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MONITORING AND PROTECTING GROUNDWATER QUALITY IN STRATIFIED AQUIFER SYSTEMS

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ABSTRACT

The quality of groundwater produced by a well in a multilayer aquifer system is the total effect of the quality of water released from each of the aquifers tapped by the well in response to pumping and/or artesian pressures. Sometimes, the quality of water produced by such a well may fail to meet the criteria set for its intended use, whereas the cause of the problem may lie in only some of the water bearing strata. The paper describes a method for stratawise water quality monitoring for identifying formations with poor quality water and drilling and designing the well so as to isolate those aquifers and thereby minimizing contamination. Results obtained from a successful experimental deep well sunk in an area where quality of groundwater for irrigation has been a major concern, are presented to illustrate the potential of the method.

INTRODUCTION

The total stock of fresh water of the earth is about 8.2 million km^3 (ref. 1) and about 97% of this total supply at any time occurs as groundwater (ref. 2). Groundwater thus forms an important source of water supply where it occurs. While developing the groundwater resource in a given area, it is important to know not only the quantity of available water but also its quality to insure its suitability for the intended use, whether for irrigation, domestic or industrial purposes. Where a single aquifer is tapped by a well, it is relatively easier to sample the water contained in the aquifer and monitor its quality. However, multilayer aquifer system is the more commonly found situation in the field. The quality of water produced by a well tapping such an aquifer system would only reflect the overall quality of the mixture of waters from different water bearing formations. If this overall quality does not meet the standard for the intended use, it may be worthwhile investigating if the poor quality water is contributed only by some of the formations while others may produce waters of acceptable quality. Such investigation could be made if it were possible to obtain water samples from individual formation strata. The next step then would be to drill and design the well so as to only produce water from the better formations with minimum or no contamination by waters from others.

The paper describes a case study where the groundwater produced by some existing wells from a multilayer aquifer system did not meet the desired quality standards for irrigation of rice crops and the methods evolved to circumvent the problem.

STATEMENT OF THE PROBLEM

In some parts of the experimental farms of the International Rice Research Institute (IRRI) boron toxicity has been identified to be a cause of the declining yields of rice crops (ref. 3). It has also been observed that the heavy clay soils of those areas have high water-soluble boron content. Analyses have revealed that boron content of plants sampled from those areas ranged from 20 to 62 ppm and the available boron in the soil ranged from 1 to 14 ppm. More than 2 ppm B in irrigation water has been reported to be harmful for rice (refs. 4 and 5). In the IRRI farm, the toxicity symptoms were observed on plants growing on soils with available B greater than 5 ppm (ref. 6). Also the boron content in these soils has been found to be increasing with time (Table 1). This build up of boron in the soil has been attributed to the groundwater used for irrigation, which contains more than 2 ppm B and the impeded drainage in the heavy clay soils. The effect of impeded internal drainage is demonstrated by a uniform distribution of boron content in a soil profile down to a depth of 80 cm in a high boron area (Table 2).

TABLE 1

Comparison of the boron content of some blocks in the IRRI farm at two sampling times (After Cayton, 1980)

Block	Boron content (ppm) of dry soil		
	1977	1979	Increase
M7	9.3	11.0	1.7
M9	9.9	10.5	0.6
M11	7.6	12.1	4.5
M12	8.5	13.0	4.5
M16	7.8	9.9	2.1

TABLE 2

Distribution of boron in the profile in Block M10 (After Ponnamperuma, 1979)

Depth (cm)	B (ppm)
0 - 30	10.0
30 - 50	10.2
50 - 80	10.7
80 - 100	6.6

Analysis of boron in irrigation waters from different wells in and around the IRRI farm showed that while some wells produced waters with as high as 2.9 ppm B, there was one which produced water with only 0.3 ppm B (Table 3). A study of the lithologic logs of these wells revealed that wells which had tapped more of pyroclastic formations also produced waters with higher B. It was decided to confirm this apparent relationship which, if found correct, could be used as a guideline for future development of groundwater in this region to avoid the water quality problem.

TABLE 3

Aquifer and water quality characteristics of deep wells within IRRI Farm.

Well #	Total aquifer thickness (m) T	Thickness of sedimentaries tapped (m)	Thickness of igneous tapped (m) I	I/T (%)	Boron in water (ppm)
IRRI-MN	50.0	11.0	39.0	2.9	78
IRRI-500	89.9	21.3	68.6	2.9	76
IRRI-X	74.1	32.9	41.1	2.2	55
IRRI-2000	79.3	51.8	27.4	1.9	31
IRRI-T	76.2	58.5	17.7	0.3	23

APPROACH TO SOLUTION

In order to identify the aquifers bearing good quality water and to establish possible correlation between the lithology of the formations and the quality of waters borne by them, it was necessary to have a method whereby water and rock samples could be collected formationwise from a test bore-hole. While collecting formation samples during the drilling of a test or a production well is rather simple and a routine practice of the drillers for the purpose of preparing a well log, collecting water samples from each of the water bearing formations is difficult and is not in practice.

To achieve the above objectives, a 25.4-cm dia test-cum-production well was drilled by the cable-tool percussion method using a "drill and drive" technique. After every 1.5 m of drilling by a 24.76 cm dia drill, a 27.3 cm OD blank casing was driven to that depth. The water and the slurried formation cuttings in the hole were bailed out before resuming drilling and the sequence repeated down to the target depth. Representative formation samples were collected and properly tagged every 1.5 m or every change of formation whichever came earlier. To avoid contamination from an upper aquifer, the first water sample from each water bearing formation was collected when the casing had been lowered to the top of that formation and the hole had been drilled 1.5 m further into the formation. In thicker aquifers a water sample was also collected every 4.5 m after the first sample to get more representative samples. The water sampler used consisted of a 35.6 cm x 7.6 cm open ended bronz cylinder which was lowered with the help of a cable to the bottom of the cased hole. The water entering the cylinder at that depth was trapped by dropping a small weight concentric with the cable which activated the closure of the cylinder from both ends by water tight rubber stoppers. The water sampler was then pulled out of the hole and the contents emptied in a clean plastic bottle by pressing a valve at the bottom of the lower stopper. It is important to note that since glass is composed of boron silicates, no glass container should be used for storing water samples collected for boron analyses.

The rock formation and water samples collected during the drilling of the test well were analyzed for their lithology and boron content respectively.

Having completed the drill-and-drive operation and having identified strata bearing good quality water the next step was to perforate the blank casing _in situ_ over corresponding depths to provide strainers for the well. The device used for the _in situ_ perfotation consisted of a heavy semi-cylindrical steel block about 61 cm in length, tapered at both ends and with a rectangular prismatic shape on one side forming a flat vertical face. This flat side had a 2.5 cm wide vertical slit. A hard tempered steel blade (16.5 cm x 5.0 cm x 1.6 cm size) tapered at one end to form a 6.3 mm wide cutting edge and rounded at the other was installed in the slit of the perforator so as to allow it to swing along its place about a bolt passing through a hole near the rounded end of the blade.

The _in situ_ perforation technique was as follows. The drill bit on the drill line was replaced by the perforator. In order to make slots in the casing at a desired depth, the perforator was lowered down to that depth with the cutting edge of the blade resting against the inside of the casing. When the line is pulled upwards the blade gets locked up against the casing. Several vertical strokes of the drill line, similar to those performed for drilling, were then made till the blade ripped through the casing making a 5 cm vertical slot about 6.3 mm wide. Once the slot was made, the blade got released from the casing indicated by a sudden, easy movement of the perforator. It is important to note that the success of this technique of _in situ_ perforation which is basically a "ripping" process depends largely on the strength of the blade. Blades made out of several different kinds of steels commercially available and subjected to different tempering treatments were tried to come up with the right combination which gave the blades the desired strength to "rip" the 5 cm x 6.3 mm slots through the 6.3 mm thick steel casing. In the latter improved trials as many as 45 slots could be made with a single blade before its edges got blunted or broken. Blunted blades could, however, be reused after sharpening. A total of 1183 slots were made along a total of length of 148' of the casing in four zones of good quality water, starting from the lowest.

RESULTS AND DISCUSSION

Table 4 presents the boron content in water samples collected at various depths below the ground surface and the lithology of the geologic formation encountered at those depths. It is seen from the Table that while the water in the sedimentary formations had B ranging from 0.7 to 1.0 ppm with an average of 0.88 ppm, the B content of water in adobe layers of volcanic origin ranged from 1.2 to 1.4 with an average of 1.27 ppm. Though the difference in these values was not very striking, it did support the earlier observations that the B content in waters in the sedimentary formations is lower than that in waters borne by pyroclastic formations.

TABLE 4

Results of water and aquifer formation analyses.

Depth (m)	Formation	B in water ppm
7.6	gravel	0.8
19.8	sandy clay	0.9
29.0	brown adobe	1.2
32.0	brown adobe	1.2
36.6	brown adobe	1.4
44.2	gravel + sand	0.8
45.7	gravel + sand	0.8
47.3	sand + clay	1.0
48.8	coarse sand	0.9
50.3	coarse sand	0.9
51.8	coarse sand	0.9
53.3	coarse sand	0.9
54.9	coarse sand	0.9
59.5	coarse sand	0.9
62.5	sand + clay	0.9
65.5	sand + clay	0.9
68.6	sandstone	1.0
74.7	sandstone	1.0
83.8	gravel + boulder	0.9
86.9	sand + clay	0.8
91.5	sand + clay	0.9
96.0	gravel + boulder	0.7

TABLE 4 (cont'd)

Depth (m)	Formation	B in water ppm
112.8	sandstone	0.9
118.9	sandstone	1.0
122.0	sandstone + gravel	0.9
128.0	sandstone + gravel	0.8

The practical utility of the above finding lies in the fact that for future development of wells in this area, it would suffice to collect formation samples in a small test bore down to the target depth of a proposed future well and study their lithology. The depth intervals can then be identified for the geologic formations which are potential aquifers and are not of volcanic origin. Having selected these formations, the next step would be to drill a production well concentric with or near the test bore by drill-and-drive method using casing pipe lengths which have been pre-perforated to tap only the selected formations.

It is important to note that unlike the usual practice, no gravel pack was provided around the well casing which was tightly driven through the formations thereby practically leaving no annular space around. With the usual well drilling procedures whereby the pre-perforated casings are lowered in the open-drilled hole and the annualar space between the casing and the formations is gravel packed, it would be impossible to prevent waters from the undesirable strata from entering the well through the gravel pack and thus causing mixing of bad quality waters with those of acceptable quality.

The drilling procedure described in this paper is capable of preventing or, at the least, minimizing such contamination. This is confirmed by the B content (1.0 ppm) measured in the water produced by the well drilled at the IRRI farm using this procedure. That the in situ perforation technique worked satisfactorily from the discharge point of view is indicated by the fact that after development, the well produced sand free water with good discharge potential. The specific capacity of the well tested at a discharge of 450 gpm (31 lit/sec) was 36.6 gpm/foot (0.78 lit/sec per meter).

REFERENCES

1 L. Huisman, Groundwater Recovery, MacMillan, New York, 1972, p. 366.

2 Johnson Div., Universal Oil Products, Ground Water and Wells, second printing, Saint Paul, Minnesota, 1972, p. 440.

3 F.N. Ponnamperuma, Soil Problems in the IRRI Farm, IRRI Thursday Seminar Paper, 8 November 1979, International Rice Research Institute, Philippines 1979.

4 J. S. Kanwar and N. S. Randhawa, Micronutrient Research in Soils and Plants in India, Indian Council of Agricultural Research, New Delhi, 1972, p. 185.

5 FAO/UNESCO, International Source Book on Irrigation, Drainage and Salinity, V.A. Kovda, C. can der Berg, R. G. Hagan, Hutchinson, London, 1973.

6 MT.C. Cayton, Laboratory and Greenhouse Studies on Boron Toxicity in Rice, IRRI Saturday Seminar Paper, 27 September, 1980, International Rice Research Institute, Philippines, 1980, p. 8.