[illegible]-WATER SUPPLY & SANITATION PROJECTS

ADVIESBUREAU VOOR WATERVOORZIENING

IWACO B.V.

INTERNATIONAL WATER SUPPLY CONSULTANTS

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With compliments

Cor Pls √ thks to iwaco

IWACO BV
P O Box 183
3000 AD Rotterdam
The Netherlands

Telephone 010-143622
Telex 24069 nl
Cables IWACO Rotterdam
Office Schiekade 189, Rotterdam

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1. Introduction.

Urban drinking water supply in Bangladesh is mainly based on groundwater use. Apart from handpumped tube-wells, some 200 motor driven production wells meet the urban demand (excl. Dhaka and Chittagong). Since the construction of tube-wells only started some thirty years back, groundwater abstraction is rather new in Bangladesh. Most of the tube-wells date from 1970 or later. However, reviewing the present condition of the wells, it appeared that about 25 went out of order, while some 75 wells show a considerable decrease in yield.

As in general no regular measurements on drawdown are carried out, the deteriorated condition of the well is only observed after the groundwater level in the well has dropped to the level of the pump. At that moment the yield of the well has already been decreased in such a way that regeneration up to the original capacity will be difficult.

Regeneration works are carried out by the Mechanical Division and Groundwater Division of DPHE. These works are hampered by the lack of funds, man-power, equipment, etc. In most cases regeneration works are taken up on emergency basis.

The life and the capacity of the wells do not solely depend on the maintenance activities. A proper well construction is the basis of a reliable yield for a long time. Besides, at the construction of the well allowance has to made for regular monitoring and maintenance activities. The intention of this paper is to give an insight in well hydraulics and guidelines on well construction, monitoring and regeneration of wells.

The text is based on the obtained experience during recent investigations within the DPHE-Water Supply & Sanitation Projects as well as on data from hand-books. A recommended bibliography, which has also been consulted in this paper, is given at the end.

2. Aquifer and well losses, condition of the well.

2.1 Different types of losses.

The flow of groundwater through the aquifer towards the well through the gravel pack (if present) and the screen openings into the well proper and inside the well through screen and casing upward to the pump, is accompanied by various losses of head, which are schematically shown in fig. 2.1.
Commonly a distinction is made in formation losses up to the well face (Δa) and in well losses from the outside of the screen/borehole to the entrance into the suction pipe of the pump (ΔW).

The aquifer losses can be subdivided in :

- the drawdown (Δs_{fu}) accompanying the flow of groundwater to a well which fully penetrates the aquifer.
- the additional drawdown ($\Delta s_{w,p}$) due to the effect of partial penetration.

(- the additional drawdown due to partial perforation of the screen in case of a non-shrouded well is, because of the use of continious slotted strainers negligible small.).

The well losses are composed of :

- the losses at and close by the bore hole face ($\Delta W,b$)
- the losses due to flow through the gravelpack in case of a shrouded well ($\Delta W,g$).
- the losses due to flow through the screen openings into the well proper ($\Delta W,s$).
- the friction losses inside the screen and rising main ($\Delta W,f$).

Written in a formula the following expression holds true :

$$s = \Delta a + \Delta W$$

$$s = (\Delta s_{fu} + \Delta s_{w,p}) + (\Delta W,b + \Delta W,g + \Delta W,s + \Delta W,f)$$

(s = observed drawdown)

2.2 Determination of well losses.

The aquifer losses can be determined by various methods but will not be detailed in this paper (see lit 3, 5.5). If a testwell or observation well is available close to the main well, the drawdown in the observation well is already a rough indidation for the aquifer losses. Secondly the difference in drawdown between both the wells tells something about the well losses. As stated above, the well losses may be caused by different flow resistancies.

Well losses at and near the bore-hole face ($\Delta w, b$).

Most of the wells in Bangladesh are made according to the rotary drilling system making use of drilling mud. This mud, more or less containing clay, may penetrate the aquifer decreasing the permeability of the well's surroundings.

Besides, due to the fluid circulation the bore-hole may be covered by mud crust, which hampers the flow to the well. These losses are fully related to the well construction and well development . They can not be easily determined before hand. As in general the groundwater flow will be laminar in this zone, relatively high laminar flow losses may indicate their presence.(step-drawdown test, see fig. 2.3).

Well losses due to flow through the gravelpack incase of a shrouded well. (Δ w, g).

If the well is provided with a proper artificial gravelpack the flow losses in the gravelpack zone are :

$$\Delta w, g = \frac{Q}{2 \pi k_g h_g} \ln \frac{r_w}{r_s}$$

k_g = permeability gravelpack (m/day)
h_g = thickness gravelpack (~ length strainer) (m)
r_w = diameter bore-hole (m)
r_s = diameter screen (m)

Assuming a gravelpack with a grainsize 3 to 4 times the average grainsize of the aquifer, the permeability will be 9 to 16 times the aquifer permeability (square relationship). Therefore, but also because of the limited thickness, the theoritical losses in the gravelpack will be negligible low. However, due to drilling mud remnants and material from the bore hole, parts of the gravelpack may be less permeable than expected.

Well losses due to flow through the screen openings into the well proper ($\Delta w, s$).

The head loss due to flow through a screen opening may be calculated as :

$$\Delta W,S = \frac{V_e^2}{\mu^2 \, 2g}$$

V_e = entrance velocity (m/sec)
μ = coefficient of contraction -
g = gravity constant (m/sec^2)

The wells used for public water supply are usually provided with a continuous slotted stainless steel screen of 6" diameter and a length of 100 ft. In case of a non-clogged screen of slotsize 10 the percentage open area is about 9. For larger slotsizes the percentage open area increases. So for a well discharging 40,000 Igph (182 m^3/h), with this type of screen the entrance velocity is :

$$V_e = \frac{Q}{a\, o\, g\, h\, \pi d_o} \quad \frac{1}{3600} \quad = 0.04 \text{ m/sec}$$

This causes a head loss of :

$$\Delta W,S = \frac{(0.04)^2}{(0.65)^2 \; 2 \; 9.8} \qquad = 2 \; 10^{-4} \text{ m or}$$

negligible small.

However with the head loss Δ w,s proportional to the square of the entrance velocity this type of well losses may sharply increase when a considerable part of the open area is clogged. According to the above mentioned equation these losses are of the turbulent type and may be indicated by a step-drawdown test if the friction losses are known.

Well losses due to friction losses by flow inside the screen and rising main. (Δ w, f).

After having passed the well screen openings the groundwater flows upward through the inside of the screen and casing to the lower end of the suction pipe of the pump. This flow is accompanied by friction, while a further loss of piezometric head occurs by conversion into velocity head. Assuming the inflow to be divided equally over the full length of the screen and calculating the losses from the bottom of the well upward gives :

$$\Delta w,f = \left\{ \frac{1}{3} \lambda_s \frac{h}{d_0} + \lambda_c \frac{L}{d_0} + 2 \right\} \frac{V_0^2}{2g}$$

λ_s = friction factor of the screen (–)
λ_c = friction factor of the rising main (–)
d_0 = diameter well (m)
h = length of the screen (m)
L = length of the rising main (m)
V_0 = flow velocity inside the rising main $\left\{ \frac{Q}{1/4 \pi d_0^2} \right\}$ (m/sec)
Q = discharge well (m^3/sec)
g = gravity constant (m/sec^2)

Although the friction factors λ_c and λ_s depend on the wall roughness, the diameter of the well and the so called Reynolds number : $R_e = \frac{v_0 \, ^1\!/_4 \, d_0}{\nu}$, in which ν is the kinematic viscosity, values of λ_c = 0.025 and λ_s = 0.04 may be reasonable for an average G.I. pipe and a continuous slotted stainless steel screen. On the basis of these values discharge - friction losses curves are given in fig.2.2 for a well varying in depth but provided with a 6" dia, 100 ft long screen.

As the flow velocity in the upper casing (12" - 15") in which the pump is installed, is considerably lower in comparison to the 6" rising main, the friction losses for this part of the well are neglegted.

From fig. 2.2 it is obvious that for high capacity wells in deep aquifers (coastal belt region) the friction losses become a considerable part of the drawdown.

2.3 Step-drawdown tests, interpretation of the results.

A step-drawdown test may be a helpfull experiment to get an insight in the type of head losses. By this method the steady state drawdown at various discharges of the well is determined. This yields a discharge-drawdown curve (fig.2.3.a). The relation between the discharge and the drawdown can be expressed by :

$$s = BQ^n + CQ^m$$

in which B, C, n and m are constants.

Although the constants n and m may vary it is of common practice to split up the total drawdown in laminar flow losses (B Q, n = 1) and turbulent flow losses(CQ^2, m = 2).

Aquifer losses (Δ a) are (in general) of the laminar type while the friction losses inside the screen and rising main (Δ w, f) are due to turbulent flow. Losses due to flow near and through the screen may be turbulent or laminar (Δ w,b, Δw, g, Δ w, s) but one should assume an increase in turbulent flow conditions towards the screen.

The constants B and C can be calculated by plotting s/Q against Q. This yields a straight line, at which B is the intercept of the s/Q - axis and C is the tangent of the line. (fig. 2.3.b).

In theory only 2 points will suffice to determine these coefficients but more measurements will contribute to the reliability of the curve. Next, in order to get steady state drawdowns it is important to carry out each pumping step sufficiently long. By knowing the coefficients B and C the maximum yield at a maximum (permissible) drawdown can be calculated.

On the basis of the results of the step-drawdown test together with the calculated aquifer losses (Δ a) and friction losses (Δ w, f) the condition of the well can be analysed (fig. 2.3.a). As indicated before the remaining head losses are related to the drilling method and rate of development and should be negligible small in case of a properly developed well.

Remarks.

1. Well losses are generally high for deep tube-wells. Therefore the drawdown in the pumped well is no (visible) direct indication for the cone of depression in the aquifer. For example in Khulna the observed drawdown in the well varies from 15 to 20 m, while the aquifer losses are in general less than 2 m. This gives indications for the rate of interference between two or more wells, which will be less than expected on the basis of observed drawdowns in the production wells.

2. If the turbulent well losses are an important part of the total drawdown of the well, the specific capacity expressed in m^3/hr per m. drawdown or Igph per ft drawdown is not a proper parameter for the well condition.

Because this parameter depends on the discharge according to :

$$s = BQ + CQ^2 \quad \text{or} \quad \frac{Q}{s} = \frac{1}{B+CQ}$$

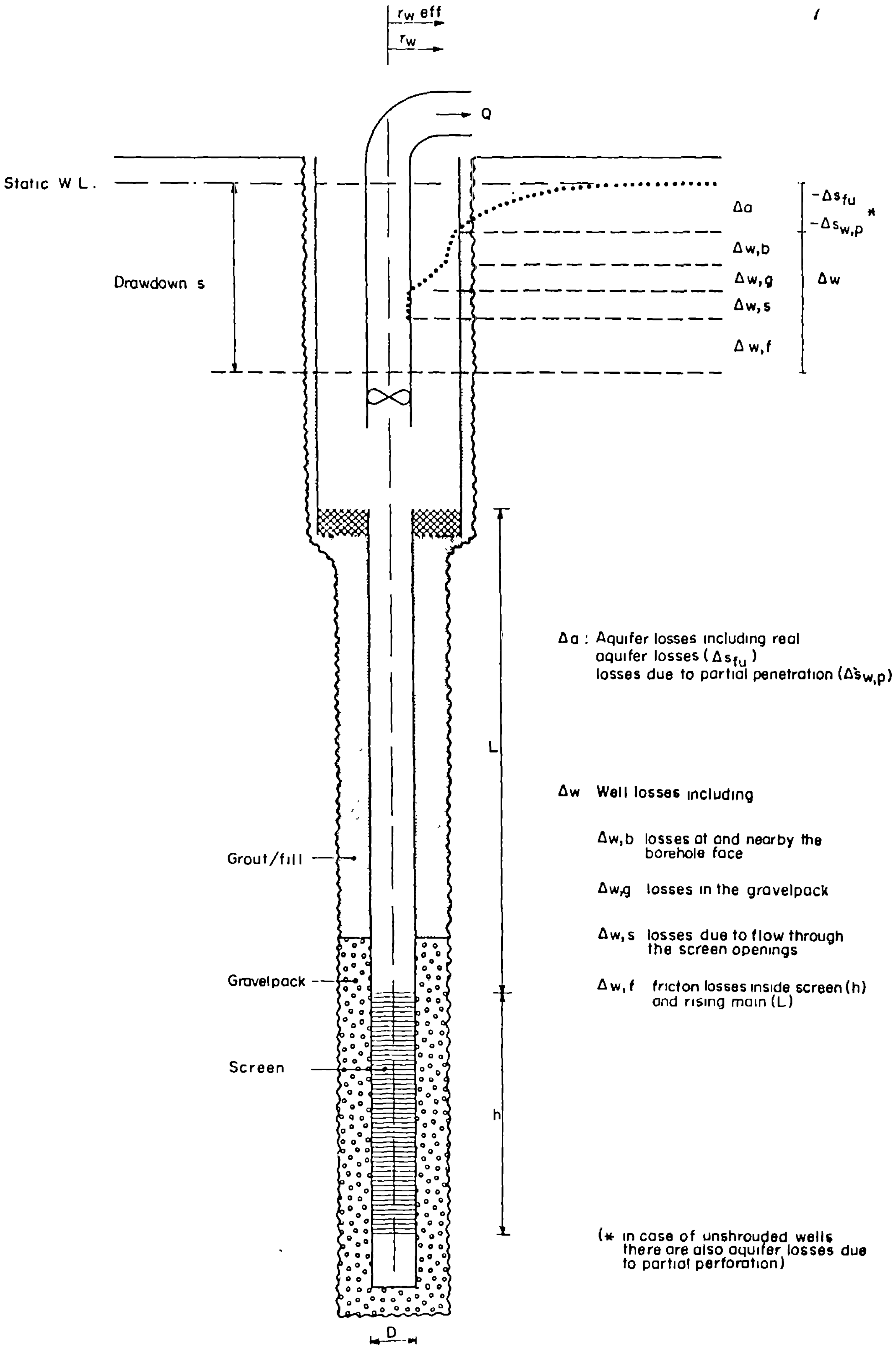
Only in case $C \rightarrow 0$ (turbulent flow losses $\rightarrow 0$) the quotient Q/s becomes constant.

3. The installation of an observation well in the gravelpack opposite the screen of the main tube-well is recommendable. The difference in drawdown between this observation well and the main tube-well is an indication for the head losses in the screen ($\Delta w,s$) and the friction losses ($\Delta w,f$).

Observations in such a well gives an insight in the fact whether the well is clogged in the gravel-pack or the screen (see 3). and fig.3.1.b).

Figure 2.1

WELL AND AQUIFER LOSSES AT A SHROUDED WELL



Δa : Aquifer losses including real aquifer losses (Δs_{fu}) losses due to partial penetration ($\Delta s_{w,p}$)

Δw Well losses including

$\Delta w,b$ losses at and nearby the borehole face

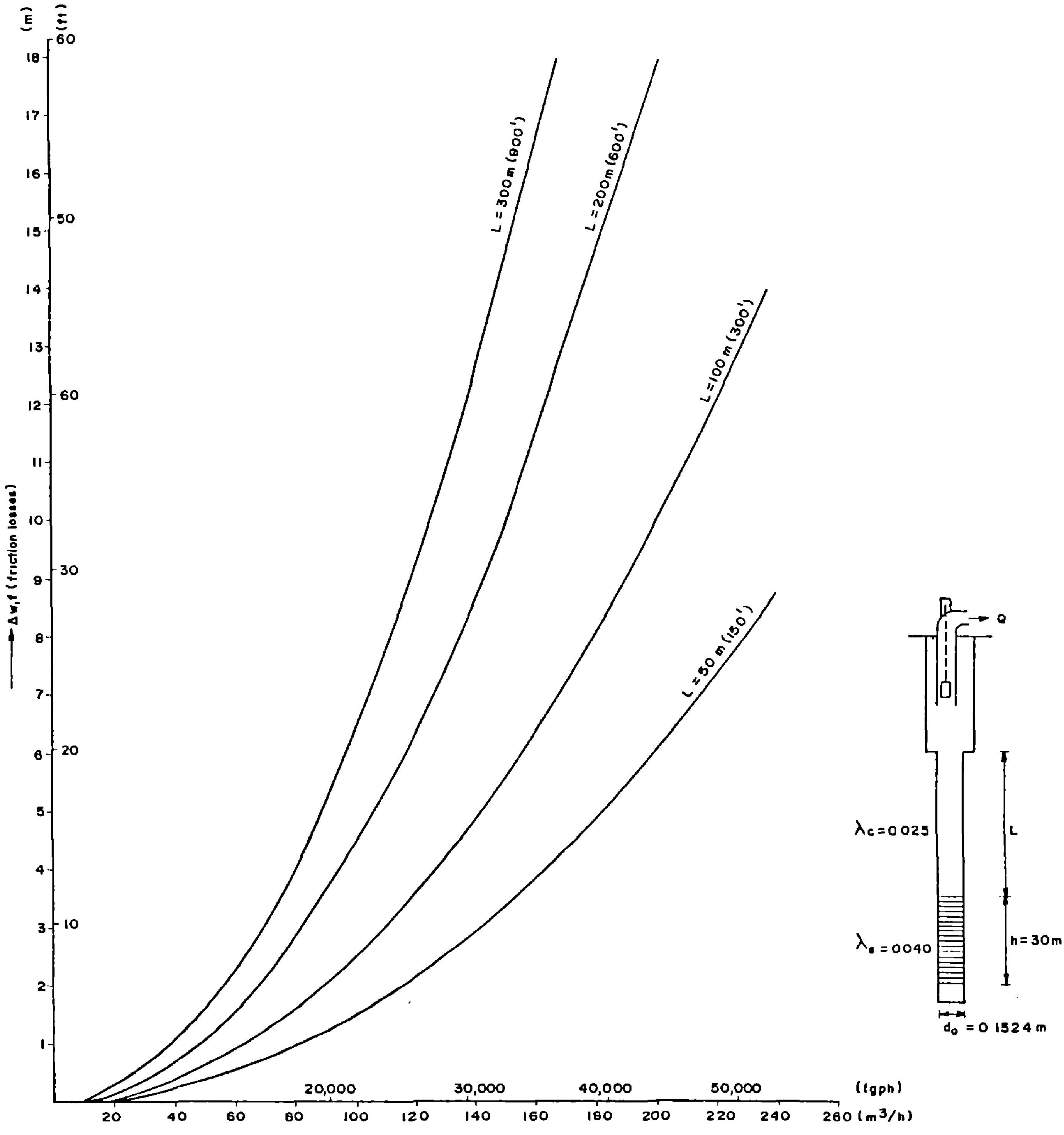
$\Delta w,g$ losses in the gravelpack

$\Delta w,s$ losses due to flow through the screen openings

$\Delta w,f$ fricton losses inside screen (h) and rising main (L)

(* in case of unshrouded wells there are also aquifer losses due to partial perforation)

Figure 2.2



$$\Delta w,f = \left\{ {}^{1}/_{3}\ \lambda_s\ {}^{h}/_{d_o} + \lambda_c\ {}^{L}/_{d_o} + 2 \right\} \frac{v_o^2}{2g}$$

$$v_o = \frac{Q}{{}^{\pi}/_{4}\, d_o^2}$$

RELATION DISCHARGE-FRICTION LOSSES FOR 6" DIA TUBEWELL AT DIFFERENT LENGTHS OF THE RISING MAIN

3. Causes of clogging of wells.

An increase in flow resistance, causing a decrease in wall yield can be attributed to incrustation of the well screen, to cloggging of the screen and the formations around it by deposition of material in, on and around the screen openings and the pores of the gravelpack and aquifer. Clogging may be due to mechanical, chemical, or bacteriological action or a combination of these process.

3.1 Mechanical clogging.

Mechanical clogging often occurs in undeveloped wells in fine grained formations, which are pumped at a high capacity. This results in high flow velocities, able to pick up and transport fine soil particles to the well. However, not all these particles are carried through the well screen openings. Partly they are retained by binding, clogging the pores of the formations, lowering the porosity and increasing the resistance against groundwater flow. Even after intensive development, this phenomenon may occur with gravel-packed wells and an excessive thickness of the gravel wall. In that case the distance of the outer circumference to the well centre is too large for an effective cleaning of the natural formations around it.

Since most of the wells in Bangladesh are inadequately developed, mechanical clogging is a common feature. It often happens that after the construction of the well the discharge is far below the expected yield. Analysing pumping-test data it appears that sometimes even more than 80% of the screen is clogged by fine sand, silt, etc. Unproper development may have an acceleration effect on the mechanical clogging process, as initial clogged parts of the screen increases the velocity of flow in the clean parts of the screen or surrounding material. (fig. 3.1.a). Consequently soil particles are picked up and carried towards the well from a distance previously uncleaned even by heavy development. And again the free flow part of the screen will be shrinked.

The carbon-dioxide content is proportional to the partial pressure of the gaseous carbon-dioxide with which it is in contact. As the partial pressure increases with depth, large contents of carbon-dioxide can stay in solution under high pressure in the water at great depth and through the absence of a free atmosphere. Both circumstances change drastically when the water flows towards the well and through the screen openings. This flow is accompanied by formation losses, decreasing the pressure, while in the well itself carbon-dioxide can escape to the atmosphere.
The chemical reaction indicated above will now go to the left , precipitating calcium carbonate, which cements the sand grains together, ultimately building up a wall of considerable thickness around the screen and into the formation.

An indication of the sensivity of the well for calcium carbonate incrustation can be obtained by the Langelier index :

$$L = pH - pH_s$$ in which pH_s is

the saturation pH which depends on :

- alkalinity
- hardness
- total solids
- temperature

according to the relation :

$$pH_s = A + B - \log[Ca^{++}] - \log[M\text{-alkalinity}]$$

In this formula A and B are constants related to the content of solids and the water temperature while the calcium concentration and M - alkalinity is expressed in mg/L $CaCO_3$. In case of a positive L - index the water is over-saturated with $CaCO_3$ and thus incrustating, whereas a negative value points to under - saturation.

3.3.1. Sulphate reducing bacteria

Clogging of wells which abstract anaerobic water is not likely due to iron-and manganese oxidation. Wells of this type, regenerated by chemical treatments show often, apart from higher iron values, an increased sulphate content during the first period of testpumping. Investigations in the Netherlands also indicated that clogging of most of the gravel-packed wells did not take place close or upon the screen but in the formation (fig. 3.1.b). Therefore, clogging may be due to an - inprinciple - natural process within the aquifer, which takes place more intensively around the well. In natural environments sulphate reducing bacteria, which need for their development organic matter, promote the following process :

$$2\,CH_3CHOHCOOH \;(\text{lactate}) + SO_4^{2-} \rightarrow H_2S + 2\,CH_3COOH \;(\text{acetate}) + 2\,HCO_3^-$$

and.

$$Fe^{2+} + H_2S \rightarrow FeS_{(s)} + 2\,H$$

Besides FeS also other forms of iron sulphides may be produced (Fe S_2 or pyrite). Treatment of the well by a proper oxidising agent transforms the sulphides into sulphate. For example the oxidation of FeS by hypochlorite can be presented as follows :

$$FeS_{(s)} + 4\,Cl^- + 4\,ClO^- \rightarrow Fe^{2+} + SO_4^{2-} + 8\,Cl^-$$

Regarding the investigations on regeneration in Khulna, also increased sulphate contents were found during testpumping after chemical treatment (fig. 3.2). Although only a few tests have been carried out so far, this type of clogging may be important in the Khulna region as well as elswhere in Bangladesh (see also lit. 5.6).

3.4. Clogging of screens due to return flow of water.

Most of the DPHE wells are provided with a non-return flow valve, which prevents the water from the pipe-line system to enter the well after stopping the pump. Nevertheless, the majority of valves of these tube-wells are not working properly at present. The water returning to the well soreen may have a different water quality which favours the ologging of the soreen.

- mixing of different types of water from different wells.
- chemioal processes due to pressure/temperature changes (release CO_2, etc.).
- enrichment with oxygen (overhead tanks, taps, production wells which suok air, etc.).
- pollution (during non supply hours, the entrance of (sub)-surfaoe water through leaks in the pipe-lines.).

Up to the present this cause of clogging, which is of chemical or bio-chemioal nature, has not been investigated, but may play a role of interest.

3.5. Clogging due to sand entrance.

Sand yielding and through that choking up of the well happens frequently in Bangladesh and may be due to (fig. 3.3.) :

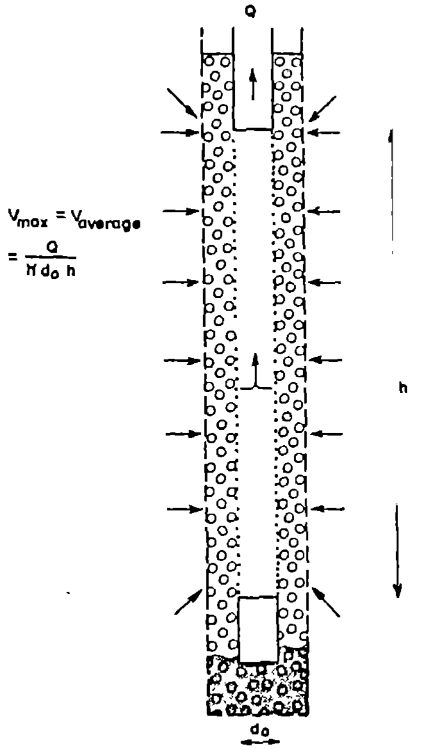
- corroded soreen.
- corroded casing, reducer etc.
- construction errors (leaking joints etc .).
- improper gravelpack / screen design.

When a well screen is corroded, the slot openings may become several times larger than the original width of the openings. Usually this allows sand to enter with the water being pumped. Choking up due to sand entrance is a common phenomenon in locally manufactured (brass) screens, particularly if they are installed in corrosive (brackish) groundwater.
In the coastal belt region the upper casing of a well may pass a saline zone, which water favours the corrosion of the casing. Corrosion of casing, (mild steel) allowing the entrance of sand has recently been observed in some old wells in Khulna.

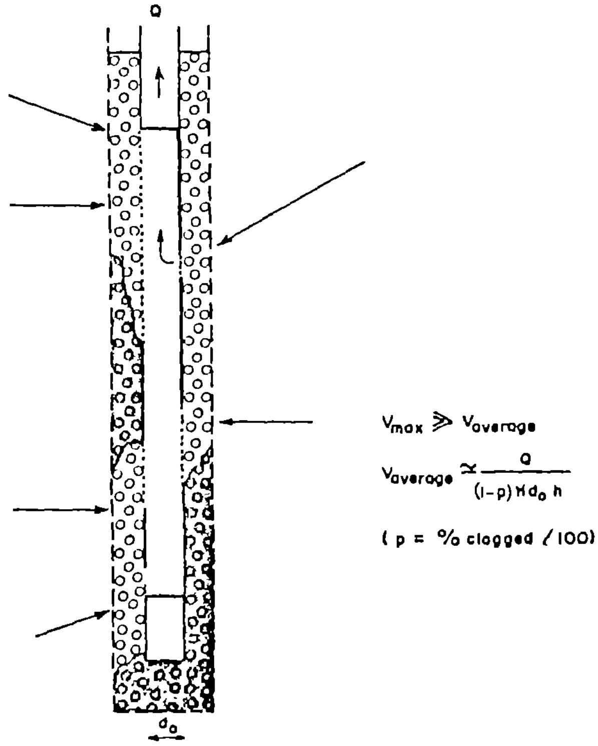
Leakage through joints, in particular sand cement joints is a relatively frequent phenomenon. Loose sand cement joints can easily break during regeneration works but also an increase in drawdown may damage such a joint.

Last but not less frequent is sand yielding due to unproper gravelpacking and wrong screen design. The use of too coarse gravel allows fine sand particles to pass the gravel wall and to enter the well screen.
This process is more likely to occur if the gravelpack thickness is limited and there is doubt about the centralised position of the screen. (see 4.3.1).

Figure 3.1

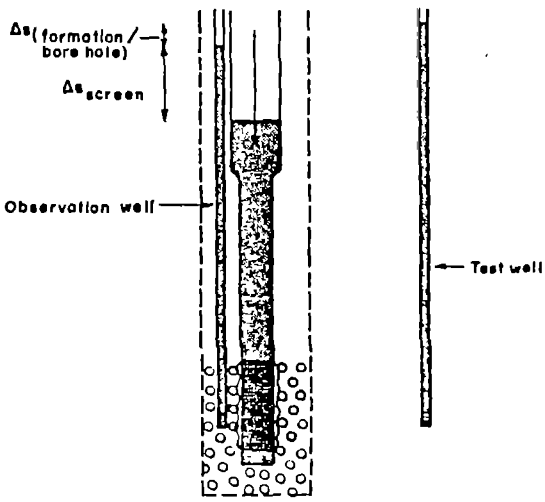


Uniform flow to a properly developed well

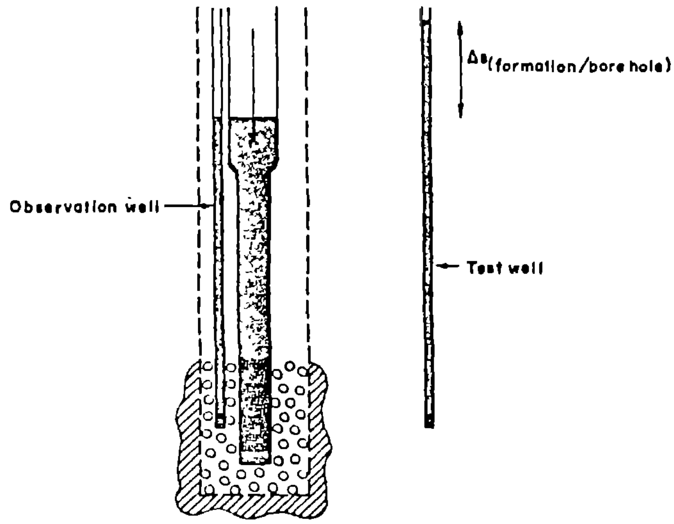


Non-uniform flow to a un-properly developed and incrustated well

Fig.3.1a



Incrustation of the screen



Clogging at the borehole-face and in the formation

Fig.3.1b

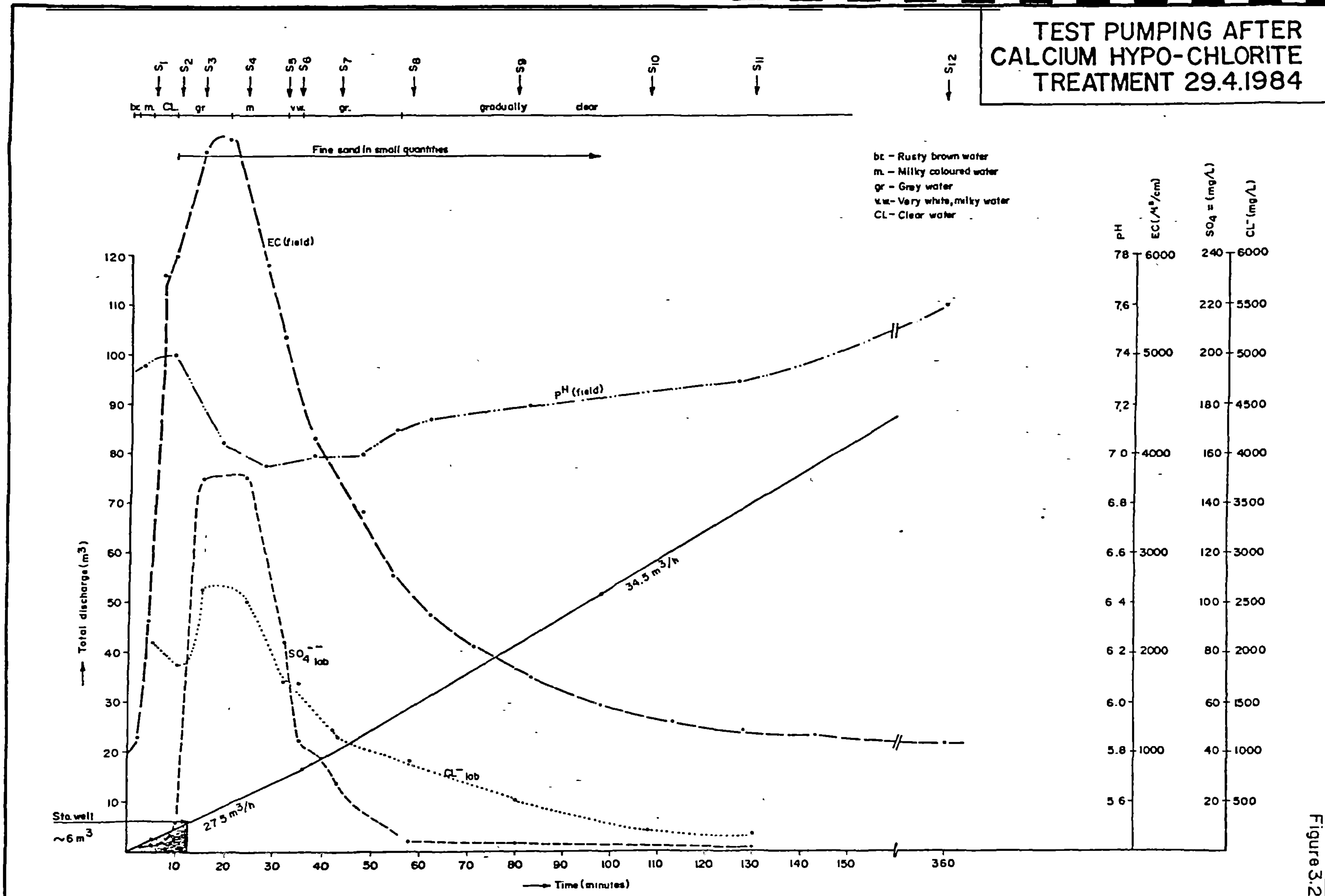
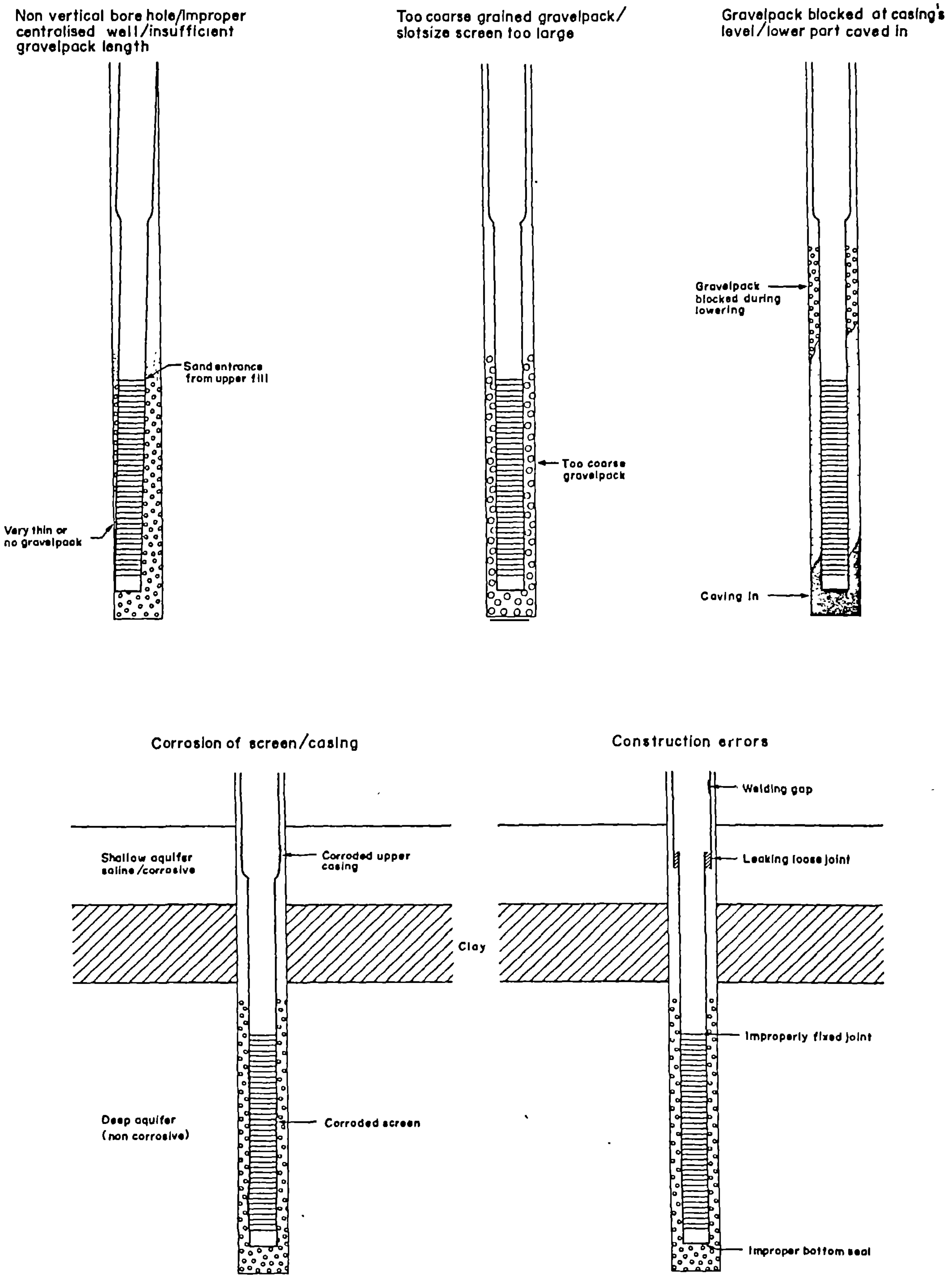

TEST PUMPING AFTER CALCIUM HYPO-CHLORITE TREATMENT 29.4.1984
S1 S2 S3 S4 S5 S6 S7 S8 S9 S10 S11 S12
br. m. CL. gr m v.w. gr. gradually clear
Fine sand in small quantities
br. – Rusty brown water
m. – Milky coloured water
gr – Grey water
v.w.– Very white, milky water
CL – Clear water
EC (field)
pH (field)
SO4-- lab
CL- lab
34.5 m3/h
27.5 m3/h
Sto. well ~6 m3
Total discharge (m3)
Time (minutes)
pH
EC (μS/cm)
SO4 = (mg/L)
CL- (mg/L)

Figure 3.2

Figure 3.3

SAND PUMPING



4. Well construction

4.1 Present method of well construction

The present urban drinking water supply is mainly based on 6 inch dia wells which are provided with a stainless steel, continuous slotted screen connected to a galvanised iron (G.I) rising main of the same diameter.

The upper casing, which has a lower diameter (12" - 15") to install the pump is usually made of mild steel (M.S). Brass screens and P.V.C. screens are less common in the urban water supply of Bangladesh. Locally made brass screens are used for small diameter wells (4"-2"), mainly in the private sector. Also brass screens are found in some old wells made by DPHE. P.V.C. screens are sometimes used in shallow production wells.

Shallow wells to 400 ft differ in construction from deep wells. Several rigs, operating throughout Bangladesh are available for the installation of these wells (fig.4.1.a). Drilling of large diameter holes up to the above mentioned depth makes it possible to place a proper gravelpack around the screen. These wells are usually installed as a whole including the upper casing, which is connected to the 6 inch rising main by a welded reducer.

The construction of deep wells (> 400 ft) is more complicated. As only a few rigs are available in the country for making deep drillings, most of these tubewells are manually constructed (fig.4.1.b.). These wells are made by the jet system (manually rotary straight flush) using several casings. The number of casings applied depends on the depth of the drilling. The last temporary casing installed will generally have a 8" diameter leaving only a limited space for an artificial gravelpack. In general no attempts are made to shroud the well.

After installation of the screen with the permanent rising main, all temporary casings, except for the outer one (12" - 15"), are withdrawn, while the upper temporary portion of the rising main is unscrewed and removed. The overlap portion between the outer casing and the upper portion of the rising main is filled up with a sand-cement mortar (loose joint).

Recently a number of deep wells has been made in Khulna by the DPHE drilling rig. This machine makes bore-holes by rotary straight flush drilling.
Although a depth of 800 to 900 ft may be reached, the maximum bore-hole diameter at this depth is about 12". Depth and limited space require special attention to the construction of a gravelpack.

Most of the wells made by this rig are constructed with a loose joint. Now it has been possible to install the well as a whole by using a lost drum casing.

Nevertheless experiments are still going on to improve the well construction. A detailed description of drilling activities in Khulna is given in lit.5.1.

In fig.4.1. three different types of well construction, which are practised at present are given:

* construction of a shallow well by hydraulic rotary drilling.

* construction of a deep well by the manual water-jet system (making use of several temporary casings)

* construction of a deep well by the DPHE rig making use of an upper 'lost' drum-casing.

4.2 Drilling methods

Water well drilling can be done in numerous ways and one can refer to several hand books (lit.2,4.). The relevant drillings for the Bangladesh situation will briefly be discussed below:

4.2.1. Hydraulic rotary drilling with reverse circulation

Hydraulic rotary drilling with reverse circulation is a proper system to construct large diameter bore-holes in soft unconsolidated formations as enountered in Bangladesh. The system is based on the principle that the drilling fluid and its load of cuttings move upward inside the drill-pipe and are discharged by the pump into the drilling mud-pit. The fluid returns to the bore-hole by gravity flow. It moves down the annular space around the drill pipe to the bottom of the hole, picks up cuttings and re-enters the drill pipe through ports in the drill bit (fig.4.2.b).

In comparison to straight flush rotary drillings the system with reverse circulation has the following advantages:

* possibility of construction of large diameter boreholes, as cuttings are removed through the drill pipe.

* accurate sampling, due to high velocity inside the drill pipe.

* thin drilling mud, avoiding difficult well-development.

* use of low head centrifugal mud pump, or no pump is required if air-lift is used.

The method requires a static water level of about 10 ft or more below ground and sufficient water supply. As only a light filter cake is developed, the loss of water through sand formations may be high.

An open borehole of the same large diameter (24" or more) facilitates the placement of a proper gravelpack. The gravelpack materials can easily be dropped through a 2" conductor pipe, avoiding separation of fine and coarse fractions. Also accurate measurement of the depth of gravelpacking is possible. The large diameter of the bore-hole allows installation of the well as awhole including the screen, rising main and upper casing, which has a larger diameter to install the pump.

Another advantage of the system is the possibility of installation of cheap P.V.C. wells, which are not liable to heavy forces during installation.

At present hydraulic rotary drilling rigs with reverse circulation are operating in Bangladesh only for shallow to medium deep wells.

4.2.2 Hydraulic rotary drilling with straight circulation.

Straight flush rotary drilling is based on the principle of forcing water down through hollow drill pipes with the help of a pressure pump (mud pump). With high velocities it emerges from narrow openings in the drill bit, squirts against the bottom of the hole and supports the drilling action by jetting. After this the water flows upward in the annular space outside the drill pipes, taking the broken fragments to the surface in suspension.(fig.2.4 a). The main disadvantage of the system is that only small diameter holes can be drilled, unless a very high capacity mud-pump

is used. With the present DPHE drilling rig, which is based on this system only holes up to 12" diameter can be made (apart from an upper wider bore-hole up to 100 - 120 ft). This limits the possibilities of proper gravelpacking, which is done at present by dumping from the top.(fig.4.1.c).

For safety reasons screens with slotsize 20 (0.5 mm) are used in Khulna, whereas, based on the grainsize distribution of the deep aquifer, slotsize 30 (0.75 mm) should be more appropriate.

Installation of P.V.C. screens with this method is rather risky and not tried at the moment.

The straight flush system, particularly in very deep wells requires the use of a proper viscose drilling fluid. Usually a mixture of bentonite and local clay is applied. However, remnants of drilling fluid may hamper the development of the well, which proved to be the case in several deep wells in Khulna.

As more sophisticated methods are available for development of wells (calgon, water-jet, compressor) this is not an unsurmountable problem.

4.2.3. Manual waterjet/rotary drilling with temporary casing.

This system which has been described in 4.1. is widely used in Bangladesh. (see fig.4.1.b).

In constructing a shallow well the system allows proper gravelpacking. A temporary outer casing provides a good centralized position of the screen, while there are no possibilities of caving in, as compared to the open borehole methods. Also the installation of an observation well can be arranged.

Deep wells of more than 400 ft made by the manual system can not be shrouded and have to be equipped with small slotted screens. Development of manual constructed wells is not so problematic, as the bore-hole diameter is small and no thick drilling mud is used.

4.3 Well construction related to longevity of the well. Well screen and gravelpack.

As explained in chapter 2 the maintenance of the well yield depends to a great extent on the slotsize of the screen and the build-up of a natural or artificial gravelpack.

If there is no possibility of making an artificial gravel-pack, the design of slotsize should be based on the grain-size distribution of the formation. Most of the aquifers in Bangladesh consist of fine to medium sands having average grainsizes of 0.2 - 0.3 mm. Therefore screens with narrow slits are required (slotsize 10). Apart from a rapid blocking in future of these fine openings the development of the well may face problems, in particular if a thick drilling mud and a relatively large drilling diameter have been applied.

Much better results can be obtained by inserting an artificial gravelpack between the well screen and the formation. In this way the desired degree of retention of aquifer material is effected by the gravel, allowing the use of larger screen openings.

Various sophisticated design methods and criteria are recommended in literature (Lit.1,2,4), which will not be detailed in this paper. A safe design is to use gravel (or better coarse sand) having an average diameter of 4 x d 75(p) of the finest sand-layer(s) (d 75(p) is the diameter at which

75% of the sample is passed). This means that at a $d_{75(p)}$ - value of 0.25 mm a gravelpack of 1 mm grainsize diameter should be used.

For practical reasons one will usually sieve out the fraction between 0.75 mm and 1.25 mm, which allows the installation of a screen with slotsize 30 (0.75 mm).

The thickness of the gravelpack should be at least 7.5 cm, but preferable 20 - 25 cm. This requires a minimum bore-hole diameter of 30 cm (12"), if a 6" screen is used.

Continuous slotted screens having a large open area percentage are very much suitable . in case of non-shrouded wells.

But also for gravelpacked wells screens of such a type are recommended. Low flow velocities will lengthen the life of the well even if a part of the screen is clogged.

4.3.2 Well screen and well casing materials related to chemical attack.

Natural groundwater may be corrosive or incrusting, dependent on the type of well material and the type of groundwater. Hard waters, which occur throughout Bangladesh are usually non-corrosive, but if the salinity of the water is high they can corrode iron and steel rapidly. Also brass material (brass screens) is rather sensitive for corrosion. Upper casings of wells are usually made of mild steel (M.S.- casing).

In the Khulna region, where the upper casing may be installed in a very saline upper aquifer, some old wells have already been abandoned due to corrosion of the casing (sand yielding). Therefore, much attention should

be paid to the steel quality, wall thickness and protecting layers of these casings.

Apart from corrosion of natural groundwater, regeneration works of wells are in general carried out with the use of chemicals which may attack the well screen and well casing. In this context the use of P.V.C. material, which is nearly insert is recommended. But also different types of stainless steel screens can stand concentrated acid and chlorine solutions. On the other hand the use of chemicals for regeneration of brass wells is very limited.

4.3.3 Strength of the well

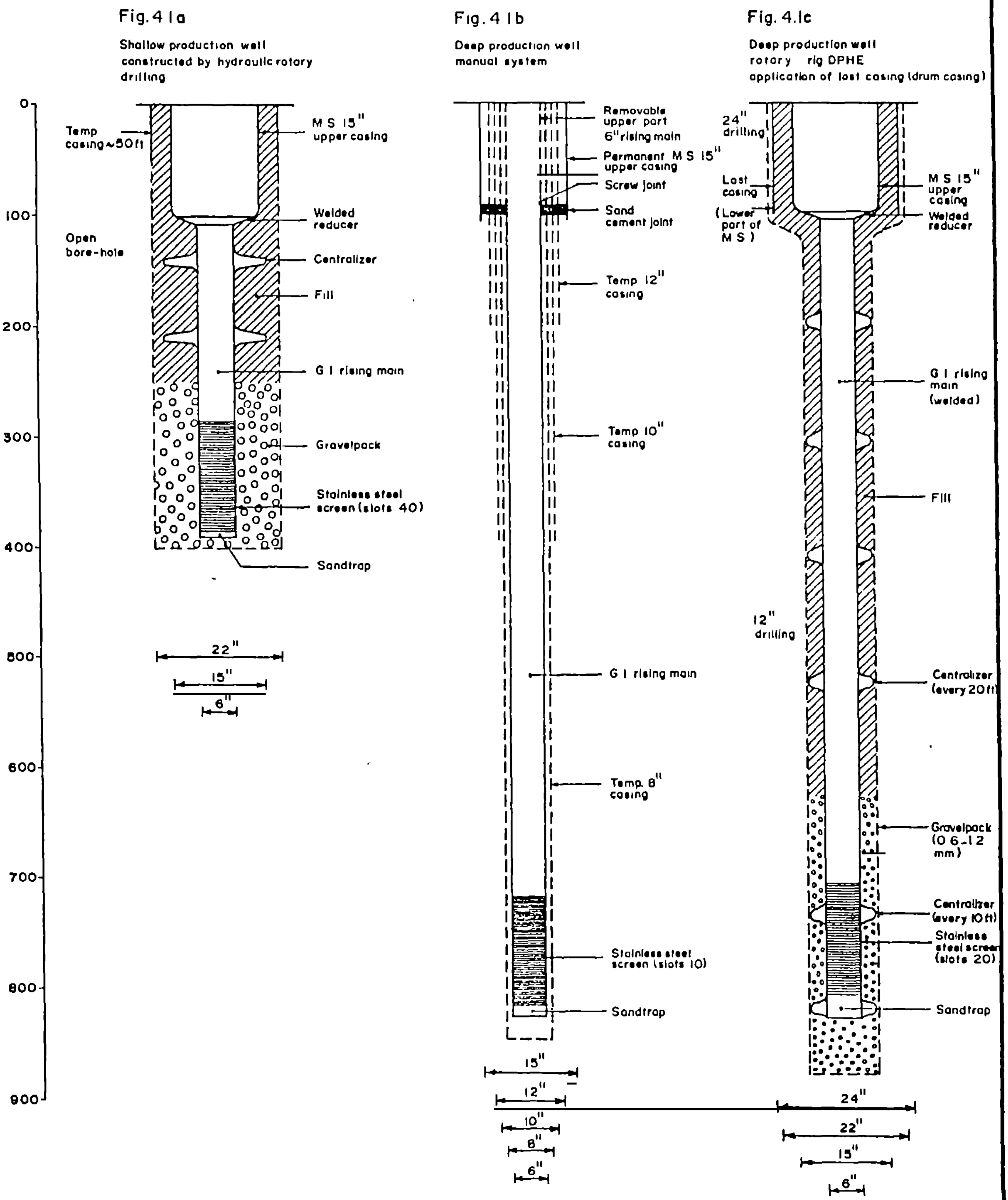
In general, during normal operation the well is not exposed to heavy forces. However, for development and regeneration of the well, which is often carried out by compressed air, considerable (temporary) forces on the casing may occur. But also the screen and well casing needs to be strong to allow mechanical cleaning of the well (brushing, water-jetting, etc.).

Therefore, it is recommended to avoid 'loose' sand cement joints (fig.4.1.b), which have proved to break rather soon during these works. Wells which have been lowered as a whole making use of a welded reducer (fig.4.1.a,c) do not easily face these problems.

If the lower part of the well is constructed of P.V. C. (strainer + lower casing) and the upper casing of steel much attention should be paid to the joint between these materials. In general PVC joints require more attention. As regeneration activities require the installation of small diameter pipes inside the screen and casing the inside of the well needs to be as smooth as possible.

Figure 4.1

CONSTRUCTION OF SHALLOW AND DEEP PRODUCTION WELLS



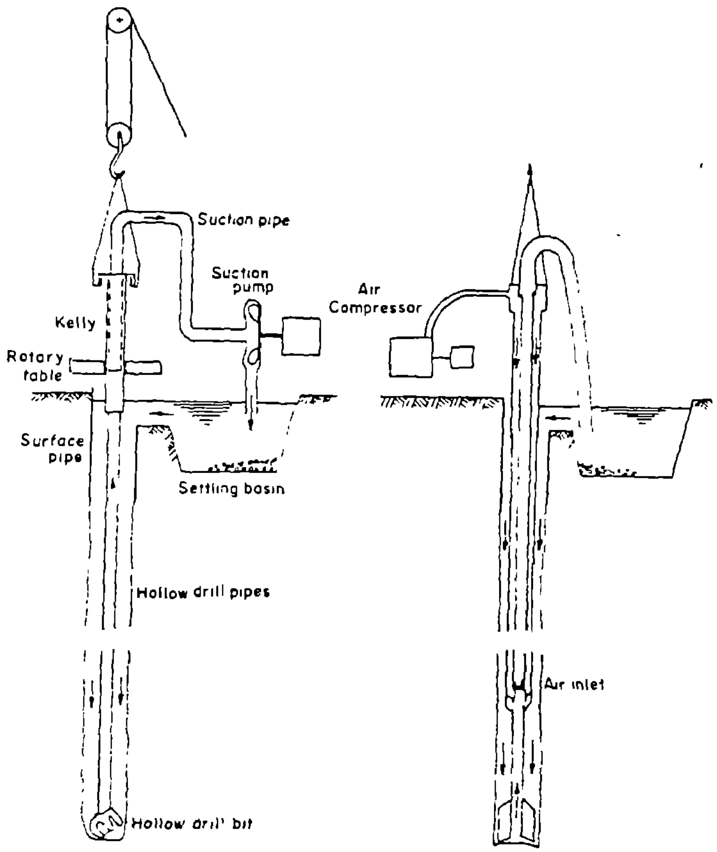


Fig. 4 2b: Hydraulic rotary drilling with reverse circulation

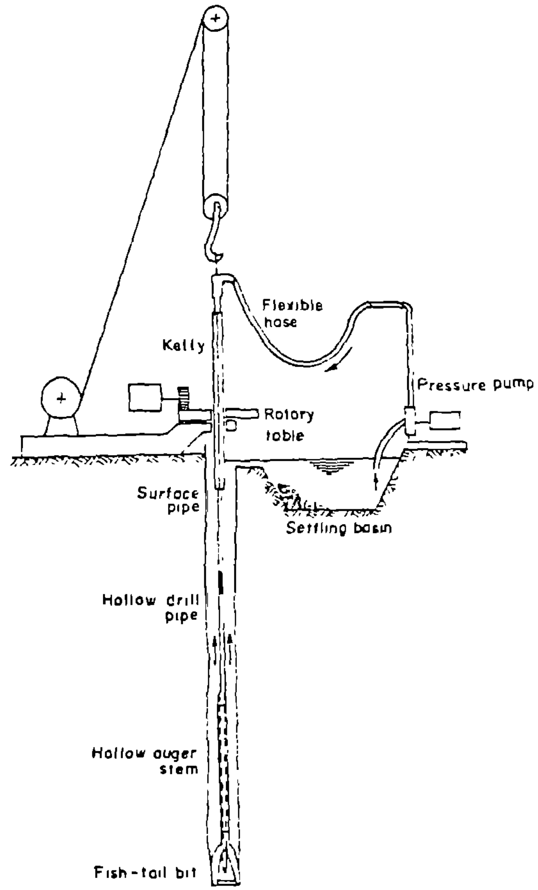


Fig 4.2a: Hydraulic rotary drilling with straigth circulation

Figure 4.2

4.3.4. Provisions for monitoring

In order to locate the clogging of the well, the installation of an observation well in the gravelpack around the screen is always recommendable (see 2,8.2).

A small diameter (1½") pipe provided with a short screen can easily be installed constructing a shallow well,but in case of deep wells it remains difficult.

Proper monitoring of the well requires also:

- a device (or at least an open hole) to measure the water level inside the well with a proper water level indicator.
- a flow meter or a permanent orifice pipe constructed at a T-piece outside the pumphouse.
- proper arrangement of sluice-valves
- a tap for taking representative samples.

4.3.5 Remaining aspects

Although no specific investigations have been carried out to find out whether wells could get clogged due to return flow into the casing, it is known that most of the sluice valves and non-return valves are leaking water during non-supply hours. Therefore, proper construction and maintenance of these devices require attention.

5. Well development

Well development includes all the activities to achieve a proper well yield at minimum well losses. Development work is an essential operation in the completion of a well.

It aims:

* cleaning of the well screen/gravelpack which may be clogged by remnants of drilling mud, clay etc.

* increasing the permeability/porosity in the vicinity of the well by removal of fine sand.

* rearrangement of sand particles and stabilizing the sand formation around the screen, so that the well will yield water free of sand.

Gravelpacking favours last mentioned objectives. In case of an unshrouded well a natural gravelpack needs to be build up. That means there should be a gradually change in coarseness of the sand particles towards the well screen. As already explained in chapter 2 the well losses - apart from friction losses in the casing - become very less if proper well development is done.

Along with cleaning, the fundamental intent in the development operation is to cause reversals of flow through the screen openings that will rearrange the formation particles. This is essential to release bridging of groups of particles. (fig.5.1). These flow reversals can be obtained in different ways:

* over-pumping and alternately starting and stopping the pump.

* water jetting by special weter jetting tools.

* short circuit water jetting by submersible pump.

* section wise cleaning of the screen.

* surging by surge plunger.

* surging by compressed air without air-lift pumping.

* surging and air-lift pumping
* alternately air-jetting and air-lift pumping.
* chemical cleaning.

5.1. Overpumping and alternately starting and stopping the pump

The system of over-pumping is widely used in Bangladesh. A high yield - up to 250 percent of the desired capacity - is in general obtained by using a high capacity compressor. The system of over-pumping is less effective since no flow reversals are introduced. Better results are obtained by putting the pump on and off but the method remains poor in comparison to jetting and surging methods.

5.2. Water Jetting by special water jetting tool.

Jetting with water at high velocity is an effective method of well development. As the energy is concentrated over a small areas, the effect of cleaning and desanding may be great. A relatively simple jetting tool (fig.5.2.c.) together with a high-pressure pump and the necessary hose and piping, are the principal items of equipment needed. Preferably the jetting tool should be designed with minimum four nozzles spaced at 90 degrees obtaining a hydraulically balanced unit. The lowest velocity of which a water jet may be considered effective is about 100 ft per sec (30 m/sec). A high water jet velocity requires a high pressure. The size of the nozzle should not be taken smaller than 3/16 inch in order to obtain some "impuls" from the jet. The required high pressure makes high demands upon the quality of the rising tubes/pipes. Leakage of these pipes/tubes may nullify the whole operation as extra orifices are introduced. Therefore only properly threaded G.I.pipes, screwed by

using special tape should be used. P.V.C. pipes are probably too weak. The disadvantage of pipes is that the whole construction cannot be tried overground, prior to lowering, in order to check its water proofness. In that respect hose pipes are more suitable.

Water jetting in deep wells require - apart from a pre-pressure in the nozzles - an additional pressure to overcome the friction losses in the rising pipes/tubes. The following example may clarify this:

Minimum water jet velocity	:	$V_o = 30$ m/sec
Orifice diameter ¼ inch	:	$d_o = 6.35 \; 10^{-3}$ m
Orifice cross section area	:	$A_o = 3.17 \; 10^{-5}$ m^2
Coefficient of discharge	:	$\mu = 0.8$
Number of nozzles	:	4
Diameter of rising pipe 1½ inch	:	$d_p = 0.038$ m
Cross section area pipe	:	$A_p = 1.14 \; 10^{-3}$ m^2
Depth of the well 800 ft.	:	$L = 240$ m
Friction coefficient pipe	:	$\lambda = 0.02$
Gravity constant	:	$g = 9.8$ m/sec^2

Pre-pressure in orifice	:	$h_j = \frac{V_o^2}{2g} = 46$ m
Discharge per nozzle	:	$Q_o = \mu V_o A_o = 7.6 \; 10^{-4}$ m^3/sec
Total discharge	:	$Q_p = 4 \, Q_o = 30.4 \; 10^{-4}$ m^3/sec
Velocity rising pipe	:	$V_p = \frac{Q_p}{A_p} = 2.7$ m/sec
Friction losses in rising pipe	:	$h_p = \frac{\lambda L}{d_p} \frac{V_p^2}{2g} = 47$ m
Required pressure pump	:	$h_j + h_p = 93$ m

Above mentioned system requires a pump with a capacity of 11 m³/hr at a pressure of 93 m (or 135 P.S.I.). By using a 2 inch rising pipe the friction losses become considerably less:

v_p = 1.5 m/sec

h_p = 11 m

Therefore, strong hose-pipes with a minimum diameter of 2 inch may be recommended for water jetting in the deep Bangladesh wells. Hose-pipes of one length without couplings, winched upon a hose-reel should be used. Several plastic hose-pipes from the local market in Dhaka have recently been tested, but quite of a lot of them could not stand a pressure of 100 PSI.

The water jet system for well development has recently been tried out in Khulna. For the non-availability of strong hose-pipes of one length, pieces of 2 inch fire-brigade hose-pipes were jointed together in order to test the system. A newly constructed well at the News Print compound was developed in this way, yielding reasonable results.

5.3. Short circuit water jetting by submersible pump.

To avoid long hose-pipes and possibly high friction losses a submersible pump may be installed in the screen. A submersible pump of 4 inch outer diameter should be used in 6 inch strainers. The submersible pump abstracts water from a lower part of the screen and releases it somewhat higher by a special jetting pipe (fig.5.2.a). For deep wells the weight of the whole construction may become considerable due to the length of the electrical cable. Therefore, the submersible pump should be hanged up on a strong cable and, at regular intervals, the electrical line needs to be fixed to this cable.

This system has not yet been tested in the DPHE wells, but according to foreign experts it proved to be successful elsewhere in the world.

5.4. Section wise cleaning of the screen

Section wise pumping is often applied for well development, although not in Bangladesh. By this method water is abstracted

only from a part of the screen in cutting off the remaining part by rubber seals (fig.5.2.b).

If no back-washing possibilities are present the system is comparable to over-pumping. Better results are obtained by alternately pumping and back-washing. In the deep tubewells in Bangladesh proper sealing of the screen may face problems.

5.5 Surging by surge plungers.

A widely used method of well development is surging by a surge plunger or surge block, which is a type of piston to be operated up and down in the casing. By this action an alternately flow is introduced. Besides, the generated shock-waves may have a favourable effect on the well development. Pumping of water is also possible by using a valve-type plunger.

As the method needs enough weight to be attached to the surge plunger to make it drop readily on the downstroke, a rig or a proper winch should be applied. Apart from this, proper sealing of the casing may be difficult in Bangladesh.

Care should be taken by using surge plungers if the strength of the well is doubtfull (loose joints).

5.6. Surging by compressed air without air-lift pumping

~~Surging by compressed air is basically not different~~ from surging with a surge-plunger. In this system the upper part of the casing is closed by a welded cover. Air from a suitable air-compressor is introduced into the well to push the water level down. This should be followed by a quick rise by opening the air-release valve. Surging without air-lift pumping does not require a high capacity compressor if

compressed air can be stored in a sufficient large reservoir.

The system is successfully used for regenration of wells (see 8.6.9, fig.8.2) in Khulna and other towns in Bangladesh.

5.7. Surging and air-lift pumping

With the methods of surging and water jetting as described before no discharge of water is obtained. In order to remove fine sand, clay and drilling mud remnants surging needs to be followed by pumping up. This can be done by installation of a pump, but it is more effective to combine surging and air-lift pumping in one construction. The equipment for this purpose is shown in fig.5.3. By closing valve b and c and opening valve a air from the compressor is introduced into the well through pipe L and will push the water level down.

Opening valve c will release the air. In this way the equipment is suitable for surging (see also Lit.5.1)

Discharge of water can be obtained by closing valve a and opening of valve b. Air is led through the air-line pipe into the well and will lift the water through the space between the air-line pipe and the drop pipe. Now the equipment is working as an air-lift pump.

The capacity of an air-lift pump depends on: (fig.5.4).

- capacity of compressor (in volume of free air)
- pressure at which such a capacity is still to be obtained
- total lift. (L)
- submergence ratio of the air-line pipe (W/L)
- design of the equipment, ratio diameters drop pipe/air-line pipe.

For development of 6 inch wells in Bangladesh designed at a capacity of 125 m^3/hr (27.500 Igph) or less (see 6) a compressor of 0.118 m^3/sec (250 CFM) free air at a pressure of 100 PSI (69 m) will be adequate.

For example:

static w.l.	4 m
drawdown	12 m
lift	16 m
Air-line pipe	40 m
Submergence ratio (W/L)	$\frac{(40 - 16)}{40} = 0.6$

This yields by using a compressor of 0.118 m^3/sec a capacity of (fig.5.4.c.) 0.44 m^3 water per m^3 free air (3.3 USGPM/CFM of free air) or 187 m^3/hr.

In some areas in Bangladesh the static water level drops so far below the ground surface, that a considerable lift is involved. Consequently the air-line pipe needs to be installed deeper in order to obtain a reasonable submergence percentage. For development of these types of wells compressors operating at higher pressures may be more suitable.

The graph in fig.5.4.c is valid for a properly designed air-lift installation. For low discharge rates (25-50 m^3/hr) a 4 inch or 5 inch drop pipe together with a 1½ inch air pipe should be installed. For higher discharges (50-100 m^3/h) a 6 inch/2 inch combination may be used. (Lit.2). The well being installed according to the 'loose joint' system, air-lift pumping can easily be carried out by using the 6 inch temporary extension pipe as pumping pipe.

5.8 Alternately air-jetting and air-lift pumping.

This is an effective method for shallow wells. Fig.5.4 b shows the system. Air-jetting or back-blowing is arranged

by lowering the air-line pipe beyond the drop pipe. The method requires a flexible arrangement, that is the air-line pipe needs to be moved up and done in the drop pipe. But also the drop pipe should easily be adjustable for cleaning the hole screen length.

The system offers no perspectives for deep wells in Bangladesh. For instance the pressure in a screen placed at a depth of 800 ft will be some 240 m (348 PSI). Air-jetting at this depth is only possible by using a compressor of say at least 400 PSI. Apart from the availability of such a compressor, extremely high demands will be made upon the strength and quality of the air-line pipe.

5.9 Chemical cleaning.

Chemicals like polyphosphates (Calgon) or sodium hypochlorite have an dispersing action on clay and silt particles. They can easily break the gel properties of of the drilling mud.

Therefore, removal of drilling mud remnants and clay can successfully be done by introducing these chemicals into the well and the gravelpack/formation.

After pouring the solution through a small diameter pipe (say 1½ inch) surging should be done to push the chemicals through the screen into the formation (see 8 ,well - regeneration).

Well development in this way was successfully undertaken at the Ferryghat compound in Khulna (lit.5.2) where the yield of a recently constructed well was increased from 47 m^3/h to 95 m^3/h at 20 m drawdown. Some 100 kg of Calgon had been applied while surging was done by the pump of the well.

Comparable results are obtained in other countries by using sodium hypochlorite.

Figure 5.1

BUILDING A NATURAL GRAVELPACK

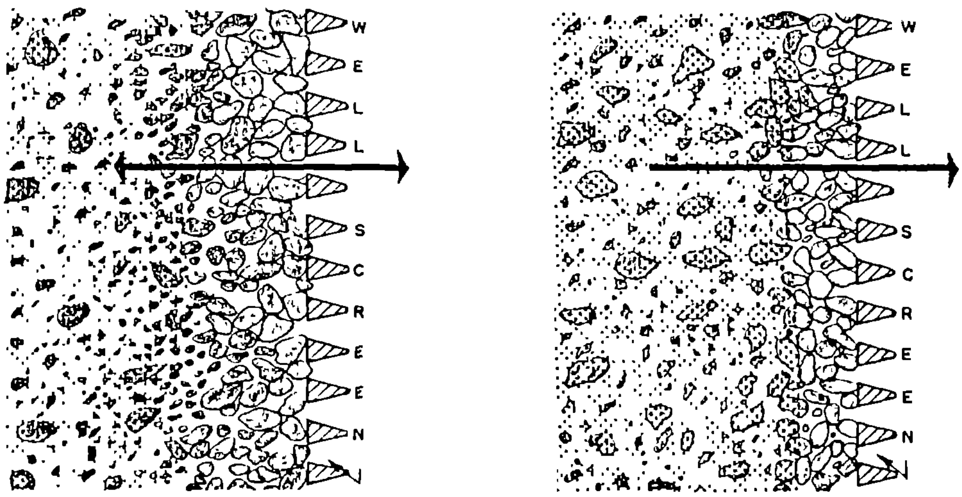


Fig. 5.1a: Effective development by reversing flow

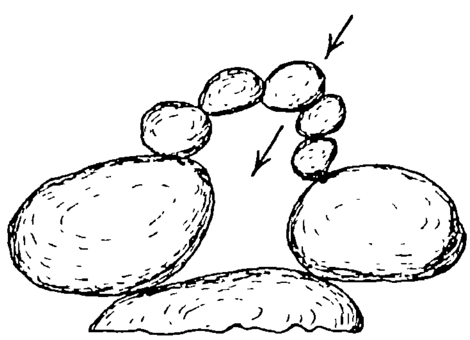


Fig. 5.1b : Arches of sand grains

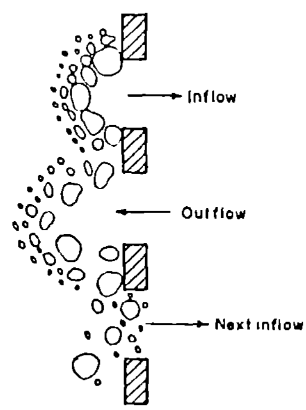


Fig. 5.1c : Sand bridging and its elimination

Figure 5.2

SYSTEMS OF WATER JETTING AND BRUSHING

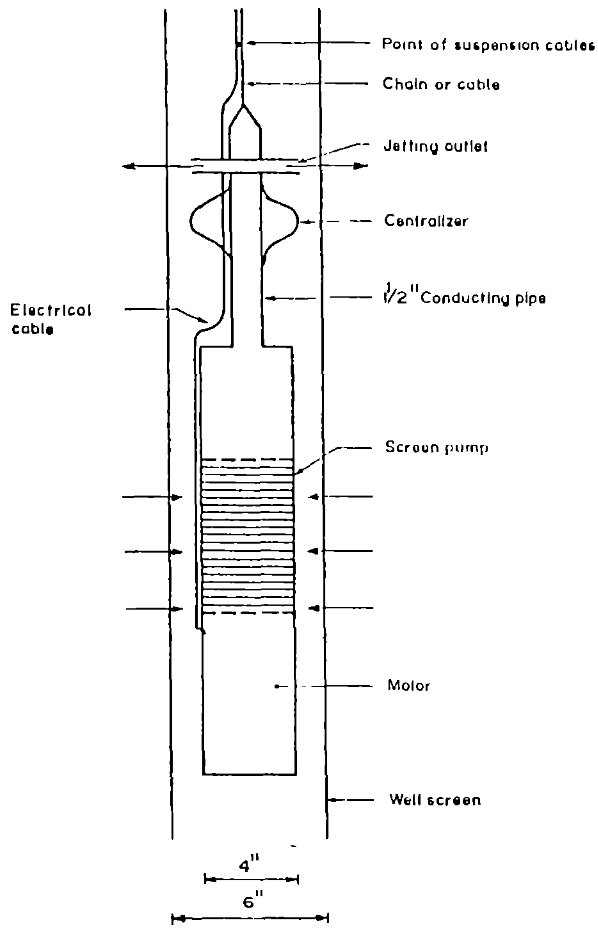


Fig 5.2a: Short circuit water jetting by submersible pump

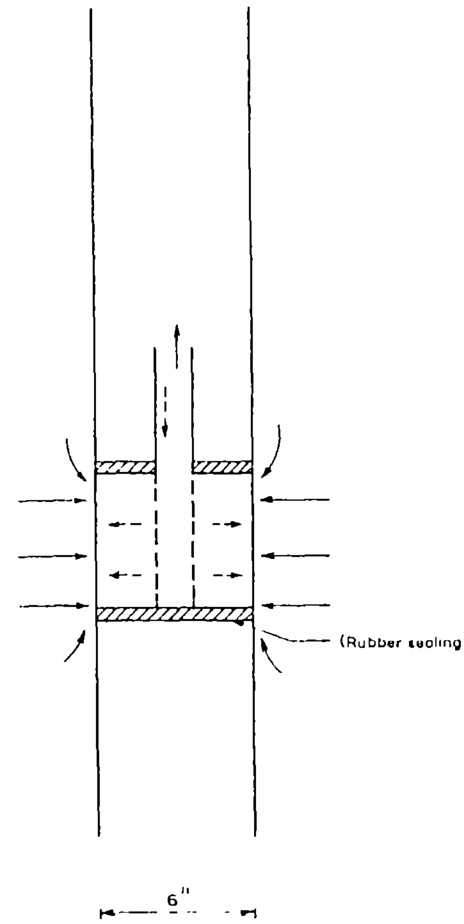


Fig. 5 2b · Section wise cleaning

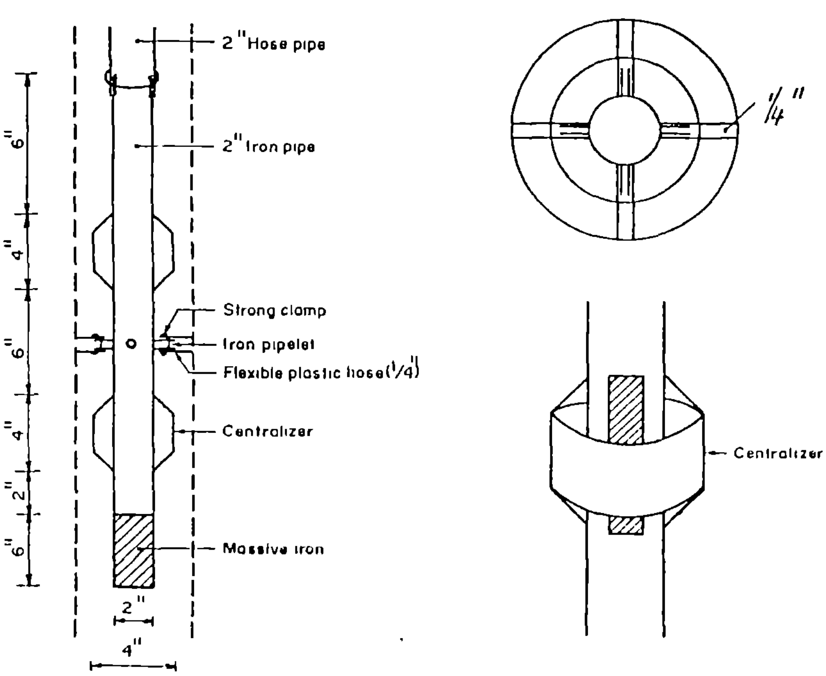


Fig. 5 2c Four nozzle water jetting tool

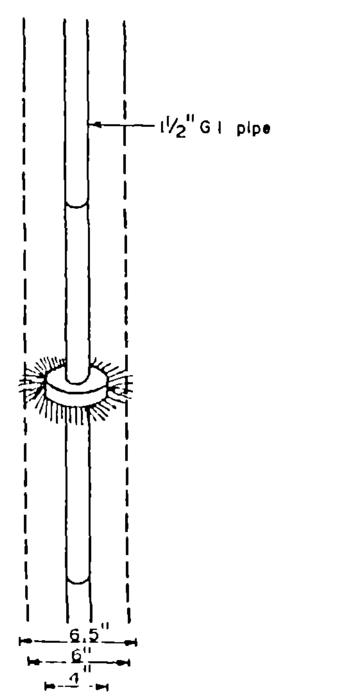
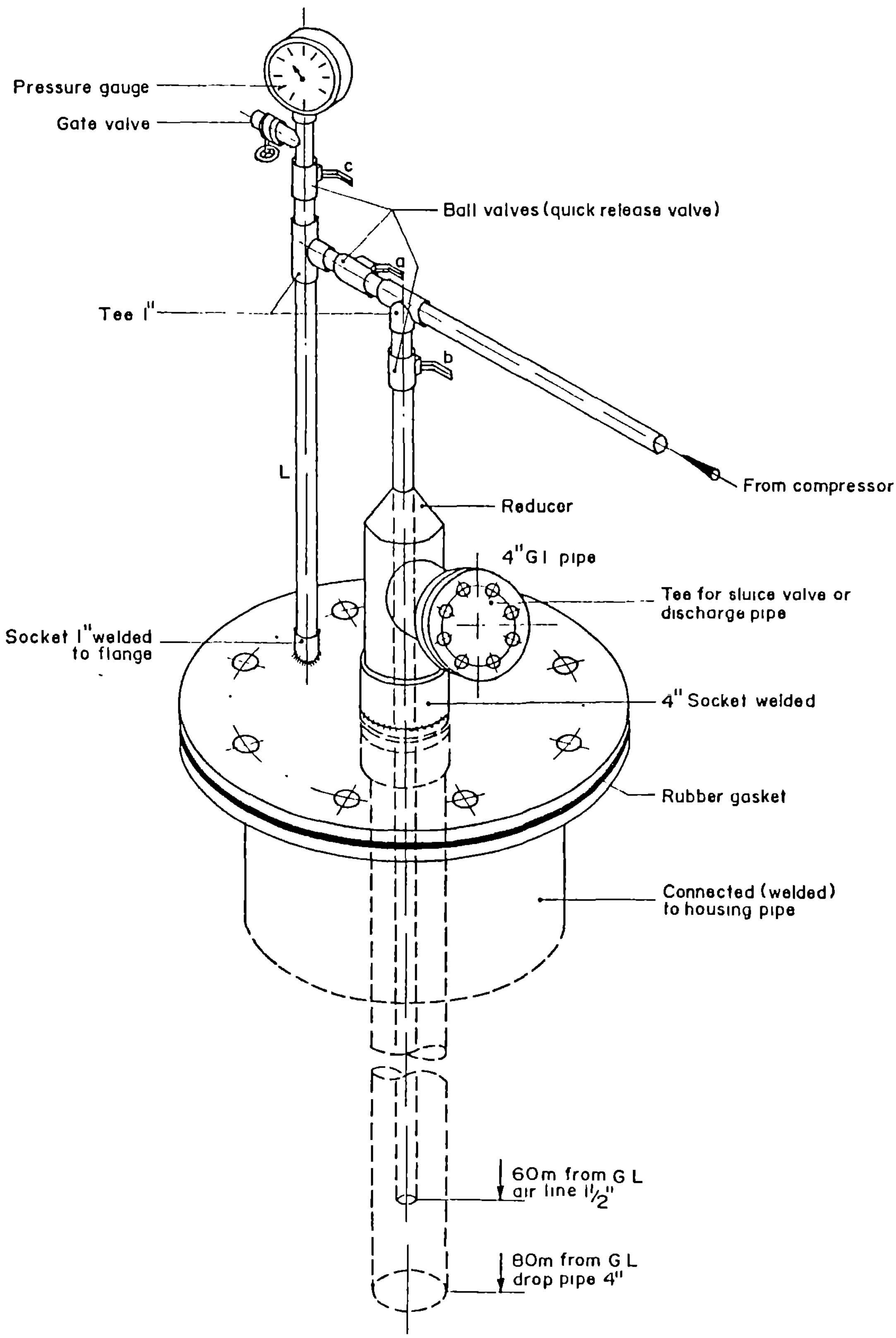


Fig. 5.2d. Brushing equipment

Figure 5 3

CONNECTION DIAGRAMME FOR SURGING AND AIR-LIFT PUMPING OF 6" DIA WELL WITH AIR COMPRESSOR



Not to scale

Figure 5.4

SYSTEM OF AIR-LIFT PUMPING

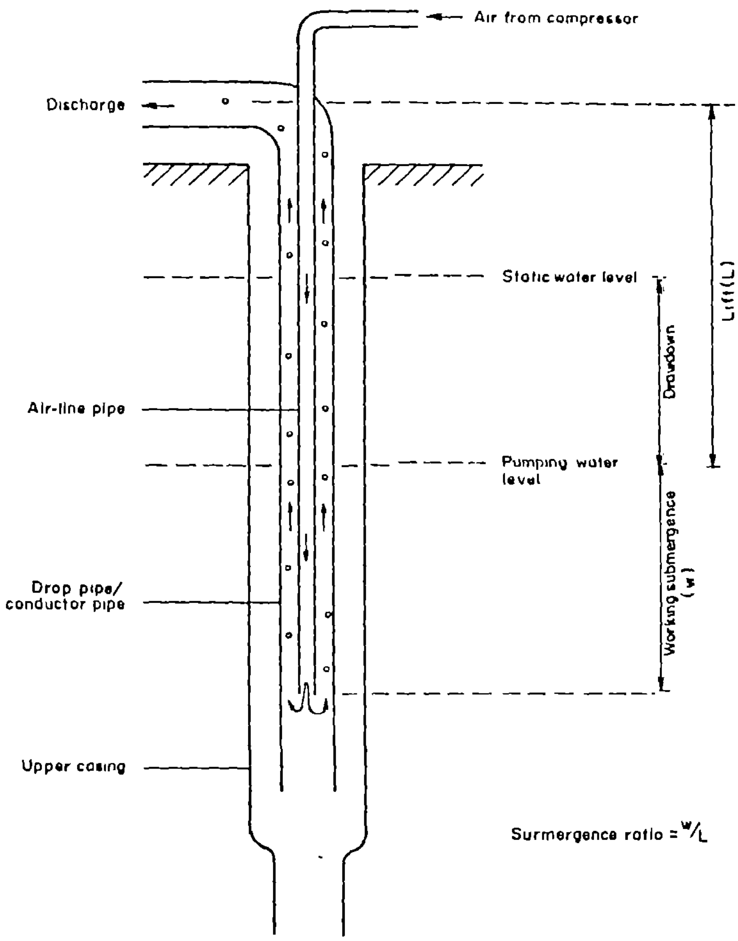


Fig. 5.4a: Arrangement of installation

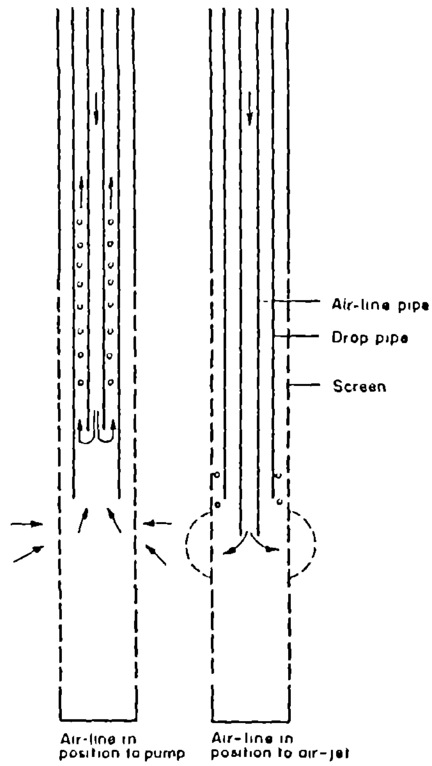


Fig. 5.4b: Alternately air-lift pumping and air-jetting

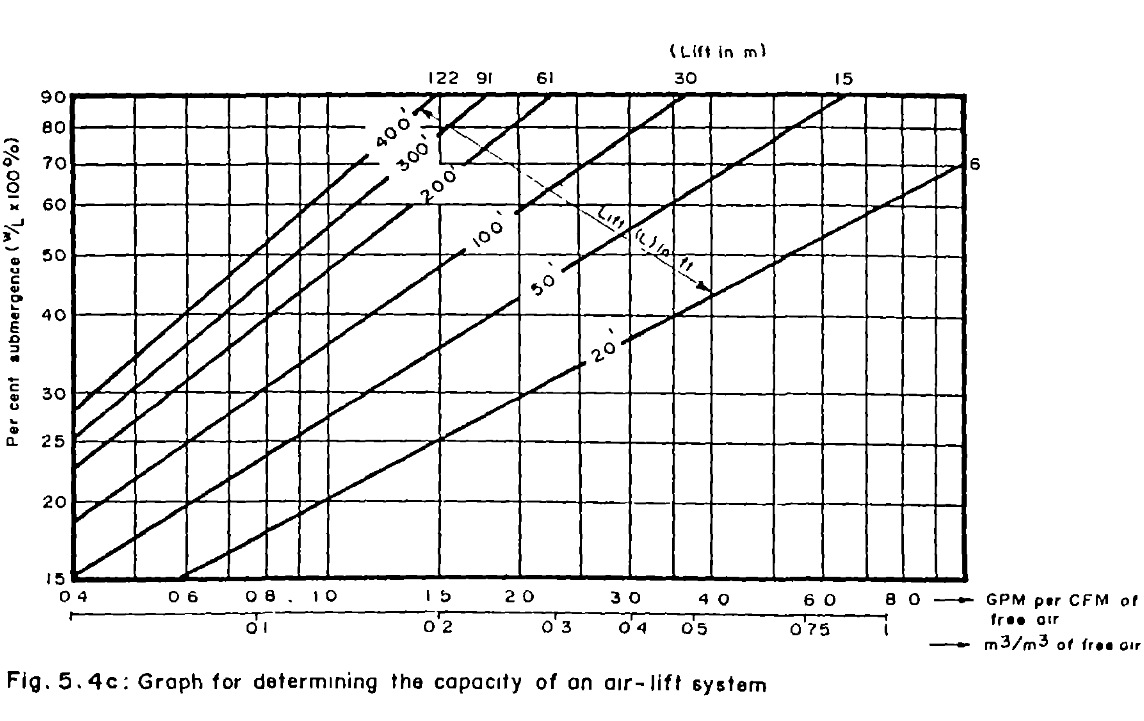


Fig. 5.4c: Graph for determining the capacity of an air-lift system

6. Safe Yield.

The safe yield - in terms of life of the well - depends on the danger of clogging and according to most experts is a function of the velocity at which the groundwater approaches the well:

$$V_{max} = \frac{Q_{max}}{m\, d_o\, h} \quad \text{in which}$$

d_o is the diameter and h is the length of the well screen. In case of unshrouded wells d_o is equivalent to the diameter of the screen enlarged with a zone of the natural formation, that is washed by the well development; while at wells with an artificial gravelpack d_o is equivalent to the radius of the borehole. No unanimity exists, however, regarding the way in which the velocity must be limited to assure a long useful live for the well, for example:

Sichardt : $V_{max} = \frac{1}{30}\sqrt{k}$ (m/sec)

Gross : $V_{max} = 2\ d_{40\,passing}$ (m/sec) (d_{40} in m)

KIWA (Netherlands, in fine to medium sands) : $V_{max} = 2.1 \times 10^{-3}$ (m/sec)

Assuming a fine to medium grained aquifer ($d_{40} \sim 0.2 \times 10^{-3}$ m) having an average permeability of 0.0005 m/s the above methods give the following results:

Sichardt $V_{max} = 0.7 \times 10^{-3}$ m/sec

Gross $V_{max} = 0.4 \times 10^{-3}$ m/sec

KIWA $V_{max} = 2.1 \times 10^{-3}$ m/sec.

Note that these values are far below the recommended maximum entrance velocities for screens : 30×10^{-3} m/sec (lit.2). On the basis of a debatable entrance velocity of 0.75×10^{-3} m/sec and an effective borehole diameter of 0.2 m the yield of a 6 inch dia unshrouded well with a 100 ft long strainer should not exceed some 50 m^3/hr (11,000 Igph). Gravelpacked wells made in 12" boreholes (DPHE drilling rig, Khulna) may be designed on 75 m^3/hr (16,500 Igph), while shallow shrouded wells of 20" diameter may safely abstract 125 m^3/hr (27,500 Igph).

It should be noted, that this design is based on a proper well development, assuming a more or less equal flow density to the well. One can imagine that if a considerable part of the screen/gravelpack is blocked, the flow velocity in the cleaned portion of the well may easily exceed the above mentioned maximum values (fig.3.1.a).

At present the capacity of the pump is usually based on the pumping test results, that means the pump capacity is chosen somewhat lower than the maximum yield of the well. The maximum yield depends more or less on the available drawdown or the difference between the position of the pump and the static water level. As natural groundwater levels may fluctuate considerably throughout the year the yield at minimum available drawdown should be determined.

The design of pump in this way has the following disadvantages:

* In general flow velocities near the well will be much higher than the desired values due to the relatively high transmissivities of the Bangladesh aquifers.
* This can be proved by the following example of an unshrouded well with 100 ft long strainer.

Available max.drawdown	15 m	
Well losses	10 m	
Available max.aquifer drawdown	5 m	(s)
Effective radius of the well	0.1m	(r)
Radius of influence	5000 m	(R)
Transmissivity	1500 m^2/day	(KD)

According to $Q = \frac{2\pi KDs}{\ln (R/r)}$

Q = 4355 m^3/day (181 m^3/h or 40,000 Igph)

The velocity of flow at the bore-hole face is:

$$V = \frac{Q}{\pi d h} = \frac{181}{\pi 0.2 \; 30} = 9.6 \text{ m/hr} = 2.7 \times 10^{-3} \text{ m/sec.}$$

Since the aquifer losses are generally small, the well losses account for a major part of the drawdown. This allows apart from friction losses by flow inside the casing/screen considerable losses near and inside the screen openings. These losses are usually related to the development of the well as found by pumping test analysis of several wells in Bangladesh. Therefore, in spite of an originally reasonable yield the capacity of the well will tend to decrease rather soon due to unproper development.

At a decreasing yield the pump may suck air rather soon. This damages the pump and favour incrustation. At least it requires the replacement of a pump with less capacity, if no regeneration works can be done.

Pumping at maximum drawdown requires more energy:

$$P = \frac{\rho g QH}{10^3 \eta} \text{ KW} \quad \text{with}$$

ρ	=	density of water	(1000 kg/m^3)
g	=	gravity constant	(9.8 m/sec^2)
Q	=	discharge	(m^3/sec)

H = head (m)

η = overall efficiency ($\cong$ 0.7 = η pump η motor η cable $\cdot \eta$ transformer)

The energy costs proportial to the total head of the pump, an extra drawdown of 5 to 10 m will require 12.5 to 25% more energy (total head $\cong$ 40 m).

Therefore, it is recommendable to design the well capacity on the maximum allowable entrance velocity and to develop the well properly allowing a low drawdown for long time.

7. Recording, monitoring of the well.

7.1 Basic data of the well.

Together with a monitoring report, data on the original design and construction of the well are required for regeneration works. For example, the construction of the screen/gravelpack as well as the method of drilling/well development may indicate the type of clogging, while the type of material/joints may exlude some regeneration methods.

The following data of the well should be recorded:

Drilling system.

* data and duration of drilling.
* type of drilling (manual with casing, straight flush, reverse circulation, etc.).
* use and type of drilling fluid.
* particulars of the drilling fluid (viscosity, specific weight, sand content)
* bore-hole diameter(s)/depth of drilling.
* casualities during drilling (caving in, hard layers etc).

Construction of the well proper.

* working drawing indicating : total depth of the well, screen length, length of casing(s), joints, reducers, sand-trap etc., diameters, type of materials, wall-thickness, type of construction, observation well,etc.
* type of shrouding, gravelpack design, total volume of gravel applied, method of inserting, particulars during lowering.
* type of screen, slotsize.
* details of centralizers : number, diameter, construction, etc.
* details of installation : verticality,duration of lowering, obstacles, recharge through screen, etc.
* placement of observation well : depth, length of screen, position in gravelpack.

Construction of pump, motor, elevated parts.

* working drawing and ground-plan of the pump-house: working drawing of the pump, motor, pressure meter(s), device(s) for water level observations, non-return valve, sluice valve(s), flow meter, priming unit, chlorination unit, T - piece(s), tap(s), etc.
* scheme of the electrical system with details.

Data on development of the well.

* method of development (surging with compressed air, air-jetting/air-lift, water jetting, overpumping, chemical treatment, etc.).
* initial discharge and discharge after development (related to drawdown).

* water quality observations during development : sand contents, drilling mud remnants, etc.
* duration of development works.
* leakage of casings.

Hydrogeological data

* Bore-log and construction graph of test well(s)
* Position of test well(s) and other neighbouring production wells (distances).
* Sieve analysis results.
* Data of geophysical logging (resistivity logging, temp. logging)
* Pumping test report including : static w.l, pumping w.l. ,drawdown, discharge, duration of pumping test/ recovery test, transmissivity, storage coefficient, well losses, aquifer losses, step-drawdown curve,etc.
* Water quality report : electrical conductivity, temperature, P^H, hardness, chloride, iron, manganese, sulphate, bicarbonate, CO_2 , etc., water quality of upper layers.

  For each well a separate file should be maintained.

7.2 Monitoring of the well.

In order to take the proper measures in time the condition of the well should be checked regularly.

Monitoring of the well needs to be done on :

- static level
- pumping level (and drawdown).
- pressure in pipe-line system direct after the pump.
- discharge,
- running hours,
- water quality,
- water levels of test well, observation well, if present.

- condition of sluice-valves, flow meters, non-return valves, etc.
- condition of electrical system.
- condition of pump, chlorination unit, etc.

Monitoring requires proper devices as mentioned in 4.3.4

7.2.1 Frequent observations

Measurements on static water level, pumping water level, pressure in the pipe line system, running hours and - if present - the reading of a flow meter should preferably be done by the pump driver. He also can keep an eye on the water quality (sand content !) and the condition of the mechanical/ electrical system.

These data should daily be recorded in a log-book of the well which has to be checked regularly by an officer of the government department in charge of the water supply management. An example of such a daily report is given in fig 7.1. Proper and clear instructions have to be given to the pump driver how and when to take the measurements and how to fill in the log-book. For example, observations of water levels should be done after at least 1 hour after stopping or running the pump. Flow meter reading needs to be done before running or after stopping the pump. It is desirable that the responsible man has some insight in the necessity of monitoring. There is no need to have the records in English. In case of casualities the pump driver should directly inform the officer in charge.

The presence of a proper flow meter will facilitate determination of the yield as indicated in fig.7.1. But, at present only a few wells are provided with such a device.

In order to have a rough idea about the yield of the well one can follow the fluctuations of the pressure meter installed on the out-going pipe line directly after the pump.

This pressure meter should be 'calibrated' during the discharge measurements with the help of an orifice meter, or drum with sufficient content. (fig 8.1.).

7.2.2 Regular well inspection.

On the basis of the daily reports the condition of mainly the well proper can simply be monitored. Nevertheless a more detailed inspection once a month or once in two months will be required to get a complete picture of the pumping station. Apart from a review of water quantity data the report should include water quality data, and mechanical/ electrical particulars, as well as recommendations on regeneration, discharge measurements, repair, replacement etc. An example of a fictitious monthly tubewell report is given in fig.7.2

This montly inspection survey should be carried out by a capable officer (water supply engineer/geohydrologist) who will also check the daily reports of the well. He is also the right person to carry out the discharge measurements as well as the regeneration works.

If the yield has been decreased considerably he will advise to regenerate the well.

Figure 7.1

DAILY TUBEWELL REPORT

Town : Khulna
Location : Toltola (P 28)
Month : April 1985
Installed discharge : 55 m³/hr
Drawdown : 9 30 m
Date : 20.3 1985

Total running hrs 258
Discharged volume 14115 m³
Av discharge 54.7 m³/hr
Av. drawdown 10.4 m

Date	Static water level (m)	Pumping water level (m)	Drawdown (m)	Pressure in pipe line (PSI)	Running time	* Total running hrs. per day	Flow meter reading (m³)	* Discharged volume	* Discharge (m³/hr)	Remarks : - Power (voltage) - Water quality (sand) - Condition pump/motor, valves etc. - Supply change
31.3 1985							4033			
1.4.1985	2.85	12.15	9.30	30	4.10/9 30; 2.30/6.00	8.83	4518	485	54.9	
2.4 1985	2.80	12.20	9.40	30	4.30/9.30; 2.30/6.30	9.00	5004	486	54.0	
3.4.1985	...	...	...	...	...	...	...	...	...	
4.4.1985	...	...	...	...	...	...	...	...	...	
...	...	...	...	...	...	...	...	...	...	
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...	...	...	...	...	...	...	...	...	...	
29. 4 1985	.	..	.		...	...	17698	...	...	
30 4 1985	2 60	14 13	11 53	30	4 30/9 30 2 30/6 30	8 50	18148	450	52 9	
		av d.d	10.4			258		14115		

* To be filled in by officer in charge

Figure 7.2

Monthly tube-well report.

Town - Khulna

Location - Taltala P28

Date - 1 - 5 - 1985.

Water quantity.

Last regeneration/installation of tube-well	31-3-1985
Installed capacity/drawdown	55 m^3/hr -9.30 m
Av. discharge / drawdown previous month	54.7 m^3/hr-10.4 m
Total discharged volume after installation/ regeneration	18148 m^3
Total discharged volume in previous month	14115 m^3
Running hrs previous month	258 hrs.
Pressure in pipe line system	30 PSI
Drawdown test well	1.8 m
Specific yield after install./regeneration	5.9 m^3/hr/m d.down
Average specific yield last month	5.2 m^3/hr/m d.down
Present specific yield in percentage of original yield	88 %
Drawdown observation well in gravelpack	5.0 m
Necessity for regeneration/rehabilitation	no

Water quality.

Sand contents	no
Electrical conductivity	800 μS/ cm
Iron	2 mg/L
pH	7
Colour	clear

Figure 7.2 (Cont)

Mechanical part.

Condition of motor/pump	:	good
Condition non-return valve	:	Leaking
sluice valve	:	good
flow meter	:	to be checked by orifice test.
pressure meter	:	some times blocked
tap	:	stolen /to be replaced
water-level meter	:	battery to be replaced
priming unit	:	good
chlorination unit	:	dosage acc. to statement
supply of bleaching powder	:	sufficient in stock

Electrical part.

Lines, switches, meters, transformer	:	volt meter out of order since 8 - 4 - 1985
Voltage (av)	:	370 V
Power breaks	:	regularly in the afternoon

Recommendations. : continuing present supply, repair of tap, replacement of rubber seal non-return valve and pressure meters. Discharge measurement by orifice meter.

8 Rehabilitation of wells.

8.1. General.

In general wells are liable to clogging even if a proper design and construction has been followed. Consequently the yield of newly constructed wells will gradually decline. The fastness of clogging, however, depends on the groundwater quality, type of formation, well construction, well performance, etc, as discussed in chapter 3. Apart from clogging, the well may need repair or rehabilitation after some time due to sand yielding, damage of pump/casings, broken joints. Regeneration of wells is practised all over the world and usually-in-view of cost-benefit ratios - it is economically paying. Only if the construction costs become very cheap regeneration may be dissuaded.

Wells can be regenerated in different ways. The methods can be divided into three major systems :

1) Direct mechanical cleaning :
   - brushing after withdrawal of the screen
   - brushing in the well by fixing brushes on a small dia pipe to be lowered into the well.

2) Cleaning by water flow:
   - over-pumping, intermittent pumping by means of the installed pump.
   - surging and air-lift pumping by compressor.
   - surging by surge-block/surge-plunger
   - water jetting by special water-jetting tools and a rising pipe/tube.
   - short circuit water jetting by submersible pump.
   - section-wise cleaning by sealing parts of the screen

3) Cleaning by air :

   air-jetting by compressor with air-jetting tool.
   alternately air-jetting and air-lifting.

4) chemical treatments :

acids
chlorine/hypochlorides
polyphosphates.

8.2. Preparatory works and investigations.

The yield being decreased (or drawdown being increased) considerably, one will decide to take up regeneration of the well. But, prior to these works a proper insight in the present condition of the well will be required. Therefore, basic data of the well and aquifer as mentioned in 7.1 and the information obtained from the monitoring programme (7.2/7.3) have to be studied. If information on waterquality is lacking, a complete (as possible) chemical analysis will be required. The most important parameters to determine are :
electrical conductivity, temperature, hardness, alkalinity, p^H, total solids, chlorides, iron and manganese.

From a near test well and/or observation well placed in the gravelpack zone of the main tube-well one may already obtain information about the decrease in yield :

- fall in water level in test well, observation well and main tube-well more or less equal. → local/regional sinking of the water table, condition of the well unchanged.
- no fall in water level in test-well: observation well and main tube-well show an equal fall in water level. → clogging at the bore-hole face. (fig. 3.1.b)
- no fall in water level in test-well and observation well, considerable difference in water level between observation well and main tube-well. → clogging of the screen, incrustation. (fig. 3.1.b)

More information of the condition of the well has to be obtained from a step-drawdown test.

During this test the water level/drawdown in the well is measured at different discharges. This yields a discharge-drawdown curve(fig.2.3). In order to obtain a more or less steady state situation each stage of the test will usually require 0.5 - 1 hr. Some 4 to 6 stages will be sufficient to obtain a reliable discharge-drawdown curve. Interpretation of this graph together with information of the aquifer can be helpfull to get an insight in the head losses (aquifer/well losses, see chapter 2.). The graph is also a help to calculate the yield at a certain drawdown or the reverse.

In general , due to the non-availability of flow-meters, discharge measurements needs to be done with the help of an orifice meter. A circular orifice weir is the most commonly used device to measure the yield of a turbine or submersible pump(fig. 8.1.a). The orifice itself is a perfectly round hole in the centre of a circular steel plate (lit. 2.). In fig. 8.1.b and fig. 8.1.c graphs for calculation of the yield are given. If the yield is less than 5.000 Igph (~ 25 m^3/h) the method may become less accurate. Then preferance should be given to the container method, that is : one observes the time required to fill a container of known volume. This method-although it may need a large container - is also to be applied for determining the discharge of air - lift pumps.

After lifting the pump the depth of the well should be checked and if a part of the well is filled up one can try to recover some material (grease on iron pin, bailer, etc). The investigations should also include the inspection of casing(s), joint(s), presence of obstacles, etc.

8.3. Direct mechanical cleaning.

Screens which can be lifted through a casing of larger diameter can easily be cleaned overground by brushing. Such screens are usually jointed to the upper casing by a lead or rubber packer. Nevertheless withdrawing of screens and reinstallation is rather costly and fails often. As the DPHE wells are constructed with a permanent screen, usually welded or screwed to an upper casing this method has no significance at present.

Effective brushing in the well requires a strong, preferably metal brush with flexible thin wires of a diameter which allows passing the slits of the screens. The diameter of the brush should be somewhat larger than the inside diameter of the screen. In order to obtain a strong and stiff construction the brush should be fastened (welded) to iron pipes. Several brushes may be fixed. In deep wells, as present in Bangladesh, the total weight of the pipes ($1\frac{1}{2}$ inch G.I. pipes in general) does not allow fast vertically brushing. In general the construction is lowered by a chain pully or winch, while horizontal brushing is performed by rotating the pipes. Fig. 5.2.d gives an example of a brushing tool.

Brushing is usually carried out as a part of the total regeneration works. Therefore the effect of brushing of wells in Bangladesh is rather unknown. A few wells in Khulna, tested after brushing prior to further regeneration did not show any significant improvement, although scrapings containing iron/carbonate were pumped out.

One can imagine that, brushing has little effect if the clogging is located outside the screen in the gravelpack or in the formation .

8.4. Cleaning by water flow.

Intermittent pumping causes irregular flow through the screen and can easily by done by the installed pump. Due to the inertness of the system and the relatively low flow velocities the method is practically ineffective. Pumping at a higher discharge rate may give some results but requires usually a pump at greater depth.

Surging by compressed air will cause - apart from a return flow through the screen - a shock wave in the well. This may loosen the incrustants, but the method is more suitable for rearrangement of the gravel/sand particles outside the screen, releasing fine sand silt and clay (see 5 , well development). Surging combined with air-lifting is more effective (fig. 5.3) as a stronger outgoing flow is initiated. Meanwhile the scrapings and soil particles can be removed. Air -lifting, however, requires a high capacity compressor, while simply surging can be done by a small capacity compressor (see 8.6.9. and fig. 8.2).

Surging by a plunger causes a similar effect as compressed air. The method, however, as explained in 5.5 is less fruitfull in Bangladesh.

Methods of water jetting (special water jetting tools, section wise cleaning, short circuit water jetting by a submersible pump) are suitable methods in case of clogging by fine sand, silt, clay etc. In this case regeneration of the well means redevelopment of the well. For removal of incrustants water jetting may be helpfull, but requires a proper construction of the water jetting tool and high jet velocities.

5. Cleaning by air.

Air-jetting can only be done in case of a rather shallow screen and a high capacity compressor. The air-jetting system described in chapter 5 is not yet tested within the DPHE well regeneration works.

6. Chemical treatments.

Chemical treatments have proved to be very effective in well regeneration. The most widely used chemicals are :

acids	- muriatic / hydrochloric acid
	- sulfamic acid
	- oxalic acid
chlorine and-hypochlorite-solutions	- sodium hypochlorite
	- calcium hypochlorite
	- bleaching powder
	- chlorine gas
polyphosphates	- sodium-hexameta phosphate.

Most of the chemicals mentioned above are available in Bangladesh, possibly with the exception of sodium hypochlorite and chlorine gas. In the following chapters their action, application and use will (briefly) be discussed.

8.1. Hydrochloric acid. (HCl)

Hydrochloric acid is a strong oxidising agent and it readily dissolves calcium and magnesium carbonates. Iron and manganese hydroxides and oxides are also quite soluble in hydrochloric acid. They will, however, precipitate out if the p^H increases, say above 3 to 4. To remove these compounds, then, the proper strength of acid must be maintained until it is pumped out of the well. To help keep iron in solution, a chelating agents may be added to the acid. Rochelle salt or citric acid are materials which will serve this purpose.

Although most incrustants are acid-soluble, some regeneration works reveal inadequate results. This may be due to clogging beyond the screen (dilution effect) or due to mechanical clogging.

Hydrochloric acid is available in Bangladesh at acid grade of 25 - 28 %. Handbooks (lit. 2,4) recommend to use an amount of acid of this strength of 1½ to 2 times the volume of water in the screen. This amount will assure filling the screen, plus additional acid to keep the solution up to good strength as the chemicals react with the incrusting materials. On the ground of these directives an amount of some 1000 litres should be required for the Bangladesh situation (volume of a 6 inch, 100 ft strainer: 0.55 m^3).

As hydrochloric acid is an agressive liquid care must be taken in handling and all safety measures should be exercised. Pouring the acid solution into the well should be done with P.V.C. conducting pipes.

Hydrochloric acid attacks many metals and alloys, particularly copper alloys. Even some stainless steel screens are not safe in this respect. The damage caused by the acid may not show up for some time after treatment of the well. Proably the use of stainless steel type 316 or 312 may be safe. Nevertheless the use of an inhibitor is recommended. Wells made of P.V.C can be treated without any problem. As only a small number of production wells are constructed with P.V.C. - screens the application of hydrochloric acid in Bangladesh will be limited in the nearest future.

Recently a P.V.C. well in Rajshahi has been regenerated by some 200 litres of hydrochloric acid. Although this amount was far below the recommended quantity the yield of the well had been increased from 70 m^3/h up to 125 m^3/h at 14 m drawdown. It should be mentioned that this well abstracts rather hard water (Ca / Fe / Mg - carbonate).

Well regeneration by hydrochloric acid (but also sulfamic acid) does not take long. A contact time in the well of 4 - 6 hours is sufficient.

8.6.2. Sulfamic acid (NH_3 SO_3)

Sulfamic acid is being used increasingly for well regeneration. Although it is more costly than hydrochloric acid, it is more convenient and safer to use. Sulfamic acid is a dry, granular material that becomes a strong liquid acid when dissolved in water. Sulfamic acid in the amount of 1 kg in 1.8 litre of water should have the same strength as a 28 percent hydrochloric acid solution. However, such a high concentration can not be obtained regarding the solubility of the granular material. Nevertheless a slurry can be poured into the well giving an equivalent strength inside the screen. Usually together with the acid a mixture is made of diethylthiourea (inhibitor), chelating agents, wetting agent and sodium chloride.

For 1000 litres of solution (see 8.6.1) the following chemicals may be mixed :

300	kg	of	sulfamic acid
20	kg	of	nitric acid (chelating agents)
17	kg	of	diethylthiourea (inhibitor)
3.5	kg	of	pluronic F 68 or L 62 (wetting agent)
150	kg	of	sodium chloride

Sulfamic acid attacks metals more slowly than does hydrochloric acid. Proably it has no effect on type 304 stainless steel well screens.

The introduction method is similar to that of the hydrochloric acid treatment. Since it's action is a little bit slower, a somewhat longer contact time in the well is required (12 - 24 hours).

Sulfamic acid is available in Bangladesh, but its price is rather high ( ). So far as we (Netherlands - Project team) know it has not yet been tried out in Bangladesh.

8.6.3. Oxalic acid ($C_2O_4H_2$ - $2H_2O$)

Oxalic acid is a weak acid and according to some specialists it is more effective to dissolve iron precipitates in comparison to strong acids as hydrochloric acid and sulfamic acid. This may be seen by the way it interact. with iron compounds. The dissolving of iron precipitates does not only take place due to the lowering of the p^H value. The conjugate base part of the oxalic acid reacts with iron to form a complex which eventually forces more of the iron precipitate to dissolve.

The oxalic acid is available in granular form (also in Bangladesh) and is easy to handle. As a weak acid it does not attack the material of the well.

Experience outside Bangladesh has shown that an acid concentration of 1.5 - 2 % by weight may be recommended for well treatment. On the basis of a quantity of 1000 litres some 30 kg will be required taking into account that some mixing and losses will take place.

For effective treatment the acid should stay in the well for 12 - 24 hours.

A treatment with oxalic acid has recently been carried out at the R.A.F. camp well in Khulna (lit. 5.6) . The results of this regeneration were reasonable, but not hart breaking :
from 11 m^3/h to 29 m^3/h.

8.6.4. Sodium hypochlorite (Na ClO)

Sodium hypochlorite is being widely used in well regeneration in some European countries (The Netherlands). Particularly in wells which are clogged outside the screen by iron sulphides and micro-biological activity these chemicals are found successfull.

Sodium hypochlorite is formed by passing, active chlorine through a solution of sodium hydroxide :

$$Cl_2 + 2\,NaOH \rightarrow NaCl + NaClO + H_2O$$

It reacts with iron sulphide, deposited under influence of sulphate reducing bacteria in the following way :

$$FeS_{(s)} + 4\,Cl^- + 4\,ClO^- \rightarrow Fe^{2+} + SO_4^{2-} + 8\,Cl^-$$

Herewith iron and sulphate is released.

Sodium hypochlorite is available in liquid form. It is prepared in several strengths by many different producers. The maximum seems to be about 20 per cent available chlorine. Recommendations are given to use the full strength of the solution (~ 15 %). So far as our information concerned it is not available in the open market in Bangladesh.

Clogging zones of iron sulphide present in the gravelpack or in the natural formation, the quantity of solution required may be more than recommended for removal of incrustants from the screen. Consequently more attention has to be paid to the surging activities.

Care should be taken in handling the solution, although sodium hypochlorite is not so dangerous than strong acids. It may be agressive to some metals and alloys.

An additional effect of sodium hypochlorite is its dispersing effect on clay and silt. This is because of the sodium content. Therefore, sodium hypochlorite is successfully used for well development particularly if a heavy drilling mud has been used (see 5.9).

The solution is kept for 2 - 4 days in the well, during which period, surging is carried out.

8.6.5. <u>Calcium hypochlorite</u> Ca $(ClO)_2$

Calcium hypochlorite is a white, granular material containing about 70 per cent available chlorine by weight. To distinguish this chemical from chlorinated lime or bleaching powder, it is commonly referred to as high-test calcium hypochlorite. As sodium hypochlorite it is normally used for disinfecting and water treatment purposes.

For removal of iron sulphide calcium hypochlorite may react in a similar way as described for sodium hypochlorite.

In order to obtain a solution with a strength of 15% active chlorine as recommended for the sodium hypochlorite application, some 0.2 kg should be diluted in 1 litre of water. So for 1000 litres one needs 200 kg. In this case the hypochlorite is working as an oxidising agent. The well being clogged in the gravelpack requires more solution (see 8.6.7).

However for the removal of slime deposits caused by bacterial growth a much lower concentration of active chlorine is required. Handbooks mention concentrations of 100 to 200 mg/L. For this purpose a few kg of calcium hypochlorite are already sufficient for a solution of 1000 litres. But as bacterial activity may be concentrated beyond the screen a much larger quantity of solution should be used and pushed through the screen by surging.

Calcium hypochlorite has no peptising and dispersing action. Therefore it is not suitable for re-development.

A concentrated chlorine solution is agressive and may attack weak metals and alloys (brass).

In Khulna calcium hypochlorite (60 % available Cl_2) has been used for well regeneration. In the R.A.F - camp production well, here, a quantity of 50 kg was mixed in the well giving an estimated chlorine content of about 4 - 5 %. The treatment resulted in an increase in yield of 29 m^3/hr to 51 m^3/ hr measured at a drawdown of 20 m.

8.6.6. Bleaching powder and chlorine gas.

Bleaching powder is a type of chlorinated lime., comparable to calcium hypochlorite, but in general it is polluted and has a low percentage active chlorine (max. 25 %). However the action and use are similiar to calcium hypochlorite. Bleaching powder is widely used in Bangladesh for disinfection and treatment purposes.

Chlorine gas may be very effective, but it needs special equipment for handling and proportioning.

8.6.7. Sodium-hexa-meta-phosphate.

Sodium-hexa-meta-phosphate is a glassy polyphosphate which is usually called Calgon. It is produced by a thermal process from sodash and foot-grade phosphoric acid. It contains not less than 67 % P_2O_5. Calgon is essentially neutral having a p^H of 6.7 to 7.0 in 1 % solution. Calgon has unusual properties which have led to its wide-spread use in water treatment. For example it prevents the precipitation of calcium carbonate (declining hardness) and it favours the formation of thin phosphate films on metal surfaces to control corrosion. But one of the most striking properties of Calgon in its pronounced ability to disperse finely divided metal oxides and salts, including calcium carbonate, clays and similiar materials. Therefore calgon is successfully used for well regeneration an development of wells and in Bangladesh it has successfully been tried out in many wells.

As calgon is not agressive it can be used without damage in any type of well. The chemicals are available in granular form and storage as well as handling is very convenient.

Generally between 15 and 30 kg of calgon are used for 1000 litres of water. If clogging is supposed to occur beyond the screen, so that the solution has to be pushed into the formation, a solution of 1000 litres will not be sufficient.

In the case of a gravelpacked well a rough estimate of the required solution may be obtained on the basis of the volume of the gravelpack zone and the screen together. For example a 6 - inch dia screen of 100 ft length shrouded in a 20 - inch bore-hole requires a minimum volume of:

$$\left[\left\{ \tfrac{1}{4} \pi (d_b^2 - d_w^2) p \right\} + \tfrac{1}{4} \pi d_w^2 \right] l$$

d_b = bore-hole diameter
d_w = screen diameter
p = porosity gravelpack
l = length of screen

or in the metric system :

$$\left[\left\{ \tfrac{1}{4} \pi \left(0.5^2 - 0.15^2\right) 0.3 \right\} + \tfrac{1}{4} \pi (0.15)^2 \right] 30 = 2.14 \ m^3$$

Good results are recently obtained in Khulna by using 50 kg of Calgon. Although the addition of calcium hypochlorite or bleaching powder is recommended in litterature (lit. 2,4) the advantage of these additives did not show up in Khulna.

If frequent surging can be done the chemicals are allowed to remain in the well for 24 to 48 hours. If surging is not possible or desirable equally good results usually can be obtained without surging by allowing the Calgon charge to remain in the well for at least one week. Recent regenerations in Khulna, Kustia and Rajshahi were carried out by leaving the calgon solution 4 to 5 days in the well. Calgon is available in the open market in Bangladesh.

8.6.8 Method of introducing chemicals.

In order to obtain a suitable concentration two systems of mixing can be followed:

- preparation of a solution of desired strength before hand and replacing the original volume of the well (part of the well)
- preparation of a high concentrated solution and mixing with the water volume of the well (part of the well)

Both systems can not be observed seperately, since replacement without mixing and conversely is not possible.

Solutions which will be prepared at field strength before hand are usually from chemicals available in liquid form : hydrochloric acid, sodium hypochlorite. From other agents in solid form a higher concentration can be made and poured into the well where it mixes with the water of the well.

Introducing a highly concentrated fluid or slurry into the well has the following disadvantage :

- due to the higher specific weight seperation of fluids may occur, and consequently the chemicals will concentrate in the lower part of the screen and sand-trap.
- in case of deep wells a considerable part of the solution will remain in the conducting pipe if no proper measures are taken. (contents 1½" conducting pipe of 800 ft : 280 litres).

A disadvantages of preparation the solution before hand may be that a too weak concentration is obtained due to mixing in the screen and aquifer. Therefore a middle course may be followed.

On the basis of the results of the present regeneration programme in Khulna the following mixing procedure may be adopted : 50 kg of chemicals (Calgon, Calcium hypochlorite, Oxalic acid) in 250 -500 litres of water. The chemicals can easily be dissolved in water in 200 *l* clean oil drums.

The solution should preferably be poured into the well by $1\frac{1}{2}$ inch threaded P.V.C. pipes. The threads of these pipes must be in good condition. A funnel is required. It is recommended to introduce the solution at different depths in the well. For example one may drop one third half-way the screen, another third at the top of the screen and the last quantity some 50 - 100 ft above the screen. However, for very deep wells this system may not work, as the storage capacity of the conducting pipe will be very high. In that case one has to introduce more solution at the first stage, while the last stage should be completed by adding sufficient clear water into the conducting pipe.

Directly after pouring the chemicals a quantity of clean water may be added to the production well in order to push the regeneration fluid through the screen ($\sim$ 200 litres).

8.6.9. Physical agitation.

The chemicals should react with the incrustants or clogged material. Therefore, the treatment solution should be brought to these clogged zones and the effectiveness of the regeneration is usually improved by well agitation as described in 8.3, 8.4 and 8.5. The intensity of surging, however, depends on the type and place of clogging as well as on the introduced chemicals. For example if the clogging is located outside the screen in the gravelpack or natural formation (fig. 3.1.b) surging has to be done to push the treatment solution through the screen to the proper clogging zone. But if only the well screen is incrustated, intensive surging may waste a good deal of the chemicals through preferent, permeable zones in the screen/gravelpack. In that case it is wise to leave the solution in the screen more or less in rest.
As a common practise during the recently carried out regeneration works with calgon, oxalic acid and calcium hypochlorite, the solution was not disturbed for 12 - 24 hours.

After reinstallation of the pump surging can be exercised by putting the pump on and off without discharging water. This method may be rather effective if only the screen is incrustated and a strong oxidising agent is used (e.g. hydrochloric acid).

But if the clogging is located outside the screen, the solution inside the well should be forced into the formation/gravelpack. For that surging needs to be done by compressed air or a surge-block. It is a misunderstanding that for this type of surging a high capacity compressor is required, as no pumping by air-lift is to be done. During the first regeneration works in Khulna a high capacity compressor was hired.
A special device (fig. 5.3) was constructed to allow both surging and air-lifting. When this compressor was not available anymore a small capacity compressor (0. 286 m^3/min, max. pressure 7 bar) connected with an extra reservoir was used.

This reservoir was constructed from a 15 inch casing with a length of 10 ft. : 0.35 m^3. (fig. 8.2.). The aim of the system is to fill the reservoir up to the maximum pressure by the compressor and subsequently to release the air into the upper casing of the well which has been closed by a welded cover.

A pressure meter is installed at the top of the casing. Apart from direct reading from this meter, the rate of pushing the water level down can easily be calculated (see Annex 2)
The effectivity of surging depends more on the diameter of the casing than on the depth of the static water level. After each surge movement one has to wait about 10 minutes before the reservoir is refilled up to the desired pressure. The fastness of releasing the air depends on the degree of clogging of the well and the condition of the casings and joints. If the well is nearly chocked up a quick release of air will give a 'temporary' extra pressure in the well. This may easily damage a sand-cement or 'loose' joint. Ther fore an insight in the capacity of the well before surging is required. A well of good construction still yielding some 5.000 Igph does not face these problems.

Surging with this type of compressor was successfully carried out in many wells under regeneration. Usually the compressor was used for 4 - 6 hours a day.

8.10 Test pumping.

After the treatment a (step-drawdown) pumping test will usually be performed to determine the new condition and yield of the well.
Since the first discharge of the well after a (chemical) regeneration may be heavily polluted by reaction products, scrapings and remnants of the treatment fluid, precautions must be taken to avoid damage to the surroundings of the well. In any case the connection to the pipe-line system should be cut off.

Figure 8 1

DISCHARGE MEASUREMENTS BY ORIFICE METER

(From literature 2)

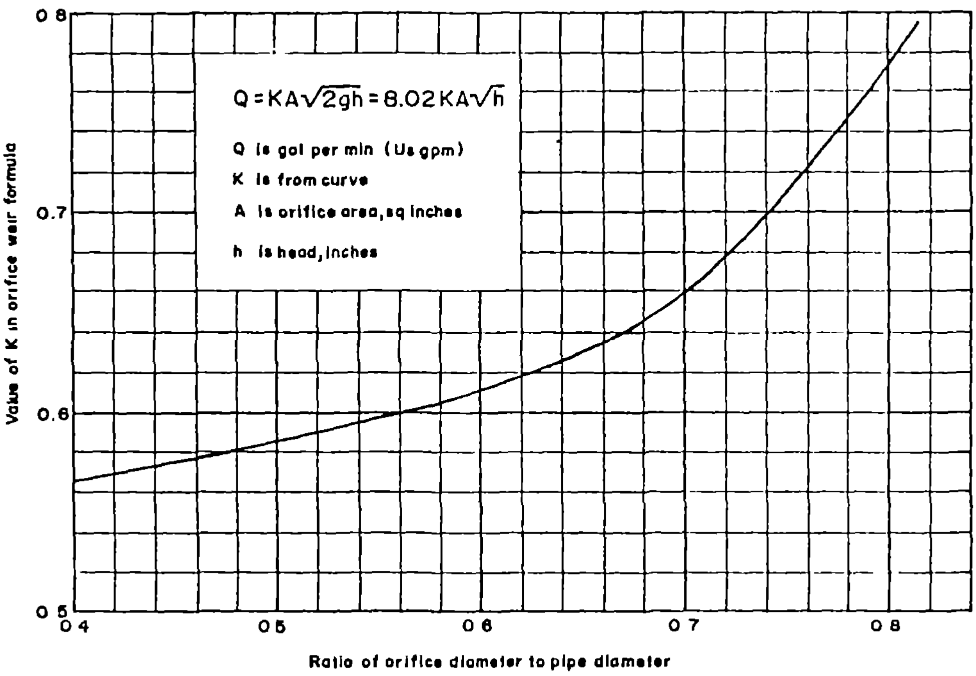


Fig. 8.1a. Graph for determining the discharge coefficient

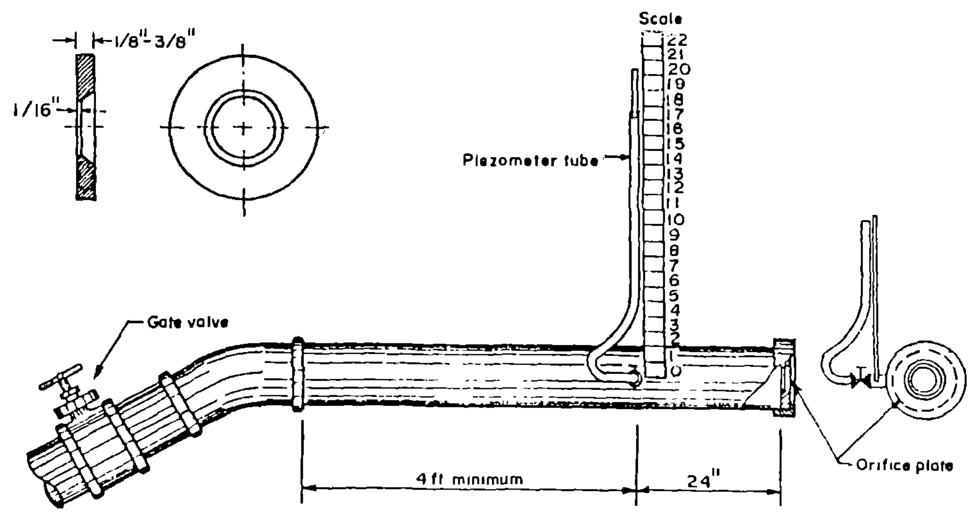
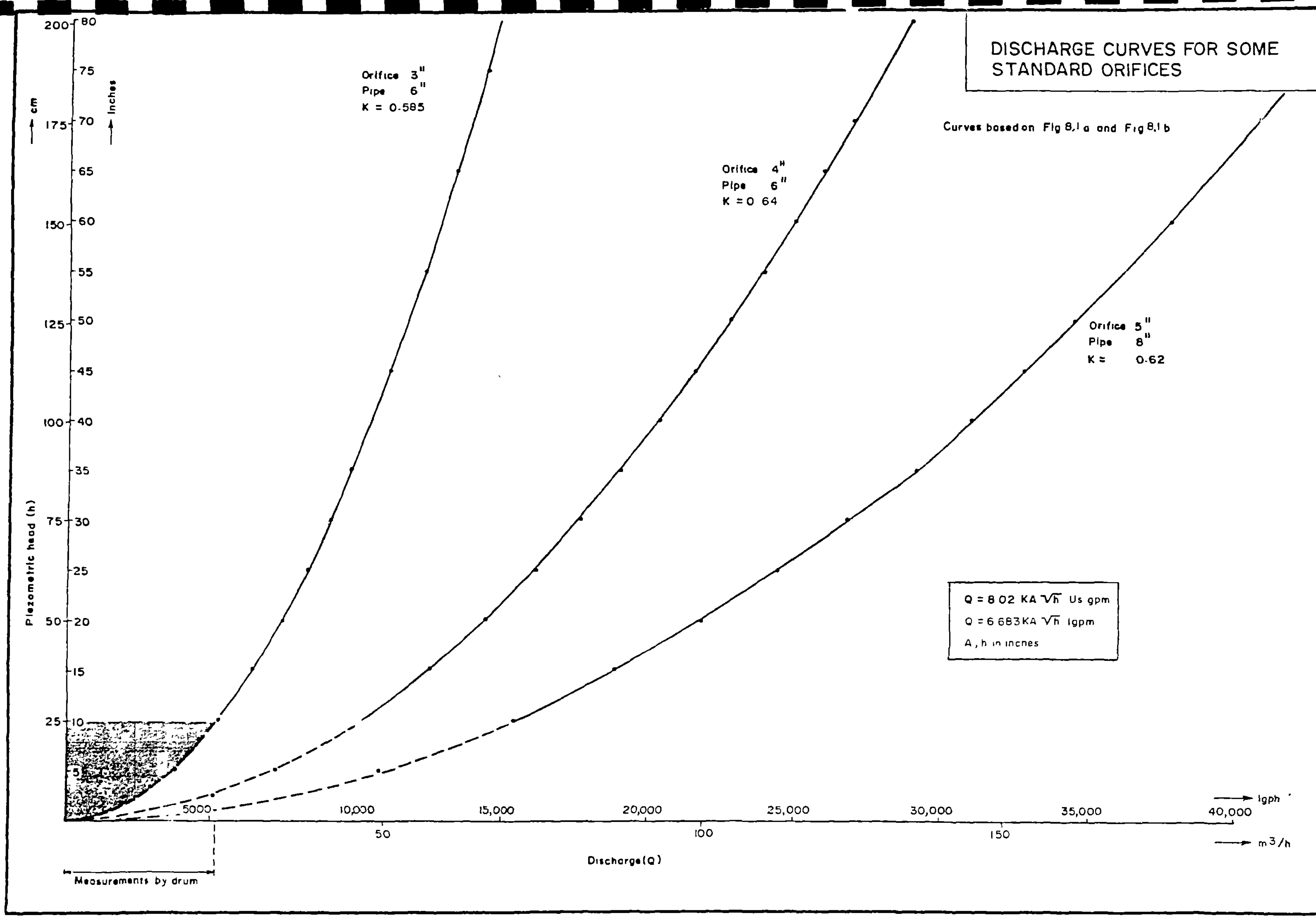


Fig. 8.1b Construction of orifice meter

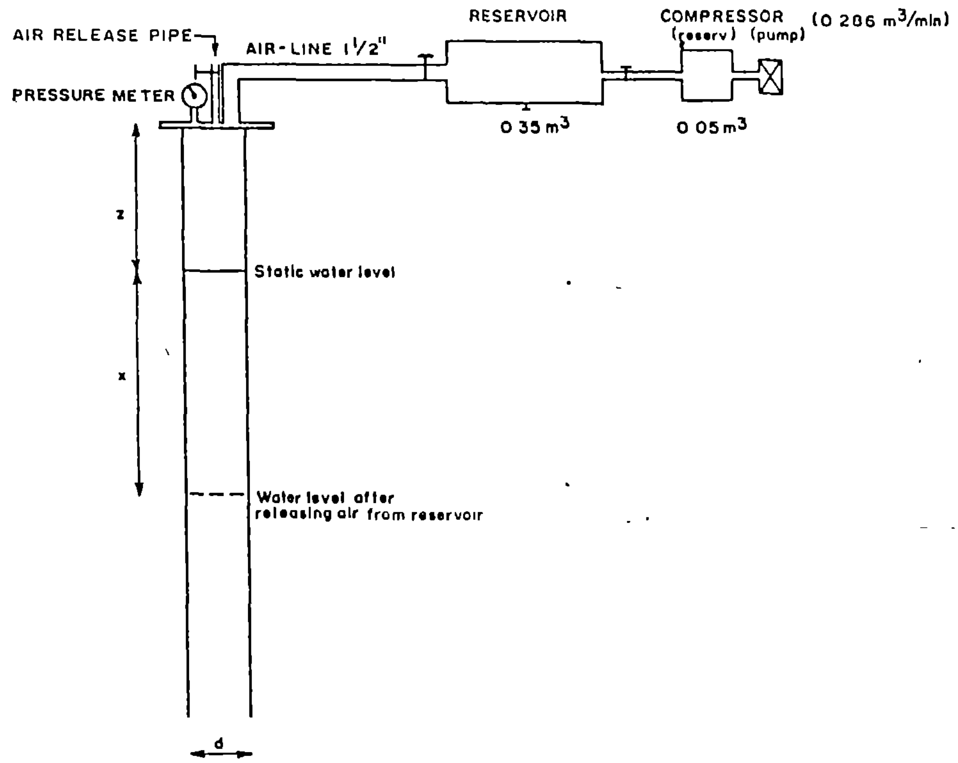


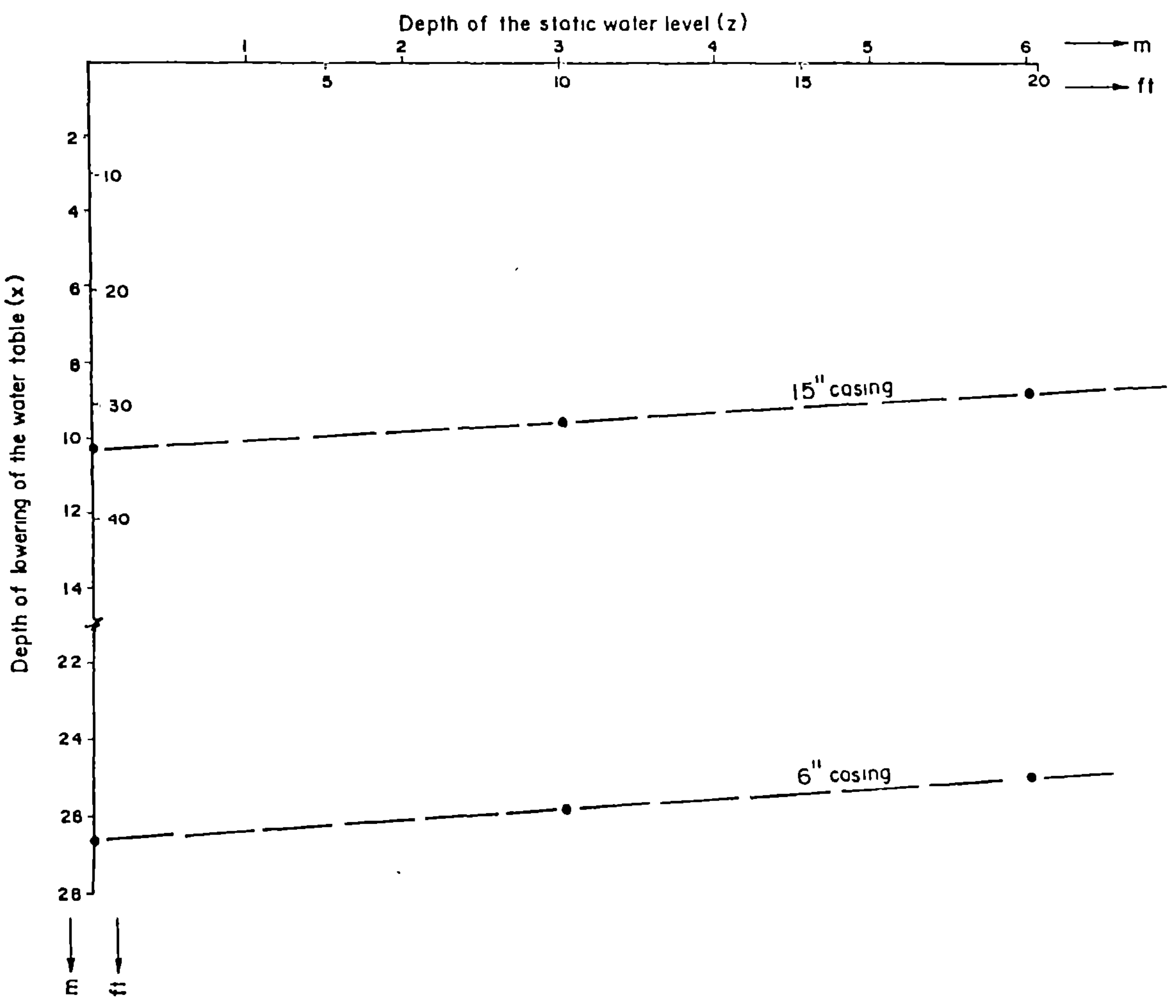
DISCHARGE CURVES FOR SOME STANDARD ORIFICES
Curves based on Fig 8.1 a and Fig 8.1 b
Orifice 3" Pipe 6" K = 0.585
Orifice 4" Pipe 6" K = 0 64
Orifice 5" Pipe 8" K = 0.62
Q = 8 02 KA √h Us gpm
Q = 6 683 KA √h Igpm
A, h in inches
Piezometric head (h)
cm
Inches
200 175 150 125 100 75 50 25
80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5
Discharge (Q)
5000 10,000 15,000 20,000 25,000 30,000 35,000 40,000 Igph
50 100 150 m3/h
Measurements by drum

Figure 8 1c

Figure 8.2

SURGING WITH SMALL CAPACITY COMPRESSOR





Accurate sampling and observation during the first time of pumping may help to get an insight in the clogging process and the way the treatment fluid reacts. Colour, sand content, scrapings and smell are indicators for that. A more scientific approach may be followed by sampling and analysing the water. The most import parameters to be determined are electrical conductivity, p^H, hardness, iron and further manganese, sulphate and bi-carbonate. The first parameters can easily be determined by field kits on the spot.

9. Cost/benefit analysis of well regeneration.

Regeneration of a 6 inch dia well by a Calgon treatment of 50 kg with the help of a small capacity compressor involves (on the average) the following costs :

- Chemicals, 50 kg Calgon at Tk. 90/- per kg	Tk.	4500/-
- Lifting and re-installation of pump	Tk.	1000/-
- Lowering $1\frac{1}{2}$ inch P.V.C. pipe mixing Calgon, pouring into the well, fixing surging equipment.	Tk.	800/-
- Surging 4 days, 5 hrs/day	Tk.	300/-
- Writing off/interest small air-compressor with reservoir (Tk. 30,000/ 20 per cent a year/ 20 wells a year)	Tk.	300/-
- Maintenance, hire charge PVC pipes, etc.	Tk.	300/-
	TAKA	= 7,200/-

Although a considerable part of the work may be executed by DPHE/Municipality, the costs are on the basis of labour/contractor charges. Nevertheless the costs of chemicals constitute a major part of the total costs. Above mentioned price of Calgon is a free market price, so that in case of bulk purchase by (international) tender a lower price may be expected.

Calcium hypochlorite costs locally about Tk. 55/kg and oxalic acid Tk. 70/kg. Treatments in Khulna were carried out with 50 kg of these chemicals, so that these types of regeneration are even cheaper than the calgon treatments.

But, since only a few tests with these chemicals are carried out, so far, it is more realistic to base the cost benefit analysis on the use of calgon. Besides, one should take into consideration the positive effect of calgon in re-development of the well, a necessity for many wells in Bangladesh.

In the begining of the well regeneration programme in Khulna a larger quantity of calgon was applied (100 - 200 kg). But later during the programme the same results were obtained by using 50 kg of Calgon. So a considerable saving.

The use of a high capacity compressor is recommendable in some cases, particularly if re-development of the well is required. On the other hand the real costs of regeneration will be considerably increased by applying that equipment:

Compressor	250 CEM/10 bar	: Tk. 800,000/-
15 per-cent a year	a year/20 wells	= Tk. 6000/-/well rega.

Regeneration of wells is found most effective when the treatment is taken up in an early stage of the deterioration process. Usually it is recommended to start regeneration if the yield has decreased to 80 - 70% of the original value.

Although some wells, in particular inproper developped wells, may be restored to their original yield, in many cases the new discharge appears less. Nevertheless regeneration lengthen the life of the well which may be presented in fig. 9.1. If the life of the well is doubled (reg. effect 50 %) from, say 12.5 to 25 years by regular regeneration every 2 years, simple economical comparison between treated and non-treated wells results:

* 6 inch well, 500 ft, stainless steel stainer	Tk. 500,000/-
12 regenerations at Tk. 7500/-	Tk. 90,000/-
	590,000/-
* 2 wells, 6 inch, 500 ft, stainless steel strainer.	Tk. 10,00,000/-

Only in case of very cheap constructions regeneration of wells may not be economically feasible.

TENTATIVE TIME-DRAWDOWN CURVES FOR WELLS UNDER REGENERATION AND NON-TREATED WELLS

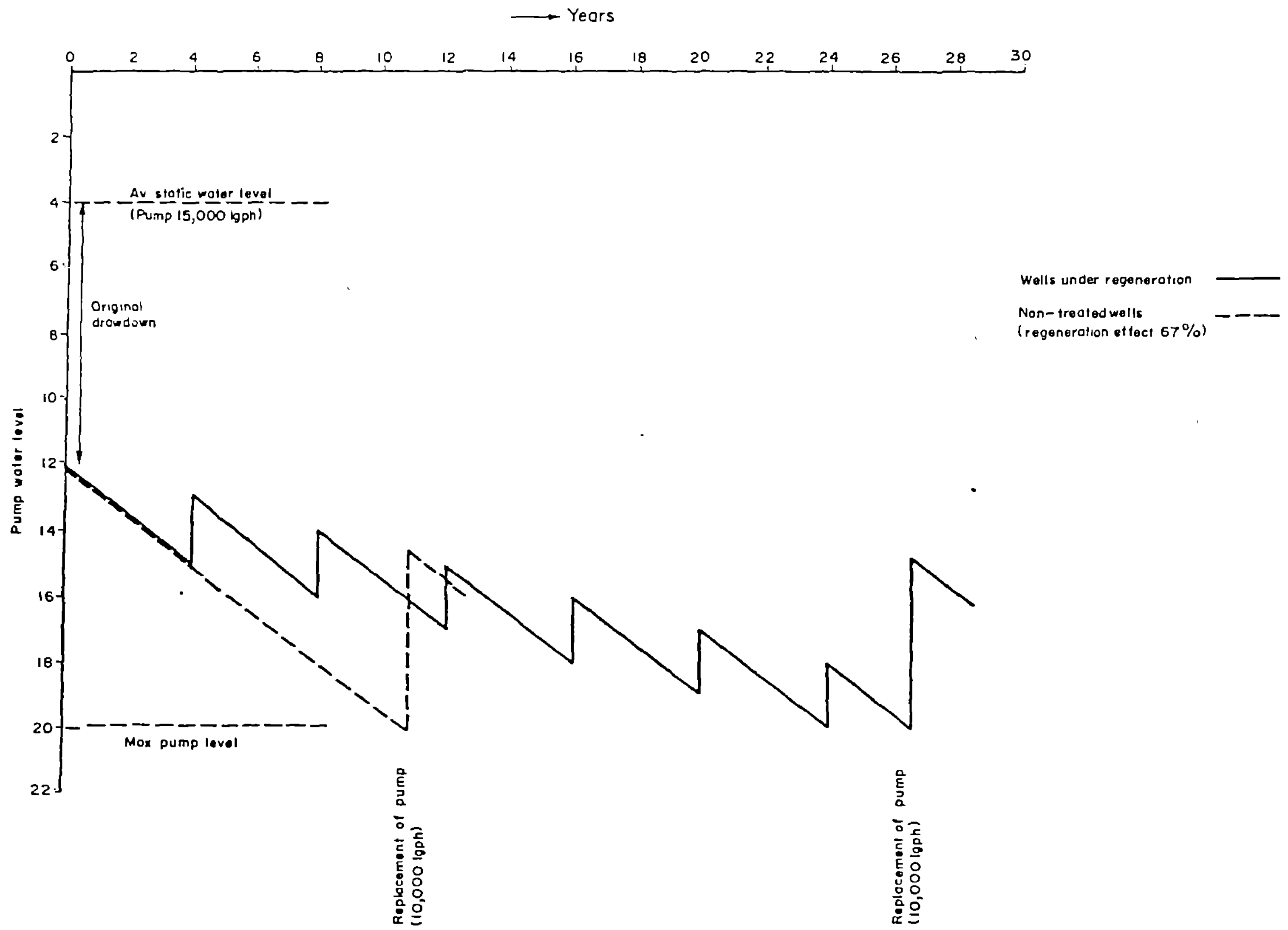


Figure 9.1

10. Consulted and recommended litterature.

1. Huisman, L., 1972. Groundwater recovery. The Mac-Millan Press Ltd, London, 336 pp.

2. Johnson, E.E., 1966. Groundwater and wells. Johnson Division, UOP INC., Saint Paul, Minnesota, 440 pp.

3. Kruseman, G.P., and N.A. de Ridder. 1970. Analysis and evaluation of pumping test data. Intern. Inst. Land Reclamation and Improvement - Bull 11, Wageningen, The Netherlands.

4. U. S. Department of The Interior. 1977. Groundwater Manual. Denver, 480 pp.

5. Notes DPHE Drinking Water Supply and Sanitation Projects:

   5.1 Note on deepwell drilling and well regeneration in Khulna Bangladesh. Rotterdam, october 1983.

   5.2 Note on well development at Ferryghat, Khulna, november, 1983.

   5.3 Note on well regeneration works of Tarerpukur pumping station, Khulna, march 1984

   5.4. Report on regeneration of the Aroapara well at Kushtia, march 1984.

   5.5 Determination of aquifer and well characteristics of tube-wells used for public water supply in Bangladesh, may 1984

   5.6 Note on well regeneration works of R.A.F camp pumping station Khulna, may 1984.

Various other papers have been consulted, among others of the KIWA - institute in the Netherlands.

Annex 1.

Conversion table.

	FPS - system to SI - system			
Length.	1 ft	=	0.3048	m
	1 mile	=	1609	km
Area.	1 ft^2	=	0.0929	m^2
	1 acre	=	4047	m^2
Volume.	1 ft^3	=	0.02832	m^3
	1 US gallon	=	3.785	litre
	1 Imp. "	=	4.546	litre
	1 US "	=	3.785×10^{-3}	m^3
	1 Imp "	=	4.546×10^{-3}	m^3
Discharge.	1 ft^3/sec	=	0.02832	m^3/sec
	1 IGPH	=	4.546×10^{-3}	m^3/h
Transmissivity.	1 Imp. gallon/ day/ ft.	=	0.01492	m^2/day
Pressure.	1 PSI	=	6.895×10^3	N/m^2 or Pa
	1 PSI	=	0.068	atm.
	1 PSI	=	6.8	m water column.
	1 atm.	=	1.013	bar
	1 atm.	=	10.1	m water column.
Salinity.	1 ppm	=	1	mg/L.

Calculation effect of compressed air.

According to the law of Boyle, the product of pressure and volume of a closed gas system is constant : P x V = constant.

The content of the compressor with additional reservoir is 0.4 m^3.
(see fig. 8.2). Having the static water level at a depth of z in an upper casing with diameter d and neglecting the volume of the jointing air pipes the following air balance can be made :

$$\frac{1}{4} \pi d^2 z P_A + 0.4 P_C = \left\{ \frac{1}{4} \pi d^2 (x + z) + 0.4 \right\} P_C$$

in which :

P_A = normal atmospherie pressure (1 bar ~ 10 m water column)
P_C = pressure in the reservoir(s) of compressor (atmospheric pressure + over_pressure)
P_R = resulting pressure in the jointed system after releasing of air.
x = the depth of lowering of the water table.

The resulting pressure P_R will be equal to the atmospheric pressure plus the amount of lowering :

$$P_R = P_A + x$$

(in m. water column)

This yields :

$$\frac{1}{4} \pi d^2 z P_A + 0.4 P_C = \left\{ \frac{1}{4} \pi d^2 (x + z) + 0.4 \right\} P_A + x$$

Example Tarerpukur well:

P_A = 10 m water column
P_C = 80 m " " (7 + 1 bar)
d = 0.38 m
z = 3 m

$$\left(\frac{1}{4} \pi (0.38)^2 \times 3 \times 10 \right) + (0.4 \times 80) = \left\{ \frac{1}{4} \pi (0.38)^2 (3 + x) + 0.4 \right\} 10 + x$$

$$35.4 = (0.113\,x + 0.74)(10 + x)$$

or

$$x^2 + 16.55\,x - 247.8 = 0$$

$$(x + 26.1)(x - 9.5) = 0$$

$$x = 9.5 \text{ m.}$$

This means that the water level can be pushed down by 9.5 m.

Reservoir filling.

The capacity of the compressor is 0.286 m^3/ min air of 1 bar,
The time of filling the reservoir will be :

$$\frac{0.4 \times 7}{0.286} = 10 \text{ minutes.}$$