HYDRAULIC EVALUATION OF CONVENTIONAL AND MODIFIED TUBEWELLS IN BARIND PROJECT

Submitted by

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In partial fulfillment of the requirements

for

The Degree of Master of Engineering
(Water Resources)

DEPARTMENT OF WATER RESOURCES ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING & TECHNOLOGY
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CERTIFICATE

This is to certify that this project work has been done by me and neither this project nor any part thereof has been submitted elsewhere for the award of any degree or diploma.

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We hereby recommend that the project report presented

By

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entitled **"HYDRAULIC EVALUATION OF CONVENTIONAL AND MODIFIED TUBE - WELLS IN BARIND PROJECT"** be accepted as fulfilling this part of the requirements for the Degree of Master of Engineering (Water Resources)

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ABSTRACT

Barind in north-west Bangladesh is the land where surface water is very limited. So groundwater exploitation for irrigation is being practiced for the last 24 years through deep tubewells (DTW). At present more than 6300 DTWs are operating in the Barind area. But in some locations, it was observed that DTW discharge was below the acceptable limit (1.20 cusec). In order to overcome this difficulty an innovative well design involving four screens projecting upward was developed and implemented. This study was taken up to compare the performance of conventional wells with that of the modified wells.

For this study 10 conventional and 10 modified wells were selected considering lithological condition, well construction and range of discharges. Analysis of the step drawdown test data was done to compare the performance of modified wells with that of the conventional wells. Five parameters namely specific capacity, screen entrance velocity, well loss, well efficiency and well deterioration index were chosen to assess the performance of the wells. The performance of wells in respect of specific capacity could be significantly improved (24%) through design modification. In modified design, use of longer screen and increased well radius made the entrance velocity lower than the conventional wells but this modification seem not to be cost-effective as the entrance velocity was found to be lower than the recommended value of 3 cm/sec. The values obtained for well loss could be reduced and also the well efficiency could be improved through modification of design. Also the values of well deterioration index was calculated and it was found that the well have been moderately deteriorated irrespective of its design.

Also the hydraulics of the modified wells was considered and it was found that the main reason for the improved performance was that the wells had their screens at shallow depth, which reduced the vertical component of flow thereby reduced the drawdown.

A numerical model was used to gain an understanding of the effect of design modification on well performance. Results of numerical model simulations indicate that

the drawdown at both the abstraction as well as observation wells were considerably less for the modified design. This supports the idea that the drawdowns are reduced due to reduction in vertical component of flow.

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LIST OF ABBREVIATIONS

BMDA	Barind Multipurpose Development Authority
BIADP	Barind Integrated Area Development Project
BWDB	Bangladesh Water Development Board
BST	Bangladesh Standard Time
BADC	Bangladesh Agricultural Development Corporation
CL	Clay Loam
CS	Coarse Sand
DOM	Department Of Meteorology
DTW	Deep Tubewell
EPC	Engineering and Planning Consultant
FAO	Food and Agriculture Organization
FSL	Fine Sandy Loam
FAP	Flood Action Plan
FG	Fiber Glass
FS	Fine Sand
GSB	Geological Survey of Bangladesh
GRP	Glass Fiber Reinforced Plastic
IDA	International Development Agency
LWC	Lower Well Casing
L	Loam
MPO	Master Plan Organization
MS	Medium Sand

MOA	Ministry of Agriculture
MML	Mott MacDonald Ltd.
NW	North West
PWL	Pumping Water Level
SS	Stainless Steel
SL	Silt Loam
SiCL	Silty Clay Loam
SCL	Sandy Clay Loam
SC	Specific Capacity
STW	Shallow Tubewell
SWL	Static Water Level
SRDI	Soil Resources Development Institute
SPARRSO	Space Research and Remote Sensing Organization
T	Transmissivity
UNDP	United Nation Development Program
UWC	Upper Well Casing
WARPO	Water Resources Planning Organization

CHAPTER – 1

INTRODUCTION

1.1 General

Bangladesh has an area of 14.4 million hectares lying in the delta of three of the world's great rivers- the Ganga, the Brahmaputra and the Meghna, of which 7.56 million hectares (53%) are cultivable. At present, almost all the arable land is cultivated, but only 0.98 million hectares are triple cropped, 3.90 million hectares are double cropped and the remaining are single cropped. With this cultivation, the country still suffers from food deficiency. Due to increasing growth of population and land constraint the horizontal expansion of cultivation are greatly hampered, and to overcome the situation and self-sufficiency in food grains the cropping intensity and yield need to be increased. To fulfil the demand of food for increased population, the production of food grain needs to be increased through irrigation, use of fertilizer, high yielding variety, proper management and crop diversification. Out of these, water is the foremost input for crop production. However, the expansion of irrigation is particularly constrained by non-availability of surface water during the dry season. As a result, tapping of groundwater for irrigation by deep tubewell technology was introduced in the country by the Department of Food and Agriculture in 1958 with the sinking of five DTWs in the districts of Rangpur and Dinajpur (EPADC, 1969).

The Barind area is one of the driest parts of northwest region and the surface water supplies are particularly limited. Due to limited surface water no major irrigation facilities have been developed in this area. So, cropping intensity is low in this area compared to other parts of the country (Ahmed, 1994).

To promote irrigation facilities to boost up cropping intensity, the Ministry of Agriculture, Bangladesh initiated a project namely Barind Integrated Area Development Project (BIADP) covering 15 Thanas in 1985, which was expanded to 25 Thanas in 1991. The principal objective was to achieve multipurpose development to improve the quality of life of the people of the project area and to support sustainable agricultural growth while maintaining ecological balance.

1.2 Background of the Study and Problem Identification

Initially, in 1976 the Bangladesh Agricultural Development Corporation (BADC) was assigned with the task of implementing a project under which 122 DTWs were installed in the Barind area. Over passage of time, having observed the potential of the project, the BIADP authority installed 2524 DTWs in the project area under phase-1 (1985–1990). But in some locations, it was observed that DTW discharge was below the acceptable limit (1.2 cusec). The irrigation wells yielding 1.2 cusec discharge was considered as the wells having poor performance from the view point of normal design practices. Then the project authority urged how to improve the discharge capacity of those tubewells. As a result an innovative well design involving four screens projecting upward was developed and implemented. Better discharge has been obtained even from the wells at the same location by adopting modified technique matching the actual field condition. Examples are there in Barind tract that by adopting the innovative technique in 13 sites which are declared to be abandoned, the production wells have been successfully constructed and produced the desired discharge (Asaduzzaman, 1989). The modified design has the screens projected above the level of the pump which allows their screens to start at a much smaller depth than a conventional well.

In the second phase of the project (1990-98) an additional 3800 DTWs were installed using both conventional and modified design. At present, about 6300 DTWs (including.900 modified design) are in operation in the study area (BMDA, 1998). Since the Barind tract is an important zone for groundwater exploitation in Bangladesh, so proper management of groundwater is essential. In this study an attempt has been made to compare the performance of conventional well with that of the modified well as well as to get an understanding of the hydraulics of the modified well.

1.3 Objectives of the Study

The present study were undertaken with the following objectives :

i) To compare the performance of conventional wells with that of modified wells in Barind area.

ii) To gain an understanding of the hydraulics of modified wells using a numerical model.

CHAPTER – 2

DESCRIPTION OF THE PROJECT AREA

2.1 Location of the Study Area

The Barind area covers in 25 Thanas of Rajshahi, Chapai Nawabgonj and Naogaon districts in northwest Bangladesh (Figure 2.1). The area lies in between latitudes 24° N and 25° 30′ N and longitudes 88° E and 89° E with a total area 5558 km². The area is bounded in the north by the Bangladesh-India International boundary, in the east by the river Atrai and Little Jamuna, in the west and the south by the river Ganges. The selected tubewells for this study are located in Thana Godagari and Tanore of Rajshahi District; Gomastapur and Nawabganj sadar of Chapai Nawabgonj District and Dhamurhat of Naogaon District.

2.2 Physiography, Lands and Soils.

The Barind is one of the major physiographic units of Bangladesh. It is distinct in landform, topography, drainage and vegetation cover. (Ahmed, 1994).

Physiography

The Barind tract lies about 15m to 25m above the surrounding floodplains. The area is characterized by terraced topography and is not flooded during the annual monsoon. The tract is mainly level in the east but more dissected in the higher undulated topography of the west. In the east the Pleistocene sediments of the tract are slightly tilted and pass under the adjoining floodplain sediments. In the west the hilly tract is dissected by narrow valleys where the summits are level, and the slopes and valley sides are terraced. Locally dome shape summits occur due to closer dissection. The tract is dissected into a number of blocks by the rivers Mahananda, Atrai, Punarbhaba, Little Jamuna and Siba.

Physiographic Units

In the study area five physiographic units are described by Espinosa *et al* (1968). They can be categorized into two dominant land forms : the Barind tract and the Floodplain (Figure 2.2).

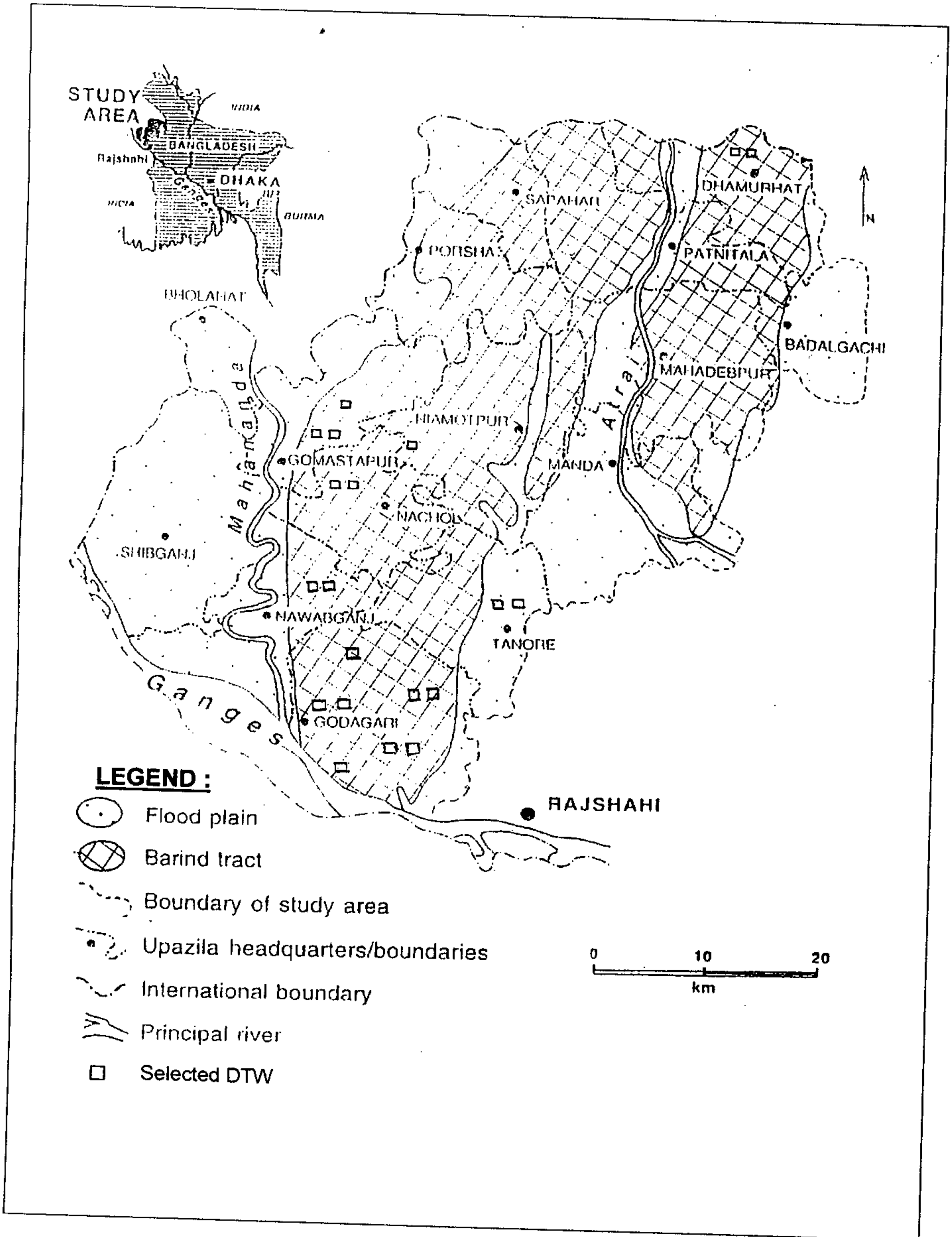


Fig. -2.1 : Map of the Barind area showing the selected DTW

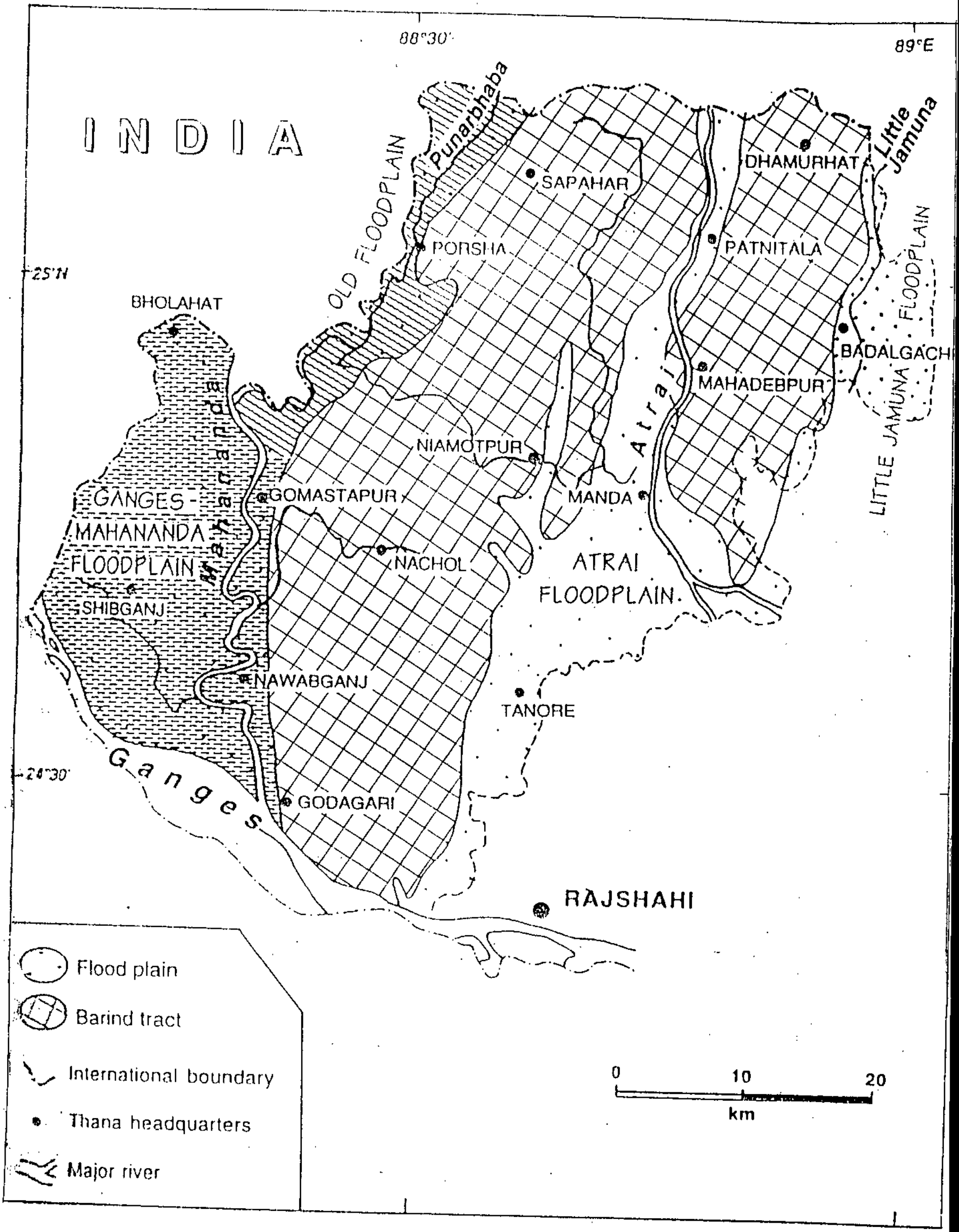


Fig. 2.2 : Generalised Physiographic map of the Barind area

Drainage System

The Barind tract is drained by an intricate network of rather narrow streams, which only have flow during the wet season. The Atrai, the Little Jamuna and the Sib collect most of their drainage water in the east while runoff from the west drains to the Mahananda and the Ganges rivers. All these rivers have a long history of migration and formation of floodplains.

Besides the main streams there exists a network of drainage channels, locally called the *Kharies*. Most of these become dry in the dry months. There are many man made standing surface water bodies called ponds. Another type of surface water body of the area is the low lying swampy lands locally known as *bils*. Some of them are large and perennial.

Land Classifications and Land Use

Lands of the study area may be divided into different categories for agricultural and hydrological purposes. One classification (MPO) has been made on the basis of the depth of flooding (Table 2.1).

Table 2.1 : Classification of Land Height and Flooding

Land Type	Description	Depth of Flooding	Identifying Crop
F0	High land	0	HYV rice in wet season
F0	Medium High	< 30 cm	Ditto
F1	Medium High	30 - 90 cm	Local Aus and T Aman
F2	Medium Lowland	90 - 180 cm	B Aus and B Aman in wet season
F3	Lowland	180 - 300 cm	Only B Aman possible in wet season
F4	Very Lowland	>300 cm	B Aman not possible but supports local Boro in dry season
F5	Open water	-	-

Present landuse in the area is mainly determined by elevation of land in relation to flooding during the monsoon and by the soil moisture content in the dry season

(Espinosa *et al*, 1968). Rice is the most common and important crop in the area both in terms of area of cultivation and crop value. Transplanted and broadcast Aman are the main types with little Aus and Boro. High yielding varieties of Aus are now being cultivated under irrigation coverage provided by groundwater. Other cash crops include jute, sugarcane and mango with little amount of mustard, lentils, wheat, barley and potatoes during the winter and vegetables during the monsoon. Table 2.2 gives the intensity of landuse and main cropping practices of the area.

Table 2.2 : Landuse in and Around the Barind Area (After Espinosa *et al*, 1968)

Landuse	**Approximate % of Total Area**	**Cropping Sequence**	
		Major	Minor
Perennial crops	3	Sugarcane, mango	Banana, jackfruit, betel vine
Triple cropped	5	Aus/Jute – transplanted Aman-Rabi crops; mixed Aus and broadcast Aman-Rabi crops	Aus-mahskalai-Rabi crops
Double cropped land	29	Aus/Jute – Rabi crops or fallow; Aus/Jute – transplanted Aman- fallow	Broadcast Aman-Rabi crops; mixed Aus and broadcast Aman-fallow
Single cropped land	50	Transplanted – Aman fallow; broadcast Aman- fallow	Boro-fallow; Aus-fallow
Grassland and barren	3	Unimproved grassland, fallow	
Homestead, urban and water	10	Horticultural crops and Aus on homestead sites	

Soils

Soil is important both from the agricultural and hydrological point of view. The soil composition, structure, properties and depth of the soil profile plays a vital role in the landuse and cultivation pattern. It also plays a very important role in the infiltration/ recharge to the aquifer.

WARPO (1992) has classified soils of the study area into 8 different categories based on their physical porperties : Fine Sandy Loam (FSL), Silt Loam (SL), Loam (L), Silty Clay Loam (SiCL), Clay Loam (CL), Basin Clay (BC), Silty Clay (SiC), and Sandy Clay Loam (SCL). Joshua and Rahman classified the soils in the Barind into four categories : silt loam (SiL), silty clay loam (SiCL), clay loam (CL) and clay (Cl) and described their physical properties. In the same study the floodplain soils are categorized into five categories : sandy loam (SL), silt loam (sand) (SiLS), silt loam (silt) (SiLSi), silty loam (clay) (SiLC) and silty clay loam (SiCL).

Table 2.3 : Summary Descriptions of General Soil Types of the Barind Area (After UNDP/FAO, 1988)

Soil Type	Characteristics
Calcareous Alluvium (non-saline)	Raw or stratified alluvium; calcareous throughout or within 125 cm from surface
Non Calcareous Alluvium	Raw or stratified alluvium; not calcareous
Calcareous Dark Grey Flood Plain Soils (non-saline)	Seasonally flooded soils with a complete B horizon which is dominantly gray and or has prominent gleyans; calcareous throughout or within 125 cm from surface
Non Calcareous Grey Flood Plain Soils (non-saline)	Seasonally flooded soils with a complete B horizon which either is dominantly dark and or has prominent dark gleyans; calcareous throughout or within 125 cm from surface
Acid Basin Clays	Poorly drained, grey or dark grey heavy clays with a cambic B horizon which are potentially toxically acidic within 125 cm from surface
Shallow and Deep Grey Terrace Soils	Poorly drained, grey silty soils overlying grey, heavy or dominantly red mottled, Madhupur Clay at 20 - 60 cm. Mainly medium to strongly acid throughout.

2.3 Climatology :

The Barind tract in NW Bangladesh in particular has a severe and arid dry season between November and May which brings drought and day time temperatures can exceed 40^0 C. As in other parts of the country, three distinct seasons occur, defined on the basis of rainfall distribution and temperature conditions. The pre-monsoon period (March to May) is hot and has periodic thunder showers derived from the Bay of Bengal. The monsoon or rainy season (June to October) brings frequent storms accounting for 85% of the annual precipitation. The winter (November to February) has day time temperature between 10° to 20° C and is almost rainless.

The seasonal distribution of rainfall, temperature and humidity gives the most useful indication of the climatic conditions. Other factors such as sunshine hours and wind speeds are of secondary importance.

2.3.1 Rainfall

Rainfall in the Barind has three sources:

- westerly anticyclonic depressions during the winter.
- northwesterly thunderstorms during the early summer, and
- monsoonal rains carried by the southwesterly trade winds during the summer.

The amount of winter anticyclonic rainfall is very small; only a few percent (1 - 5%) of the annual total falls during this period. After the winter rain there is a dry interval before the pre-monsoon thundery rains start brought in by the northwestern thunderstorms and occasionally accompanied by hail due to a sudden temperature drop. About 15 to 20% of the total annual rain takes place during the three pre-monsoon months although it is very unreliable.

There are 15 recording stations within the study area where daily rainfall records are kept and these records are available from the BWDB. The daily data shows a single rainstorm can reach up to 150 mm and single day rain up to 50 mm is very common in the monsoon. The number of rainy days in the study area ranges from 57 days to 105 days and there is little variation over the whole study area.

The annual rainfall from years 1972-94 are shown in figure 2.3 as measured at six different stations within the study area and its variation from 965 mm to 2000 mm. The isohyetal map collected with the long term average shows the areal distribution of rainfall in the study area. There is a general trend of higher rainfall from west to east (Figure 2.4).

The mean annual rainfall is important for the assessment of annual recharge to the aquifer but the amount of winter and pre-monsoon rain could considerably reduce the irrigation requirement and hence the amount of groundwater discharge required from the tubewells.

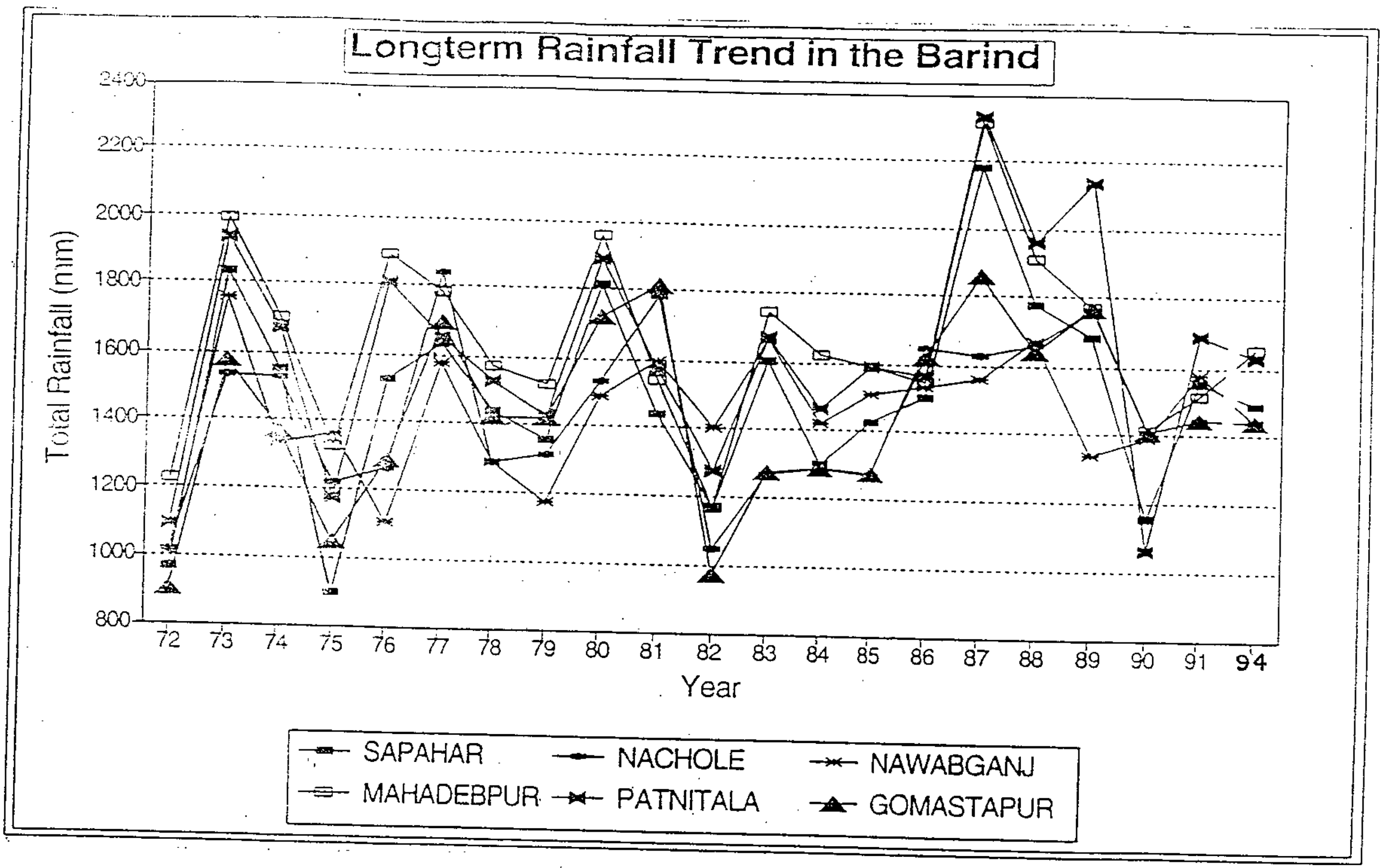


Fig. 2.3 : Longterm Rainfall Trend in the Barind

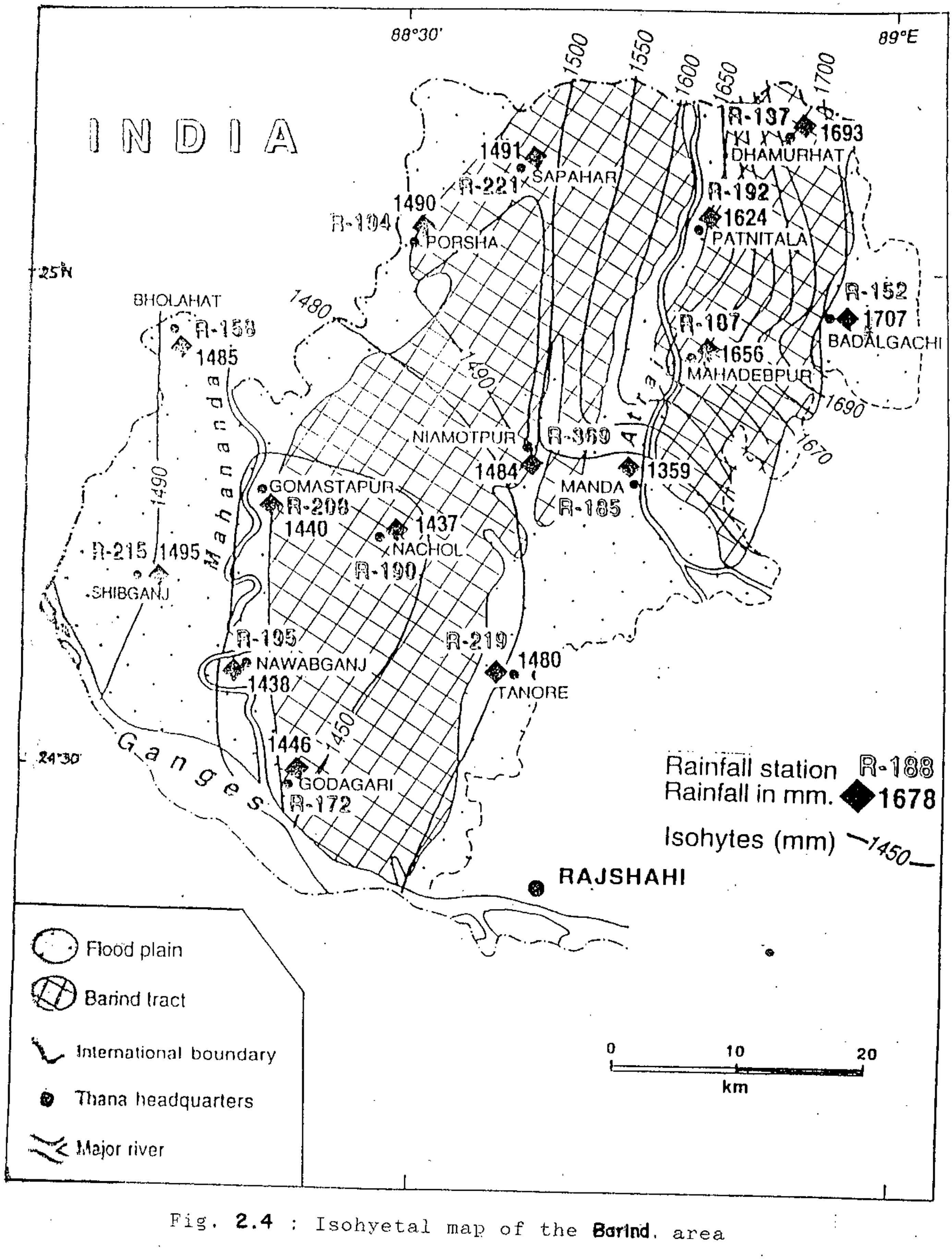


Fig. **2.4** : Isohyetal map of the **Barind** area

2.4 Water Resources Availability

The Barind hydrologic cycle consists of the following components :

- rainfall
- surface runoff
- evaporation from surface water bodies
- evaporation from ground surface
- infiltration
- vadose water
- ground water
- evapotranspiration
- irrigation back flow
- seepage to the rivers
- infiltration from rivers to the aquifers

Figure 2.5 shows the schematic diagram of the Barind hydrologic cycle. After rain, water reaching the ground surface is divided into a number of components - part is evaporated immediately after reaching the surface due to high temperature, a major part passes to the surface water bodies through the undulating surface and the *kharies*, part of it infiltrates into the confining clay and a component of this eventually reaches to the aquifer through the clay. Water is lost as evaporation and evapotranspiration from the surface water bodies, irrigation channels, irrigated lands and shallow aquifers. Part of the irrigation water percolates into the aquitard and aquifer. Groundwater flows to the rivers as base flow during the winter and water from surface water bodies infiltrates into the aquitard and aquifer in wet season.

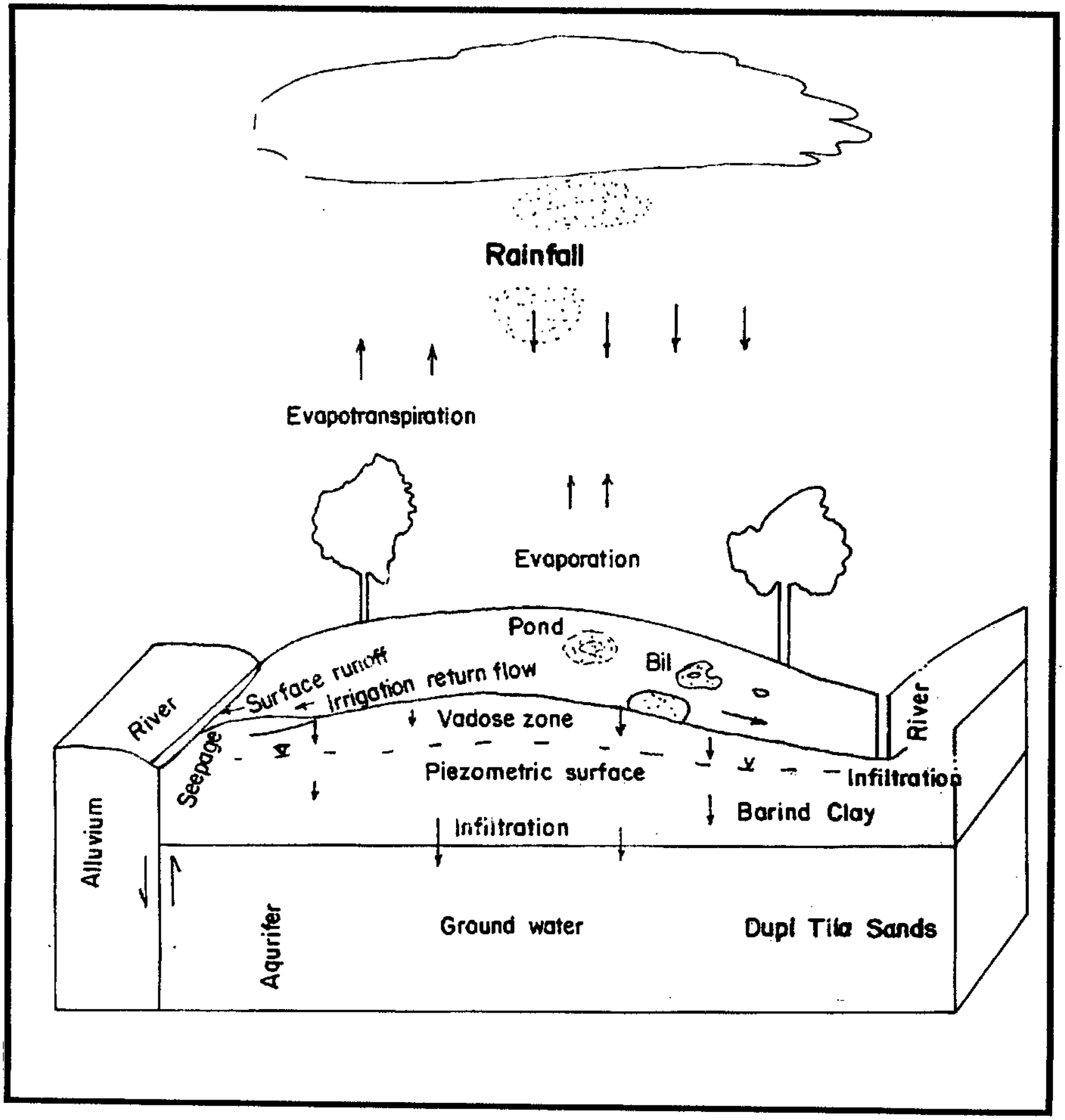


Fig. 2.5:Schematic diagram of the hydrologic cycle of the Barind area

2.5 Lithology

The subsurface lithology of the study area varies significantly from place to place. Figure 2.6 shows the drilling logs of the selected DTW. In this area, the lithology reveals that, almost in all cases, the first 0-15 m are hard clay to sandy clay, afterwards, FS to MS, MS to CS and finally, either fine sand or hard rocks where the drilling was stopped. In the Barind tract, fine sand to medium sand are predominant and their length varies from 20-35 m. For almost all cases the drilling was stopped either due to heavy stone or fine sand with plastic clay. Past observations show that mostly a very good sand layer of 1 to 2 m was found before the boulder was encountered. From the field experience the project authority feels that usually after crossing this heavy boulder either very coarse sand layer or plastic clay continues up to a considerable depth.

2.6 Static Water Level and Transmissivity

Static water level information has been collected to understand the configuration of the ground water-table in the subsurface. As the details of the exact location of wells were not available, the longitude and latitude were considered. The total area were divided into several grids and the approximate location of tubewells were considered. which covered about one fifth of the total area. The static water mapping of the study area shown in Figure 2.7. It is revealed that as one moves in the south-west and north-west direction, the static water level is found to be low and that level is found to be the suction limit of shallow tubewells. So in that direction DTWs were essential, but careful attentions were needed to pay in installing the DTW. Because the spacing within the contour revealed that in this area the BMDA authority had already installed enough tubewells and stress on groundwater use was higher then other locations. So, it was requested to avoid that area to install more new wells. This kind of mapping may be used to determine the best location of installing new tubewells. Since groundwater for irrigation is becoming more important, so with the help of such contouring of static water level, it will be possible to take proper decisions for future planning.

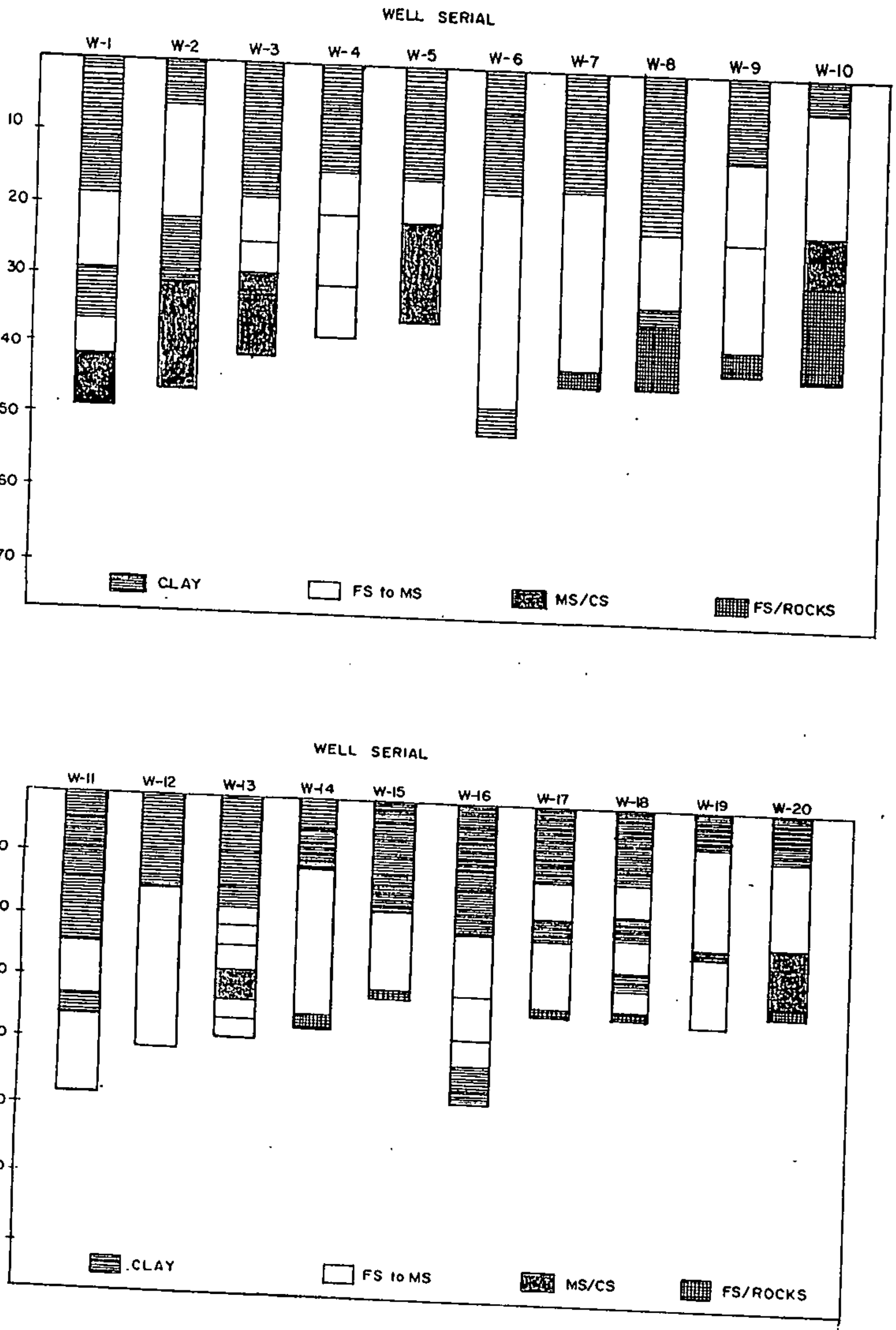


FIG. 2.6: LITHOLOGY OF THE SELECTED WELLS

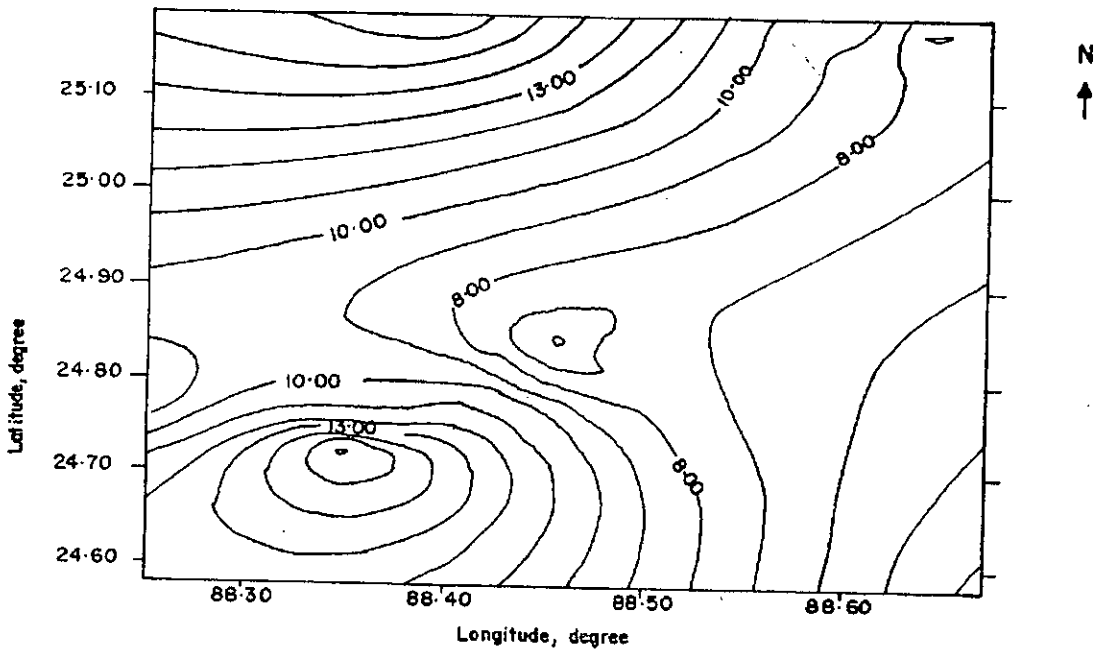


Fig NO. 2·7 : Contours of static water level (in meters) in Barind Tract of Bangladesh

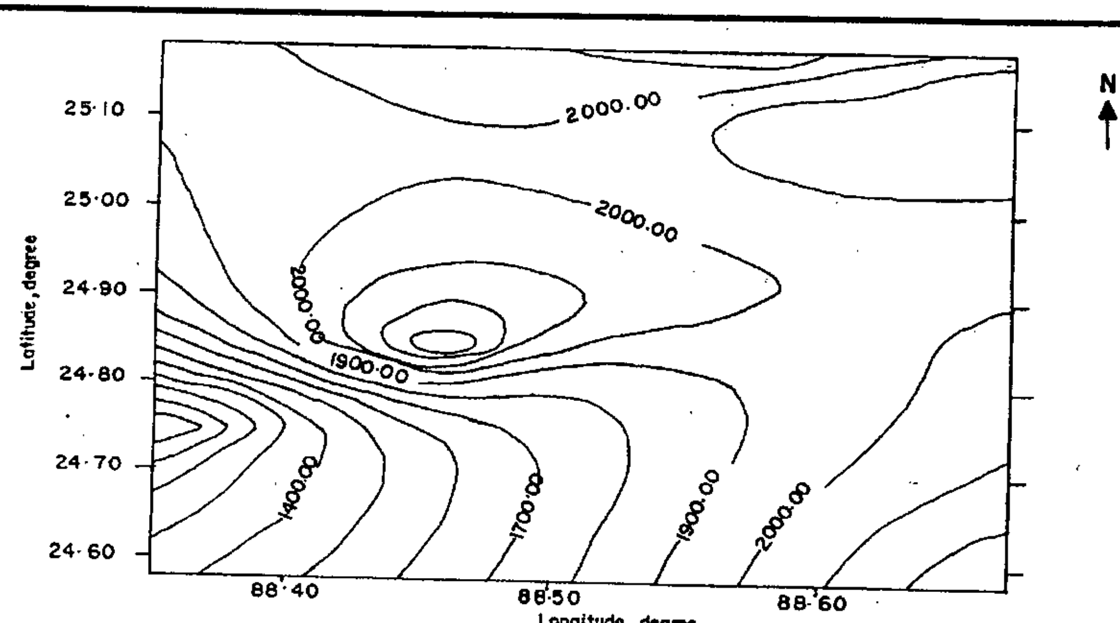


Fig No. 2·8 : Contours of transmissivity (m^2/day)

in Barind Tract of Bangladesh

The contours of transmissivity map has been collected from BMDA office (Fig-2.8). This shows the configuration of transmissivity varying from place to place. It is seen that the static water had no impact on transmissivity but it varies with aquifer formation. This also revealed that there had enough tubewells in low transmissivity area but few wells in high transmissivity areas. So, with the help of the contours it is possible to find out the suitable location for installing new wells.

2.7 Groundwater Investigation

A detailed hydrogeological and groundwater survey of Bangladesh was conducted by UNDP in February 1978; the project continued for almost four years (UNDP 1982). The survey found that in Barind area the main aquifer does not occur in the upper 300m; groundwater potential is limited to development from relatively thin, fine grained sand zones that occur within the clay sequence and the aquifer is capable of supporting only small domestic needs. Elsewhere in the report it is stated that the transmissivity is "unknown but estimated to be extremely low for development" that the water level is 5 – 12 m below ground surface, the total dissolved solids are in the range of 200 – 300 mg/l with the potential recharge estimated to be less than 80 mm/year.

An example of tubewell development, consider the deep tubewell which was installed in Godagari Thana in 1982. The tubewell was constructed with a total depth of 56.4 m having a screen of 21.5 m in length and 0.15 m in diameter. The tubewell discharge (3060 m^3/day) was satisfactory (Asaduzzaman, 1989).

A groundwater investigation was carried out by Bangladesh Water Development Board in 1989 and it was found that only shallow tubewells could be constructed with suction pumps to withdraw water which would be used for domestic purposes (BWDB, 1989).

2.8 Recharge to Aquifer

Various attempts have been made to estimate recharge of Barind aquifer. Table 2.4 gives Thanawise estimates of recharge in Barind area. These estimates were made on the basis of water level fluctuation (Khan, 1993 and MML, 1994).

A direct approach using some form of water balance is more reliable. This often involves some form of soil moisture water balance (Rushton and Ward, 1979). But a soil moisture water balance is unlikely to be appropriate in the Barind area where almost 70% of the area is covered by rice fields which have puddled beds to minimize seepage losses. The extensive area of rice fields would appear to indicate that recharge to the Barind aquifer will be limited. However, a number of field observations indicate that recharge could be significant (Asaduzzaman and Rushton, 1998).

- there is little surface drainage in the Barind area suggesting that much of the precipitation infiltrates. Furthermore, at the end of the monsoon there was no evidence of damage due to any runoff following heavy monsoon rainfall.

- Farmers like deep water on their rice fields because it reduces weed growth, and offers some insurance against irregularities of supply, but it is wasteful because it causes lateral percolation loss into the bunds (the bunds of the rice fields are high, often in the range 0.3 to 0.5 m) and thence down the ground water (Walker and Rushton, 1986).

- however, two weeks after the end of the monsoon season the depth of water in most of the rice fields was small suggesting that much of the water had infiltrated into the aquifer.

- field studies and mathematical modeling by Walker and Rushton (1986) have shown that substantail quantities of water can pass through the bunds of rice fields into the underlying aquifer (the loss can be as high as 20 mm d^{-1} when expressed as a depth of water.)

From the above information it seems likely that much of the monsoon rainfall is collected in the rice fields and then infiltrates into the aquifer system. The rice fields are therefore a very efficient recharge system.

Table 2.4 : Thanawise Groundwater Potential in Barind Area

District	Thana	Available recharge (Mm^3)	Usable recharge (Mm^3)	Potential recharge (Mm^3)
		3	4	5
Naogaon	Atrai	197.19	197.19	262.92
	Badalgachi	52.000	65.000	86.660
	Dhamurhat	78.810	98.520	131.36
	Manda	87.720	109.66	146.21
	Mahadebpur	116.76	145.95	194.60
	Naogaon	106.43	133.04	177.38
	Niamatpur	97.700	122.13	162.84
	Patnitala	81.720	102.16	136.21
	Porsha	73.760	92.210	122.94
	Raninagar	134.13	167.67	223.56
	Shapahar	75.000	93.760	125.01
	Total	1061.78	1327.29	1769.69
Na. Gonj	Bholahat	42.550	53.200	70.930
	Gomstapur	106.79	133.49	177.98
	Nachol	53.370	66.720	88.960
	Nawabgonj	202.08	252.61	336.81
	Shibgonj	185.30	231.63	308.84
	Total	590.09	737.65	983.52
Rajshahi	Bagha	58.950	73.700	98.260
	Bagmara	161.59	202.00	269.33
	Charghat	24.340	30.430	40.530
	Durgapur	68.110	85.130	113.51
	Godagari	112.58	140.70	187.60
	Mohanpur	54.120	67.660	90.210
	Paba	86.390	107.99	143.98
	Puthia	50.820	63.520	84.700
	Tanor	64.750	80.940	107.92
	Total	681.65	852.07	1136.04
Grand Total		2333.52	2917.01	3889.25

Source : Khan, 1993 and MML, 1994.

2.9 Well Design and Construction

Well performance and production life can be enhanced greatly by proper design and operation. Using screen entrance velocity as the only criteria is not sufficient for describing flow around the well and in many cases leads to an overly optimistic design. An irrigation well is designed and constructed to take advantage of natural condition at a given location to obtain the highest yield available from the aquifer.

In Barind area in many locations the transmissivities are moderate to high which should allow pumping yields to be at least $4000m^3d^{-1}$ (Asaduzzaman and Rushton, 1998). In order to make good use of the aquifer resources, appropriate technology is required for well construction. A specific example will be used to illustrate the development of an alternative well design for locations where conventional well design failed to produce an adequate yield. The aquifer system has a 4.8 m layer of clay directly beneath the ground surface, this is underlain by 24.4m of water-bearing strata consisting of fine sand, medium sand, coarse sand and gravel. Beneath the water-bearing strata is a thick clay which extends for at least 32m.

For the initial well design in 1976, a solid casing was installed extending for 15.2 m with a further 9.1m of 0.203m diameter slotted screen as shown in Figure 2.9(a). The rest water level is at a depth of 4.8m; to allow a sufficient depth of water over the pump the lowest safe pumping level is 13.4m. Hence the pumped drawdown cannot exceed 8.6m. In a pumping test with an abstraction rate of 2447m^3 d^{-1} the pumped drawdown was 7.44 m hence the specific capacity is 330 $m^3 d^{-1} m^{-1}$. This yield of 1 cusec is hardly sufficient for effective irrigation by a number of farmers.

In 1986 a new well was constructed within 30m of the first well, the aim of this new well was to provide an increased yield. The new borehole was drilled at 1.016m diameter; this is more than double the diameter of the original bore hole. The solid casing in this new well extends for 22.6m and there are four screen of 0.152m diameter projecting upwards from the base of the solid casing, as shown in Figure 2.9(b). The hole is back filled with pea gravel so that the volume of gravel pack associated with this borehole is approximately 20.8m^3 compared to 3.3m^3 for the original design.

Different designs of well used in the Barind project are shown in Figure 2.10. A conventional well (Figure 2.10.a) has a single screen below the pump which must always be submerged. The design shown in Figure 2.10(b) has a double screen which makes it easier for large quantities of water to enter, but it is similar to a conventional well in that the pump is above the screen. The well shown in Figure 2.10(c) is frequently used in the Barind project. It has four screens, which are placed above the pump allowing a larger drawdown while still keeping the pump submerged. Figure 2.10(d) shows a combination of screen both above and below the pump which would be used to tap layered aquifer (Asaduzzaman, 1989).

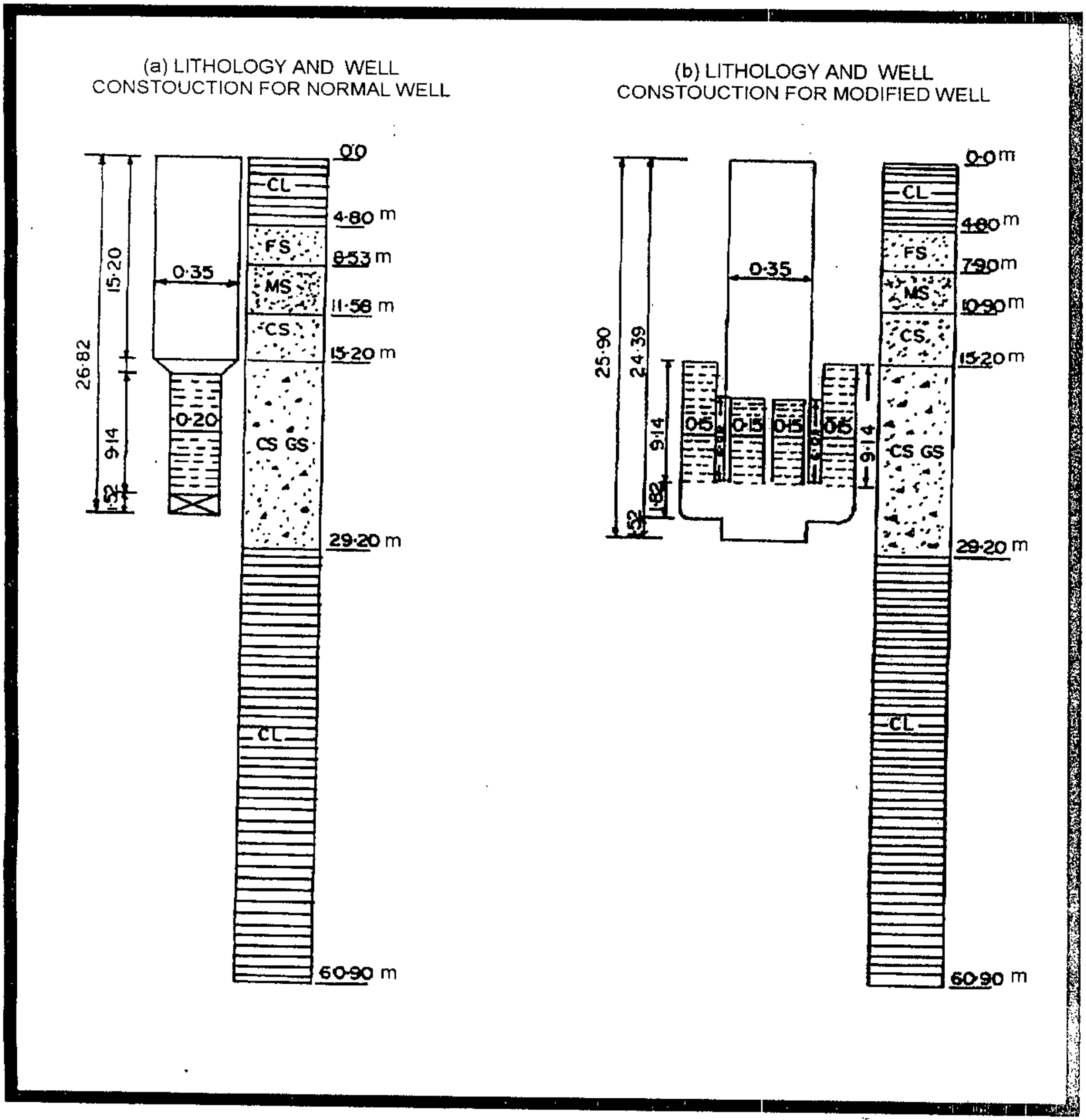


FIG 2.9-(a) Conventional (b) Modified design of well construction.

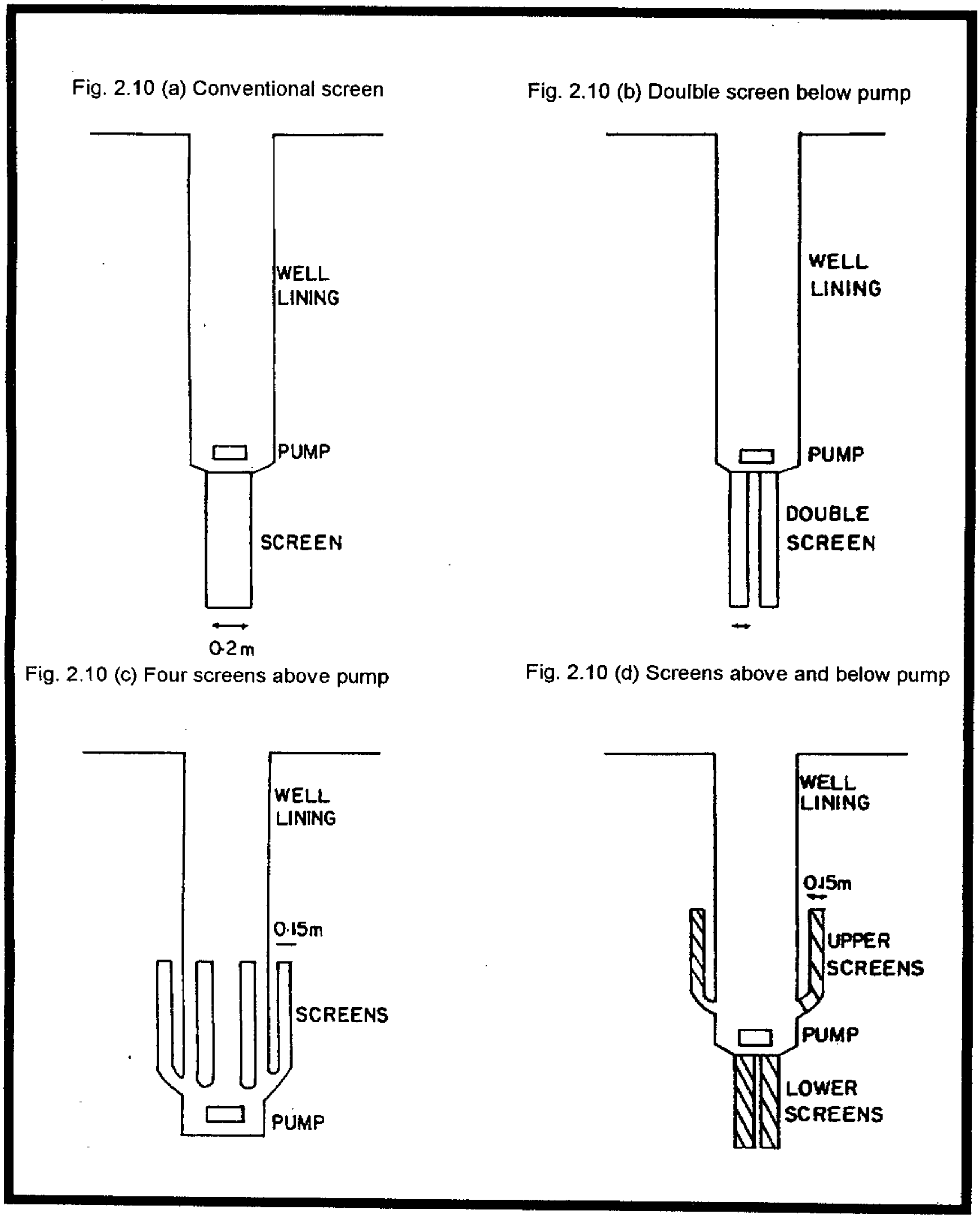


Fig - 2.10 : Different Designs of well used in the Barind project.

2.9.1 Well Drilling Methods

There are various methods of well drilling such as :

i) Cable Tool Percussion Method

ii) Hydraulic Rotary Drilling Method

iii) Reverse Circulation Method

iv) Jet Drilling

v) Hydraulic Percussion Method

vi) Air Rotary Drilling

Of the above methods, Reverse Circulation (RC) method was used for drilling the wells in the study area. However, Water Jetting was also applied in a few cases.

Reverse Circulation offers the cheapest way for drilling large diameter holes. Reverse Circulation utilize a suitable vacuum pump or air lift to abstract water and drill cutting through the drill-stem. This is discharged into a settling pit and the water allowed to return to the borehole by gravity, after the cut material has settled out. One of the advantages of the reverse circulation method is that little or no additives are required in circulating water and thus the formation of a mud cake on the borehole wall is minimized. Thus any addition of clay, bentonite, cement or cow dung should be avoided.

In the study area, the Upper Well Casing consists of 35 cm diameter mild steel pipes and the Lower Well Casing are either 15 cm or 20 cm diameter of Stainless Steel (SS) or Glassfiber Reinforced Plastic (GRP) with a slot size of 1 mm and percentage open area 12% and 15% respectively. Both vertical turbine pumps and submersible pumps are used for different heads and capacity (usually 0.056 m^3/sec).

2.9.2 Drilling of Large Diameter Hole

The drilling is normally done with 46 cm to 56 cm size cutter for normal tubewell and for modified tubewell, 1.02m cutter is used with some extra arrangement. The Photograph 1 (Plate 2.1) shows, the additional, and elongated cutter with the original one. In case when the hard sharped additional cutter is not available at the site, the drillers usually collect one pair of plough share from the farmer's house and welds these at the outer surface of the original cutter. The photograph no. 2 (Plate 2.1) shows the plough share. The plough share will work effectively so long no hard rock, heavy boulders and stones are encountered. The drilling of 1.02 m dia. some times invites problem of caving of the bore-hole. In that case precautions are taken by placing the temporary casing of 1.12m diameter up to a depth of upper clay layer. This could be seen in the photograph of 3, 4, 5 and 6 (Plate 2.1).

2.9.3 Different Joint System of Upper Casing With Modified Placement of Screens

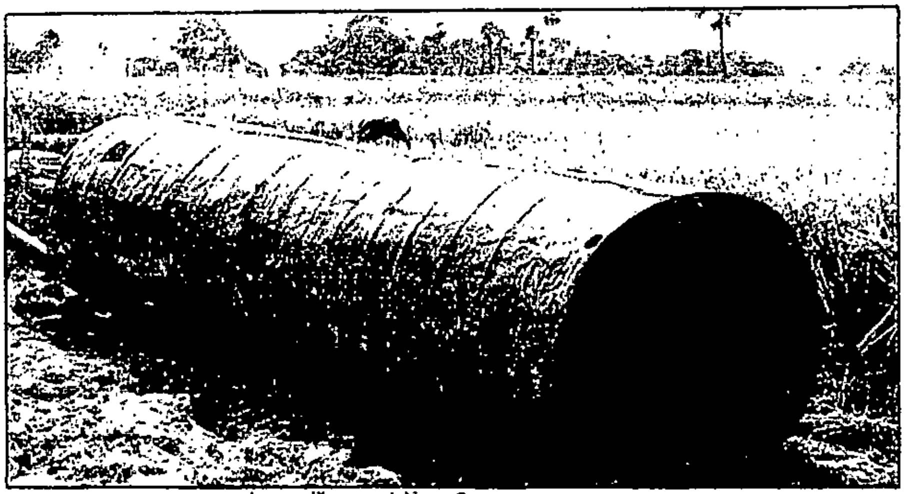
Till to-date all together four different types of joining system were tried successfully in the Barind area. These are shown in plate 2.2. These joining system could be prepared at the drilling site but requires more time and for this, the installation of well components will get delayed causing subsequent collapse of the bore hole. Hence it is advisable to keep these ready in advance to avoid the delay and any problems at the site.

PLATE : 2.1- Drilling of Large diameter hole for Modified design of well

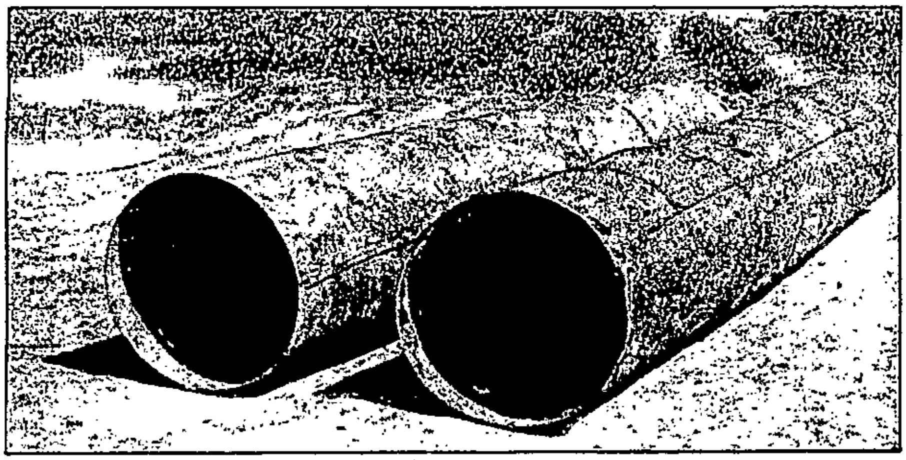
Photograph No- 1

Photograph No- 2

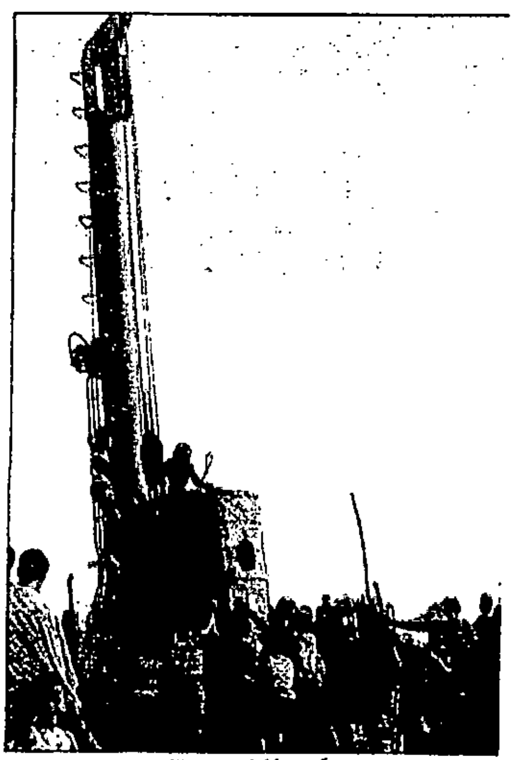
PLATE : 2.1 : Continued



Photograph No — 3



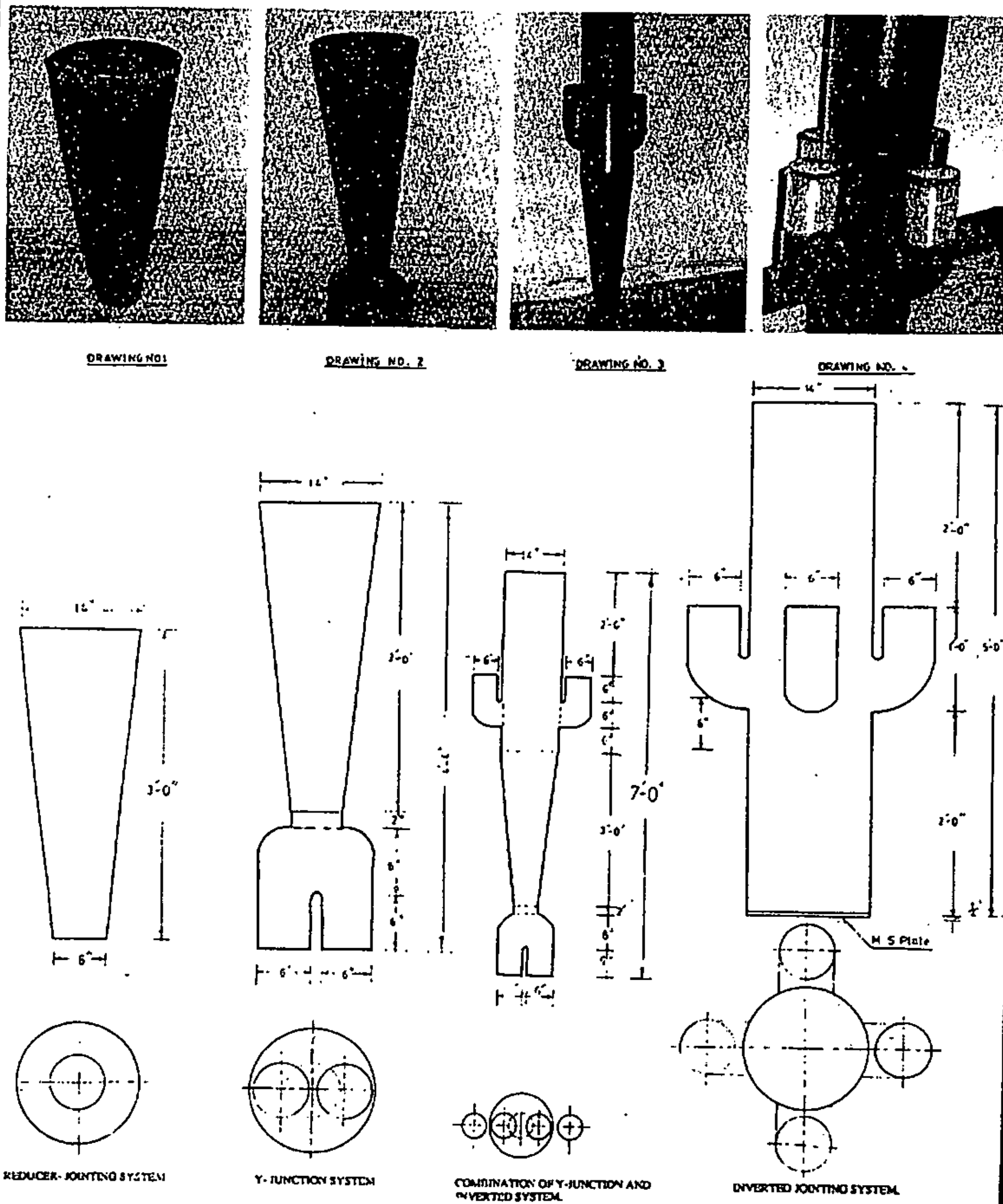
Photograph No — 4



Photograph No — 5

Photograph No — 6

PLATE : 2.2 Different jointing system used for modified design of well



METHODOLOGY

3.1 Introduction

Present study has been selected to compare the performance of conventional wells with that of the modified wells as well as to get an idea of hydraulics of the modified wells using selected parameters. The whole procedure consists of selection of tubewells, parameter choice, data collection from primary and secondary sources, data presentation and analysis of data. The above tasks have been performed systematically with some limitations. Details are described in the following sections.

3.2 Selection of Tubewells

In study area more than 6300 DTWs are in operation at present to meet the irrigation demand. For this study in order to compare the performance of conventional wells with that of the modified wells 10 conventional and 10 modified wells were selected considering the following criteria :

i) both data related to construction (borelog and well fixture) and the performance tests (step drawdown test) should be available in BMDA office for the well concerned.

ii) wells were selected in such a way that a pair of conventional and modified wells should be located close to each other.

iii) the sample should include the wells of different ages.

iv) in the west, the tract is hilly and dissected by narrow valley and usually the soils up to a depth of 25 m is hard clay, locally known as 'tough' Barind area. On the other hand in the east, it is nearly level and major soils are mixed yellowish brown and grey light loams to clay loams, which is locally known as 'soft' Barind area. On the basis of the above criteria, wells were selected in soft and tough Barind area.

The locations of the selected wells are shown in Table 3.1. The borelogs and well construction details are shown Figure 3.1.

Table 3.1 : Details of Selected Wells in the Study Area

Type of Well	Well Serial	Location	Date of Development	Tube Well Design				
				Housing			Screen	
				Total Length (m)	Diameter (mm)	Pump Setting (m)	Diameter (mm)	Length (m)
Conventional	1	Vaspur	26.03.87	50.06	356	31.70	150	24.40
	2	Olineamatpur	21.03.87	45.42	356	28.96	150	24.40
	3	Chaitannapur	27.03.87	38.41	356	23.78	150	24.40
	4	Majhihati	12.08.87	36.28	356	23.78	150	24.40
	5	Prashadpur	12.05.87	38.10	356	22.56	150	24.40
	6	Kuclapara	26.09.87	49.08	356	25.00	150	21.34
	7	Jhini	08.10.88	69.20	356	32.60	150	24.38
	8	Pakir	12.07.88	45.10	356	25.30	150	18.28
	9	Bongpur	20.10.88	56.10	356	25.30	150	24.38
	10	Kashipur	03.02.93	57.30	356	30.20	150	24.38
Modified	11	Vaspur	04.05.95	46.95	356	43.60	150	34.75
	12	Olineamatpur	12.08.95	40.85	356	38.72	150	46.34
	13	Chaitannapur	24.01.95	37.80	356	34.45	150	36.58
	14	Majhihati	27.02.95	36.58	356	32.93	150	36.58
	15	Prashadpur	10.03.95	32.62	356	31.40	150	36.58
	16	Kuclapara	15.12.97	46.95	356	40.55	150	48.78
	17	Gomostapur	09.03.95	33.84	356	31.40	150	36.58
	18	Gomostapur	24.03.95	37.20	356	34.45	150	36.58
	19	Nadore	04.04.94	39.60	356	32.20	150	34.48
	20	Khelna	24.04.88	49.70	356	25.90	150	34.38

Source : BMDA Office.

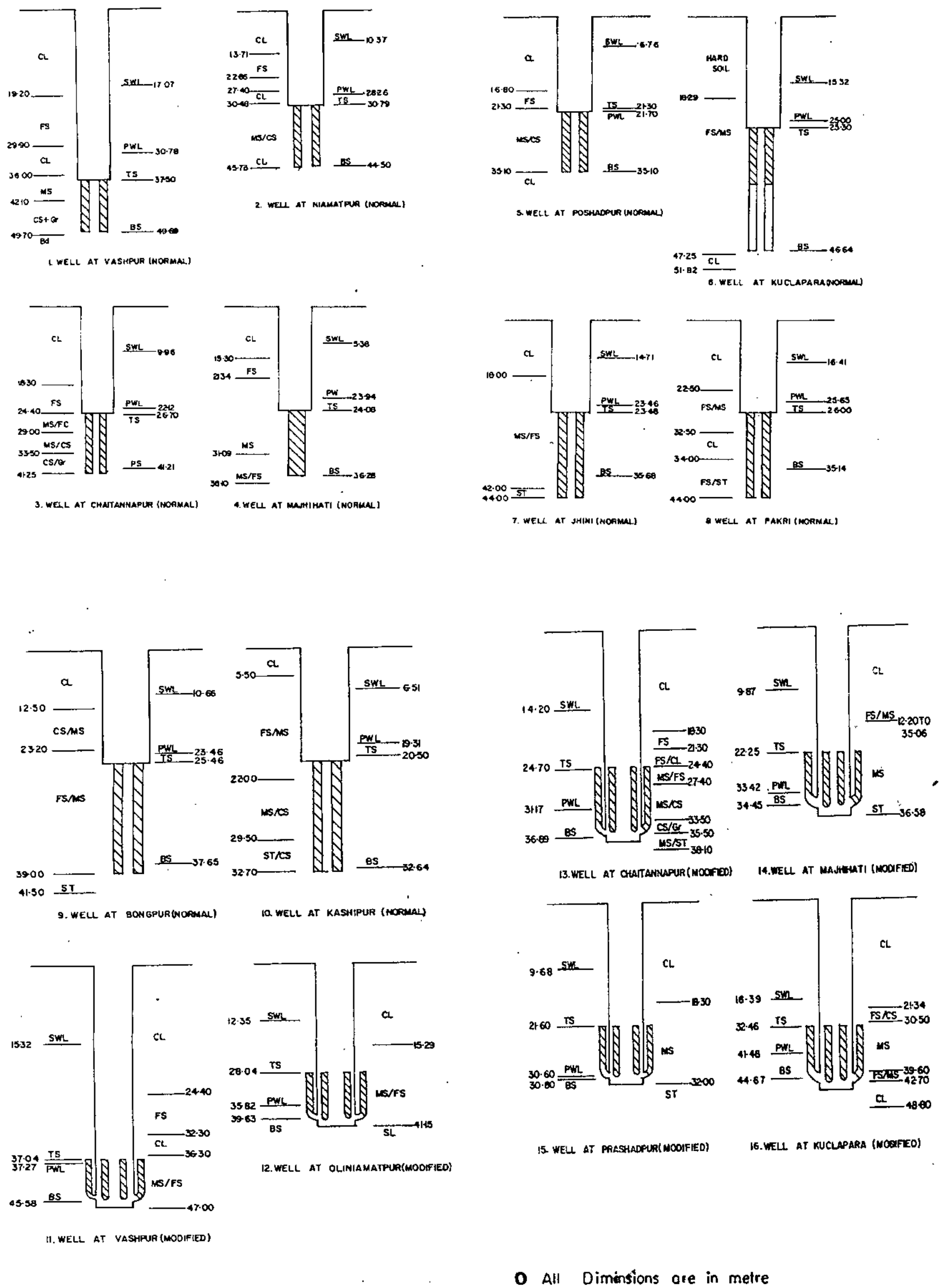
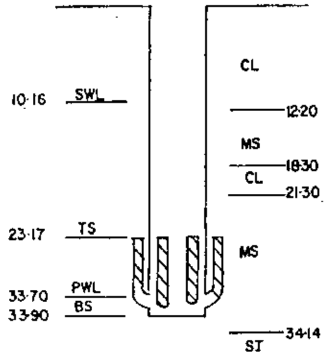
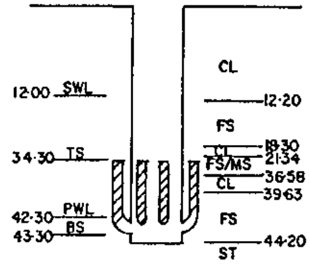


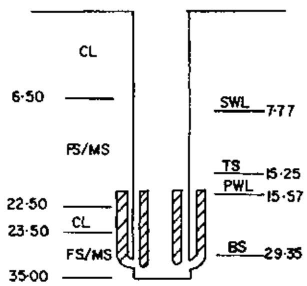
Fig. 3.1 Lithology and well construction for selected wells



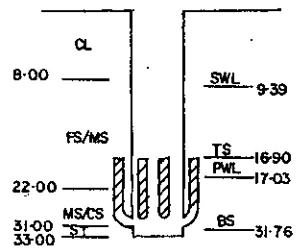
17. WELL AT GOMOSTAPUR (MODIFIED)



18. WELL AT GOMOSTAPUR (MODIFIED)



19. WELL AT NADORE (MODIFIED)



20. WELL AT KHELNA (MODIFIE)

O All Dimensions are in metre

Fig. 3.1 Continued

Also to understand the hydraulics of the modified well and the effect of design modification on performance of well two long term pumping test data sets were selected for Karmudanga and Chandlai aquifer. BMDA and BWDB conducted the tests in 1988 and 1986 respectively.

3.3 Performance Evaluation Approaches and Parameters

The comparison of the performance was made using the parameters: specific capacity, screen entrance velocity, well loss, well efficiency and well deterioration index. The detail procedures followed to determine each of the parameters are discussed in the following sections.

3.3.1 Specific Capacity

If the operating discharge is divided by the drawdown of a production well, the specific capacity is obtained. Specific capacity is a measure of the productivity of a well. From step drawdown test, the drawdown of a well is

$$s = (B_1 + B_2)Q + CQ^2$$

Where,

s = drawdown, m
Q = discharge, cumec
C = non-linear well loss coefficient
B_1 & B_2 = linear aquifer and well loss coefficient respectively.

Therefore, the specific capacity is

$$\frac{Q}{s} = \frac{1}{(B_1 + B_2)Q + CQ^2} \text{-------------------} (3.1)$$

Any significant decline in the specific capacity of well can be attributed either to a reduction in the transmissivity due to a lowering of the groundwater level in an unconfined aquifer or to an increase in well losses associated with varies type clogging or the deterioration of the well screen.

3.3.2 Screen Entrance Velocity

The most frequently used criteria for sizing a well screen is probably have been the screen entrance velocity concept. Because it is apparent that as groundwater converges towards a well its velocity increases. Different authors suggested that the velocity limit at the entrance of the strainer should be equal to 3 cm/sec and the upper limit of this velocity is up to 6 cm/sec. To express the velocities in terms of screen size, the following equation is applied,

$$V_S = Q/(C\pi D_S L_S P) \quad \text{(3.2)}$$

Where,

V_S = optimum screen entrance velocity, cm/sec

Q = is the discharge, cumec

C = clogging coefficient

D_S = screen diameter, cm

L_S = screen length, m

P = percent open area in the screen

In the study area, the project authority usually used 12% to 15% open area screen for Fiber Glass (FG) and Stainless Steel (SS) filter respectively. For determination of screen entrance velocity the data required for well construction details was collected from BMDA. For calculation of screen entrance velocity, it was assumed that, during development of well 100% of the opening area of a screen remains free and after time being 50% of the opening area of a screen will be blocked by aquifer materials.

3.3.3 Well Loss

Well losses are divided into linear and non linear head losses. Linear well losses are caused by damaging of the aquifer during drilling and completion of the well. These losses comprise, head losses due to compaction of the aquifer material during drilling, head losses due to plugging of the aquifer with drilling mud which reduces the permeability near the bore-hole, head losses in the gravel pack and head losses in the screen. Amongst the non-linear well losses are the friction losses that occur inside the well screen and in the suction pipe where the flow is turbulent, and the head losses that occur in the zone adjacent to the well where the flow is usually also turbulent. All these well losses are responsible for the drawdown inside the well being much greater than one would expect on theoretical grounds.

The well performance tests are mainly two types : steps and recovery test. However, the main objective of any well performance test is to split the total drawdown into different loss components. Here, the step drawdown test is used for the analysis.

Step Drawdown Test

It is a single well test (first performed by Jacob in 1947) in which the well is pumped at a low constant discharge rate until the drawdown within the well stabilizes. The pumping rate is then increased to a higher constant discharge rate and the well is pumped until the drawdown stabilizes once more. This process is repeated through at least three steps, which should all be of equal duration say, form 30 minutes to 2 hours each.

For the drawdown in a pumped well, Jacob gave the following equation :

$$s_w = B(r_{ew}, t) + CQ^2 \qquad \text{.....................(3.3)}$$

Where, $B(r_{ew}, t) = B_1(r_{ew}, t) + B_2$ ....(3.4)

$B_1(r_{ew}, t)$ and B_2 = linear aquifer and well loss coefficients respectively ;
C = non-linear well loss coefficient ; r_{ew} = effective radius of the well ;
r_w = actual radius of the well ; Q = discharge ; T = pumping time

Like, Jacob, different research have also found considerable variations in water level in and outside of the wells and tried to explain it mathematically in more exact form. Rorabaugh (1953) suggested that Jacob's equation should be:

$$s_w = BQ + CQ^p \qquad \text{.....................(3.5)}$$

Where, p have the values of 1.5 to 3.5, depending on the value of Q. But the value of p = 2, as proposed by Jacob is still accepted (Ramey 1982; Skinner 1988).

Various methods are available to analyse the step drawdown test. The methods based on Jacob's equation are :

i) The Hantush-Bierschenk method determines B and C which can be applied in confined, leaky or unconfined aquifers ;
ii) The Eden-Hazel method can be applied in confined aquifers which gives the value of well loss coefficients as well as estimates of the transmissivity of the aquifer.

In this study, Hantush-Bierschenk method was used to determine the losses.

Hantush-Bierschenk's Method

The procedure suggested by Hantush (1964) and Bierschenk (1963) is applicable if the following assumptions and conditions are satisfied :

i) The aquifer is confined or leaky.
ii) The aquifer has an infinite areal extent.
iii) The aquifer is homogenous, isotropic and of uniform thickness over the area influenced by the test.
iv) Prior to pumping the piezometric surface is horizontal (or nearly so) over the area that will be influenced by the test.
v) The aquifer is pumped step-wise at increased discharge rate.
vi) The well penetrates the entire thickness of the aquifer and thus receives water by horizontal flow.
vii) The water removed from storage is discharged instantaneously with decline of head.
viii) The diameter of the well is small, i.e. the storage in the well can be neglected.
ix) The flow to the well is in an unsteady state.
x) The non-linear well losses are appreciable and vary according to the expression CQ^2

Applying the principle of superposition to Jacob's equation, Hantush (1964) expressed the drawdown, $s_{w(n)}$ in a well during the n-th step of a step-drawdown test as:

$$S_{w(n)} = \sum_{i=1}^{n} \Delta Q_i B(r_{ew}, t - t_i) CQ_n^2 \text{ ----------------- } (3.6)$$

Where, $s_{w(n)}$ = total drawdown in the well during the n-th step at time t

r_{ew} = effective radius of the well

Q_n = constant discharge during the n-th step

t_i = time at which the i-th step begins($t_i = 0$)

$\Delta Q_i = Q_i - Q_{i-1}$ = discharge increment beginning at time t_i

Q_i = constant discharge during the i-th step of that preceding the n-th step.

The sum of increments of drawdown taken at a fixed interval of time from the beginning of each step ($t - t_i = \Delta t$) can be obtained from equation (3.6).

$$\sum_{i=1}^{n} \Delta S_w(i) = S_{w(n)} = B(r_{ew}, \Delta t) Q_n + CQ_n^2 \text{ ----------------- } (3.7)$$

Where, $\Delta s_{w(i)}$ = drawdown increment between the i-th step and that preceding it, taken at time ($t_i + \Delta t$) from the beginning of the i-th step. Equation (3.7) can be written as,

$$\frac{s_{w(n)}}{Q_n} = B(r_{ew}, \Delta t) + CQ_n \text{ -------------------------- } (3.8)$$

A plot of $s_{w(n)}/Q$ versus Q_n (Appendix – C) on arithmetic paper will yield a straight line whose slope is equal to C. The ordinate of this straight line at zero discharge gives the value of B.

3.3.4 Well Efficiency

Well efficiency is a measure of the effectiveness of a well in extracting water from and aquifer. Mogg (1969) computed the well efficiency using the ratio of the actual specific capacity at the well design rate after 24 hours of continuous pumping to the maximum specific capacity. In general, the maximum (or theoretical) specific capacity is calculated from the formation characteristics of the well and on the basis of pumping.

Well efficiency is sometimes characterized by the level to which the water level falls in a pumping well. The difference between the Static Water Level (SWL) and the Pumping Water Level (PWL) is the drawdown, and the greater the drawdown, the less efficient the well. Lowered efficiency results in increased pumping costs. According to Kwaecki (1995) the most accepted from to define the well efficiency is

$$Efficiency(\%) = \frac{Aquifer\ \ Loss}{Aquifer\ \ Loss + Well\ \ Loss} * 100 \text{-----------------}(3.9)$$

Where, aquifer loss, is a function of aquifer characteristics and cannot be affected by the well design. The well is affected by the well and can be reduced by good well design.

In this study the well efficiency was calculated using the following formula

$$E_w = 100 * \frac{BQ}{s_w} \text{------------------------}(3.10)$$

Where, BQ is the aquifer loss and s_w is the drawdown in the well

3.3.5 Well Deterioration Index

The deterioration index of a well normally changes with discharge. The specific capacity versus discharge relationship of a new well must be known in order to determine what decrease in well efficiency has occurred over time. The specific capacity for pumping rates are necessary to normalize the specific capacity in future i.e. compared to a corresponding specific capacity for the discharge at the time of measurement.

If discharge is divided by the drawdown in a pumping well, the specific capacity of the well is obtained. This is a measure of the productivity of the well, clearly the larger the specific capacity, the better the well (Todd, 1980). Starting from the approximate non-equilibrium equation and including the well loss,

$$S_w = \frac{2.3Q}{4\pi T} \ln \frac{2.2Tt}{r_w{}^2 S} + CQ^n \text{ ---------------------- } (3.11)$$

So that the specific capacity

$$\frac{Q}{S_w} = \frac{1}{2.3/4\pi T)\ln(2.25Tt/r_w{}^2 S) + CQ^{n-1}} \text{ ------------- } (3.12)$$

This indicates that the specific capacity decreases with Q and t, the well data plotted in Figure D.1 to D.9 of Appendix D demonstrate this effect. To calculate the deterioration index (I_d), the original specific capacity versus discharge were plotted and for the same discharge the new specific capacity were calculated from the figure. The deterioration index was determined both for modified and normal wells using the following formula :

$$I_d = \frac{SC_{act}}{SC_{new}} * 100 \text{ ---------------- } (3.13)$$

Where,

I_d	=	well deterioration index in percentage
SC_{act}	=	measured specific capacity from the well test
SC_{new}	=	either the specific capacity from the original step-drawdown test at the same discharge or the theoretical specific capacity.

For determination of well deterioration index, recent step drawdown test data are very essential, but in this study only nine recent step drawdown test (well 3, 6, 7, 8, 9, 10, 13, 19 and 20) data were available out of 20 selected wells.

3.4 Hydraulics of Modified Well

Hydraulics of modified wells were studied through closely examining the borelog and the results of a long term pumping test carried out on a modified well at Kurmudanga, Shapahar by BMDA in 1988.

Further to this the effect of design modification on the performance of well was investigated using a radial flow model. The lithology of the Barind area shows that the aquifer consists of two zones overlaying by a clay layer with a low permeability layer separating the two productive zones. Therefore, it is quite appropriate to use the radial flow model developed by Rathod and Rushton (1991). The main features of the model are described below :

It is a numerical model which represents both the radial and vertical flow of water and is applicable to aquifers that is divided into two layers with a low permeability layer above the top aquifer and also a low permeability layer between the two aquifers. The input into the program includes the following data :

- the thickness, vertical and radial permeabilities, storage coefficients (confined and unconfined) for each layer.
- the well radius, radius of influence and static water level
- the pumping rate and time
- the number and distance of observation borehole
- a well loss factor which lowered the permeability close to the well to represent well loss

The model has a provision to use extra information about permeabilities and storage coefficient for nodes which were at certain radial distances from the pumped well. This facilities allowed to represent the modified design in the model.

RESULTS AND DISCUSSION

To achieve the objectives of comparing the performance of modified wells with that of the conventional wells in Barind area and to understand the hydraulics of modified wells an analysis of data has been performed and a two-zone radial flow model was used. The methodology of this analysis was elaborated in chapter three and the results of this analysis obtained are presented in the following sections.

4.1 Performance of Wells

The performance of the modified wells were compared with that of the conventional wells using the indicators such as specific capacity, entrance velocity, well loss, well efficiency and well deterioration index. Each of the indicators were assessed using the data from step drawdown test performed at the time of well completion and development. The results are presented and discussed in the following articles.

4.1.1 Specific Capacity

The specific capacity is an important criteria to measure the performance of a well. It also represents the productivity of the aquifer. Table 4.1 shows the specific capacities of the selected wells. It is apparent from the table that the specific capacity varied from 0.13 m^2/min to 0.31 m^2/min with an average of 0.21 m^2/min for conventional wells and 0.17 m^2/min to 0.44 m^2/min with a mean of 0.26 m^2/min for modified wells. This means that the specific capacity for modified well has been increased by around 24%.

From these data, it is clear that the considerably larger drawdown have been obtained in case of modified wells. This is because the pumped water level is able to go much lower for the modified wells than for the conventional wells. For conventional well design the screen is placed below the pump which means that the pump water level must be a few meters above the screen to keep the pump submerged. On the other hand in the modified design, the screen rises upwards from the pump which means that the pump is set at a much greater depth and the pumped water level can be much lower. By having the screen higher than for a conventional wells, vertical flow is reduced.

Table 4.1 : Specific Capacity of the Selected Wells

Type of Well	Well Location	Pumping Rate (m^3/m)	Drawdown (m)	Specific Capacity ($m^3/min/m$)	Average Specific Capacity ($m^3/min/m$)
Conventional	Vaspur	1.73	9.69	0.17	0.21
	Neamatpur	1.75	13.41	0.13	
	Chait. Pur	1.73	9.07	0.19	
	M.ajhihati	2.07	15.54	0.13	
	Prashad pur	2.62	14.83	0.17	
	K.kulapara	2.07	6.59	0.31	
	Jhini	1.70	7.21	0.23	
	Pakri	1.70	7.35	0.23	
	Bongpur	1.70	5.90	0.28	
	Kashipur	1.70	6.22	0.27	
Modified	Vaspur	3.40	14.53	0.23	0.26
	Neamatpur	3.40	15.55	0.22	
	Chait. Pur	3.40	12.20	0.28	
	M.ajhihati	3.40	16.15	0.21	
	Prashad pur	3.40	16.88	0.20	
	K.hulapara	3.39	16.10	0.21	
	Gomostapur	3.40	16.86	0.21	
	Gomostapur	3.40	20.76	0.17	
	Nadore	3.36	7.90	0.42	
	Khelna	3.36	7.65	0.44	

It can also be noted from Table 4.1 that, the value of specific capacity varied considerably among the wells (0.13 m^2/min to 0.31 m^2/min for conventional wells and 0.20 m^2/min to 0.44 m^2/min for modified wells) of similar group. This might be because of either a reduction in transmissivity due to the lowering of the groundwater in an aquifer or to an increase in well loss associated with clogging or deterioration of the well screen.

4.1.2 Entrance Velocity

The screen entrance velocity can be taken as an indicator of the performance of a well. The entrance velocity should be within the allowable limit of 3 to 6 cm/sec. If the flow velocity exceeds the upper limit, finer particles will be transported from the aquifer into the gravel filter. The filter will be subsequently plugged, resulting in a loss of head. The entrance velocity for each of the selected well was calculated and shown in Table 4.2. From the table it reveals that the entrance velocity for modified well varied from 1.62 cm/sec to 2.88 cm/sec with an average of 2.27 cm/sec. On the other hand the entrance velocity for the conventional well ranged from 3.25 cm/sec to 5.41 cm/sec with a mean of 4.01 cm/sec. The less value for modified well may be because of selection of screen size and better well completion. Though the low velocity for modified well means less well loss due to turbulent flow, the value less then 3 cm/sec may cause problem of incrustation and corrosion as the slot opening of the screen.

It may also be noted that the modified design of well has not been very cost effective as the entrance velocity was calculated to be lower then the recommended range. As per this study, all the selected wells in the Barind area have a velocity lesser than the critical velocity but the calculated velocity for conventional well is higher then the recommended velocity.

Table 4.2 : Entrance Velocity of Flow of the Selected Wells

Type of Well	Well Location	Design Discharge (m^3/Sec)	Diameter of the Well (cm)	% Open Area	Strainer Length (m)	Entrance Velocity (cm/sec)	Average Entrance Velocity, cm/sec
Conventional	Vaspur	0.056	0.15	15	24.40	3.25	4.01
	Niamatpur	0.056	0.15	15	24.40	3.25	
	Chait. Pur	0.056	0.15	15	24.40	3.25	
	M.ajhihati	0.056	0.15	12	24.40	4.05	
	Prashadpur	0.056	0.15	12	24.40	4.06	
	Kuclapara	0.056	0.15	12	21.34	4.64	
	Jhini	0.056	0.15	12	24.38	4.06	
	Pakiri	0.056	0.15	12	18.28	5.41	
	Bongpur	0.056	0.15	12	24.38	4.06	
	Kashipur	0.056	0.15	12	24.38	4.06	
Modified	Vashpur	0.056	0.15	15	34.75*	2.27	2.27
	Niamatpur	0.056	0.15	15	46.34*	1.70	
	C.hait. Pur	0.056	0.15	12	36.58*	2.70	
	M.ajhihati	0.056	0.15	15	36.58*	2.16	
	Prashadpur	0.056	0.15	15	48.78*	1.62	
	K.uclapara	0.056	0.15	15	36.58*	2.16	
	Gomosta pur	0.056	0.15	15	36.58*	2.16	
	Gomosta pur	0.056	0.15	15	36.58*	2.16	
	Nadore	0.056	0.15	12	34.48*	2.87	
	Khelna	0.056	0.15	12	34.38*	2.88	

Source : BMDA Office * Total Length of Four Screens For Modified Wells.

4.1.3 Well Loss and Well Efficiency

Table 4.3 shows the calculated values of well loss and well efficiency for selected wells. Tabulated values reveals that the value of well loss coefficient, 'C' varied from 0.03 to 0.83 for conventional wells and from 0.01 to 0.13 in case of modified wells.

Table : 4.3 Well Loss and Well Efficiency of the Selected Wells

Type of Well	Well Location	Discharge Q (m^3/min)	Drawdown S_w (m)	Aquifer Loss Coefficient B (min/m^2)	Well Loss Coefficient ,C (min^2/m^5)	Well Loss (m)	Well Efficiency (%)
Conventional	Vaspur	2.34	14.93	4.50	0.83	4.52	70
	Niamatpur	2.33	17.89	7.60	0.03	0.16	98
	C.hait. Pur	2.27	12.16	4.90	0.19	0.97	91
	M.ajhihati	2.69	20.56	7.04	0.23	1.66	92
	Prashadpur	3.40	19.74	5.22	0.16	1.85	89
	Kuch. Para	2.90	9.68	2.80	0.18	1.51	83
	Jhini	3.06	8.75	2.68	0.06	0.56	93
	Pakir	3.06	9.24	2.62	0.13	1.22	86
	Bongpur	3.36	12.35	3.25	0.13	1.46	88
	Kashipur	3.36	12.80	3.50	0.09	1.01	91
Modified	Vaspur	5.11	21.95	4.23	0.01	0.26	98
	Oline. Pur	5.11	23.47	4.53	0.01	0.26	98
	Chait. Pur	4.69	16.97	3.47	0.03	0.14	91
	M.ajhihati	4.92	23.55	4.68	0.01	0.24	98
	Prashadpur	4.8	23.92	4.87	0.02	0.46	98
	K.uch Para	4.70	23.09	4.28	0.13	2.87	87
	Gomostapur	4.74	23.54	4.89	0.01	0.22	98
	Gomos.tapur	4.90	33.71	5.91	0.05	1.20	86
	Nadore	3.36	7.90	1.94	0.12	1.35	83
	Khelna	3.36	7.65	2.01	0.07	0.79	88

Walton (1978) gives the value of well loss coefficient, 'C' for different conditions of the well. Accordingly it indicates that all the wells except well at Vaspur (conventional design) were properly design and developed.

It is important to note that the value of well loss coefficient for modified wells are less in comparison with conventional wells. The low value of well loss coefficient for modified well means that they are properly designed and developed and they are in a good condition. The low value of well loss for modified wells means that they are more efficient than the conventional well.

Also form Table 4.3, it is found that the value of well efficiency varied from 70% to 98% for conventional wells and 83% to 98% for modified wells. The high value of well efficiency of modified wells as compared to conventional wells were mainly due to proper design and development, adequate gravel pack and proper selection of screen slot size.

Well efficiency gives an approximate idea about the well performance and it's not recommended that a well should be accepted or rejected on the basis of this efficiency values. According to Driscoll (1986), if the efficiency of well is less then 35% then it is a quite poor well. Under this consideration all the wells including the conventional are quite efficient.

4.1.4 Well Deterioration Index

The well deterioration index was calculated for selected wells are presented in Table 4.4. Tabulated values reveal that well deterioration index varied from 45% to 93% for conventional wells and from 66% to 95% in case of modified wells.

Table 4.4 : Well Deterioration Index of the Selected Wells

Type of Well	Well Location	Measured Specific Capacity (m^2/min)	Maximum Specific Capacity (m^2/min) From Graph	Deterioration Index $I_d = SC_{act}/SC_{new}$ %
Conventional	Chaitannapur	0.18	0.40	45%
	K.kclapara	0.30	0.48	63%
	Jhini	0.35	0.48	73%
	Pakir	0.33	0.42	78%
	Bongpur	0.27	0.48	56%
	Kashipur	0.27	0.29	93%
Modified	C.haitannpur	0.28	0.30	93%
	Nadore	0.42	0.44	95%
	Khelna	0.44	0.67	66%

Table 4.4 indicates well at Nadore, Chaitannapur (both are modified wells) and Kashipur (conventional well) are almost same as the original position. Wells at Chaitannapur, Kuclapara, Jhini, Pakir, Bongpur (all are conventional wells) and Khelna (modified well) are indicated as they are deteriorating compared to the original condition.

Otto (1983) stated that well efficiency is sometimes misused and it is better to use the well deterioration index instead. However, if we compare the well efficiency and deterioration index of the well then it's clear that even though one well has a higher efficiency, it's deteriorating with respect to the original condition. The deterioration may be due to obstruction of hydraulic flow path in vicinity of the well bore or clogging of the screen opening.

4.2 Hydraulics of Modified Well

The hydraulics of modified well have been studied considering the flow mechanism and through simulation of the effect of design modification on well performance using two-zoned radial flow model.

4.2.1 Flow Mechanism

In a conventional well design, the pump is always submerged and normally placed at least 1 - 2 meter above the screen which is shown in Figure 2.10(a) & (b). A consequence of this is that for a given pumped water level (PWL), there is a minimum depth at which the well screen can start.

The modified designs have the screen going up above the level of the pump which allows their screen to start at a much smaller depth than a conventional well as shown in Figure 2.10(c) & (d). This results in water from higher aquifers being tapped without the water having to flow far below. For unconsolidated aquifer formed by sedimentary deposit the vertical conductivity are much lower than the horizontal one. Consequently reducing the amount of vertical flow results in considerably low head loss. Since the vertical flow has required the large head difference than horizontal flow.

Because of the smaller radius and higher entrance velocity the drawdown in the conventional well is relatively high. This means that the screen has to be placed at dipper position. As a result the length of vertical flow path for conventional well is relatively long. Flow to typical conventional and modified well as depicted by Hoare (1997) are shown in Figure 4.1(a) and 4.1(b) respectively.

Vertical flow occurs in the modified case, but it is small which can be seen from the pumping test results of plot number 2432 at Karmudanga, Shapahar. The layout of the observation well is shown in Figure 4.2 and the results of the pumping test are shown in Table 4.5. The discharge during pumping phase was 3663 m^3/day which was continued for 3 days and the recovery was recorded for 1 day after the pumping was stopped.

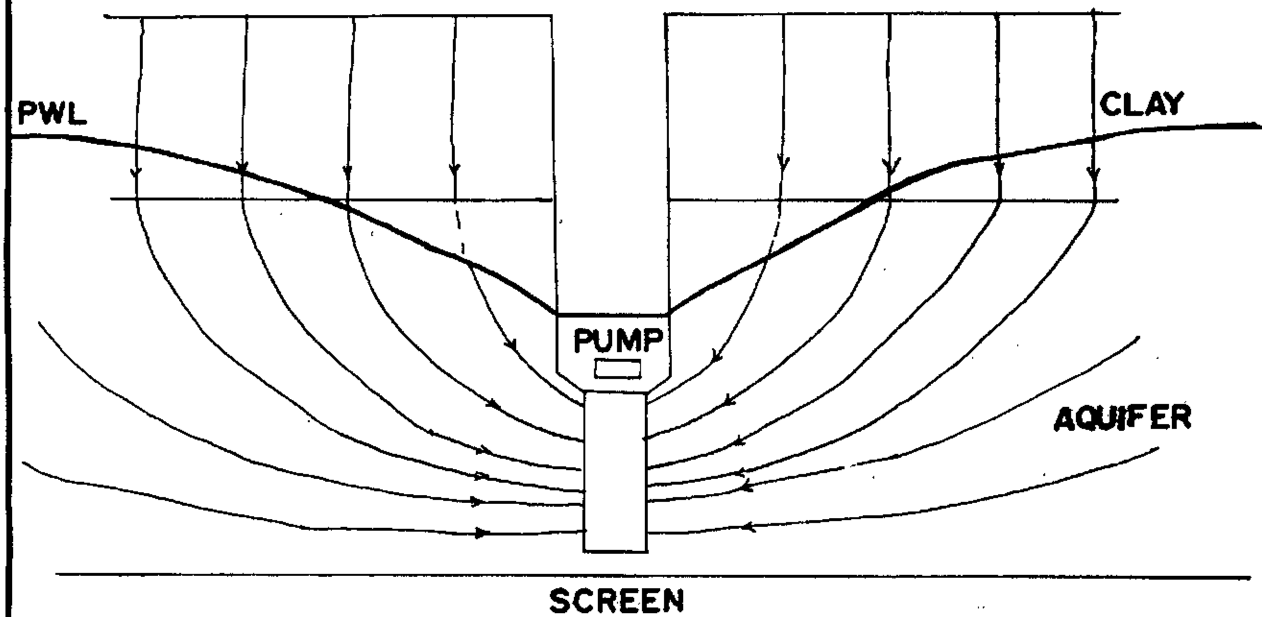


Fig.- 4.1 (a) : Flow to a conventional well

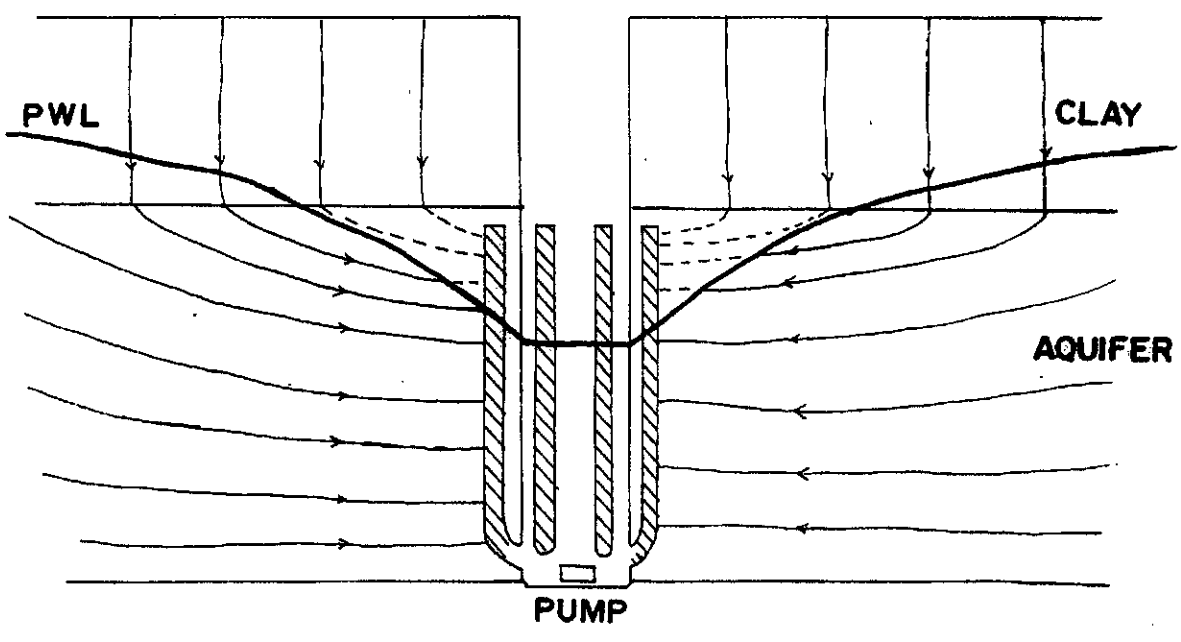


Fig.- 4.1 (b) : Flow to a modified well

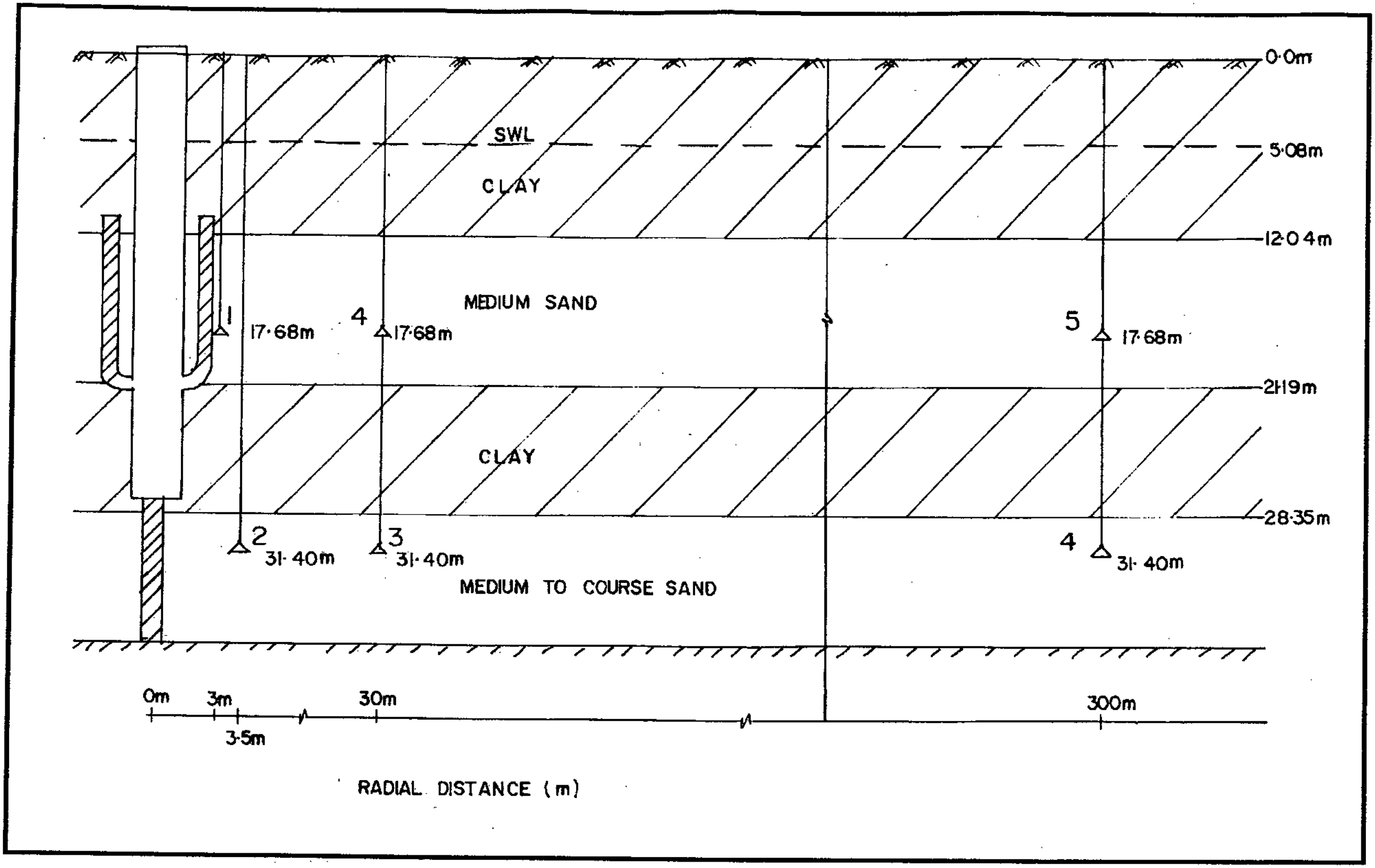


Fig. 4.2 : Details of well and Observation piezometers used in pumping test : Kurmudanga, Shapahar.

Table 4.5 : Measured Drawdowns at Different Radial Distances, Depths and Times

R(m) Depth (m)	**0** **35.98**	3 17.68	3.5 31.40	30 17.68	30 31.40	300 17.68	300 31.40
Pumping							
S (m) t = 0.5 min	**2.28**	1.03	1.13	0.06	0.12	0	0
S (m) t = 5 min	**2.53**	1.33	1.43	0.32	0.43	0	0
S (m) t = 60 min	**2.99**	1.79	1.86	0.73	0.82	0.06	0.05
S (m) t = 800 min	**3.16**	1.96	2.10	0.91	1.11	0.21	0.29
S (m) t = 4320 min	**3.28**	2.11	2.22	1.08	1.26	0.35	0.37
Recovery							
S (m) t = 0.5 min	**1.15**	1.17	1.22	101	1.10	0.35	0.34
S (m) t = 5 min	**0.87**	0.91	0.86	0.81	0.82	0.35	0.34
S (m) t = 60 min	**0.56**	0.58	0.52	0.58	0.48	0.33	0.28
S (m) t = 800 min	**0.26**	0.28	0.25	0.29	0.23	0.24	0.20
S (m) t = 1400 min	**0.17**	0.23	0.17	0.18	0.15	0.19	0.10

It is evident from Table 4.5 that the drawdown during the pumping phase is slightly more at greater depth. This means that the drawdown as well as radial flow occurred during the pumping phase.

During the recovery phase the situation is reversed. However the difference in head between the higher and the lower aquifers are small, and drawdown is greater at lower depth and so there will be a small upward component of velocity, but it is very low compared to the radial velocity.

4.2.2 Effects of Design Modification

An attempt was made to simulate the effect of design modification of a well on its performance using the two-zoned radial flow model as discussed in chapter four. At first the model was applied to derive the values of aquifer parameters by matching the model predicted drawdown with the measured ones. The values of the parameters obtained by using the model were compared with the values deduced by the analytical approach (BWDB, 1986). Then the effect of design modification of a typical modified well was predicted using the same values of the aquifer parameters but with non-standard values near the wells to represent the outer screens projecting upward. A long term pumping test was carried out on a conventional well at Chandlai, Godagari by BWDB. The well log and details of abstraction well and observation well are shown in Figure 4.3. The test pumping started from a rest condition at 7.30m with a pumping of 2938 m^3/day for 4 days and recovery continue for a further 1.97 day.

The radial flow model was used to simulate the pumping test result by using various values of aquifer parameters until a good match between the predicted drawdown and measured drawdown. The well radius was 0.10m and the maximum radial distance was used as 2000 m.

Table 4.6 : Measured and Modelled Drawdowns 4 Days After Pumping Started

Description	Abstraction Well	Observation Well Radial Distances (m)		
		5	50	100
Measure Drawdown (m) During Pumping Test	9.17	5.78	3.68	2.66
Drawdown (m) Predicted by Model	9.69	5.71	3.11	2.33

Table 4.6 shows both the measured and model predicted drawdown at abstraction as well as observation wells. It is evident from above table that there is a close agreement between the model predicted drawdown and measured drawdown. It should be noted here that in order to obtain such a matching, the value of well loss coefficient was used as 0.001 for the lower zone which is abnormally low. This might be because of error in the measuring of water level in the abstraction well.

The hydraulic properties of the aquifer at Chandlai area were determined by the aquifer test. Jacob method was used in the analysis to determine the transmissivity and storage coefficient of the aquifer. The estimated transmissivity values of different pieozometric wells varied from 408.86 m^2/day to 586.68 m^2/day. The estimated storage coefficient of the aquifer ranged from $6.41*10^{-4}$ to $3.07*10^{-3}$ and average value is $1.08*10^{-3}$. The values of the parameters derived from this analysis along with those obtained by analytical method (BWDB, 1986) are shown in Table 4.7.

Table 4.7 : Transmissivity and Storage Coefficient for Test Site Calculated by Different Method

Method of Analysis	Transmissivity (m^2/day)	Storage Coefficient
Jacob	504	0.001
Two Zone Model	432	0.003

It is seen from the table that the values of the transmissivity derived from the numerical analysis are quite close to the result obtained by using analytical method (Jacob). But the value of storage coefficient ascertained by using numerical method are considerably large than those calculated by using Jacob method. Jacob method ignores some of the important features such as well storage, vertical flow, etc. which operate under the influence of pumping. The numerical model, on the other hand, takes into consideration all these features. Therefore, the result deduced by using numerical method seem to be superior to the result obtained by analytical method.

The effect of design modification was predicted by representing a typical modified well as shown in Figure 4.4. The same values of the aquifer parameters as deduced from the pumping test were used in the predicative run. These values are shown in Table 4.8. The same values of well loss coefficient, radius of influence were used. The well radius was considered as 0.25m for modified design. It is important to note that for modified well water is abstracted from both upper and lower zones (Figure 4.4).

Table 4.8 : Parameters Deduced From Numerical Analysis of Pumping Test

Zone or Layer	Thickness (m)	Hydraulic Conductivity, (m/day)		Storage Coefficient	
		Radial	Vertical	Confined	Unconfined
Overlying	15.24 – 7.30	-	0.002	-	-
Upper	19.82 – 15.24	3.90	1.75	0.003	0.12
Middle	24.39 – 15.24	-	0.005	-	-
Lower	45.73 – 24.39	19.40	6.5	0.003	-

For modified well the screen goes up the outside of the well casing which allows the water to flow very easily through it. Therefore the outer screens were modeled by using a zone (up to a distance of 0.79m) of very high vertical and radial permeabilities and with a storage coefficient equals to 1. The purpose was to make the vertical flow of water through all the layers very easy close to the well (Hoare, 1997). However this representation of the screen is not very perfect, particularly the lower screen is single and the upper screen are double and yet they were modeled in the same way. Table 4.9 shows the results of the predictive run.

Table 4.9 : Model Predicted Drawdowns For Conventional and Modified Design 4 Days After Pumping Started

Description	Abstraction Well	Observation Well Radial Distances (m)		
		5	50	100
Drawdown (m) Predicted by Model For Conventional Design of Well	9.69	5.71	3.11	2.33
Drawdown (m) Predicted by Model For Modified Design of Well	8.31	5.50	3.02	2.28

It is seen from the table that the drawdowns both at the abstraction as well as observation wells were considerably less for the modified design. This support the idea that the drawdowns are decreased due to reduction in vertical component of flow.

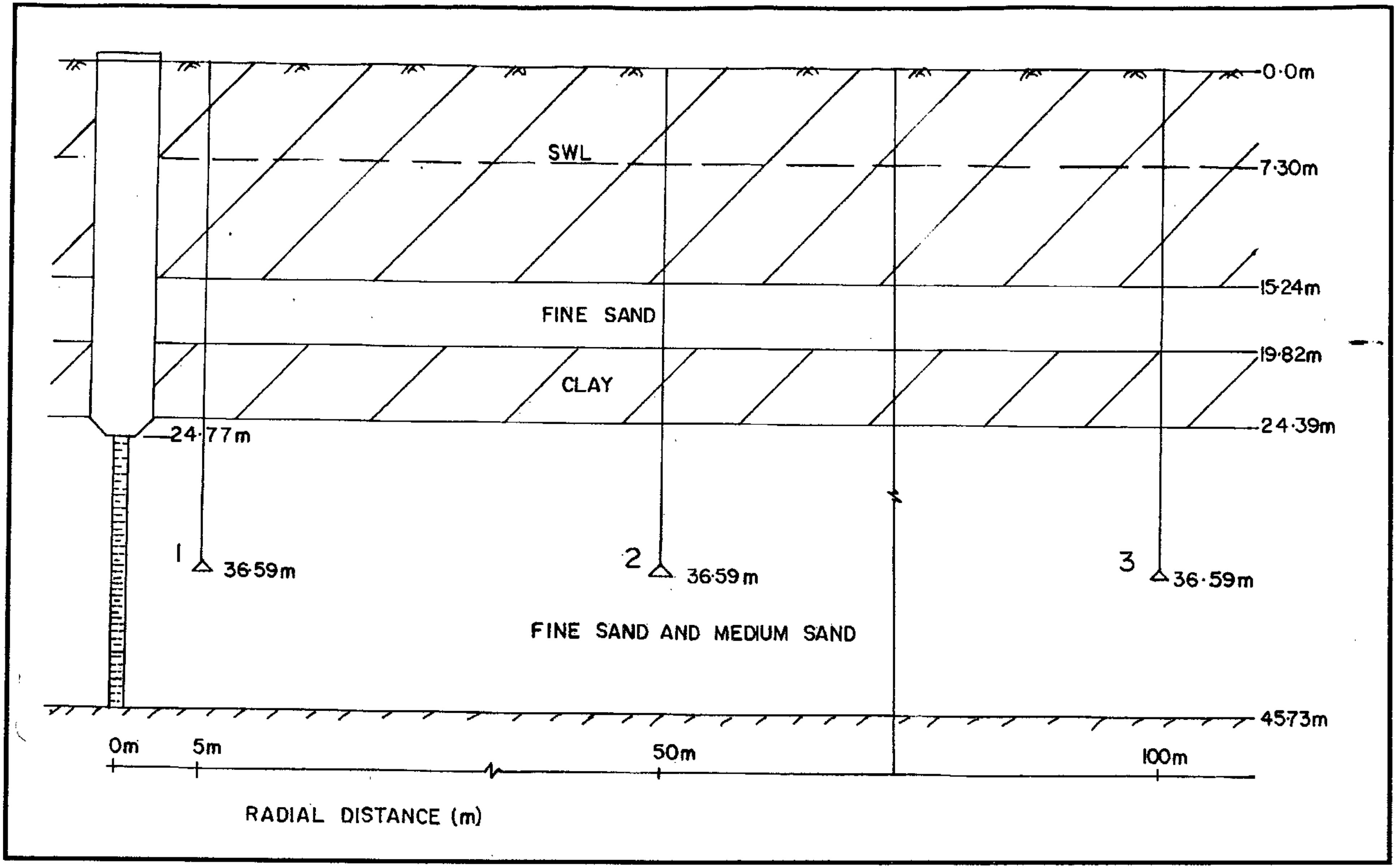


Fig. 4.3 : Details of well and Observation piezometers used in pumping test : Chandlai, Godagari.

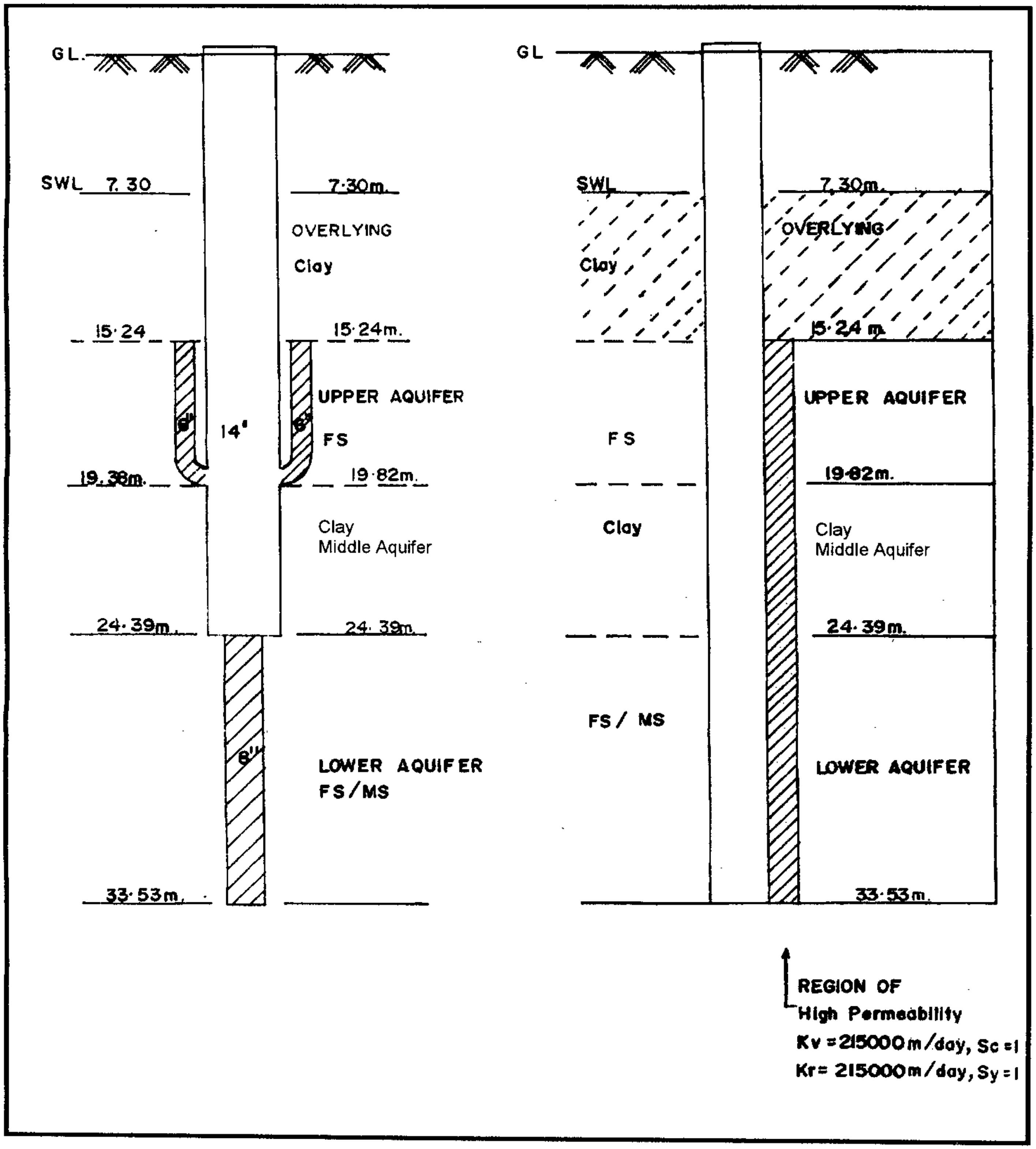


Fig. 4.4: Design and soil layer for modified well.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDY

5.1 Conclusions

Based on the findings of this study the following conclusions have been made:

1. The performance of well in terms of specific capacity could be significantly improved through modification of the design.

2. Well loss could be reduced and also the well efficiency could be improved through modification of design.

3. Use of the longer screen and increasing well radius, the entrance velocity of the modified wells were made lowered than that of the conventional design. However, this modification seems not to be cost-effective as entrance velocity of the modified design was found to be lower than the recommended value.

4. The well have been moderately deteriorated irrespective of its design.

5. Using screen at shallow depth in case of modified design reduces the vertical component of flow thereby reducing the drawdown.

6. The higher drawdown at the abstraction well could be accommodated in modified well by placing the pump below the screens thereby increasing the abstraction rate.

5.2 Recommendations For Future Study

The study was carried out to compare the performance of modified wells with the conventional wells and to gain some understanding of the hydraulics of modified wells. However, the study has some limitations, therefore the following recommendations are made for future study :

1. Present study could cover only a small number of wells to determine the deterioration index. Further study should be undertaken to determine the deterioration index of the other wells and a rehabilitation program can be taken.

2. Mapping should be done for aquifer and well parameters of all wells in the Barind area for getting quick information of the tubewells and aquifer conditions. A study can be conducted to prepare contours of well transmissivity, static water level and pumping water level to compare with the regional trends and to determine the best location for installing a new production wells.

3. In the study area, it seems that much of the monsoon rainfall is collected in the rice fields and then infiltrates in to the aquifer system. The rice fields are therefore a very efficient recharge system. Future studies should include simple lysimeter experiments in individual rice fields during the monsoon to quantify those losses from the rice fields, which become recharge.

4. The hydraulics of the modified well could not be studied adequately because the long term pumping test data were not available for both conventional and modified wells at the same location. Long term pumping test should be carried out on modified wells.

5. In model application the water level in the overlying layer remains constant. This seems not to be reasonable. Further investigation of the properties of the overlying layer should be investigated.

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APPENDICES

Appendix – A

Table A1 : Pumping Test Data of Well No. 1 (Conventional)

Time Since Pumping Started (min)	Discharge (m^3/sec)	Actual Drawdown (m)
0	-	-
10	0.028	9.27
20	,,	9.37
30	,,	9.42
45	,,	9.48
60	,,	9.52
90	,,	9.62
100	,,	9.65
120	,,	9.69
135	0.035	13.21
150	,,	13.28
180	,,	13.41
190	0.040	14.71
200	,,	14.74
210	,,	14.78
225	,,	14.83
240	,,	14.86
270	,,	14.93

Table A2 : Pumping Test Data of Well No. 2 (Conventional)

Time Since Pumping Started (min)	Discharge (m^3/sec)	Actual Drawdown (m)
0	-	-
10	0.030	11.89
20	,,	12.21
30	,,	12.54
45	,,	12.92
60	,,	13.10
90	,,	13.36
100	,,	13.39
120	,,	13.41
135	0.035	16.00
150	,,	16.18
180	0.039	16.43
190	,,	16.53
200	,,	16.71
210	,,	17.12
225	,,	17.17
240	,,	17.82
270	,,	17.89

Table A3 : Pumping Test Data of Well No. 3 (Conventional)

Time Since Pumping Started (min)	Discharge (m^3/sec)	Actual Drawdown (m)
0	-	-
10	0.040	8.66
20	"	8.71
30	"	8.81
45	"	8.97
60	"	9.00
90	"	9.02
100	"	9.04
120	"	9.07
135	0.058	10.77
150	"	10.82
180	"	10.85
190	"	10.88
200	"	10.91
210	0.064	12.06
225	"	12.10
240	"	12.14
270	"	12.16

Table A4 : Pumping Test Data of Well No. 4 (Conventional)

Time Since Pumping Started (min)	Discharge (m^3/sec)	Actual Drawdown (m)
0	-	-
10	0.035	15.42
20	"	15.47
30	"	15.51
45	"	15.54
60	"	15.55
90	0.040	17.70
100	"	18.17
120	"	18.24
135	"	18.26
150	"	18.32
180	0.044	20.17
190	"	20.47
200	"	20.48
210	"	20.48
225	"	20.50
240	"	20.50
270	"	20.56

Table A5 : Pumping Test Data of Well No. 5 (Conventional)

Time Since Pumping Started (min)	Discharge (m^3/sec)	Actual Drawdown (m)
0	-	-
10	0.074	14.58
20	"	14.77
30	"	14.81
45	"	14.83
60	"	14.83
90	0.089	16.67
100	"	17.89
120	"	17.89
135	"	17.89
150	"	17.98
180	0.096	19.13
190	"	19.43
200	"	19.46
210	"	19.48
225	"	19.72
240	"	19.74
270	"	19.74

Table A6 : Pumping Test Data of Well No. 6 (Conventional)

Time Since Pumping Started (min)	Discharge (m^3/sec)	Actual Drawdown (m)
0	-	-
10	0.058	6.29
20	"	6.42
30	"	6.50
45	"	6.55
60	"	6.59
90	0.073	6.60
100	"	8.38
120	"	8.39
135	"	8.40
150	"	8.43
180	0.083	9.67
190	"	9.67
200	"	9.67
210	"	9.67
225	"	9.67
240	"	9.68
270	"	9.68

Table A7 : Pumping Test Data of Well No. 7 (Conventional)

Time Since Pumping Started (min)	Discharge (m^3/sec)	Actual Drawdown (m)
0	-	-
10	0.028	4.35
20	,,	4.45
30	,,	4.52
45	,,	4.58
60	,,	4.63
90	,,	4.68
120	,,	4 .72
130	0.042	7. 06
140	,,	7. 08
150	,,	7. 11
165	,,	7. 14
180	,,	7. 17
210	,,	7. 18
240	,,	7. 21
250	0.050	8. 58
260	,,	8. 60
270	,,	8.65
285	,,	8.70
300	,,	8.75

Table A8 : Pumping Test Data of Well No. 8 (Conventional)

Time Since Pumping Started (min)	Discharge (m^3/sec)	Actual Drawdown (m)
0	-	-
10	0.028	4.40
20	,,	4.50
30	,,	4.58
45	,,	4.65
60	,,	4.72
90	,,	4.78
120	,,	4. 82
130	0.042	7. 00
140	,,	7. 10
150	,,	7. 14
165	,,	7. 20
180	,,	7. 23
210	,,	7. 30
240	,,	7. 35
250	0.050	8. 92
260	,,	8. 97
270	,,	9.06
285	,,	9.10
300	,,	9.11
330	,,	9.23
360	,,	9.24

Table A9 : Pumping Test Data of Well No. 9 (Conventional)

Time Since Pumping Started (min)	Discharge (m^3/sec)	Actual Drawdown (m)
0	-	-
10	0.028	5.42
20	,,	5.52
30	,,	5.60
45	,,	5.73
60	,,	5.80
90	,,	5.85
120	,,	5 90
130	0.042	8. 77
140	,,	8. 88
150	,,	8. 90
165	,,	8. 93
180	,,	8. 95
210	,,	8. 98
240	,,	9. 00
250	0.056	12. 16
260	,,	12. 23
270	,,	12.28
285	,,	12.31
300	,,	12.35

Table A10 : Pumping Test Data of Well No. 10 (Conventional)

Time Since Pumping Started (min)	Discharge (m^3/sec)	Actual Drawdown (m)
0	-	-
10	0.028	5.90
20	,,	5.98
30	,,	6.05
45	,,	6.10
60	,,	6.15
90	,,	6.20
120	,,	6.22
130	0.042	9. 31
140	,,	9. 34
150	,,	9. 37
165	,,	9. 40
180	,,	9. 42
210	,,	9. 42
240	,,	9. 45
250	0.056	12. 62
260	,,	12. 67
270	,,	12.69
285	,,	12.72
300	,,	12.75
330	,,	12.77
360	,,	12.80

Table A11 : Pumping Test Data of Well No. 11 (Modified)

Time Since Pumping Started (min)	Discharge (m^3/sec)	Actual Drawdown (m)
0	-	-
10	0.056	14.20
20	,,	14.35
30	,,	14.42
45	,,	14.48
60	,,	14.50
90	,,	14.53
100	0.071	17.91
120	,,	18.11
135	,,	18.16
150	,,	18.19
180	,,	18.22
190	0.085	21.59
200	,,	21.77
210	,,	21.85
225	,,	21.89
240	,,	21.92
270	,,	21.95

Table A12 : Pumping Test Data of Well No. 12 (Modified)

Time Since Pumping Started (min)	Discharge (m^3/sec)	Actual Drawdown (m)
0	-	-
10	0.056	15.21
20	,,	15.36
30	,,	15.44
45	,,	15.49
60	,,	15.52
90	,,	15.55
100	0.071	19.17
120	,,	19.38
135	,,	19.43
150	,,	19.46
180	,,	19.48
190	0.085	23.11
200	,,	23.29
210	,,	23.37
225	,,	23.42
240	,,	23.44
270	,,	23.47

Table A13 : Pumping Test Data of Well No. 13 (Modified)

Time Since Pumping Started (min)	Discharge (m^3/sec)	Actual Drawdown (m)
0	-	-
10	0.096	11.91
20	"	12.06
30	"	12.14
45	"	12.19
60	"	12.22
90	"	12.20
100	0.12	15.01
120	"	15.26
135	"	15.32
150	"	15.34
180	"	15.36
190	0.13	16.66
200	"	16.79
210	"	16.84
225	"	16.92
240	"	16.94
270	"	16.97

Table A14 : Pumping Test Data of Well No. 14 (Modified)

Time since pumping started (min)	Discharge (m^3/sec)	Actual drawdown (m)
0	-	-
10	0.056	15.88
20	"	16.00
30	"	16.08
45	"	16.11
60	"	16.14
90	"	16.16
100	0.071	19.84
120	"	20.04
135	"	20.13
150	"	20.16
180	"	20.17
190	0.085	23.21
200	"	23.27
210	"	23.38
225	"	23.41
240	"	23.44
270	"	23.55

Table A15 : Pumping Test Data of Well No. 15 (Modified)

Time since pumping started (min)	Discharge (m^3/sec)	Actual drawdown (m)
0		
10	-	-
20	0.096	16.15
30	,,	16.69
45	,,	16.76
60	,,	16.81
90	,,	16.84
100	,,	16.86
120	0.12	19.74
135	,,	20.75
150	,,	20.78
180	,,	20.80
190	,,	20.83
200	0.14	22.66
210	,,	22.66
225	,,	23.58
240	,,	23.58
270	,,	23.90
	,,	23.92

Table A16 : Pumping Test Data of Well No. 16 (Modified)

Time since pumping started (min)	Discharge (m^3/sec)	Actual drawdown (m)
0		
5	-	-
10	0.049	7.92
15	,,	8.00
20	,,	8.05
25	,,	8.09
30	,,	8.11
35	,,	8.13
40	0.096	15.86
45	,,	15.92
50	,,	15.97
55	,,	16.01
60	,,	16.05
65	,,	16.08
70	,,	16.10
80	0.12	20.80
90	,,	20.85
100	,,	20.89
110	0.14	23.05
120	,,	23.07
	,,	23.09

Table A17 : Pumping Test Data of Well No. 17 (Modified)

Time Since Pumping Started (min)	Discharge (m^3/sec)	Actual Drawdown (m)
0	-	-
10	0.096	16.64
20	”	16.76
30	”	16.80
45	”	16.84
60	”	16.85
90	”	16.86
100	0.12	20.78
120	”	20.93
135	”	20.98
150	”	21.00
180	”	21.05
190	0.14	23.19
200	”	23.19
210	”	23.20
225	”	23.46
240	”	23.52
270	”	23.54

Table A18 : Pumping Test Data of Well No. 18 (Modified)

Time Since Pumping Started (min)	Discharge (m^3/sec)	Actual Drawdown (m)
0	-	-
10	0.096	20.50
20	”	20.62
30	”	20.69
45	”	20.73
60	”	20.75
90	”	20.76
100	0.12	24.41
120	”	24.49
135	”	24.54
150	”	24.56
180	”	24.64
190	0.14	30.18
200	”	30.23
210	”	30.25
225	”	30.28
240	”	30.30
270	”	30.30

Table A19 : Pumping Test Data of Well No. 19 (Modified)

Time Since Pumping Started (min)	Discharge (m^3/sec)	Actual Drawdown (m)
0	-	-
10	0.028	3.20
20	,,	3.30
30	,,	3.40
45	,,	3.50
60	,,	3.58
90	,,	3.62
120	,,	3.65
130	0.042	5. 32
140	,,	5. 38
150	,,	5. 42
165	,,	5. 52
180	,,	5. 55
210	,,	5. 62
240	,,	5. 65
250	0.056	7. 68
260	,,	7. 70
270	,,	7.73
285	,,	7.76
300	,,	7.77
330	,,	7.79
360	,,	7.90

Table A20 : Pumping Test Data of Well No. 20 (Modified)

Time Since Pumping Started (min)	Discharge (m^3/sec)	Actual Drawdown (m)
0	-	-
10	0.028	3.27
20	,,	3.37
30	,,	3.45
45	,,	3.52
60	,,	3.57
90	,,	3.62
120	,,	3.65
130	0.042	5. 43
140	,,	5. 46
150	,,	5. 48
165	,,	5. 51
180	,,	5. 53
210	,,	5. 56
240	,,	5. 57
250	0.056	7. 51
260	,,	7. 56
270	,,	7.59
285	,,	7.61
300	,,	7.62
330	,,	7.65

Appendix – B

Table No. B1 : Summary of the Original Step Drawdown Test Data for Determination of Well Deterioration Index.

Type of Well	Well Serial	Discharge Q (m^3/min)	Pump Water Level (m)	Drawdown (m)	Specific Drawdown (min/m^2)	Specific Capacity (m^2/min)
Conventional	3	3.36	18.16	8.49	2.53	0.40
		4.20	21.00	11.33	2.70	0.37
		5.04	23.50	13.83	2.74	0.36
	6	3.36	15.49	7.01	2.09	0.57
		4.20	17.60	9.12	2.17	0.48
		5.04	20.00	11.52	2.29	0.46
	7	3.36	19.73	7.23	2.15	0.46
		4.20	22.00	9.50	2.26	0.44
		5.04	25.60	13.10	2.60	0.38
	8	3.36	22.00	8.28	2.46	0.41
		4.20	24.80	11.08	2.64	0.38
		5.04	26.10	12.38	2.75	0.36
	9	3.36	10.05	7.05	2.10	0.48
		4.20	12.05	10.05	2.15	0.46
		5.04	14.10	13.10	2.20	0.45
	10	3.36	16.58	11.02	3.28	0.30
		4.20	20.28	14.65	3.49	0.29
		5.04	23.30	17.74	3.52	0.28
Modified	13	3.36	19.00	10.77	3.21	0.31
		4.20	22.50	14.27	3.40	0.29
		5.04	26.21	17.98	3.57	0.28
	19	3.36	15.10	7.68	2.29	0.44
		4.20	17.35	9.93	2.36	0.42
		5.04	19.80	12.38	2.46	0.41
	20	3.36	13.15	5.02	1.49	0.67
		4.20	14.68	6.55	1.56	0.64
		5.04	16.15	8.02	1.59	0.63

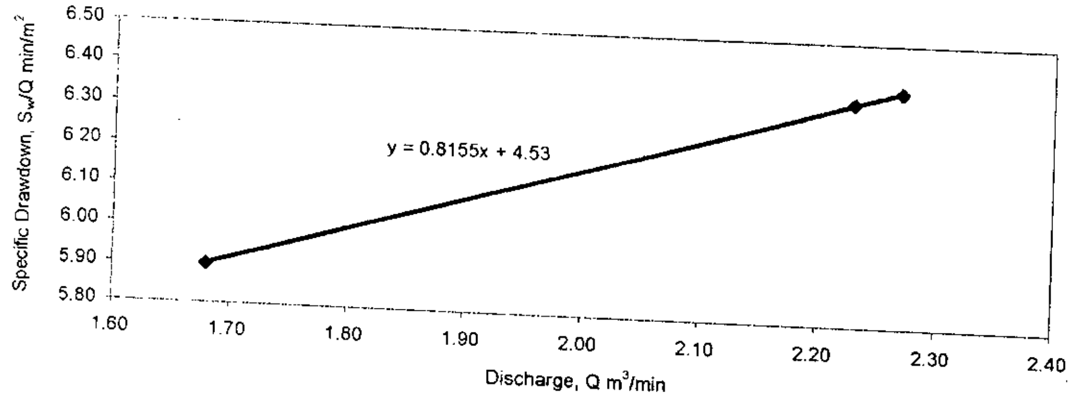


Figure C1: Graph of S_w/Q vs Q of Well 1

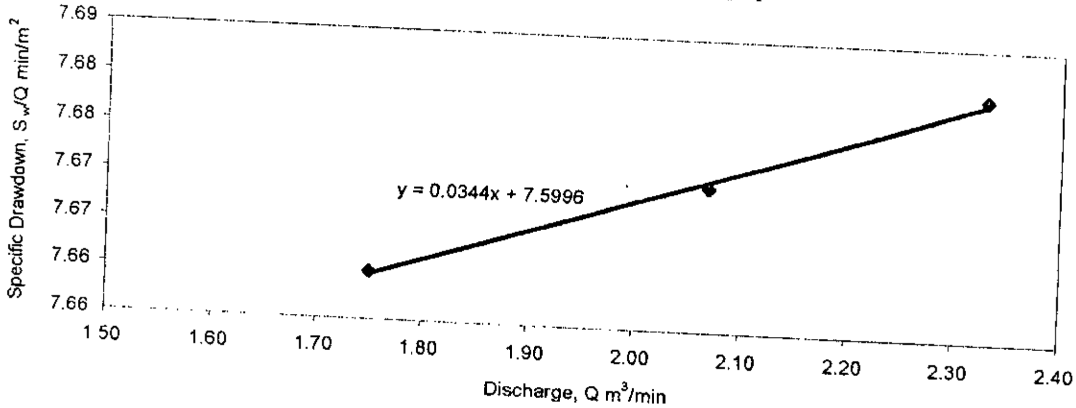


Figure C2: Graph of S_w/Q vs Q of Well 2

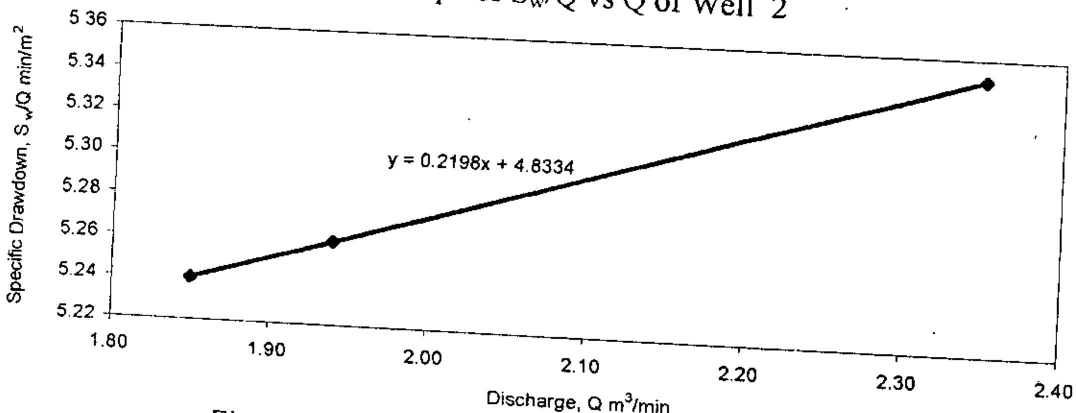


Figure C3: Graph of S_w/Q vs Q of Well 3

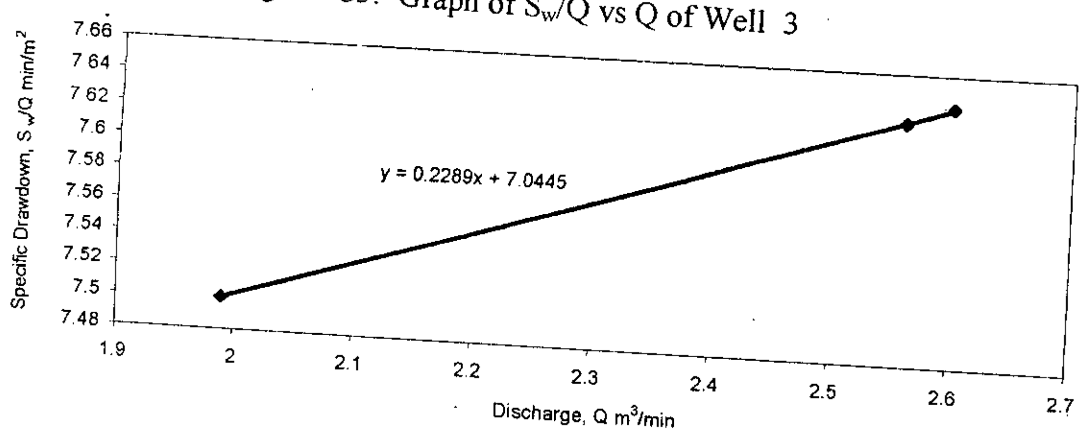


Figure C4: Graph of S_w/Q vs Q of Well 4

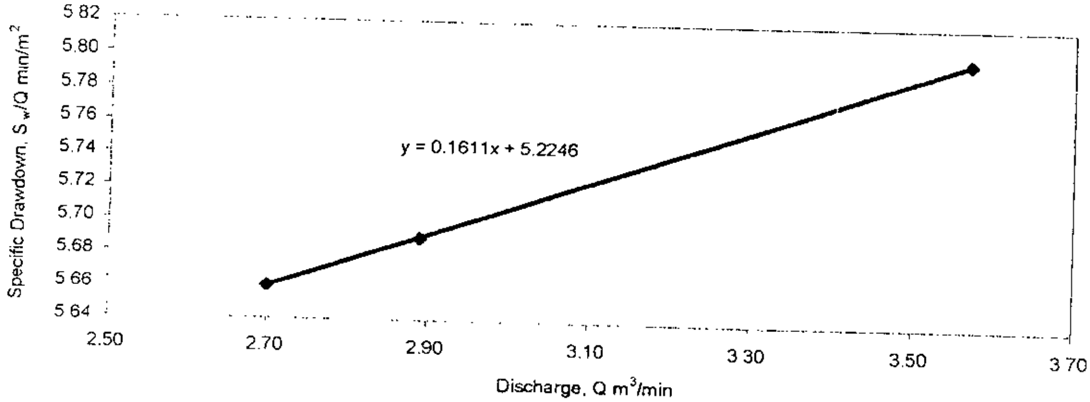


Figure C5: Graph of S_w/Q vs Q of Well 5

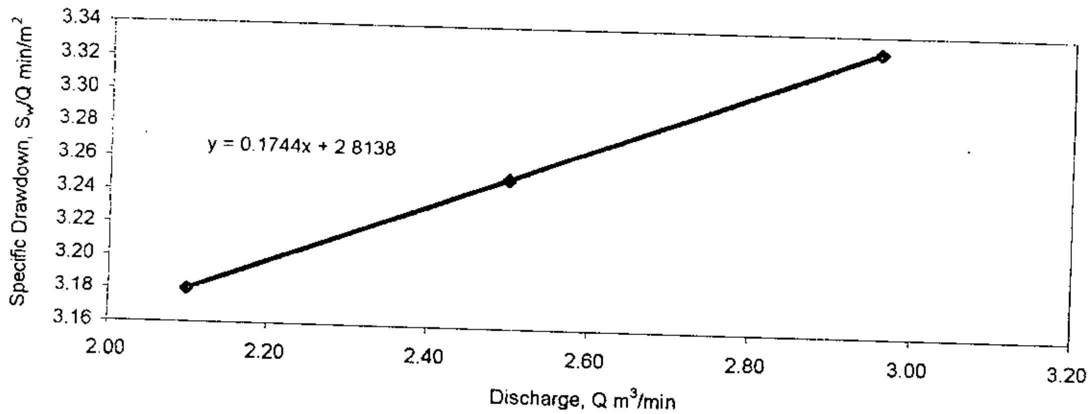


Figure C6: Graph of S_w/Q vs Q of Well 6

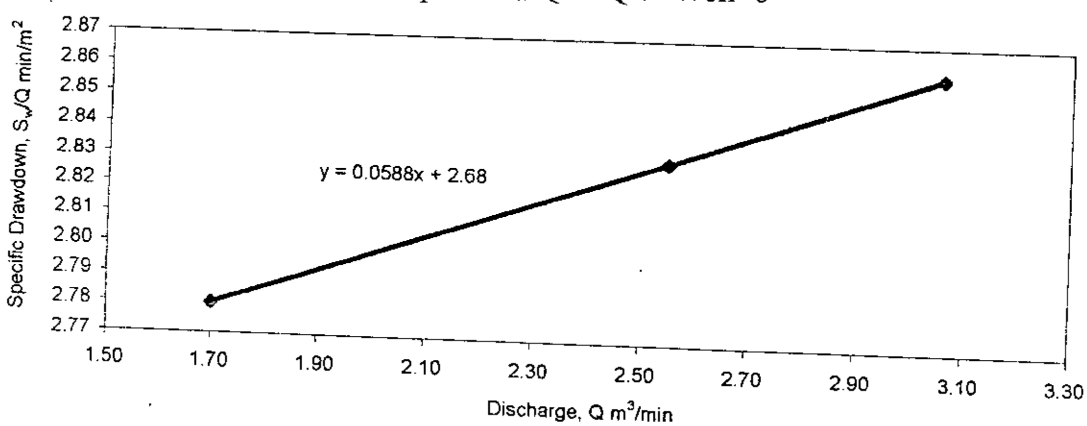


Figure C7: Graph of S_w/Q vs Q of Well 7

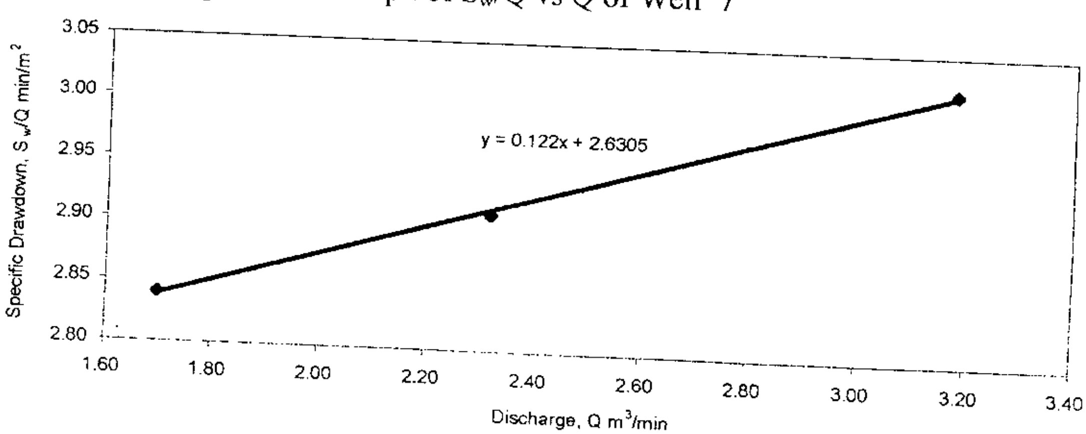


Figure C8: Graph of S_w/Q vs Q of Well 8

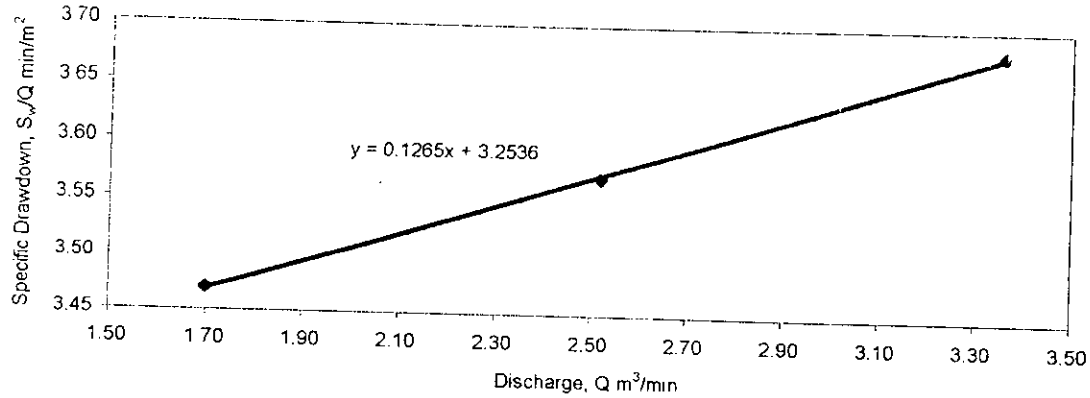


Figure C9: Graph of S_w/Q vs Q of Well 9

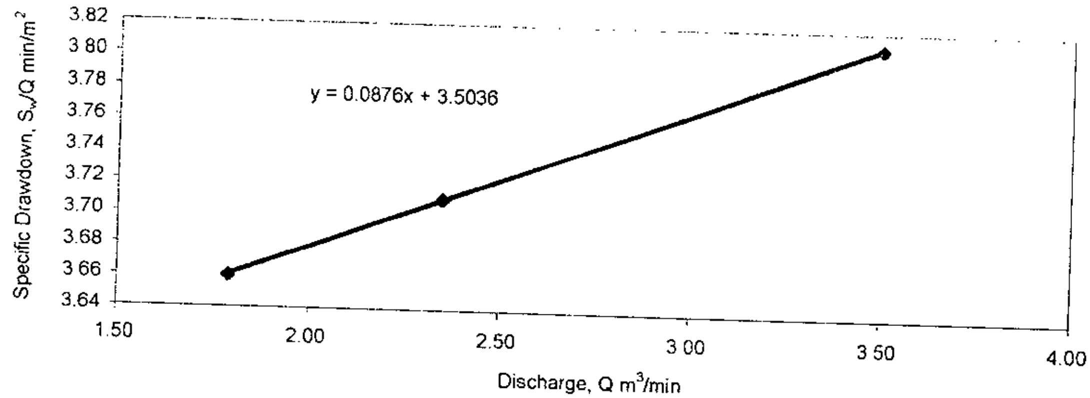


Figure C10 : Graph of S_w/Q vs Q of Well 10

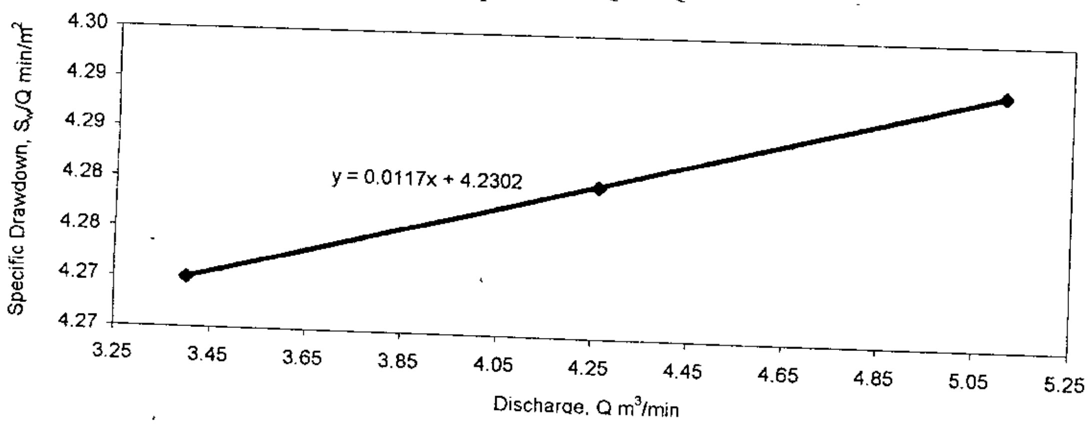


Figure C11: Graph of S_w/Q vs Q of Well 11

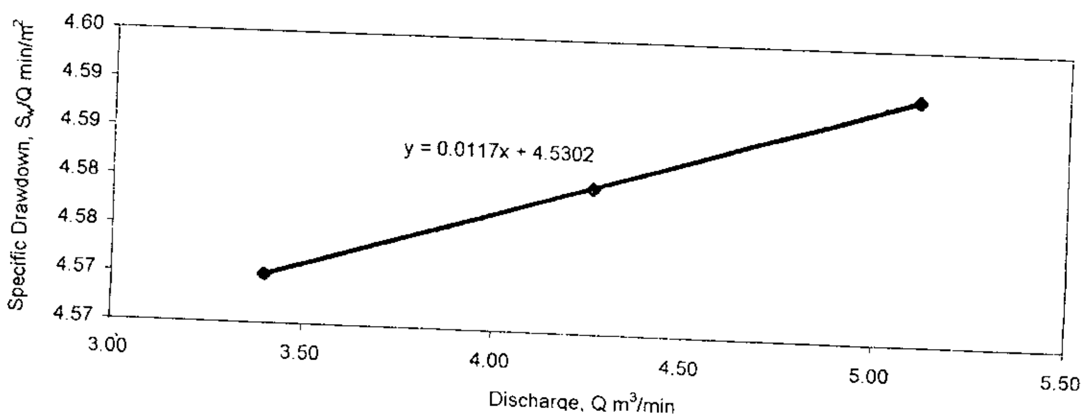


Figure C12: Graph of S_w/Q vs Q of Well 12

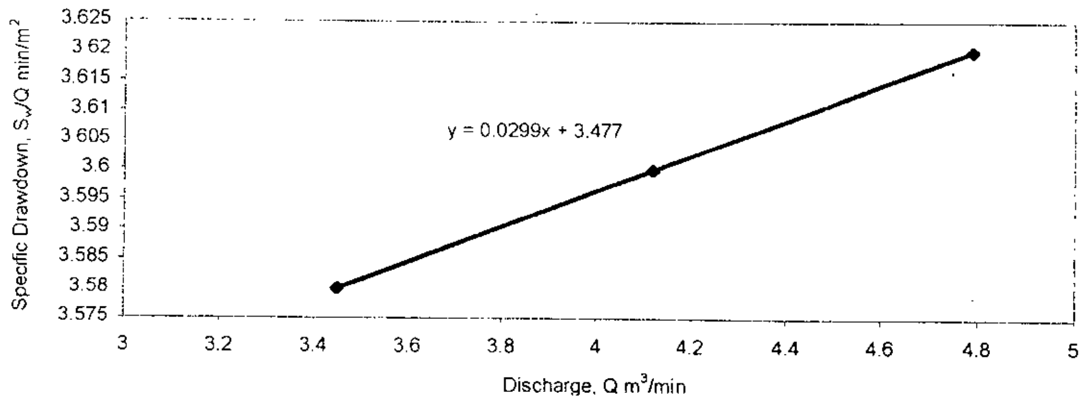


Figure C13: Graph of S_w/Q vs Q of Well 13

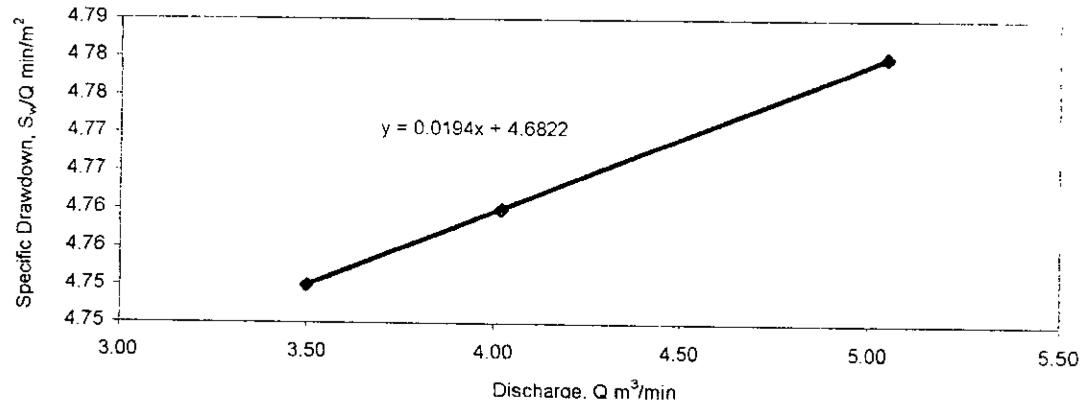


Figure C14: Graph of S_w/Q vs Q of Well 14

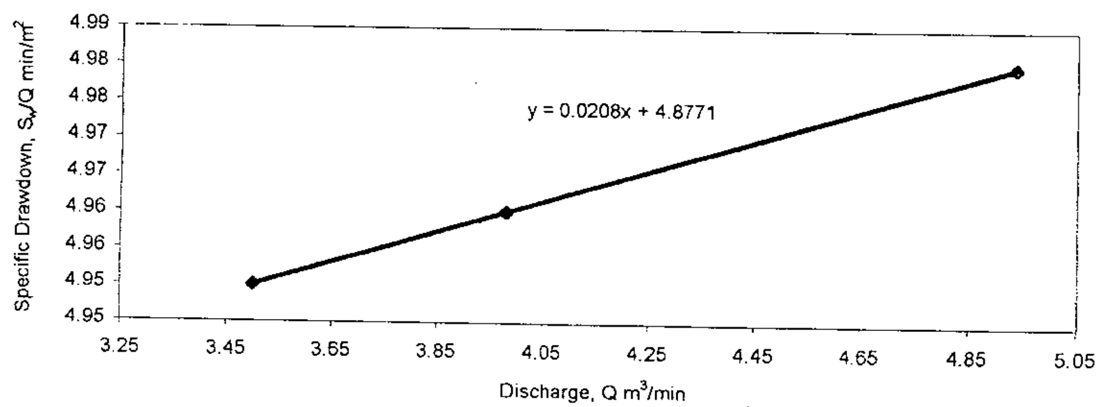


Figure C15: Graph of S_w/Q vs Q of Well 15

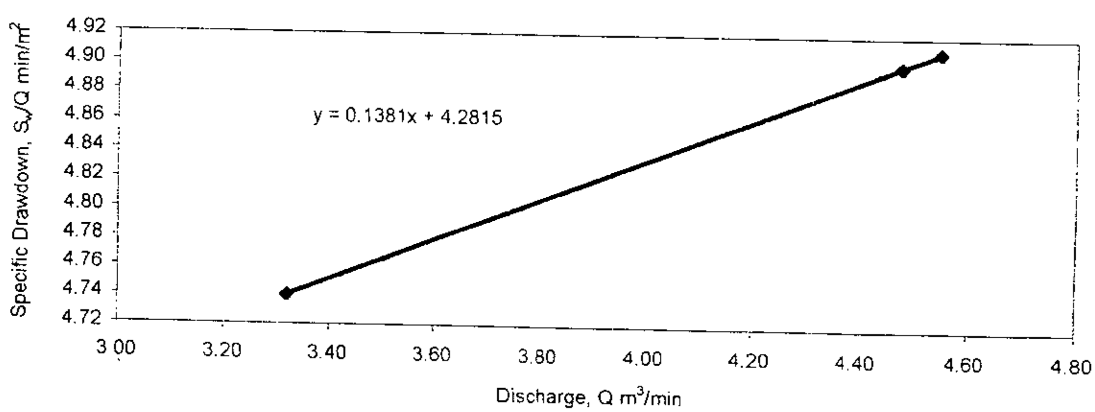


Figure C16: Graph of S_w/Q vs Q of Well 16

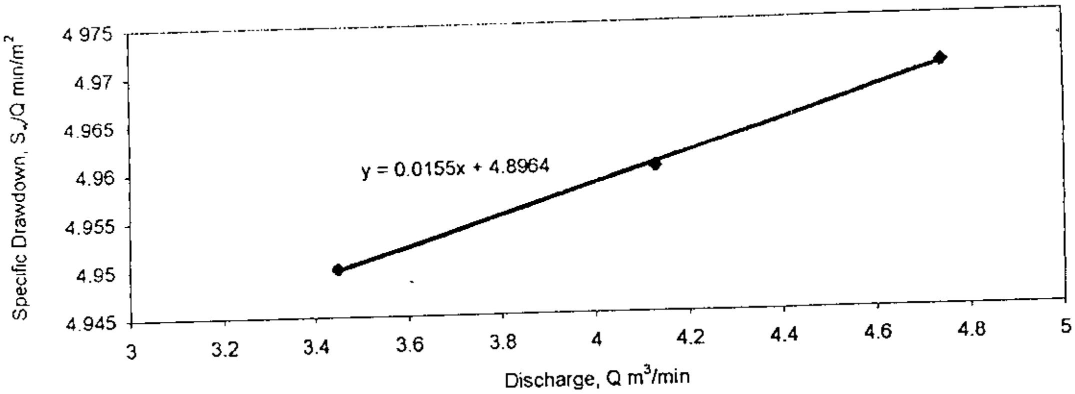


Figure C17: Graph of S_w/Q vs Q of Well 17

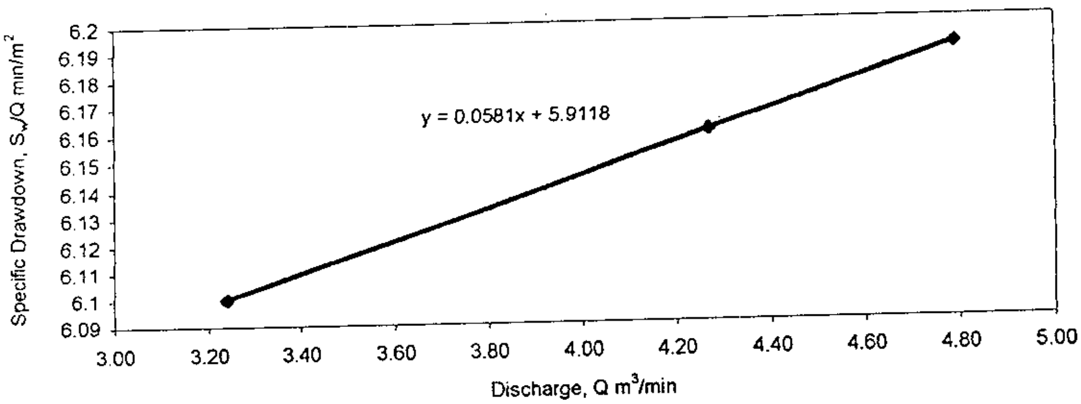
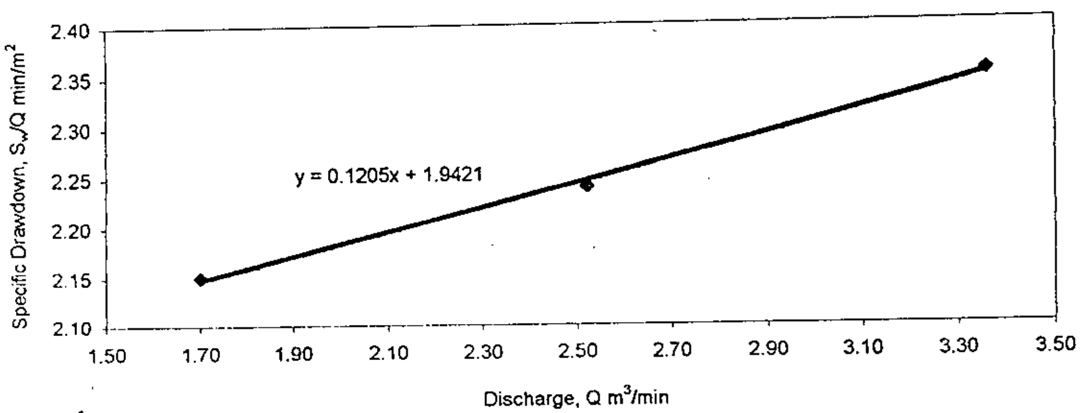


Figure C18: Graph of S_w/Q vs Q of Well 18



1 Figure C1: Graph of S_w/Q vs Q of Well 19

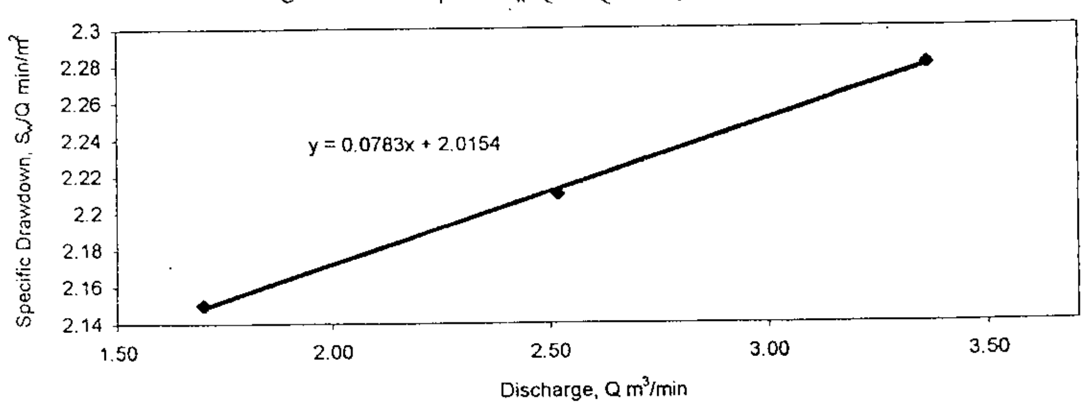


Figure C20: Graph of S_w/Q vs Q of Well 20

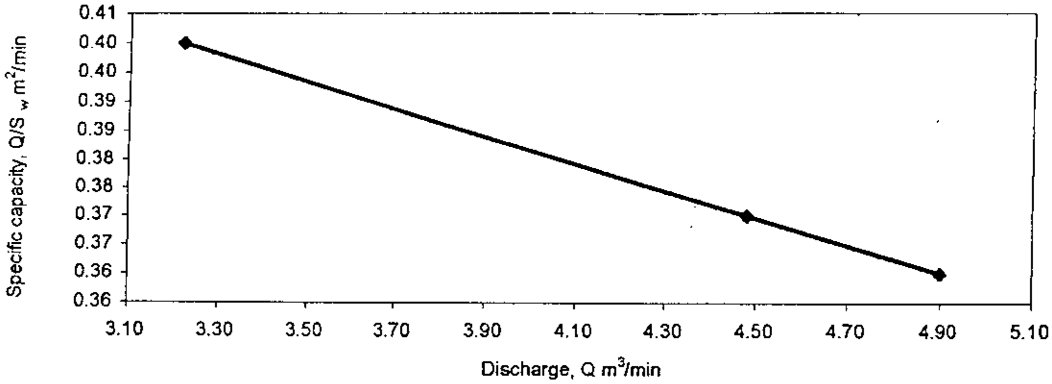


Figure D1: Plot of original specific capacity vs. discharge of well no: 3

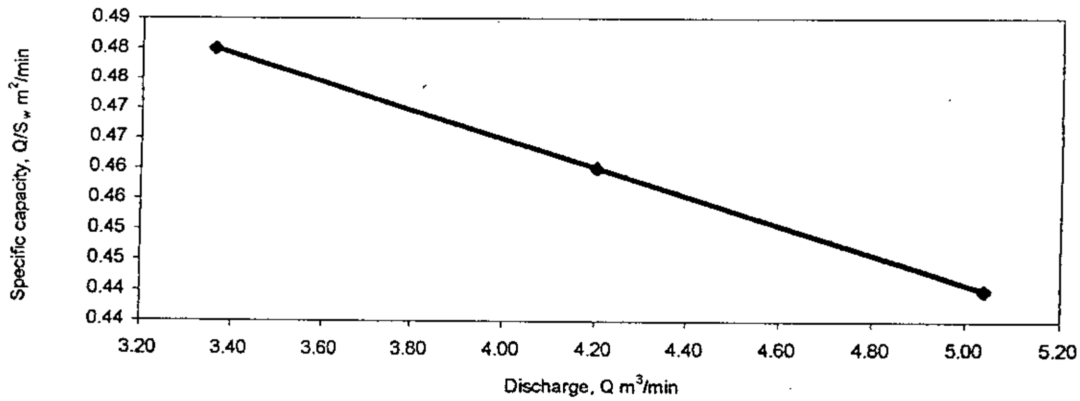


Figure D2: Plot of original specific capacity vs. discharge of well no: 6

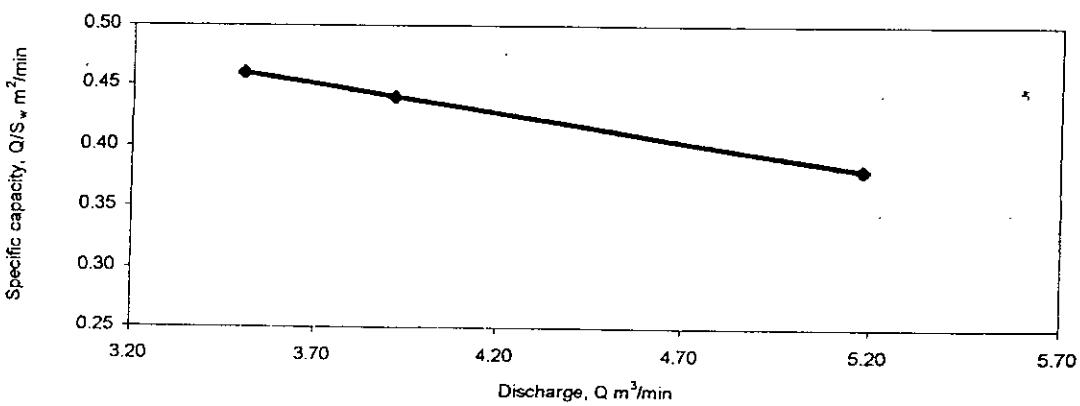


Figure D3: Plot of original specific capacity vs. discharge of well no: 7

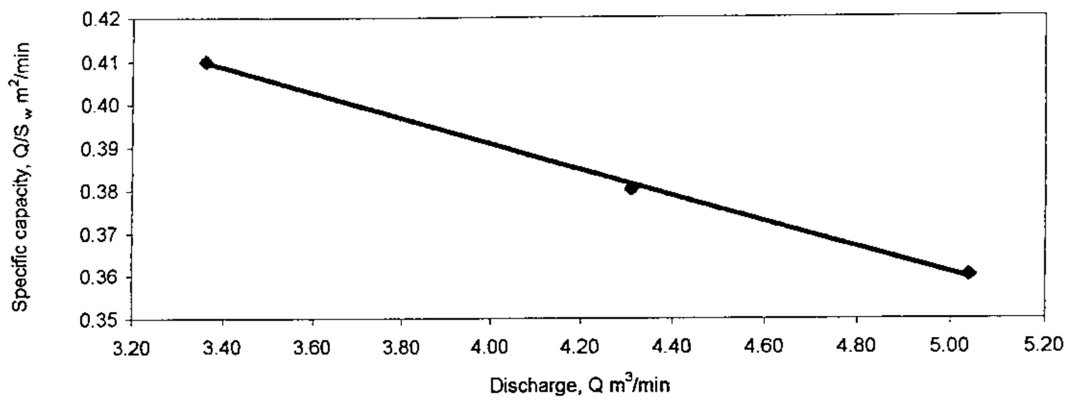


Figure D4: Plot of original specific capacity vs. discharge of well no: 8

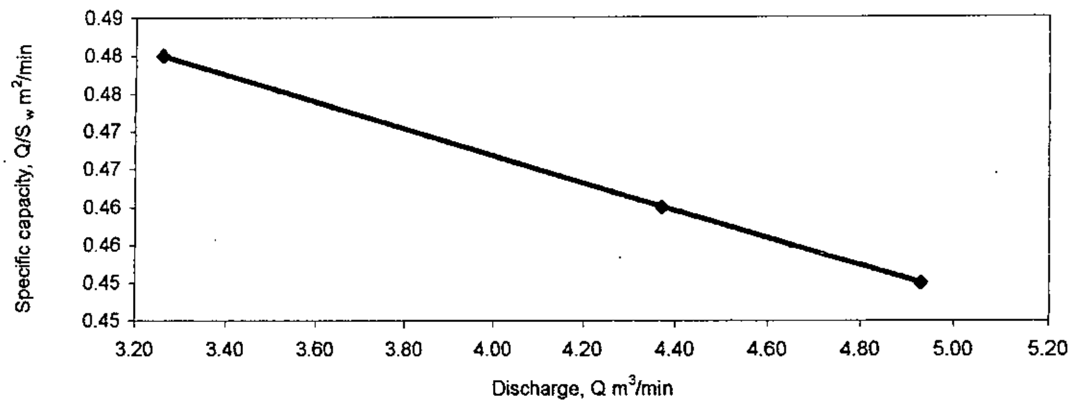


Figure D5: Plot of original specific capacity vs. discharge of well no: 9

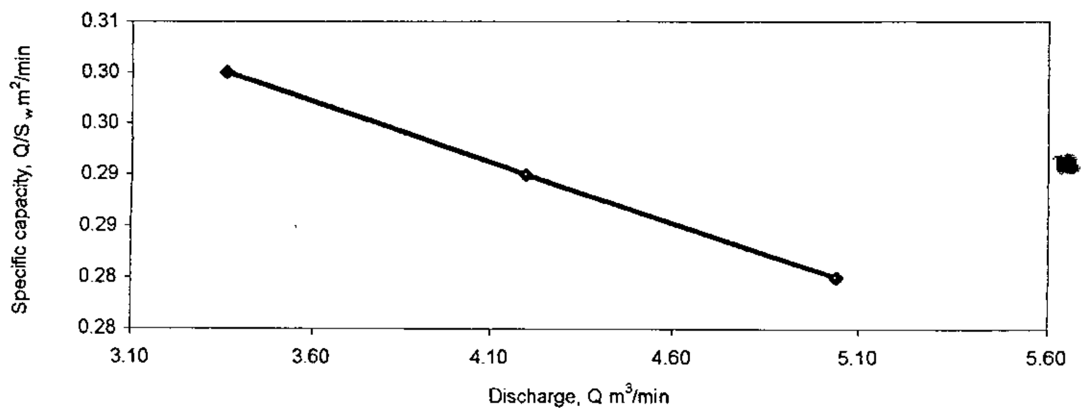


Figure D6: Plot of original specific capacity vs. discharge of well no: 10

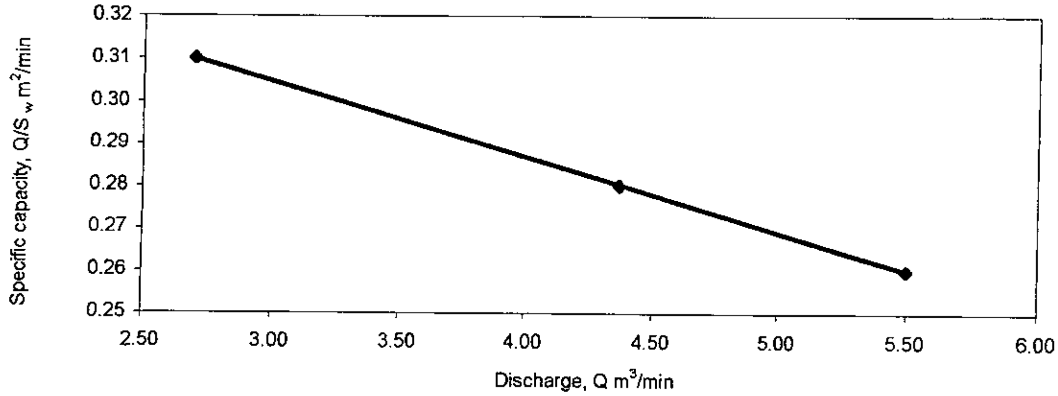


Figure D7: Plot of original specific capacity vs. discharge of well no: 13

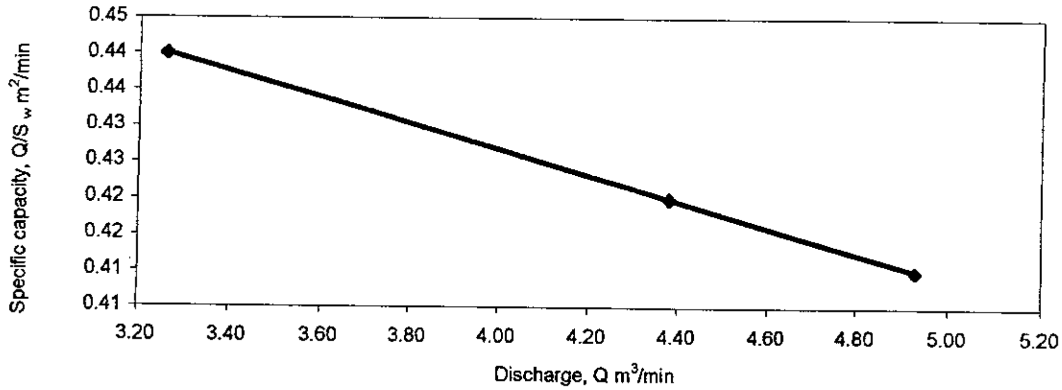


Figure D8: Plot of original specific capacity vs. discharge of well no: 19

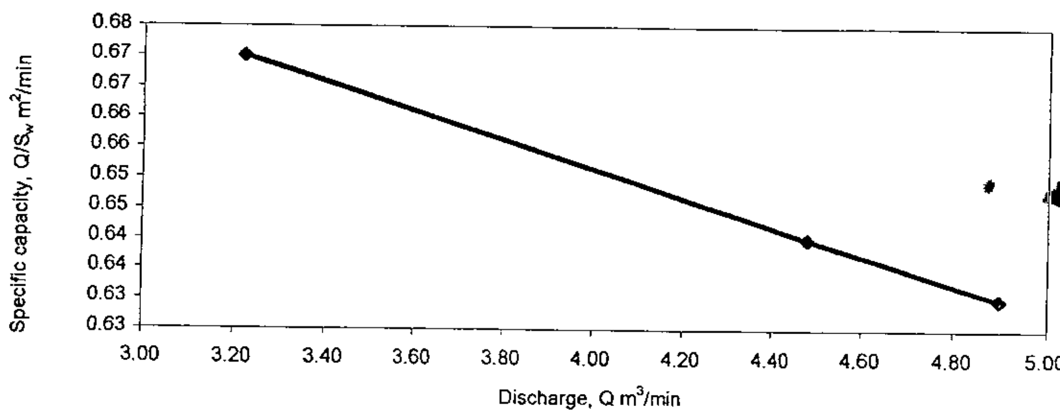


Figure D9: Plot of original specific capacity vs. discharge of well no: 20