Journal of Civil Engineering
The Institution of Engineers, Bangladesh
Vol. CE 25, No. 2, 1997

DETERIORATION OF THE YIELDING CAPACITY OF WATER PRODUCTION WELLS IN DHAKA

Md. Mujibur Rahman[1] **and Sajal Chandra Dhar**[2]

Abstract : A study has been conducted to evaluate the causes of reduction of yielding capacity of water production wells installed by Dhaka Water and Sewerage Authority (DWASA). Well performance tests were carried out on seven selected wells within Dhaka Metropolitan area. Comparative analysis of results of tests conducted during construction as well as during the present study yielded information regarding gradual deterioration of production wells. The gradual fall of static water level as well as well-clogging were identified as primary causes of the deterioration of yielding capacity of wells. It is concluded that proper well development during construction, regular well monitoring and introducing of well regeneration practice may increase the working life of DWASA wells.

KEY WORDS : Production wells; Yielding capacity; aquifer and well losses; step drawdown test; well regeneration.

INTRODUCTION

Ground water is the main source of drinking water in Dhaka city, the capital of Bangladesh. At present about 96% water supply of Dhaka is met from exploitation of ground water (DWASA, 1993). Although DWASA has taken some surface water treatment projects, ground water will continue to be a vital source of potable water supply. In 1993, DWASA was operating about 168 deep tubewells. Besides, a number of private wells are also in operation in Dhaka city. Since the inception of water supply system, about 300 wells have been drilled by DWASA, out of which more than 40% wells are not functioning at present. The reasons for deterioration of yielding capacity of these wells however, have not been properly investigated.

Dhaka city is situated on a flat plain land with an average elevation of 5 m. The aquifer system beneath Dhaka is complex in nature and functioning as a leaky, semi-confined aquifer (BWDB, 1984). Since 1969,

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1 Department of Civil Engineering, BUET, Dhaka-1000, Bangladesh

2 Bangladesh Water Development Board, Dhaka-1000, Bangladesh

DWASA has been installing gravel packed wells by reverse rotary drilling *technique (Serajudding, 1984). The tubewells* are designed to have a 20 years life with a minimum yield of 2 cusec (4896 m^3/day) of water.

The tubewells are drilled with a diameter of 560 mm (22 inch) to a depth of about 200 m (600 ft). Typically they have an upper pump housing made of mild steel, usually 460 mm (18 inches) in diameter to a depth of about 60 m (180 ft) as per DWASA design practice. The diameter of the blind pipe and strainer is 200 mm (8 inches). Previously DWASA used 50 slot screen which led to wide spread sand pumping and since about 1989 DWASA has started using 30 slot screen having an open area of at least 25%. Gravel of a ppropriate grading is placed with an average thickness of 175 mm (7 inches). Previously the wells were developed by step pumping and back washing only which is now replaced by water jetting method. When a new well is constructed, a pump (submersible or turbine) with a capacity of 200 m^3/hr (2 cusec) with 70 m dynamic head is installed.

AQUIFER AND WELL LOSSES

The fall of static water (STW) level from its original position during pumping in a well (Figure 1) is termed as average draw down (ADD) which is primarily composed of two loss components: aquifer losses (Δa) and well losses (Δw).

ADD = (Pumping water level– Static water level)

or, $s = \Delta a + \Delta w$

$$= \Delta a + \Delta wl + \Delta w_t \qquad (1)$$

where, Δwl = laminar well losses

Δwt = turbulent well losses

Aquifer losses (Δa) : These losses are laminar type and occur at the interface between the aquifer and the damage zone of the well bore (zone where the permeability reduces due to accumulation of drilling remnants around the bore hole). For the case of a fully penetrating well in a confined aquifer at unsteady state condition (Cooper & Jacob, 1946), the aquifer losses can be expressed as follows :

$$\Delta_a = \frac{2.3Q}{4\pi kD} \log \frac{2.25kDt}{r_{ew}^2 S} \qquad (2)$$

where,

r_{ew} = effective radius of the well (m)

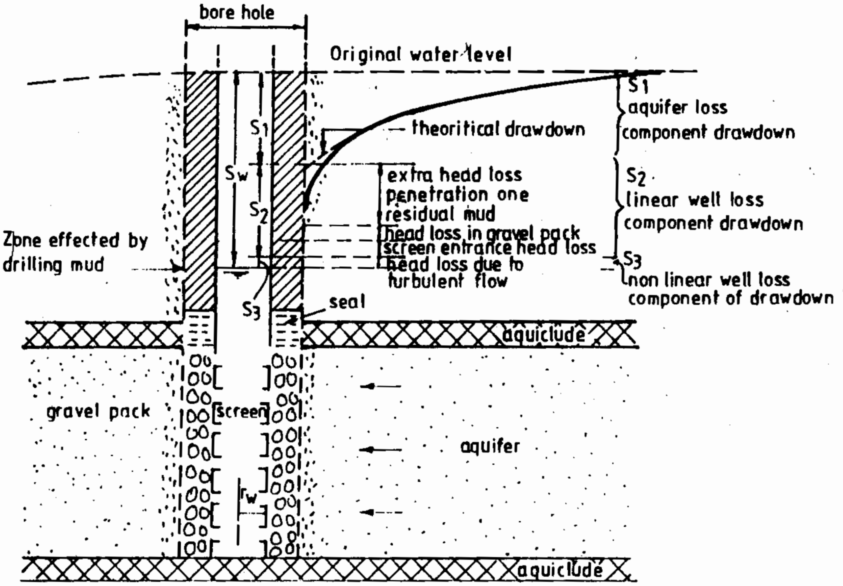

Fig 1. Various head Losses in a Pumped Well (Kruseman G.P. and Ridder N. A., 1990)

S = storativity

kD = transmisivity (m^2/day)

Q = discharge (m^3/day)

Well Losses (Δw) : The condition of a well is responsible for the occurence of the well losses. It has two components :

i) **Laminar well losses** (Δ_{wl}) : These losses occur in the damage zone and partially in the gravel pack zone.

ii) **Turbulent well losses** (Δ_{wt}) : These losses occur partially in the gravel pack zone, screen opening and the rising pipe.

TEST PROGRAM AND DETERMINATION OF LOSS COMPONENTS

Seven DWASA water production wells were selected and a number of well performance tests (step-drawdown, single well pumping and recovery tests) were carried out on them. Study had been made on the hydrogeology of Dhaka city. In addition, various water quality tests were conducted on the collected specimen from the test wells.

The transmisivity (kD) was determined from pumping and recovery tests individually. Using the storativity (0.00083, avg. for Dhaka city (*EPC, 1991*), the average drawdown (s) was segmented into its aquifer loss (Δa) and well loss (Δw) components. Subtracting the turbulent well losses (found from step-drawdown test) from the total well losses (Δ_w) the laminar well losses (Δwl) were determined. In this way the average drawdown (s) of a well was segmented into its three loss components : aquifer losses (Δa), laminar well losses (Δwl) and turbulent well losses (Δwt).

Analysis of step drawdown test : The average drawdown (s) of a well during operation may be expressed (Jacob, 1947 in Dhar, 1995) as :

$$s = B_{(r_{ew}, t)}\, Q + CQ^2 \qquad (3)$$

where

$B_{(r_{ew}, t)}\, Q$ = aquifer losses (Δa) + laminar well losses (Δwl)

CQ^2 = turbulent well losses (Δwt)

A plot of (Hantush-Bierschenk, 1964,) s/Q versus Q on arithmetic paper yields a straight line whose slope is equal to C and ordinate of zero discharge gave the value of $B_{(r_{ew}, t)}$. An one-hourly step-drawdown test was carried out with three steps after stopping the well for a long interval.

Analysis of single well pumping test : A semi-log plot of time versus drawdown curve for a fully penetrating well yields a straight line and its slope (Δs per log-cycle) can be used to evaluate the transmisivity (kD). Estimating the storativity the well losses (Δwt) can be determined from the time versus drawdown curve for,

$$t_{(s=\Delta w)} = \frac{r_w^2 S}{2.25 kD} \qquad (4)$$

= time when aquifer losses are zero

The aquifer losses can be determined deducting the well losses from average drawdown. The pumping tests were conducted by pumping the well for six hours at constant discharge.

Analysis of recovery test : A semi-log plot of residual drawdown ($S_{w'}$) versus $(t_p + t_i)/t_i$ yields a straight line and its slope (Δs per log-cycle) can be used to evaluate the transmisivity (Mathews & Russel, 1967 in Dhar, 1995) using the following equation :

$$kD = \frac{2.3Q}{4\pi\Delta_s} \quad (5)$$

where,

t_p = total pumping time

t_i = time since pumping stopped.

Estimating the storativity (S) the skin effect [*skin* $\frac{Q}{2\pi kD}$] or the linear well losses can be determined from the time versus residual drawdown curve at,

$$\frac{t_p + t_i}{t_i} = \frac{21.25\ kDt_p}{r_w{}^2S} \quad (7)$$

Now, deducting the laminar and turbulent well losses from the average drawdown (s) the aquifer losses (Δa) can be determined. The recovery tests were performed

after 6 hours pumping at a constant discharge from the initial condition. Besides, the aquifer losses can also be evaluated mathematically using the transmisivity (found individually for both of the single well pumping and recovery test) and estimated storativity.

The amount of three loss components of ADD were determined from test results both during construction and the present study. The test results during construction described the well condition immediately after construction. The comparison of construction period and present test results showed the deterioration trend of the wells. During comparison, the aquifer losses were considered to be unchanged because of the absence of any major hydrogeological changes in the study area.

The losses due to partial penetration were not evaluated which was a limitation of the study. However, the strainers in the test wells were found to be distributed over the entire thickness of the aquifer which reduced the partial penetration effect to a considerable extent.

RESULTS AND DISCUSSIONS

Well Condition Immediately after Construction

The average drawdown was found to vary between 5.47 to 15.53 m if the wells were operated at a discharge 4896 m^3/day for 24 hours (Table

1). However, a significant part of average drawdown was well losses (30 to 74% of ADD) which were not related to the aquifer characteristics but to the well condition. The well efficiency was found to vary between 26.4 to 69.8%. The turbulent well losses were found to vary between 0.36 to 2.27m (7 to 15% of ADD) and the laminar well losses were found to vary between 1.24 to 6.28 m (12 to 66% of ADD).

Table 1 Past & Present Condition of Test Wells at Design Discharge ($4896m^3$ day for 1 day)

Well Location & Number	Average Draw down (m)		Transmisivity (m^2/day)*	Aquifer Losses (m)	Laminar Well Losses (m)		Turbulent Well Losses (m)		Efficiency (%)	
	Past	Present			Past	Present	Past	Present	Past	Present
Uttara-4,515	9.73	9.80	1663	4.18	4.49	4.53	1.06	1.10	42.9	42.7
Banani-5,518	9.23	10.26	1403	4.91	3.59	3.64	0.74	1.71	53.2	47.9
Lalmatia, 307	9.53	10.37	2848	2.52	6.28	5.68	0.73	2.17	26.4	24.3
Dupkhola, 108	10.69	15.14	916	7.34	1.24	6.22	2.10	1.58	68.7	48.5
Agamusi Lane, 218	5.47	9.07	2042	3.44	1.67	3.51	0.36	2.12	62.9	37.9
Gandaria, 116	6.32	12.51	1574	4.41	1.29	7.03	0.63	1.08	69.8	35.3
Rampura, 622	15.53	26.64	864	7.76	5.48	15.54	2.27	3.34	49.9	29.1

*Average transmissivity (KD) of present pumping and recovery test data.

Present Well Condition

During the present study the average drawdown were found to have increased in all test wells compared to the construction time lest results and it varied from 9.07 m to 26.64 m. The corresponding well efficiencies were also reduced in all the test wells as indicated in Table 1. The turbulent well losses were found to vary between 1.10 to 3.34 m (9 to 23% of ADD) while the laminar well losses varied between 3.51 to 15.54 m (35 to 58% of ADD)

Reduction of Yielding Capacity

The additional fall of pumping water level (at 4896 m^3/day) from the time of construction to the time of this study was segmented into its fall of static water level and increment of well losses components and their comparison is showed in Figure 2. At the primary stage the fall of static water level was found to be dominating to lower the PWL for any well.

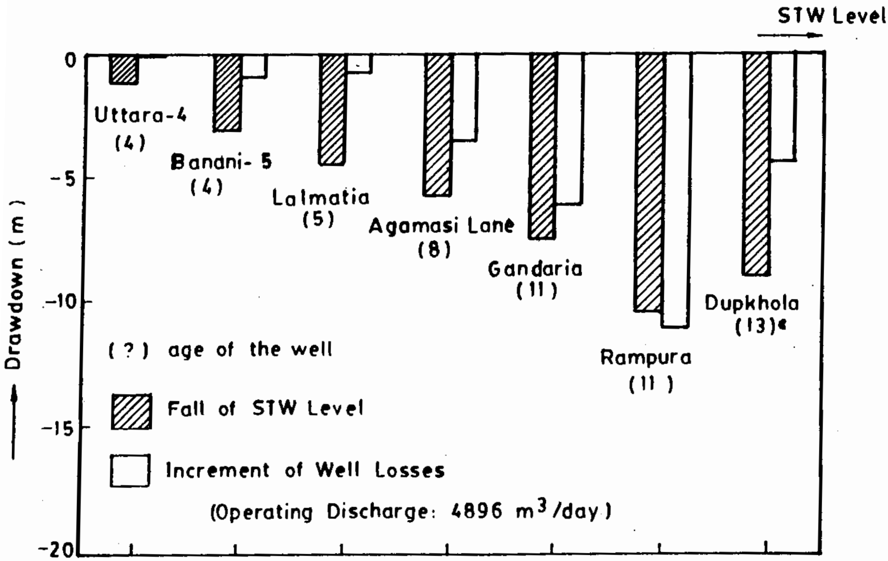

Fig 2. STW Level Fall and Increment of Well loss Components of Total Fall of PWL

Fall of STW level : The least square curve drawn from data of BWDB sample piezometers (Figure 3) located in the study area depicted the

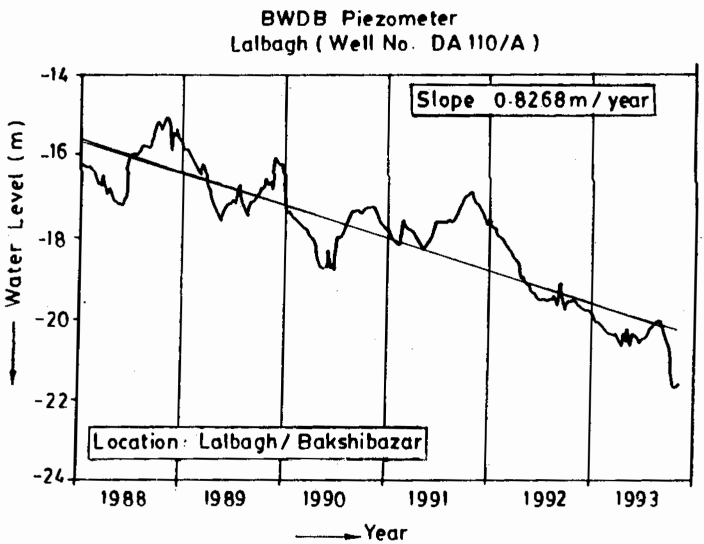

Fig 3. Hydrograph of BWDB Piezometer

gradual fall (0.53 to 0.83 m/year). The ground water contour (Figure 4), prepared using BWDB piezometric data showed the areawise fall of water level in the study area compared to its surrounding areas. The piezometric water levels were also found to be influenced by seasonal changes.

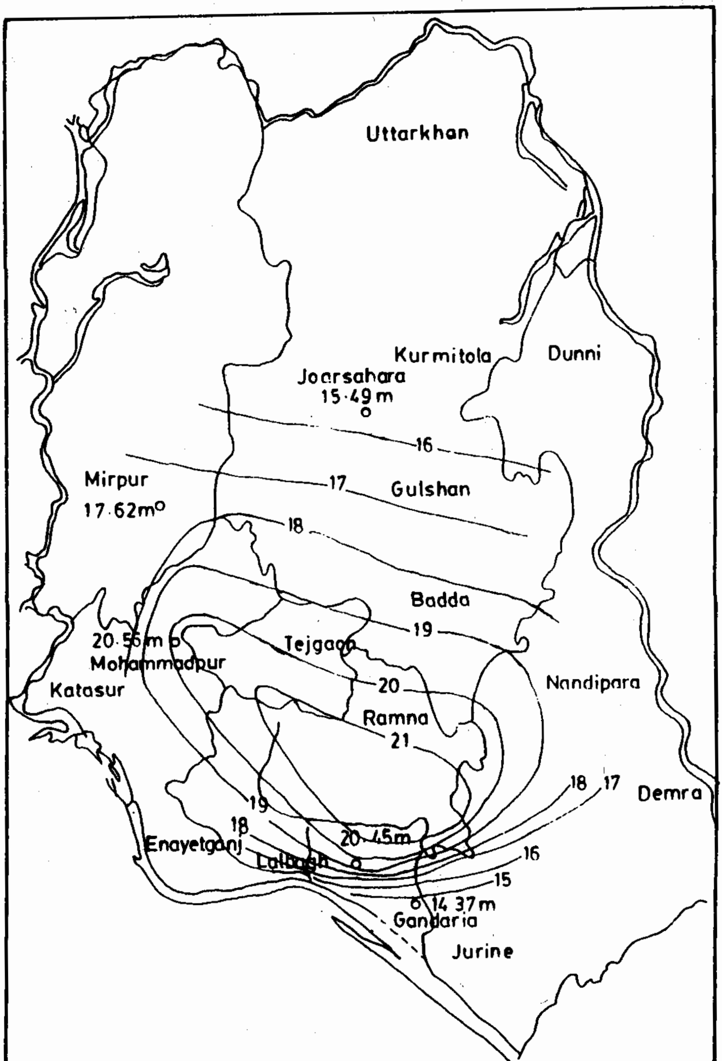

Fig 4. Deepest Static Water Level in 26th April, 1993

Well interference

As it was impossible to determine practically the effect of well interference, an approximate analysis (Thies unsteady flow formula for confined aquifer) was carried out to get an idea about the intensity of well interference (Table 2) and its effects on lowering the PWL of the wells. The interferences were evaluated in the seven test wells considering that the wells were interfered only by DWASA wells located within 1 km while operated at 2 cusec discharge for 24 hours. Additional drawdown due to interference were varied between 0.97 to 3.70 m. Higher drawdown due to interference were found to occur in old Dhaka because the wells were closely located.

Table 2 Analysis of Well Interference

Operating Discharge and time=4896 m3/day for 1 day		
Well Location & Number	#Number of InterferingWells	Additional drawdown due to well interference. Drawdown (m)
Uttara-4,515	2	0.968
Banani-5,518	2	1.219
Lalmatia (OHT) 307	5	2.007
Dupkhola 108	5	3.690
Agamusi lane 218	7	3.357
Gandaria (DIT) 116	4	3.033
Rampura 622	2	2.100

\# Interfering wells are only DWASA wells located within 1 Km and their approximate distance form the test wells were determined from zonewise map of DWASA wells.

Increment of well losses : The first graph of Figure 5 shows the discharge (Q) versus drawadown (s) or various losses components curves of a typical test well using its data of tests conducted during present study. From the figure it was clear that the well contained a larger part of well loss components. The second graph of Figure 5 shows the comparison of construction and study time discharge (Q) versus drawdown (s) curve which perfectly describes the well deterioration or the increment of pumping water level. Well losses were found to increase in all the test wells. Higher efficiency reduction was found in the wells (Table 3) which were much older. During the test program, it was observed (Dhar, 1995) that most of the test wells were operated at higher discharge (Uttara-4:2.90 cusec; Agamusi Lane : 2.58 cusec; Lalmatia well : 2.34 cusec; etc.) than the design specification (2 cusec).

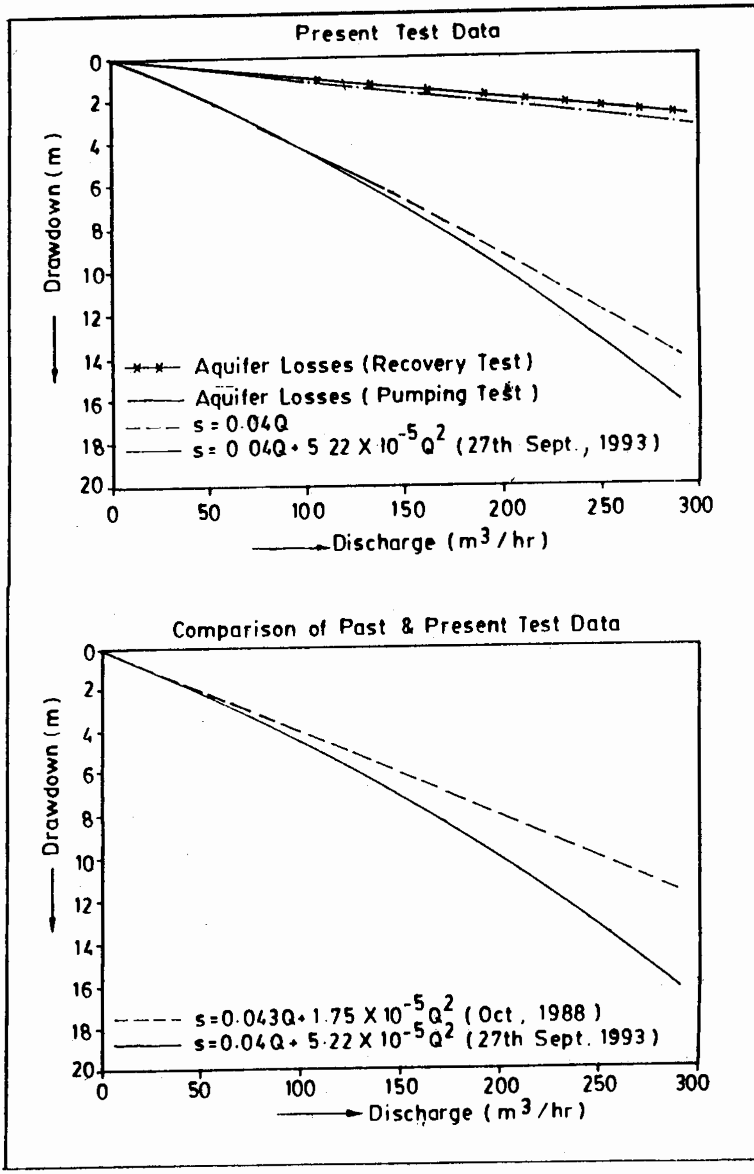

Fig 5. Discharge vs Drawdown (Data from Step Drawdown Test) (Well No. 307, Lacation : Lalmatia, Age : 5 Years)

Table 3 Reduction of Well Efficiency with Time

Well No. & Location	Age of the well	Specific Capacity (Q/S)			Well Efficiency in Percent		
		Past	Present	Reduction in percent	Past	Present	Reduction
Uttara-4,515	4	5.0	500	0.6	42.9	42.7	0.5
Banani, 518	4	530	477	10.0	53.2	47.9	10.0
Lalmatia (OHT), 307	5	514	472	8.2	26.4	24.3	8.0
Dupkhola, 108	8	458	323	29.5	68.7	48.5	29.4
Agamusi Lane, 218	10	895	540	39.7	62.9	37.9	39.8
Gandaria, 116	11	775	391	49.5	69.8	35.3	49.4
Rampura, 622	13	315	184	41.6	49.9	29.1	41.7

The water quality of test wells showed that the possibility of various types of chemical and bacteriological clogging were negligible except some iron salt precipitation (Dhar, 1995). The ground water contained some corrosive properties but it was not favorable for the survival of both iron and sulfate reducing bacteria. As the well fixture units were made of different metals, the galvanic and bimetallic corrosion might occur in the wells. But there was no possibility of organism induced corrosion.

CONCLUSIONS AND RECOMMENDATIONS

Both the fall of STW level and increment of well losses were responsible for the fall of PWL of wells in the study area. At initial stage, the fall of STW level was dominant in lowering the PWL.

Overall lowering of groundwater level in Dhaka city, seasonal fluctuation and interferences from newly constructed tubewells were responsible for lowering the static water level. Among them, lowering of STW level due to seasonal fluctuation and well interference were recoverable.

It may be concluded that occurrence of laminar well losses were mainly responsible for serious well deterioration. However, the occurrence of turbulent well losses were also considerable. Perhaps, higher operating discharge and preliminary clogging (due to improper well development after construction in some cases) increased the entrance velocity into the well and through the strainer slots which pulled the fine aquifer particles and clogged the well screen. The process is termed as mechanical clogging which eventually increased the laminar well losses.

From the water quality tests it may be concluded that the deposition of chemical precipitates or the bacterial growth were not mainly responsible for well clogging. The possibility of organism induced corrosion in the wells was negligible. Although the water contained some corrosive properties but the overall situation was not severe.

The analysis of the present study suggests that the following steps be carefully considered in order to minimise deterioration of yielding capacity of wells.

i) Wells are to be developed properly after construction to ensure its longevity.

ii) Operating a well at a discharge higher than design specification must be prohibited. If mechanical plugging occurs, the discharge should be reduced accordingly in order to lower the screen entrance velocity.

iii) Proper well monitoring is necessary to predict the occurrence of clogging and reduction of yielding capacity. Appropriate well monitoring may identify the appropriate time for well regeneration.

iv) Well regeneration should be a regular program of DWASA to rehabilitate its inefficient wells to improve their yielding capacities.

v) As the occurrence of chemical clogging is not severe, mechanical agitation with application of some calgon may be sufficient to regenerate the deteriorated wells.

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