	34.8	61.3	41	41	81	51	6	1.6		473	4.39	29.9	0.03	3 413	56	0.49	2.14	14/8		
W/12	Semra	77/78	120.8	101.4	34.7	45.5	46	46	63	73	14	1.4		569	6.80	23.2	0.04	2 651	58	0.51	3.47	14/8		
W/13	W Pauni	77/78	124.8	110.4	26.1	39.6	40	47	81	58	12	4.4		572	4.60	34.5	0.03	3 939	100	0.87	4.02	14/8		
W/14	Bankatti	77/78	123.9	119.0	43.5	26.9	47	50	81	62	14	4.7		472	4.47	29.3	0.03	3 345	124	1.09	4.87	14/8		
W/15	E Pauni	77/78	123.8	138.7	42.7	40.2	37	47	75	63	18	2.4		400	12.70	8.7	0.11	998	25	0.22	2.76	14/8		
W/16	N Supauli	77/78	118.2	112.6	41.8	49.0	40	63	94	67	15 +	0.5	122	473	9.16	14.3	0.07	1 636	33	0.29	2.68	14/8		
W/17	Khauria	77/78	121.1	124.0	42.6	39.6	40	45	78	56	4	1.6		450	6.86	18.2	0.05	2 078	52	0.46	3.16	14/8		
W/18	S Supauli	78/79	115.2	118.3	39.4	41.6	42	48	75	64	24 +	2.2	160	550	6.92	22.1	0.05	2 518	60	0.53	3.67	14/8		
W/19	E Semri	78/79	123.2	140.9	45.4	36.2	35	49	96	51	24 +	4.2		563	11.30	13.8	0.07	1 578	44	0.38	4.32	14/8		
W/20	Tukuligarh	78/79	121.5	118.9	42.8	40.7	41	49	72	68	24	2.5		565	5.70	27.5	0.04	3 140	77	0.68	3.86	14/8		
W/21	Dubaulia	78/79	127.4	140.0	47.0	41.7	49	79	93	85	32	8.0		385	8.75	12.2	0.08	1 394	33	0.29	2.56	14/8		
W/22	Betahi	78/79	123.5	141.0	45.0	41.9	41	65	96	68	28	3.5		518	8.83	16.3	0.06	1 858	44	0.39	3.43	14/8		
W/23	Dogna		126.4	121.0	41.3	42.5	42	62	77	81	12	7.7		432	4.71	25.5	0.04	2 906	68	0.60	2.83	14/8		
W/24	Sudafarsatica		122.1	130.0	45.0	41.0	41	65	65	76	14	3.5		464	3.40	37.9	0.03	4 323	105	0.92	3.14	14/8		
W/25	Madangunj		122.5	132.0	45.4	47.9	48	64	87	74	24	3.2		473	4.41	29.8	0.03	3 398	71	0.62	2.74	14/8		
W/26	W Kewalpur		121.3	141.4	45.4	42.0	42	42	100	42	26	2.0		495	5.55	24.8	0.04	2 826	67	0.59	3.27	14/8		
W/27	E Kewalpur		124.0	137.5	45.1	42.0	42	46	92	50	24	4.4		497	8.68	15.9	0.06	1 814	43	0.38	3.29	14/8		
W/28	Bihuli		117.8	130.1	40.0	42.0	42		89		15 +	3.7	341	486	3.99	33.8	0.03	3 859	92	0.81	3.21	16/10		
W/29	Pakadihwa		119.0	137.5	42.7	32.7	45	51	82	62	22 +	2.1	304	518	3.86	37.3	0.03	4 251	130	1.14	4.40	16/10		
W/30	N Guraulia		115.8	149.0	45.7	53.1	53	58	106	55	18 +	1.9	159	473	5.05	26.0	0.04	2 967	56	0.49	2.47	16/10		
W/31	Puraini		117.9	136.0	42.7	47.5	48	62	93	67	16 +	0.9		473	3.32	39.6	0.03	4 513	95	0.83	2.76	16/10		
W/32	Rajahar		119.4	136.0	46.0	47.3	47	61	90	68	23	2.0		495	3.35	41.0	0.02	4 681	99	0.87	2.91	16/10		
W/33	Manpakadi		116.0	143.3	45.7	49.8	50	66	97	68	15 +	0.5		473	2.86	45.9	0.02	5 239	105	0.92	2.64	16/10		
W/34	Gurauli		112.6	163.4	45.7	59.8	59	70	123	57	21 +	4.1	259	527	5.37	27.3	0.04	3 109	52	0.46	2.45	16/10		
W/35	Sitalpat		117.7	150.6	44.8	41.0	50	60	110	55	22 +	0.5	259	519	2.39	60.3	0.02	6 879	168	1.47	3.52	16/10		
W/36	E Sitalpat		118.7	184.0	40.9	60.6	60	67	144	47	22	5.2		473	6.14	21.4	0.05	2 440	40	0.35	2.17	16/10		
W/37	Kunwari		114.6	162.0	50.3	55.9	56	60	112	54	12 +	2.9	322	540	3.63	41.3	0.02	4 713	84	0.74	2.68	16/10		
W/38	Madhubani		109.4	190.0	48.5	67.3	48	80	142	56	12 +	5.5	245	608	6.31	26.8	0.04	3 053	45	0.40	2.51	16/10		
W/39	Sisawa		110.7	164.0	46.0	57.8	57	65	121	54	25 +	5.7	400	408	8.98	12.6	0.08	1 439	25	0.22	1.96	16/10		
W/40	Belahia		112.1	175.3	47.5	48.3	47	65	137	47	12 +	5.4	218	432	26.55	4.5	0.22	515	11	0.09	2.48	16/10		
W/41	Bhaglapur		110.3	176.2	53.7	51.9	60	70	122	57	6 +	6.1	540	540	3.80	39.5	0.03	4 502	87	0.76	2.89	16/10		
W/42	Kotihawa		116.6	169.2	46.9	60.0		100	126	79	12 +	3.4	362	475	3.70	35.7	0.03	4 067	68	0.59	2.20	16/10		
W/43	Amuwa		117.4	164.0	46.3	63.1	70	90	123	73	15 +	0.7	21	473	6.15	21.4	0.05	2 437	39	0.34	2.08	16/10		
W/44	W Sekhuwani		118.8	161.0	46.9	54.6		68	118	59	13	1.7		495	3.40	40.4	0.02	4 612	84	0.74	2.52	16/10		

Table I.6 : Deep Tubewell Data, Bhairahawa Lumbini Groundwater Irrigation Project, Rupandehi District

File : V3-T1-6.wk1 10-May-94

DTW Nr	Location	Date drilled (finyear)	Elev (m asl)	Total depth (m)	Pump chamber (m)	Screen (m)	Sand screened (m)	Total sand (m)	Prod. string (m)	Sand in prod string	Sand in top 50 m (m)	SWL (m)	Free Flow (m3/h)	Test yield (m3/h)	Sw (m)	SC (l/s/m)	SD (m/l/s)	Kd [logan] (m3/d/m)	K screen (m/d)	SC/screen (l/s/m2)	Q/screen (l/s/m)	UWC/LWC diam (in)	Design: Yield/dd (m3/h:m)	Comments
W/45	Kanari		115.5	163.0	47.4	54.6	67	80	116	69	22 +	1.7	182	513	16.14	8.8	0.11	1 007	18	0.16	2.61	16/10		
W/46	Sarjuganj		124.0	151.0	45.7	70.1	70	72	110	65	25 +	5.2		500	3.86	36.0	0.03	4 104	59	0.51	1.98	16/10		
W/47	Rehara		120.3	160.0	45.1	56.4	63	70	112	63	26 +	1.7		473	2.05	64.1	0.02	7 310	130	1.14	2.33	16/10		
W/48	Remganj		114.9	164.0	46.0	60.2	60	78	121	64	10 +	0.1	30	518	5.25	27.4	0.04	3 126	52	0.46	2.39	16/10		
W/49	W Khangaon		109.8	167.7	45.4	49.2		94			24 +	3.0	136	563	10.15	15.4	0.06	1 757	36	0.31	3.18	16/10		
W/50	E Khangaon		112.0	162.1	42.0	61.9		63			15 +	2.8	204	454	12.44	10.1	0.10	1 156	19	0.16	2.04	16/10		
W/51	Dayanagar		112.6	164.0	47.2	56.4		57	117		15 +	2.2	160	462	7.51	17.1	0.06	1 949	35	0.30	2.27	16/10		
W/52	W Semri		113.3	158.0	45.7	77.0	77	78	115	68	26 +	3.0	295	482	4.57	29.3	0.03	3 341	43	0.38	1.74	16/10		
W/53	Bahata		114.9	154.0	46.2	62.5	75	90	108	83	21 +	2.7	75	409	26.13	4.3	0.23	496	8	0.07	1.82	16/10		
W/54	S Madanganj																							
W/55	Chhapia		113.7	139.6	46.9	46.5		47			18 +	1.0	86	473	5.21	25.2	0.04	2 876	62	0.54	2.82	16/10		
W/56	Madangunj		100.7	159.7	45.7	46.1		56			16	0.5		473	6.26	21.0	0.05	2 394	52	0.46	2.85	16/10		
W/57	Juda II		116.6	153.0	42.7	44.6		51			16 +	3.0	155	473	2.65	49.6	0.02	5 655	127	1.11	2.95	16/10		
W/58	Bharaulia		118.7	159.3	46.0	54.6		60			16 +	0.0		473	2.66	49.4	0.02	5 633	103	0.90	2.41	16/10		
W/59	S Madanjung II		114.7	157.6	45.7	45.4		49			18 +	2.7	295	554	3.89	39.5	0.03	4 512	99	0.87	3.39	16/10		
W/60	Bahghusari		112.9	156.4	45.8	49.4		54			18 +	3.5	518	518	3.50	41.1	0.02	4 689	95	0.83	2.91	16/10		
W/61	Baidauli		113.9	161.5	45.7	40.3		46			14 +	1.8	182	473	3.46	38.0	0.03	4 331	108	0.94	3.26	16/10		
W/62	Bardawa		113.6	163.4	46.0	51.2		52			14 +	4.1	209	454	13.17	9.6	0.10	1 092	21	0.19	2.46	16/10		
W/63	Jamahami		116.9	160.3	45.7	54.2		55			18 +	1.6		497	16.53	8.3	0.12	953	18	0.15	2.55	16/10		
W/64	Bauratola		117.6	157.3	46.0	43.9		57			30 +	1.8	192	540	3.23	46.4	0.02	5 296	121	1.06	3.41	16/10		
W/65	Chamkipur		118.5	157.0	43.3	60.4		60			14 +	2.4	204	671	6.26	29.8	0.03	3 396	56	0.49	3.09	16/10		
W/66	Thatarihwa		116.2	172.0	45.7	53.8		54			8 +	1.6	184	592	14.66	11.2	0.09	1 279	24	0.21	3.06	16/10		
W/67	Baraulia		116.2	168.6	46.0	48.3		49			18 +	1.6	182	473	6.75	19.5	0.05	2 220	46	0.40	2.72	16/10		
W/68	Gangolia		115.9	157.3	46.7	49.1		50			16 +	1.5	148	563	3.15	49.6	0.02	5 662	115	1.01	3.18	16/10		
W/69	Pathardanda II		115.9	149.4	49.4	48.8		49			22	0.1		518	2.91	49.4	0.02	5 639	116	1.01	2.95	16/10		
	STAGE I	Average		143.9	43.9	48.8		59		63	17.75			494	6.80	27.1	0.05	3 090	66	0.58	2.82			
Stage II phase I																								
TW/1	Harharwa	83/84	96.0	193.0	44.2	47.9		65		44	12 +	5.9	134	437	21.70	5.6	0.18	638	13	0.12	2.53	16/10	300/12.7	S :[S slotted MS casing]
TW/2	Pipra	83/84	92.8	194.0	51.2	48.7		71		50	14 +	8.8	156	484	42.49	3.2	0.32	361	7	0.06	2.76	16/10	300/23.3	gS :[gS galvanised screen]
TW/3	Bhilarhawa	83/84	97.3	163.1	49.7	30.5		51		45	15 +	4.3	190	441	37.94	3.2	0.31	368	12	0.11	4.02	16/10		JS :[JS Johnson screen]
TW/4A		85/86abd																				16/10		
TW/4B	Mahadewa	86/87	99.3	131.0	29.8	43.6		80		79	13 +	8.9	255	431	17.07	7.0	0.14	800	18	0.16	2.75	16/10	300/10.9	gS
TW/5	Ekla	84/85	94.8	180.1	47.0	62.7		77		58	2 +	0.7	65	420	31.15	3.7	0.27	427	7	0.06	1.86	16/10	300/20.1	S
TW/6	Mangalpur	85/86	99.0	182.0	43.3	31.0		38		27	5 +	3.4	0	250	27.00	2.6	0.39	293	9	0.08	2.24	16/10	300/35.8	S
TW/7	N Ahirauli	85/86	100.7	163.0	46.3	55.5		90		77	27 +	7.4	228	402	17.27	6.5	0.15	737	13	0.12	2.01	16/10	300/10.8	gS
TW/8	Amauli	85/86	98.7	167.0	45.1	43.7		53		43	3 +	7.1	221	452	19.76	6.4	0.16	725	17	0.15	2.87	16/10	300/11.7	gS
TW/9	Gobrauli	85/86	98.1	166.1	43.9	38.6		53		43	32 +	9.4	245	452	21.47	5.8	0.17	667	17	0.15	3.25	16/10	300/13.4	S
TW/10	Bhaglapur	84/85	96.0	195.0	45.7	43.2		57		38	8 +	4.4	90	301	35.39	2.4	0.42	269	6	0.05	1.93	16/10	300/34.7	S
TW/11	E Bharaulia	84/85	96.9	222.0	64.0	39.8		60		38	2 +	5.7	65	275	47.66	1.6	0.62	183	5	0.04	1.92	16/10	275/47.6	S
TW/12	W Bharaulia	84/85	98.5	198.0	49.4	26.2		54		36	6 +	5.8	125	265	45.17	1.6	0.61	186	7	0.06	2.81	16/10	265/45.2	S
TW/13	Sonbarsa	84/85	94.2	206.0	53.4	51.5		79		52	10 +	5.4	102	456	21.75	5.8	0.17	664	13	0.11	2.46	16/10	300/11.5	gS
TW/14A		85/86abd																				16/10		
TW/14B	S Ahirauli	86/87	96.1	145.0	39.6	34.6		35		33	12 +	6.8	212	463	17.29	7.4	0.13	848	25	0.22	3.72	16/10	408/10.4	S
TW/15	Mainaia	84/85		156.0	49.7	55.9		56		53	20	11.0	0	484	4.26	31.6	0.03	3 599	64	0.56	2.41	16/10	300/2.1	S
TW/16	S Bharaulia	85/86	96.3	174.0	50.3	41.2		51		41	6 +	4.3	98	311	41.42	2.1	0.48	238	6	0.05	2.10	16/10	300/38.8	gS
		STAGE II phase 1		177.2	47.0	43.4				42	11.69			395	28.05	5.4	0.25	611	13	0.12	2.31			

Table I.6 : Deep Tubewell Data, Bhairahawa Lumbini Groundwater Irrigation Project, Rupandehi District

File : V3-TI-6.wk1

10-May-94

DTW Nr	Location	Date drilled (finyear)	Elev (m asl)	Total depth (m)	Pump chamber (m)	Screen (m)	Sand screened (m)	Total sand (m)	Prod. string (m)	Sand in prod string	Sand in top 50 m (m)	SWL (m)	Free Flow (m3/h)	Test yield (m3/h)	Sw (m)	SC (l/s/m)	SD (m/l/s)	Kd [logan] (m3/d/m)	K screen (m/d)	SC/screen (l/s/m2)	Q/screen (l/s/m)	UWC/LWC diam (in)	Design: Yield/dd (m3/h:m)	Comments
Stage II phase II																								
TW/17	Gobrauli	89/90		162.0	40.5	47.5		58		48	7 +	4.9	65	265	26.23	2.8	0.36	320	7	0.06	1.55	16/10	300/12.8	S:screen clogged:subseq SC reducec
						47.5								428	24.53	4.8	0.21	553	12	0.10	2.50			SC decline
TW/18A		88/89abd																						
TW/18B	Kurmindihawa	90/91		131.8	42.6	27.0		43		48	6 +	5.1	95	431	12.37	9.7	0.10	1 104	41	0.36	4.43	16/8	300/10.6	JS :subseq SC reduced
TW/19A		88/89abd																						
TW/19	Dhauthamiya			188.3	46.5	40.8					+	8.0		240	36.68	1.8	0.55	207	5	0.04	1.63			screen clogged/ruptured
TW/19B	Dhauthamiya	91/92		145.0	43.0	23.0		32		31	9 +	6.4	108	350	14.15	6.9	0.15	784	34	0.30	4.23	14/8	300/300/11.:JS	
TW/20A		87/88abd																						
TW/20	Gidahiya										+	8.3		165	41.16	1.1	0.90	127						
TW/20B	Gidahiya	90/91		144.8	42.5	27.0		35		34	18 +	7.1	188	484	20.72	6.5	0.15	740	27	0.24	4.98	16/8	300/11.0	JS
TW/21	Pauwa	87/88		175.0	43.2	41.4		46		35	6 +	7.4	108	230	34.75	1.8	0.54	210	5	0.04	1.54	16/8	300/26	S :screen clogged
	Pauwa													230	34.75	1.8	0.54	210						2047-11-5
TW/22	N Pauwa	88/89		130.0	43.0	24.0		46		53	10 +	1.3	30	441	12.30	10.0	0.10	1 136	47	0.41	5.10	14/8	300/8.4	S :SC declined to 8.38 in '92
TW/23	Sihawa	88/89		124.0	38.9	31.0		41		48	12 +	2.9	45	278	33.60	2.3	0.44	262	8	0.07	2.49	14/8	225/26.6	S
TW/24A	Lalpur	88/89abd																						
TW/24B	Lalpur	91/92		164.5	43.9	19.0		25		21	4 +	4.5	90	390	19.37	5.6	0.18	638	34	0.29	5.70	14/8	300/13.9	JS
TW/25A	E Bhairawa	87/88abd									+	3.7		250	34.81	2.0	0.50	228						
TW/25B	E Bhairawa	89/90abd																						
TW/25C	E Bhairawa	91/92		173.5	42.5	22.0		26		20	17 +	6.3	40	311	32.15	2.7	0.37	306	14	0.12	3.93	14/8	300/31	JS
TW/26	S Sihawa	88/89		160.0	37.0	38.0		49		40	4 +	1.9	54	221	34.32	1.8	0.56	204	5	0.05	1.62	16/8	200/25	S
TW/27A	Bhairawa 2	87/88abd									+	3.5		314	33.97	2.6	0.39	293						
TW/27B	Bhairawa	89/90		145.0	45.3	36.0		47		47	10 +	3.4	27	257	40.28	1.8	0.56	202	6	0.05	1.99	16/8	200/27	S
TW/28	Jogada 1										+	5.6		150	22.04	1.9	0.53	216						
TW/28II	Jogada 2										+	5.2		288	33.39	2.4	0.42	273						
TW/28A		88/89abd																						
TW/28B		89/90abd																						
TW/28C	Jogada	90/91		152.8	43.9	24.0		37		34	17 +	5.4	32	301	37.39	2.2	0.45	255	11	0.09	3.48	14/8	250/30.3	JS
TW/29A		88/89abd																						
TW/29B	Ramawapur	90/91		140.0	41.0	27.0		37		37	3 +	3.9	30	300	21.70	3.8	0.26	438	16	0.14	3.09	16/10	300/24	JS
TW/30A		88/89abd																						
TW/30B	Madhubani	90/91		114.0	45.5	24.0		28		41	3 +	4.8	50	300	20.14	4.1	0.24	472	20	0.17	3.47	14/8	300/20.1	JS
TW/31A		88/89abd																						
TW/31B	Bankasiya	91/92		167.0	48.5	18.0		43		36	3 +	4.8	54	300	25.22	3.3	0.30	377	21	0.18	4.63	14/8	300/31.2	JS
TW/32A	Wazirganj	89/90abd									+	4.5		155	40.20	1.1	0.93	122						
TW/32B	Wazirganj	91/92		170.0	48.5	21.0		34		28	16 +	3.9	54	300	28.59	2.9	0.34	332	16	0.14	3.97	14/8	300/28.6	JS
TW/33A		89/90abd																						
TW/33B	Piparpatiya	90/91		175.0	46.0	30.0		33		26	9 +	2.5	16	281	43.21	1.8	0.55	206	7	0.06	2.60	16/8	225/28.7	JS :SC changing
TW/34	Mahilwari	89/90		168.0	38.4	38.8		41		32	14 +	0.7	18	210	31.44	1.9	0.54	212	5	0.05	1.50	16/10	210/31.4	S
TW/35	Mahilwar	89/90		130.8	52.9	24.0		50		64	31 +	4.3	72	382	23.00	4.6	0.22	526	22	0.19	4.42	16/10	300/22.7	gS
TW/36	Tulsipur	90/91		118.0	46.5	18.0		27		38	1.5	0.2	0	285	15.99	4.9	0.20	565	31	0.27	4.40	14/8	300/17.3	JS
TW/37A		89/90abd																						
TW/37B	Patijiya	90/91		162.0	47.5	21.0		28		24	3 +	1.0	16	343	15.06	6.3	0.16	722	34	0.30	4.54	14/8	300/12.9	JS
TW/38	Sipawa	89/90		161.5	39.4	39.0		40		33	16	0.3	0	320	29.77	3.0	0.34	341	9	0.08	2.28	16/8	275/23.6	S
Sample No 23		STAGE II phase 2		140.1	43.8	29.5				27	9.54			297		2.9	0.28	331	12	0.09	1.86			

Table I.6 : Deep Tubewell Data, Bhairahawa Lumbini Groundwater Irrigation Project, Rupandehi District

DTW Nr	Location	Date drilled (finyear)	Elev (m asl)	Total depth (m)	Pump chamber (m)	Screen (m)	Sand screened (m)	Total sand (m)	Prod. string (m)	Sand in prod string	Sand in top 50 m (m)		SWL (m)	Free Flow (m3/h)	Test yield (m3/h)	Sw (m)	SC (l/s/m)	SD (m/l/s)	Kd [logan] (m3/d/m)	K screen (m/d)	SC/screen (l/s/m2)	Q/screen (l/s/m)	UWC/LWC diam (in)	Design: Yield/dd (m3/h:m)	Comments
Stage III																									
WW/1	Jharbaira	92/93		139.0	42.0	22.0						+	6.3	108	300	23.63	3.5	0.28	402	18	0.16	3.79	16/10		Much sand in Dev
WW/2A	Dhauthi	92/93		154.0	39.5	13.0						+	4.4	18	100	31.98	0.9	1.15	99	8	0.07	2.14	12/8		needs rehab/chem treatment.12/8 is 60 ha 2 loop system
WW/2B	Dhauthi	92/93		134.8	41.8	12.0						+	5.5	22	250	15.29	4.5	0.22	518	43	0.38	5.79	14/10		
WW/3	Asidhawa	92/93		166.8	41.5	18.0								108	350	30.07	3.2	0.31	369	20	0.18	5.40	400/250	300/	SS
WW/4	Shivapur W	92/93		129.0	44.0	19.0								24	300	21.03	4.0	0.25	452	24	0.21	4.38	400/250		needs redev: high sand
WW/5	Bangain	92/93		129.0	41.0	17.0						+	1.6	52	400	11.50	9.7	0.10	1 102	65	0.57	6.53	14/10		SS
WW/6A		92/93																							Abd:insufficient aquifer
WW/6B	W Bhujauli	92/93		133.0	40.1	20.0								11	200	38.43	1.4	0.69	165	8	0.07	2.78	16/10		SS :needs rehab,polyphos.
WW/7	E Bhujauli			157.8	45.0	21.0																	16/10		in progress
WW/8	Sandi	91/92		167.5	45.0	20.0						+	3.1	61	350	15.22	6.4	0.16	729	36	0.32	4.86	400/250	300/12.6	SS
WW/9	N Nanauli	91/92		125.8	37.9	17.0							0.7	0	325	10.75	8.4	0.12	958	56	0.49	5.31	14/10		SS :demand 225m3/h
WW/10	Sitapur	91/92		165.0	46.2	17.0						+	2.6	108	328	14.73	6.2	0.16	705	41	0.36	5.36	14/10	300/13.7	good sand control
WW/11	S Nanauli	92/93		125.0	41.6	21.0						+	0.9	72	350	13.42	7.2	0.14	826	39	0.34	4.63	16/10	300/10.4	
WW/12	Sarhawa	91/92		124.0	35.8	21.0						+	0.9	26	400	12.69	8.8	0.11	999	48	0.42	5.29	14/8	300/8.4	
WW/13A																									Abd:insufficient aquifer
WW/13B	E Bakauli			152.5	48.7	25.0																	16/10		SS
WW/14	Semra	91/92		124.0	31.0	15.0						+	0.2	9	200	8.40	6.6	0.15	754	50	0.44	3.70	12/8	225/9.8	initial v high sand:3 loop
WW/15	N Kharenchawa	91/92		124.0	38.8	16.0						+	3.3		325	11.07	8.2	0.12	930	58	0.51	5.64	14/10	300/10.1	SS
WW/16	S Kharenchawa	91/92		121.0	38.0	15.0						+	3.7	72	300	14.68	5.7	0.18	647	43	0.38	5.55	300/250	300/14.7	
WW/18	Chamkia	92/93		177.5	45.0	17.0																	16/10		
WW/19	Parora			163.8	47.7	15.0																	16/10		Drilling depth may exceed final depth quoted
		STAGE III		142.8	41.6	17.9									299		5.0	0.20	568	33	0.23	3.39			
6	10	6	5	5	6	5	6	5	5	5	6	2	4	6	6	6	6	6	6	5	6	6 •	7	6 •	20

Table I.7 : Deep Tubewell Data, Parsa and Bara Districts

File : V3-TI-7.wk1

17-Dec-93

DTW Nr	Location	Drill date	Total depth (m)	Pump chamber (m)	Screen (m)	Top screen (m)	Screened intervals (m)	Sand in well (m)	Screen blank (m)	Installed depth (m)	SWL [m]	Test yield (m3/h)	Sw (m)	SC (l/s/m)	SD (m/l/s)	Kd [Logan] (m3/d/m)	K screen (m/d)	SC/screen (l/s/m2)	Q/screen (l/s/m)	UWC/LWC Diam (in)
N-1	Rampur	6.76	156.7	52.9	35.4	62.6	62.62-68.52,95.02-100.92 106.82-124.52,130.42-136.32	39	86.4	139.3	8.10	252.0	8.50	8.2	0.1	939	27	0.23	1.98	14/10
N-2	Laharwa Tole	4.76	174.0	52.9	44.1	59.2	59.22-68.02,103.42-124.02 147.62-162.33	42	112.4	165.3	10.10	252.0	5.40	12.9	0.1	1 478	34	0.29	1.59	14/10
N-3	Korria Tola	4.76	168.9	53.9	41.3	101.5	101.52-125.18,139.82-157	65	107.0	160.9	8.93	289.8	4.42	18.2	0.1	2 077	50	0.44	1.95	14/10
N-4	Bishwombarpur	5.76	172.0	52.8	41.3	103.2	103.20-126.80,135.60-141 153.30-165.10	53	115.8	168.6	8.60	180.0	3.95	12.6	0.1	1 444	35	0.31	1.21	14/10
N-5	Shitalpur	5.76	153.7	52.9	41.2	104.4	104.42-129.42,135.72-147	55	98.2	151.1	11.10	289.8	5.75	14.0	0.1	1 597	39	0.34	1.95	14/10
N-6	Sisahniya	3.76	153.7	52.9	41.3	100.6	100.62-130.12,133.02-144	47	95.2	148.1	9.20	283.3	5.77	13.6	0.1	1 556	38	0.33	1.91	14/10
N-7	Balirampur	12.76	142.9	54.0	42.0	84.5	84.52-90.52,99.52-135.52		85.0	139.0	9.65	252.0	6.20	11.3	0.1	1 288	31	0.27	1.67	14/10
N-8	Motisar	7.76	144.5	52.9	41.3	94.6	94.62-135.92	58	86.5	139.4	6.90	288.0	6.85	11.6	0.1	1 332	32	0.28	1.94	14/10
N-9	Motisar	7.76	144.6	52.9	41.3	88.7	88.72.130.18	64	86.5	139.4	7.90	7.9	5.90	0.4	2.7	42	1	0.01	0.05	14/10
N-10	Dohari	5.76	181.1	52.9	38.3	62.1	62.12-76.82,109.22-126.92 162.32-168.22	39	118.8	171.7	6.00	6.0	10.05	0.2	6.0	19	0	0.00	0.04	14/10
N-11	Buniyad	2.78	146.3	53.9	44.2	84.3	84.34-87.84,93.14-122.64 128.54-140.34	56	86.4	140.3	8.70	8.7	5.35	0.5	2.2	52	1	0.01	0.05	14/10
N-12	Awadhpur	1.77	162.8	53.5	42.0	74.3	74.37-80.37,110.97-140.97 147.57-154.57		102.5	156.0	8.83	8.8	11.35	0.2	4.6	25	1	0.01	0.06	14/10
N-13	Barewa	3.77	159.8	54.0	42.0	101.8	101.8-137.82,150.00-157.00		104.0	158.0	10.35	10.4	7.38	0.4	2.6	44	1	0.01	0.07	14/10
N-14	Khutwa	3.76	150.6	52.9	41.2	77.0	77.02-118.22	74	85.2	138.1	6.30	6.3	4.18	0.4	2.4	48	1	0.01	0.04	14/10
No.9	Chorni	4.76	162.8	52.9	44.3	91.8	91.80-115.46,118.48-130.3 145.19-153.00	63	104.7	157.6	5.30	5.3	6.75	0.2	4.6	25	1	0.00	0.03	14/10
No.12	Pataura	5.76	153.7	52.8	41.3	103.5	103.46-144.80	57	95.7	148.5	9.40	9.4	3.23	0.8	1.2	92	2	0.02	0.06	14/10
No.19	Bisamerpur	4.76	150.6	52.8	38.4	56.1	56.10-62.10,96.90-124.40	47	83.3	136.1	10.00	10.0	6.48	0.4	2.3	49	1	0.01	0.07	14/10
No.18	Bhawanipur	3.82	2.2	55.5	33.6	108.9	108.87-127.47,133.17-137 153.50-164.50	47	112.1	167.6										16/10
No.2	Parwanipur	2.82	156.5	54.8	42.4	100.9	100.94-125.26,128.31-146	50	94.7	149.5										16/10
No.15	Inarwa	6.81	144.3	52.6	41.0	93.0	92.98-133.99	44	84.8	137.5										16/10
No.8	Khutwa	6.81	129.0	53.5	43.2	76.7	76.74-119.98	50	69.5	123.1										16/10
No.17	Bhaluhi	5.81	164.6	52.8	43.6	91.8	91.75-116.58,125.57-131.8 143.88-156.42	61	106.7	159.5										16/10
	Average		142.4	53.3	41.1			53						6.2	1.7	712	17	0.15	0.86	

prod production   Sw drawdown   Kd transmissivity   SC specific capacity   SD specific drawdown   UWC/LWC upper/lower well casing

Table I.8 : Deep Tubewell Design and Production Data, Parsa and Bara Districts

File : V3-TI-8.wk1 17-Dec-93

TW nr	Location	Date drilled	Total depth (m)	Housing dia/length (m)	Housing dia/len (m)	Screen dia/len (m)	Prod. string (m)	Screen length (m)	SWL (m)	Test yield (l/s)	Sw (m)	Spec cap (l/s/m)	Spec DD (m/l/s)	Kd (logan) (m3/d/m)	K screen (m/d)	SC/m (l/s/m)	Q/m screen (l/s/m)	T (NK est) (m3/d/m)	Comments.
1	Bhatuda	5.68	82.8	350/28	200/27.5	200/27.16	54.7	27.2	4.27	57.5	7.01	8.2	0.1	936	34	0.24	2.12	955	fg:inop 88
2	Parwanipur	5.68	118.3	350/29.8	200/58	200/30.69	88.7	30.7	4.60	60.6	5.49	11.0	0.1	1 259	41	0.27	1.97	1 260	fg
3	Jitpur		61.0						4.57	50.8	10.06	5.0	0.2	575				590	fg
4	Bahuarwa		107.0						3.96	62.1	4.87	12.8	0.1	1 455				1 640	fg
5	Chainpur		100.0						4.88	59.4	4.11	14.4	0.1	1 647				1 635	fg
6	Rampur	6.68	131.6	350/29.6	200/72.3	200/19.88	92.2	19.9	8.53	60.6	5.18	11.7	0.1	1 334	67	0.17	3.05	1 320	fg:inop 91
7	Pursauni	6.68	114.3	350/31.2	200/51.5	200/32.01	83.5	32.0	7.32	60.6	4.11	14.7	0.1	1 682	53	0.28	1.89	1 670	fg:inop 90
8	Pursauni	6.81	123.1	400/53.51	250/26.3	250/43.24	69.5	43.2	6.71	60.6	3.96	15.3	0.1	1 746	40	0.38	1.40	1 710	ms
9	Parwanipur	4.76	157.6	350/52.92	250/60.4	250/44.28	104.7	44.3	3.35	54.9	6.10	9.0	0.1	1 027	23	0.39	1.24	1 025	ms
10	Barewa KMC	8.68	155.0	400/50.5	250/62	250/42	104.0	42.0	6.71	53.0	5.49	9.7	0.1	1 102	26	0.37	1.26	1 090	ms
11	Parwanipur		131.0							56.3	6.46	8.7	0.1	995				1 266	ms
12	Motisar	4.76	148.5	350/52.8	250/54.39	250/41.3	95.7	41.3	10.82	99.8	8.81	11.3	0.1	1 291	31	0.36	2.42	1 335	ms
13	Rambon		58.0						1.98	95.5	10.82	8.8	0.1	1 007				980	ms:inop
14	Loharwatola		142.0						10.73	85.2	10.73	7.9	0.1	906				930	ms:inop
15	Inarwa	6.81	137.5	400/52.64	250/42.98	250/41.01	84.0	41.0	9.81	87.4	6.60	13.2	0.1	1 511	37	0.36	2.13	1 645	ms
16	Bhatauda	4.69	165.0	400/50.5	250/72	250/42	114.0	42.0	10.26	103.5	11.87	8.7	0.1	995	24	0.37	2.47	1 110	ms:inop
17	Bhaluhi	5.81	159.5	400/52.79	250/62.09	250/43.63	105.7	43.6	9.14	105.4	6.81	15.5	0.1	1 766	40	0.38	2.42	1 810	ms
18	Bhawanipur	5.81	167.0	400/55.53	250/77.5	250/33.6	111.1	33.6	12.42	72.3	8.82	8.2	0.1	935	28	0.29	2.15	935	ms
19	Bishwanberpur	4.76	155.0	400/50.5	250/62	250/42	104.0	42.0	12.44	94.1	7.99	11.8	0.1	1 343	32	0.37	2.24	1 370	ms
20	Laiparsa	5.69	155.0	400/50.5	250/62	250/42	104.0	42.0	4.94	86.5	16.41	5.3	0.2	601	14	0.37	2.06	635	ms
N-0(T-3)	Jagannathpur	71	200.0						7.00	40.5	3.25	12.5	0.1	1 421				150	ms
T-1	Motisar	71	175.0						4.00	20.0	14.70	1.4	0.7	155				150	ms
T-2	Zitkaiya	71	191.0						1.60	20.0	14.00	1.4	0.7	163				160	ms
	Avg:		136.3				94.0	37.5				9.9	0.2	1 124	21	0.20	1.25	1 103	
GWRDP-1	Sripur Auraha	3.92	140.0	250/41.3	150/48.8	150/36	84.8	36.0	7.51	119.0	10.20	11.7	0.1	1 331	37	0.32	3.31		
GWRDP-2	Sathi Auraha	4.92	128.0	250/37.25	150/49.83	150/39.92	89.8	39.9	4.71	152.0	7.32	20.8	0.0	2 368	59	0.35	3.81		
GWRDP-3	Fatepur Bara	5.92	125.0	250/37	150/39	150/24	63.0	24.0		54.0			0.0				2.25		
GWRDP-4	Shankarsaraiya	7.92	106.0	250/32.5	150/17.8	150/36	53.8	36.0	2.72	141.0	34.80	4.1	0.2	462	13	0.32	3.92		
GWRDP-5	Lepti Birta Parsa	91/92							5.84	161.0	8.99	17.9	0.1	2 042					
GWRDP-6	Belwa Parsa	91/92							-	-									
GWRDP-7	Gorpasar, Parsa	91/92							2.85	138.0	16.75	8.2	0.1	940					
GWRDP-8	Jasaili Parsa	91/92							4.22	155.0	7.11	21.8	0.0	2 486					fg fibreglass
																			ms mild stee
	Average		124.8				72.8	34.0				12.1	0.1	1 376					
			134.6				89.3	36.7				10.4	0.1	1 183	21	0.20	1.50	1 103	

Table I.9 : Deep Tubewell Design & Production Data; Sarlahi District File : V3-TI-9.wk1 10-May-94

Well Nr	Location	Village name	Total depth (m)	Screen length (m)	Top screen (m)	Screen intervals (m)	SWL (m bgl)	PWL (m bgl)	Yield (l/s)	Sw (m)	SC (l/s/m)	SD (m/l/s)	Kd [logan] (m3/d/m)	K screen (m/d)	SC/screen length (l/s/m2)	Q/screen length (l/s/m)	Casing diameter (m)
J21	Horticulture Farm	Nawalpur	70.0	23.0	45.0	45.00-68.0	22.00	29.74	16.0	7.74	2.1	0.48	236	10	0.09	0.70	12/8
J22	National Oil Seed Centre	Nawalpur	72.5	21.0	46.0	46.00-53.0 55.00-65.00, 67.00-69.00	21.00	37.50	45.0	16.50	2.7	0.37	311	15	0.13	2.14	12/8
J23	Sagarmatha Forest Dev Project	Sagarmatha	97.6				16.50	35.00	30.0	18.50	1.6	0.62	185				12/8
J24	Sagarmatha Forest Dev Project	Sagarmatha	110.0				15.52	29.00	40.0	13.48	3.0	0.34	338				12/8
S-1	Gair		100.0						fail								10/9
S-2	Birnagar		77.0	18.0			6.40	9.75	66.6	3.35	19.9	0.05	2267	126	1.10	3.70	10/9
S-3	Shivanagar		73.0	30.0			3.35	6.70	71.2	2.35	30.3	0.03	3455	115	1.01	2.37	10/9
S-4	Salimpur		98.0	18.0			6.10	9.76	73.1	3.66	20.0	0.05	2278	127	1.11	4.06	10/9
S-5	Chainpur		99.0				9.14	14.02	52.9	4.88	10.8	0.09	1236				10/9
S-6	Bheli		85.0	30.0												0.00	10/9
S-7	Laxmipur		107.0	30.0			2.74	5.79	80.4	7.05	11.4	0.09	1301	43	0.38	2.68	10/9
S-8	Kaurena		101.0	24.0			4.27	7.32	68.6	3.05	22.5	0.04	2565	107	0.94	2.86	10/9
S-9	Bishampur		104.0	18.0			7.32	12.81	44.2	5.49	8.1	0.12	918	51	0.45	2.46	10/9
S-10	Kaurena		101.0	30.0			4.27	7.93	65.6	3.66	17.9	0.06	2044	68	0.60	2.19	10/9
S-11	Simra		107.0	22.0			2.13	5.18	76.2	3.05	25.0	0.04	2849	130	1.14	3.46	10/9
No2	Sugar Factory		60.3	19.5			13.80	19.20	27.0	5.40	5.0	0.20	570	29	0.26	1.38	12/6
No3	Sugar Factory		60.0	18.0			14.40	19.20	29.0	4.80	6.0	0.17	689	38	0.34	1.61	12/6
	Average		89.6	23.2							11.0	0.17	1328	72	0.63	2.12	

Table I.10 : Deep Tubewell Design and Production Data, Mahottari District; Investigation DTWs

File : V3-TI-10.Wk1 10-May-94

DTW Nr	Location	Total depth (m)	Cased (m)	UWC depth (m)	Screen length (m)	Screen interval (m)	SWL (m)	Test yield (l/s)	DD (m)	SC (l/s/m)	SD (m/l/s)	Kd (m3/d/m)	Kd (logan) (m3/d/m)	K screen (m/d)	SC/screen length (l/s/m2)	Q/screen length (l/s/m)	UWC/LWC diam (mm)
M1	Jaleshwar	170.4	137.0				0.33	12.0	6.30	1.9	0.53	840	217				150/150
M2	Matihani	157.0	130.0	39.0			3.65										250/150
M3	Exraiha	93.3	92.0	29.0			1.79	48.4	22.00	2.2	0.45	510	251				250/150
M4	Siawakataiya	94.0	92.0	35.0			2.61	3.0	9.03	0.3	3.01	50	38				250/150
M5	Pokharvinda	109.3	108.0	33.0			+art	3.0	14.28	0.2	4.76	10	24				250/150
M6	Raghunathpur	112.9	111.0	34.0			5.73	1.4	24.60	0.1	17.08	2	7				250/150
M7	Aurhi	152.4	151.5	34.0				20.0	17.37	1.2	0.87	1140	131				250/150
M8	Hathilet	82.9					7.55					20					
M9	Bhangha	137.8	137.0	36.0			3.65	27.8	20.61	1.3	0.74	1690	154				250/150
M10	Matihani	138.0	128.2	36.0			18.00										250/150
M11	Laxminiya	123.0	118.8	44.0			32.17	57.1	1.97	29.0	0.03	23400	3308				250/150
M12	Hathilet	107.9	108.8	52.0			+art	25.8	3.43	7.5	0.13	570	858				250/150
M13	Sundarpur	150.0	112.5	29.0			+art	8.0	24.10	0.3	3.01	50	38				250/150
M14	Sripur	151.6	110.0	30.0			+8.25	18.9	4.55	4.2	0.24	1320	474				250/150
M15	Bishamvarpur	115.9	104.0	27.0			+17.61	26.0	30.45	0.9	1.17	420	97 ff20				250/150
M16	Ratauli	159.0	100.5	30.0			1.64	11.0	27.82	0.4	2.53	220	45				250/150
M17	Mahottary	135.0	131.0	31.0			0.32	28.6	22.93	1.2	0.80	300	142				250/150
M18	Bhargarsar	143.7	140.6	35.0			0.39	46.9	18.55	2.5	0.40	430	288				250/150
M19	Ramnagar	150.0	146.6	44.0			22.94	50.0	3.14	15.9	0.06	17800	1816				250/150
M20	Ramnagar	142.6	142.5	45.0			38.30	16.0	0.90	17.8	0.06	2340	2028				250/150
M21	Bijalpura	100.0	91.6	31.0			7.51	54.5	2.27	24.0	0.04	4750	2736				250/150
M22	Bijalpura	100.0										10400					150/150
M23	Sahorwa	167.7															
M24	Dhamaura	181.0		39.0				22.0									250/150
M25	Paraul	182.0	182.0	39.0			+art	20.0	24.80	0.8	1.24	250	92				250/150
M26	Hathilet	153.0	153.0	56.0			40.51	21.0	1.21	17.4	0.06		1979				250/150
M27	Bhargasar		141.0				1.47	35.2	4.20	8.4	0.12	610	957				50/50
M28	Bhargasar						0.51	35.2	3.57	9.9	0.10	580	1125				50/50
M29	Belgachi	121.0		62.0			33.65	34.4	1.42	24.2	0.04	1890	2759				250/150
M30	Kisannagar	122.0	122.0	50.0			53.00										250/150
M31	Pashupatinagar	163.0	163.0	44.0			16.93	52.0	7.43	7.0	0.14	2800	798				350/150
M32	Bharatpur	113.0	113.0	34.0			10.31	18.0	18.16	1.0	1.01	1100	113				350/200
M33	Laxminiya	152.4	152.0	58.0			28.28	28.9	1.66	17.4	0.06	8800	1985				250/150
M34	Bijalpura	153.0	153.0	45.0			17.10	41.9	2.70	15.5	0.06	2160	1772				250/150
M35	Phulhatta	213.0	213.0	28.0			+0.6	38.0	7.55	5.0	0.20	400	574 ff 12				250/150
M36	Pipra	222.0	222.0	34.0			+art	25.0									250/150
M37	Gausala	186.4	183.5	36.0			4.69	40.0	6.47	6.2	0.16	2300	705				250/150
M38	Hattishawa	145.5	145.5	34.0			+art	14.0	32.46	0.4	2.32	120	49				250/150
M39	Ekrahiya	220.0	208.5	31.0				15.0									250/150
M40	Dhirapur	205.0	199.5	29.0			+art	26.0	6.30	4.1	0.24	190	471				250/150
M41	Laxminiya	138.6	199.5	49.0			29.14	37.0	3.13	11.8	0.08		1348				250/150
M42	Bijalpura	95.0	90.3	47.0			19.37	30.0	1.66	18.1	0.06		2061				250/150
M43	Manarakatti	213.0															
M44	Khuttapiprari	187.0	184.1	32.0			+art	14.5									250/150
M45	Kisannagar	138.0	118.5	52.0			41.50	72.0	1.84	39.1	0.03	4150	4463				250/150
	Average	146.5		38.8						8.0	1.13	2776	827				

Table I.11 : Deep Tubwell Design and Production Data, Mahottari District

File : V3-TI-11.Wk1

17-Dec-93

Well nr	Location	Village name	Total depth (m)	Screen length (m)	Screen top (m)	Screen distribution		SWL (mbgl)	PWL (mbgl)	Yield Q (l/s)	DD (m)	SC (l/s/m)	SD (m/l/s)	Kd [Logan] (m3/d/m)	K screen (m/d)	SC/screen length (l/s/m2)	Q/screen length (l/s/m)	UWC/LWC diam (in)	Comment
FA05	Harigurgama		177.0	27.2			+	2.40	14.96	21.0	17.36	1.2	0.83	138	5	0.04	0.77	10/8	2.7 l/s freeflow
FA04	Ranja		176.0	30.0			+	9.50	2.65	34.7	12.15	2.9	0.35	326	11	0.10	1.16	10/8	23 l/s freeflow
FA03	Sundo		113.0	30.2			+	2.60	4.10	47.4	6.70	7.1	0.14	807	27	0.23	1.57	10/8	19.6 l/s freeflow
J18	Farmer B B Rana	Ram Nagar	81.0	24.4	36.4	36.35-42.29,60.55-79		22.00	54.00	15.0	32.00	0.5	2.13	53	2	0.02	0.62	6/6	
J19	Farmer Bedman Singh	Aaurhi	111.0	36.7	55.0	54.98-58.00,62-64.98 74.93-92.98,96.88-109		1.00	7.00	60.0	6.00	10.0	0.10	1140	31	0.27	1.64	10/6	
J20	Sagarmatha forest project	Hathilet	94.5	24.7	56.3	56.30-68.60,74.8-87.2		42.00	60.00	25.0	18.00	1.4	0.72	158	6	0.06	1.01	8/8	
M1	Jaleswor		169.0	15.0				3.70	6.00	12.0	2.30	5.2	0.19	595	40	0.35	0.80	6/6	
M2	Matihani		157.0	18.0				3.70		fail								10/6	
M3	Jikraiya		150.0	16.0				1.80	24.30	49.0	22.50	2.2	0.46	248	16	0.14	3.06	10/6	
M4	Siswa Katayia		144.0	7.0				1.80	39.80	3.0	38.00	0.1	12.67	9	1	0.01	0.43	10/6	
M5	Pokharbhinda			23.0				0.00	14.00	3.0	14.00	0.2	4.67	24	1	0.01	0.13		
M6	Raghu Nathpur			17.0				0.00	23.00	2.0	23.00	0.1	11.50	10	1	0.01	0.12		
M7	Aurhi			27.0				4.00	19.00	20.0	17.00	1.2	0.85	134	5	0.04	0.74		
M9	Bhangaha			23.0				9.40	29.40	20.0	20.00	1.0	1.00	114	5	0.04	0.87		
M10	Laxminiya			22.0				19.85	24.70	25.0	4.80	5.2	0.19	594	27	0.24	1.14		
M11	Ramnagar			22.0				24.09	29.43	27.0	5.34	5.1	0.20	577	26	0.23	1.23		
M14	Mahoyani			18.0				0.60	23.20	29.0	22.60	1.3	0.78	146	8	0.07	1.61		
M16	Bishahambhanpur			14.0				0.00	24.30	26.0	24.30	1.1	0.93	122	9	0.08	1.86		
M18	Sundarpur			20.0				0.00	23.80	18.0	23.80	0.8	1.32	86	4	0.04	0.90		
M22	Bhangarsar			20.0				1.82	17.83	33.0	16.01	2.1	0.49	235	12	0.10	1.65		
M24	Bijalpur			10.0				8.80	38.10	25.0	1.80	13.9	0.07	1584	158	1.39	2.50		
	Average		137.3	21.2						23.6		3.1	1.98	355	20	0.17	1.19		

Table I.12 : Tubewell Design & Production Data; Dhanusha District

DTW Nr	Location	Village name	Total depth (m)	Screen length (m)	Top screen (m)	Screened intervals (m)	SWL (m bgl)	PWL (m bgl)	Yield (l/s)	Sw (m)	SC (l/s/m)	SD (m/l/s)	Kd (Logan) (m3/d/m)	K screen (m/d)	SC/screen length (l/s/m2)	Q/screen length (l/s/m)	UWC/LWC diam (in)	Comment
FA01	Hardinath		133.1	30.2			+5.5	0.2	48.6	5.5	8.8	0.1	1002	33	0.29	1.61	10/8	27.8 l/s freeflow
FA02	Ghurgas		127.0	11.0			+7.2	9.9	42.9	17.1	2.5	0.4	286	26	0.23	3.90	10/8	9.3 l/s freeflow
FA06	Janakpur		176.0	27.5			+1.8	6.1	47.3	7.9	6.0	0.2	683	25	0.22	1.72	10/8	18.5 l/s freeflow
N1	Birendra Bazar	Bharatpur 1	124.0	30.0	70.0	70-75, 87-92,98-118	34.0	44.9	26.5	10.7	2.5	0.4	284	9	0.08	0.88	14/8	
N2	Chhayhatar Bigha	Bharatpur 2	162.0	42.8	86.3	86.25-116.25,124.5-129.5, 151-159.25	41.0		30.0							0.70	14/8	
N3	Murgiya	Yagya bhumi 3	124.9	26.0	78.3	78.25-83.25,86.25-91.25, 94-101.75,108.25-116.5	52.0		20.0							0.77	14/8	
N4	Lalvitti	Hariharpur	105.0	35.0	68.8	68.75-103.75	62.0		15.0							0.43	14/8	
N5	Dhalkebar Chauk	Dhalkebar	121.3	30.8	84.5	84.50-115.25	60.0		20.0							0.65	14/8	
N6	Lalkanpur	Bharatpur	104.8	30.0	66.0	66-71, 77-102	32.0	37.9	8.8	22.4	0.4	2.5	45	1	0.01	0.29	14/8	
N7	Keshar kutti	Yagya bhumi	165.0	30.0	102.5	102.5-117.5,128.5-133.5, 144.5-149.5,155-165	30.0		30.0							1.00	14/8	
N8	Kishanpur	Yagya bhumi	120.3	30.0	79.3	79.25-89.25,91.75-114.75	31.0		35.0							1.17	14/8	
N9	Digamharpur	Digambarpur	133.5	35.0	95.8	95.75-130.75	28.5		20.0							0.57	14/8	
N10	Hariharpur	Hariharpur	120.0	35.0	70.0	70-75,90-120	30.5	34.9	27.0	4.5	6.1	0.2	690	20	0.17	0.77	14/8	
N11	Umaprempur	Umaprempur	129.0	45.0	64.0	64-84,102-127	33.0		40.0							0.89	14/8	
N12	Singahimadan	Singyahi	87.7	21.0	44.7	44.7-55.7,75-85	1.0		40.0							1.90	8/8	
N13	Bakchaura	Bakchaura	158.0	40.0	72.0	72-82,122-127,133-158	0.2		40.0							1.00	14/8	
N14	Hanuman Nagar	Janakpur town Panchayat	173.8	27.5	115.5	115.5-121,127-132.5,154-171	0.5		50.0							1.82	14/8	
N15	Sonapada	Binni basaiya	175.0	33.0	90.0	90-95.5,119.5-125,147-169	0.5		50.0							1.52	14/8	
N16	Umaprempur Ward 2	Umaprempur	124.8	40.0	62.8	62.75-82.75,93.75-97.75, 109.75-127.75	10.0		10.0							0.25	14/8	
N17	Kathapulla	Hansa Kathpulla	144.0	40.0	102.0	102.0-142.0	0.0		10.0							0.25	14/8	
N18	Kumraha tole	Hansa Kathpulla	154.0	30.0	119.0	119.0-154.0	0.0		10.0							0.33	14/8	
N19	Puspalpur	Puspalpur	125.3	22.0	89.5	89.5-95.0,103.25-119.75	45.0	60.0	15.0	15.0	1.0	1.0	114	5	0.05	0.68	14/8	
N20	Bhiman Chauk	Yagyabhumi	119.5	32.8	66.0	66.00-71.00,83.95.75 101.75-116.75	42.0		15.0							0.46	14/8	
N21	Dada tole	Yagyabhumi	97.8	35.0	60.0	60-95	38.0		15.0							0.43	14/8	
N22	Mal tole	Umaprempur	132.0	32.5	66.0	66-77, 105.00-112.65	45.0		10.0							0.31	14/8	
N23	Mirchaiya	Mirchaiya, Sirha Dist	140.0				+1.0	5.0	25.0	6.0	4.2	0.2	475				14/8	
N24	Kesharkutti	Yagyabhumi	182.0														14/8	
N25	Janaki temple	Janakpur town	174.8	24.8	86.7	86.74-97.99,133.5-139 160.49-171.49	1.0		25.0							1.01	4/4	
N26	Parwanipur	Bara district	122.5	35.0	67.5	67.5-77.5,95.5-120.5	7.0		30.0							0.86	8/8	
J1	Dhalkebar	Dhalkebar	115.0	31.9	43.0	43.00-53.30,57.48-61.05 67.25-72.65,91.01-96.4 100-102.8	45.0	68.0	4.0	23.0	0.2	5.8	20	1	0.01	0.13	6/4	
J2	J A D P	Naktajhij	135.0	27.0		58.50-61.50,67-76 81.50-91.50,96-102	14.4	27.5	11.0	13.2	0.8	1.2	95	4	0.03	0.41	6/6	
J3	Tobbaco Factory	Mahendra Nagar	116.6	40.1		41.65-46.70,58.58-73.7 50.00-74.73,82.54-95.61 98.64-110.00	6.0	21.0	20.0	15.0	1.3	0.8	152	4	0.03	0.50	12/8	
J4	Hardinath Farm N0 2	Baniniya	160.0	33.0		67.75-69.25,83-105 143.50-149.00	3.4	27.6	30.0	31.0	1.0	1.0	110	3	0.03	0.91	12/8	
J5	Hardinath Farm N0 4	Baniniya	104.5	30.3		63.50-69.00,71.75-88.25 93.75-102.00	2.0	27.0	35.0	29.0	1.2	0.8	138	5	0.04	1.16	12/8	
J6	IAP Area No 1	Saphi Ramdaiya	130.0	33.0		48.50-59.50,81.5-92.5 93.75-102.00	1.3	11.4	44.0	12.6	3.5	0.3	398	12	0.11	1.33	12/8	

Table I.12 : Tubewell Design & Production Data; Dhanusha District

File : V3-TI-12.wk1

17-Dec-93

DTW Nr	Location	Village name	Total depth (m)	Screen length (m)	Top screen (m)	Screened intervals (m)	SWL (m bgl)	PWL (m bgl)	Yield (l/s)	Sw (m)	SC (l/s/m)	SD (m/l/s)	Kd (Logan) (m3/d/m)	K screen (m/d)	SC/screen length (l/s/m2)	Q/screen length (l/s/m)	UWC/LWC diam (in)	Comment
J7	IAP Area No 2	Saphi Ramdaiya	130.0	33.0		52.00-57.50,63-80.5 90.50-101.50	1.3	15.4	36.0	16.7	2.2	0.5	246	7	0.07	1.09	12/8	
J8	IAP Area No 3	Saphi Ramdaiya	130.0	33.0		53.00-58.50,64-75 86.00-91.50,97-108	3.2	9.9	35.0	13.1	2.7	0.4	304	9	0.08	1.06	12/8	
J9	IAP Area No 4	Saphi Ramdaiya	146.0	33.0		47.00-58.00,63.5-80 85.50-91.00	5.4	17.0	40.0	22.5	1.8	0.6	203	6	0.05	1.21	12/8	
J10	IAP Area No 5	Saphi Ramdaiya	130.0	33.0		49.25-54.75,63-68.5 82.25-87.75,96-112.5	1.8	20.6	35.0	22.4	1.6	0.6	178	5	0.05	1.06	12/8	
J11	IAP Area No 6	Saphi Ramdaiya	132.0	33.0		47.00-52.50,63.5-69 74.50-85.50,91-102	1.3	15.0	30.0	16.3	1.8	0.5	210	6	0.06	0.91	12/8	
J12	IAP Area No 7	Saphi Ramdaiya	156.0	33.0		51.50-68.00,79-90 123.00-128.50			25.0	0.0						0.76	12/8	
J13	IAP Area No 8	Saphi Ramdaiya	200.0	44.0		52.50-58.00,80-85.5 96.50-102.00,107.5-113 145.00-156.00,173.5-184.5	3.6	11.0	24.0	14.6	1.6	0.6	187	4	0.04	0.55	12/8	
J14	IAP Area No 9	Saphi Ramdaiya	130.3	35.8		39.55-42.30,53.3-56.05 61.55-69.80,75.3-83.55 89.05-102.80	5.4	6.8	44.0	12.2	3.6	0.3	410	11	0.10	1.23	12/8	
J15	Horticulture Farm	Janakpur town Panchayat	139.0	33.6		58.26-61.36,65.26-80.32 86.58-95.80,120.74-127	1.0	15.6	35.0	16.6	2.1	0.5	241	7	0.06	1.04	6/6	
J16	Fishries Dev Centre	Janakpur town Panchayat	140.0	25.5		49.20-56.32,86.16-91.66 115.59-122.30,131.07-137.25	1.5	13.7	45.0	15.2	3.0	0.3	338	13	0.12	1.76	12/8	
J17	Ghorghas	Ghorghas	166.0	39.3		85.68-94.00,110.25-121.87 127.78-130.83,140.97-146.72 151.24-162.00	1.4	25.0	48.0	26.4	1.8	0.5	208	5	0.05	1.22	12/8	
T1	Dharapani	Dharapani	160.0	30.0	83.3	83.30-98.30,108.3-118.3 148.30-153.30	46.0	68.1	35.0	22.1	1.6	0.6	181	6	0.05	1.17	14/8	csg reduction at 50 in T series wells
T2	Puspalpur	Puspalpur	130.0	35.0	75.0	75.00-85.00,95-120	dry			0.0							14/8	
T3	Bharatpur	Bharatpur	85.0	30.0	35.0	35.00-60.00,70-75	24.0	31.0	40.0 16.7	7.0 6.8	5.7 2.5	0.2 0.4	652 282	22	0.19	1.33	14/8	
T4	Kumraha	Kumraha	180.0	50.0	49.5	49.50-59.50,70.15-80.15 90.20-95.20,105.35-120.35 165.50-175.50	31.6	44.5	10.0	12.9	0.8	1.3	89	2	0.02	0.20	14/8	
T5	Godar	Godar	135.0	45.0	65.0	65.00-70.00,80-90 100.00-130.00,	22.8	45.6	45.0 9.7	22.8 15.5	2.0 0.6	0.5 1.6	225 71	5	0.04	1.00	14/8	
T6	Dhalkebar	Dhalkebar	145.5	45.0	65.0	65.00-75.00,90-115 120.00-130.00	63.7	84.5	15.0	20.8	0.7	1.4	82	2	0.02	0.33	14/8	
T7	Gauripur	Gauripur	130.0	50.0	50.0	55.00-55.00,65-75 90.00-125.00	20.9	36.5	25.0 15.2	15.6 12.5	1.6 1.2	0.6 0.8	183 139	4	0.03	0.50	14/8	
T8	Radhapur	Radhapur	150.0	35.0	50.0	50.00-60.00,85-90 105.00-120.00,140-145	23.8	37.5	42.0 36.5	13.7 10.0	3.1 3.7	0.3 0.3	350 416	10	0.09	1.20	14/8	
T9	Mangalpur	Mangalpur	170.0	50.0	94.0	64.00-104.00,129-169	23.7	34.7	50.0	11.0	4.6	0.2	520	10	0.09	1.00	14/8	
T10	Sarda	Sarda	160.0	45.0	95.0	95.00-110.00,120-150	18.2	42.2	10.0	23.9	0.4	2.4	48	1	0.01	0.22	14/8	
T11	Gohiya	Gohiya	155.0	35.0	100.0	100.00-110.00,130-155	27.9	35.6	40.0	7.7	5.2	0.2	596	17	0.15	1.14	14/8	
T12	Janakinagar	Janakinagar	165.0	45.0	95.0	95.00-105.00,130-165	12.6	45.2	10.0	32.7	0.3	3.3	35	1	0.01	0.22	14/8	
T13	Kajararamaul	Kajararamaul	170.0	40.0	95.0	95.00-100.00,120-135 140.00-165.00	9.3	51.4	10.0	42.1	0.2	4.2	27	1	0.01	0.25	14/8	
T14	Laliya	Laliya	165.5	75.0	72.0	72.00-97.00,109-159	4.6	16.4	30.0	11.8	2.5	0.4	290	4	0.03	0.40	14/8	
T15	Hanspur-Kathapulla	Hanspur-Kathapulla	175.0	50.0	120.0	120.00-170.00	+art	45.9	7.0	45.9	0.2	6.6	17	0	0.00	0.14	14/8	
T16	Jatiyahi	Jatiyahi	160.0	60.0	85.0	85.00-95.00,105-155	2.3	36.0	25.0	33.7	0.7	1.3	85	1	0.01	0.42	14/8	
	Average		141.2	35.7							2.3	1.1	263	7	0.06	0.72		

Table I.13 : Deep Tubewell Design and Production Data, Siraha District

File : V3-TI-13.wk1

17-Dec-93

DTW Nr	Location	Date drilled	Total depth (m)	UWC (m)	Screen (m)	Top screen (m)	Screened intervals (m)	Screen black (m)	Sand in S + B (%)*	Sand in top 50 m (m)	SWL [m]	Test yield (m3/h)	Sw (m)	SC [l/s/m]	SD [m/l/s]	Kd [logan] [m3/d/m]	K screen [m/d]	SC/screen length [l/s/m2]	Q/screen length [l/s/m]	UWC/LWC diam [in]	Comments
SIRDP : Lahan, Siraha																					
1	Bhagawanpur	3.82	134.4	30.8	25.6	42.3	42.3-48.2,74.9-81.5 90.8-93.9,106.1-109.1 120.7- 127.7	96.9	31	12.8	3.40	54.0	3.40	4.4	0.23	503	20	0.17	0.59	12/8	sand ingress, fail well
2	Bhagawanpur Simria	4.82	130.2	30.5	15.2	56.7	56.7-62.8,91.1-100.1	69.6	39	10.1	4.34	84.1	9.23	2.5	0.40	289	19	0.17	1.54	12/8	
3	Bhagawanpur Mohuri		98.4	30.1	18.2	44.9	44.9-47.9,58.9-61.94 71.9-75,86.3-95.4	65.3		19.2	3.66	133.0	13.10	2.8	0.35	322	18	0.15	2.03	12/8	
4	Inaruwa	4.82	130.2	30.0	18.8	47.0	47-50,65-68.7 86.7-92.7,121.3-127.4	97.4	35	17.1	4.50	96.0	5.68	4.7	0.21	535	28	0.25	1.42	12/8	
5	Gamaria	5.82	124.1	27.1	21.1	33.8	33.8-39.2,45.2-47.9 57.9-62.8,85.6-88.4 91.6-96.9	69.8	69	35.1	3.96	71.0	4.14	4.8	0.21	543	26	0.23	0.93	12/8	
9	Kasaha Ayodhyanagar	3.84	91.7	40.2	15.1	48.5	48.5-54.5,69.2-78.3	38.1	58	35.7	25.00	61.2	1.29	13.2	0.08	1503	100	0.87	1.13	12/8	
10	Bishnupur Katti	4.84	103.6	43.3	16.9	50.0	50-56,79.8-82.8 87.1-95	51.7	41	21.3	34.10	78.8	2.13	10.3	0.10	1171	69	0.61	1.29	12/8	
11	Govindpur	5.84	104.0	40.0	24.0	40.0	40-46,68-71 73-77,86-94	54.0	71	18.4	23.16									12/8	fail well
12	Dharampur	6.84	118.9	53.4	17.6	50.0	50-58.2,69.4-73.1 79.2-85.3	31.9	61	33.5	32.92									8/8	
6 ?	Mirchaiya		108.2	47.6	19.2	47.6	47.6-52.4,62.5-67.7 96.3-132.3	84.7													fail well
13	Kalidhog Gulm: Chauharwa .	3.85	114.9	44.0	18.3	22.0	22-25.9,37.7-41.8 45.9-56.2	?	44	21.6	7.01	37.3	3.65	2.8	0.35	324	18	0.15	0.57	8/8	
14	Chainpur: Dhangari	4.86	128.9	44.2	18.5	45.7	45.7-50.3,69.8-77.8 92-97.9	53.7	38	19.2	23.17									14/8	low Q
15	Bhadaiya: Ganeshpur	7.86	101.2	33.9	25.2	33.9	33.9-39.9,50.6-55 70-75.2,79.7-84.6 88.8-93.5	59.6	54	35.4	7.01	95.6	6.73	3.9	0.25	450	18	0.16	1.05	14/8	
	Average			13.0	18.1									5.5	0.24	627	35	0.31	0.59		
Siraha:																					
2/R9	Tudkiya		55.5	32.0	8.2	32.6	32.6-34.7,43.3-49.4	17.4	47		23.36	43.0	2.60	4.6	0.22	524	64	0.56	1.46	250/150	
1/R9	Masarnia		80.0	32.9	12.3	33.5	33.5-35.9,45.4-47 71-78.6	45.7	27		35.50	54.5							1.23	250/150	
1/R2	Bhulkia		96.7	40.0	8.5	84.0	84-87.1,90-95.4	55.4	15		22.76	43.0	3.96	3.0	0.33	344	40	0.35	1.40	250/150	
1/R3	Chiza Bari		39.3	27.7	7.7	28.6	28.6-36	?	39		15.67	106.0	8.61	3.4	0.29	390	51	0.44	3.82	250/150	
5/R3	Vishnupur		69.8	56.4	7.0	56.4	56.4-57.3,61-66.5	?	69		47.56	81.8							3.25	150/150	
	Average			5.0	8.7									3.7	0.28	419	52	0.45	1.86		
	Average all			18.0	15.7									5.0	0.25	575	39	0.34	0.90		

Table I.14 Deep Tubewell Design and Production Data, Saptari District

File: V3-TI-14.wk1

10-May-94

DTW Nr	Location	Drill date	Total depth (m)	Pump chamber (m)	Screen (m)	Top screen (m)	Screened intervals (m)	Sand in top 50m (m)	SWL (m)	Test yield (m3/h)	Sw (m)	SC Cap (l/s/m)	SD (m/l/s)	Kd (Logan) (m3/d/m)	K screen (m/d)	SC/screen length (l/s/m2)	Q/screen length (l/s/m)	UWC/LWC Diam (in)	Comments
	SIRDP:Lahan,Saptari		# wellstring depth only																All SIRDP wells have saw slot casing
	6 Hardiya	2.83	150	40	25.4	43.1	43.1-46.0,58.2-66.4 78.6-81.7,87.8-98.7	20.1	18.3									12/8	
	7 Pipra,Chahaka	4.83	109	30	21	32.9	32.9-36.9,55.8-59.7 71.0-74.1,94.8-104.8	26.8	18.3	96.0		12.8	0.08	406	19	0.61	1.27	12/8	
	8 Daulatpur Laxmipur	5.83	147	40	30.6	48.2	48.2-51.2,75.6-81.7 88.1-93.6,11.0-107.3 130.4-139.6	8.9	18.3									12/8	
	16 Madhupatti Birnagar	5.83	183					1.5											
	17 Kusaha	5.83	199					4.3											
	18 Mohanpur	2.83	138	49.4	27.4	53.8	53.8-59.7,82.6-94.6 125.1-134.1	32.0	34.7									14/8	
	19 Kanakpatti	4.83	135					42.4											
	20 Prasauni	6.83	161					0.0											
	21 Sitapur	6.83	185					22.9											
	22 Ghogampur	4.83	180	55.8	35.7	91.7	91.7-97.8,115.8-128.0 150.9-162.9,165.9-170.8	36.3	35.7									14/8	
ER-1	Sakhara	5.77	80#	29.8	6.2	70.7	70.7-76.5		3.8	125.0		18.5	0.05	586	95	2.98	5.60	10/6	
ER-2	Sakhara	5.77	24#	30.48	3	21.24	21.24-24.24		3.8	12.0		23.5	0.04	744	248	7.83	1.11	6/6	
ER-3	Raj Biraj [water tank]	5.77	94.5#	34.6	6.1	85.7	85.7-91.8		14.8	15.4		1.6	0.63	51	8	0.26	0.70	10/6	
ER-4	Raj Biraj [SP camp]	5.77	34.75#	30.48	3	31.1	31.1-34.1		7.7	12.0		34.0	0.03	1077	359	11.33	1.11	6/6	
ER-5	Nakati Raipur	6.77	54.6#	31.1	5.3	47.7	47.7-53.0		8.4	10.8		0.8	1.33	24	4	0.14	0.57	10/6	
ER-6	Rupani	6.77	54.6#	30.48	2.4	50.52	50.0-52.4		11.9	74.0		1.0	1.00	32	13	0.42	8.56	6/6	
ER-7	Kwerbana	6.77	17#	12.2	2.6	12.2	12.2-14.8		3.3									6/6	
ER-8	Fattepur	6.77	28#	23.9	3.7	23.9	23.9-27.6		4.5	12.0		11.0	0.09	348	94	2.97	0.90	6/6	
ER-9	Burmojhia	6.77	45.7#	25.6	6.3	39.3	39.3-45.0		5.0	12.8		19.3	0.05	612	97	3.07	0.56	10/6	
	Average			33.13	12.76							12.2	0.17	204	49	0.78	1.07		

Table I.15 : Deep Tubewell Design & Production Data, Sunsari District File : V3-TI-15.wk1 10-May-94

Well Nr	Location	Total depth (m)	Screen length (m)	Screen top (m)	Screen distribution (m)		SWL (m bgl)	PWL (m bgl)	Discharge Q (l/s)	Sw (m)	SC (l/s/m)	SD (m/l/s)	Kd (Logan) (m3/d/m)	K screen (m/d)	SC/m screen (l/s/m2)	Q/m screen (l/s/m)	UWC/LWC diam (in)
SS.1	Tarahara	25.0	6.0	14.0	14-17,39.5-22.5												10/8
SS.2	Duhabi	162.7	25.0	92.0	92-103.9,144.5-152.4 154-160												10/6
SS.3	Itahari	78.0	6.1	69.8	69.8-75.9	+	3.53		0.5	25.20	0.0	53.38	2	0	0.00	0.08	10/6
SS.4	Jhumka	53.0	8.7	41.7	41.9-44.5,48.8-54.7	+	0.50		36.9	5.80	6.4	0.16	726	83	0.73	4.25	10/6
SS.5	Jalpapur	27.4	2.8	24.0	24-26.8		3.18		2.3	0.30	7.6	0.13	866	309	2.71	0.81	6/6
SS,6	Bhokraha	33.0	6.1	25.8	25.8-31.9		2.70		18.5	3.42	5.4	0.19	616	101	0.89	3.03	10/6
SS,7	Betamara	165.0	5.1	157.9	157.3-163		3.49		12.1	13.11	0.9	1.08	105	21	0.18	2.37	10/6
SS,8	Belahajhora	71.7	18.7	54.9	54.9-68.6		5.57		51.1	0.45	113.5	0.01	12 950	693	6.07	2.73	10/6
SS,9	Belahajhora	69.2	6.0	60.0	60-66				0.0								6/6
SS,10	Duhabijhora	83.8	6.1	76.2	76.2-82.3				0.0								6/6
SS,11	Duhabijhora	55.0	12.0	40.9	40.9-53				0.0								10/6
SS,12	Pakali	74.5	7.0	66.0	66-73		7.90		2.3	0.50	4.6	0.22	519	74	0.65	0.33	6/6
SS.13	Amahibelaha	62.0	12.0	44.0	44-53,56-61				0.0								10/6
ss.14	Jadibuti Tarahara	30.8	7.7	14.0	14-15.2,17.7-21.3,23-25.9		3.70		16.2	1.86	8.7	0.11	993	129	1.13	2.10	10/6
	Average		9.2						11.7	6.33	12.3	6.91	1 398	176	1.55	1.96	

Table I.16 : Deep Tubewell Design and Production Data, Exploration Drilling in Jhapa District

File : V3-TI-16.wk1 — 17-Dec-93

Nr	Location	Elev (m)	Total depth (m)	Screenable material in interval: 0-50 (%)	50-100 (%)	100-150 (%)	150-200 (%)	200-250 (%)	250-300 (%)	UWC length (m)	Screen length (m)	Top of screen (m)	Screen Zone (m)	Sand screened (m)	Prod. string (m)	Q (l/s)	Well effic (%)	SD* (m/l/s)	SC* (l/s/m)	Kd (m3/d/m)	K (screen zone?) (m/d)	K (screen) (m/d)	SC/screen (l/s/m2)	Well type	UWC/LWC diam (in)
JICA Wells :																									
EX-1	Patharia	65.0	300.0	62.0	82.0	76.0	72.0	94.0	92.0	60	30.0	248	248-282	30	225		96	0.55	1.8	967.0	21.0	32.2	0.06	A	12/6
Obs 1			100.0	74.0	90.0																				
EX-2	Garamuni	109.5	300.0	74.0	42.0	50.0	48.0	54.0	46.0	60	42.0	243	243-293	42	236		83	0.56	1.8	409.0	15.2	9.7	0.04	A	12/6
EX-3	Dangebari	96.5	300.0	66.0	60.0	44.0	32.0	44.0	56.0	60	27.0	202	202-288	27	231		95	0.38	2.7	1198.0	32.4	44.4	0.10	A	12/6
EX-4	Rajgarh	75.0	250.0	48.0	74.0	76.0	64.0	68.0		60	27.0	202	202-244	27	187		58	0.35	2.8	1198.0	32.2	44.4	0.10	A	12/6
Obs 2			100.0	68.0	64.0																				
EX-5	Prithivinegar *	81.0	250.0	52.0	64.0	44.0	60.0	68.0		60	24.0	206	206-243	24	186		52	0.48	2.1	486.0	8.0	20.3	0.09	A	12/6
EX-6	Balubari	78.0	250.0	62.0	68.0	40.0	52.0	86.0		60	27.0	214	214-241	27	184		85	0.60	1.7	731.0	16.6	27.1	0.06	A	12/6
EX-7	Haldibari	96.5	200.0	28.0	58.0	30.0	48.0			60	21.0	140	140-186	21	129		59	0.73	1.4	296.0	9.9	14.1	0.07	A	12/6
Obs 3			100.0	40.0	70.0																				
EX-8	Prithivinegar **	77.0	200.0	64.0	44.0	52.0	70.0			60	21.0	167	167-193	21	136		81	0.45	2.2	645.0	22.2	30.7	0.11	A	12/6
EX-9	Anarmuni	119.5	200.0	72.0	48.0	28.0	62.0			60	21.0	149	149-197	21	140		54	0.47	2.1	382.0	13.2	18.2	0.10	A	12/6
EX-10	Samamati	91.0	150.0	84.0	48.0	82.0				60	15.0	100	100-134	15	77		88	0.30	3.4	925.0	22.0	61.7	0.22	A	12/6
Obs 4			100.0	70.0	72.0																				
EX-12	Gherabari	70.5	150.0	98.0	50.0	70.0				60	15.0	123	123-145	15	88		76	0.26	3.9	1278.0	35.5	85.2	0.26	A	12/6
EX-13	Pathamari	71.0	100.0	76.0	72.0					30	21.0	46	46-72	21	45		85	0.16	6.5	2734.0	66.7	130.2	0.31	B	12/6
EX-14	Surunga	99.0	100.0	96.0	80.0					30	30.0	57	57-95	30	68		37	0.38	2.6	1115.0	27.9	37.2	0.09	B	12/6
EX-15	Jamirgarhi ***	110.0	100.0	48.0	44.0					30	12.0	39	39-94	12	67		23	0.41	2.4	664.0	21.4	55.3	0.20	B	12/6
[obs 5]			100.0	68.0							12.0	37													
	Average			65.8	59.5	53.8	56.4	69.0	64.7									0.40	2.7	930.6	24.6	40.7	0.13		
GWRDB Wells :																									
J-1	HT Garden		88.4								16.9					1.8			0.4	45.0					250/150
J-2	Charali		124.9								20.0					11.5			0.5	587.0					250/150
J-3	Kankai		85.9								8.7					2.5			3.6	295.0					250/150
J-4	Bhalu Gaon		137.2								17.9					2.0			1.7	287.0					250/150
J-5	Gwal Duba		137.2								12.5					41.7			23.2	820.0					250/150
J-6	Bhawani Pur		137.2								15.3					12.9			0.7	469.0					250/150
J-7	Prakash Pur		148.4								18.3					5.3			0.3						250/150
J-8	Mahesh Pur		146.3								24.4					14.3			4.8	633.0					250/150
J-9	Gol Dhap		146.3								36.3					10.0			1.9	226.0					250/150
J-10	Ghailadubba		144.8								24.4														250/150
J-11	Prithivinegar		155.5								21.5					39.0			5.2						250/150
J-12	Rajgadhat		167.7								33.2					43.0			8.4	1750.0					250/150
J-13	Tangan Duba		158.5								25.5					41.0			2.4	1440.0					250/150
J-14	Damak		75.1								24.1					25.0			8.3	670.0					350/200
J-15	Sanischare		73.1								33.5														350/200
J-16	Kakarbhitta		159.7								67.0														
	Average		130.4								25.0								4.7	656.5					

Notes : All JICA exploratory wells are screened with Johnson types WwRb and gravel packed : casings zinc coated ms
* completed in terrace alluvium?
** m-f sand in 0-50m interval:terrace alluvium?
*** fine to very fine sand in 0-50m interval
Well type A: 1.5mm oa 39% Well type B: 2mm oa 46% Well type C: >1mm slot oa >8%#

APPENDIX II

SHALLOW TUBEWELL CONSTRUCTION DATA

Table II.1 : Shallow Tubewell Data; Kailali and Kanchanpur Districts (UNDP/GWRDB Programme)

File : V3-TII-1.wk1 10-May-94

TW Nr	Location village	Drill date	Depth drilled (m)	Casing length (m)	Screen length (m)	Aquifer litho	SWL (m)	PWL (m)	Q (l/s)	Sw (m)	SC (l/s/m)	SD (m/l/s	Kd [Logan] (m2/d)	Kd [Nk] (m2/d)	K screen (m/d)	SC/m screen (l/s/m2)	Q/m screen (l/s/m)
(a) Kailali District													noneq		###		
UN 01	Bishnukantipur	8.89	14.3		3.7	G	1.29	1.36	16.6	0.07	237.1	0.0	27 046		7 310	64.09	4.49
UN 02	Dhusi	8.89	23.5		3.7	GS	2.70	2.88	17.0	0.18	94.4	0.0	10 771		2 911	25.53	4.59
UN 03	Joshipur	8.89	21.9		3.7	GS	2.31	2.45	16.0	0.14	114.3	0.0	13 034		3 523	30.89	4.32
UN 04	Simri		26.5		3.7	GS	2.82	3.71	15.8	0.89	17.8	0.1	2 025		547	4.80	4.27
UN 05	Kota	3.89	50.3		6.1	SG	5.22	5.45	10.4	0.23	45.2	0.0	5 157		845	7.41	1.70
UN 06	Thabai	5.89	22.5		3.6	GS	5.32	5.85	12.9	0.53	24.3	0.0	2 767		769	6.74	3.57
UN 07	Basauti	4.89	56.4		1.8	S											
UN 08	Prithivipur N	3.89	30.5		5.5	GS	3.00	6.70	8.7	3.70	2.4	0.4	268		49	0.43	1.58
UN 09	Udashipur	3.89	54.9		6.1	S											
UN 10	Phulbari	12.88	32.6		4.2	S	4.17	5.23	8.0	1.06	7.5	0.1	861		205	1.80	1.90
UN 11	Bhada	1.89	21.3		6.1	S											
UN 12	Maghi	3.89	19.9		3.7	GS											
UN 13	Dhangadhi Village	12.89	40.0		5.5	SG	4.62	4.90	12.0	0.28	42.9	0.0	4 888		889	7.79	2.18
UN 14	Dhangadhi Town	1.89	35.5		5.5	G	3.98	6.88	14.2	2.90							
UN 15	Rajpur	12.89	32.6		3.7	G											
UN 16	Dhanchauri	5.89	19.8		3.0	GS	3.11	5.05	14.4	1.94							
UN 17	Lalpur	1.89	10.7		3.7	G	2.22	2.94	16.3	0.72	22.6	0.0	2 582		698	6.12	4.41
UN 18	Teghari	6.89	11.9		3.1	G											
UN 19	Katachhe	1.9	10.7		3.7	G											
UN 20	Khareity	2.9	19.2		3.0	GS											
UN 21	Banbehda	2.9	10.2		2.7	SG											
UN 22	Tikapur	12.89	10.7		3.7	G	2.43	2.49	15.0	0.06	250.0	0.0	28 512		7 706	67.57	4.05
UN 23	Durgauli	12.89	10.7		3.7	G	2.25		15.5								4.19
UN 24	Ghaugurdi	12.89	20.2		3.6	GS	4.71	4.82	12.0	0.11	109.1	0.0	12 442		3 456	30.30	3.33
UN 25	Numuwabojhi	5.90	33.5		2.7	SG	3.32	3.90	2.5	0.58							
UN 26	Simthali	4.90	17.1		2.7	S											
UN 27	Sripur	4.90	44.0		6.7	S											
UN 28	Kanari	2.90	21.3		2.7	SG	2.74	2.89	4.7	0.15							
UN 29	Bijuliya	2.90	16.5		3.5	SG	4.13										
UN 30	Baliya	11.89	13.7		3.7	S	2.16	2.27	14.0	0.11	127.3	0.0	14 515		3 923	34.40	3.78
UN 31	Rampur	2.90	21.3		5.5	S	4.99	5.12	7.0	0.13	53.8	0.0	6 141		1 117	9.79	1.27
UN 32	Chharra	2.90	16.5		3.6	S	3.86	3.99	12.6	0.13	96.9	0.0	11 054		3 071	26.92	3.50
(b) Kanchanpur District																	
UN 01	Kankar		17.7		6.1	S	0.81		16.8	0.06	280.0	0.0	31 933		5 235	45.90	2.75
UN 02	Pachkaria	2.89	36.9		6.1	S			12.6								
UN 03	Piparia	2.89	32.6		6.1	S											
UN 04	Mahuwaphanta	2.89	16.5		3.1	G	5.26		16.0	0.08	200.0	0.0	22 810		7 358	64.52	5.16
UN 05	Mataia	3.89	33.5		6.1	SG			14.0	0.18	77.8	0.0	8 870		1 454	12.75	2.30
UN 06	Shantipur	1.89	42.9		6.1	S			9.5								
UN 07	Jain	2.89	48.8		8.0	S	2.48		8.0	0.65	12.3	0.1	1 404		175	1.54	1.00
UN 08	Bansa	3.89	36.6		5.7	S	0.36		4.0	0.50	8.0	0.1	912		160	1.40	0.70
UN 09	Bani	1.89	51.8		5.1	G	3.40		5.0	0.15	33.3	0.0	3 802		745	6.54	0.98
UN 10	Banjaria	2.89	50.3		1.9	S											
UN 11	Pachui	2.89	37.2		6.1	S	2.10		13.9	0.30	46.3	0.0	5 284		866	7.60	2.28
UN 12	Amilia	4.89	32.0		4.6	SG	3.70		14.6	0.05	292.0	0.0	33 302		7 240	63.48	3.17
UN 13	Daijee	3.90	30.5		4.2	S	3.10		7.9	1.90	4.2	0.2	474		113	0.99	1.88
UN 14	Ultakham	1.90	8.2		2.7	G											
UN 15	Gaddachauki	2.90	8.2		2.7	G											

Table II.2 Shallow Tubewell Data, Kapilvastu and Nawalparasi Districts (UNDP/ GWRDB Programme)

Tubewell Nr.	Location village	Drill date	Depth drilled (m)	Casing length (m)	Screen length (m)	Aquifer litho	SWL (m)	DWL (m)	Q (l/s)	DD (m)	SSSC Cap (l/s/m)	SD DD (m/l/s)	Kd (Logan) (m2/day)	Kd (NK) (m2/day)	K screen (m/d)	SC/m screen (l/s/m2)	Q/m screen (l/s/m)
Kapilvastu District																	
UN 01	Amuwa		39.00			GS											
UN 02	Birpur	1.88	42.00		5.5	G	13.36										
UN 03	Gorusinghe	2.88	40.00														
UN 04	Simarsat	2.88	40.00		5.5	SG	2.24	5.93	3.00	3.69	0.81	1.23	92.7		16.86	0.15	0.55
UN 05	Bijgauri	3.88	50.00		5.5	SG	3.59	5.35	12.00	1.76	6.82	0.15	777.6		141.38	1.24	2.18
UN 06	Loharaula	3.88	44.00		6.0	G	2.87	4.59	12.00	1.72	6.98	0.14	795.7		132.61	1.16	2.00
UN 07	Nandnagar	4.88	29.00		4.5	G	13.02										
UN 08	Bharsarwa	4.88	54.00		8.0	GS	2.27										
UN 09	Dhamauliya	4.88	55.00		14.0	G	1.69	6.50	5.00	4.81	1.04	0.96	118.6		8.47	0.07	0.36
UN 10	Harnampur	5.88	54.00		8.0	GS	1.75	4.79	2.50	3.04	0.82	1.22	93.8		11.72	0.10	0.31
UN 11	Karmahawa	5.88	40.00		5.5	G	2.39	4.76	14.00	2.37	5.91	0.17	673.7		122.49	1.07	2.55
UN 12	Auraiha	5.88	34.00		5.5	GS											
UN 13	Sultanpur	5.88	62.00		5.5	G	3.75	7.46	1.40	3.71	0.38	2.65	43.0		7.82	0.07	0.25
UN 14	Akbarpur	5.88	50.00		5.5	GS											
UN 15	Amuwa	5.88	68.00		5.5	GS	1.33	6.43	2.00	5.10	0.39	2.55	44.7		8.13	0.07	0.36
UN 16	Mahuwa	5.88	50.00		5.5	S	4.50	6.89	2.20	2.39	0.92	1.09	105.0		19.09	0.17	0.40
UN 17	Babudihawa	5.88	40.00		5.5	G	2.68	7.54	0.25	4.86	0.05	19.44	5.9		1.07	0.01	0.05
UN 18	Motipur	5.88	66.00		6.0	GS	4.90										
UN 19	Jurpaniya	5.88	48.00		5.5	SG	0.99	4.91	5.00	3.92	1.28	0.78	145.5		26.45	0.23	0.91
UN 20	Kushahawa	5.88	56.00		5.5	SG											
UN 21	Gorusinghe	5.88	68.00		16.5	GS	0.62	4.82	11.00	4.20	2.62	0.38	298.7		18.10	0.16	0.67
UN 22	Bhitriya	5.88	40.00		11.0	GS	2.47	5.38	2.00	2.91	0.69	1.45	78.4		7.13	0.06	0.18
UN 23	Bharampaniya	6.88	66.00		5.5	SG											
	Average		49.347		6.326				3.1456	2.02	1.3666	1.5340	155.86		24.8250	0.2176	0.5125515
Nawalparasi District																	
UN 01	Rampurwa	1.88	28.3		5.4	G	1.25										
UN 02	Badera	1.88	2.8		6.5	GS	1.05										
UN 03	Parasi	1.88	38.4		11.0	GS	2.45										
UN 04	Jamuniya	3.88	40		6.0	GS	3.25	7.6	3.5	4.35	0.80	1.24	91.8		15.29	0.13	0.58
UN 05	Paldanda	3.88	49		10.0	GS	3.6	9.17	6	5.57	1.08	0.93	122.9		12.29	0.11	0.60
UN 06	Dabila	3.88	45		7.5	G	6.54										
UN 07	Kuniya	3.88	12		5.5	S	2.79	5.46	14	2.67	5.24	0.19	598.0		108.73	0.95	2.55
UN 08	Raninagar	3.88	5.5		1.9	G	3.8										
UN 09	Kharahani	3.88	33.5		13.0	GS	3.23	6.2	20	2.97	6.73	0.15	768.0		59.08	0.52	1.54
UN 10	Banjariya	4.88	63		20.0	GS	3.63										
UN 11	Parsawal	4.88	38		14.0	G	3.96										
UN 12	Lalpati	4.88	38		14.0	GS	3.73	7.55	3	3.82	0.79	1.27	89.6		6.40	0.06	0.21
UN 13	Gobrahiya	4.88	39		13.0	G											
UN 14	Surajpura	5.88	33		15.0	GS	2.92	7.46	20	4.54	4.41	0.23	502.4		33.49	0.29	1.33
UN 15	Guthi Parsauni	5.88	19.5		8.0	G	3.68	9	12	5.32	2.26	0.44	257.3		32.16	0.28	1.50
UN 16	Bisnupura		16.8		7.8	S	4.8	8.68	4	3.88	1.03	0.97	117.6		15.07	0.13	0.51
UN 23	Sunwal	6.88	50.5		8.0	G	0.5										
	Average		32.488		9.8				10.312	1.94	1.7181	0.4172	195.95		21.7312	0.1905	0.6790529

Table II.3 Shallow Tubewell Data, Birganj Community Wells: Parsa and Bara Districts

File V3-T-II-3.wk1

TW Nr	Location village	Drill date	Depth drilled (m)	Casing length (m)	Screen length (m)	Aquifer Lith	SWL (m)	Q (l/s)	Sw (m)	SC	SD (m/l/s)	Kd (Logan) (m2/d)	Kd (NK) (m2/d)	K screen (m/d)	SC/screen length (l/s/m2)	Q/screen length (l/s/m)	Remarks
S-1	Rajghatta	4.85	41.5	29.5	12.0	Gs	1.62	10.5	3.86	2.7	0.4	310		26	0.23	0.88	Not in use;capped
S-2	Rajghatta	4.85	41.5	32.5	9.0	Gs	2.89	10.5	1.88	5.6	0.2	637		71	0.62	1.17	Well located outside pumphouse.
S-3	Behari	4.85	43.0	31.0	12.0	Gs	0.59	10.5	4.78	2.2	0.5	251		21	0.18	0.88	In use
S-4	Bathnaha Simra	4.85	28.0	13.0	15.0	G	1.08	10.5	2.00	5.3	0.2	599		40	0.35	0.70	In use
S-5	Auraha Simra	2.85	34.0	19.0	15.0	Gs	1.02	10.5	5.13	2.0	0.5	233		16	0.14	0.70	Damaged
S-6	Pipra Simra	2.85	32.0	20.0	12.0	Gs	2.30	8.0	4.54	1.8	0.6	201		17	0.15	0.67	Fine Sand pumping with water
S-7	Auraha Simra	3.85	30.0	12.0	18.0	Gs	0.70	10.5	2.46	4.3	0.2	487		27	0.24	0.58	Not in use
S-8	Auraha Simra	4.85	33.0	21.0	12.0	G	2.80	10.5	2.95	3.6	0.3	406		34	0.30	0.88	In use
S-9	Simra V.D.C	4.85	22.5	13.0	9.0	Gs	3.00	11.4	2.97	3.8	0.3	438		49	0.43	1.27	In use
S-10	Simra V.D.C	4.85	28.6	16.6	12.0	Gs	3.90	10.0	2.06	4.9	0.2	554		46	0.40	0.83	In use
S-12	Bathnaha Simra	5.85	30.0	18.0	12.0	Gs	1.57	10.0	3.39	2.9	0.3	336		28	0.25	0.83	Not in use
S-13	Bathnaha Simra	6.85	26.0	17.0	9.0	G	1.40	10.5	1.68	6.3	0.2	713		79	0.69	1.17	Damaged,filled up.
S-14	Bathnaha Simra	6.85	29.0	17.0	12.0	Gs	2.65	10.5	3.88	2.7	0.4	309		26	0.23	0.88	Damaged, filled up.
S-15	Bajni Simra	5.85	31.0	19.0	12.0	Gs	2.00	10.5	2.52	4.2	0.2	475		40	0.35	0.88	In use
S-17			33.0	18.0	15.0	Gs	2.90	10.5	2.76	3.8	0.3	434		29	0.25	0.70	
S-19	Teda Ramban		25.0	13.0	12.0	G	3.00	16.1								1.34	Capped, not in use
S-20	Solakpur		25.0	13.0	12.0	Gs	2.04	12.0								1.00	Capped,not in use.Damaged
S-22	Solakpur		28.0	16.0	12.0	Gs	2.40	14.0								1.17	Damaged, filled up.
S-25	Teda		16.5	9.3	7.2	Gs	1.60	10.7	4.14	2.6	0.4	295	307	41	0.36	1.49	Well in use:Kd 307[NK]
S-26	Jitpur V.D.C	3.85	34.2	32.2	11.0	Gc	3.08	10.5	1.43	7.3	0.1	837		76	0.67	0.95	Damaged
S-27	Parsawa	5.85	17.0	8.0	9.0	Gs	3.73	10.5	3.43	3.1	0.3	349		39	0.34	1.17	To be equipped
S-28	Jitpur	5.85	25.0	13.0	12.0	Gs	3.19	10.5	1.53	6.9	0.1	783	888	65	0.57	0.88	In use
S-29	Koniha Belwa	5.85	16.5	7.5	9.0	Ms	2.30	13.5								1.50	In use
S-30	Khoniha Belwa	5.85	20.0	8.0	12.0	Gs	3.04	14.0								1.17	In use
S-31	Sukhchana	4.85	25.0	13.0	12.0	ms											Capped,not in use.
S-32	Sukhchana	5.85	25.0	13.0	12.0	ms											Capped,not in use;pitted 0.2m
S-34	Pampur Tokuni	5.85	19.0	7.0	12.0	ms		10.5								0.88	Not in use
S-35	Banipur	5.85	19.0	7.0	12.0	ms	2.11	7.5								0.63	Capped,not in use
S-36	Buniyad	5.85	19.0	7.0	12.0	ms											Not in use
S-37	Gangapur	1.85	19.8	12.2	9.6	cS	2.70	8.0	4.20	1.9	0.5	217	376	23	0.20	0.83	In use but giving sand
S-38	Brampuri	4.85	21.6	12.6	9.0	cS	3.00	9.2								1.02	In use
S-39	Uttarzitkaiya	5.85	19.0	7.0	12.0	cS											Capped, not in use.
S-40	Pangapur		28.0	16.0	12.0	fS											In use, giving fine sand
S-41	Bishwambhapur	1.85	24.6	15.3	9.3	mS	4.70	7.0	3.20	2.2	0.5	249	324	27	0.24	0.75	Capped, not in use: sunk by 0.5m
S-42	Phulbariya		25.0	11.5	13.5	cS											Damaged, sunk by 0.23m.
S-43	Phulbariya	5.85	19.0	10.0	9.0	cS	3.60	10.2								1.13	In use
S-44	Bishwambhapur		31.0	19.0	12.0	cS											Sunk by 1.0m.
S-45	Chhotiphulbara		31.0	19.0	12.0	cS											In use, giving sand
S-46	Ramban Simra	5.85	28.0	16.0	12.0	GS	3.43	8.0	2.96	2.7	0.4	308		26	0.23	0.67	In use
S-48	Bajni Simra	5.85	28.0	16.0	12.0	GS	1.26	10.5								0.88	Sunk by 3m and 3m casing added
S-49	Narbasti Simra	5.85	29.0	17.0	12.0	GS	2.90	10.5								0.88	
S-52	Rajghatta	5.85	15.0	9.0	6.0		2.73	9.0	3.53	2.5	0.4	291		48	0.42	1.50	Not in use,no pump house
S-54	Rajghatta	6.85	13.0	7.0	6.0		1.97	10.5	1.44	7.3	0.1	832		139	1.22	1.75	Not in use
S-55	Rajghatta	6.85	18.0	9.0	9.0		2.65	10.5	1.93	5.4	0.2	620		69	0.60	1.17	Not in use
S-57	Bajni Simra	5.85	33.0	21.0	12.0		2.55	10.5								0.88	Not in use
S-58	Khapartatta	5.85	22.0	10.0	12.0												Capped, not in use.
S-59	Belwa V.D.C	5.85	19.0	10.0	9.0		3.70	10.1								1.12	Group of 7,unused/capped.
S-60			15.0	6.0	9.0		1.40	4.0								0.44	
S-63	Chomi V.D.C	6.85	16.0	7.0	9.0												
S-64	Bhodaha	6.85	16.6	9.6	9.0			10.5								1.17	Damaged
	48 no		25.4	14.5	11.2			10.1		3.9	0.3	447	474	44	0.39	0.79	

Table II.4 : Shallow Tubewell Data; Birganj area; Bara, Parsa Districts

File : V3-TII-4.wk1

17-Dec-93

TW Nr	Location village	Drill date	Depth drilled (m)	Casing length (m)	Screen length (m)	Aquifer litho	SWL (m)	Q (l/s)	Sw (m)	Spec Cap (l/s/m)	Spec DD (m/l/s)	Kd (Logan) (m2/d)	Kd (NK) (m2/d)	K screen (m/d)	SC/m screen (l/s/m2)	Q/m screen (l/s/m)	Remarks
(a) Parsa District																	
UNP-01	Sukjachaina	5.90	44.2	40.7	5.0	S	3.29	2.5	4.3	0.6	1.71	67	114	13	0.12	0.50	All STWs reported completed
UNP-02	Madhawala	5.90	42.7	38.7	5.5	S	2.17	9.2	5.6	1.6	0.61	186	979	34	0.30	1.67	with 4in MS slotted casing/screen
UNP-03	Ashawari	5.90	41.2	37.2	5.5	S	2.97	2.0	5.0	0.4	2.49	46	15	8	0.07	0.36	UNB Bara:UNP Parsa
UNP-04	Ranigang	5.90	45.7	35.7	5.5	S	2.48	3.1	4.9	0.6	1.59	72	156	13	0.11	0.56	All UNP STWs by manual methods:
UNP-05	Ramnagar	5.90	41.2	42.1	3.6	S	3.53	2.2	5.5	0.4	2.48	46	34	13	0.11	0.61	20 by THokuwa,5 sludge. Site
UNP-06	Inarawa	5.90	45.7	35.7	5.5	S	3.25	3.7	1.6	2.4	0.42	272	126	49	0.43	0.67	supervision by GWRDB hydrogeol+
UNP-07	Chiljhapti	5.90	44.2	40.2	5.5	GS	1.64	1.8	5.7	0.3	3.15	36	70	7	0.06	0.33	junior hydrogeol
UNP-08	Bajnari	5.90	36.6	38.7	5.5	S	2.85	6.5	5.6	1.2	0.85	134	736	24	0.21	1.18	S =0.0001
UNP-09	chormi	6.90	42.7	28.5	8.1	GS	2.89	0.0	0.0								Fluctuation of discharge
UNP-10	Pokhara	6.90	45.7	35.1	7.6	GS	2.09	8.0	5.1	1.6	0.64	179	322	24	0.21	1.05	S =0.00016
UNP-11	Bhauri	6.90	16.8	43.3	2.4	S	4.07	1.0	3.1	0.3	3.12	37	83	15	0.13	0.42	
UNP-12	Nichuta	6.90	41.2	11.3	5.5	G	2.56	4.0	5.7	0.7	1.43	80	4	14	0.13	0.73	
UNP-13	Bairiya	6.90	45.7	37.8	3.4	S	2.64	1.1	4.8	0.2	4.32	26	195	8	0.07	0.32	
UNP-14	Kataiya	6.90	41.2	40.2	5.5	S	3.20	0.0	0.0								Poor discharge
UNP-15	Murali	6.90	41.2	35.7	5.5	S	2.44	1.0	6.0	0.2	6.00	19	121	3	0.03	0.18	
UNP-16	Sripur	6.90	17.8	35.7	5.5	S	9.50	0.0	0.0								Poor discharge
UNP-17	Pandeypur	6.90	15.5	12.3	5.5	SG	2.06	10.0	6.1	1.6	0.61	186	611	34	0.30	1.82	S =0.0000006
UNP-18	Hardaspur	6.90	15.5	13.1	2.4	GS	3.32	0.0	0.0								
UNP-19	Masjidwa	6.90	10.6	10.0	5.5	GS	3.22	2.0	4.5	0.4	2.24	51	36	9	0.08	0.36	
UNP-20	Subarnapur	6.90	14.6	5.1	5.5	GS	3.20	17.3	2.9	5.9	0.17	676	481	123	1.08	3.15	S =0.00049
UNP-21	Malebasoi	6.90	10.6	9.1	5.5	GS	3.88	18.0	2.8	6.4	0.16	725	628	132	1.16	3.27	
UNP-22	Sedwa	6.90	21.6	5.1	5.5	GS	1.43	18.0	2.2	8.2	0.12	937	912	170	1.49	3.27	S =0.0000053
UNP-23	Paterwa	6.90	13.4	16.1	5.5	GS	1.55	18.0	4.2	4.3	0.23	491	1 002	89	0.78	3.27	
UNP-24	Sidhapur	6.90	18.9	7.9	5.5	GS	1.98	18.0	2.9	6.1	0.16	701	1 221	127	1.12	3.27	
UNP-25	Bahimar	7.90	45.7	13.4	5.5	GD	5.48	0.0	0.0								No pumptest;low discharge.
(b) Bara District																	
UNB-01	Chatapipra	1.90	44.8	38.7	7.0	GS	1.31	17.0	4.8	3.5	0.28	401	938	57	0.50	2.43	S =0.0011
UNB-02	Pheta	1.90	50.3	36.6	9.2	SG	4.30	10.0	2.2	4.6	0.22	526	461	57	0.50	1.09	
UNB-03	Simra	1.90	42.7	42.1	8.2	GS	10.30	0.0	0.0								
UNB-04	Matiarwa	1.90	42.6	31.7	11.0	SG	3.49	12.0	0.2	66.7	0.02	7 603	728	691	6.06	1.09	S =0.002
UNB-05	Bariyarpur	1.90	45.7	37.1	5.5	SG	3.72	7.0	0.4	17.1	0.06	1 947	648	354	3.10	1.27	S =0.000000018
UNB-06	Kabahigoth	1.90	45.7	37.2	8.5	SG	2.97	10.0	2.9	3.4	0.29	393	531	46	0.41	1.18	S =0.00012
UNB-07	Khesraul	1.90	16.6	39.7	6.0	G	4.00	11.0	1.0	10.8	0.09	1 230	1 000	205	1.80	1.83	S =0.00027
UNB-08	Kudawa	2.90	23.2	11.1	5.5	GS	5.70	7.0	2.8	2.5	0.39	289	300	53	0.46	1.27	
UNB-09	Badharwa	2.90	43.3	17.1	6.1	SG	2.66	16.0	0.6	26.7	0.04	3 041	1 750	499	4.37	2.62	
UNb-10	Bodhban	2.90	19.8	34.2	9.1	GS	2.49	20.0	4.3	4.6	0.22	529	738	58	0.51	2.20	S =0.0017
UNB-11	Kolvi	2.90	45.7	13.7	6.1	GS	2.98	14.0	0.3	51.9	0.02	5 914	7 000	969	8.50	2.30	
UNB-12	Bairiya	2.90	47.0	40.2	5.5	S	3.50	0.0	0.0								Fluctuation of W/L
UNB-13	Paterwa	2.90	41.8	41.5	5.5	GS	3.45	5.0	5.0	1.0	1.00	114	250	21	0.18	0.91	
UNB-14	Nijgarh	3.90	13.1	34.4	6.9	GS	15.90	0.0	0.0								
UNB-15	Bishanpurwa	3.90	46.7	10.1	3.0	S	4.19	6.0	4.0	1.5	0.67	171	300	57	0.50	2.00	S =0.00042
UNB-16	Pathalaiya	3.90	26.2	43.4	3.0	GS	17.80	22.0	4.7	4.7	0.21	536	2 200	179	1.57	7.33	
UNB-17	Umjan	3.90	47.0	20.7	5.5	SG	1.20	0.0	0.0								Fluctuation of W/L
UNB-18	Lautan	3.90	41.2	41.5	5.5	S	2.50	2.0	3.6	0.6	1.81	63	100	11	0.10	0.36	
UNB-19	Bisrampur	3.90	39.6	35.7	5.5	S	4.77	1.0	2.9	0.3	2.94	39	20	7	0.06	0.18	
UNB-20	Bijarpur Tora	3.90	35.1	28.0	11.6	GS	2.01	25.0	4.2	6.0	0.17	687	1 500	59	0.52	2.16	S =0.000097
UNB-21	Surahi	3.90	45.7	29.6	5.5	G	2.30		0.0								
UNB-22	Simraumagarh	3.90	16.6	40.2	5.5	S	3.51	8.0	5.1	1.6	0.63	180	300	33	0.29	1.45	S =0.00094
UNB-23	Parwanipur	7.90	42.7	11.1	5.5	GS	5.13	12.2	2.2	5.5	0.18	627	830	114	1.00	2.22	
UNB-24	Maihariya	7.90	41.7	35.1	7.6	SG	3.18	10.0	4.6	2.2	0.45	251	620	33	0.29	1.32	
UNB-25	Mahendra Nagar	7.90		30.7	11.0	S	2.64	8.3	5.5	1.5	0.66	174	530	16	0.14	0.75	
	50 no		34.8	29.0	6.0			7.6		6.5	1.07	742	715	111	0.97	1.57	

Table II.5 : Shallow Tube Well Data, Morang and Jhapa; UNDP/GWRDP Programme

TW nr	Location village	Drill date	Depth drilled (m)	Casing length (m)	Screen length (m)	Aquifer litho	SWL (m)	DWL (m)	Q (l/s)	DD (m)	SC (l/s/m)	SD (m/l/s)	Kd [Logan] (m2/day)	Kd [Nk] (m2/day)	K screen (m/d)	SC/m screen (l/s/m2)	Q/m screen (l/s/m)
Morang District																	
UN 01	Biratnagar		30.5		9.4	GS	0.28	3.28	23.0	3.0	7.67	0.13	874.4		93.0	0.82	2.45
UN 02	Sikiyahi	10.88	38.1		14.6	S	2.60	5.77	18.5	3.2	5.84	0.17	665.6		45.6	0.40	1.27
UN 03	Pothiyai	10.88	36.6		3.0	SG	1.41	6.98	4.5	5.6	0.81	1.24	92.1		30.7	0.27	1.50
UN 04	Karsiya	10.88	36.6		3.1	S	1.10	5.82	10.0	4.7	2.12	0.47	241.6		77.9	0.68	3.23
UN 05	Majhare	1.89	39.6		6.1	SG	2.72	7.21	5.0	4.5	1.11	0.90	127.0		20.8	0.18	0.82
UN 06	Thalaha	1.89	40.2		4.6	SG	1.56	8.40	5.0	6.8	0.73	1.37	83.4		18.1	0.16	1.09
UN 07	Darbesha	1.89	40.2		6.1	SG											
UN 08	Kaseni	1.89	16.8		3.1	SG											
UN 09	Surat	1.89	41.2		6.1	SG	2.10	4.21	20.0	2.1	9.48	0.11	1081.0		177.2	1.55	3.28
UN 10	Kureli	1.89	35.1		5.2	S	2.73	8.17	6.2	5.4	1.14	0.88	130.0		25.0	0.22	1.19
UN 11	Gobindapur	1.89	30.5		5.6	SG	1.71	6.54	14.0	4.8	2.90	0.35	330.6		59.0	0.52	2.50
UN 12	Pothari	1.89	40.5		5.5	SG	3.17	7.57	11.0	4.4	2.50	0.40	285.1		51.8	0.45	2.00
UN 13	Urlabari	3.89	15.2		3.1	G											
UN 14	Daleli	5.89	28.3		5.9	G											
UN 15	Karoon	6.89	30.5		5.7	SG	2.57	8.58	10.0	6.0	1.66	0.60	189.8		33.3	0.29	1.75
UN 16	Kanepokhari	7.89	24.3		6.3	G	6.56	8.31	6.0	1.8	3.43	0.29	391.0		62.1	0.54	0.95
UN 17	Baijnathpur		43.6		6.2	SG											
UN 18	Salakpur	7.89	27.4		6.3	G	2.60	7.58	4.0	5.0	0.80	1.25	91.6		14.5	0.13	0.63
	Average		33.1						7.6		2.68	0.48	269.6		41.7	0.37	1.33
Jhapa District																	
UN 01	Prithvinagar		35.1		9.2	GS											
UN 02	Maheshpur	3.89	21.3		5.8	GS	0.51	8.02	7.5	7.5	1.00	1.00	113.9		19.6	0.17	1.29
UN 03	Gherabari	3.89	29.9		6.1	SG											
UN 04	Phulbari	3.89	16.8		4.7	GS	2.32	6.90	15.0	4.6	3.28	0.31	373.5		79.5	0.70	3.19
UN 05	Lakhanpur	6.89	15.2		3.2	GS	2.56	8.51	8.7	6.0	1.46	0.68	166.8		52.1	0.46	2.72
UN 06	Sitapuri	6.89	27.4		3.0	GS	0.62										
UN 07	Kankai	6.89	43.9		10.2	G	6.70	8.19	8.3	1.5	5.57	0.18	635.3		62.3	0.55	0.81
UN 08	Gwaldubba	6.89	36.6		6.2	S	0.77	1.49	6.0	0.7	8.33	0.12	950.4		153.3	1.34	0.97
UN 09	Kukkagachhi	6.89	35.1		7.3	S											
UN 10	Keradhap	6.89	36.6		7.6	SG											
UN 11	Duttabari	6.89	38.1		9.1	GS	2.95	3.56	20.0	0.6	32.79	0.03	3739.3		410.9	3.60	2.20
UN 12	Satashi	6.89	34.8		6.2	S	0.58	0.99	4.0	0.4	9.76	0.10	1112.7		179.5	1.57	0.65
UN 13	Bareghare	6.89	25.9		6.1	G											
UN 14	Sangambasti	6.89	36.6		6.0	SG	0.37	8.78	5.4	8.4	0.64	1.56	73.2		12.2	0.11	0.90
UN 15	Panchgachhi	6.89	35.1		6.2	SG	1.57	7.20	8.0	5.6	1.42	0.70	162.1		26.1	0.23	1.29
UN 16	Ghailadubba	6.89	38.1		6.0	G	0.08	8.64	10.3	8.6	1.20	0.83	137.2		22.9	0.20	1.72
UN 17	Satigatta	7.89	32.0		9.3	G	1.73	8.00	3.0	6.3	0.48	2.09	54.6		5.9	0.05	0.32
UN 18	Gaurigunj	7.89	27.4		4.6	S											
UN 19	Godldhap-4	1.90	29.0		9.0	SG	1.20	6.12	12.0	4.9	2.44	0.41	278.2		30.9	0.27	1.33
	Average		31.3						6.0	3.1	3.80	0.45	433.2		58.6	0.51	0.97

APPENDIX III

1993 SHALLOW TUBEWELL SURVEY: WELL CONSRUCTION DATA

Table III.1 : 1993 Shallow Tubewell Survey; Well Construction Data File : V3-TIII-1.wk1 17-Dec-93

Nr	District	Well type	Depth (ft)	Casing (ft)	Screen (ft)	Cdiam (ins)	Sdiam (ins)	Pump install time (days)	Delay reason *	Year	Method	Driller	Fluid	Pump manufacturer	Country**	Diesel/ electric	Artes flow	Engine HP	Outlet (ins)
1	Chitwan	S	35	25.0	10.0	4	4	15		2044	Man	Project	Water	Usha	I	D	N	5.0	4.0
2	Chitwan	D	19	15.0	0.0	40	0	11		2044	Man	Private	Water	Kilsokar	I	D	N	7.0	4.0
3	Chitwan	D	19	11.0	8.0	45		6		2040	Man	Private		Usha	I	D	N	5.0	3.0
4	Chitwan	S	30	20.0	10.0	4	4	8		2043	Man	Private	Mud		I	D	N	5.0	4.0
5	Chitwan	D	24	24.0	0.0	42	0	20	L	2048	Man	Private	Water	Kilsokar	I	D	N	7.0	4.0
6	Chitwan	S	26	26.0		4	4	8		2049	Man	Private	Mud	Crompton	I	E	N	1.5	1.5
7	Chitwan	S	45	35.0	10.0	4	4	5		2043	Man	Private	Mud	Wilson	I	D	N	5.0	4.0
8	Chitwan	S	40	30.0	10.0	4	4	12		2043	Man	Private	Mud	Usha	I	D	N	8.0	4.0
9	Kailali	S	47	37.0	10.0	4	4	4		2046	Man	Private	Mud	Usha	I	D	N	5.0	4.0
10	Kailali	S	65	55.0	10.0	4	4	7		2038	Man	Private	Mud	Usha	I	D	N	5.0	2.5
11	Kailali	S	45	35.0	10.0	4	4	15		2046	Man	Private	Mud	Kilsokar	I	D	N	7.0	4.0
12	Kailali	S	50	40.0	10.0	4	4	3		2044	Man	Private	Mud	Kilsokar	I	D	N	5.0	3.5
13	Kailali	S	4	30.0	10.0	4	4	4		2050	Man	Project	Water	Kilsokar	I	D	N	8.0	3.0
14	Kailali	S	40	30.0	10.0	4	4	2		2040		Private	Mud	Bharat Shakı	I	D	N	8.0	3.5
15	Kailali	S	58	48.0	10.0	4	4	15	B	2038	Man	Private	Water	Kilsokar	I	D	N	7.5	4.0
16	Kailali	S	75	65.0	10.0	4	4	5		2044	Man	Private	Mud	Kilsokar	I	D	N	7.5	3.5
17	Kailali	S	57	47.0	10.0	4	4	7		2041	Man	Private	Mud	Usha	I	D	N	5.0	3.3
18	Kailali	S	65	55.0	10.0	4	4	3		2044	Man	Private	Mud	Usha	I	D	N	5.0	3.3
19	Banke	M	200	180.0	20.0	4	4	28		2046	Rig	Private	Water	Narayani Kil	N	D	N	7.5	4.0
20	Banke	S	25	16.0	9.0	2	2	1		2044	Man	Private	Water	Gremyotom	I	E	N	1.0	1.0
21	Bardiya	S	60	35.0	25.0	4	4	6		2047	Man	Private	Water	Narayani Kil	N	D	N	7.5	3.0
22	Banke	S	65	47.0	18.0	4	4			2048	Man	Private	Water	Bharat Shakı	I	D	N	8.0	2.8
23	Banke	S	35	25.0	10.0	4	4			2049	Man		Water	Kilsokar	I	D	N	7.5	4.0
24	Banke	S	50	30.0	20.0	4	4	3		2040	Man	Project	Water	Usha	I	D	N	6.5	2.5
25	Banke	S	46	36.0	10.0	4	4	5		2048	Man	Private	Water	Kilsokar	I	D	N	7.5	2.8
26	Banke	S	40	30.0	10.0	4	4	5		2044	Man	Private	Mud	Ajit	I	D	N	7.0	3.0
27	Dang	S	35	25.0	10.0	4	4	4		2040	Man	Private	Water	Kilsokar	I	D	N	5.0	3.5
28	Dang	S	60	50.0	10.0	4	4	5		2045	Man	Project	Water	Kilsokar	I	D	N	5.0	3.5
29	Dang	S	25	20.0	5.0	4	4	1		2048	Man	Private	Water	Kilsokar	I	D	N	7.0	3.5
30	Dang	S				4	4	12		2047	Rig	Project	Mud	Narayani Kil	N	D	N	7.5	3.5
31	Dang	T	296	'147.6	147.6	6	6	24		2048	Rig	Project	Water			E	N		3.0
32	Dang	S	35	25.0	10.0	4	4	5	C	2042	Man	Private	Mud	Kilsokar	I	D	N	7.5	4.0
33	Dang	S	50	40.0	10.0	4	4	4		2049	Rig	Private	Water	Kilsokar	I	D	N	5.0	3.0
34	Kapilvastu	S	110	100.0	10.0	4	4	8		2049	Rig	Private	Water	Kilsokar	I	D	N	5.0	
35	Kapilvastu	S	135	120.0	15.0	4	4	19		2049	Rig	Project	Water	Kilsokar	I	D	N	7.0	
36	Kapilvastu	S	45	25.0	20.0	4	4	2		2046	Man	Project	Water	Bharat Shakı	I	D	N	8.0	
37	Rupendehi	S	40	30.0	10.0	4	4	3		2047	Man	Private	Water	Kilsokar	I	D	N	7.0	
38	Rupendehi	S	40	30.0	10.0	4	4	3		2048	Man	Project	Water	Narayani Kil	N	D	N	7.5	2.5
39	Rupendehi	S	40	25.0	15.0	4	4	3.5		2049	Man	Private	Water	Narayani Kil	N	D	N	7.5	3.0
40	Rupendehi	S	13	101.0	24.0	4	4	7		2024	Man	Private	Mud	Ajit	I	D	N	8.0	2.5

Table III.1 : 1993 Shallow Tubewell Survey; Well Construction Data

File : V3-TIII-1.wk1 — 17-Dec-93

Nr District	Well type	Depth (ft)	Casing (ft)	Screen (ft)	Cdiam (ins)	Sdiam (ins)	Pump install time (days)	Delay reason *	Year	Method	Driller	Fluid	Pump manufacturer	Country**	Diesel/ electric	Artes flow	Engine HP	Outlet (ins)
41 Rupendehi	S	35	25.0	10.0	4	4	8		2049	Man	Private	Water	Narayani Kil	N	D	N	7.5	2.5
42 Jhapa	S	110	60.0	50.0	4	4	5		2046	Man	Private	Water	Kilsokar	I	D	N	7.0	2.5
43 Jhapa	S	40	20.0	20.0	4	4	2		2048	Man	Private	Water	Narayani Kil	N	D	N	7.0	3.5
44 Jhapa	D	15	14.5	0.0	36	36	10		2040	Man	Private		Usha	I	D	N	5.0	3.5
45 Jhapa	S	44	20.0	24.0	4	4	5		2028	Man	Private	Water	Kilsokar	I	D	N	5.0	2.5
46 Jhapa	S	48	28.0	20.0	4	4	8		2045	Man	Private	Water	Usha	I	D	N	6.5	3.5
47 Sunsari	S	70	30.0	40.0	4	4	12		2045	Man	Private	Water	Kilsokar	I	D	N	5.0	3.5
48 Siraha	S	70	35.0	35.0	4	4	6		2032	Man	Private	Water	Kilsokar	I	D	N	5.0	
49 Dhanusha	S	54	27.0	27.0	4	4	2		2049	Man	Private	Water	Kilsokar	I	D	N	5.0	2.5
50 Dhanusha	S	60	42.0	18.0	4	4	4		2042	Man	Private	Water	Kilsokar	I	D	Y	5.0	
51 Sarlahi	S	70	40.0	30.0	4	4	9		2040	Man	Private	Water	Yanmar	J	D	N	5.0	
52 Sarlahi	S	100	70.0	30.0	4	4	2		2045	Rig	Private	Water	Bharat Shakt	I	D	N	5.0	
53 Sarlahi	D	21	21.0	0.0	36	0	15		2047	Man	Private	Water	Usha	I	D	N	5.0	
54 Sarlahi	S	65	45.0	20.0	4	4	2		2042	Rig	Private	Water	Yanmar	J	D	N	5.0	
55 Rautahat	S	40	20.0	20.0	4	4	2		2042	Man	Private	Water	Kilsokar	I	D	N	7.0	2.5
56 Parsa	S	40	20.0	20.0	4	4	7		2042	Man	Private	Water	Kilsokar	I	D	N	5.0	
57 Parsa	S	60	40.0	20.0	4	4	1		2048	Man	Private	Mud	Narayani Kil	N	D	N	7.0	2.0
58 Parsa	S	40	25.0	15.0	4	4	7		2042	Man	Private	Water	Kilsokar	I	D	N	5.0	
59 Parsa	S	45	20.0	25.0	4	4	2		2047	Man	Private	Water	Bharat Shakt	I	D	N	5.0	2.0
60 Parsa	S	280	200.0	80.0	4	4	12		2041	Rig	Private	Water	Usha	I	D	N	6.0	2.5
61 Bara	S	71	35.0	36.0	4	4	15		2043	Man	Private	Water	Bharat Shakt	I	D	N	5.0	2.3
S.1 Chitwan	S								2044				Ajit	I	D	N	6.5	
S.2 Chitwan	S	50			5	5	11	C	2044	Man	Private	Water	Usha	I	D	N	6.5	4.0
S.3 Chitwan	D	30			36	36	15			Man	Private	Water	Kiloskar	I	D	N	5.0	
S.4 Rupandehi		35	20.0	15.0	4	4			2047	Man	Private	Water	Bharat Shakt	I	D	N	7.0	
S.5 Kapilvastu	S							C	2047	Man	Private	Water						
S.6 Kapilvastu	S	148	108.2	39.4	4	4	2 Yrs	S	2048	Rig	Project	Mud	Kiloskar	I	D	N	6.0	2.0
S.7 Dang	S						5		2046	Rig	Project	Mud	Kiloskar	I	D	N	7.5	4.0
S.8 Dang	S	35	25.0	10.0	4	4	0.5		2044	Man	Private		Kiloskar	I	D	N	5.0	4.0
S.9 Dang	S	45	38.0	7.0	4	4	5		2044	Man	Private		Kiloskar	I	D	N	5.0	4.0
S.10 Dang	S	45	35.0	10.0	4	4	11		2045	Man	Private		Bharat Shakt	I	D	N	7.0	4.0
S.11 Dang	S	30	20.0	10.0	4	4	6		2043	Man	Private		Kiloskar	I	D	N	5.0	4.0
S.13 Banke	s	53	43.0	10.0	4	4	10		2046	Man	Private		Narayani Kil	N	D	N	7.0	4.0
S.14 Banke	s	43	33.0	10.0	4	4	4		2042	Man	Project	Water	Usha	I	D	N		4.0
D.1 Rupandehi	D	381			6	6	2 Yrs		2042	Rig	Project	Water	PS 40	I	E	N	75 kw	
D.2 Rupandehi	D	361							2037	Rig	Project		Kiloskar	I	E	N	75 kw	
D.3 Nawalparasi	D	390	272.2	118.0	6	6	45		2046	Rig	Project		VT	J	D	N		

Notes : * L = Loan adminstration; B = Bureaucratic; C = Contractor delay; S = Material shortage
** I = India; N = Nepal; J = Japan

APPENDIX IV

SUMMARY OF INTERVIEWS WITH STW DRILLING CONTRACTORS

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Table IV.1 : Summary of Interviews with Drilling Contractors

Nr	Location	Contractor Name	Target	Method	Drilling diameter [in]	Gravel pack	Drilling fluid	Drilling problem	Drill time for 15 m [day]	Drill time for 40 m [day]	Sample	Supervise	Screen source	Screen type	Screen choice
1	Chitwan: Amrit Magar	Bhakta Bahadur Vishowkarma	sufficient sand, gravel	Thokuwa hammer	4	no	dung	congl. boulder	5-7	12-15	no	none	ADBN	MS:drill slot pipe	None;
2	Chitwan: Sukra Nagar	Raju Sunwar	sufficient sand,grav	Thokuwa hammer	4	no	dung	congl. boulder. dung used in fs	4-7	10-15	no	none	ADBN	MS:drill slot pipe	None;
3	Rupandehi: Hati Bangai	Mustafa Musalman	sufficient sand,grav	Sludge	1.5,3,5	only in fs	dung, clay, water	boulders, dung used as binder	3	10	yes, self	none	market	MS:rope or nylon mesh wrap on drilled slot pipe	based on fm size;contractor judgement
4	Nawalparasi: Germi	Fulhare Chamar	sufficient sand,grav	Sludge [Dhikuli]	4,6		water	boulder	5	-	self	none	ADBN	rope or nylon mesh wrap on rod base pipe	fm size;
5	Kapilvastu: Motipur	[Finnida] Ram Sunder Prajapati	sufficient sand,grav in 40m	machine perc.	6-8	if fs or clay	bentonite	boulder	10	-	self	Snr driller, Finnida	Finnida	MS,1.5mm slot	Finnida+ contractor; based on fm size
6	Dang-Deukheri Lamahi, Arjun Kola	Ram Sunder Prajapati	sufficient sand-grav, up to client depth limit	machine perc. [Speedstar]	4,6in, 95/8in	yes	bent+ barite	boulder	5	7	self	client engineer+ contractor	market	MS slotted pipe;brass net wrap	based on fm size, availability

Table IV.1 : Summary of Interviews with Drilling Contractors

Nr	Devt. time [hour]	Devt method	Drilling costs [NRs] for final depth: 25-35'	35-60'	60-100'	Screen Blockage	Comment
1	8	manual pump	2000	2500	3000	nr	Some sand ingress reported. Inflexibility in pipe slot size, and 1 aperture only used in Chitwan. Development or development revisits to meet 6 l/s ADBN criteria only. No routine development used.
2	8-12	manual pump	2000	2500	3000	nr	Some sand ingress reported. Contractor develops well even if only water used in drilling. Within one year maintenance period will redevelop, else redrill/ reinstall at own cost. Otherwise farmer pays for redevelopment. Sand ingress ascribed to aperture size and irregular operation of well. "Hard work and low pay. Risk should not be borne by contractor."
3	6-24	cent. pump	ADBN Rs 35/ft;farmer gives Rs300+food. Private:Rs35/ft +labour charge Pipe/screen supply from ADBN else private purchase				Allow two inch annular space for gravel pack; pea size gravel. Pack used if find sand cannot be controlled by net/coir wrap. Pack added by pouring; Developing time depends on turbidity or sand. Contractor has to redrill if discharge low. Thinks slot blockage by rust,sand. Probably needs more flexibility with slot size. Mentions low rates; "we are supported by farmers food". Report that some contractors blacklisted. Some sand ingress reported;
4	2-3	cent. pump; water	Rs 35/ft	-	-		Course sand pack with two inch annular space. If problems, ADBN staff supervise. Uses nylon for Course sand, rope wrap for fine sand. Prefers locally available nylon rope wrap screen. Some sand ingress reported; said to be caused by screen slot size.
5	12	pump-wash through else compressor	Rs 2500/m [8in], Rs 2000/m[6in] in boulder fm [inc drill,dev, install]			some mud block	Finnida sponsored contractor. If pack used, four inch casing and 8 inch bore. Finds 1.5 and 3 mm slot useful. Uses two to eight mm pack in find sand or clay to stop caving. No pack used if water drilled. Routine developed by pumped wash water and air jetting if necessary. Contractor believes screen block by rust. Also reported screen collapse because of poor verticality and strength loss by rusting. No responsibility after handover. Development Rs 1 500 /h (compressor).
6	12	bailing,air surge, back wash, compressor	general: Rs2500/m 4in Rs3000/m 6in Rs3500/m 8in inc drill,dev Estimates Rs 55000 for 60ft well; Rs140000 for 100ft			some mud block;also fs,rust block	Four inch gravel pack annulus. Finds 1.5 and 3 mm slot useful. Pack used to stop fines ingress; use routinely. 70 mm annular space for pack; 4 to 6 mm pack. If low discharge, redevelops otherwise redrills well. Thinks that find sand entry is because no proper gravel pack is used. Mentioned failure by pipe rust reduced slot strength.

Table IV.1 : Summary of Interviews with Drilling Contractors

Nr	Location	Contractor Name	Target	Method	Drilling diameter [in]	Gravel pack	Drilling fluid	Drilling problem	Drill time for 15 m [day]	Drill time for 40 m [day]	Sample	Supervise	Screen source	Screen type	Screen choice
7	Banke: Nepalganj, Phultekra	Suresh Bahadur [uses two methods]	sufficient sand-grav	Sludge [Dhikuli]	4	used with water	water some dung		1-5	-	self	ADBN	ADBN	MS slot pipe	based on fm size,
				Thokuwa	4	no	water				no	ADBN		MS perf pipe	
8	Banke: Nepalganj Parapur	Ram Kishan Sonakthar	sufficient sand/grav	sludge	3-6	yes	water+ dung		3-4	-	yes	ADBN	market [ADBN coupon]	slotted screen	fm size
9	Dhangardi [ILC prog under GWRDB]	Munir Khan [can use several drilling methods]	sufficient sand/grav	sludge	2,3,4in; [3-6in ream]	yes	water, dung	boulder	5	-	yes	self?	market	MS/rope or coir wrap on steel rod [fs fm.] Else slotted pipe	based on fm size; availability
9	Dhangardi [ILC prog under GWRDB] Jhangatpur	Ganga Ram Urao [can use several drilling methods]	adeq sand +grav	Thokuwa	4	no	none	boulder	4	-	self	client farmer!	market; perf. at workshop	MS drilled slot 3mm,6mm	fm size
10	Deukheri Gangaparaspur	Nain Bahadur Pun	adeq sand +grav	Thokuwa	4	no	none		4-5	-	self, during washing	none	ADBN	MS slotted pipe	availability in ADBN stock

Table IV.1 : Summary of Interviews with Drilling Contractors

Nr	Devt. time [hour]	Devt method	Drilling costs [NRs] for final depth: 25-35'	35-60'	60-100'	Screen Blockage	Comment
7	0.5 3-4	hand	Rs30/ft Rs50/ft above 100ft				1.6 mm slot used. Pack used for find sand and only with waterflush drilling. Uses 4 inch annular space and 2 to 8 mm grading. Contractor may have to redrill if low discharge overwise redevelop if farmer has sand ingress. Some slot collapse for Thokuwa; rare for sludge. Screen cost Rs 160/ft and casing Rs 55/ft.
8	9	manual pump	general: up to depth: 80-90ft Rs25/ftADBN 80-90ft Rs25/ftPRIV >90ft Rs32/ft screen: Rs 200/ft[local fab.] csg 255/ft[MS] STW cost say Rs 15000 for 15m STW				4 inch annular space over pack; pack 2 to 8 mm. 1.5 mm slot usual. Gravel pack used in Nepalganj area else problems. If farmer says discharge too low then contractor attempts to compromise, otherwise casing may pull out. Fine sand problems, contractor may have to redevelop.
9	5-8	cent pump; bailing	- screen:Rs334/ft[MS] csg:Rs223/ft[MS] Dev:Rs1500/well Total for drill,dev,csg-scr: STW td15m Rs25000 STW td40 Rs55-60000	Rs55/ft	Rs75/ft		Uses mud in deeper layers? 50 mm annulus with pack. Can drill 100 m rotary, 40 m bogi and pressure sludge. Thinks 3 mm and 6 mm most useful in area. Gravel pack used if fines encountered. Pack has 2 inch annulus. Pack grading bigger than slot size. Sand ingress common; contractor ascribes this to short pumping, fuel saving and no proper supervsion. Contractor responsible for well for 6 months. Other general contractor comments: - contractors are 'in loss,and are at risk. - ADBN, GWRDB cost estimations are not satisfactory and no proper supervision and maintenance of STW. - Should be managed by goverment.
9	5-8	sludge action in csg-scr; with water +dung	- screen:Rs334/ft csg:Rs223/ft Dev:Rs1500/well Total for drill,dev,csg-scr: STW td15m Rs25000 STW td40 Rs55-60000	Rs55/ft	Rs75/ft	fs	Works for ILC under GWRDB? Agreement between contractor and GWRDB. Agreement based on price and yield and subject to yield approval by farmer else redrill or redevelop. Contractor thinks that sand problems because "no proper operation" and also fine formation. Some pipe collapse on hammering in boulders. Prices as last contractor (ILC).
10	8	water wash cent pump	2150	3000	-	None	Receives Rs 3 000 on well completion. Contractor has to give one year guarantee after full payment. Few drilling problems. Works on ADBN unit rate basis for drilling, installing and developir

Table IV.1 : Summary of Interviews with Drilling Contractors

File : V3-TIV-1.wk1

Nr	Location	Contractor Name	Target	Method	Drilling diameter [in]	Gravel pack	Drilling fluid	Drilling problem	Drill time for 15 m [day]	Drill time for 40 m [day]	Sample	Supervise	Screen source	Screen type	Screen choice
11	Motipur	Ram Sunder Prajapati	Finnida give price/yield target;Dev decides depth; 30-40m typ.	machine perc [PIlcon or Speedstar]	6-8	yes	bentonite	boulder, mud loss	10 [120hrs]	-	yes	Snr driller +Finnida	Finnida	MS slotted 1.5mm	Finnida+ contractor; on fm size
12	Dang-Deukheri: Maurighat	Tikat Ram Chaudhari	adeq sand +grav for 3m screen	Thokuwa	4	no	none	boulder, sticky or hard clay?	2-6	-	observes only	ADBN overseer	ADBN	MS slot for fine fm.else drilled perf.	fm size
13	Banke: Bankati	Juman Shek	adeq sand +grav	Thokuwa	1.5-4 [6ream]		water	boulder	6-7	15	no	none	ADBN	MS perf pipe	avail at ADBN
14	Banke: Chapagouli Kohalpur	Sukai Balmik	sand	wash bore	1.5,4	no	water	boulder	1	-	self	no	market	Ms perf pipe for 4in STW: rope wrap in fs.Uses 2in pvc in HTW	owner choice
15	Dang: Goltakuri	Ek Raj Dangi	adeq sand +grav	Thokuwa	4	no	water	boulder	6		no	ADBN, self	ADBN	Typically, 3m perf pipe used in area	perf or slot available

Notes:

nr none reported
fs fine sand
perc percussion

perf perforated
cent centrifugal

Table IV.1 : Summary of Interviews with Drilling Contractors

Nr	Devt. time [hour]	Devt method	Drilling costs [NRs] for final depth: 25-35' 35-60' 60-100'	Screen Blockage	Comment
11	12	washout with cent; may use air compressor	Rs2500/m drill,install,dev 8in Rs2000/m drill,install,dev 6in Dev by compressor Rs1500/h MS csg,5.4mm wall Rs500/m slotting[local] Rs305/m		Typically 8 inch bore for 4 inch casing. Thinks 1.5 mm and 3 mm screen useful. Gravelpack used to stabilise formation in fine sand or clay. (How effective are the development/tools?) Redevelop/redrilling depends on Finnida decision. Some sand ingress; contractor ascribes this to poor development, incorrect screen placment or rust (slot). Some screen collapse ascribed to rust, nonvert pipe.
12	2-8	cent pump	Cost to drill,case,install,dev: 30-40ft Rs3000 40-50ft Rs4000 50-60ft Rs6000[failure] 50-60ft Rs5000[sucessful] Cost to drill,install,dev: up to 40ft Rs2250 up to 50ft Rs2500 up to 60ft Rs3000	none seen	ADBN agreement : 6 l/s min. Contractor stands damage to gear or casing screen. Drilling along foothills difficult. ;may take 30 days to drill for 15 m in boulders. Technique : at each 5 ft penetration they wash and develop well and test for 6 l/s. Thinks tool damage and screen loss should be borne by ADBN.
13	0.5	water	Cost to drill,install,dev: up to 40ft Rs2000 40-45ft Rs2200 50-55ft Rs2600 Cost to drill,case,install,dev: 15m RS12000 40m RS36000	mud,sand	Uses 6 mm perforated screen and pack in fine sand 2 inch annulus. Pack material is 6 to 25 mm through tremie? Contractor mentioned fine sand problem or mud as defects causing screen collapse. ADBN keeps Rs 500 guarantee, if no farmer complaint it is received after one year.
14		none	drill,install,dev: Rs15/ft ,50ft 4in Rs20/ft ,50-60ft 4in Rs30/ft ,>60ft 4in Total cost 40ft STW RS 2100		
15	2-6	cent pump, water	Drill/dev,install cost: Rs 2150 up to 40ft Casing cost Rs160/ft screen cost Rs220/ft Cost estimate for STW:4in 40ft depth: wages Rs2150 pipe Rs 3200 screen Rs2200		Received 3 months thokuwa training in ADBN office. Thokuwa posible in this limited area. Some design flexiblity : Redevelop or redrill may be required; Some fine sand entry problems -

APPENDIX V

GROUNDWATER ENGINEERING

APPENDIX V

GROUNDWATER ENGINEERING

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APPENDIX V

GROUNDWATER ENGINEERING

V.1 General

The groundwater engineering aspects of strategy development cover several topics including the following:

- design yield
- pump type
- well configuration and hydraulic design
- borehole construction methods
- operation and maintenance
- economic optimisation

For several aspects, there is a range of solutions, some of which reflect the ideal or possible and some the present experience. The methodology adopted is to develop a series of type designs and examine the economics and optimum performance for each design over a range of parameters covering the hydrogeological properties as reviewed in Chapter 2. However, there are many aspects where the ultimate choice may be dictated by broader social and economic issues.

The choice of diesel or electric power is an example of this as described in Box V.1. It is concluded that the preferred solutions range from government operated and managed high capacity electric driven wells to small capacity diesel wells where the inherent flexibility and mobility will be more valuable to some farmers than low financial operating costs. The economic comparisons herein are restricted to direct costs.

A consistent theme in assessing design decisions is whether the choice is largely reactive being imposed by circumstances or a genuine choice because a range of options exist.

V.2 Design Yield and Well Component Diameter

Excluding shallow tubewells where yields are controlled by suction ie drawdown, a series of preferred tubewell yields exist and sometimes the designer merely selects a yield compatible with the demand. The preferred yields correspond to the maximum efficiency point for each pump bowl diameter and impeller combination. For a fixed speed motor, particularly synchronous, electric motors, the target yield is also fixed; diesel engines may be geared or governed to match a range of target yields. At medium to high lifts, three or more pump stages can be used and pump manufacturers can produce near optimal efficiency over a series of bands of discharge. For example, the nominal 12 inch bowl used in BLGWP III can satisfy a range of duties with reasonable efficiencies.

In practice the actual yield will vary between tubewells with change in specific capacity and static water level and will vary at any well due to changes with time. Farmers then accommodate sub-optimal pumping by varying the duration of pumping (for changes in yield) and incurring the extra costs (for changes in efficiency).

Box V.1 : Power Sources

Issue	Diesel	Electric
Time to commission	quick	may be slow if grid extension needed
Participation/cost sharing	costs easily shared on basis of fuel provided	best suited to flat rate charges
Fringe uses	Possible via PTO for threshing etc	unlikely
Duty matching	good since speed can be changed	fixed speed so yield may vary with time
Supply reliability	due to any inherent unreliability	may be impaired by load shedding
Maintenance	regular	few needed
Repair	often locally available	specialised
Client of institutions	not significant	NEA
Possible subsidy	difficult due to border	easy
Attendant (starting)	necessary	avoidable
Attendant (operation)	preferred	unnecessary

Table V.1 shows selected pump sizes and duties quoted in MMP (1992) Supplement 2.2/4.1 and as quoted in Nepal in recent tenders.

TABLE V.1

Pump Sizes and Duties

Speed (rpm)	Q (l/s)	H (m)	Pump bowl dia (mm)	Min casing dia (inches)
1450	20	9	191	
	30	9.1	241	
1500	10	22	-	8
	20	20	-	8
	30	20	-	9
	56	18	280	14
2200	14	18	165	8
	28	18	190	9
2900	10	24	142	8
	14	20	142	8
	20	20	166	9
	28	20	185	10
	30	27	198	10

Figure V.1 shows these data compared with the nominal limits presented in Driscoll (1986). For DTW planning, these discharge limits have to be translated into maximum internal casing diameters taking into account the usefulness of slightly greater clearance at deeper settings and larger diameters. The following combinations are recommended:

Casing nom ID	(inch)	8	10	12	14	16
Max discharge	(l/s)	15	30	45	100	>100
	(m^3/h)	50	100	150	350	

In some instances, a slight reduction in UWC diameter may be possible by switching to electric submersible pumpsets. However, operating efficiencies are usually lower especially if the total head requirement is low. In the case of the 10 inch casing particular care is needed to ensure that the nominal diameters give suitable clearance.

Criteria exist for selection of diameter of lower well casing (LWC) which includes both blank casing and well screen. AWWA/ASTM A100 recommends limiting up-hole velocity to around 1.5 m/s. MM (1992) describes how an optimum tubewell design can be evolved for certain areas of Bangladesh; the optimum 56 l/s well would have a rising velocity of around 1.7 m/s. Using the latter figure, the following apply:

LWC dia	(inch)	4	6	8	10	12
Limiting discharge	(l/s)	13	30	52	83	120
	(m^3/h)	50	108	192	300	433
Friction loss	(m/100 m)	2.7	1.9	1.2	0.9	0.7
Energy loss	(kW/100 m)	0.6	1.0	1.1	1.4	1.6

In the above, friction losses per 100 m of LWC have been calculated using standard charts for black steel pipe as shown in Driscoll (1986). For wells with a long (more than around 100 m), length of LWC and high ratio of blank to screen (more than 50:50), the effective length may be taken from the base of the UWC to the depth of the topmost 1/3 position on the wellscreen.

In tubewells with a long screen length in relation to blank casing in the LWC, the above losses do not apply since the effective roughness within the screen is substantially different from smooth black pipe.

Using a limiting velocity criteria may have economic justification since the friction loss translates into an energy loss in addition to the loss of velocity head at the UWC/LWC reducer. An energy loss of 1 kW has a present value of :

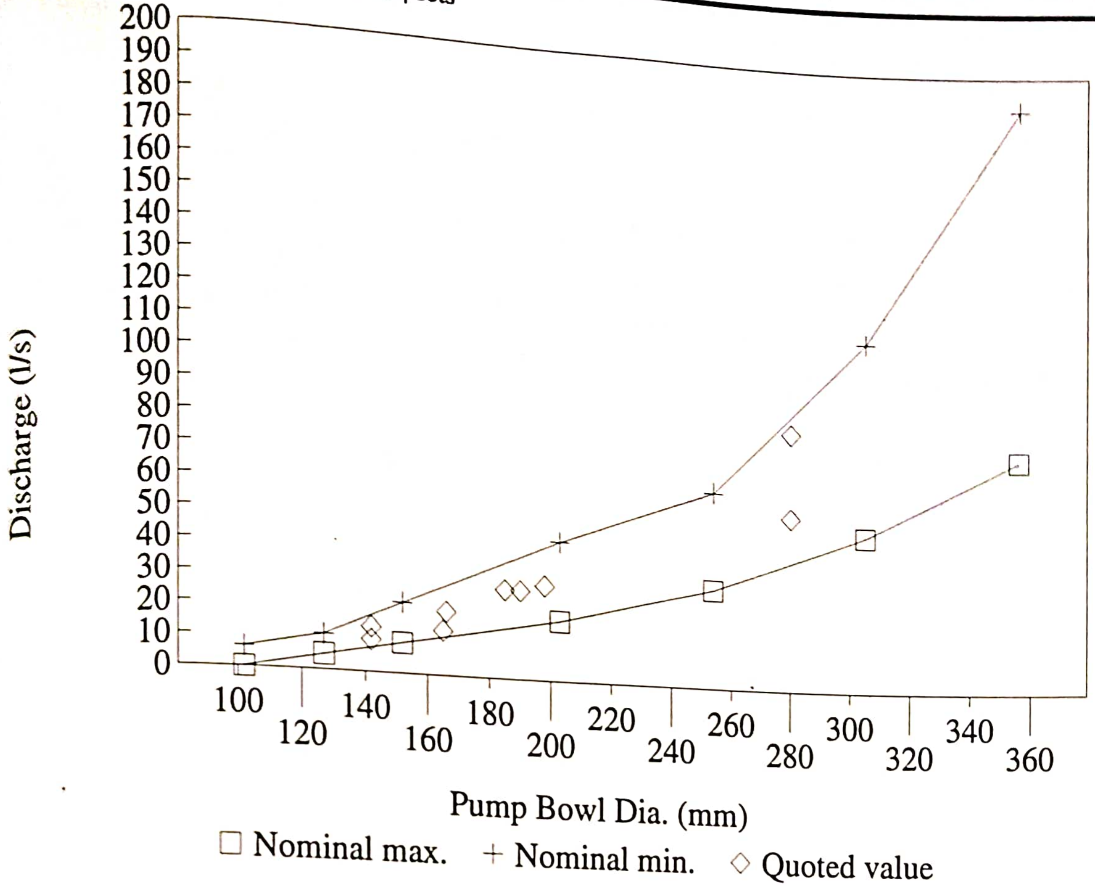
$$PV = 10.6\ ARC \quad = Rs\ 10.6 \times 1 \times 1100 \times 2.6$$
$$\approx Rs\ 30\ 000$$

for a 20 year economic life, 7% discount rate, 1 100 annual operating hours and Rs 2.6 economic marginal cost of electricity. This latter is of a similar order of magnitude to a diesel fuel cost of Rs 3.7/kWh (for Rs 12/l and 0.31 l/kWh consumption).

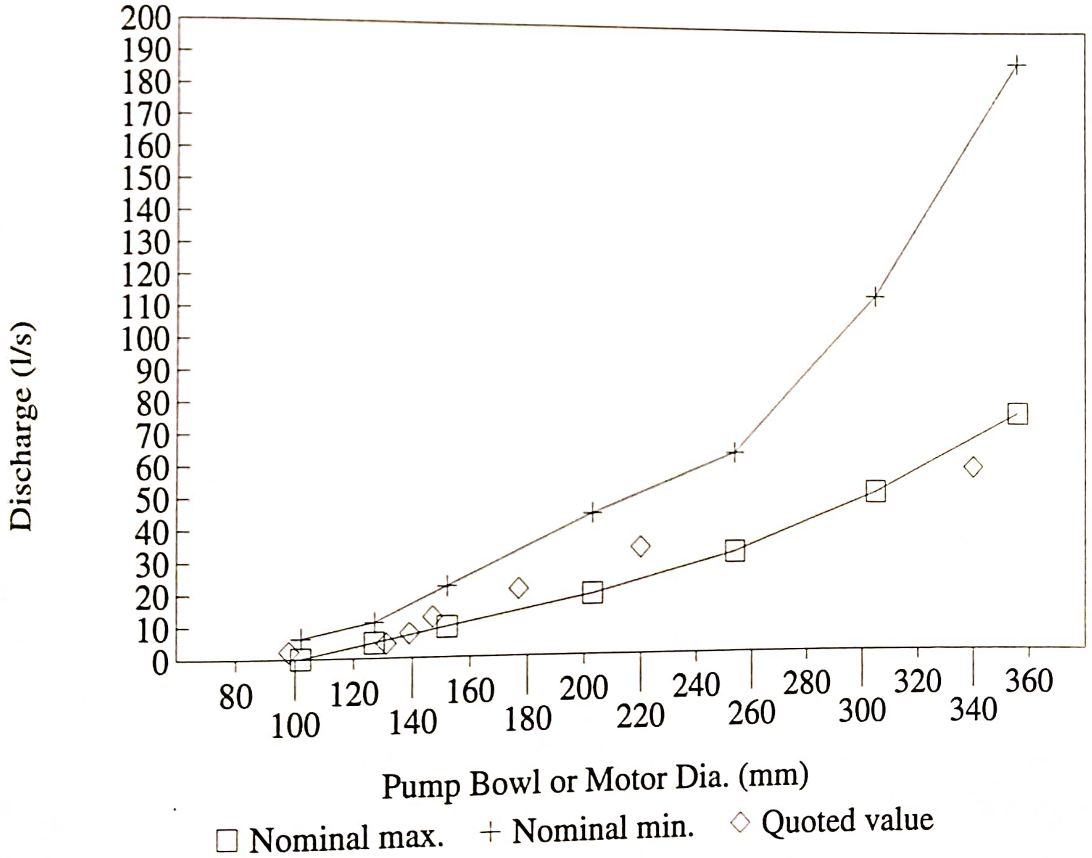
In some circumstances, particularly where total screen lengths are long, the LWC string may itself have a change in diameter. If inflow to the well is uniform across all screen sections, the upflow velocity at the midpoint of the screen will be half the design flow. A diameter reduction at the topmost 1/3 position on the screen is then unlikely to produce a significant increase in upflow losses. Although this degree of sophistication in well design should eventually be applied in Terai, the state of knowledge about the uniformity or otherwise of inflows does not permit this option to be assured of success at present.

Pump Yield and Diameter

A Quotes for Vertical Lineshaft Pumpsets



B Quotes for electric submersibles - 2900 rpm



Source: GDC, Nominal pump diameters as quoted in Driscoll (1986)

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V.3 Well Construction

V.3.1 Drilling

The actual well construction techniques adopted in Terai to date vary enormously, partly due to the range of conditions encountered and partly due to the need to utilise the plant and materials available rather than the optimum for the task. Early attempts to utilise percussion rigs or reverse circulation (RC) rigs were abandoned as well depths increased and artesian conditions were encountered.

Although percussion rigs are now developing a role for moderate diameters and depths, RC drilling is rarely used, particularly for irrigation wells and all DTW drilling is carried out by direct circulation (DC) mud flush.

Direct Circulation

The use of DC mud flush has profound implications for well design and economic optimisation since drilling costs are heavily dependent on diameter and final well performance may be also affected. The main advantage is the ability to cope with a wide range of depths and drilling conditions. Taking a base case of around 8 inch (220 mm) nom. bit diameter which is manageable with a 5x6 duplex mud pump with limited or no reaming, additional cost elements can be approximated as follows :

Bit diameter (in)	(mm)	Mud Use (%)	Time (%)	Est Cost (%)
8	(200)	100	100	100
12¼	(311)	200	200	130
14	(356)	260	300	170
17½	(445)	500	450	220
20	(508)	560	500	250

Mud drilling always involves a fine balance between sufficient up-hole vèlocity to clear cuttings (0.2 to 0.4 m/s), viscosity to lift cuttings and pump pressure. Drill pipe size affects both annular up-hole velocity and internal friction losses. It is understood that some rigs in Nepal are equipped with 8x10 duplex mud pumps as opposed to 5x6. The larger pumps can produce around 8 times the discharge of the smaller, provided suitable drill pipe is also available, and should be able to handle the bigger drilling diameters with fewer or no reaming passes.

If the mud pump is undersized or operating inefficiently, the driller is usually forced to drill at a small diameter, then ream out to successively larger diameters. The mud costs then become additive as each reaming pass is likely to require a supply of fresh mud. Furthermore, there is usually a need to increase the viscosity to offset the lower up-hole velocity, this in turn makes accurate formation sampling difficult and increase the bottom hole pressures which in turn increase formation damage owing to mud invasion, filtrate loss and build up of wall cake. These factors then lower the productivity of the tubewell.

In artesian zones, mud weight may have to be increased by adding barytes or more bentonite. It is understood that present practice is to build up mud weight to 10.3 to 11 lb/gall on the basis that artesian zones may occur. These limits can be related to the depth and overpressure of an aquifer by the formula given in USGS/USAID (1972):

$$M=8.33\frac{M+D}{D}$$

This gives the following overpressure for the lower mud weight limit:

Depth (m)	50	100	150	200	250	300
Overpressure (m)	11.8	23.6	35.5	47.3	59.1	70.9

This provides an excessive factor of safety compared to recent drilling results which indicate a maximum artesian pressure of around 4 to 5 m at 50 m depth or 8 to 10 m at 200 m. The consequences of excess mud weight are increased cost of mud chemicals (barytes has a unit price comparable to bentonite) and increased formation damage. These problems are exacerbated in deeper holes.

A reduction in mud weight would produce a slight reduction in fuel consumption, and also wear and tear, and an increase in NPSH available to the mud pump.

There appears to be scope for drilling nearer to optimum performance providing the following steps are taken :

- survey or levelling from a nearby DTW to estimate the likely piezometric level and check any artesian over-pressure;
- reduced use of barytes;
- possible use of viscosifiers (CMC etc), thinners (quebracho or kutch) and pH treatments;
- possible use of larger diameter drill pipe;
- possible use of additional trailer or skid mounted stand-alone mud pumps;
- aiming for mud viscosity of 34 seconds rather than around 37 when drilling in any fine sands.

The actual rig capacity may itself produce hole diameter related costs as well as non-linear depth related costs. If a rig has to operate beyond its standard design limit, the driller is often forced to first drill at a slim diameter to the required depth. This permits use of smaller diameter drill rods and drill collars to get a reasonably straight and vertical initial borehole. This can then be reamed out with large diameter rods but with lighter or no drill collars such that the rigs mast and torque limits are adhered to. As discussed earlier, each reaming pass produces time and materials related costs and may adversely affect tubewell productivity.

Reverse Circulation

The main limitations to using RC techniques for DTW construction are its inapplicability in flowing artesian conditions or formations with large boulders and the relative shortage of suitable equipment and experienced personnel in Nepal.

The potential advantages are significant and include :

- excellent formation recovery especially in the silt, very fine sand and fine sand categories. This permits accurate screen or gravel pack selection and sizing;
- relatively thin or absent wall cake and thus simple well development;
- fast drilling; 6 m/h is readily achievable although triple shift operations are usually needed to complete a DTW in one pass;
- cheap drilling; amortisation costs can be spread over 50 or more boreholes per year rather than the 10 or fewer achieved with DC rigs, bits are cheaper and very few fluid or mud chemicals are needed;
- little diameter dependence since cost and speed are not much affected in the range from 16 to 27 inch borehole dia. Smaller diameter drilling is possible although rare;
- optional use of glass reinforced plastic (GRP) LWC since diameter dependence is insignificant.

It appears there may be scope for using this drilling technique in the finer aquifers of the southern Terai. Minor changes to present practice would be required insofar as a small airlift or electric pumped STW would be needed at most sites to provide drilling water and a site preparation crew would be required to prepare a large mud pit and, where necessary, an elevated drilling platform.

The equipment and experience limitations could be overcome by :

- procurement of customised rigs. These are likely to be top head drive truck, tractor or trailer mounted. If dual purpose, either small diameter DC or DTH drilling options could be added.

- modification of existing table driven rigs albeit subject to possible torque limitations. RC pumps, swivels, kelly bars, table bushings and large diameter drill rods would be needed. Other than the pump, all of these could be useful in large diameter DC drilling although some further modification of the swivels might be needed.

- on the job training.

V.3.2 Casing and Screen

Casing and screen design combinations cover a range of choice of materials, lengths of installation and dimensions (wall thickness, slot width, etc) consistent with achieving the required hydraulic performance and strength to avoid damage or distortion during construction, operation and maintenance.

Once a material of construction is chosen, thus fixing the modulus of elasticity and yield strength, the hydrostatic collapse strength of a pipe largely depends on the ratio of the diameter to the wall thickness. The standard dimension ration (SDR) of a pipe is defined as the ratio of the outer diameter to the minimum wall thickness and, as described in ASTM 480 F, the collapse pressure is constant irrespective of diameter for a given SDR.

The longitudinal tensile strength, and often the coupled joint strength as well, is a function of the cross sectional area of the pipe wall as is the volume of material incorporated in the pipe. This last determines the major portion of cost.

These relationships can be formulated thus :

Cost = A x D + B x D x t

$$t = \frac{D}{D_r}$$

$$\frac{Cost}{D} = A + \frac{B \times D}{D_r}$$

where A and B are constants, D is diameter, t is wall thickness and D_r is the dimension ratio.

Figure V.2 shows the variation of unit cost for a number of different materials and strengths and these are discussed in relationship to types of well components below :

UWC

Steel

The material of choice for large diameter UWC is mild steel since it is readily available, easily jointed to any length by cutting or welding and is reasonably cheap. The use of screw-threaded couplings increases the factory price but can lead to faster installation or removal from a tubewell in addition to removing the need for welding equipment on site. The possible problem of corrosion can be overcome by painting or use of sufficient wall thickness to give a reasonable life expectancy. Where externally grouted to combat artesian pressure, corrosion is reduced by the cement cover. In two string completions, drilling through can be readily accomplished without damage to steel UWC. Lineshaft turbine pumps can be safely operated inside a steel housing.

Unit costs (Rs/m per inch of dia) in the range 8 to 16 inch diameter approximate to :

$$\frac{Cost}{D}=160+1.1\times D$$

Locally produced 4 inch diameter 4.5 mm thick, black, steel pipe has been quoted at around Rs 300 per metre.

Care is needed when specifying steel casing for use as UWC since the minimum wall thickness recommended on corrosion grounds may produce a nominal strength much in excess of the design strength requirement. The required collapse pressure for UWC is less than LWC due to the shallower setting depth. Accordingly seamed pipe of low yield strength is often adequate where overall cost is a major consideration. API standard well casing to specification 5A should always be avoided due to its high cost and tightly controlled production standards. Line pipe to API 5L, water well casing to BS 5879 or steel pipe to ASTM Grade A will usually be more than adequate.

Thermoplastic

Thermoplastic materials are in widespread use internationally for well casing and screen since the material is corrosion resistant and relatively cheap in small diameters. The materials may be a modified PVC, HDPE, ABS or polyolefin but due to the resulting modulus of elasticity an SDR of 17 to 20 is often used in water wells. The resulting wall thickness is often excessive at diameters exceeding 12 inches and such pipe is rarely available. Thermoplastics may be competitive with steel for wells of depths less than around 60 m and diameters of less than 8 inches. Its use is not normally recommended with lineshaft pumps but there is no special problem with electric submersibles or centrifugal suction pumping. The possible constraints are verticality and straightness and to a lesser extent abrasion and fatigue. Future investigation in the Terai might permit the use of thermoplastics in UWC if these constraints can be overcome.

Thermoplastics are not suitable for two string completions unless a special steel shoe is added for subsequent drilling through. Care is needed if thermoplastics are to be grouted over the depth of the UWC since the heat of hydration can weaken or distort the UWC. It is understood that HDPE as manufactured in Nepal is used for some hand pump water supply tubewells although PVC is mostly used in such wells installed through government programmes. HDPE is not likely to be a material of choice for UWC or LWC in irrigation wells. It has been reported during this study that 4 inch dia fabric wrapped HDPE is now used in some districts of Eastern Terai to make shallow tubewells. PVC became widely used in Bangladesh for STWs once local manufacture and marketing started and the same should happen in Terai; indeed the process may already have started since locally produced PVC has come on to the market in the last year or so. However, hammer drilling (Thukwa) is not possible with PVC so its use is limited to sludged, jetted or bored tubewells. The few factories producing PVC in Nepal seem to mainly sell screen and pipe at 1.5 to 2 inch diameter for use in handpump tubewells. At least one factory (Panchakanya Group at Bhairahwa) has provided a sample of 4 inch diameter ribbed wellscreen to DIN 4925 and should be able to provide larger diameter blank pipe for use as UWC if the demand arose. Nepal Group at Dharan can also produce DIN or BS standard casing and screen.

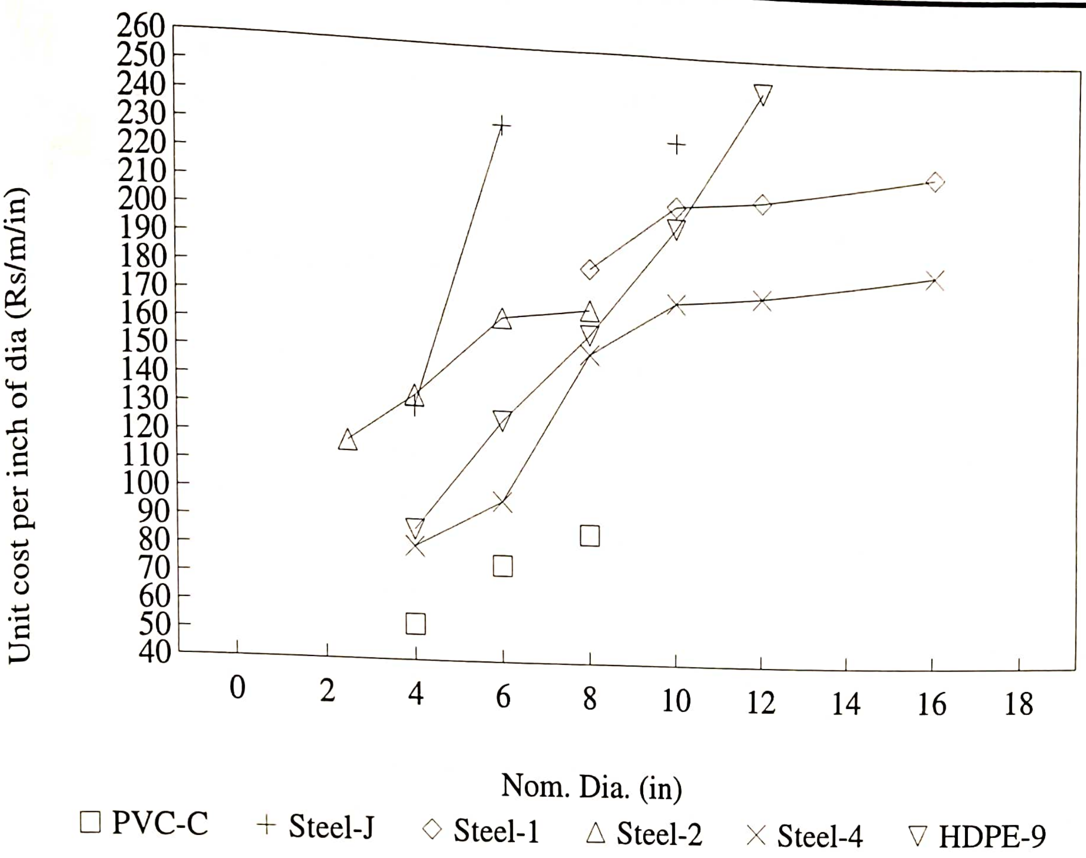
An issue with PVC is the choice of solvent welded or threaded couplings. Solvent welding is normally easy with STWs since the material can be made up and then run in the borehole. In DTWs and at 6 inch diameter, threaded couplings may be preferred by some drillers. Where used, a broad flat thread to BS 879 is more satisfactory than 8 per inch Vee threads. Although the latter match the readily available steel pipe threads they are harder to machine and can give poor joint strength.

Manufacturers in Nepal have indicated they can produce whatever connection, thread form or slot width that may be needed.

It is possible that a slight modification to the available PVC specifications could be achieved by say, raising the Vicat temperature from the present 83 degrees. This would increase the toughness of the casing and screen produced and lead to less damage in handling and transit. The Terai manufacturers carry out compounding in-house, rather than using pelletised PVC, and so any design changes could be easily achieved.

Figure V.2

Unit Cost of Casing



Quoted Steel Costs (Rs/ft)

Project/ Source	Jugera	BLGWP Quote 1	BLGWP Quote 2	BLGWP Quote 3	BLGWP Quote 4
Material					
16" steel casing		3518			2936
12" steel casing		2513			2097
10" steel casing	2300	2069			1727
8" steel casing		1466	1341		1223
6" steel casing	1400		984		585
4" steel casing	525		541		322
2.5" steel casing			295		
10" screen		2576		2165	6569
8" Screen	1800		2202	1722	4897
6" screen					
4" screen	560		1107		

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LWC

Steel

The factors governing the use of steel pipe in blank LWC are largely the same as for UWC. However, its use as well screen poses several concerns:

- control of slot width below 1 mm may be difficult;

- erosion and corrosion of slots, especially at the stress affected point of the end of each slot, may lead to widening of the slot and eventual failure due to sand ingress through the enlarged openings. Such a mechanism was largely implicated in the high rate of replacement wells required in the extreme north-west of Bangladesh within 8 to 15 years of commissioning of projects there. However, there have not as yet been any such reports from the early tubewell projects in Nepal.

- gross open areas of more than around 15% are almost impossible to achieve and given the tendency for simple ferrous materials to promote chemical and bacteriological corrosion and encrustation, significant clogging may occur. Clogging due to rust has been found to occur in some slotted pipe during storage prior to installation in Terai. Thus wide (>1.5 mm) slots are preferable.

Nevertheless, slotted steel pipe is the only material suited to hammered or driven wells and is readily used in STWs where a working life of over 7 years might be considered satisfactory.

Thermoplastic

The available locally produced thermoplastic appears to be suitable for blank casing and screen to depths of at least 60 m. Purpose designed thermoplastic casing and screen is available on the international market and can be used to depths exceeding 150 m. There is no special reason why the PVC casing produced in the Terai could not be subjected to appropriate design checks, quality control and testing so that its depth rating met the needs of some DTWs in the Terai. Slot width can be easily as small as 0.5 mm (with an attendant moderately low gross percentage open area), the material is inert and does not promote encrustation or corrosion and locally made material is relatively cheap. Interestingly, samples supplied by two different factories in Terai were slotted at the works to around 0.2 mm. This may reflect the supplier's experience that this is what is in demand by the private market. The larger slot widths used in high performance irrigation wells would have to be specified at the time of ordering.

The use of thermoplastic in wells with LWC of 6 inch or less diameter and depths of 40 m or less should be actively promoted in the Terai. Its role at larger depths and diameters needs further attention.

Budget costs for PVC ribbed screen with bell ended screw couplings are around Rs 90/m per inch of diameter. HDPE class V costs are around Rs 94/m per inch of diameter. The former is also available with (slightly cheaper) solvent welded joints whereas the latter is normally butt welded by heating.

GRP

GRP has been widely used in DTWs in nearby countries since it combines the strength advantage of steel with the corrosion/encrustation advantages of thermoplastics. Slot widths to around 0.8 mm are readily attainable as is a gross open area of up to 12%. However, its use in DC drilled holes in the Terai should be avoided if possible since the normal spigot and socket belled coupling has a larger outer diameter than other LWC materials and this induces a drilling cost penalty. In RC drilled holes this disadvantage disappears and wells depths of up to 100 m should be easily achievable.

Ex factory cost for GRP lie around Rs 350/m per inch of diameter with a 10% surcharge for slotting.

Wirewound Screen

Purpose built wirewound well screens are available to suit a large number of different conditions. Slot width can be carefully controlled to suit very fine formations and good corrosion resistance can be obtained by using stainless steel or thermoplastic wires. The latter are relatively weak and their use in holes deeper than 50 m or requiring very energetic well development is rare. Galvanised steel screens are also available and may cost around 60% of the equivalent type 304 stainless steel although life expectancy may be lower owing to corrosion.

Costs of wirewound screen are very sensitive to design parameters owing to the costs of raw materials and of fabrication. Thus a change from say 2.0 mm slot medium strength to 0.5 mm high strength screen requires a heavier gauge wire, greater ratio of wire to void and increased number of vertical rods. The resulting cost penalty is between 40 and 50%. Furthermore, the use of 2.9 m as opposed to 5.8 m lengths of screen or couplings as opposed to welding rings can add to unit costs by Rs 1 600 and Rs 450 respectively.

Base cost for 1 mm slot stainless steel wirewound screen in 5.8 m length with weld collars is around 575 Rs/m per inch of diameter.

Other Screens

As in neighbouring countries, there are a number of other materials used in tubewells. These include, gauze wrapped drilled or slotted pipe, coir wrapped pipe and slotted bamboo. Although capital costs are very low, there are disadvantages in terms of longevity, sand control and ease of development.

The use of such materials can be discouraged by the availability of properly engineered cheap alternatives of which slotted PVC is the foremost contender.

V.3.3 Well Development

The objective of well development is to achieve a stable sand free discharge with as high a specific capacity as possible. This last implies removing all clogging material introduced by drilling and usually removing some of the fine fraction of aquifer material as well.

The techniques employed in Terai have been developed in response to a wide range of downhole conditions and equipment limitations. All the drillers and technical staff involved in tubewells appear to understand some of the principles and the basic requirements. Typical practices are presented in Box V.2 and the techniques are discussed below.

Box V.2 Well Development Related to Drilling Technique

Developing Method	Sludge	Thukwa	Percussion	DC	RC	DTH
Bailing	Y	Y	Y	-	-	-
Surge block	P	P	P	-	-	-
Washing	-	-	-	Y	Y	-
Chemical	-	-	S	S	-	-
Air Surging	-	-	Y	Y	Y	Y
Over pumping	Y	Y	Y	Y	Y	Y

Y Nearly always carried out
P Partial
S Sometimes carried out
\- Never or very rarely carried out

Bailing

This is a highly appropriate technique for manually drilled tubewells since neither specialist equipment nor a separate water source are needed. It is however slow. Although a slow and gentle start to development is always recommended as a way of removing heavy drilling fluids, it is difficult to build up the discharge rate to the normal operational level.

Surge Block

If a bailer has a close fit within the screen, some surging action through the screen will take place as the bailer is raised and lowered. The effect may be concentrated near the pumping water level within the well as a result.

However, a purpose constructed surge block incorporating a rubber seal or packer is much more effective and allows each section of screen to be developed in turn. If the surge action is too vigorous, screen damage may occur and some care is needed with weaker screen materials. The method is very suitable for percussion drilled tubewells with slotted steel or PVC or wirewound screens. In manually drilled tubewells or those with gauze or coir wrapped screens or slotted bamboo with an irregular internal cross section, surging with a loose fit bailer should be less-risky.

Washing

All DC drilled tubewells in Terai are developed by washing with clean water to displace drilling mud.

A clear distinction must be made between washing which removes mud from inside the tubewell and some of the screen slots and jetting which agitates gravel pack and formation material outside the screen and may also remove mud cake. For jetting to achieve its potential, the energy of the water being injected must pass though the screen slots. It is therefore vital that the jet nozzles are offset from the inside face of the screen by a small distance; Driscoll (1986) recommends 25 mm diameter clearance. In addition, the number and diameter of nozzles must be sized in relation to the volume and pressure capacity of the delivery pump so that the resulting exit velocity is of the order of 50 m/s or more.

Ideally the resulting debris should be evacuated from the tubewell while jetting takes place. This happens naturally in flowing artesian wells. In large diameter wells, say more than 10 in diameter UWC, it is possible to simultaneously pump by airlift.

Jetting is easily performed in DC drilled wells because the rig's mud pump is ideally suited to the task. In manual or percussion drilled wells a centrifugal irrigation pump or double acting donkey pump may be cheap and readily available alternatives.

In all cases a supply of clean water is a constraint. Where water is brought to site by tanker, a circular tarpaulin or plastic lined ground tank can be used to store 4 to 5 m^3 ready for jetting. The use of such tanks is strongly recommended because of the time that is now being lost waiting for water to be delivered. In other wells, bailing or airlifting from the well itself may be the best solution. However, the water so produced should be stored for a short while to settle out silt and sand.

Jetting with properly designed tools is strongly recommended. No extra costs are allocated because the equipment and time related costs are presently incurred with washing. Provision of water storage at the site would also be cost neutral since the minor capital expense would be quickly covered by reduced standing time while waiting for water.

Dispersants

Calgon/sodium hexametaphosphate is sometimes used in DC drilled tubewells in the Terai. In addition to the cost of the chemical, 24 or 48 hours may be spent waiting for the dispersive effects to act on the mud cake.

A few issues arise:

- If the dispersant is jetted through screen, its action on wall cake is enhanced. This is not achieved by merely washing as is done at present.

- If airlift equipment can be brought on site not more than 2 days after injection, the main drilling equipment could rig down and move immediately injection ceases. If airlift equipment cannot be supplied at the appropriate time, a suction pump or turbine pump could be used to clear out the tubewell.

- Internationally recommended practice is to add a biocide such as sodium hypochlorite along with any phosphate-based dispersant. This reduces the risk of stimulating biofouling. However, if the tubewell is airlifted and tested sufficiently soon and with sufficient total abstraction, the phosphate solution will be pumped out and the risk of biofouling reduced. Present practices are therefore probably adequate.

- Dispersants could be used in manually or percussion drilled holes if needed.

- Dispersants should not be needed in RC drilled tubewells.

The use of dispersants in a DC drilled well with 8" dia screen costs around Rs 250 per metre of screen for chemicals. If the rig remains stood over the hole, this incurs a high opportunity cost but since this is easily avoidable, its economic cost is taken as zero for this study.

Airlifting

Airlifting is nearly always carried out by the major contractors and government agencies or projects equipped with drilling rigs. However, compressor ratings in some cases are not adequate to deal with the deepest screens; a nominal 10 kg /cm^2 machine may in practice be limited to a 70 m airline setting depth. It is very likely that some of the deeper set screens in the Terai have never been directly airlifted and it is possible that they have become backfilled by debris from airlifting in higher screens. Setting the airline in the tailpipe is a good method of clearing it out but the same pressure limitations apply.

A common view expressed during field interviews was that the available compressors also suffered from lack of volume capacity. The evidence for this is airlift discharge being significantly less than design or test production rates. However, a good solution to this problem is to use a fabricated airlift tool rather than an open ended airline. The tool forces the available air to concentrate over each 3 or 6 m section of screen at a time. In addition the tool forces flow in and out of the screen and into the gravel pack during surging. This therefore produces a better development action by focusing the air produced by the available, smaller (and less expensive) compressor.

As a further enhancement that could be readily achieved, the airline may be run through a valved tee sitting on top of the UWC. This permits occasional back pressuring rather than just the backwashing action achieved by surging.

The cost of airlifting is taken to be around Rs 12 000 /well using existing equipment.

Rawhiding/Overpumping

This techniques is also successfully used in Terai tubewells. Minor modifications are possible and could include use of packer type zone isolating tools (as recommended for use as the airlift tool) to focus the effect on individual screen lengths thus reducing the overall pump capacity required. In parts of Bangladesh, the use of compressors on RC drilled holes is often avoided altogether by reliance on pumping alone. This reduce the capital and maintenance needs of the drilling equipment package. However, if the antecedent development techniques are properly carried out, pumping is the preferred way of giving the final polish to the development.

The cost of rawhiding and overpumping for Terai wells is normally covered in the well testing.

In conclusion, all the techniques currently employed could be enhanced by minor modifications to existing equipment. Most of the enhancements would focus the available development energy on individual portions of screen, a section at a time, thus promoting :

- maximum development on each screen section;
- uniform inflow across the whole screen length and a reduction in maximum entry velocity;
- reduced sand production during operation.

It seems likely that the apparent specific capacity results being achieved in tubewells could be improved by at least 10 to 20% and the average improvement would be much greater as the number of very low performance wells was reduced.

V.4 Gravel Pack and Screen Design

The tubewell design criteria used for the selection of a type of gravel pack or screen slot width, type and effective length are the first real opportunity for the designer to select an option rather than merely reacting to the prevailing circumstances.

V.4.1 Screen Entry Velocity

Present practice for Terai tubewells appears to rely largely on application of an effective screen entry velocity irrespective of whether the tubewell is to be naturally or artificially gravel packed.

ASTM/AWWA A100 contains a special warning relating to entry velocity criteria and suggests that whereas many workers prefer to adhere to an upper limit of around 3 cm/s, some well designers have successfully worked with much higher limits. The ASTM recommendation is to use the 3 cm/s limit unless there are prevailing circumstances that suggest otherwise. The 3 cm/s limit is widely quoted elsewhere in the literature such as the EPA (1975) guidelines as quoted in Driscoll (1986).

The velocity limits in the literature are often based on examinations carried out in the USA, of clogging owing to invasion by formation fines. However, although velocities of more than 6 cm/s were originally recommended by Walton (1970, 1962) for highly permeable materials, it is not clear if the sample of tubewells examined were largely naturally or artificially gravel packed and/or the tubewells were constructed in well or poorly sorted formation materials.

Figure V.3 shows the Driscoll (1986)/EPA (1975) limits in comparison with those originally proposed by Walton.

More recent examination of chemical encrustation and biofouling, as presented in Howsam et al (1992) suggests that low entrance velocities are helpful in these respects also. This conclusion is repeated in relation to corrosion of screen slots in metallic casings in Driscoll (1986).

The role of the pore water velocity at the gravel pack-aquifer boundary, defined as the approach velocity, is less clearly understood. In a natural pack well, there may be no clear cut boundary and so the screen slot velocity may be a useful index measure of the whole pack system. The grading of each annular band around the screen will be fixed by the slot width and so ultimately pore velocities and drag forces on potentially clogging fines will be closely related to the slot velocity.

In an artificially gravel packed tubewell the situation is arguably very different. The gross approach velocity can be calculated assuming that the discharge is distributed over a cylinder whose diameter is that of the drilled hole and length totals that of the screen installed. The net approach velocity could then be calculated by assuming some value for porosity. This in turn may be more sensitive to degree of sorting than actual D_{10} or D_{50} particle sizes. The main rationale for this approach is that the fine formation particles that are likely to move and thus cause clogging cannot "know" what the screen slot geometry and open area are because they are separated from it by the gravel pack.

The recognition that, for an artificially gravel packed well, the screen velocity relates to the gravel pack but the approach velocity relates to the formation fines can be incorporated in a design approach that considers both.

Laboratory tests on screens for the Deep Tubewells II project in Bangladesh as contained in MM (1991) and BGS (1992) show clearly that the effective internal roughness of a screen rises with entrance velocity and so the upflow component of drawdown in the tubewell is increased. However, selection of a suitable screen diameter and thus rising velocity can reduce the energy losses.

A final consideration often advanced by manufacturers of wirewound screens is that the entry velocity is itself important in energy terms. Cursory examination dispels this myth, since complete dissipation of the velocity head would give an energy loss of:

$$\frac{V^2}{2g}$$

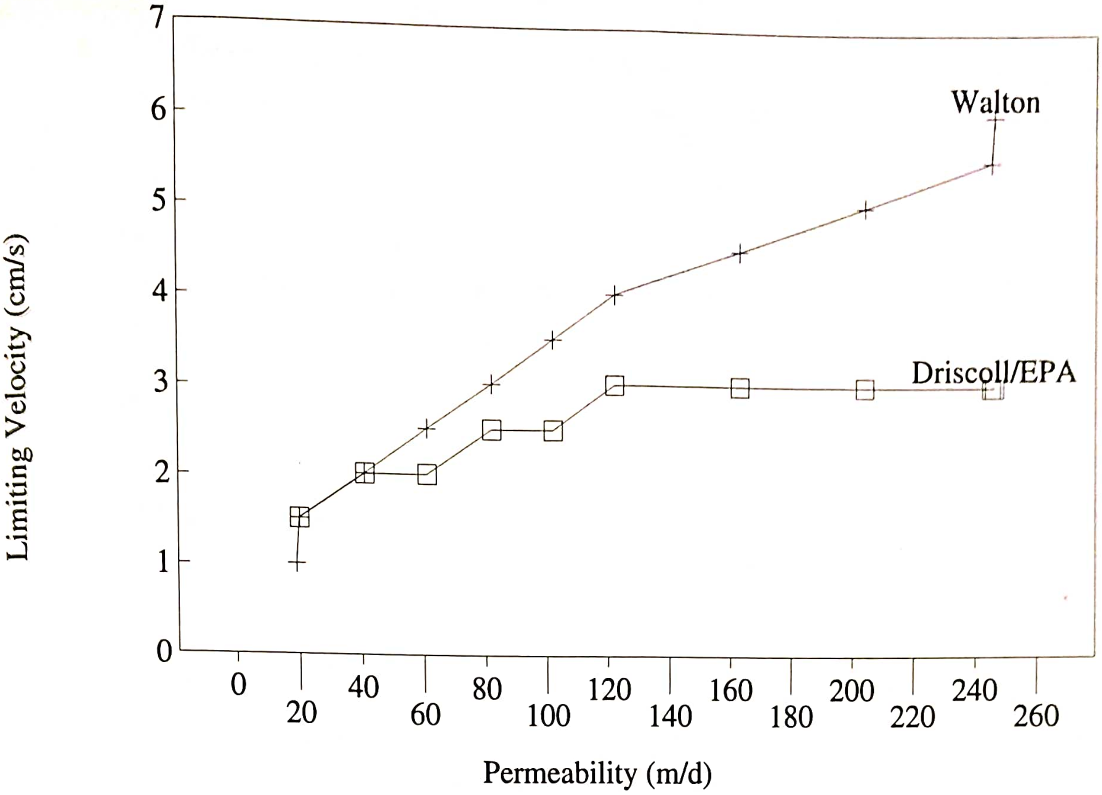
Clearly, if V is around 3 cm/s, it is one and a half orders of magnitude less than the velocity head loss at the UWC/LWC reducer described in Section V.2 above.

The overall conclusion from the review carried out for this study and comparison with neighbouring countries is that the present situation in the Terai is often very conservative and leads to exaggerated concerns about screen entrance velocity. These concerns have led tubewell designers to aim for larger diameters, slot widths and percentage open areas than may be strictly necessary and undervalue the role of screen length in reducing drawdown and operating costs as described below.

V.4.2 Screen Length

One of the most important choices faced in tubewell design is that of preferred screen length. As the screen length increases, so the effective transmissivity increases and so the specific capacity increases. The resulting reduction in drawdown at the design discharge then produces a saving in operating costs for energy, and a reduction in the capital costs for UWC and pumping equipment. However, the overall depth and cost of drilling increases. The balancing of the costs and benefits can be carried out by optimisation of the screen length.

Screen Entrance Velocity



If a screen entry criterion only is used and it is too liberal, the tubewell may end up with a short length of large diameter, high open area screen but a low specific capacity. If the criterion is too strict, the tubewell may end up being drilled to an inordinate depth in the search for suitable screenable material.

Present design practices in the Terai do not appear to give much consideration to screen length as it effects transmissivity and thus drawdown at operational yields and overall UWC and LWC depths.

V.4.3 Gravel Pack

The choice of type or grading of pack and the choice of accompanying screen slot opening then dictate what is defined as "screenable aquifer", ie the type of formation that can be exploited without excessive development times or bulk removal of formation and subsidence at the wellhead.

Tubewells in the Terai have been constructed with both artificial and natural gravel packs. The early Bhairahwa Lumbini wells were built using around 1.5 mm to 2 mm slotted pipe and a natural pack. The excellent specific capacities achieved are attributable to:

- adequate screen lengths owing to use of a velocity limit and open area of 10 to 14%.

- the practice of placing screen only against formations that are dominantly coarse sand (0.6 to 2 mm grain sizes) and fine and coarser gravel (>2 mm grain size). Such a coarse material has a higher permeability than say fine to medium sand since permeability goes up with the square of the effective grain size;

- In the Stage 1 area, sufficient screenable aquifer exists within the top 200 m of the sedimentary sequence;

- well development is likely to have been effective due to a combination of high artesian pressure balancing bottom hole mud pressure (reducing mud invasion), slim drilling diameter minimising formation damage (see Section V.3.1 above) and good well development facilitated by the thin annulus and natural breakdown of wall cake by artesian inflow.

In the Stage 2, Phase 1 area, the formation grading is probably finer, and excessive sand production occurred in several tubewells. This has been largely overcome in subsequent BLGWP tubewells and in many other parts of the Terai by using a gravel pack. The packs now most commonly used in the Terai have a D_{10} around 2.5 mm and so provide sand control over formations with a D_{10} around the boundary between medium and coarse sand.

It may be that this type of pack is as fine as can be placed with the prevailing tubewell construction techniques. If a finer formation grain size is to be exploited, several options could be considered:

- Subject to the limitations described in Section V.3.1 above, RC drilling could be employed. The larger diameter and thinner borehole fluid permits finer gravel packs to be placed without problem.

- Install LWC strings using a washdown fitting in the tailpipe. The fitting is connected to drill rods and thus the rig's pump. This allows any backfill in the drilled hole to be circulated out. This has the incidental advantage that wallcake scratchers and centralisers can be fitted to on the outside of the LWC which helps development. Once the LWC is correctly located, the gravel pack is circulated through the mud pump and pumped into position. The process is likely to be easier in tubewells designed as two string completions and tubewells where the screen is not spread over a long length of LWC in a series of short individual sections.

- Use a narrower slot and go back to natural rather than artificial packs.

The outstanding advantage of exploiting finer formations is the dramatic increase in the percentage of the drilled section that can be defined as "screenable aquifer". The fact that these formations may be of lower permeability is less significant than the ability to install long contiguous lengths of screen section in moderately deep tubewells and thus achieve low capital and operating costs.

V.4.4 Design Considerations

The preceding discussion leads to the following design procedures and parameters which should be considered for use in the Terai. The resulting formulations are then carried forward to Section 4 below in which the economic optima are deduced for each standard tubewell design.

The relationships between the screen open area, screen type and minimum available slot width for typical well screens are shown in Table V.2.

TABLE V.2

Minimum Screen Slot Width and Open Area

	Open area (%)					
Screen type	5	8	10	12	14	25
Steel slotted	1.1	1.1	1.1	1.1	1.6	-
GRP slotted	0.8	0.8	0.8	0.8	-	-
PVC slotted	0.5	0.7	1.6	2.0	-	-
Wirewound	0.25	0.25	0.25	0.4	0.5	0.6

The above data could normally be altered slightly to suit specific needs subject to confirmation by the manufacturers concerned. This particularly applies to wirewound screen because of its sensitivity to strength requirements. In the, case of PVC ribbed screen as opposed to slotted blank pipe, it is possible that the ribs act as a conduit that slightly increases the effective open area in terms of potential clogging and head losses due to convergence of flow lines outside the slot.

The data clearly show how wirewound screens can be used to give reasonable open areas for relatively fine slot widths.

The resulting discharge and velocity relationships are summarised in Table V.3 for different assumed tubewell configurations, limiting velocities and open areas of screens. Several conclusions can be drawn as follows:

- The permissible specific discharge, ie the inflow per unit length of screen, is always higher, for an approach velocity limit rather than an entrance velocity. This applies for values as low as 2 cm/s and if the porosity used is as low as 20%

- The higher permissible entry velocity (5.5 cm/s) used for gravel pack gives a proportionally higher specific discharge than if a limit of 3 cm/s used for natural pack;

- In the case of an STW with 4 inch screen, the clogging problem is considered less serious than possible sand pumping since the well may be treated as having a lower life expectancy. The approach velocity criterion, based on an assumed effective radius, gives a minimum screen length of around 8 m for a 15 l/s discharge.

The present condition of tubewells in the Terai could provide a useful guide to the relevance of any velocity criteria to be used in the future. Recently recharged groundwater can be expected to have a moderate oxygen content and this may explain the absence of any reports of high iron concentrations or sulphide gas production in Terai tubewells. This suggests that biofouling or encrustation may not be affecting tubewell performance. However, some field measurements of actual inlet velocities (based on flow logging during pumping), CCTV survey to check for screen damage, corrosion or clogging by slimes and repeat specific capacity pump tests during normal operation would appear to be a priority investigation task. The results of the pump tests would be compared with the original commissioning data and any trend with time should be identifiable.

The next consideration is the choice of length of UWC. Several factors have to be taken into account most of which merely relate to the need to get adequate pump submergence and accommodate the ultimate drawdowns:

- If artesian pressure has to be withstood, the UWC should be grouted at its toe into an aquitard. A setting depth within an aquifer may allow flow to pass up inside the tubewell to the level of the topmost screen, out into the aquifer and gravel pack and then up the annulus to the shallower aquifers.

- Long term water levels may decline due to regional exploitation of the aquifer. In water table aquifers this decline is likely to be fairly small, say 3 m, whereas in high pressure artesian aquifers it would be larger, say 15 m.

- Pumping water levels within a well will be lower than observed during pump tests since these are of relatively short duration.

- Clogging may reduce the specific capacity with time.

- The eventual specific capacity cannot be accurately predicted. The tubewell can however be designed assuming a lower value of permeability than is the average for the aquifer and area in question. A value of around two standard deviations below mean has been successfully used in Pakistan in conjunction with a factor of safety (FOS) of 2 m and a rounding (R) to the next standard UWC pipe length.

The initial design interrelationships for a well of design capacity Q, 10% (CQ^2) well losses regional decline D and short term drawdown s_w can be formulated:

$$UWC = 1.6 * 1.3 * Q/(K_2 * SL * 0.9) + SWL + D + FOS + R$$

$$SL = 1.3 * Q/(s_w * K * 0.9)$$

If the screenable aquifer forms a fraction p of the drilled section then the total depth (TD) will be:

$$TD = UWC + SL/p + 1.5$$

The factor of 1.6 is used to allow for derating from a predicted short term value of specific capacity to the long term.

As a summary of the considerations set out in this report, the standard tubewell design configurations for optimisation and economic analyses can be taken as shown in Table V.3.

TABLE V.3

Summary of Well Configurations

Item	Well type: A	B	C	D	E	F	G	H	I
Maximum Discharge (l/s)	120	90	60	60	45	30	30	15*	15**
UWC dia (in)	16	14	14	14	12	10	10	8	4
Min UWC (m)	40	20	20	20	20	20	20	20	12
LWC dia (in)	10	10	8	8	8	6	6	4	4
DC/RC/Manual	DC	DC	DC	RC	DC	DC	RC	DC	M
Drill dia U (in)	22	20	20	22	17.5	17.5	16	14	6
Drill dia L (in)	17.5	17.5	14	16	14	12	16	10	10
Screenable aquifer P %	20-40	20-40	40	60	40	40	60	40	40
Average effective permeability k (m/d)	40-100	30-60	30-50	40-60	40-60	40-60	40-60	40	60

Notes:

* Forced mode pump sets

** Suction mode pump sets

Source: GDC