

# Hydrogeological Potentiality of Intensive Farmer-Managed Tubewell Irrigation Systems in Bangladesh: A Case Study

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## ABSTRACT

A FIELD STUDY was conducted in 10 farmer-managed deep and shallow tubewell irrigated areas of Barind Tract Groundwater Basin, Bogra, Bangladesh. This had the specific objectives of: (i) assessing the groundwater recharge in the study area, (ii) evaluating the fluctuation of groundwater table of aquifers and its response on rainfall and river water levels in the vicinity, (iii) evaluating the aquifer characteristics and properties, and (iv) recommending the safe utilization of tubewells based on discharge-drawdown relationship and well spacing for sustainable groundwater management in crop production.

The study indicated that the intensity of tubewells at present are 5 per square kilometer ( $\text{km}^2$ ) with an average discharge capacity of about 56 liters per second (lps). The average irrigated acreage of all the tubewells was 0.83 hectare/lps under the rice crop which was much above the national average (0.40 ha/lps). During the 10 years from 1977 to 1986, the groundwater table was lowered indicating the highest lowering upto 7.87 meters (m) in the month of March. This was below the operation level of shallow tubewells. A multiple regression relationship with groundwater table (Y) as dependable variable, and rainfall (X1) and river stage (X2) as independent variables was accomplished. The study revealed that there is a significant direct relationship among rainfall, groundwater table fluctuation and stream flow. The lithological investigations indicated that 100 percent screenable materials were available from a depth of 12 m and beyond. The average transmissivity and storage coefficient values were 4,388 square meters per day ( $\text{m}^2/\text{day}$ ) and 0.000587, respectively, which indicated that the study area has potential for tubewell utilization. A model for safe well spacing was developed between discharge versus spacing of wells. The findings indicated that for shallow wells with a discharge rate from 11 to 20 lps, the spacing was in the range of 122 to 250 m. However, for deep tubewells with discharge capacities of 47 to 54 lps the spacing was in the range of 300 to 390 m for safe and sustainable utilization of groundwater.

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## INTRODUCTION

Groundwater in Bangladesh generally occurs under normal water table conditions, but in some areas, particularly in deeper aquifer, the water may be under semi-artisan or artisan conditions. The depth of the water table varies from zero to more than 15 m below the ground surface depending upon the location and season. Hydrogeologically, the upper fine sand and lower medium sand from one hydraulically interconnected aquifer was covered by a semi-permeable, semi-confining layer of silt and clay (Master Plan Organization [MPO] 1984). The static water level generally lies within the semi-confining layer. The deep tubewells (DTWs) and shallow tubewells (STWs), all extract water from a common aquifer, although from different but hydraulically connected layers.

Bangladesh can be divided into four major groundwater zones: (i) younger alluvium, (ii) complex geology, (iii) older alluvium, and (iv) coastal area (Jones 1972). Among the older alluvium, surface deposits in the area consist of fine grained older alluvium, chiefly the pleistocene Madhupur clay formation. The finer material is extended to great depths in some areas and therefore very little attempt has been made to develop large-capacity wells. Geophysical investigations indicate that there are some relatively good prospects of groundwater development in Bogra District and in the southern part of Tangail District.

Surface water is scarce in many parts of Bangladesh (mainly North and North West part of Bangladesh) during the irrigation season, so that groundwater has to be developed as an alternate and dependable source. But groundwater is also limited and there exists many constraints for its development. Therefore, it is essential to determine the quantity of groundwater that can be withdrawn safely for different uses. Groundwater withdrawal causes large decline in groundwater levels during the dry season in some typical areas where use has increased greatly in recent years (MPO 1984). The areas are Bogra, Rajshahi, Comilla, Dhaka and Mymensingh districts. Haq and Sattar's (1986) study at Bangladesh Rice Research Institute, Gazipur, indicated that the groundwater table during the dry season over a six-year period progressively declined and was close to 1.7 m per year. This yearly lowering of the groundwater table could be an indication that the annual rates of withdrawal from the groundwater basin has been greater than the yearly rates of recharge. The present study aims to find out the geohydrological potentiality of intensive deep and shallow tubewell farmer-managed irrigation systems for the safe utilization of groundwater.

The specific objectives of the study were as follows:

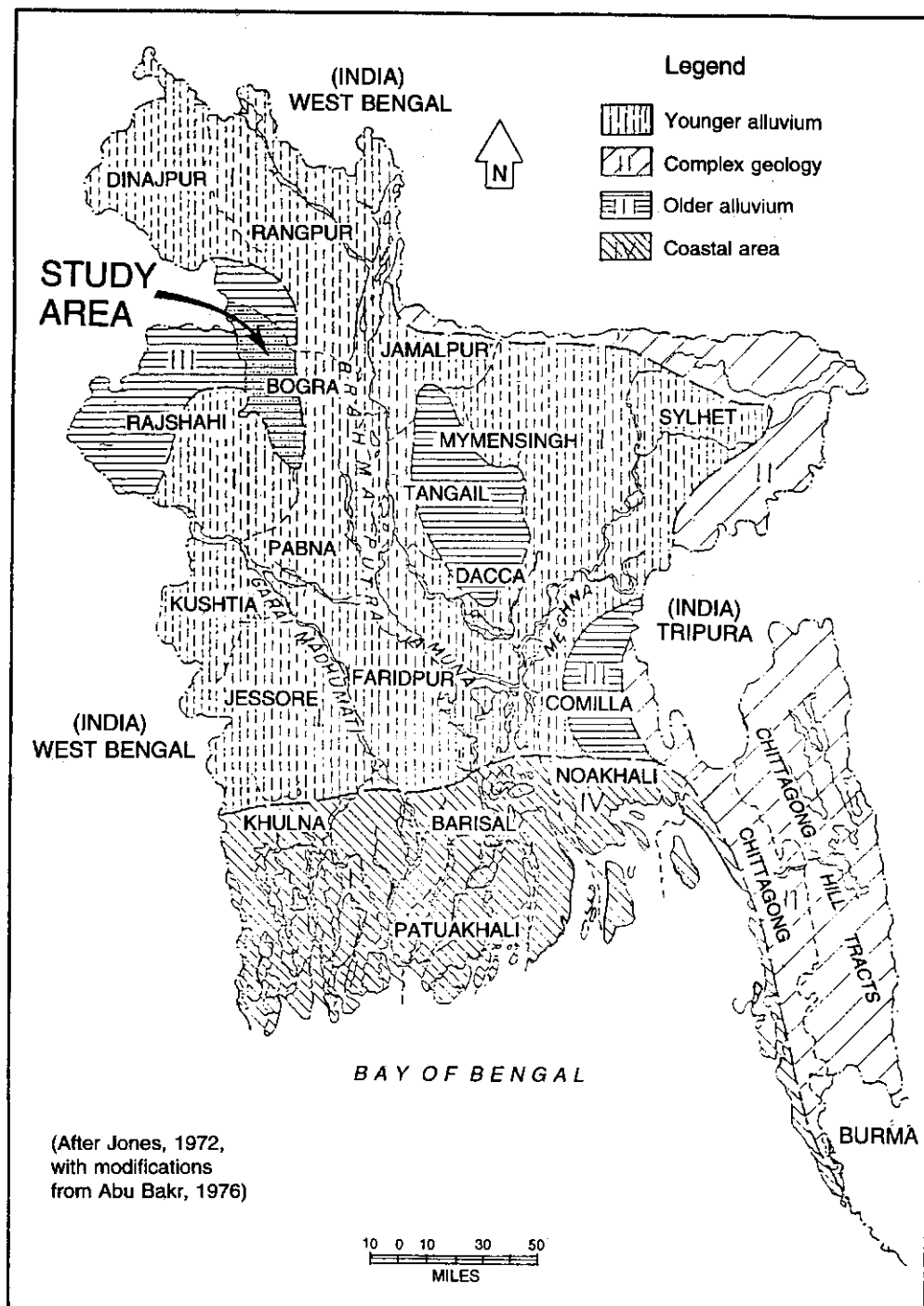
- i) To assess the groundwater recharge in the study area.
- ii) To evaluate the fluctuation of groundwater table of aquifer and its response on rainfall and river levels in the vicinity.
- iii) To find out the aquifer characteristics and properties.
- iv) To determine the safe utilization of tubewells for sustainable groundwater management.

## MATERIALS AND METHODS

### Selection of the Study Area

The study area has been selected based on the geohydrological zones of Bangladesh (Figure 1.1). It is mainly occupied by pleistocene deposits, i.e., Barind Tract of Bogra District (Morgan and

Figure 1.1. Approximate boundaries of groundwater areas.

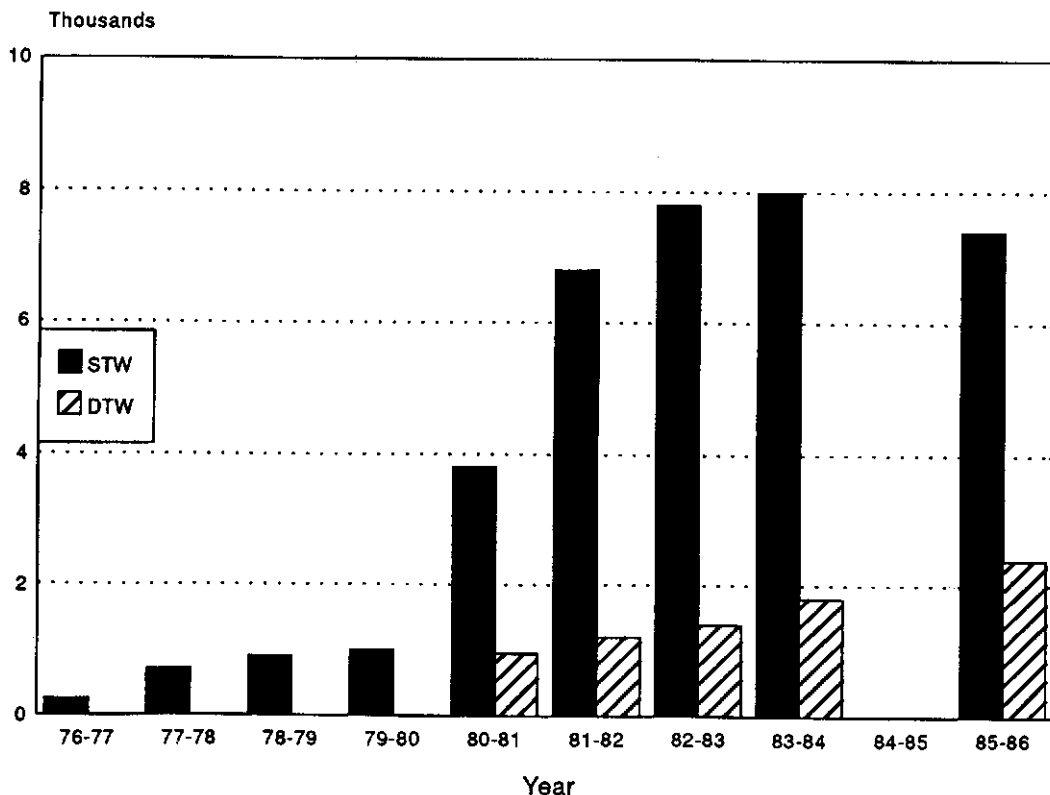


McIntire 1959). The Karatoa River flowing toward the south-west at the western margin of Kahalu Upazilla has a great effect on the groundwater reserve. To fulfill the objectives of the study a pilot area has been selected in Kahalu Upazilla covering 10.10 km<sup>2</sup>, which has one of the most intensive DTWs and STWs in the Bogra District. The deep tubewell location map upazilla-wise, and the location of shallow wells within the study region were obtained from the Bangladesh Agricultural Development Corporation (BADC) local office. Annual increment of DTWs and STWs for greater Bogra District from 1976/77 to 1983/84 together with the 1985/86 tubewell status of present Bogra District are shown in Figure 1.2.

### Farmer-Managed Irrigation System (FMIS)

Ten DTWs and STWs which are farmer-managed were selected for this study. The DTWs have been mainly implemented by the Bangladesh Agricultural Development Corporation (BADC) since 1977, and groups of farmers enjoy the use of the DTWs on a rental basis of taka (Tk) 3,500 (approximately US\$145) per year. However, by 1981 rental procedures were discontinued and DTWs were sold for Tk 70,000 (approximately US\$3,000) to the farmer groups. The procedures to procure deep tubewells begin with farmers who either organize themselves or are organized into user groups. Mandal (1982) provides examples in which the farmers themselves took the initiative to form a management committee to procure a deep tubewell and to manage the wells by themselves. The shallow tubewells are mainly procured and managed by the individual farmers.

Figure 1.2. Yearwise increment of STWs and DTWs in Bogra District, from 1976 to 1986.



## Hydrogeological Information

The groundwater table was measured daily by using the electric probe method from seven production wells (DTWs) and eight installed observation wells for monitoring the groundwater table in the study area. Rainfall data and river water levels were collected from the local Bangladesh Water Development Board (BWDB) office for a period of 10 years from three gauging stations of major rivers; namely, Nagor, Karotoa and Katakhal, which are the main aquifer-connected rivers within the study basin. Eight available deepwell logs were analyzed on the basis of soil texture. These were plotted on positive and negative axes of aquifer as probability of occurrence of hydrogeology. The aquifer characteristics were determined through a pumping test using Jacob's method with the approaches of time-drawdown, distance-drawdown and recovery method. An attempt was made to find out the safe distance from DTW to STW by step drawdown test through the relationship between discharge ( $Q$ ) versus radius of interference ( $R$ ). Two deep tubewells and one shallow tubewell were selected for the test. The production wells were pumped at several successively higher pumping rates and drawdown for each rate was measured in each observation well. In each step, the radius of interference was determined from the drawdown curve. Each of the tubewell discharge was measured by horizontal scale (L-Scale) and their respective service area was recorded.

## RESULTS AND DISCUSSION

### Seasonal Fluctuation of Groundwater Table

Measurement of depth to water table in tubewells provides the record of change in the groundwater storage. Some records aid in determining the relationship of various facts such as the recharge of the groundwater reservoir. Weekly water table data were compiled for the analysis. The groundwater level starts rising from the latter part of May or June and it rises until the beginning of October. Ten-year secondary groundwater monitoring data have been used to show the behavior of the groundwater table (see Figure 1.3).

### Rainfall Pattern

Annual rainfall of Bogra District from the year 1977 to 1986 indicates that 92 percent of the annual rainfall occurred from May to October and the rest from November to April. These rainfall variations directly affect groundwater recharge (see Figure 1.3).

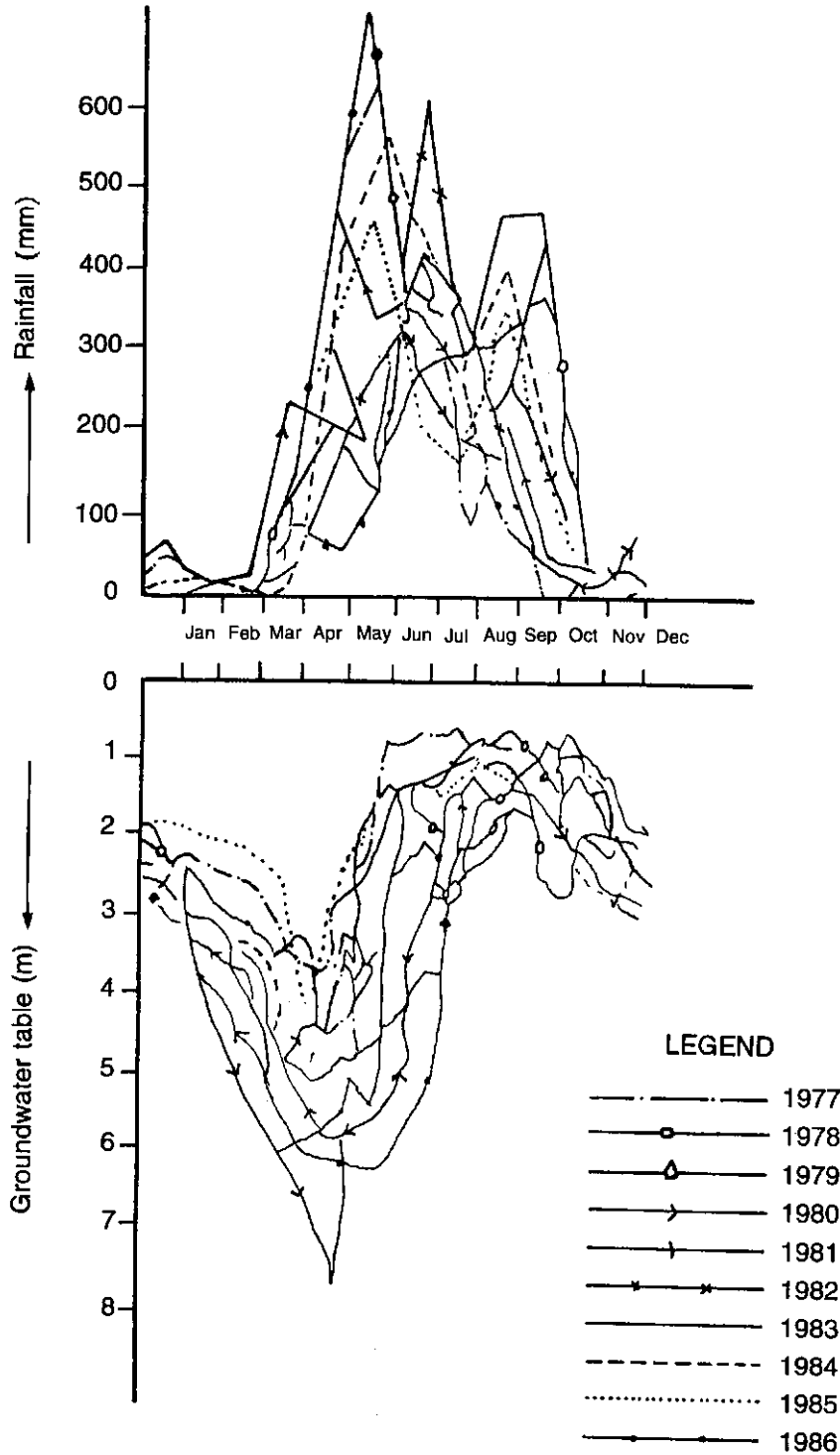
### Assessment of Surface Water

The river water level data of Bogra District showed the maximum flow from June to October and the minimum in the month of April. The highest and lowest river water levels were 15.75 m and 11.21 m in the year 1984 and 1983, respectively (see Figure 1.4).

### Relationship between Rainfall, River Level and Groundwater Table

An investigation was carried out to analyze the interrelationship between rainfall and groundwater table as well as river level data, within the few selected sites of the study area. The analysis was made on the basis of monthly records of rainfall, groundwater table and river level. A multiple

Figure 1.3. Fluctuation of groundwater table and the rainfall pattern, from 1977 to 1986.

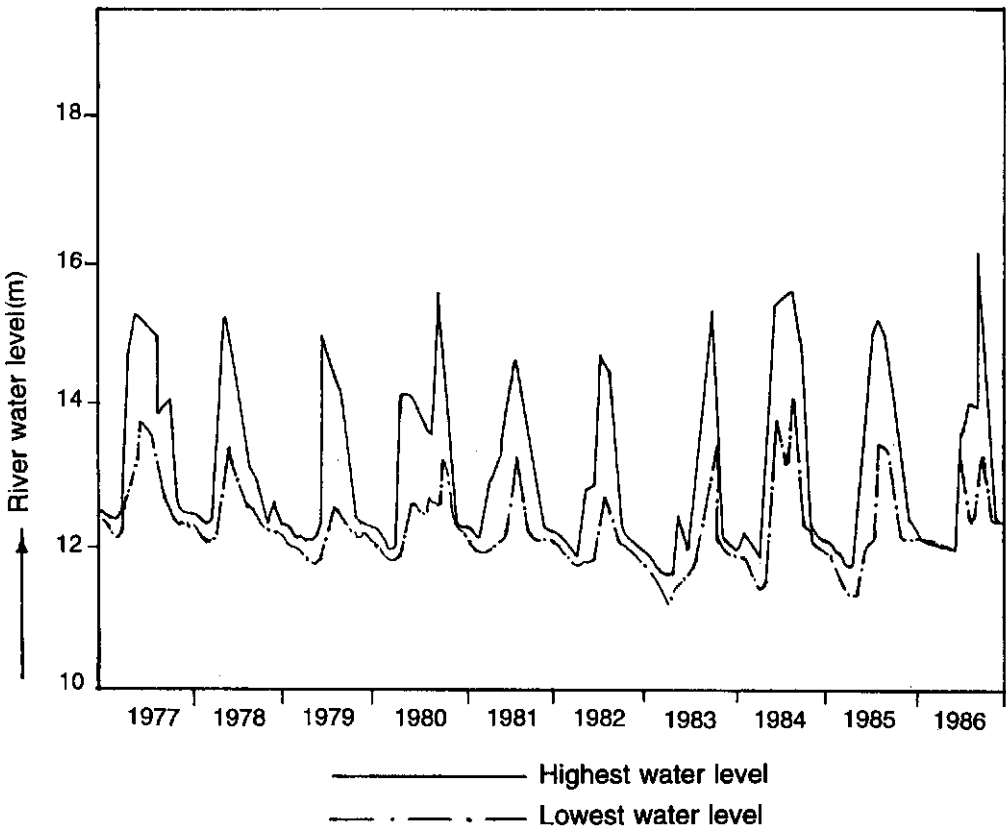


correlation analysis was made to establish the response of groundwater table (Y) to rainfall (X1) and river level (X2) and is given by the following equation:

$$Y = 12.5647 + 0.0399 X_1 + 0.7675 X_2 \quad (r^2 = 0.60^*)$$

The equation indicates a significant relationship between groundwater table, rainfall and river level, and shows that the rise in both groundwater table and surface water levels are influenced directly by rainfall. The river water level starts rising from the latter part of April upto the first part of August and it falls sharply at the end of the monsoon (September/October). The groundwater level, on the other hand, starts to rise from the latter part of April upto October and then declines until April of next year.

Figure 1.4. Hydrographs showing the highest and lowest water levels of Karatoa River, from 1977 to 1986.



## **Lithological Characteristics**

One test boring of 3.8 cm diameter was done upto a depth of 60 m to determine the continuity of aquifer depth on the study area. Samples were taken at every 1.5 m intervals to observe the lithology of subsurface formation. The stratigraphic views of lithological log of underground soil formation consists of clay, silt, very fine sand, fine sand, medium sand, coarse sand and gravel. From the lithological investigation it was found that the first screenable material begins from a depth of 12 m. The extent of this screenable material could not be identified since the bore log information beyond a depth of 60 m is not available. On the other hand, the BADC bore log analysis reveals that the first possible screenable aquifer can be expected with a 12 percent probability at a 9 m depth. Below a 9 m depth, the percent of nonscreenable material reduces sharply and varies from 12 to 15 percent (Figure 1.5). From 21 m upto a depth of 58 m, the probability of screenable material is 100 percent and suitable for installing both shallow and deep tubewells. The test boring indicated that 100 percent screenable material was available from a depth of 12 m and above, whereas, BADC boring logs indicated that 100 percent screenable material is obtainable from a depth of 21 m and beyond.

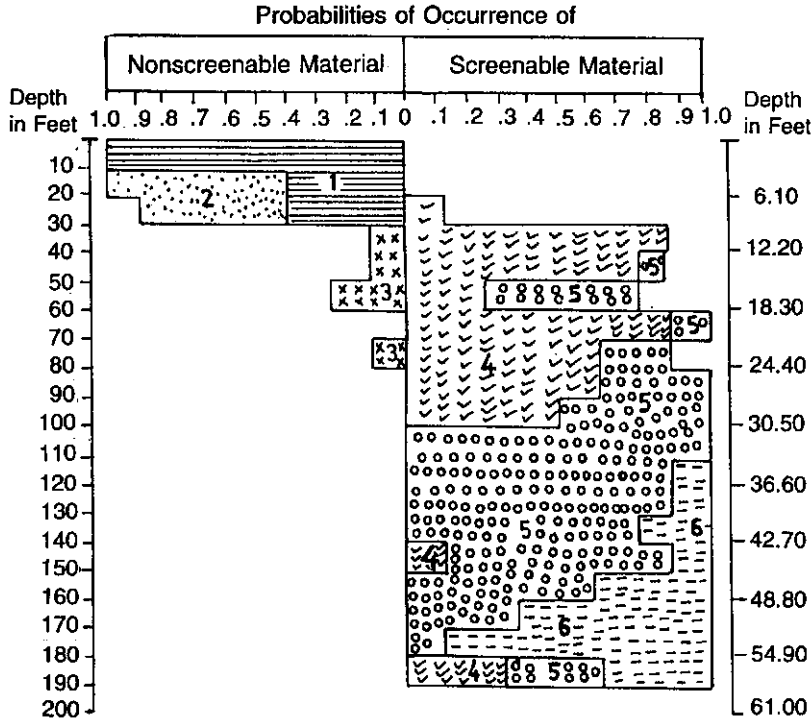
## **Determination of Aquifer Characteristics**

The yield of a well depends on the characteristics of the aquifer formation such as transmissivity (T) and the storage coefficients (S) as well as the design and construction of the well. Transmissivity indicates how much water will move through the water bearing formation. Water storage coefficient is the volume of water that the aquifer releases from or takes into storage per unit surface area (Michael 1985). Transmissivity and storage coefficient are two important parameters for estimation of groundwater resources of an area. Johnson (1986) stated that transmissivity and storage coefficient are especially important because they define the hydraulic characteristics of the water bearing formation. If these two coefficients can be determined for a particular aquifer, predictions of great significance can usually be made.

The aquifer characteristics were determined through a pumping test using Jacob's method. Three types of analyses were performed, these are: (i) time drawdown, (ii) distance drawdown, and (iii) recovery methods. One deep tubewell was selected for the pump test. Five observation wells were installed radially in a straight line to record water response to pumping. The distance of the observation wells were from 10 m to 360 m. To estimate the aquifer properties (T&S), mathematical and graphical solutions for one set of data were made. Transmissivity values were 4,562 m<sup>2</sup>/day, 4,214 m<sup>2</sup>/day by time drawdown method (Figures 1.6a, 1.6b, and 1.6c). The storage values were 0.000648 and 0.000527 by time drawdown and distance drawdown methods, respectively. These values are much higher than the values obtained by Sir MacDonald and Partners (1977). The values indicate that the aquifer has good potential for groundwater development.



Figure 1.5. Probability of occurrence of hydrogeology interpretation (based on 8 wells).



CODE	LITHOLOGY
1	Clay, silty clay
2	Silt, silty and sandy clay
3	Very fine sand, very fine to fine sand
4	Fine sand, fine to medium sand
5	Medium sand, medium to coarse sand
6	Coarse sand, coarse sand with gravel

Figure 1.6a. Time drawdown analysis by Jacob's method.

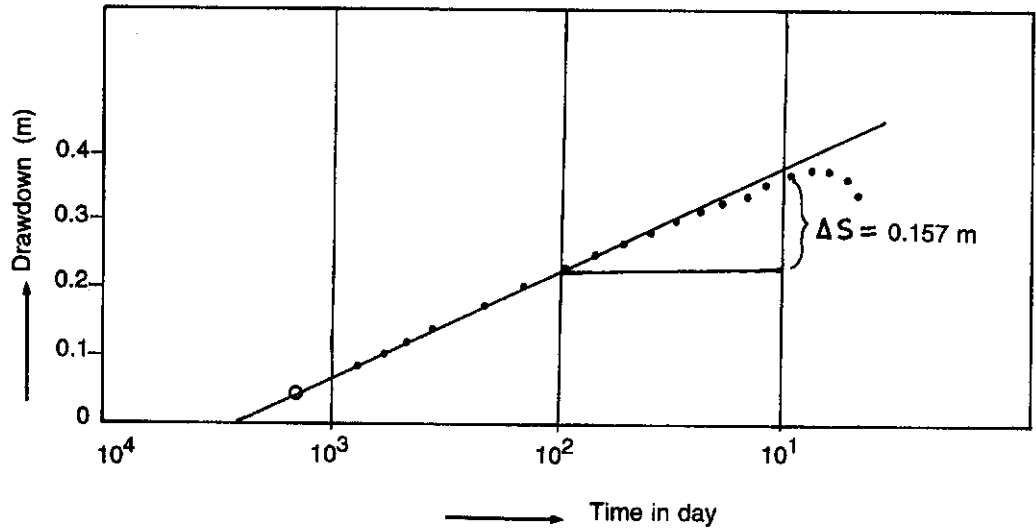


Figure 1.6b. Recovery solution for transmissivity.

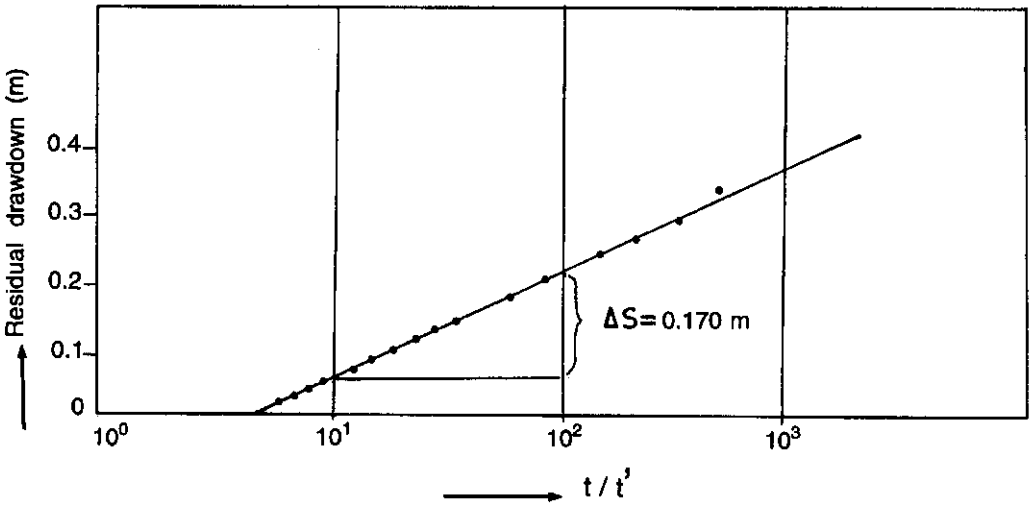
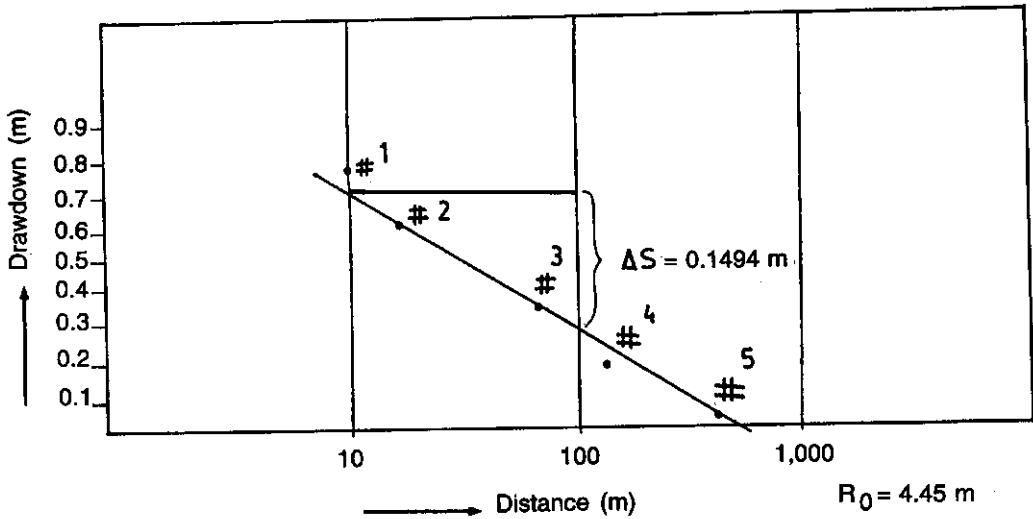


Figure 1.6c. Distance drawdown analysis by Jacob's method.



### Model for Safe Well Spacing

A linear regression model was developed between discharge versus radius of interference. The model shows that there is a significant relationship between discharge and radius of interference. At the higher discharge rate the spacing of wells will also be higher as compared to the lower discharge rate (Table 1.1). A type curve has also been developed by plotting discharge ( $Q$ ) versus radius of interference ( $R$ ) on normal graph paper (Bangladesh Rice Research Institute [BRRI] 1989). From the type curve the spacing for any particular discharge rate can be estimated (Figure 1.7).

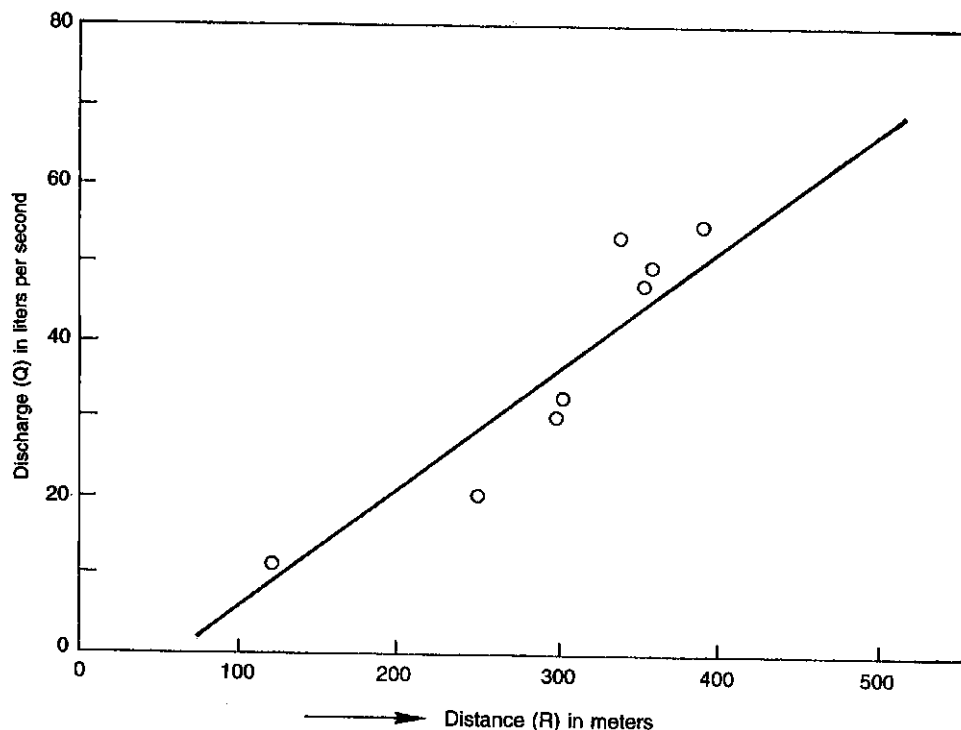
Table 1.1. Discharge versus spacing for deep and shallow tubewells at Kahalu Upazilla, Bogra.

Sl. number	Discharge (lps)	Spacing (m)
1	11 <sup>a</sup>	120
2	20 <sup>a</sup>	250
3	47 <sup>b</sup>	355
4	57 <sup>b</sup>	390
5	30 <sup>b</sup>	300
6	50 <sup>b</sup>	360
7	32 <sup>b</sup>	305
8	54 <sup>b</sup>	340

<sup>a</sup> Indicates the discharge of shallow wells.

<sup>b</sup> Indicates the discharge of deep wells.

Figure 1.7. A type curve of discharge versus distance for production wells.



## Tubewell Performance and Utilization

The irrigated hectareage of the tubewell (area irrigated per unit time), discharge per unit time and the total amount of water applied are shown in Table 1.2. A maximum of 1.24 ha/lps was drawn from DTW No. 10 by operating the pump for 1,660 hrs, and a minimum of 0.56 ha/lps was drawn from DTW No. 5 by operating the pump for 1,583 hrs, during the dry season for rice cultivation. On average, irrigated hectareage of all tubewells was 0.83 ha/lps. Therefore, the tubewells under study were utilized upto their optimum level.

## Advantages and Disadvantages of Intensive DTWs and STWs

The advantages of intensive DTWs and STWs are as follows: (i) can be used as a supplementary irrigation source during high water demand of the crop, (ii) allows to increase cropping intensity by alternative sources of water, (iii) permits an increase of the service area through a combination of deep and shallow wells even if the topography of the service area is not level, and (iv) enables more economic use of water by DTWs and STWs where the water table is near the ground surface.

The disadvantages are as follows: (i) low discharge of wells if there is interference of DTWs and STWs located in the same vicinity which increases the cost of operation, and (ii) high risk of crop production during the dry season, particularly under STWs if the water table goes below the operation level.

Table 1.2. Water utilization in selected deep tubewells at Kahalu Upazilla, Bogra.

Deep tubewell number	Location (village)	Total operating hours	Discharge of pump (lps)	Total area irrigated (ha)	Area irrigated per unit discharge (ha/lps)
1	Narhatta	1,390	74.00	44.20	0.60
2	Buril	1,316	42.00	35.51	0.85
3	Damai	1,350	39.10	29.15	0.75
4	Raushan Chapor	1,349	39.37	38.92	0.99
5	Katnahar	1,583	39.84	22.27	0.56
6	Kait	1,152	34.5	26.87	0.78
7	Vagdubra	1,500	40.55	28.34	0.70
8	Muril	1,620	38.50	40.49	1.05
9	Vishropur	1,620	41.42	30.36	0.73
10	Bokra	1,660	45.62	56.41	1.24

Note: Command area of shallow tubewells was not included.

## SUMMARY AND CONCLUSION

The study area has an intensive development of tubewells for crop production. The intensity of tubewells per km<sup>2</sup> is 4 to 5 with discharge capacities ranging from 11 to 57 lps. The increasing number of DTWs and STWs may lower the groundwater table further in the study area from year to year, due to overdraft which was observed during the course of the study. There is a significant relationship between rainfall, groundwater table fluctuation and stream flow in the vicinity. The groundwater level started to rise after one month from the commencement of rains when the cumulative total of rainfall reached 15 cm. The study also indicated that the stream flow influences groundwater recharge favorably. The lithological investigation showed that the 100 percent screenable material lie 12 m from the ground surface and extend up to a 60 m depth. The aquifer characteristics such as transmissivity and storage coefficient were determined from pump test data. The results indicated that the aquifer has good potential for groundwater development. But the present trend of increasing the number of deep tubewells and shallow tubewells installed every year in the study area may lower the groundwater table below the operation level. This was indicated during the test of radius of interference between deep and shallow wells at full operation time. However, this issue can be solved technically from the findings of the study by using the distance drawdown and spacing relationships. Hence, a proper policy should be implemented in future for installation of wells in farmer-managed tubewell irrigation systems, with a view to attaining sustainability in groundwater management.

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