INNOVATION OF INVERTED-WELL CHANGES THE CONCEPT OF CONVENTIONAL WELL DESIGN

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ABSTRACT

Barind Tract of Bangladesh is one of the driest parts of the region where surface water supplies are limited. Large parts of this tract used to be fallow land because there were no major irrigation facilities until mid 1980s. A detailed hydro geological and groundwater survey of Bangladesh was implemented by UNDP in February 1978; Barind was described as follows, "the zone lie on the western Rajshahi known as Barind Tract. Thick clay deposits have been proven by test drilling which indicates that the main aquifer does not exist in the upper 300 m. Therefore groundwater potential is limited to development from relatively thin, fine grained sand zones that appear within the clay sequence. The aquifer is capable of supporting only small domestic needs".

The above mentioned theoretical study result of UNDP is surpassed by the innovation of "INVERTED WELL". This was the outcome of the actual field trials to meet the local need and match available aquifer conditions that was not suitable for conventional well design. However, desired improved yield from aquifers of limited saturated thickness using inverted wells were achieved.

Despite initial surveys which indicated the non-availability of major groundwater resources, till to-date there are around 6625 successful drilled wells are irrigating about 400,000 acres producing approximately one million metric ton of cereals food. Irrigated crop production in Barind area has brought about positive changes in rainfall trend. The average rainfall seems to have increased by 7.3 cm over the last 15 years period, which causes increase in humidity and improvement of the environment.

Keywords: Irrigation; Groundwater; Limited Aquifer; Inverted Well

INTRODUCTION

Bangladesh is a land of rivers and is crossed by numerous tributaries of the Ganges-Brahmaputra river system. Every year an enormous volume of water passes through Bangladesh to the Bay of Bengal to the south, the main source of this water is monsoonal rainwater and ice melt from the Himalayas. As the country is very flat and of low elevation, flooding occurs almost every year and is a major problem. However, the physiography of the country is not suitable for regulating the flow of large volumes of surface water.

Despite the annual threat of flooding, agriculture in Bangladesh is dependent on irrigation during the dry eight months from mid-October to mid-June when rainfall is minimal. Groundwater supplies about 75% of dry season irrigation and almost all municipal water supplies. Groundwater, used for irrigation, is becoming increasingly important for food production since floods often damage rain fed crops. Groundwater has been the backbone of the green revolution which has made Bangladesh virtually self-sufficient in rice production since the mid 1990s (Ahmed, 1994).Irrigation in north-west Bangladesh is almost entirely dependent on groundwater. The Barind Tract is one of the driest parts of the region where surface water supplies are particularly limited. Despite initial surveys which indicated the non-availability of major groundwater resources, significant developments have occurred.

INITIAL STUDIES

A detailed hydro geological and groundwater survey of Bangladesh was implemented by UNDP in February 1978; the project continued for almost four years (UNDP 1982). Evaluation of data led to the identification of 15 zones for possible groundwater development. Each zone was evaluated for its development potential based on aquifer characteristics; various development constraints were identified. Barind was described as follows, "the zone lies in the western Rajshahi District and consists of older alluvial deposits known as the Barind Tract. Thick clay deposits have been proven by test drilling which indicates that the main aquifer does not occur in the upper 300 m. Therefore groundwater potential is limited to development from relatively thin, fine grained sand zones that occur within the clay sequence. 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." Bangladesh Water Development Board (BWDB, 1989) considered that only shallow tube wells should be constructed with suction pumps to withdraw the water which would be used for domestic purposes.

HISTORY OF DEVELOPMENT IN THE RAJSHAHI BARIND

The Barind Tract is distinguished by hard red soils which are different from those in other parts of Bangladesh. The tract extends over Rajshahi, Dinajpur, Rangpur and Bogra Districts of Bangladesh and Maldah District of West Bengal of India. The Rajshahi Barind Tract is located between 24˚23' to 25˚15' north latitude and 88˚2' to 88˚57' east longitude. The temperature varies between 44˚C and 6˚C; the climate is dry apart from the monsoon from mid June to mid October. Annual rainfall varies between 1400 to 1700 mm; an increase in annual rainfall appears to have occurred following the development of dry season irrigation and afforestation. The location of the study area is shown in Fig. 1.

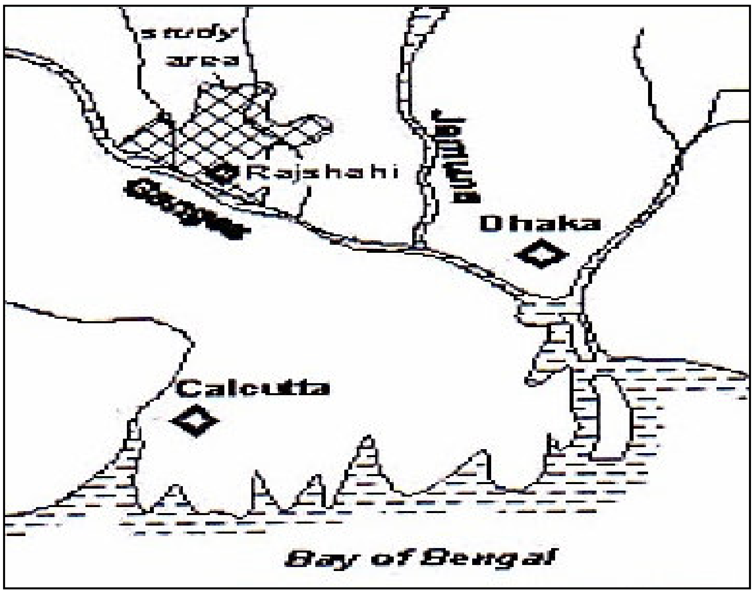

Fig. 1 Location map of Rajshahi Barind

A report published in 1989 by the Bangladesh Water Development Board (BWDB, 1989) describes work carried out in 1988-89 in which 117 exploratory test holes of varying depth from 92 m to 152m were drilled in Barind. Of these, 12 holes were logged by the Institute of Nuclear Science and Technology. Seventy-seven new observation wells of depths ranging from 30 – 40 m were installed to measure groundwater fluctuation. Twenty-four pumping tests were conducted for estimating aquifer hydraulic properties.

The data from these field investigations allowed reliable estimates of the location, extent of aquifers and realistic estimates of the aquifer properties. Recharge values were estimated from the water table fluctuation; quoted values vary between 180 mm and 600 mm in a year. Unlike the earlier UNDP estimates, these values are based on field measurements although there is uncertainty about this method since factor other than recharge can influence water table fluctuations. The quoted values do suggest that tubewell yields may be sustainable.

INVERTED WELLS

To illustrate the differing distributions of sands and clay in the study area, Figure 2 contains strata logs for six locations, which are plotted relative to non-pumping water levels (sometimes called static water levels or rest water levels). The screened section of the well should start at 25 m or more below the non-pumping water level. With strata logs for locations A, B, and C, the permeable aquifer extends from 23 to 43 m below this 25 m depth. Consequently, conventional well construction can be used as illustrated by the borehole for Fig.3. The borehole was drilled at 0.51 m (20 inch) diameter, a solid casing of 0.36 m diameter (14 inch), extends for 24.2 m below the non-pumping water level (27.2 m below ground level). There is a reducer of 1 m depth with screen of 0.2 m diameter (8 inch) which is 21.3 m long. Hence the total depth of the assembly lowered into the borehole is 49.5 m. A yield of 7340 m^3/d (3 cusec) is achieved with a pumped drawdown of 13.5 m.

Conventional well construction is not suitable for locations D (27.4 m from non-pumping water level to the base of the lowest aquifer), E (19.2 m to the base of the lowest aquifer) and F (27.1 m to the base of the lowest aquifer) since at most there are only a few meters of permeable strata below 25 m. An alternative form of well construction is required in which the pump is positioned at a greater depth than for a conventional well with an increased area of slotted casing. This can be achieved using an inverted well. In an inverted well the solid casing, which serves as a housing for the pump, extends to the bottom of the lowest permeable strata.

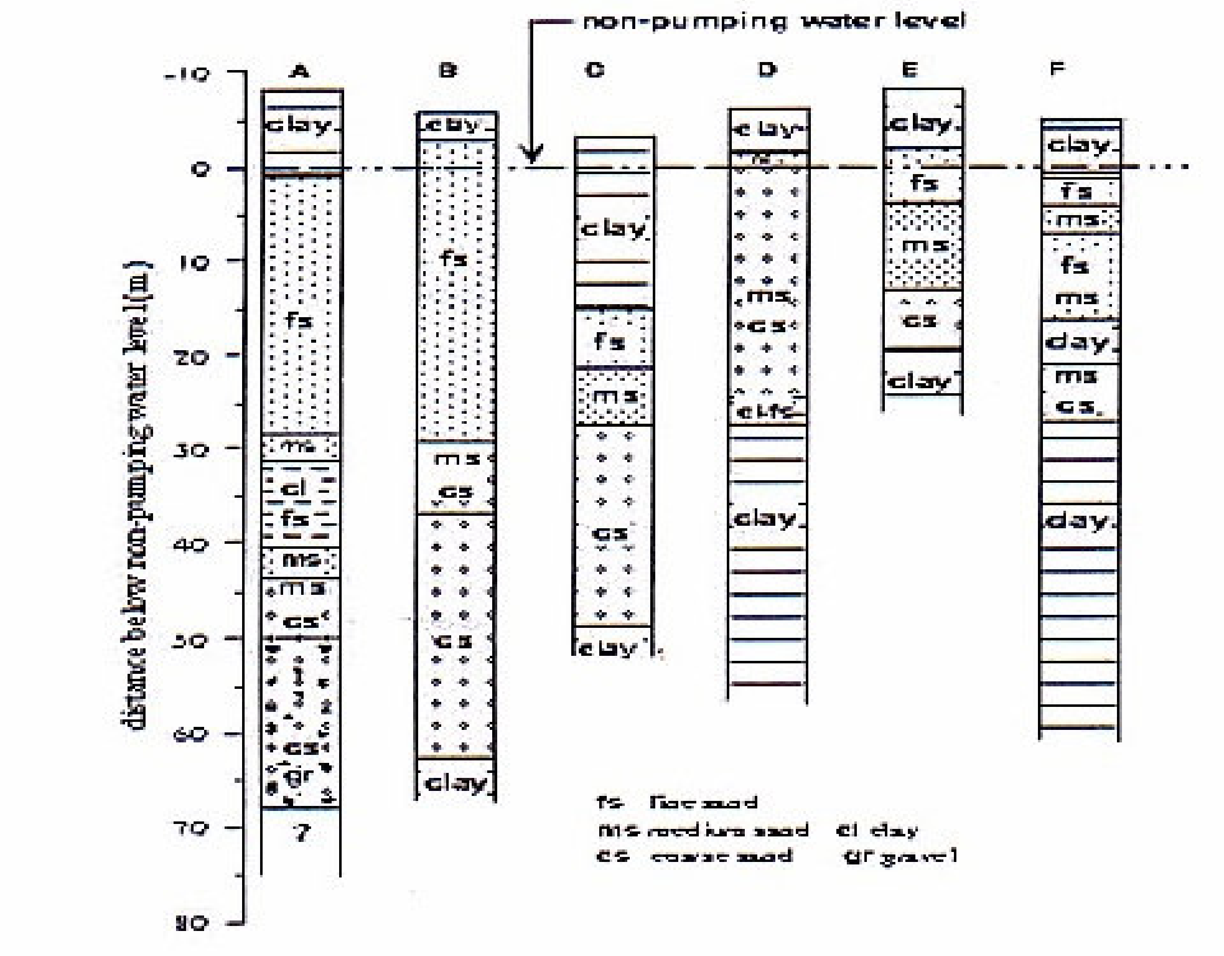

Fig. 2 Strata of six bore logs

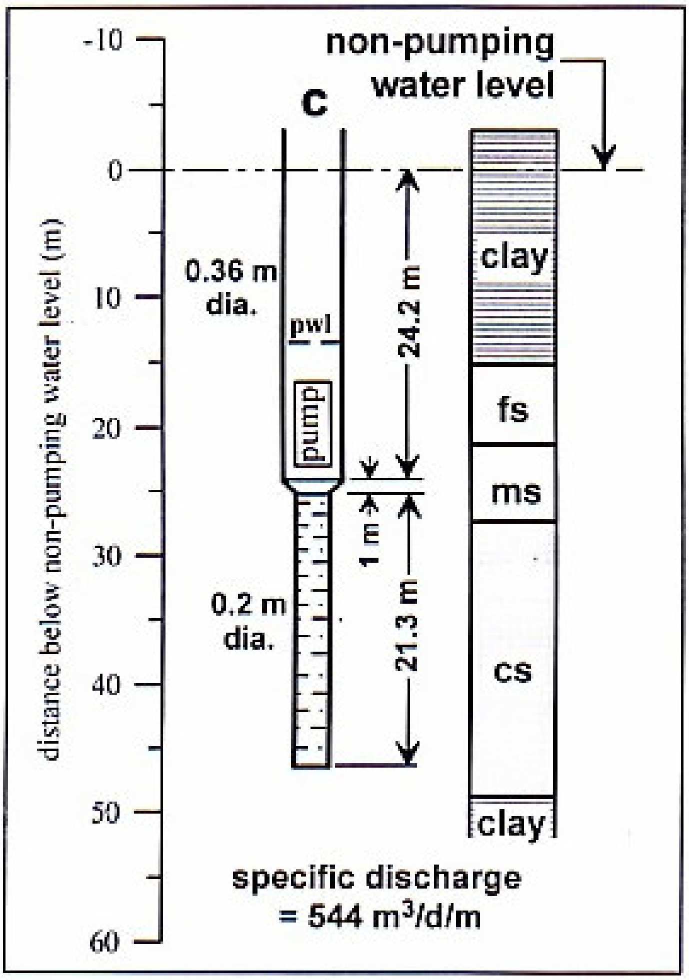

Fig.3 Conventional well at location C.

Inverted wells are used for locations D, E and F as shown in Fig. 4. A connector is provided at the bottom of the solid casing which allows two or four vertical screens to be constructed projecting upwards along the side of the casing from the connector. Alternative arrangements have been explored in the Barind aquifer for different lithology with some screens projecting upwards and others projecting downwards.

For location D the drilled diameter is 1.02 m to a total depth 28.3 m below ground level which is equivalent to 22.2 m below non-pumping water level. A connector is added at the bottom of the 0.36 m diameter solid casing. Two upward projecting vertical screens are provided, each of 0.15 m diameter and 12.2 m in length. The hole is backfilled with gravel to the ground surface. A discharge of 7340 m^3/d is achieved with a pumped drawdown of 7.02 m; hence the specific capacity is 1045 m^3/d/m. This high specific capacity occurs due to the higher hydraulic conductivity of the medium sand/coarse sand layers.

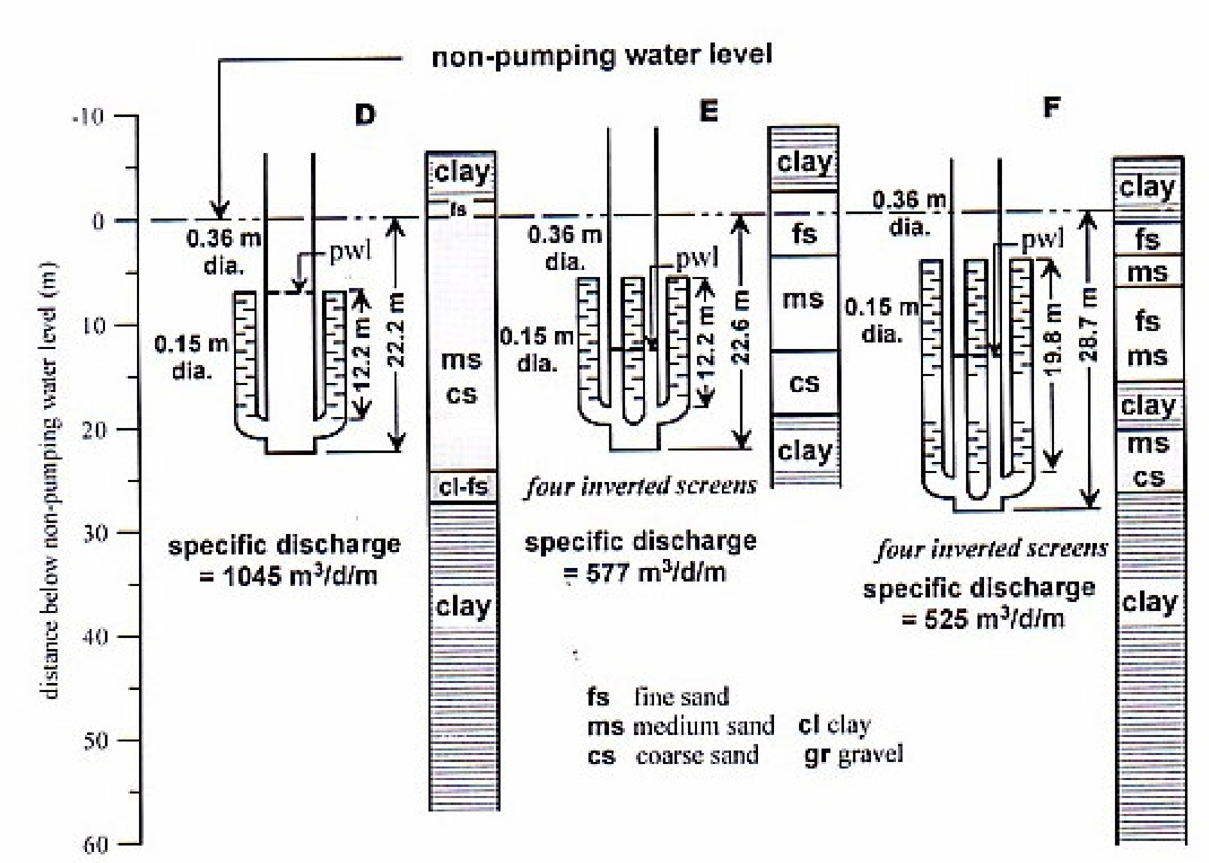

Fig. 4 Inverted wells at locations D, E and F.

For location E, the depth below non-pumped water level to the effective base of the aquifer is only 19.2 m. The connector at the base of the 0.36 m diameter solid casing extends 3.4 m into the clay. Four inverted screens are provided, each of 0.15 m diameter and 12.2 m long. The pumped drawdown of 12.7 m is roughly at the mid depth of the inverted screens; with a pumping rate of 7340 m^3/d, the specific capacity is 577 m^3/d/m. For location F. four inverted pipes are provided, each of 0.15 m diameter with two screened sections totaling 15.2 m, to achieve a yield of 7340 m^3/d; the pumped drawdown is 14.0 m giving a specific capacity of 525 m^3/d/m. For each of the three locations in Fig. 4, the use of an inverted well permits a yield of 7340 m^3/d to be obtained despite the limited depth of the aquifer.

Improved Yield from Inverted Wells

At certain locations in the Barind aquifer, conventional wells have been replaced by inverted wells. An inverted well requires a drilled hole of 1.02 m (40 inch) diameter. The modified construction of the well does incur additional costs due to the drilling of a larger diameter hole, additional screen lengths and a greater volume of the gravel pack. Usually these additional costs are more than compensated by increased discharges. Comparisons between conventional and inverted wells at the same location are illustrated in Table 1. An increase in yield is achieved for each location due to the larger pumped drawdown for the inverted wells. Yields for the conventional wells are between 2450 and 3670 m^3/d; for the replacement inverted wells the yield for one well is 6120 m^3/d, the other four wells can provide 7340 m^3/d (3.0 cusecs). Pumped drawdown increase by between 3% and 90%.

Table 1 Comparison of conventional and inverted wells at five locations

	conventional					Inverted				
No.	Length (m)	Screened length (m)	Qmax (m^3/d)	d/down (m)	Specific discharge (m^3/d/m)	Length (m)	Screened length (m)	Qmax (m^3/d)	d/down (m)	Specific discharge (m^3/d/m)
1.	29.3	9.1	2450	7.44	330	29.3	2×9.1+ 2×6.1	7340	7.65	960
2.	36.6	2×12.2	3670	14.8	248	32.0	4×9.1	6120	19.0	322
3.	50.0	2×12.2	3380	13.7	247	46.9	4×8.7	7340	21.9	335
4.	39.0	15.2	2940	4.7	626	32.6	4×9.1	7340	8.9	825
5.	44.8	2×12.2	3030	16.9	179	40.8	4×11.6	7340	24.7	297

Improvements in well yields depend on increased specific discharges (the discharge per unit drawdown). For one location, no. I, the ratio of specific discharges for the inverted well and the conventional well is 2.9, three wells are in the range 1.3 to 1.35, the fifth well has a ratio of 1.66. Changes in specific discharge depend on the permeability of the strata through which the well penetrates and also on the design of the well. Using the Thiem formula (Todd 1980), assuming that the effective radius of the well equals the radius to the edge of the gravel pack (0.254m for a conventional well and 0.508 m for the inverted well) and using an effective outer radius of 300 m, the increase in specific discharge for the inverted well is 11%. Alternatively using classical steady-state leaky aquifer analysis, the increase in specific discharge is 9%. Therefore the increased diameter of drilling and the use of a permeable gravel pack should result in an increase in the specific discharge of about 10%.

REASONS FOR SUCCESS

Currently the Barind aquifer is supplying sufficient water for extensive irrigation. However to understand the reasons for the current yield and to assess the sustainability of this yields it is necessary to examine carefully the nature of the aquifer system, the likely recharge, the design and operation of the pumps and wells and what can be learnt from the response of observation wells. Despite initial surveys which indicated the non-availability of major groundwater resources, till to-date there are around 6625 successful drilled wells are irrigating about 161943.3 ha. (400,000 acres) producing approximately one million metric ton of cereals food. Irrigated crop production in Barind area has brought about positive changes in rainfall trend. The average rainfall seems to have increased by 7.3 cm over the last 15 years period that caused the increase in humidity and improvement of the environment.

CONCLUSIONS

Conventional wells frequently fail to provide high yields when the lowest permeable zone is less than 30 m below the non-pumping water level even though there is sufficient recharge to the aquifer to maintain a high yield. However, by adopting the alternative design of an inverted well, in which the solid casing extends over the full depth of the permeable aquifer and with screens projecting upwards alongside the solid casing, substantial increases in the yield of the well can be achieved.

The use of inverted wells has been pioneered in the Rajshahi Barind, Bangladesh. In locations where the depth to the permeable strata is limited, inverted wells provide sufficient water for irrigated rice during the dry season. The main reasons for increased yields from the wells are that the pump can be set lower with increases in screen area and volume of gravel pack leading to higher specific capacities. The two-zone radial flow model is used to represent approximately the flow processes which occur during a routine step-pumping test in an inverted well. From the simulation, reasons for the increase in specific discharge can be identified; they include more conductive flow paths due to the increased dimensions of the gravel pack and contributions from the confined storage and the specific yield.

Having constructed wells which can draw substantial quantities of water from aquifers of limited depth, the question remains as to whether there is sufficient recharge to maintain these yields. For the study area, the potential recharge is high due to losses from flooded rice fields. Furthermore, in the Rajshahi Barind the permeability of the uppermost clay layer is sufficient for the potential recharge to pass through the underlying aquifer system. The fact that the recharge is sufficient to maintain the abstractions is confirmed by the recovery each year of groundwater heads in observation wells.

RECOMMENDATION

A theoretical study has to be conducted in order to put a theoretical base for the design of inverted wells instead of conducting the design on the base of experience alone.

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