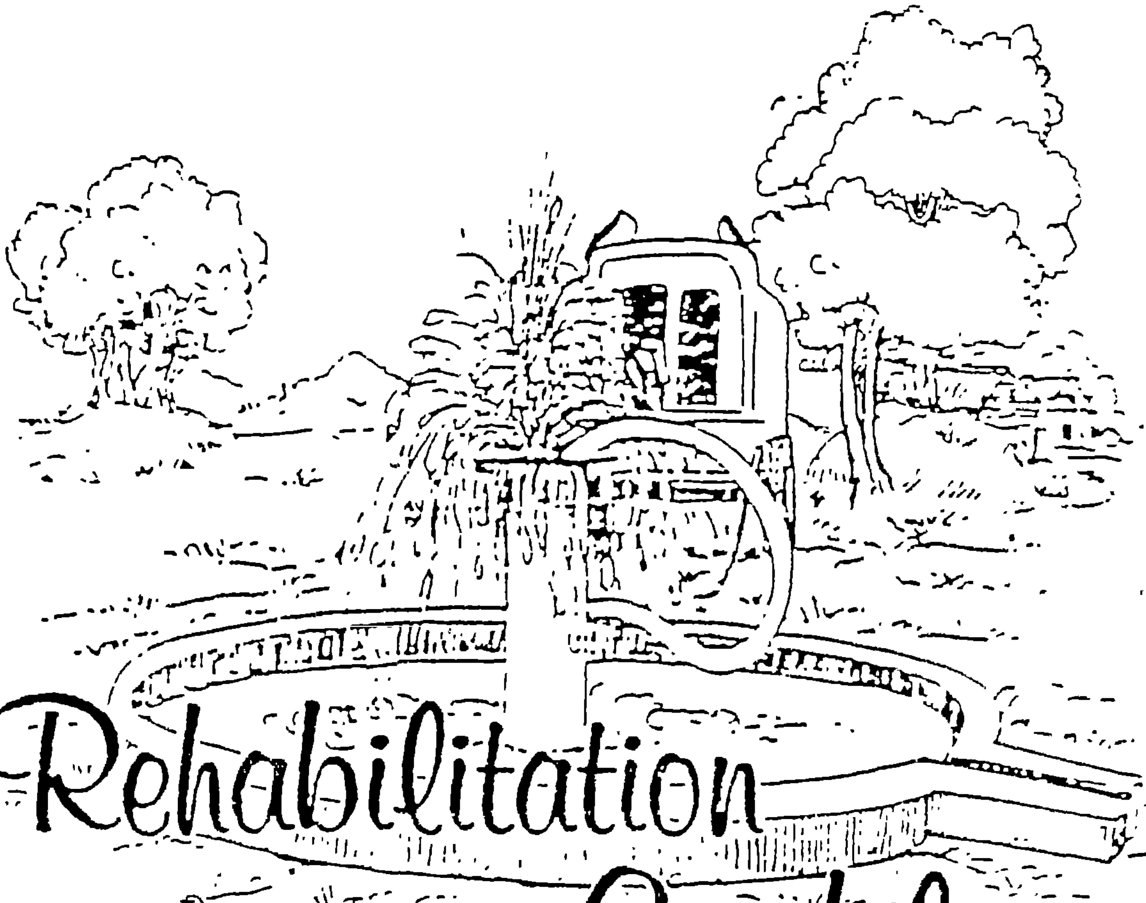

Rehabilitation Guidelines

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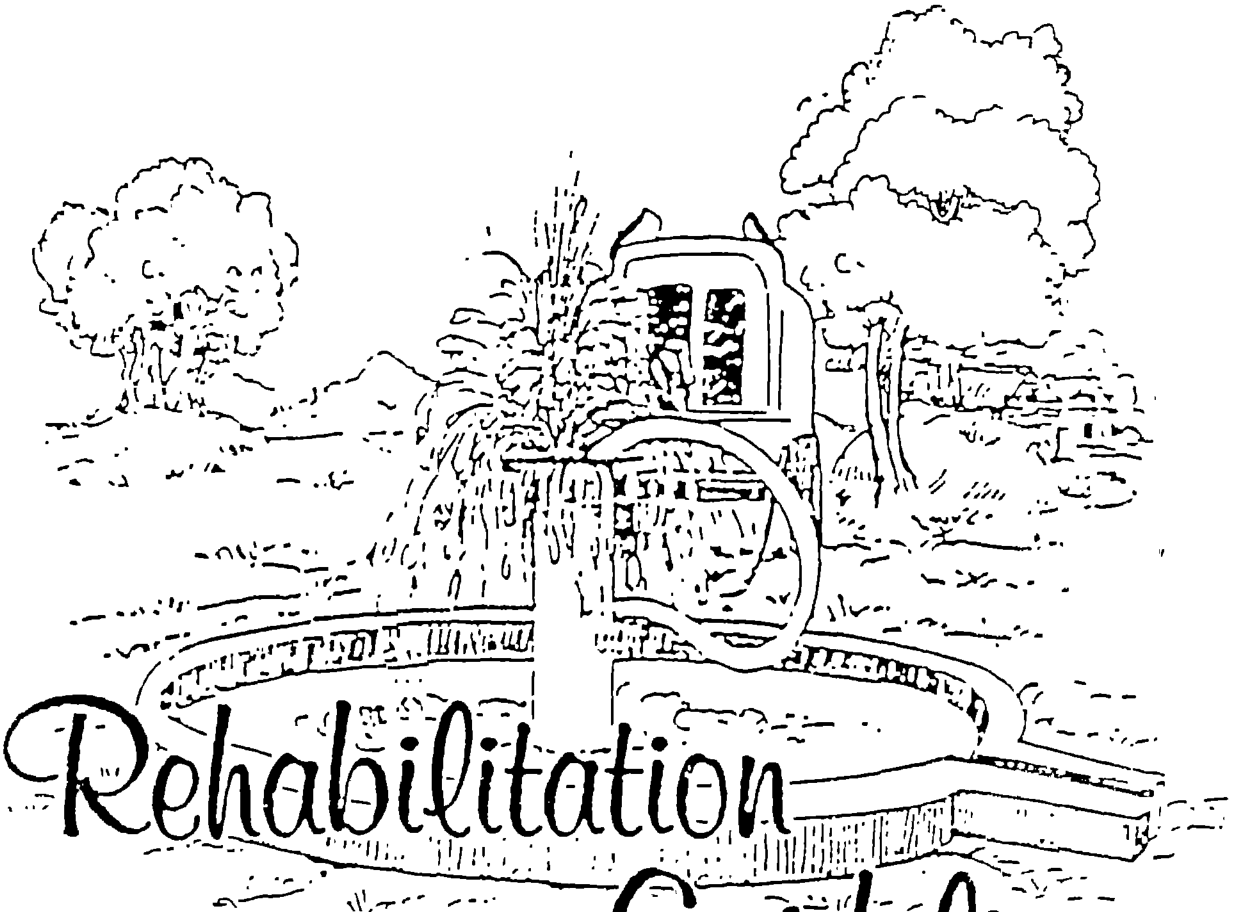

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December 91

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The Rehabilitation Guidelines have been compiled with information from many sources, both formal and informal.

Groundwater & Wells, Second Edition, by Fletcher G. Driscoll and published by Johnson's Filtration Systems Inc., USA and IS:11632-1986, Indiand Standards - Code of Practice of Rehabilitation of Tube Wells, published by the Bureau of Indian Standards, New Delhi, have provided excellent references. The principles and techniques laid down in these documents have formed the essential core of these Guidelines.

A very major contribution has come from colleagues in the Danida Project Directorate by way of field experiences and reports which have led to the formulation of field procedures that are appropriate to this project area, of assessments of successes and failures, and of data processing methods. Special mention is due to the project staff, of both the Field Division and the Maintenance Division, working in Delang block, where most rehabilitation trials have been conducted so far. Acknowledgement is also due to the data processing personnel attached to the Chief Adviser's Office of the Project.

Contributions are acknowledged from consultants to the project. Mr. L. V. R. Reddy undertook systematic rehabilitation of problem wells and provided corresponding documentation. Dr. Peter Howsam helped in conceptualisation and definiton of problem wells and proposed corresponding solutions. Dr. B. K. Handa established the current expanded field based water chemistry testing and monitoring regime.

Successive Project Directors and Chief Advisers have provided the institutional and managerial support to continue rehabilitation attempts since 1988, without which the compilation of these Guidelines would not have been possible.

By no means are the Guidelines complete or comprehensive as yet, even for the needs of this Project. Acknowledgement is due to those who have commented on it at different stages of its compliation. It is hoped that such feed back will continue to come from those who read these Guidelines and use them, in order to improve subsequent versions of this document.

13th. December 1991
Bhubaneshwar

Raj Kumar Daw
Maintenance Adviser
Danida Project Directorate

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Annexures

1 Preliminary Data Assessment:

1.1 Status Survey data, results of earlier water quality analysis, well drilling data and earlier rehabilitation efforts show that some Gram Panchayats in different blocks of the project have a very high incidence of problem wells. This data will be
* examined* to verify if there are consistent patterns of water quality related problems in relation to area, well depth and other factors.

1.2 For this purpose, past records of tube wells (drilling, geological, geophysical, water quality tests, maintenance, functionality) will have to be brought together in the Data Bank and analysed. This comprehensive data processing has been partially achieved by accessing original well construction data and correlating it with Status Survey Data.

1.3 Gram Panchayats with a high incidence of problem
* wells will need* detailed comments and reinterpretation of hydrogeological and hydrochemical data to determine nature of specific hydrogeological, hydrochemical or well construction problems to be anticipated in that geographic area.

1.4 With such integrated data interpretation, the need for "saturation rehabilitation" (meaning rehabilitation of every well in a GP with a high percentage of problem well occurrence, whether an individual well in that GP shows a problem or not)
* will be evaluated*. The following flow chart in Fig.1 attempts to detail the above process and to outline how rehabilitation may be implemented in the Project.

1.5 Rehabilitation of a well shall attempt to restore the well to its original drilled/cased depth, restore/ improve the water quality from the well, restore the yield of the well to support the use of a hand pump and rejuvenate the pump installation, using non-corrodible components where ever necessary; painting and numbering the pump and repairing the platform and drain. The eventual aim of the rehabilitation programme is to bring the well to a level so as to maximise its level of utilisation by potential users.

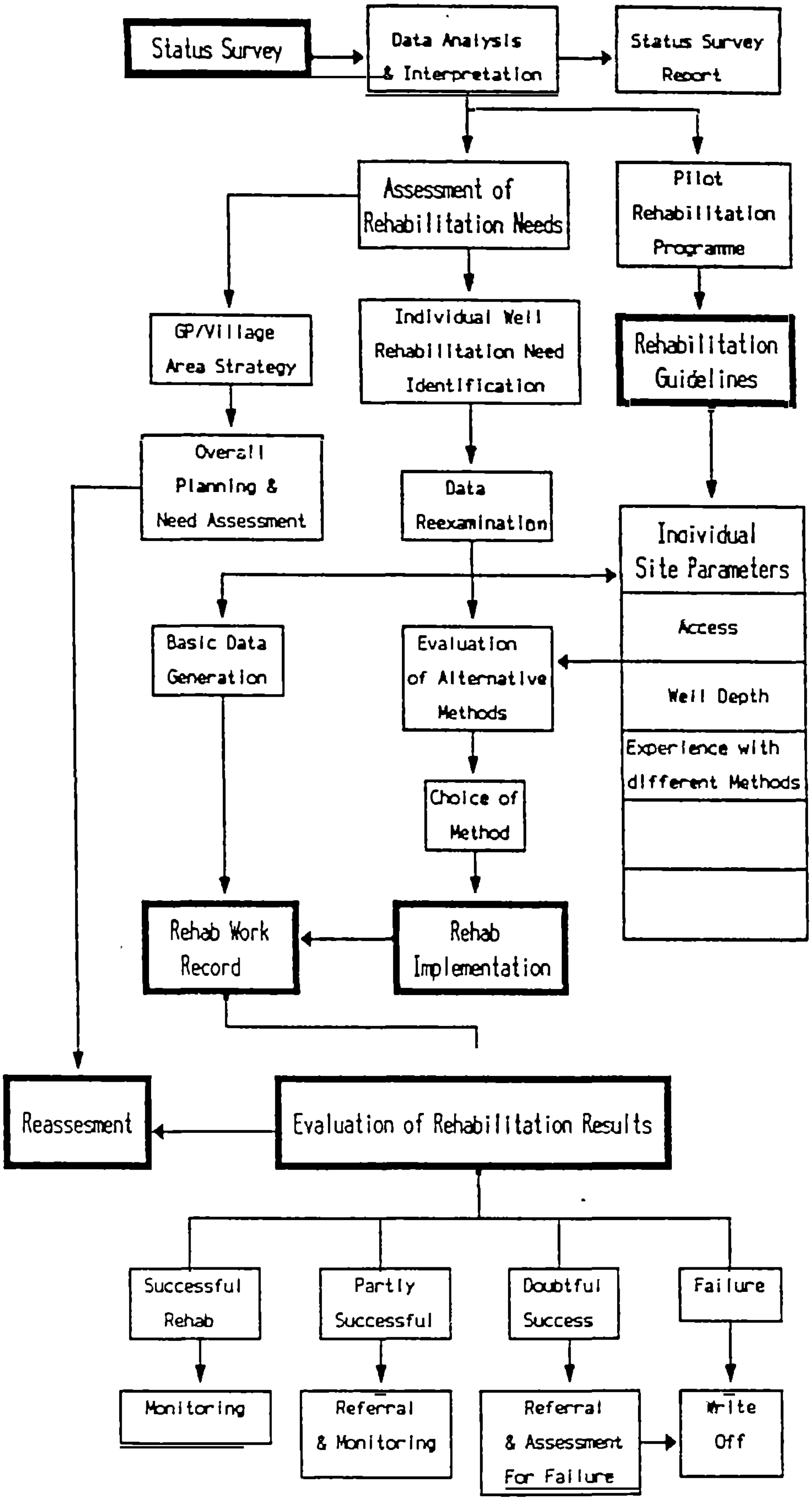


Fig. 1 : Rehabilitation Implementation Process

2 Rehabilitation Work Record :

2.1 Where rehabilitation is to be attempted, a record of the basic data of each well with well construction data, Status Survey Data and other information will be initiated* as the base line field record for undertaking well rehabilitation. Further, a work record of each well where rehabilitation is attempted shall be prepared by the group (Division/Sub-division) undertaking the rehabilitation of a well. The consolidated document containing the basic data and the field work data shall constitute the Rehabilitation Work Record for that well. A draft Work Record is annexed to these Guidelines.

*

3 Field Procedures:

3.1 Field Procedures - First Stage :

The following sequence of preparatory activities will be followed for individual wells identified for rehabilitation :

1. The hand pump will be removed by the concerned JE and a pump removal record will be completed to note the condition of the pump as it is removed.

2. With the Work Schedule record as the point of reference, the depth of the well will measured by plumbing to verify if substantial sedimentation has occurred or if the expected screen area is free. Different sizes of the plumb diameters can be used to locate the Reducer Socket level above which the Upper Well Casing is expected to be 125 mm or 100 mm in diameter and below which the Lower Well Casing and Screen of 50 mm dia. is expected. Under normal circumstances, a blank pipe of 2 m length is the lowest piece in the casing assembly, above which a screen length of 4 m is to be expected.

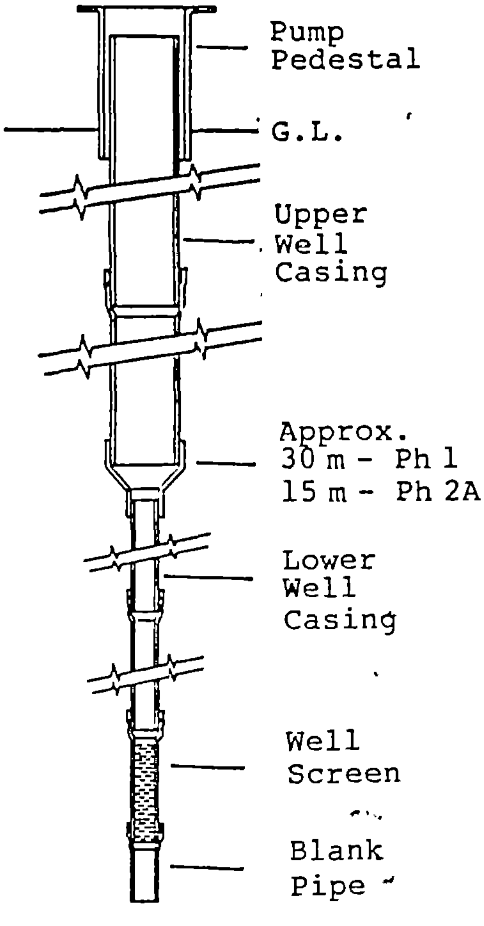


Fig.2 : General Casing Configuration

Fig.2 gives the general layout of the casing assembly of the tube wells constructed by the project. This configuration is not be expected in "Rejuvenated" wells, where basic well records will generally not be available.

3. If the plumbing probe does not reach to within 6 m from the recorded depth of the well, it is an indication that sedimentation has occurred in the well to the extent that the screen area is not free. In the extreme, it could also indicate that debris has fallen into the well, there could be an obstruction or a casing break has led to the entry of formation material into the well.

4. In such cases where the screen area is not free, the screen area will be cleaned by over pumping or water injection alternating with over pumping (in that order of feasibility and depending upon well depth using pumps or air-lifting). Hand operated means such as over-pumping with Tara DA pumps, hand sludging, water injection-cum-over pumping with Donkey pumps should also be attempted, especially in inaccessible sites. The debris coming from the well in the initial cleaning should be examined, collected where they are significant, and immediately labelled indicating date, site and circumstances in which they were collected. Attempts to clean and reach the well screen depth would indicate whether a well has actually sedimented excessively (as compared to the plumbing observation)

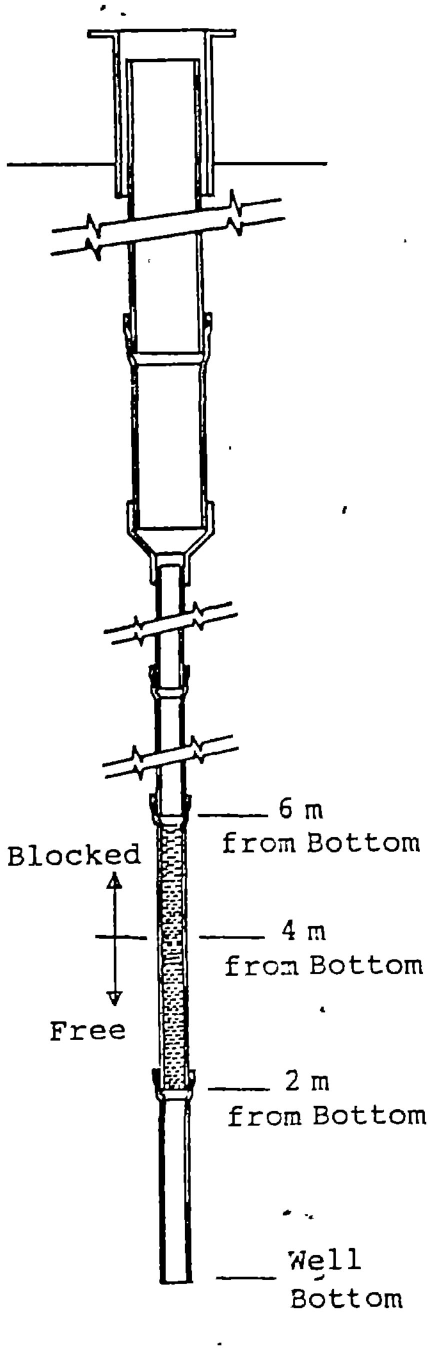


Fig. 3 : Free & Blocked Casing

or whether the screen area has remained free of obstruction.

5. Absence of initial sedimentation (or partial sedimentation in the screen area) or an easy access to the screen depth would be the first indication of a potentially successful rehabilitation. As a point of reference and for a quantitative guideline, 50% of the screen length becoming free should be considered as "adequate" for the next stage of rehabilitation. This means that well depth measurement before or after the preliminary cleaning should not be less by more than 4 m of the recorded well depth for the screen to be "adequately" free. This has been illustrated in Fig.3.

6. Inability to reach the stated well depth and screen area must be clearly recorded. This would be an automatic condition for "less than satisfactory" rehabilitation on the criterion of well depth. Such wells will be referred to WRD* for an opinion and significant sediments collected from the well should forwarded to WRD along with a description of the field observations.

7. Further steps of rehabilitation of wells with "adequately" free screen area or "blocked" screen area have been discussed later.

3.2 Field Procedures - Second Stage:

1. Where the screen area becomes "adequately" free before or after the above preparatory procedures, sterilising chemicals like Sodium Hypochlorite (Na OCl) shall be placed at the screen depth with a drop pipe. The details for application of chemicals has been outlined separately in "Procedure for Chemical Treatment".

2. Emulsifying chemicals like Sodium Tripolyphosphate (STP) will be applied ONLY in wells with low yield reports, where sedimentation is not easily dislodged in the initial cleaning, and where the well depth is measured to indicate that the screen area is blocked as indicated in Fig. 2. The application of STP is being discouraged because the application of such emulsifying/dispersing chemicals rehabilitation is said to accelerate bacteriological activity leading to biofouling. This issue will have to resolved separately later with a microbiologist's opinion.

3. For accelerating the process of penetration of chemicals in the formation, the alternative method now used is to gradually pour water into the well

from the top so that the chemicals in the screen area will be carried into the formation as the water level in the well recedes to its SWL. This is a method recommended both in the book Groundwater & Wells and IS:11632-1986 on rehabilitation of wells. Relevant portions of both these documents are copied and attached to these Guidelines.

4. After application of chemicals, agitation of water in the well is necessary to increase the extent of sterilising emulsifying actions of the chemicals.

5. Where sites can be reached by compressors, agitation can be effectively done by using and air line to lift the water column in the well and then by allowing it to drop suddenly by shutting off the air (as suggested in Groundwater & Wells). However, it must remembered that water is not to be pumped out of the well for achieving agitation. It is only to be lifted and dropped repeatedly by turning on and turning off the compressor.

6. When sites cannot be reached by compressors, movement of the chemicals in the formation by agitation shall be attempted by using a surge plunger. This can be done by using the Tara DA pump's riser pipes and pump rods with the piston reversed or by using a wooden cylindrical block in the lower well screen (just below the Reducer Socket) with the Tara pump's rods. The buoyancy of the hollow PVC rods of the Tara

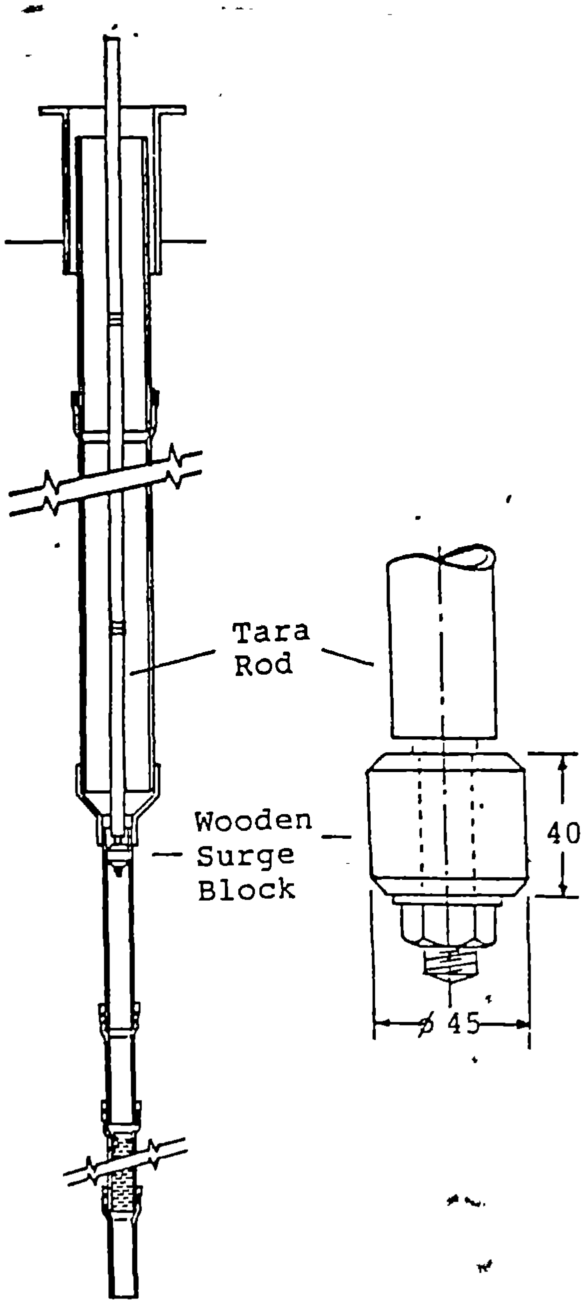


Fig. 4 : Using a Wooden Surge Plunger with Tara Rods

pump make it very easy to handle and decrease the effort needed for operation of the surge plunger. So far,development of a surge plunger to be used in the upper well casing has not been satisfactory.

7. After application of chemicals and agitation for atleast 30 minutes by any method, the well will be capped and allowed to stand overnight.

3.3 Field Procedures - Third Stage:

1. The well will be dewatered, cleaned and redeveloped by air-lifting, over pumping or by an alternating a sequence of water injection followed by over pumping, till the water coming from the well is adequate in quantity, clear and free from residual chlorine. Assuming the achievement of these results, the well depth will again be measured and recorded.

2. The application of mechanised or powered techniques will depend upon the accessibility of each site and the availability of equipment. The air-lift method using compressors can be used for surging, over pumping and yield estimation. The technique of air-lifting has been explained in excellent detail in Groundwater & Wells, from which the relevant chapter has been copied and annexed.

3. Manual methods of cleaning such as hand sludging, surge plunger application, Donkey pump and Tara pump use for sediment removal, agitation, water injection or over pumping will be applied in cases when sites are inaccessible to mechanised equipment. Hand sludging and surge plunger use is to be favoured when low yields or prolonged discharge of fine grained aquifer material is observed or when sediments to not dislodge easily. Surging equipment for such applications have still to be developed.

4. Yield estimation of selected rehabilitated wells will be made, especially where low yield was a reported problem or observed during rehabilitation. Air-lifting or test pumping techniques to draw water and yield measurement over a V Notch have to be used depending upon the site conditions.

5. Rehabilitation will be considered initially successful when :

   - When water pumped from the well shows no traces of residual chlorine.

- When clear water is continuously delivered from the well for at least 30 minutes at a rate of at least 15 lpm (hand pump discharge is 12 lpm) by the rehabilitation pumping method (not by a separate hand pump) at the end of the well cleaning sequence.

- When the post-rehabilitation well depth measurement indicated that the well screen area is "adequately" free.

6. On the assumption that rehabilitation is successful by the above criteria, the "successfully rehabilitated well" will be fitted with an appropriate hand pump. At the very least, the old pump will be thoroughly overhauled before refitting. Most rehabilitated wells will be fitted with non-corrodible below-ground pump components. Finally, pumps on rehabilitated wells will be repainted, and the last two digits (pump number) of the registration number of the pump will be also be painted in a different colour, in large letters on the pump pedestal.

7. In case waste water disposal has been recorded as a definite problem in the Status Survey, the site will be referred to SED for an alternative waste water disposal specification, especially in cases where the original waste water disposal path has been changed by the users. In cases of drains that are suitably oriented but are in need of repair, in such cases the drains should be repaired or reconstructed directly with intimation to SED.

8. After reinstallation of a hand pump on a rehabilitated well, an on-site observation of water chemistry (and later, microbiology) will be made, preferably within two to three days, to establish the post-rehabilitation water chemistry base line data. For this purpose the Laboratory will need advance information on rehabilitation work programmes in order for the Chemists to draw and test samples of rehabilitated wells.

9. The restoration of potability of water from a rehabilitated well will be an important yardstick for measurement of rehabilitation results. This will be assessed by quantitative and qualitative comparisons of hydrochemical (and microbiological) parameters of the rehabilitated well immediately after rehabilitation against standards set in IS:10500-1983. The chemical parameters will be gradually defined for rehabilitation purposes but will follow the principle of in-situ observations of the Status Survey.

10. Field work records will be maintained in prescribed forms as a part of the Rehabilitation Work Schedule. These Work Schedules will be returned to the PMD* immediately upon completion of work on a well.

4 Rehabilitation Approach vis-a-vis Well Depth:

4.1 Wells that are less than 45 m deep and accessible to compressors will be scheduled for cleaning by air-lift redevelopment. 47 wells were rehabilitated by this method, with a fair degree of success during March - June 91, thereby establishing the applicability of the air-lift method of well cleaning and over-pumping in shallow wells. A detailed report on these 47 wells is available separately.

4.2 Deeper wells will need compressors with higher operating pressure (up to 10 bar) and jet, submersible or centrifugal pumps for over pumping and/or back-washing. The application of high pressure (about 8 to 10 bar) in deeper wells (beyond 100 m depth) has to be carefully monitored in order to reduced the possibility of casing failure by formation pressure if the over pumping is high enough to empty a well and create a substantial difference in head to the point of collapse of the well screen. Different methods of back-washing, over pumping, surging have still to be attempted to make the strainer area accessible for placement of sterilising chemicals. A reduction of up-hole velocity in the upper well casing is to be expected due to the increase in the casing cross-sectional area from 50 mm dia to 125 mm dia. The modified use of the "Eductor Pipe" principle, using Tara pump riser pipes may prevent velocity drop and thus improve the efficiency of removal of sediments and water during over pumping.

4.3 If the strainer area becomes accessible, the placement of chemicals and further well cleaning will follow the procedures outlined earlier in 3.2 and 3.3.

5 Rehabilitation Approach vis-a-vis Status Survey Findings:

5.1 The strategy for rehabilitation should be based on the findings of the Status Survey. In some cases the strategy will not simply be a choice of if and how to rehabilitate or replace the tube wells, but it will be necessary to consider alternative options.

5.2 The Analytical methodology used for processing the data from the Status Survey is annexed separately.

To briefly explain this methodology; three main parameters have been assessed in the Status Survey.

- Usage of the Pump
- Water Chemistry
- Pump condition (including Yield & Waste Water Disposal)

Each of these three parameters have then been classified as GOOD, POOR and BAD.

Table 1 below gives the Rehabilitation Need in very generalised terms, for each classification of each parameter.

Table 1 : Generalised Rehabilitation Need Assessment

Parameter	Category		
	Good	Poor	Bad
Usage	NA	RA	RA+FO
Water Chemistry	NA	WC	WC+WR
Pump Condition	NA	RP	WC+WR/WWA/ CR+WRD

Explanation of Abbreviations used in Table 1, above:

1. NA : No Action
2. RA : Assessment of Reason for Rejection
3. WC : Well Cleaning
4. RP : Rectification or Replacement of Pump
5. RA+FO : Rejection Reason Assessment + Follow up
6. WC+WR : Well Cleaning + Referral to Water Resource Division
7. WWA : Waste Water Alternative necessary
8. CR+WR : Complex Rehabilitation + WRD Referral
9. FL : Failure consideration

6 Rehabilitation Approach vis-a-vis Types of Problems:

6.1 Problem wells needing rehabilitation so far have shown the following types of problems:

1. Unacceptable Iron Content
2. Unacceptable Salinity
3. Unacceptable Yield
4. Unacceptable Taste
5. Unacceptable Odour
6. Unacceptable Colour
7. Unacceptable Waste Water Disposal
8. Unacceptable Pump Condition

The options available for tackling each of the above problems are outlined below.

6.2 Unacceptable Iron Content : The indications of unacceptable iron in the well water will be available from the water chemistry observations at the time of the Status Survey. The options are to abandon well or to rehabilitate it with the possibility of an iron removal plant at some point in future. If rehabilitation is attempted on such wells, then all below-ground pump parts must be replaced with non-corrodible components.

The Project's and wider experience indicate the following to be effective solutions:

1. Testing for iron bacteria (using a BART Test Kit) is necessary. If bacteria present, treat tube well with sodium hypochlorite and replace all down-hole pump parts with PVC/SS components. This will reduce but not remove the problem and therefore regular maintenance, i.e. cleaning and sodium hypochlorite treatment may be required. This problem can be reduced by minimising the development of the aerobic/anaerobic interface within the pump/well.

2. Test for sulphate-reducing bacteria (using a BART Test Kit). If bacteria present, replace all down-hole pump parts with PVC/SS components after treating the tubewell with sodium hypochlorite.

6.3 Unacceptable salinity : Assessment, primarily by geophysical logging, is to be done to identify the source of salinity. If the saline water is found to be entering the well via the screened part of the aquifer, then the only option is to abandon the well. If it is found to be entering the well via casing joints/breaks, then, if it is occurring within the

upper well casing, it is technically possible to seal the leakage points. However, this option should not be considered until pilot trials are conducted to assess the ease of application and effectiveness of sealing. Furthermore, considering the difficulties, effort and the high possibility that the work will not be successful, rehabilitation may not be a feasible option in the cases of salinity due to leaking casing.

If the salinity increase is accompanied by a reduction in yield, which in turn is found/assumed to be due to a clogged screen and/or a filled up screen/casing then cleaning of the well by procedures outlined in Section 3 above, may result in reduced salinity levels and increase in yield. However, it is likely that in such cases, repeated rehabilitation/ maintenance will be required.

6.4 **Unacceptable Yield** : This is assessed by a physical measurement and/or from users' experience. Firstly, the pump must be good operational condition. The next check is to ascertain whether casing/screen is filled up with sediment. If so, then the well has to cleaned out using methods outlined in Section 3. If the clogging suspected to be within the gravel pack and/or at the borehole surface, then attempt development using STP combined with physical methods such as surging and airlift pumping have to be attempted. Again, this problem is likely to re-occur and the well will then require regular cleaning.

6.5 **Unacceptable Taste**

1. If this is due to iron, then proceed as in 6.2.
2. If it is due to hydrogen sulphide then proceed as in 6.2, except that hydrogen sulphide should be measured instead of iron.
3. If it is due to salinity then proceed as in 6.3.
4. If it is due to other causes, check and remedy, if possible, any surface water pollution to the well, otherwise abandon.

6.6 **Unacceptable Odour** : This would probably be due hydrogen sulphide and 'other causes'. Approach as for taste problems in 6.2.

6.7 **Unacceptable Colour:**

1. If this is due to iron then proceed as in 6.2.

2. If it is due to fine/colloidal clay particles, then geophysical logging could be used to verify if screen section is placed in a clay or sand layer.

   - In the former case, i.e. clay, the well has to be abandoned.

   - In the later case, i.e. sand, the well needs to be developed using STP together with physical agitation by water jetting, or by airlift surging/pumping or by using surge block.

3. If the problem is due to fine sand or other formation particles:

   - For sand, the grain size has to be checked and if found smaller than screen slot size then the formation around the screen has to be developed in order to remove the fine material from around the screen area and form a natural filter.

   - If the sand grain are larger, it is indication of a casing/joint break, in which case the well should probably be abandoned.

   - For corrosion-derived iron particles, all below-ground pump parts will need to be replaced with non-corrodible components.

6.8 **Unacceptable Waste Water Disposal:**

This problem could have arisen for a number of reasons:

- The original waste water disposal specification was not followed.

- The original waste water disposal specification was followed but was changed by some of the users.

- The original waste water disposal specification was followed but has gradually deteriorated.

In each of these cases, very close interaction is needed between the Project (SED) and the users. If an acceptable alternative solution emerges then it must be implemented immediately.

If an acceptable solution does not emerge, the extreme possibility of sealing off such a well should not be ruled out if the situation warrants this.

7 Rehabilitation Specifications, Successes, Difficult Cases & Failures:

7.1 The implementation of the above guidelines detailed in Sections 3, 4 and 5 above will lead to the development of Well Rehabilitation Specifications for problem wells where the chances of successful rehabilitation is high as well.

7.2 In following the above sequences, there will a number of wells where the first attempts of rehabilitation will not yield satisfactory results.

7.2 Also, the procedure of identifying wells and GPs where the probability of success of rehabilitation is high, will automatically generate an identification of GPs and rehabilitation cases which may be potentially difficult.

7.3 A systematic identification of such cases, followed by closely monitored attempts to rehabilitate such wells has to be attempted. The measures propose in Section 6 above (based upon suggestions of the Appraisal Mission of Dec. 90) would be particularly relevant.

7.4 There will emerge a group of wells where repeated rehabilitation efforts will still not have resulted in successful rehabilitation. This group will lead to the formulation of failure criteria for rehabilitation.

7.5 Any tube well that has not been successfully rehabilitated or has been rejected by users after successful "technical" rehabilitation or is defined as not worth attempting rehabilitation, must be backfilled and sealed to prevent contamination and intermixing of groundwater (backfilling or sealing by cement or cement + bentonite or bentonite with or without local clays where suitable) Casing string and screen to be retrieved wherever feasible.

8 Monitoring :

8.1 Any tube well that has undergone rehabilitation should be monitored to assess the degree and duration of the effectiveness of the rehabilitation.

The essential components of the monitoring of rehabilitation are detailed below.

8.2 **Assessment of Initial Rehabilitation Results :** Periodical review of the results emerging from rehabilitation of problem wells on the basis of restoration/improvement of well depth, water chemistry and pump/well condition must be made in the form of reports with presentation of data of the 3 Status Survey parameters, i.e., utilisation, water chemistry and pump performance. Apart from resulting in a better understanding of the phenomenon of "problem wells', it will also lead to an evolution of the monitoring strategy itself for application on the larger rehabilitation programme.

8.3 **Time related behaviour of water quality after rehabilitation :** While initial rehabilitation results may be successful in the first instance, technical rehabilitation should be considered successful if the phenomenon of deterioration of water quality can be retarded, if not eliminated. This can be done by chemical analysis of water samples on a basis similar to the Status Survey. Such analysis should be done for all wells just after completion of rehabilitation and then at least on a quarterly schedule.

As the numbers of wells getting rehabilitated will gradually keep increasing, it will be necessary to reduce the number of wells being constantly monitored. A methodology for monitoring a limited number of wells will have to be formulated. It will also be necessary to conduct analysis of a limited number of samples for a larger number of chemical parameters. The introduction of microbiological testing must also occur at some point of time in future since it is to be expected that some rehabilitated wells will again deteriorate with time.

The evolution of the water chemistry and microbiology monitoring regime can not be clearly formulated now and will take shape as experience is gathered.

8.4 Pump Performance : The monitoring of performance of pumps will be mainly through the existing maintenance system monitoring by JEs and FOs with additional attention from MD HQ since some new configurations of

pumps will be installed. Water level measurements, pump discharge performance, pump leakage detection will be the three main technical criteria to be monitored.

8.5 Usage Assessment : The maintenance system will give the first indications of changes in utilisation patterns after rehabilitation. This can be substantiated by periodical Utilisation Studies by SED on a sample basis to obtain a representative coverage. SED will need to formulate criteria for identifying the sample of pumps that will be subject to periodical utilisation studies.

Secondly, utilisation reassessment will be needed for wells showing low utilisation due to unsatisfactory rehabilitation, deterioration after rehabilitation and lastly due to social rejection.

8.6 Data Processing : The above monitoring will result in a vast volume of data which have to be continuously updated and processed in order to give management indicators about the direction in which rehabilitation is progressing.

Annexure 1

Procedure for Chemical Treatment

Before well cleaning or redevelopment, the tube well needs to be chemically treated for sterilising the well against bacterial growth that may have occurred. The chemical commonly used is Sodium Hypochlorite in combination with Sodium Carbonate. The specific functions of these chemicals are as follows:

1.1 Sodium Hypochlorite (NaOCl) is particularly effective for well sterilisation, especially in wells containing organisms like Sulphate reducing bacteria, and Iron bacteria. The Chlorine concentration required in the well is 1000 ppm. To obtain this concentration, the following formula is useful:

$$\text{Weight of NaOCl (Kg)} = \text{Volume of water in well (liters)} \times \frac{\text{Desired Concentration}}{\text{Concentration of Cl in Sterilant}}$$

If available Chlorine in Sodium Hypochlorite solution is 5.25 %, then :

$$\text{Weight of NaOCl (Kg)} = \text{Volume of water in well (liters)} \times \frac{0.001}{0.0525}$$

1.2 Sodium Carbonate (Na_2CO_3) is used as a wetting agent (ref: Pg.4, item 7.1, IS:11632-1986)along with the use of Phosphates which are sometimes glassy. The use of 1 Kg. of Sodium Carbonate is recommended per 400 liters of water in the well.

1.3 Sodium Tripolyphosphate - STP ($Na_5P_3O_{10}$) is effective for removal of Bentonite stresses and clay particles from the formation and will help in dispersing the remanent of drilling mud around the well screen area. The recommended usage is 3.5 Kg. to 4.5 Kg. per 400 liters of water in the well. This chemical will be used only in the cases of low yielding wells. STP can be applied in the well by first mixing it with Calcium Carbonate in warm water then adding Sodium Hypochlorite to the suspension.

2. Application of Sodium Hypochlorite & its Removal:

Step 1: The calculated quantity of Sodium Hypochlorite is mixed in a plastic bucket of 15 liters capacity, with water and is stirred well. The person mixing the solution should

use gloves and cover his face with a cloth against the strong smell of chlorine gas that comes from this chemical.

Fig. 5 : Mixing & Application of Chemicals

Step 2: The solution is diluted with 5 times its volume of water and injected at the strainer depth by means of a 25 mm diameter pipe lowered in the well to the well bottom (ref: Pg.5, item 7.1, Para 8,IS:11632-1986). The solution has a higher specific gravity and displaces water upward and outward from the well as the pipe is raised and lowered repeatedly by about 1.5 m.

Step 3: When the solution is placed at the screen, the drop pipe is removed. Then about 100 liters of water (about half the volume of water in 15 m length of 125 mm dia upper well casing) is slowly poured directly into the upper well casing (and through the drop pipe) to displace the solution from the screen and force it into the formation. Use of a surge plunger could be made, if available, as per guidelines on Pg.5, item 7.1, Para 8, IS:11632-1986.

Step 4: The tube well is kept capped overnight with chemicals in the well.

Step 5: The next day, the well is cleaned by backwashing and/or over pumping.

Step 6: A test for residual Chlorine is conducted using Ortho Toliodine reagent. When the flushed water is free from residual Chlorine, the hand pump can be reinstalled.

3. Application of Sodium Tripolyphosphate & its Removal:

Sodium Tripolyphosphate is usually applied along with Sodium Carbonate as a wetting agent and in combination with Sodium Hypochlorite as the sterlising agent. The method of application and removal of the chemicals is the same as in the case of Sodium Hypochlorite. However the mixing of the chemicals has to be different.

Sodium Tripolyphosphate has to be carefully mixed before application. This is because STP, if not mixed properly and clog well screen almost permanently. A solution is prepared in a plastic bucket of 15 liters capacity, with warm water and is stirred well. The solution is then sieved through a plastic mesh of 150 mesh size. This is an absolute precondition to the application of Sodium Tripolyphosphate.

The calculated quantities of Sodium Hypochlorite and Sodium Carbonate are mixed independently in separate buckets, thoroughly by hand, but using rubber gloves.

The solutions of the 3 reagents are then mixed together and then applied to the well, following Steps 2 to 4 outlined above and removed as mentioned in Steps 5 & 6.

Annexure 2

Experiences with Chemical Application & Rehabilitation Methods

The first properly documented attempts of well rehabilitation was done with a Donkey Pump by Drilling Division during 1988. This method was used because high pressure jetting trials indicated that there was almost total dissipation of energy from high pressure jets against the cylindrical inner surface of the PVC well screen. The Donkey Pump rehabilitation method was extremely time consuming and the results from 9 wells treated with this method did not show encouraging results. A detailed report was prepared. Fig. 6 shows the layout of this system.

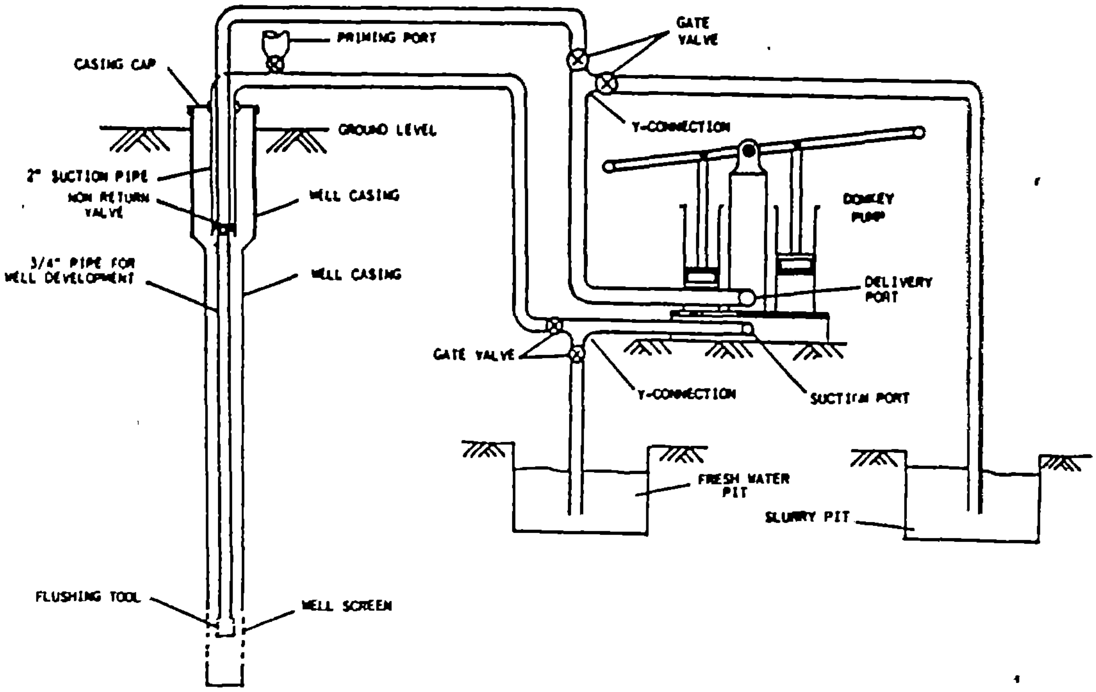


Fig. 6 : Schematic Layout for Water Injection & Over pumping with Donkey Pump

Compressors were used during 1989-90 to push chemical into the formation around the screen area. The practice was to cap the well, build up as air pressure of 4 bar over the water column and hold this pressure for a duration of 30 minutes in order to force the chemicals through the screen into the formation. The pressure was then be released to allow water to flow back into the well. A sequence of pressurising and decompressing the well was done at least twice with the intention of moving the sterilising chemical in the formation. However, this procedure occasionally led to the compressed air finding a leak in the casing and escaping from the casing, through the old drilling annulus and emerge from under the pump platform and has now been abandoned. Figs. 7.1, 7.2 and 7.3 shows the stages of this method.

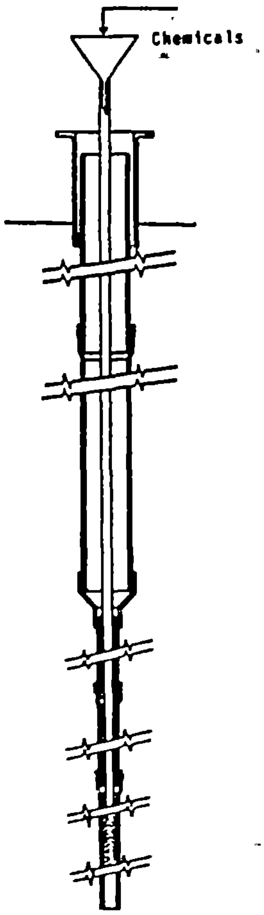


Fig. 7.1
Placement
of Chemicals

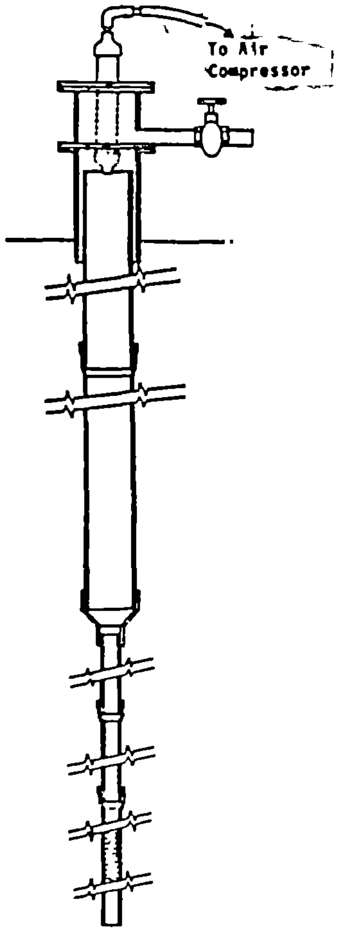


Fig. 7.2
Pressurising
the Well

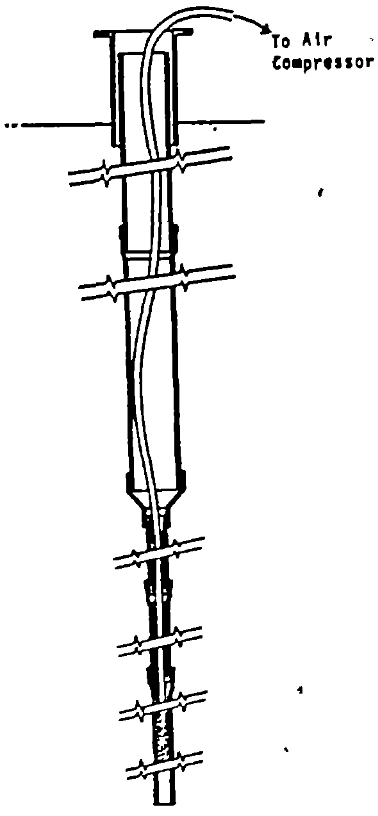


Fig. 7.3
Well Cleaning &
Over pumping by Air-lift

The next set of trials were during the latter part of 1989, when 50 wells were rehabilitated mainly using the air-lifting technique for over pumping in wells upto 100 m deep. These trials indicated that this method had a high degree of success in shallower wells but showed a high degree of failure for deeper wells. A detailed report was prepared on these trials.

During March - June 91, 47 wells in the depth range of less than 45 m were rehabilitated by using cleaning chemicals and the air-lift method of well cleaning and over pumping (Figs.7.1 & 7.3), with a fair degree of success. These wells were within the range of 45 m depth. This established the applicability of the air-lift method of well cleaning and over-pumping in shallow wells. A detailed report on these 47 wells was prepared separately.

By November 91, three other methods of over pumping was attempted in wells around and over 100 m deep. Two of the three methods hold promise, but need further trials.

The first method was the use of the Tara DA pump assembly to manually over pump the wells. In the four wells where this method was tried, the initial results have been encouraging but the wells had insignificant sedimentation. Further trails are planned, with an attempt to mechanise the operation. Fig. 8 is a schematic illustration of this method.

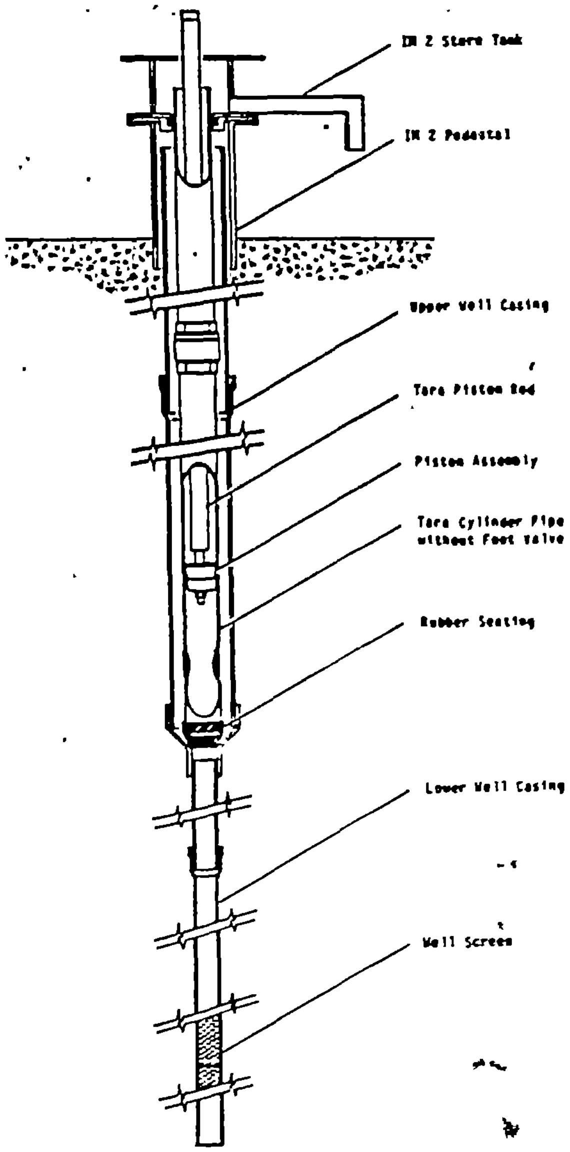


Fig. 8 : Manual Well Cleaning & Over pumping using the Tara DA Pump components

The second method was to use a combination of 25 mm ND PVC pipe with 8 mm ND pneumatic hose as an eductor pipe and an air-line to follow the air-line pumping principle. Two attempts by Maintenance Division using this method produced unsatisfactory results. Field Division Bhubaneshwar has also reported unsatisfactory results using this method. Therefore, further trials with this air-line combination will be carefully reassessed. This method has been illustrated in Fig. 9.

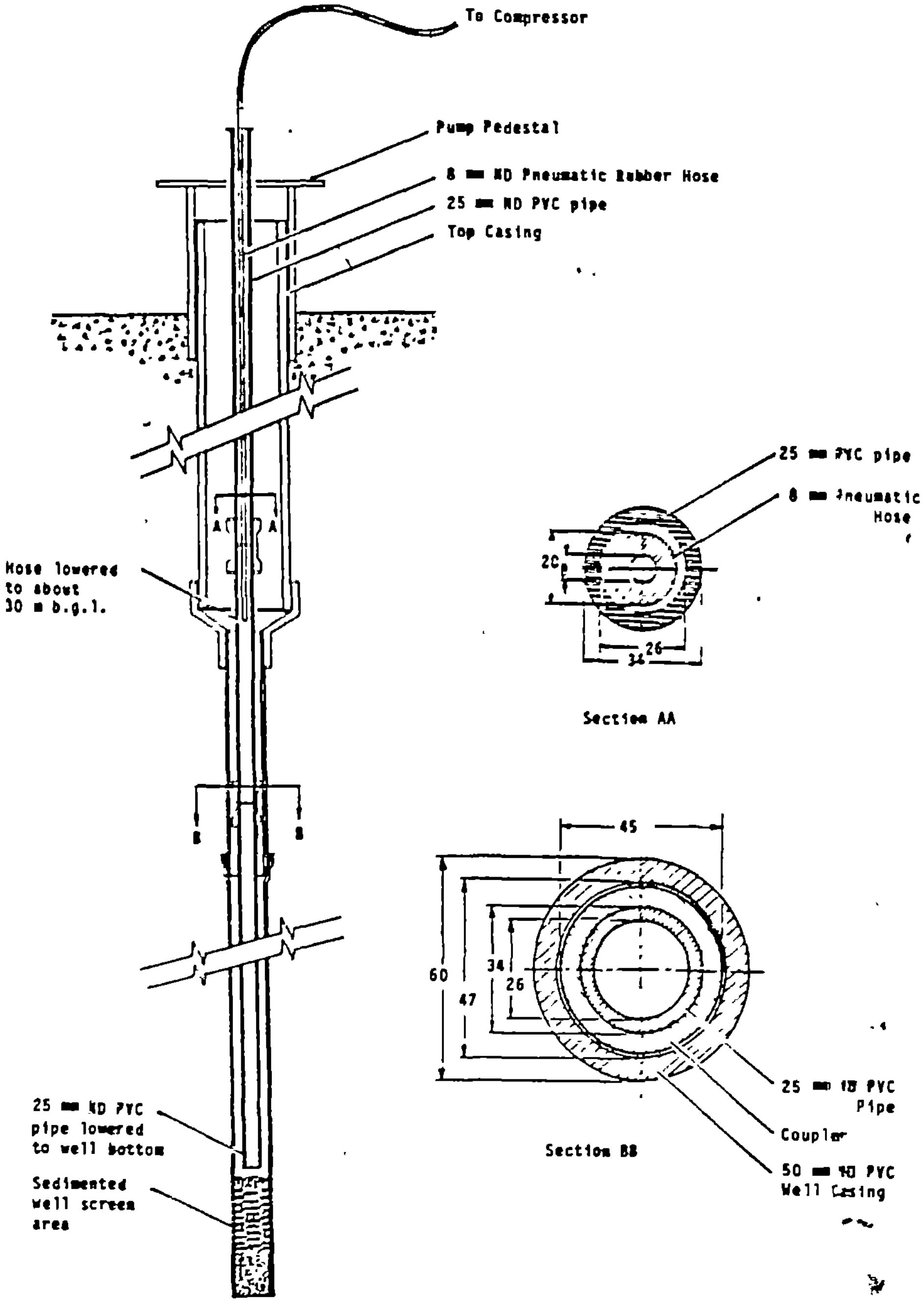


Fig. 9 : Schematic Layout of Well Cleaning Procedure using 25 mm ND PVC pipe and 8 mm ND pneumatic hose

The third method attempted was to use a high pressure compressor, operating at 10 bar, to air-lift directly from the lower well casing from depths of upto 130 m. The air lift succeeded by starting the air discharge when the compressor hose reached 60 m to 80 m bgl, and then lowering the hose further to the bottom of the well. Adequate over-pumping was achieved, but the wells were influenced by factors such as low yield and no sedimentation in the screen segment. So though the initial experience has been positive, the method needs to be tried in high discharge wells, and in wells with blocked screens. The methods used are basically the same as those illustrated in Figs. 7.1 & 7.3

Annexure 3

REHABILITATION BASIC DATA & WORK RECORD SUMMARY:

BASIC RECORD

1. Regn. No. : ....
2. Gram Panchayat : . . . .
3. Village : . . . .
4. Habitation : . . . .
5. Date of well drilling: . . . .
6. Depth drilled: . . . .
7. Type of Pump installed:

Sl. No.	Date	Pump Type	Remarks
6.1			
6.2			

STATUS SURVEY RESULTS

8. Pump Condition: . . . .
9. Pump Utilisation: . . . .
10. Chemical Analysis Results: . . . .
11. Problem Summary: . . . .
 . . . .

REHABILITATION WORK RECORD SUMMARY:

1 WELL DETAILS:

1.1 Date of pump removal: . . . .

1.2 Well depth measured: . . . . m

1.3 Depth measured after initial cleaning: . . . . m

1.4 Method of initial cleaning: . . . .

1.5 Duration : . . . . hrs./min.

2 CHEMICAL USED

Sl. No.	Date	NaOCl lit	Na_2CO_3 Kg	STP Kg	
2.1	.....	.....	.....	.....	....
2.2	.....	.....	.....	.....	....

3 WELL CLEANING

Sl. No.	Date	Method	Duration (hr/min)	Result (Satisfactory/Unsatisfactory)
3.1	.....	....	....	....
3.2	.....	....	....	....
3.3	.....	....	....	....

4 RESULTS OF WELL CLEANING

4.1 FULL WELL DEPTH WAS REACHED : Yes/ No
4.2 YIELD WAS MORE THAN 15 LPM : Yes/ No
4.3 WATER WAS CLEAR & COLOURLESS : Yes/ No
4.4 WATER WAS ODOURLESS : Yes/ No

15 PUMP REINSTALLATION DETAILS

15.1 Date: . . . .

15.2 Water level (b.g.l.) in well : . . . . . m

15.3 Pump Type details: . . . .

16 Notes on Platform/Drain/etc.: . . . .

WATER CHEMISTRY RECORD :

Block :............ G.P:.....................

Village:............... Pump Regd.No : ....

Test No.	Odo-ur	True Col-our	Par-tic-les	pH	Tur-bid-ity	EC	Fe++	Cl			
Results from Status Survey	Date of Observations:					Field Chemist:					
1.											
2.											
3.											
Post-Rehabilitation Results	Date :					Field Chemist:					
1.											
2.											
3.											
Post-Rehabilitation Results	Date:					Field Chemist:					
1.											
2.											
3.											
Post-Rehabilitation Results	Date:					Field Chemist:					
1.											
2.											
3.											
Post-Rehabilitation Results	Date:					Field Chemist:					
1.											
2.											
3.											
Post-Rehabilitation Results	Date:					Field Chemist:					
1.											
2.											
3.											
Post-Rehabilitation Results	Date:					Field Chemist:					
1.											
2.											
3.											

Codes:

Odour : 1: No Odour 2: Rotten Egg 3: Others
Particles : 1: Absent 2: Present

Detailed Time Record of Redevelopment

Sl. No.	Date	Chemical Treatment		Air pressure applied				Observations
		Time	Name & Quantity	Time Record			Pressure	
				Start	Stop	Duration		

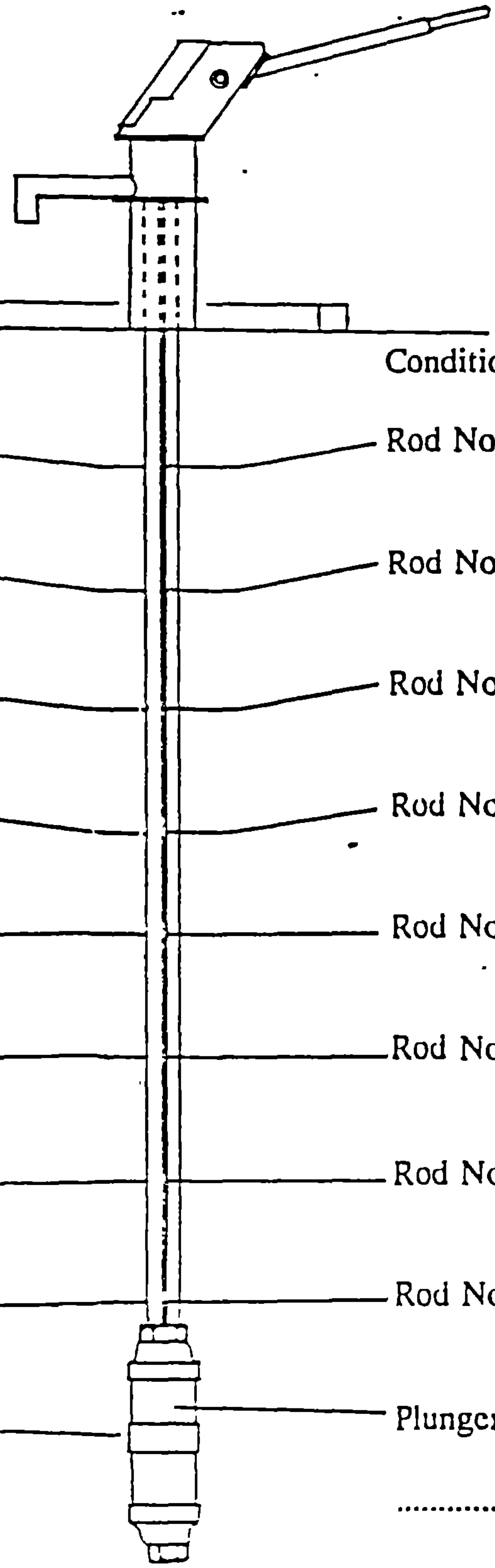
Prepared by:.......................... Date:.......................

FIELD NOTE SHEET
HAND PUMP REMOVAL

Block: **Date:**

G.P., Village, Hab.:

Regn. No.:



Condition of Pipes	Condition of Rods
Pipe No.1............	Rod No.1.................
Pipe No.2............	Rod No.2.................
Pipe No.3............	Rod No.3.................
Pipe No.4............	Rod No.4.................
Pipe No.5............	Rod No.5.................
Pipe No.6............	Rod No.6.................
Pipe No.7............	Rod No.7.................
Pipe No.8............	Rod No.8.................
Cylinder	Plunger Rod
....	....

Notes: ....

....

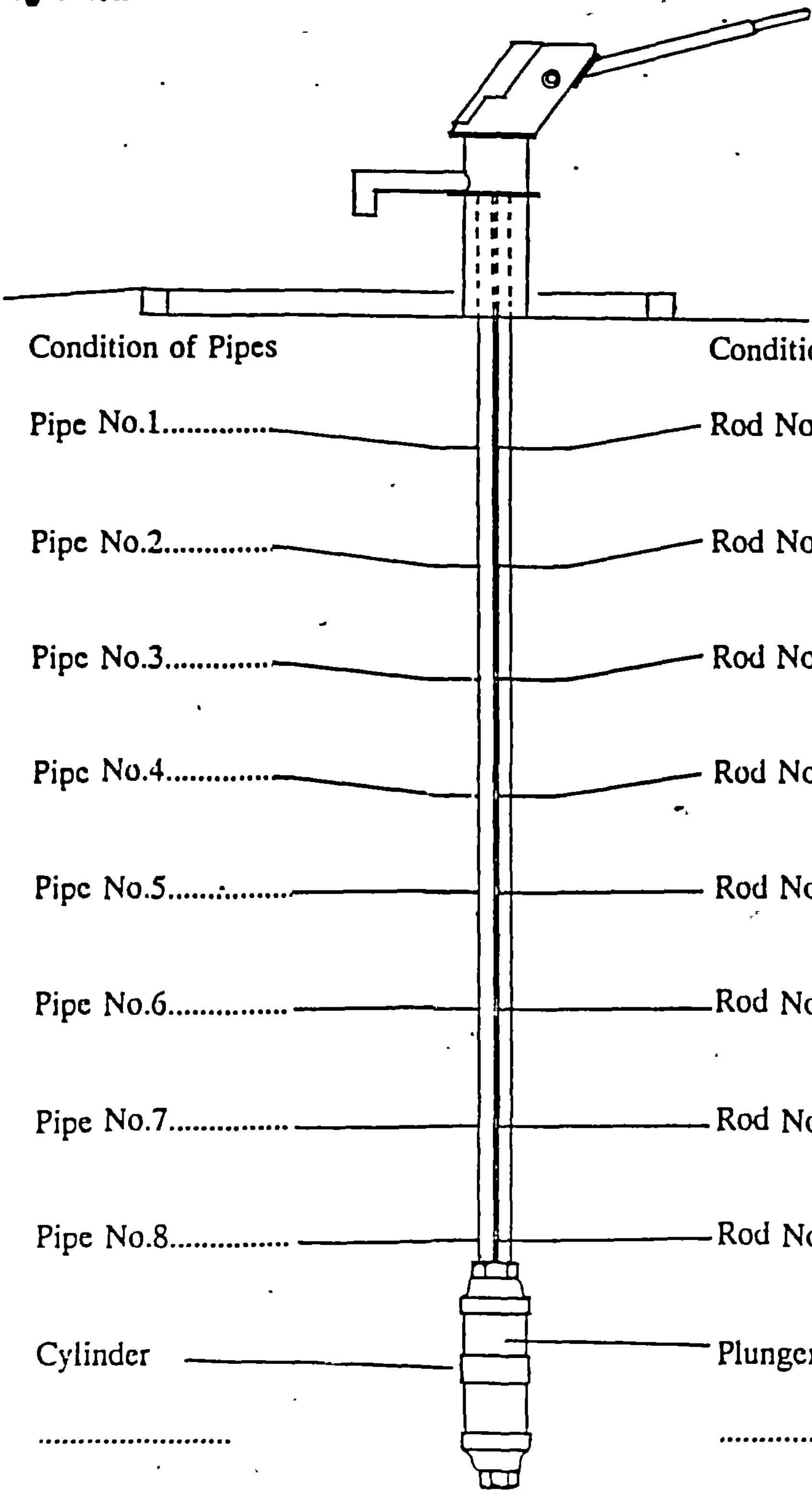
Prepared by:..................................... Date:...

FIELD NOTE SHEET
HAND PUMP REINSTALLATION

Block: **Date:**

G.P., Village, Hab.:

Regn. No.:



Condition of Pipes	Condition of Rods
Pipe No.1............	Rod No.1.................
Pipe No.2............	Rod No.2.................
Pipe No.3............	Rod No.3.................
Pipe No.4............	Rod No.4.................
Pipe No.5...............	Rod No.5.................
Pipe No.6..............	Rod No.6.................
Pipe No.7..............	Rod No.7.................
Pipe No.8..............	Rod No.8.................
Cylinder	Plunger Rod
....	....

Notes: . . . .

. . . .

Prepared by:.................................... Date:...

Annexure 4

Methodology for Data Analysis of Status Survey

1 Main Parameters

1.1 Data pertinent to comprehensive classification of a pump, by the extent of its 'problem', was collected in 3 main areas :

1. Usage of the Source
2. Water Chemistry of the Source
3. Well & Installation Condition of the Source

1.2 Data on the above aspects were collected with questionnaires, field tests and observations. For the purpose of identifying and categorising problem pumps the methodology for data analysis using the three above mentioned parameters is as follows :

2 Usage:

2.1 Form 2, of the Status Survey was used to collect field data for assessment of usage of a source.

2.2 With reference to the total number of households identified as potential users of a source, the Usage parameter for a source was categorised as follows:

Table 1 : Overall Classification of Usage

Sl. No.	Overall Usage Classification	Preliminary Classification
1	GOOD	Used by 75% or more of the total number of potential users as a drinking water source.
2	POOR	Used by less than 75% to more than 50% of the total number of potential users as a drinking water source.
3	BAD	Used by less than 50% of the total number of potential users as a drinking water source.

2.3 The above categorisation made it possible to arrive at an overall classification of Usage of any source into one of the 3 main categories of 'Good', 'Poor' and 'Bad'.

3 Water Chemistry:

3.1 Form 4 of the Status Survey recorded the results of field chemical analysis results of 8 parameters, in a sequence of 3 rounds of tests for each well. The procedure for categorising this data was based on the application of IS:10500-1983 which are the Indian Standards for Test Characteristics for Drinking Water. The method of categorisation of the 8 parameters, using IS:10500-1983 is given below :

Table 2 : Application of IS:10500-1983 for Preliminary Classification of Chemical Tests

Sl. No.	Water Quality Parameter	Code/Value/ Range	Categorisation	Codes used in analysed data
1	Odour	None=1	Good	O
		H_2S=2, Other=3	Bad	
2	True Colour (Hazen Units)	≤ 50	Good	L
		> 50	Bad	
3	Particles	None=1	Good	P
		Present=2	Bad	
4	pH	> 8.5	Bad (Alkaline)	A
		≤8.5,≥6.5	Good	
		< 6.5	Bad (Acidic)	
5	Turbidity (NTU)	≤ 25	Good	T
		> 25	Bad	
6	TDS = (0.65xConductivity in micro-siemens)	≤ 3000	Good	E
		> 3000	Bad	
7	Iron (Fe^{++}) (in mg/l)	≤ 0.3	Good	F
		> 0.3 ; ≥ 1.0	Permissible	
		> 1.0	Bad	
8	Chlorides (in mg/l)	≤ 250	Good	C
		> 250; ≤ 1000	Permissible	
		> 1000	Bad	

3.2 Based upon the above preliminary classification, it was possible to classify each of the 8 parameters of Water Chemistry into 3 qualitative descriptions of Good, Poor and Bad in the following manner:

Table 3 : Overall Classification of Water Chemistry from Preliminary Classification

Sl. No.	Overall Water Chemistry Classification	Preliminary Classification by IS:10500
1	GOOD	All parameters classified either as 'Good' or as 'Permissible'. No parameters with 'Bad' classification.
2	POOR	Only parameters of Odour, Particles, True Colour &/or Trubidity classified as 'Bad'.
3	BAD	Parameters of TDS, Iron &/or Chlorides classified as 'Bad'.

4 Well & Installation Condition:

4.1 Form 4 of the Status Survey was also used to record the physical condition of the pump installation and record problems with the pump or well by classifying seven main problems into 3 categories of 'Severe', 'Medium' and 'Slight'. The seven parameters used to assess the condition of the well or pump were as follows :

Table 4 : Parameters & Codes used of Well & Installation Condition

Sl. No.	Well/Pump Condition Parameter	Codes used in analysed data
1	Pump Condition	P
2	Pedestal Shaking	S
3	Platform needs Repairs	R
4	Drain needs Repairs	D
5	Waste water disposal problem	W
6	Pump is Malfunctioning	M
7	Low Yield	Y

4.2 The responses to the above 7 parameters could be either 'Severe', 'Medium' or 'Slight', depending on the degree of problem observed. The three possible responses to the 7 parameters were reduced to three possible overall categories of well & installation condition of Good, Poor and Bad by the following method:

Table 5 : Overall Classification of Well & Installation Condition

Sl. No.	Overall Classification	Preliminary Classification
1	GOOD	All parameters classified as 'Slight' or not recorded as a problem. No parameters with 'Medium ' or 'Severe' classification.
2	POOR	Any parameters classified as 'Medium' and 'Severe' classification for any parameter other than Yield and Waste Water Disposal.
3	BAD	For Yield and Waste Water Disposal parameters classified as 'Severe'.

5 Overall Categorisation:

5.1 From the above methodology it was possible to define the level of problems in a problem pump by using three parameters (USAGE, CHEMISTRY, CONDITION) and by assigning them any one of three main classifications (GOOD, POOR, BAD) to the three parameters as indicated in Tables 1, 3 and 5. This overall categorisation could be summarised as follows:

Table 6 : Overall Categorisation Summary of Problem Well Parameters

		Overall Categorisation		
		Good	Poor	Bad
Sl. No.	Main Parameter			
1	Usage (Table 1)	Used by ≥ 75% households for drinking	Used by <75% to ≥ 50% households	Used by < 50% households
2	Water Chemistry (Table 3)	No parameter classified as 'Bad'	'Bad' only for Odour, Particles, Colour, Turbidity	'Bad' classification for pH, TDS, Iron, Chlorides
3	Well & Installation Condition (Table 5)	No parameter in classifications of 'Medium' or 'Severe' problems	Any parameter in 'Medium' or 'Severe' for parameters other than Waste Water or Yield	'Severe' for parameters of Waste Water or Yield

5.2 From Table 6, it will be evident that the 3 main parameters could each be categorised into 3 overall categories and this would lead to 27 parameter-category combinations. These 27 combinations would then represent all the possible definitons of wells including the entire spectrum of problem wells.

6 Rehabilitation Needs Assessment:

The 27 combination of parameters and their categorisation is given in the form of a matrix in Table 7 below. From this table it will then be possible to asses the rehabilitation need of each individual well in general terms.

Table 7 : Generalised Rehabilitation Need Assessment

Parameter	Category		
	Good	Poor	Bad
Usage	NA	RA	RA+FO
Water Chemistry	NA	WC	WC+WR
Pump Condition	NA	RP	WC+WR/WWA/CR+WRD = FL??

Explanation of Abbreviations used in Table 7, above:

1. NA : No Action
2. RA : Assessment of Reason for Rejection
3. WC : Well Cleaning
4. RP : Rectification or Replacement of Pump
5. RA+FO : Rejection Reason Assessment + Follow up
6. WC+WR : Well Cleaning + Referral to Water Resource Division
7. WWA : Waste Water Alternative necessary
8. CR+WR : Complex Rehabilitation + WRD Referral
9. FL : Failure consideration

The above matrix will lead to the 27 combinations of parameters and their categories. These 27 combinations are given in Table 8 along with the composite rehabilitation need emerging from Table 7. The example of this analysis on Status Survey data for 33 wells of Dera G.P, Rajnagar Block is herewith attached in Table 9.

Table 8 : Generalised Rehabilitation Needs based on different Parameter & Category Combinations

No.	Usage	Water Quality	Pump Condition	Rehabilitation Needs
1.	Good	Good	Good	NA
2.	Good	Good	Poor	RP
3.	Good	Poor	Good	WC
4.	Poor	Good	Good	RA
5.	Good	Poor	Poor	WC+RP
6.	Poor	Good	Poor	RA+RP
7.	Poor	Poor	Good	RA+WC
8.	Poor	Poor	Poor	RA+WC+RP
9.	Good	Good	Bad	WWA/ (CR+WR)
10.	Good	Bad	Good	(WC+WR)
11.	Bad	Good	Good	(RA+FO)
12.	Good	Poor	Bad	WC+WWA/ WC+(CR+WR)
13.	Good	Bad	Poor	(WC+WR)+RP
14.	Poor	Good	Bad	(RA+FO)+WWA/ (RA+FO)+(CR+WR)
15.	Poor	Bad	Good	RA+(WC+WR)
16.	Bad	Good	Poor	(RA+FO)+RP
17.	Bad	Poor	Good	(RA+FO)+WC
18.	Poor	Poor	Bad	RA+WC+WWA/ RA+WC+(CR+WR)
19.	Poor	Bad	Poor	RA+(WC+WR)+RP
20.	Bad	Poor	Poor	(RA+FO)+WC+RP
21.	Good	Bad	Bad	(WC+WR)+WWA+RA/ (WC+WR)+(CR+WR)+RA
22.	Bad	Good	Bad	(RA+FO)+WWA/ (RA+FO)+(CR+WR)
23.	Bad	Bad	Good	(RA+FO)+(WC+WR)
24.	Poor	Bad	Bad	RA+(WC+WR)+WWA/ RA+(WC+WR)+(CR+WR)
25.	Bad	Poor	Bad	(RA+FO)+WC+WWA/ (RA+FO)+WC+(CR+WR)
26.	Bad	Bad	Poor	(RA+FO)+(WC+WR)+RP
27.	Bad	Bad	Bad	(RA+FO)+(WC+WR)+WWA/ (RA+FO)+(WC+WR)+(CR+WR) = FL ??

Table 9 : Status Survey Results & Rehabilitation Needs - Dera G.P., Rajnagar Block

Sl. No.	Village	Acessib-ility	Site ID	Drilling		Pump		ID Status	Status Survey Results			Rehab
				Date	Depth	Date	Type		Usage	Water Chemistry	Pump Condtion	
Block : Rajnagar, G.P. : Dera												
1	BADHI	HV	02	11/11/88	200.00	16/12/88	IMII		Good	Bad	Bad	[WC+WR]+ WWA/[CR+WR]+ RA
2	CHIMCHIRI	HV	01	09/02/89	194.00	14/11/88	IMII		Good	Bad	Poor	[WC+WR]+RP
3	DERA	HV	01	09/01/90	177.00	27/08/88	IMII		Good	Bad	Poor	[WC+WR]+RP
4	DERA		02	13/12/89	202.30	01/12/88	SL		Good	Bad	Good	[WC+WR]
5	DERA		03	03/10/90	198.30	30/04/89	IMII		Good	Bad	Good	[WC+WR]
6	DHOBEIGARH	HV	01	10/09/88	190.00	17/11/88	IMII		Good	Bad	Bad	[WC+WR]+ WWA/[CR+WR]+ RA
7	DHOBEIGARH		50				IMII	NDIR	Good	Bad	Bad	[WC+WR]+ WWA/[CR+WR]+ RA
8	GAMASIKHARA	HV	50				IMII	NDIR	Good	Bad	Poor	[WC+WR]+RP
9	GOKHANI	LV	01	05/07/88	178.00	29/10/87	IMII		Good	Poor	Good	WC
10	GOKHANI		02	12/02/90	186.30	16/11/88	IMII		Good	Bad	Poor	[WC+WR]+RP
11	GOKHANI		03	13/10/89	177.00	19/12/88	IMII		Good	Bad	Poor	[WC+WR]+RP
12	HATINA	HV	01	09/01/90	194.30	28/08/88	SL		Good	Poor	Good	WC
13	HATINA		02	10/02/89	195.30	27/10/88	IMII		Poor	Bad	Bad	RA+[WC+WR]+ WWA/[CR+WR]
14	HATINA		03	09/08/88	196.30	28/10/88	IMII		Good	Bad	Good	[WC+WR]
15	HATINA		04	12/03/89	193.00	25/11/88	SL		Good	Bad	Good	[WC+WR]
16	HATINA		05	14/06/89	196.30	29/12/88	SL		Good	Bad	Poor	[WC+WR]+RP

Table 9 (Contd.) : Status Survey Results & Rehabilitation Needs - Dera G.P., Rajnagar Block

Sl. No.	Village	Acessib-ility	Site ID	Drilling		Pump		ID Status	Status Survey Results			Rehab
				Date	Depth	Date	Type		Usage	Water Chemistry	Pump Condtion	
17	JUNUPANGARA	HV	01	09/10/89	148.30	30/08/88	INII		Good	Bad	Poor	[WC+WR]+RP
18	JUNUPANGARA		50				INII	NDIR	Bad	Good	Good	[RA+FO]
19	KAITHA	LV	01	10/07/88	204.00	15/11/88	INII		Good	Bad	Good	[WC+WR]
20	KAITHA		02	10/01/88	204.30	14/11/88	INII		Good	Bad	Poor	[WC+WR]+RP
21	KAITHA		03	10/01/88	200.30	15/11/88	INII		Good	Bad	Good	[WC+WR]
22	KAITHA		04	09/03/90	200.00	23/11/89	SL		Good	Bad	Good	[WC+WR]
23	KAITHA		50				INII	NDIR	Good	Poor	Bad	WC+ WWA/[CR+WR]
24	KATHAPANGARA	MB	01	11/03/89	174.00	21/12/88	INII		Good	Bad	Good	[WC+WR]
25	KATHAPANGARA		50				INII	NDIR	Bad	Good	Good	[RA+FO]
26	KATHUAGANDA	LV	01	12/06/89	196.00	27/12/88	INII		Good	Bad	Poor	[WC+WR]+RP
27	KATHUAGANDA		02	10/06/88	289.00	26/12/88	INII		Good	Bad	Good	[WC+WR]
28	LUNIA	FT	01	01/12/89	184.30	19/04/89	INII		Good	Bad	Good	[WC+WR]
29	MUGAKANI	HV	01	12/06/90	196.30	18/11/88	INII		Good	Bad	Good	[WC+WR]
30	NUAGAN	LV	01				INII	NDIR	Good	Bad	Poor	[WC+WR]+RP
31	NUAGAN		02	12/07/88	209.00	28/12/88	INII		Poor	Bad	Good	RA+[WC+WR]
32	PARIPANGARA	MB	01	10/05/88	195.00	03/08/89	INII		Good	Bad	Good	[WC+WR]
33	PARIPANGARA		02	10/03/88	184.30	30/10/88	INII		Good	Bad	Good	[WC+WR]

Annexure 5

1. Well Development Methods & Well and Pump Maintenance and Rehabilitation from "Ground Water and Wells", Second Edition, by Fletcher G. Driscoll, published by Johnson's Filtration Systems Inc. USA.

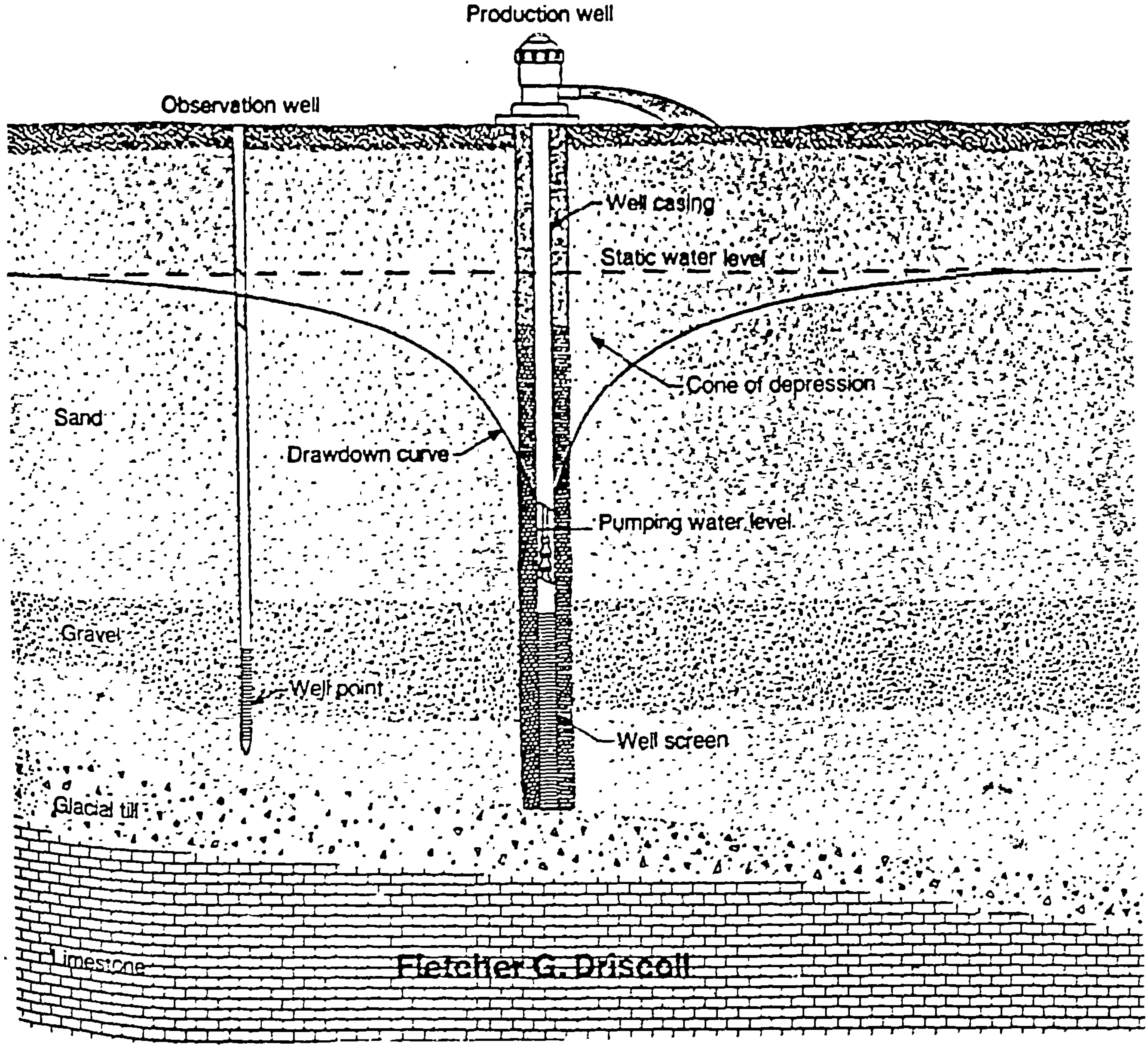
2. IS: 11632- 1986, Indian Standard for Code of Practice of Rehabilitation of Tubewells, published by Bureau of Indian Standards, New Delhi.

3. IS: 10500- 1983, Indian Standard for Test Characteristics for Drinking Water, published by Bureau of Indian Standards, New Delhi.

Groundwater and Wells

Second Edition

A comprehensive study of groundwater and the technologies used to locate, extract, treat, and protect this resource.



Fletcher G. Driscoll

CHAPTER 15

Development of Water Wells

WELL DEVELOPMENT METHODS

Different well development procedures have evolved in different regions because of the physical characteristics of aquifers and the type of drilling rig used to drill the well. Unfortunately, some development techniques are still used in situations where other, more recently developed procedures would produce better results. New development techniques, especially those using compressed air, should be considered by contractors when they buy and equip a new rig. Any development procedure should be able to clean the well so that sand concentration in the water is below the maximum allowable limit set for the particular water use.

Overpumping

The simplest method of removing fines from water-bearing formations is by overpumping, that is, pumping at a higher rate than the well will be pumped when put into service. This procedure has some merit, because any well that can be pumped sand free at a high rate can be pumped sand free at a lower rate.

Overpumping, by itself, seldom produces an efficient well or full stabilization of the aquifer, particularly in unconsolidated sediments, because most of the development action takes place in the most permeable zones closest to the top of the screen. For a given pumping rate, the longer the screen, the less development will take place in the lower part of the screen. After fine material has been removed from the permeable zones near the top of the screen, water entering the screen moves preferentially through these developed zones, leaving the rest of the well poorly developed and contributing only small volumes of water to the total yield. In some cases, overpumping may compact finer sediments around the borehole and thereby restrict flow into the screen. If more powerful agitation is not performed, an inefficient well may result. On the other hand, overpumping may be effective in filter-packed wells in competent, relatively non-stratified sandstone formations because flow toward the well bore is more or less uniform.

There is another objection to overpumping that is commonly overlooked. Water flows in only one direction, toward the screen, and some sand grains may be left in a bridged condition, resulting in a formation that is only partially stabilized (Figure 15.4). If this condition exists and the formation is agitated during normal pump cycles after the well has been completed, sediment may enter the well if the sand bridges become unstable and collapse.

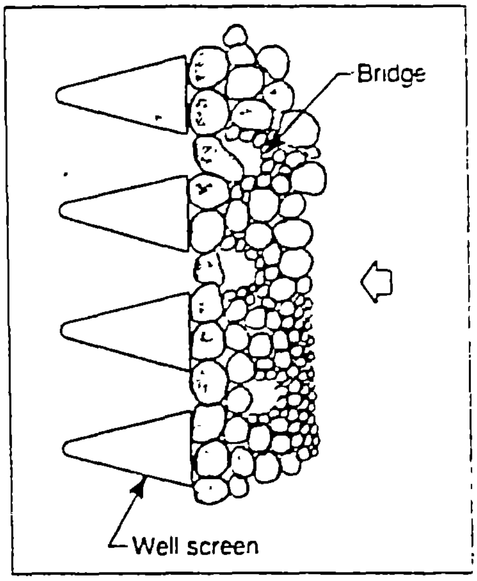


Figure 15.4. During development by overpumping, sand grains can bridge openings because flow occurs in only one direction. Once the well is placed into service, agitation by normal pump cycling can break down the bridges, causing sand pumping.

Drillers ordinarily use a test pump for overpumping operations, but when a large quantity of water must be pumped, it may be difficult to obtain equipment of sufficient capacity at reasonable cost. Therefore, the pumping equipment intended for regular well use is sometimes used for overpumping. Depending on the type of pump, this may be done either by operating the pump at a higher speed or by allowing the pump to discharge at the surface at a lower-than-normal operating pressure. There is one serious objection to performing this work with the permanent pump. Sand pumping will subject the pump to excessive wear, which over time can reduce its operating efficiency. Under severe conditions, the pump may become sand locked, either during pumping or after shut off. Should sand locking occur, the pump must be pulled, disassembled, cleaned, and repaired if necessary before being placed back into service.

Backwashing

Effective development procedures should cause reversals of flow through the screen openings that will agitate the sediment, remove the finer fraction, and then rearrange the remaining formation particles (Figure 15.5). Reversing the direction of flow breaks down the bridging between large particles and across screen openings that results when the water flows in only one direction. The backflow portion of a backwashing cycle breaks down bridging, and the inflow then moves the fine material toward the screen and into the well.

A surging action consists of alternately lifting a column of water a significant distance above the pumping water level and letting the water fall back into the well. This process is called rawhiding. Before beginning the surging operation, the pump should be started at reduced capacity and gradually increased to full capacity to minimize the danger of sand-locking the pump. In the rawhiding procedure, the pump is started, and as soon as water is lifted to the surface the pump is shut off; the water in the pump column pipe then falls back into the well. The pump is started and

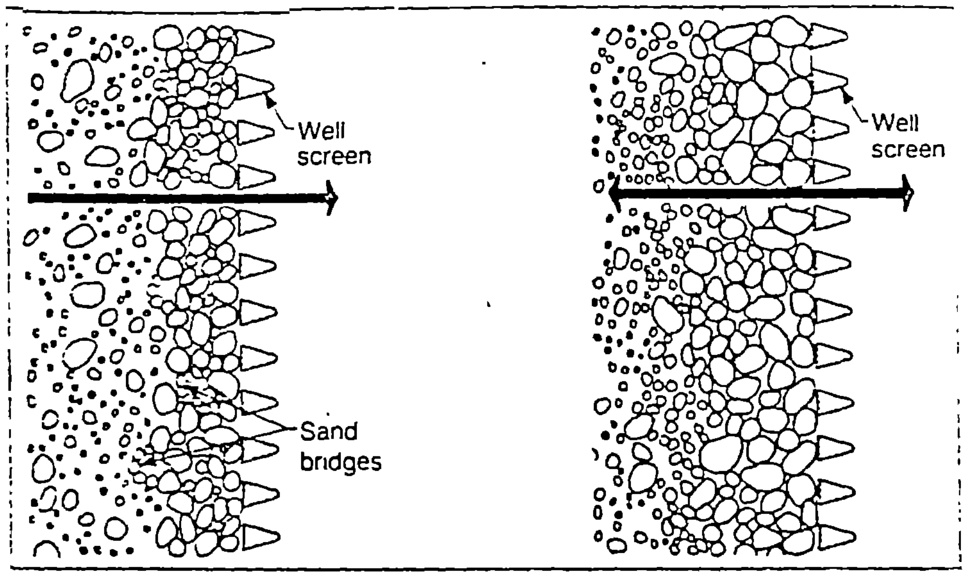


Figure 15.5. Effective development action requires movement of water in both directions through screen openings. Reversing flow helps break down bridging of particles. Movement in only one direction, as when pumping from the well, does not produce the proper development effect.

stopped as rapidly as the power unit and starting equipment will permit. To avoid damaging the pump, the control box should be equipped with a starter lockout so that the pump cannot be started when it is back spinning. During the procedure, the well should be pumped to waste occasionally to remove the sand that has been brought in by the surging action.

Some wells respond satisfactorily to rawhiding, but in many cases the surging effect is not vigorous enough to obtain maximum results. As in the case of overpumping, the surging effects may be concentrated only near the top of the screen or in the most permeable zones. Thus, the lower part of a long screen may remain relatively undeveloped.

Although overpumping and backwashing techniques are used widely, and in certain situations may produce reasonable results, their overall effectiveness in high-capacity wells is relatively limited when compared with other development methods. Other methods, as described below, are capable of removing more fine materials in less time and generally can produce higher specific capacities.

Mechanical Surging

Another method of development is to force water to flow into and out of a screen by operating a plunger up and down in the casing, similar to a piston in a cylinder The tool normally used is called a surge block, surge plunger, or swab (Figure 15.6) A heavy bailer may be used to produce the surging action, but it is not as effective as the close-fitting surge block. Although some drillers depend on surge blocks for developing screened wells, others feel that this device is not effective and that it may, in some cases, even be detrimental because it forces fine material back into the formation before the fines can be removed from the well. To minimize this problem, fine material should be removed from the borehole as often as possible.

Before starting to surge, the well should be bailed to make sure that water will flow into it. Lower the surge block into the well until it is 10 to 15 ft (3 to 4.6 m) beneath the static water level, but above the screen or packer (Figure 15.7). The water column will effectively transmit the action of the block to the screen section. The initial surging motion should be relatively gentle, allowing any material blocking the screen to break up, go into suspension, and then move into the well. The surge block (or bailer) should be operated with particular care if the formation above the screen consists mainly of fine sand, silt, or soft clay which may

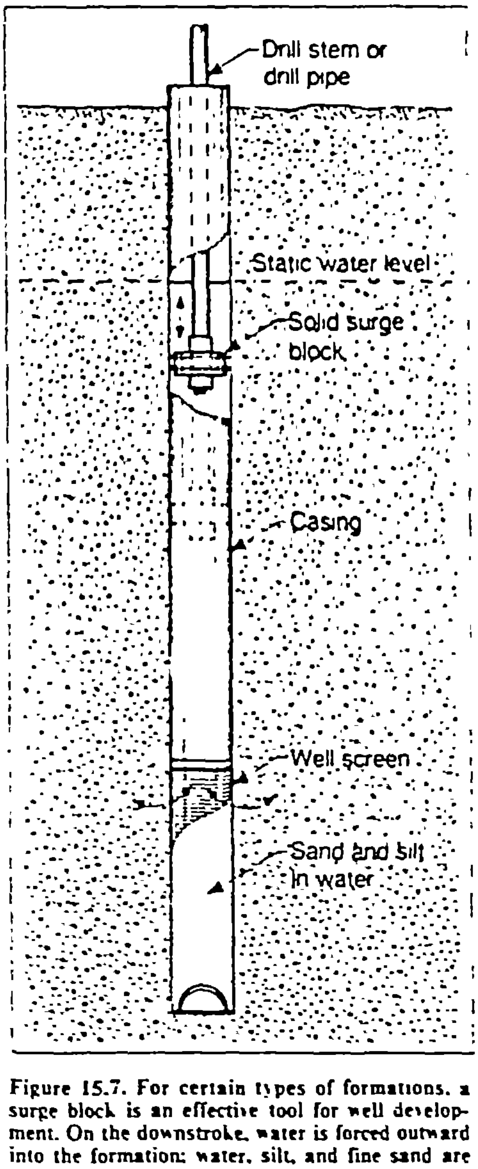


Figure 15.7. For certain types of formations, a surge block is an effective tool for well development. On the downstroke, water is forced outward into the formation: water, silt, and fine sand are then pulled into the well screen during the upstroke.

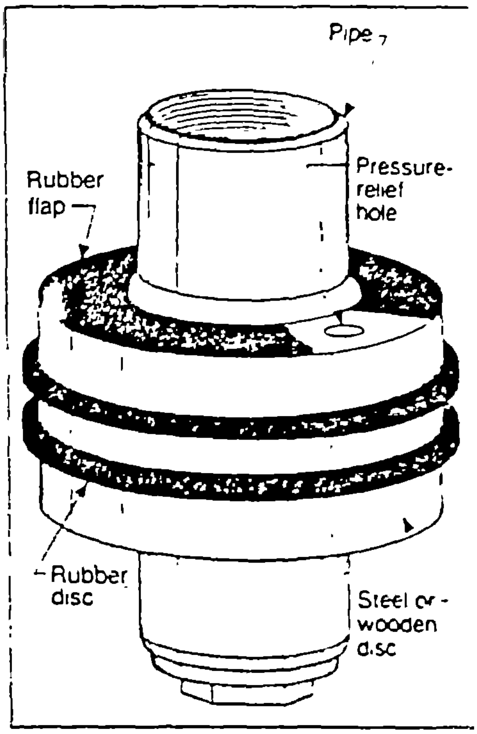


Figure 15.6. Typical surge block consisting of two leather or rubber discs sandwiched between three steel or wooden discs. The blocks are constructed so that the outside diameter of the rubber lips is equal to the inside diameter of the screen. The solid part of the block is 1 in (25.4 mm) smaller in diameter than the screen.

slump into the screen. As water begins to move easily both into and out of the screen, the surging tool is usually lowered in steps to just above the screen. As the block is lowered, the force of the surging movement is increased. In a well equipped with a long screen, it may prove more effective to operate the surge block in the screen to concentrate its action at various levels. Development should begin above the screen and move progressively downward to prevent the tool from becoming sand locked.

The force exerted on the formation depends on the length of the stroke and the vertical velocity of the surge block. For a cable tool rig, length of the stroke is determined by the spudding motion; the vertical velocity depends on the weight exerted on the block and the retraction speed. A block must be weighted so that it will fall at the desired rate when used with a cable tool rig. During retraction of the block, continue the spudding motion to avoid sand locking the block in the casing. If a rotary rig is being used, the weight on the block is provided by the drill pipe. The speed of retraction and length of pull are governed by the physical characteristics of the rig.

Continue surging for several minutes, then pull the block from the well. Air may be used to blow the sediment out of the well if development is done with a rotary rig or if an air compressor is available. Sediment can be removed by a bailer or sand pump when a cable tool rig is used. The surging action is concentrated at the top of the screen, and this effect is accentuated if the lower part of the screen is continually blocked off by the sand brought in by the development process. In general, development can be accelerated if the amount of sediment in the screen is kept to a minimum. A sump or length of casing installed beneath the screen is helpful in keeping the screen free of sediment. Continue surging and cleaning until little or no sand can be pulled into the well. Total development time may range from about 2 hours for small wells to many days for large wells with long screens.

Occasionally, surging may cause upward movement of water outside the well casing if the washing action disrupts the seal around the casing formed by the overlying sediments. When this occurs, use of the surge block must be discontinued or sediment from the overlying materials may invade the screened zone.

Surge blocks sometimes produce unsatisfactory results in certain formations, especially when the aquifer contains many clay streaks, because the action of the block can cause clay to plug the formation. When this happens a reduction in yield occurs, rather than an increase. Surge blocks are also less useful when the particles making up the formation are angular, because angular particles do not sort themselves as readily as rounded grains. In addition, if large amounts of mica are present in the aquifer, the flat or tabular mica flakes can clog the outer surface of the screen and the zone around the screen by aligning themselves perpendicular to the direction of flow. Clogging by mica can be minimized if the surging procedures are applied rather gently to the well. It is good practice to avoid overdevelopment when mica is present in the aquifer.

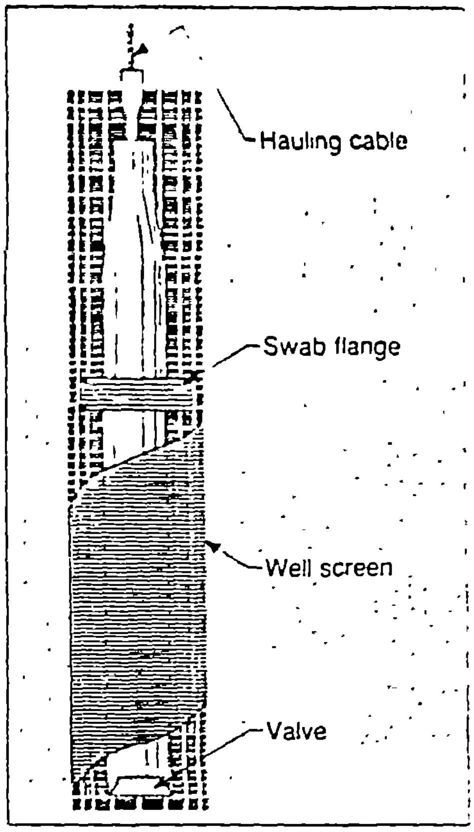


Figure 15.8. Line swabbing is used primarily in consolidated aquifers. As the swab is pulled upward at about 3 ft/sec (0.9 m/sec), high-pressure conditions at the top of the swab force water into the formation. Low-pressure conditions at the base cause flow of sand, silt, and water back into the borehole.

One other type of surging tool is called a swab. The simplest type of swab, a rubber-flanged mud scow or bailer, is lowered into the casing to any selected point below the water level and then pulled upward at about 3 ft/sec (0.9 m/sec), with no attempt to reverse the flow and cause a surging effect (Figure 15.8). The length of the swabbing stroke is usually much longer than in surging. As the scow is raised, high pressure is created near the top of the scow, which drives water into the formation. Water is drawn back into the well beneath the swab because the pressure is lower. The scow usually has a valve at the bottom which opens to increase the fall rate in the borehole. This method of swabbing, called line swabbing, is often used to clean fine material from deep wells drilled in consolidated rock aquifers. Swabbing screened wells requires special precautions, however. In tight (low-permeability) formations, for example, swabbing can result in collapsed screens, and great care must be taken to insure that the hydraulic conductivity of the formation is capable of yielding sufficient water to keep pressure differentials within reasonable limits. Avoid swabbing wells that have plastic casing or screens. Silt and silty sand formations in which screen-slot sizes are about 0.010 in (0.25 mm) or smaller are particularly troublesome, and use of a swab in this case should be avoided.

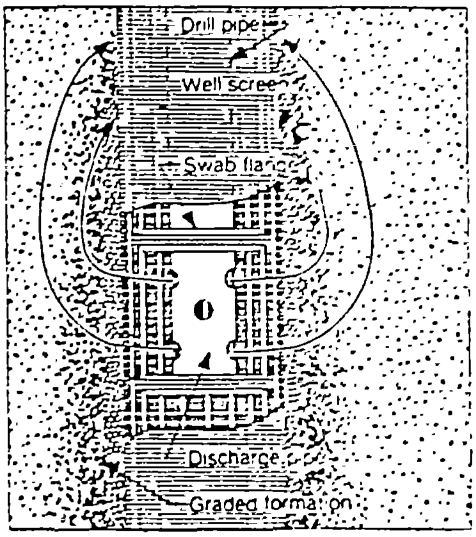


Figure 15.9. When a double-flanged swab is used, water is pumped into the formation between the flanges. Flow reenters the borehole above or below the swab. During pumping, the swab is raised and lowered over short distances.

A more effective swabbing device is shown in Figure 15.9. With this tool, water is pumped into the formation between two flanges and returns to the well bore either above or below the flanges. During pumping, the swab is raised and lowered in the borehole over short distances. Sometimes a bypass tube is installed in the double-flanged swab to facilitate the movement of water up the borehole from below the tool. The advantage of a double-flanged swab is that the energy of the water being pumped into the tool can be directed at selected parts of the formation.

In summary, surge blocks are inexpensive tools that are convenient to use and, within their limitations, do an effective job. They can be adapted for use on many types of rigs and used in combination with other development methods. In addition, surge blocks can be used for wells of any diameter or depth. Surging procedures produce good results for screen installations in zones having good porosity and hydraulic conductivity.

Air Developing by Surging and Pumping

Many drillers use compressed air to develop wells in consolidated and unconsolidated formations. The practice of alternately surging and pumping with air has grown with the great increase in the number of rotary drilling rigs equipped with large air compressors. In air surging, air is injected into the well to lift the water to the surface. As it reaches the top of the casing, the air supply is shut off, allowing the aerated water column to fall. Air-lift pumping is used to pump the well periodically to remove sediment from the screen or borehole, and is accomplished by installing an air line inside an eductor pipe in the well. Eductor systems are generally required for large-diameter wells, when limited volumes of air are available, or when the static water level is low in relation to the well depth. Most rotary rigs, however, have sufficient air capacity to use the casing as the eductor for 6- to 12-in (152- to 305-mm) diameter wells. Figure 15.10a shows the basic layout of an air-lift system and the appropriate terms.

The uphole velocities required to remove cuttings and water in air drilling were discussed in Chapter 11. Uphole velocities of 3,000 to 5,000 ft/min (915 to 1,520 m/min) are needed for dry-air drilling where little or no water is entering the borehole. For removing large volumes of water and cuttings, a surfactant is mixed into a small volume of water and then added to the airstream. The surfactant breaks up the water masses so they can be lifted to the surface at a rather low velocity [50 to 200 ft/min (15.2 to 61 m/min)], thereby reducing air-volume requirements. During air development, however, surfactants are used only when compressor capacity is insufficient to lift water to the surface. Therefore, the contractor must maintain uphole velocities in the range of 1,000 to 2,500 ft/min (305 to 762 m/min) to achieve a reasonable discharge.

Generally, it is not possible to predict what uphole velocity is actually needed because of submergence factors (discussed later), total pumping lift requirements, and

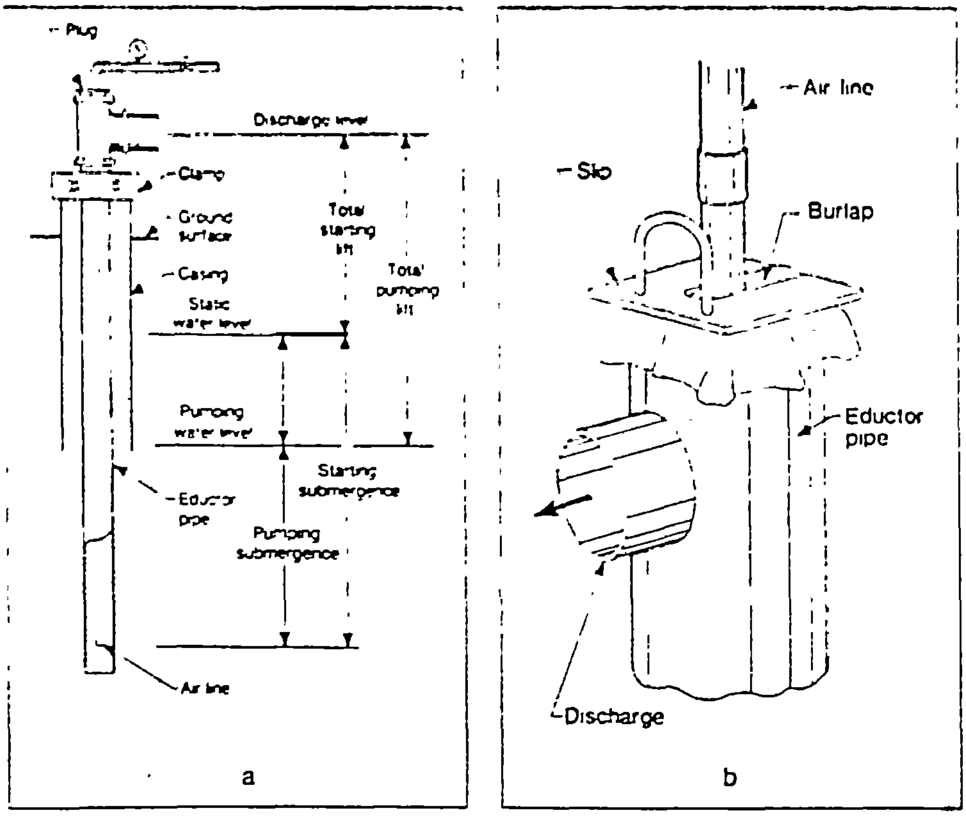


Figure 15.10a. This diagram shows common terms applied to air-lift pumping. ***(Ingersoll-Rand, 1971)*** **15.10b. In this installation, the top of the well is plugged during the air-lift with burlap and slips to direct the water to the outlet pipe.**

the non-predictable way water will enter the borehole. For example, if water enters as a high-volume, concentrated flow at a discrete point (coarse gravel layer or fracture), the uphole velocity required at that point will be quite large so the water mass can be broken up efficiently. On the other hand, if water is seeping evenly into the borehole over its entire length, the uphole velocity requirement is less because the force (velocity) needed to lift the fine water droplets is less. Thus, it is virtually impossible to predict beforehand the uphole velocities required for air development procedures. In practice, the contractor ignores uphole velocity considerations and concentrates on the air volume needed to lift the water adequately. Fortunately, research on determining the air volume required to lift a certain volume at a specified submergence and total pumping lift has been done. This information, presented later in this chapter, gives the contractor the ability to predict the volume of air that must be available to produce an adequate discharge for certain downhole conditions.

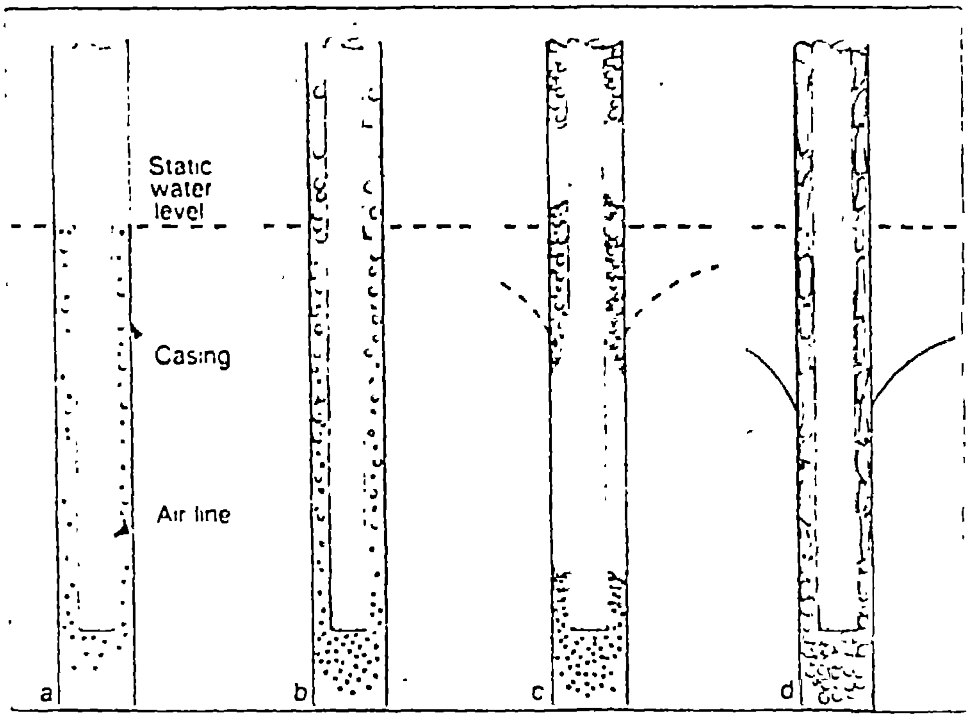


Figure 15.11. The type of discharge produced from a well during air development depends on the air volume available, total lift, submergence, and annular area. In practice, two different flow conditions can be recognized when air is used for water well development, although other flow regimes may exist at much lower or higher velocities in smaller diameter pipes [identified by Taitel and Dukler (1980) and Hestroni (1982)]. This diagram provides a qualitative illustration of how multiphase flow (water and air) occurs in the casing during air development. The percent submergence, total lift, and capacity of the compressor will control the relative proportion of air and water for a particular well. Griffith (1984) points out some of the extreme difficulties in making a rigorous analysis of multiphase systems. (a) Introduction of a small volume of air under a high head causes little change in the water level in the well. In this case, the air pressure available is just sufficient to overcome the initial head exerted by the water column. (b) As air volume increases, the water column becomes partly aerated. Displacement of the water by the air causes the water column to rise in the casing. Drawdown does not change because no pumping is occurring. (c) Further increases in air volume cause aerated slugs of water to be lifted irregularly out the top of the casing. Between surges, the water level in the casing falls to near the static level. (d) If enough air is available, aerated water will continually flow out the top of the well. With average submergence and total lift, the volume of air versus water is about 10 to 1. Higher air volumes may increase the pumping rate somewhat, but still higher rates may actually reduce the flow rate because flow into the well is impeded by excessive air volume.

Both air pressure and air volume are important in initiating and maintaining an air surging or air-lift pumping operation. For typical head conditions found in boreholes 300 to 400 ft (91.5 to 122 m) deep, the compressor used for the air supply should be capable of developing a minimum pressure of 125 psi (862 kPa). This is enough pressure to overcome the initial head created by the submergence of the air line. This head is called the starting submergence. Once the pressure initiates flow, the air capacity (volume) becomes the most important factor in successful air-lift

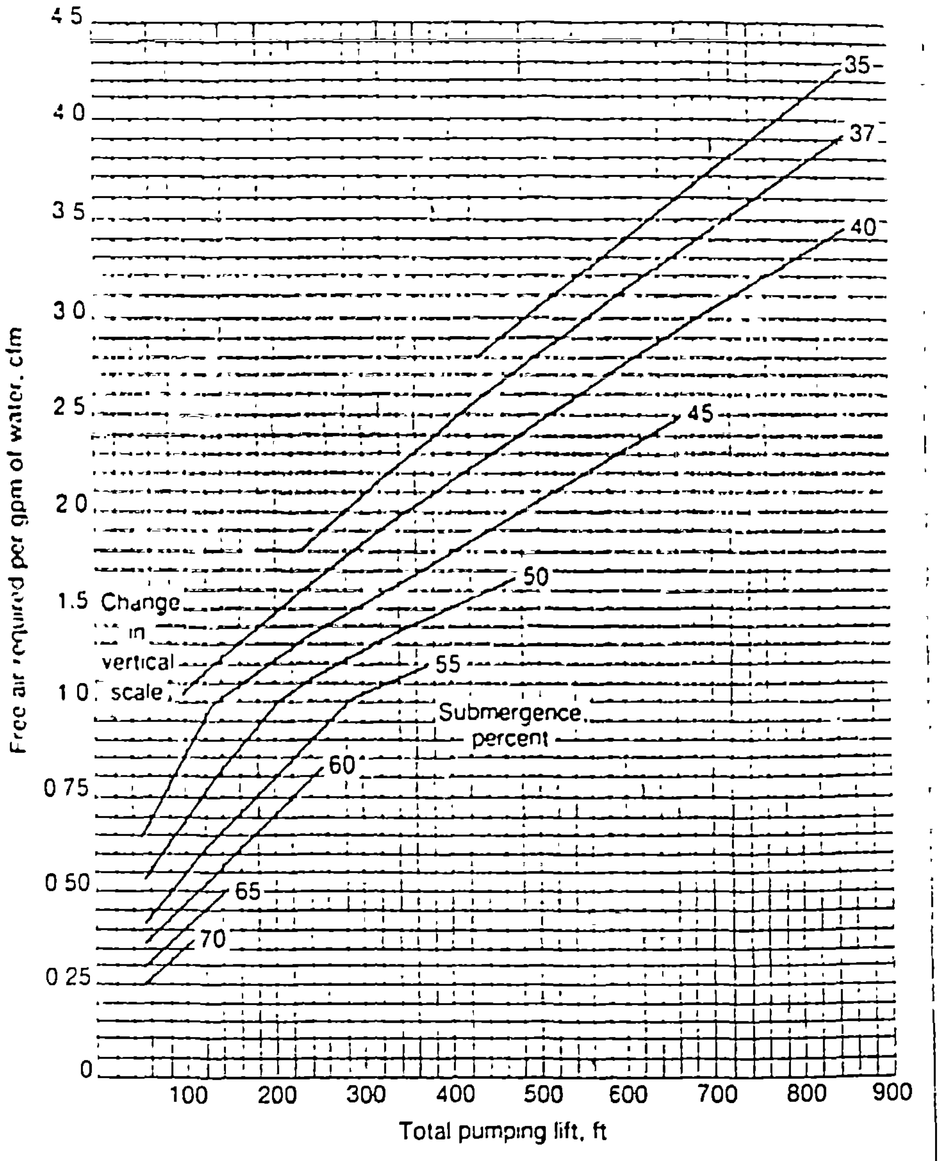


Figure 15.12. Cubic feet of air required to pump 1 gpm (5.5 m³/day) for various submergences and pumping lifts. The ratios shown here between air volume and water pumped are predicated on using the proper size eductor and casing (see Table 15.1). Field experience suggests that these air requirements may be optimistic; in practice, somewhat more air will be required than indicated. *(Ingersoll-Rand, 1971)*

pumping. Figure 15.11 illustrates how the addition of different volumes of air affects the water in the borehole. A useful rule of thumb for determining the proper compressor capacity for air-lift pumping is to provide about ¾ cfm (0.0004 m^3/sec) of air for each 1 gpm (5.5 m^3/day) of water at the anticipated pumping rate. In practice, a 375-cfm (0.2-m^3/sec) compressor can usually pump 400 to 500 gpm (2,180 to 2,730 m^3/day) with proper pumping submergence of the air line.

The volume of air required to operate an air-lift efficiently depends on the total pumping lift, the pumping submergence, and the area of the annulus between eductor and casing (Figure 15.12). To calculate pumping submergence, the length of air line below the pumping water level is divided by the total length of air line suspended in the well. For wells with about 100 to 200 ft (30.5 to 61 m) of total pumping lift, air-lift pumping is quite efficient when the air line is submerged about 60 percent of its total length during pumping (60-percent pumping submergence) (Figure 15.13). When the total pumping lift exceeds 200 ft, the pumping submergence may have to be decreased so that the start-up pressure at the bottom of the air line does not exceed the pressure capacity of the compressor. Good results can be obtained by a skillful operator while pumping with a pumping submergence as low as 30 percent. In some cases acceptable results have been obtained with a pumping submergence as low as 10 percent. The air line should not be placed all the way to the bottom of the well when pumping begins, unless required for proper submergence, because the air must then overcome an unnecessarily high pressure head.

The volume of air needed to lift water also depends on whether intermittent or steady flow is required. For development work, it is not necessary to maintain a steady discharge, and, in fact, some surging of the air lift is beneficial. If steady flow must be maintained (pumping tests, for example), the air-volume requirements will usually be greater than those given in Figure 15.12. For deep boreholes with low static water levels, the actual volume of air required may be two to three times the volume shown in Figure 15.12 to maintain steady flow.

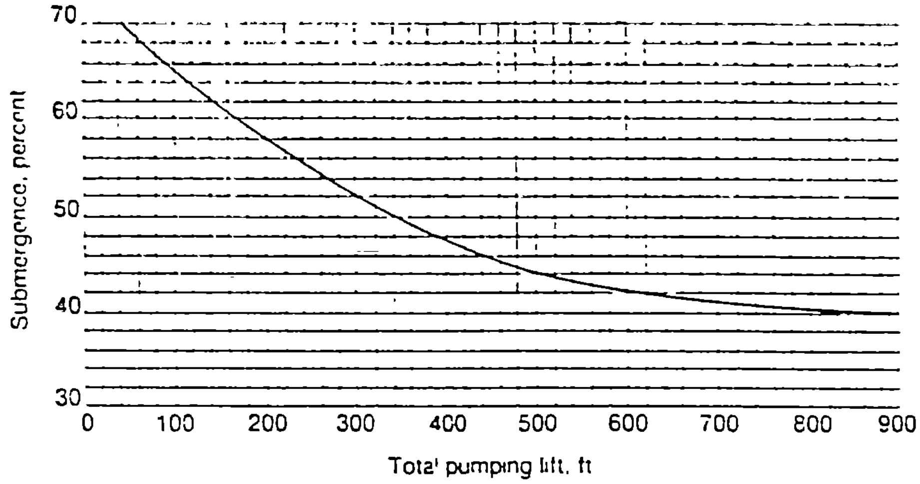


Figure 15.13. Approximate percent pumping submergence for optimum air-lift efficiency. In general, development proceeds most efficiently when the discharge is maximized. Therefore, the submergence should always be as great as possible within practical limits. *(Ingersoll-Rand, 1971)*

Figure 15.10a shows the proper method of placing the eductor pipe and air line in the well. A tee at the top of the eductor pipe is fitted with a discharge pipe at the side outlet. A bushing with the inside opening large enough to clear the couplings of the air line is connected to the top of the tee. Burlap or similar material wrapped around the air line just above the tee, and held by slips, reduces spraying around the top of the well and enables more accurate yield measurements during pumping (Figure 15.10b).

Table 15.1 lists the recommended sizes of eductor pipe and air line for air-lift pumping. Some variation from these sizes may be necessary for practical reasons, but the combinations shown generally give good results.

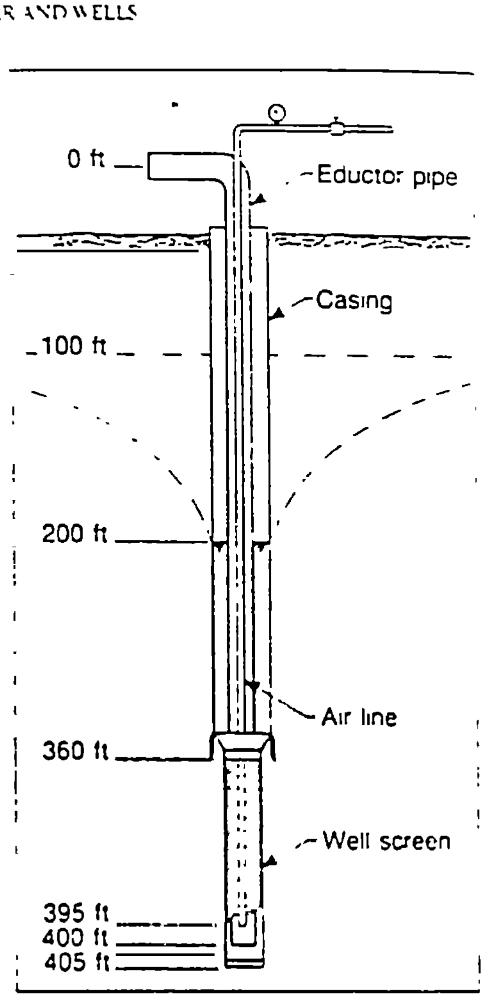


Figure 15.14. Determining the design of an air-lift system for a specific well.

Designing Air-Lift Pumping Operation

Some drillers and well construction engineers do not take the time to analyze the operational characteristics of an air lift. This practice can lead to inefficient pumping, lost time, and, in some cases, failure to pump any water. The example cited below illustrates the factors that should be considered for designing a successful air-lift pumping operation.

A borehole is completed to a depth of 405 ft and screened from 360 to 405 ft (Figure 15.14). A 10-in diameter casing is selected to minimize friction losses and provide adequate clearance for the pump bowls. Static water level is at 100 ft. Examination of the cuttings suggests that a specific capacity of 6 gpm/ft of drawdown can be obtained. It is decided to air-lift pump at a rate of 600 gpm, 20 percent above the

Table 15.1. Recommended Pipe Sizes for Air-Lift Pumping

Pumping Rate*		Size of Well Casing if Eductor Pipe is Used		Size of Eductor Pipe (or casing if no eductor pipe is used)		Minimum Size of Air Line	
gpm	m³/day	in	mm	in	mm	in	mm
30 to 60	164 to 327	4	102. or larger	2	51	1/2	13
60 to 80	327 to 436	5	127. or larger	3	76	1	25
80 to 100	436 to 545	6	152. or larger	3 1/2	89	1	25
100 to 150	545 to 818	6	152. or larger	4	102	1 1/4	32
150 to 250	818 to 1,360	8	203. or larger	5	127	1 1/2	38
250 to 400	1,360 to 2,180	8	203. or larger	6	152	2	51
400 to 700	2,180 to 3,820	10	254. or larger	8	203	3	64
700 to 1,000	3,820 to 5,450	12	305. or larger	10	254	3	64
1,000 to 1,500	5,450 to 8,180	16	406. or larger	12	305	4	102

Actual pumping rate is dependent on percent submergence.

design rate of 500 gpm. Thus, the pumping water level would be at 200 ft. From this information, it is possible to select the proper size equipment for the air lift and to estimate the potential efficiency of the system. Several steps should be followed in the analysis:

1 Determine the diameter of the eductor pipe (if required) and the air line. Table 15.1 shows that an 8-in eductor and a 3-in air line should be used for the 10-in casing. A smaller diameter eductor might be chosen, but the air-pressure requirements would rise significantly because of the additional friction effects.

2. Determine the lengths of the eductor pipe and the air line. In this instance, the air line will always stay inside the eductor pipe. The bottom of the eductor pipe is set at 400 ft, with the air line set at 395 ft. The 400-ft submergence depth is selected so that the lower end of the eductor pipe is set at a reasonable distance above the bottom of the screen.

3 Determine submergence:

$$\% \text{ pumping submergence} = \frac{\text{length of air line below pumping water level}}{\text{total length of air line}} \cdot 100$$

$$= \frac{195}{395}$$

$$= 50\%$$

Experience suggests that the air lift will be reasonably efficient at this pumping submergence; that is, the volume of water pumped per cubic foot of air is acceptable (Figure 15.13). Ideally, pumping submergence should be as great as possible, but may be limited by initial air-pressure requirements as shown in step 5.

4 Determine air-volume requirements. For a total pumping lift of 200 ft, Figure 15.12 shows that 1 cfm is required to pump 1 gpm Thus, 600 cfm are required to pump at 600 gpm.

5. Determine whether the compressor has sufficient pressure to initiate flow in the air line.

$$\text{Minimum psi requirement} = \frac{\text{length of air line} - \text{static water level}}{2.31}$$

$$= \frac{395 - 100}{2.31}$$

$$= 128 \text{ psi}$$

Thus, at least 128 psi will be needed to start the air lift for the starting submergence selected (a safety factor of 25 percent is usually added to this pressure figure). As drawdown develops, the psi requirement drops substantially because the head acting on the air line decreases.

Proper analysis of the factors affecting the air lift provides some assurance that the air-lift development procedures will function as desired. But the design of an air-lift system and the determination of its operational characteristics are not mathematically precise. Therefore, the performance obtained from a particular air-lift design may be more or less than anticipated. Thus, the contractor or engineer must be prepared to make appropriate adjustments. In general, air-lift pumping will be most efficient when the static water level is high, the casing diameter is relatively small, and the well depth is not excessive in relation to the pressure capability of the compressor.

Air Development Procedures

Air development procedures should begin by determining that groundwater can flow freely into the screen. Application of too much air volume in the borehole when the formation is clogged can result in a collapsed screen. To minimize the initial pumping rate, the air line and eductor (if used) can be placed at a rather shallow submergence. At this setting, even the introduction of large air volumes will produce only a moderate pumping rate and, therefore, will place only low collapse pressures on the well screen. Introduction of small air volumes at greater submergence also will produce low yields.

Once uninhibited flow into the screen has been established, the eductor pipe (if used) is lowered to within 5 ft (1.5 m) of the bottom of the screen, assuming that sufficient pressure is available to overcome the static head. Development can also start near the top of the screen, depending on the preference of the driller. The air line is placed so that its lower end is up inside the eductor pipe at the proper submergence level. Before blowing any water or drilling fluid out of the well with a sudden large injection of air, the air lift should be operated to pump fluids at a reduced rate from the well

Air is released into the line and the well is pumped until the water is virtually sand free. The valve at the air tank outlet is then closed, allowing the pressure in the tank to build. The actual pressure required will depend on the starting submergence; 43 psi (296 kPa) is needed for each 100 ft (30.5 m) of starting submergence. In the meantime, the air line is lowered so that its lower end is 1 ft or so below the eductor pipe. To initiate surging, the valve is opened quickly to allow air from the tank to rush suddenly into the well. This tends to drive the water outward through the well screen openings. Ordinarily, a brief but forceful head of water will also overflow or shoot from the casing and eductor pipe at the ground surface (Figure 15.15). When the air line is pulled up into the eductor pipe after the first charge of air has been released into the well, the air lift will again pump, thus reversing the flow (water flows into the well) and completing the surging cycle.

The well is pumped until the water clears up, and then another "head" of air is released with the air line set below the eductor pipe. To resume pumping, the air line is again lifted. Surging cycles are repeated until the water is relatively free of sand or other fine particles immediately after the screen has received an air blast. This indicates that development is approaching completion in the region near the bottom of the eductor pipe. The air-lift assembly is then raised to a position

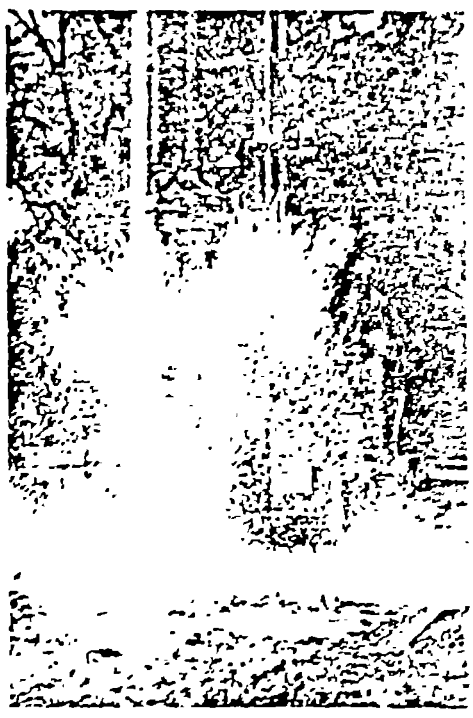


Figure 15.15. During air-lift development, brief but powerful spurts of water will be ejected from the top of the casing. *(Test Drilling Services)*

about 5 ft (1.5 m) higher and the same operations are repeated. In this way, the entire screen is developed in 5-ft intervals. From time to time, the air lift should be lowered to its original position near the bottom of the well and operated as a pump to clean out any sand that has accumulated inside the screen.

Several alternative surging procedures are available In one method, the air line is always retained within the eductor pipe. Surging is accomplished by letting the water column in the eductor pipe fall periodically. The well is then air-lift pumped until the water becomes clear. This cycle is repeated at different levels in the well screen until the well is developed. In another method, the air line is used in the casing and the well casing acts as the eductor pipe. The surging cycle is the same as described above.

Some drillers use an isolated air lift to remove sediment more effectively from the aquifer. Flanged gaskets are mounted on the top and bottom of the isolation tool (Figure 15.16). The gaskets should be snug fitting, but still allow some sediment to move around them so that sand locking does not occur. After the screen has been cleaned out initially, the isolation tool is lowered to the top of the screen and the air line is set at the proper depth. After each zone is developed by surging and air-lift pumping, the tool is lowered to the next section Thus, the formation is developed in separate stages.

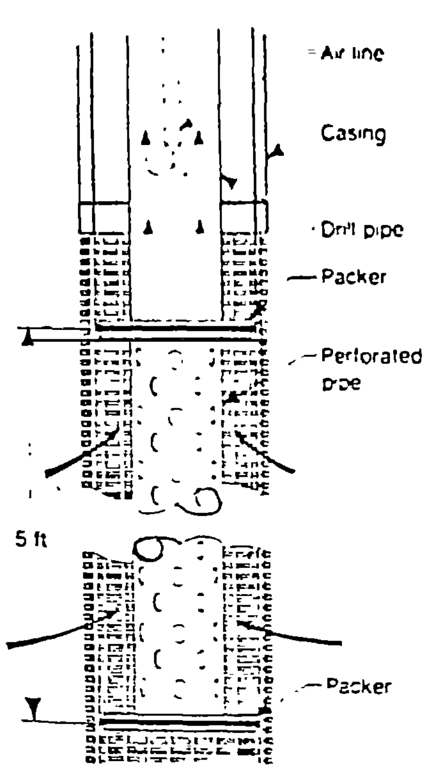


Figure 15.16. Isolation tools are used to focus the energy of air bursts on a specific part of the aquifer and to remove sediment by air lifting

Two development methods — air lift and mechanical surging — are often combined to repair drilling damage and remove fine material from the formation. This combined method is particularly suited to reverse rotary rigs equipped with air-lift assist. In this technique, a double surge-block assembly attached to the drill pipe is raised and dropped rapidly to produce the required turbulence in and near the screen Simultaneously, water is lifted with air inside the drill pipe from the zone isolated by the two surge blocks After the water becomes free of sediment, the assembly is lowered to the next section. This method is especially effective in long screens because it can concentrate the development energy on short sections of the aquifer. It is important to start this procedure at the top of the screen to avoid sand locking the assembly.

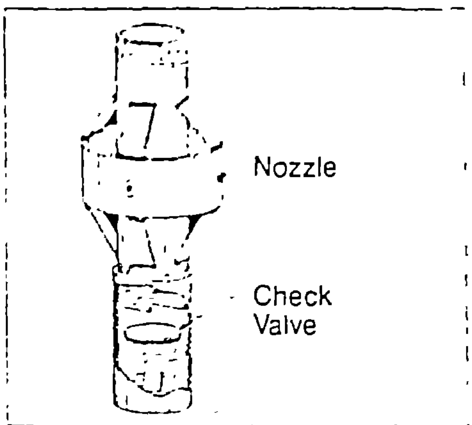
Under some conditions, the aquifer may become air locked when a large burst of air is injected into the screened area of the well. Certain kinds of formations are more prone to air locking especially those formations that consist of stratified, coarse sand or gravel lenses separated by thin, impermeable clay layers. Aquifers with good vertical hydraulic conductivity are generally not affected. Surging with air usually does not lead to air locking. If some air becomes trapped in the aquifer, however, it may impede the flow of water toward the screen. In formations susceptible to air locking, surging with air should be avoided. Other procedures such as high-velocity jetting with water or air may be more suitable in formations where air trapping is a problem.

High-Velocity Jetting

Development by high-velocity jetting may be done with either water or air. In practice, jetting with water is almost always accompanied by simultaneous air-lift pumping so that clogging of the formation does not occur. This dual process is described later in this section and is one of the most effective methods of well development. The jetting procedure consists of operating a horizontal water jet inside the well screen so that high-velocity streams of water shoot out through the screen openings. Jetting is particularly successful in developing highly stratified, unconsolidated formations.

The equipment required for jet development includes a jetting tool with two or more equally spaced nozzles, high-pressure pump, high-pressure hose and connections, string of pipe, and water tank or other water supply. The high-velocity jets force water through the screen openings, agitating and rearranging the particles of the formation surrounding the screen. The filter cake deposited on the borehole in conventional rotary drilling is effectively broken down and dispersed so the drilling fluid that has penetrated the formation can be pumped out. Jetting will also help correct damage to the formation's porosity and permeabilty resulting from drilling.

Figure 15.17 shows a jetting tool with four nozzles. Nozzles should be spaced equally around the circumference of the jetting tool to hydraulically balance the tool during operation; for example, four nozzles should be spaced 90 degrees apart. Best results are obtained if the nozzles are designed for maximum hydraulic efficiency, but horizontal holes drilled in a plugged pipe or coupling will be reasonably effective. The



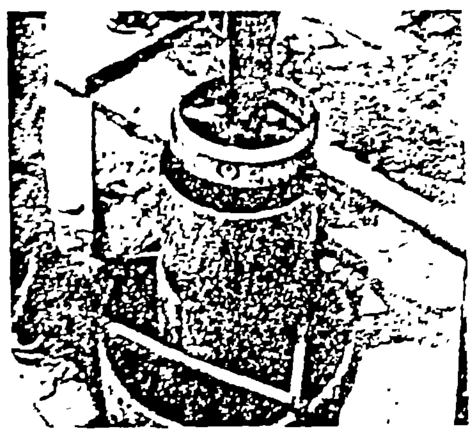


Figure 15.17. Four-nozzle jetting tool designed for jet development of well screens. The check valve allows the jetting tool to be used for intermittent pumping of the well. A plate bottom is often used in place of the check valve if the tool is not to be used for pumping. To avoid breakage, the pipe base of the tool can be made of heavy-wall pipe if it is to be attached to the bottom of the drill pipe. At right, a jetting tool is being lowered into inner casing that has been centered in the surface casing.

jetting tool should be constructed so that the nozzle outlets or holes are as close to the inside diameter of the screen as practical [generally less than 1 in (25.4 mm)].

In many jetting operations, water containing sediment is recirculated through the jetting tool, thereby causing erosion of the nozzle bores and a pronounced pressure reduction at the nozzle face. Erosion of the nozzle bores may be a significant problem if the nozzles are constructed of mild steel. Therefore, all nozzles should be constructed from stainless steel pipe or other abrasion-resistant material. High concentrations of sediment can also damage screens if the jets are directed at one area for long periods. Thus, every effort should be made to limit sediment concentration in water used for jetting.

The lowest nozzle velocity for effective jetting is considered to be about 100 ft/sec (30.5 m/sec). Much better results can be expected when the nozzle velocities are 150 to 300 ft/sec (45.7 to 91.5 m/sec). Velocities higher than 300 ft/sec may not result in sufficient additional benefit to justify the added cost. In fact, velocities obtained by using pressures higher than about 400 psi (2,760 kPa) at the nozzle may cause abrasion, depending on the screen material, the distance between the nozzle and screen body, and the amount of sediment carried in or entrained by the jetting water. In general, 200 psi (1,380 kPa) at the nozzle is the preferred operating pressure for metallic screens. Great care must be exercised in jetting screens constructed of PVC or other less abrasion-resistant materials. All jetting of PVC screens should be done only with clean water to minimize abrasion, and the pressure should not exceed 100 psi (690 kPa). Table 15.2 provides data for nozzles of several sizes at different operating pressures.

The pipe that attaches to the jetting tool should be large enough to minimize friction losses so that velocity at the nozzle is as high as possible. Sizes generally used are given in Table 15.3.

Jetting can be accomplished with virtually any drilling rig, but it is more conveniently done with rotary rigs because the mud pump can supply the required downhole pressure. When using a rotary rig, the jetting tool is attached to the lower end of the drill string and rotation is controlled by the rig. The jetting tool is placed near the bottom of the screen and rotated slowly while being pulled upward at 5 to 15 minutes per foot of screen, depending on the nature of the formation. Material loosened from the formation accumulates at the bottom of the screen as the jetting tool is raised slowly. This material is removed later by air-lift pumping or bailing. By slowly rotating the jetting tool and gradually raising it, the entire surface of the screen is exposed to the vigorous action of the jets. Several passes are made up the screen until the amount of additional material removed from the formation becomes negligible. To avoid erosion of the screen and to expedite development, the jetting tool should never be

Table 15.2. Approximate Jet Velocity and Discharge per Nozzle

Size of Nozzle Orifice		Nozzle Pressure* 100 psi (690 kPa)				Nozzle Pressure* 150 psi (1,030 kPa)				Nozzle Pressure* 200 psi (1,380 kPa)				Nozzle Pressure* 250 psi (1,720 kPa)				Nozzle Pressure* 300 psi (2,070 kPa)			
		Velocity		Discharge		Velocity		Discharge		Velocity		Discharge		Velocity		Discharge		Velocity		Discharge	
in	mm	ft/s	m/s	gpm	m³/day	ft/s	m/s	gpm	m³/day	ft/s	m/s	gpm	m³/day	ft/s	m/s	gpm	m³/day	ft/s	m/s	gpm	m³/day
3/16	4.8	100	30.5	8	44	120	36.6	10	55	140	42.7	12	65	155	47.3	13	71	170	51.8	15	82
1/4	6.4	100	30.5	15	82	120	36.6	15	95	140	42.7	21	114	155	47.3	24	131	170	51.8	26	142
3/8	9.5	100	30.5	34	185	120	36.6	41	223	140	42.7	48	262	155	47.3	53	289	170	51.8	[illegible]	[illegible]
1/2	12.7	100	30.5	60	327	120	36.6	73	398	140	42.7	84	458	155	47.3	94	512	170	51.8	[illegible]	[illegible]

*[illegible]

[illegible]

operated in a stationary position.

In general, the effectiveness of the jetting process is controlled by the open area and slot configuration of the screen and the thoroughness of the jetting operation. The screen should have as much open area as possible, and the openings should be evenly distributed around the circumference of the screen. These conditions permit the jetting action to reach a high percentage of the formation around the screen. The configuration of screen openings can either enhance or retard the velocity of the water as it passes through the screen (Figure 15.18). High-velocity jetting works effectively through V-shaped openings in continuous-slot screens, but it is less useful in punched or louvered pipe where slot configuration impedes access to the formation.

Optimal removal of sediment by jetting will depend on the time allotted to the process. Because the jetting energy can focus on only a small part of the formation at a given moment, more time may be necessary than for other methods that affect a larger portion of the formation. Less satisfactory results from jetting almost inevitably occur when not enough time is allowed for a thorough job.

Jetting with Air

Jetting with air is an alternative to water jetting. In areas where water is not readily available, air jetting is an extremely practical procedure that produces good results in both consolidated and unconsolidated formations. Its use requires less set-up time because, in most cases, air has already been used to drill the borehole. In addition, jetting with air initiates air-lift pumping, which helps remove sediment from the well. Casing size and air-line submergence will affect the efficiency of air-lift pumping. The main disadvantage of air jetting is that many rigs are equipped with compressors having limited pressure capabilities. A 125-psi (862-kPa) compressor, for example, can operate only at starting heads that are less than about 285 ft (86.9 m). Furthermore, the pressure near the bottom of the well may be so great that, even if the compressor can pump air, the actual compressed (air) volume is so small that the amount of turbulence generated may not be sufficient to develop the well effectively at that point. In certain localities, however, additional high-pressure, high-volume air com-

Table 15.3. Minimum Size of Pipe Required to Hold Friction Losses to a Total of Approximately 20 ft (6.1 m) of Head

Pumping Rate		Pipe Length							
		100 ft (30.5 m)		200 ft (61 m)		400 ft (122 m)		600 ft (183 m)	
gpm	m³/day	in	mm	in	mm	in	mm	in	mm
35	191	1½	38	1½	38	2	51	2	51
50	273	1½	38	2	51	2	51	2½	64
75	409	2	51	2	51	2½	64	3	76
100	545	2	51	2½	64	3	76	3	76
150	818	2½	64	3	76	4	102	4	102
200	1,090	3	76	3	76	4	102	4	102
250	1,360	3	76	4	102	4	102	5	127
300	1,640	3	76	4	102	4	102	5	127
350	1,910	4	102	4	102	5	127	5	127
400	2,180	4	102	4	102	5	127	5	127

pressors can be rented to help in the development process

The methodology used in air jetting is the same as that used in water jetting. Because air is a compressible fluid, however, it is not possible to specify anticipated nozzle velocities; the actual (compressed) volume of air emitted from the jetting tool will be controlled by the head of water in the casing (see Chapter 11). Ordinarily, the compressor capacity of typical rotary rigs is sufficient to create enough air to jet effectively in wells 150 to 300 ft (45.7 to 91.5 m) deep. For water well work, the nozzle sizes for an air-jetting tool are approximately the same size as those for a water-jetting tool.

In formations susceptible to air locking, an air-jetting tool with small holes drilled in the bottom should be used to develop the formation. Air coming out the bottom of this special jetting tool enhances the efficiency of the air lift, thereby entraining water, sediment dislodged by the jets, and air that could become trapped in the adjacent sediments. The tool can be pulled up periodically within the casing and used

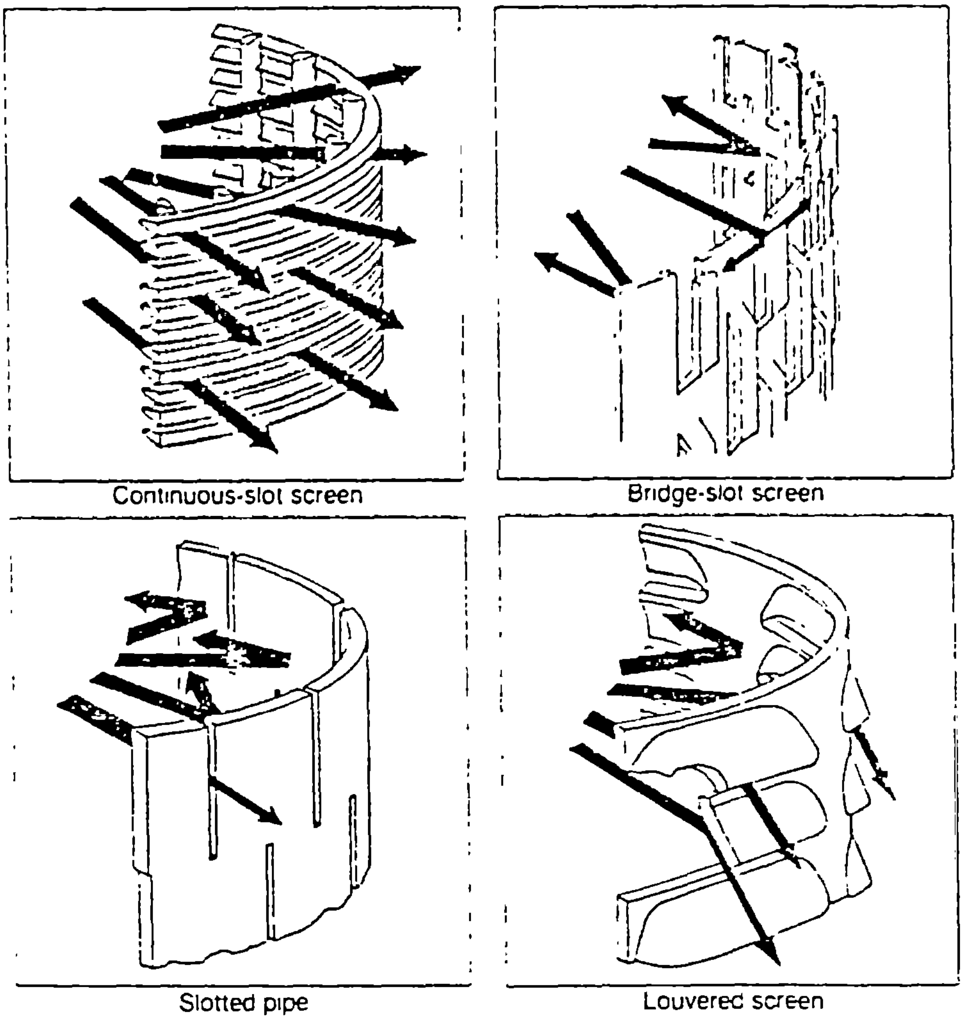


Figure 15.18. The open area of the screen and the configuration of the slot openings are important factors controlling the effectiveness of development procedures using water jetting.

solely as a conventional air-lift device.

In conclusion, development by jetting offers several advantages. Energy is concentrated over a small area with great effectiveness, every part of the screen can be covered selectively, and it is relatively simple to apply and is not likely to cause trouble from overapplication. Although water jetting imparts a more powerful force into the formation compared with air jetting, an air lift usually occurs during air jetting which assures that fines will be drawn out of the formation efficiently. In water jetting, water is being added to the formation so that fine material may not move into the screen quite as readily.

High-Velocity Water Jetting Combined with Simultaneous Pumping

Although water jetting procedures are extremely effective in dislodging material from the formation, maximum development efficiency is achieved when water-jetting procedures are combined with simultaneous air-lift pumping or other pumping methods (Figure 15.19). This combination of development techniques is particularly successful for wells in unconsolidated sands and gravels. In water jetting, water is added to the well at a rate governed by the nozzle size and the pump pressure. The volume of water pumped from the well should always exceed the volume pumped in during jetting because sediment removal is greatly enhanced with higher discharge. Thus, the water level in the well will be kept below static level and some water will move continuously from the formation into the well screen as the work proceeds. The steady movement of water into the well helps remove some of the suspended material loosened by the jetting operation. The air lift then pumps the sediment from the well before it can settle in the screen.

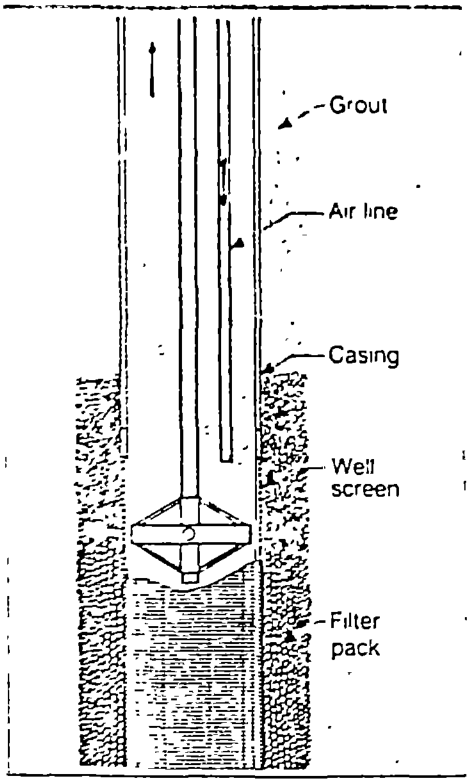


Figure 15.19. The jetting tool and drop pipe are separate from the air line so that jetting and air-lift pumping can be done simultaneously.

Table 15.1 lists the air-line diameters recommended to pump certain volumes of water. Occasionally, the size of the air line may have to be decreased somewhat so that it fits into the annulus between the jetting pipe and the casing. Another alternative is to decrease the size of the jetting pipe. The air-lift system operates best when the bottom of the air line is placed just above the jetting tool, because more suspended sediment will be carried up the borehole. When using high-velocity jetting procedures, development should start at the bottom of the screen.

The jetting water is usually clean water hauled to the drill site. In instances where sufficient water supplies are unavailable, the contractor may use the water pumped from the well. To avoid damaging the high-pressure pump, jetting nozzles, and screen, however, the fine sand pumped from the well should be settled out in a tank or settling pit before this water is recirculated. To enhance the development process, chemicals such as polyphosphates are often added to the jetting water to help break-up clays.

When air-lift pumping is impractical, a submersible pump can be used during jetting. Usually the pump must be placed well above the jetting tool so that the amount of sand passing through the pump is minimized. Thus, the pump causes material temporarily placed in suspension by the jetting action to move into the screen, but much of the material falls to the bottom. This sediment must be removed periodically during the jetting and pumping operation so the entire screen is developed.

A COMPARISON OF THREE DEVELOPMENT METHODS

Certain development methods exert more powerful cleaning forces on the formation than do others, and thus are better able to remove the drilling fluid and create a zone of high porosity and hydraulic conductivity around the screen. Results from an experimental well field at the Irrigation Research Center at Staples, Minnesota demonstrate the relative differences in three development methods. Ten irrigation wells were constructed at Staples in surficial glacial outwash, using three types of well screens. This site was chosen because of the highly uniform nature of the aquifer. All wells were drilled by the direct rotary drilling method. Two different drilling fluid additives were used — bentonite and polymer. After well construction, each screen was developed in three stages, first by overpumping, second by mechanical surging, and third by water jetting and simultaneous air-lift pumping. Each development method was continued until the water was essentially sand free. A 24-hour pumping test was conducted after each of the three development episodes, data were acquired, analyzed, and stored with the aid of a computer system. The Staples investigation is one of the few scientific studies conducted in a uniform aquifer that examines many of the well construction and completion variables that affect development.

Results of the study show that the average specific capacities of the wells drilled with bentonite improved 74 percent when overpumping was followed successively by mechanical surging and simultaneous water jetting/air-lift pumping (Figure 15.20). Drawdown data suggest overpumping is the least effective of these three development methods, whereas simultaneous water jetting/air-lift pumping removed sediment and drilling fluid that the other development methods could not dislodge. In general, test data from Staples show that the eventual specific capacity of a well depends to a great extent on what development method is used.

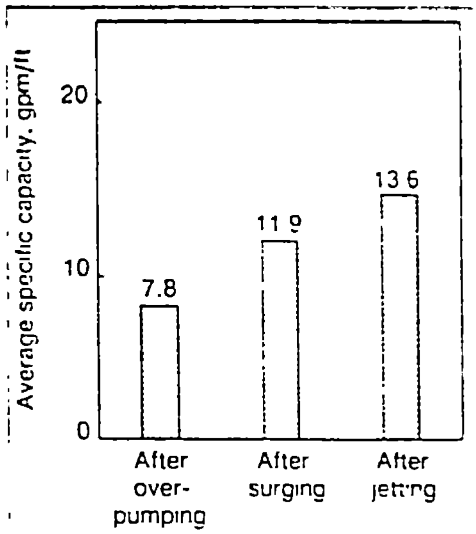


Figure 15.20. Average specific capacities of wells drilled with bentonite, after various development methods. Individual specific capacities were measured when no more sediment could be dislodged from the formation by a particular development method. (Werner et al., 1980)

As suggested earlier in this chapter, the improvement in specific capacity achieved by any development method may be seriously retarded because of limited open area. For the wells drilled with bentonite, those completed with screens having more than 15 percent open area had 52 percent greater specific capacities than those completed with screens having less than 15 percent open area (Figure 15.21). As the open area of the screen is increased, the enhanced effectiveness of the development causes a corresponding increase in specific capacity.

The specific capacity of a well is also a function of which drilling fluid is selected For each development episode, wells drilled with polymer averaged 56 percent higher specific capacities than did the wells drilled with bentonite (Figure 11.21, page 362) (Werner et al., 1980). This difference occurs because some of the bentonite penetrates farther into the formation during the drilling process than any development method can réach. On the other hand, polymeric drilling fluids beyond the reach of a development method simply break down naturally over time and thus offer no resistance to flow.

USE OF POLYPHOSPHATES IN DEVELOPMENT

Adding a small amount of a polyphosphate before or during development helps considerably in removing clays that occur naturally in the aquifer and those clays introduced into the borehole as part of the drilling fluid Polyphosphates disperse the clay particles in the formation so they can be removed. Enough time must be allowed between introduction of the polyphosphate and development, usually overnight, so the clay masses become completely disaggregated (see Chapter 11). After the polyphosphate solution is jetted or surged into the screen, water should be added to the well to drive the solution farther into the formation.

Two types of polyphosphates are used in well development — crystalline and glassy. Crystalline polyphosphates that help remove clays from the aquifer are sodium acid pyrophosphate (SAPP), tetrasodium pyrophosphate (TSPP), and sodium tripolyphosphate (STP). Sodium hexametaphosphate (SHMP) is a glassy phosphate that is readily available and therefore often used in developing wells. About 15 lb (6.8 kg) of a polyphosphate should be used for each 100 gal (0.4 m³) of water in the screen. Two pounds (0.9 kg) of sodium hypochlorite (3 to 15 percent chlorine solution) also should be added to every 100 gal of water in the well to control bacterial growth promoted by the presence of polyphosphates.

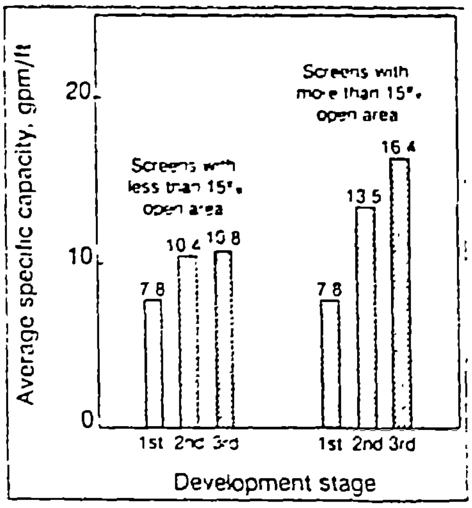


Figure 15.21. Open area of the well screen controls the effectiveness of various development methods for wells drilled with bentonite. In general, development is most effective when the screen open area is the largest. *(Werner et al., 1980, Driscoll et al., 1980a)*

Polyphosphates should be premixed before introduction into the well because they do not mix easily with cold water. Occasionally the mix water is heated to help dissolve the chemical. In general, the lighter the density, the more quickly the polyphosphate will go into solution. Sodium tripolyphosphate, for example, is available in three densities. If the polyphosphate is jetted, some contractors use a solution with twice the recommended concentration. A larger amount of polyphosphate, however, does not give significantly better results when used for drilling fluid dispersion and, under certain conditions, may cause serious problems.

Care must be exercised if SHMP is used because the phosphate can become glassy in the well under certain conditions, causing severe plugging of the formation and screen. For example, an over-rich solution of SHMP can precipitate glassy phosphates on contact with the cold groundwater found typically in northern Europe and southern Canada. These glassy precipitates are gelatinous masses that are extremely difficult to remove because no effective solvents exist. Acids will break down the glassy condition eventually, but the time required is impractical for efficient well development. Therefore, glassy phosphates should never be dumped undissolved into a well. The use of a glassy phosphate also can be undesirable in certain formations. Although little is known about the exact chemical conditions that may cause the phosphate to become semisolid in a borehole, experience has shown that the use of SHMP can be a problem in glauconitic sandstones. SHMP is available in plate form, crushed, or as a powder, which affects the density of the product.

The addition of wetting agents to polyphosphates will increase their effectiveness in disaggregating clays. One pound (0.5 kg) of wetting agent (for example, Pluronic F-68) is added to 100 gal (0.4 m³) of polyphosphate solution. Wetting agents and polyphosphates should not be used in formations with thinly bedded clays and sands, because these chemicals tend to make the clays near the borehole unstable, causing them to mix with the sand. The hydraulic conductivity of the aquifer near the borehole is then reduced and clay continually passes into the borehole during each pumping cycle.

CHAPTER 19

Well and Pump Maintenance and Rehabilitation

Well rehabilitation is defined as restoring a well to its most efficient condition by various treatments or reconstruction methods. The necessity for well rehabilitation will depend on the effectiveness of the maintenance program and how faithfully it has been followed. In some cases, a major reconstruction of the well may be necessary such as replacing the screen or lining a portion of the casing. Timely maintenance designed to overcome specific problems can sustain well performance, thereby prolonging well life.

Effective maintenance programs begin with well construction records showing geologic conditions, water quality and pumping performance, especially specific capacity. A careful study of the operating history of other wells in the local region should suggest logical steps for devising maintenance schedules or rehabilitation procedures. So many variables are involved, however, that a single maintenance program cannot be devised that will work for every hydrogeologic condition and every type of well.

Inspection and routine maintenance schedules must be established on the basis of the individual characteristics of the well and pump. It is important to take note of any changes in the operating characteristics of the well and pump, because both can deteriorate to the point where rehabilitation is difficult, if not impossible. Experience indicates that if the specific capacity of a well declines by 25 percent, it is time to initiate rehabilitation procedures. Further neglect increases costs for maintenance significantly.

To determine any loss in performance, some reference mark will be needed. Performance standards are established by conducting a pumping test as part of the completion of every new well. The data from this test should be given to the owner in the form of a written report. This will allow the well owner to monitor the performance of the well to detect any drop in yield. These data also guide a rehabilitation contractor in devising an appropriate rehabilitation procedure. A form listing the important information to be retained at the well site is in the pocket of this book.

Loss of a major water supply, even temporarily, is intolerable in many cases. Therefore, ongoing performance evaluation of the well is mandatory if well failures are to be avoided. The checklist below can be used to evaluate the performance of a well:

- What is the static water level in the production well?
- What is the pumping rate after a specified period of continuous pumping?
- What is the pumping water level after a specified period of continuous pumping?
- What is the specific capacity after a specified period of continuous pumping?
- What is the sand content in a water sample after a specified period of continuous pumping?
- What is the total depth of the well?
- What is the efficiency of the well?
- What is the normal pumping rate and how many hours per day does it operate?
- What has been the general trend in water levels in wells in the area?
- How much drawdown is created in the production well because of pumping of nearby wells?

A significant change in any of the first 7 conditions listed above indicates that a well or pump is in need of attention. For instance, a decline in the specific capacity might indicate plugging of the screen-slot openings.

Once inspection procedures have been established, they should be followed in every subsequent inspection. The pumping tests, for example, should be run for the same length of time at the same rate, and have the same period of recovery. Local well-drilling or pump-maintenance contractors are helpful in establishing procedures, and sometimes offer maintenance contracts. These individuals retain records of all maintenance they perform and provide written reports to the well owner. A typical pumping (aquifer) test data form that can be used for maintenance evaluation is in the pocket of this book.

After the pumping-test data have been recorded, they can be compared with the original numbers and an evaluation made regarding any decline in the well's performance since the last survey. Storage of well records can be facilitated by the use of computers. For relatively low cost, complete well records can be maintained that can help forecast when maintenance and rehabilitation work should be undertaken.

Table 19.1 lists the most prevalent well problems occurring in various types of aquifers and the typical maintenance frequency required. The maintenance figures in Table 19.1 are based on wells constructed to locally acceptable design and construction standards in the United States that may not be consistent with the best materials or methods available. Therefore, although these maintenance schedules are realistic in light of the materials and construction methods used, they probably indicate greater frequencies than would be anticipated if the best technology were used.

MAJOR CAUSES OF DETERIORATING WELL PERFORMANCE

Five major problems occur with wells over time. The first involves a reduction in the well yield. Well yield may be reduced by chemical incrustation or biofouling of the well screen and the formation materials around the intake portion of the well. Deteriorating screen and formation conditions can be alleviated by the maintenance procedures discussed below. Of course, other environmental factors either natural or manmade, may lead to reduced yields, but correction of these conditions may be difficult or impossible because of political, engineering, or natural constraints. For example, a general drop in the water table caused mainly by short- or long-term climatic trends will reduce well yield, as will interference from nearby wells. Also, the pumping level may drop over time in wells pumped continuously when the transmissivity of the aquifer limits the amount of water that can reach the wells, even

Table 19.1. Most Prevalent Well Problems Occurring in Various Types of Aquifers and the Typical Maintenance Frequency Required

Aquifer Type	Most Prevalent Well Problems*	Major Maintenance Frequency Requirement (Municipal)
Alluvial	Silt, clay, sand intrusion; iron precipitation; incrustation of screens, biologic fouling; limited recharge; casing failure	2-5 years
Sandstone	Fissure plugging; casing failure, sand production; corrosion	6-10 years
Limestone	Fissure plugging by clay, silt, and carbonate scale	6-12 years
Basaltic lavas	Fissure and vesicle plugging by clay and silt; some scale deposition	6-12 years
Interbedded sandstone and shale	Low initial yields, plugging of aquifer by clay and silt; fissure plugging; limited recharge; casing failure	4-7 years
Metamorphic	Low initial yield, fissure plugging by silt and clay; mineralization of fissures	12-15 years
Consolidated sedimentary	Fissure plugging by iron and other minerals; low to medium initial yield	6-8 years
Semiconsolidated and consolidated sedimentary	Clay, silt, sand intrusion; incrustation of screens in sand and gravel wells; fissure plugging of limestone aquifers in the interbedded sand, gravel, marl, clay, silt formations; biologic fouling; iron precipitation	5-8 years

*Excluding pumps and declining water tables.

Estimates of major maintenance frequencies are based on the following assumptions:

1 Wells are being pumped continuously at the highest sustained rate they are capable of producing
2 Major maintenance is required when the sustained yield decreases to 75 percent of the initial yield
3 Major maintenance is considered to represent a cost expenditure of approximately 10 percent of the total current replacement cost. Minor maintenance is excluded.
4 Wells are designed in accordance with current practices, not necessarily in accordance with best available technology

(After Gass et al.)

though enough water may exist in the aquifer on a regional basis.

Plugging of the formation around the well screen by fine particles is the second factor in deteriorating well performance. Small particles in most unconsolidated formations are disturbed during pump cycling, and while temporarily in suspension they move gradually toward the screen. This same phenomenon apparently occurs in wells constructed in igneous and metamorphic rock, where the original specific capacity is often reduced 10 to 20 percent within a few months of operation. Small particles accumulate in the cracks, fissures, joints, fractures, or cavities that provide most of the water to the well.

The third factor in well failure is the onset of sand pumping. Some wells always pump sand, a condition usually attributable to poor well design or inadequate development. Other wells may begin to pump sand after months or years of service. Localized corrosion of the well screen or casing, or incrustation on only a portion of the screen, can produce higher velocities through either the corroded openings or the nonincrusted areas of the screen. Sand grains moved by these higher velocities may erode and enlarge the screen openings mechanically, allowing larger grains to enter the screen (Figure 19.1). Thus, corrosion and incrustation are major factors in sand pumping problems that develop over time. In some well-cemented sandstones removal of the cement by water passing into the well can weaken the sandstone to the point where sand particles begin to move into the well. If this situation occurs, sand pumping may increase steadily.

The fourth cause of well failure involves the structural collapse of the well casing or screen. This type of failure is often produced by low-pH (acidic) waters containing high total dissolved solids and carbon dioxide concentrations that combine to cause electrolytic corrosion along the casing below the static water level.

Figure 19.1. Erosion of this well screen resulted from incrustation that caused high flow velocities through the remaining open area.

The last factor affecting well performance, although indirectly, is the condition of the pump. Mistakes in the design and construction of the well can cause severe damage to the pump over time. The impellers, impeller housing, and pump shaft are particularly susceptible to sand pumping. Corrosion of pump parts is also another serious problem in low-pH waters. Either of these conditions can drastically reduce the efficient life of the pump.

WELL FAILURE CAUSED BY INCRUSTATION

Chemical and biological incrustation are major causes of well failure. Water quality chiefly determines the occurrence of incrustation. The surface characteristics of the screen itself may also play a part in regulating the rate at which incrustation occurs. If the screen is constructed of rough-surface metal, for example, incrustants may build up at a faster rate. The kind and amount of dissolved minerals and gases in natural waters determine their tendency to deposit mineral matter as incrustation.

Groundwater normally moves slowly through soil, sand, and gravel, and is in contact with the minerals of these earth materials for hundreds to thousands of years. The time is so long that the water, with its dissolved mineral salts, is in quasi-chemical equilibrium with its environment. Thus, the water may be nearly saturated with the major minerals in the aquifer materials. Any change in the chemical or physical conditions upsets the equilibrium and may cause precipitation of relatively insoluble materials. The chemical equilibrium is upset when the well is pumped; in general, the greater the drawdown, the greater the disequilibrium will be.

Deposition of only a minute fraction of the minerals in the water will cause serious clogging. If material is dropping out of the water entering a screen 20 ft (6.1 m) long, 12 in (305 mm) in diameter, and pumping 500 gpm (2,730 m^3/day) at a rate of 1 mg/l, a deposit of 6 lb (2.7 kg) per 24 hours would result. Assume the material is half calcium carbonate and half magnesium carbonate, with an average specific gravity of 3.0. If the porosity is 20 percent, all of the voids in the sand through a thickness of 6 in (152 mm) outside the screen would be completely filled in 293 days.

The incrustation often forms a hard, brittle, cementlike deposit similar to the scale found in water pipes. Under different conditions, however, it may be a soft, pastelike sludge or a gelatinous material. The major forms of incrustation include: (1) incrustation from precipitation of calcium and magnesium carbonates or their sulfates; (2) incrustation from precipitation of iron and manganese compounds, primarily their hydroxides or hydrated oxides; and (3) plugging caused by slime-producing iron bacteria or other slime-forming organisms (biofouling).

Causes of Carbonate Incrustation

Chemical incrustation usually results from the precipitation of carbonates, principally calcium, from groundwater in the proximity of the well screen. Other substances, such as aluminum silicates and iron compounds, may also be entrapped in the scalelike carbonates that cement sand grains together around the screen. The deposit fills the voids, and the flow of water into the well is reduced proportionately.

The probable explanation for this phenomenon is as follows. Calcium carbonate can be carried in solution in proportion to the amount of dissolved carbon dioxide in the groundwater. The ability of water to hold carbon dioxide in solution varies with pressure — the higher the pressure, the higher the concentration of carbon dioxide. When water is pumped from a well in an unconfined aquifer, the water table is drawn down to produce the necessary gradient or pressure differential in the water-bearing formation to cause water to flow into the well. The hydrostatic pressure in the deeper portions of the water-bearing formation is thus decreased, with the greatest change being at the well. Because of the reduction in pressure, some carbon dioxide is released from the water. When this occurs, the water is often unable to carry its full load of dissolved calcium carbonate and part of this material is then precipitated onto the well screen and in the formation materials adjacent to the well screen. Pumping a well in a confined aquifer produces a similar pressure reduction and resulting precipitation.

Formation of calcium carbonate precipitate from calcium bicarbonate is the classic example:

$$Ca(HCO_3)_2 \xrightarrow{-\Delta P} CaCO_3\downarrow + CO_2\uparrow + H_2O$$

where ΔP is a change in pressure. Solubility of calcium bicarbonate on the left side of this equation is about 1,300 mg/l; solubility of calcium carbonate on the right side is about 13 mg/l. Carbon dioxide (CO_2) escapes when the head, or pressure, is reduced.

Magnesium bicarbonate changes to magnesium carbonate in the same manner when the carbon dioxide is released, but magnesium carbonate incrustation occurs only in special instances because it is still soluble at concentrations over 5,000 mg/l (Kemmer, 1979). Precipitation occurs, therefore, only when the carbonate concentration exceeds this level.

Causes of Iron and Manganese Incrustation

Many rocks throughout the world contain iron and manganese, and are the source of iron and manganese ions found in groundwater if the pH is about 5 or less. During pumping, velocity-induced pressure changes can disturb the chemical equilibrium of the groundwater and result in the deposition of insoluble iron and manganese hydroxides. These hydroxides have the consistency of a gel, and may occupy relatively large volumes; over time, they harden into scale deposits. Dissolved iron is affected by pressure reduction as indicated:

$$Fe(HCO_3)_2 \xrightarrow{-\Delta P} Fe(OH)_2\downarrow + 2CO_2\uparrow$$

Solubility of ferrous hydroxide on the right side of this equation is less than 20 mg/l. If oxygen is introduced by aeration during pumping, additional precipitation of ferric hydroxide occurs:

$$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3\downarrow$$

Solubility of ferric hydroxide on the right side of this equation is less than 0.01 mg/l.

Soluble manganese becomes insoluble in the same way as iron

$$2Mn(HCO_3)_2 + O_2 + 2H_2O \rightarrow 2Mn(OH)_4\downarrow + 4CO_2\uparrow$$

Further oxidation of the hydroxides of iron and manganese, or an increase in pH, causes the formation of hydrated oxides containing these ions. Ferrous iron in solution, for example, can react with oxygen to form ferric oxide

$$2Fe^{++} + 4HCO_3^- + H_2O + \tfrac{1}{2}O_2 = Fe_2O_3 + 4CO_2 + 3H_2O$$

The ferric oxide is a reddish brown deposit similar to rust, whereas the hydrated ferrous oxide is a black sludge. The insoluble manganese oxide is also black or dark brown. Iron and manganese deposits are often found associated with calcium- and magnesium-carbonate scale.

Sometimes the chemical deposits are hardly noticeable. For example, samples of the formation sand adjacent to well screens at a city in Michigan, an industrial plant in northern Indiana, and a plant in southern Illinois revealed no extraneous material in the sand voids, but all the sand particles were coated with hydrated iron oxide These wells had suffered severe reduction in specific capacity over a period of three or four years. It is also quite possible that ferrous hydroxide, a white and fluffy precipitate, had been lodged in the voids of the formation but was broken up when the samples were taken and was unnoticeable.

In the cone of depression around a well in an unconfined aquifer, air enters the voids and oxidizes iron in the films of water adhering to individual sand grains. If pumping is started and stopped intermittently, a coating of iron oxide can build up, thereby gradually reducing the void space in this part of the formation. This action reduces the formation's storage capacity in the vicinity of the well, and the cone of depression enlarges more rapidly than it would otherwise.

Prevention and Treatment of Incrustation Problems

Thus far, a means of preventing the incrustation of well screens has not been found One unique method does exist, however, that is designed to reduce the amount of iron incrusting materials reaching the well screen. This method, called the Vyredox System, uses a series of injection wells located in a circle around the production well Oxygenated water is injected into the wells to oxidize iron in solution and promote the growth of iron bacteria so that little iron reaches the production well. See Chapter 23 for a more detailed description of this method.

For most wells where incrusting materials cannot be removed before reaching the well, several actions can be taken to delay incrustation and make it a less serious problem. First, the well screen should be designed to have the maximum possible inlet area to reduce the flow velocity to a minimum through the screen openings Second, the well should be developed thoroughly. Third, the pumping rate may be reduced and the pumping period increased, thereby decreasing entrance velocities. Fourth, the pumping load may be divided among a larger number of smaller diameter wells instead of obtaining all of the supply from only one or a few larger diameter wells

Fifth, a more frequent maintenance or cleaning procedure for each well should be practiced wherever local experience shows considerable difficulty from incrustation. In these areas, a qualified water well contractor should be called to perform the necessary maintenance. Corrective measures should not be put off until drastic means must be taken. Contractors generally know the best procedure to use from their past experience in the local area.

In localities where incrustation of wells is prevalent, samples of the incrusting materials and the water should be analyzed. Samples of the incrustants can often be obtained from the outer surfaces of pumps, suction pipes, or well screens. The constituents will normally include calcium carbonate, iron oxide, silica, aluminum silicate, or organic material. The material causing the clogging will usually be a mixture of several things, not a single substance. Recent research has shown, for example, that incrustants on the outside of a well screen may consist of precipitated elements from the groundwater, whereas most of the depositional products on the inside of the screen originate from the screen itself (Figure 19.2a and b). The proportions of the various substances shown by the chemical analysis should indicate the kind of treatment and the type of chemicals that would be most successful in recovering well yield.

Acid Treatment of Wells

Chemical incrustation can best be removed by treating the well with a strong acid solution that chemically dissolves the incrusting materials so they can be pumped from the well. Strong acids are used more often than any other type of chemical for well rehabilitation. Their chief value lies in their ability to dissolve mineral scale as well as some of the iron deposits formed by iron bacteria. The acids most commonly used in well rehabilitation are hydrochloric (HCl), sulfamic (H_3NO_3S) and hydroxyacetic ($C_2H_4O_3$).

Hydrochloric (Muriatic) Acid

Hydrochloric acid (prepared commercially under the name muriatic acid) is one of the most effective acids for removing mineral scale. Commercially prepared hydrochloric acid is a clear to yellowish solution of hydrogen chloride gas dissolved in water. It is available in several strengths that are identified by degrees Baumé*; common strengths are 18 and 20 degrees Baumé which are 28 and 31 percent hydrochloric acid, respectively. Hydrochloric acid is commonly ordered with an inhibitor that minimizes the acid's corrosive effect on metal wells screens, casing, and pump components.

In treating wells, hydrochloric acid is usually introduced into the well screen by conducting it from ground surface through a small-diameter plastic or black iron pipe. It is best to use a quantity of acid equal to the amount of water in the screen plus an additional volume of 25 to 50 percent. To reach farther into the formation, acid volumes of up to twice the screen volume can be used. Table 19.2 shows the proper amount of hydrochloric acid to use in small- and large-diameter wells.

Although it is an extremely effective well cleaner, hydrochloric acid has a number of drawbacks. It is extremely dangerous to handle. Once placed in the well, the acid produces large quantities of toxic fumes that are expelled from the well bore within moments. Inhalation of these toxic fumes will cause death, and contact of the liquid with human tissue can easily result in serious injury.

Figure 19.2a. Incrustants have formed on the inside and outside of this steel pipe-based well screen that is wrapped with a slotted-brass filter. Visual examination of the incrustants suggests that the porous incrustants on the inside of the screen contain different minerals than the dense, well-bonded incrustants on the outside.

Sulfamic Acid

Sulfamic acid† is a dry, white, granular material that produces a strong acid when mixed with water. Its solubility in water increases with temperature, ranging from

*Degrees Baumé is a scale referring to the specific gravity of the solution as determined by the acid concentration. As the degrees Baumé increase, the strength of the solution also increases.

†Also known as aminosulfonic, amidosulfonic, and amidosulfuric.

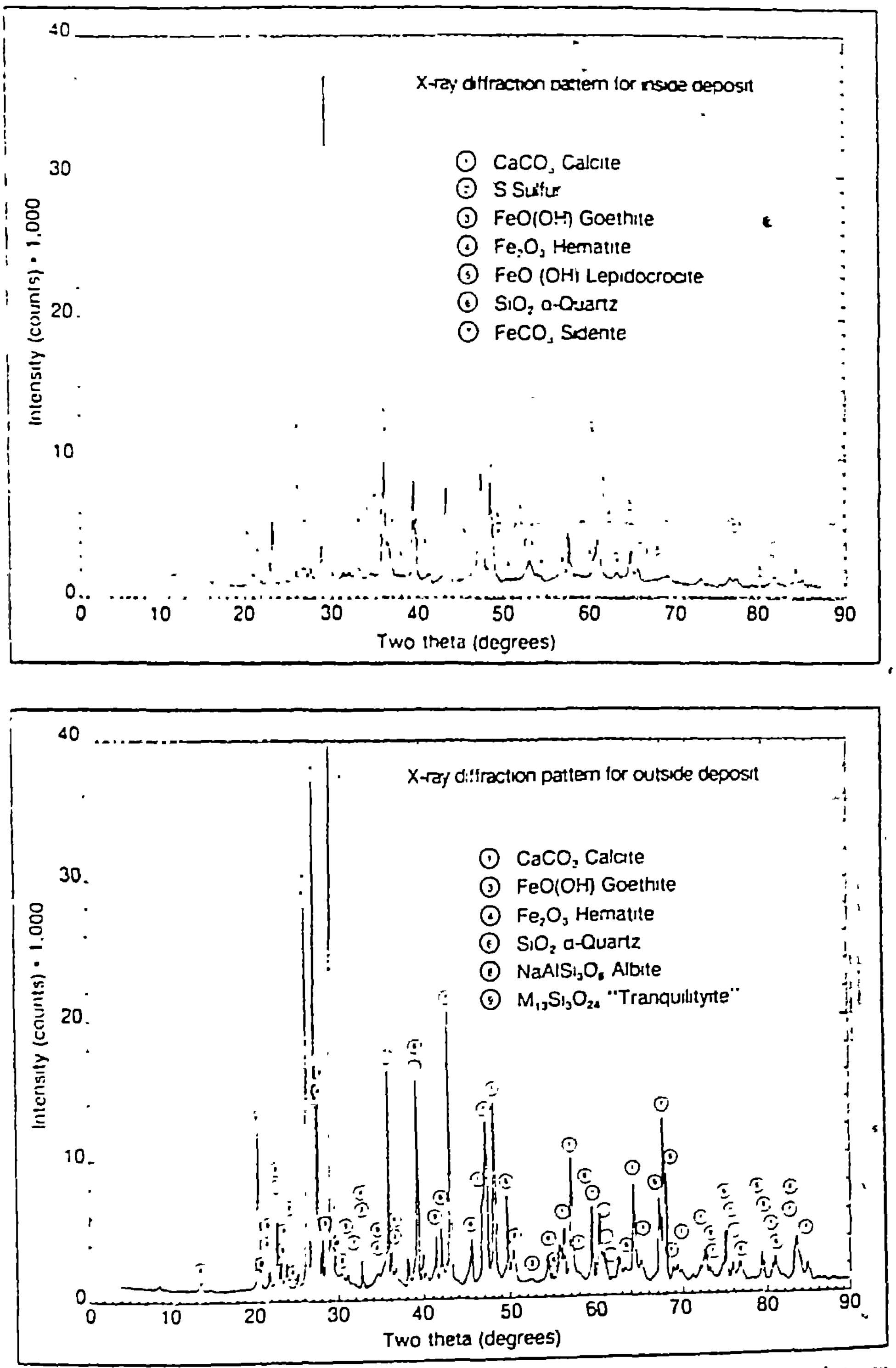


Figure 19.2b. Comparison of the x-ray diffraction patterns illustrates the chemical differences between incrustants. The incrustants on the inside of the screen consist principally of goethite, siderite, and lepidocrocite, which are indicative of iron and steel corrosion. Incrustants on the outside of the screen are derived mainly from the groundwater and include calcite, quartz, hematite, albite, and goethite.

15 to 20 percent by weight at most prevailing groundwater temperatures.

Although it is more expensive than hydrochloric acid and is less aggressive, sulfamic acid offers a number of advantages. In its dry form, it is relatively safe to handle; the dry material does not give off fumes and will not irritate dry skin. If spillage occurs, it may be cleaned up easily and safely, thus providing for safer shipping and handling. If mixed at the surface, however, sulfamic acid should be handled as if it were hydrochloric acid. During treatment, this slowly dissolving acid releases dangerous fumes at a relatively slow rate; nevertheless, proper ventilation should always be provided. Less corrosion of pumps, screens, and casings will occur when an inhibitor is added to the acid. For example, little corrosion results when stainless steel well screens are treated repeatedly with an inhibited sulfamic acid. Sulfamic acid is available in pelletized, granular, and powdered form. The pelletized form is used in wells completed with relatively short screens where the screens are located at the bottom of the well. Because the pellets are heavier than water, they sink through the column of water standing in the casing and then dissolve inside the screen. The pellets should

Table 19.2. Amount of Hydrochloric Acid Required to Treat an Incrusted Screen

Screen Diameter		Amount of HCl Acid (18° to 20° Baumé) per ft (0.3 m) of Screen	
in	mm	Gallons	Liters
1½	38	0.11 - 0.14	0.42 - 0.53
2	51	0.20 - 0.24	0.76 - 0.91
2½	64	0.33 - 0.39	1.25 - 1.48
3	76	0.46 - 0.56	1.74 - 2.12
3½	89	0.63 - 0.75	2.38 - 2.84
4	102	0.81 - 0.98	3.07 - 3.71
4½	114	1.04 - 1.25	3.94 - 4.73
5	127	1.28 - 1.53	4.84 - 5.79
5½	140	1.54 - 1.85	5.83 - 7.00
6	152	1.84 - 2.21	6.96 - 8.36
7	178	2.50 - 3.00	9.5 - 11.4
8	203	3.26 - 3.92	12.3 - 14.8
10	254	5.10 - 6.12	19.3 - 23.2
12	305	7.35 - 8.82	27.8 - 33.4
14	356	10.0 - 12.0	37.9 - 45.4
16	406	13.1 - 15.7	49.4 - 59.4
18	457	16.5 - 19.8	62.6 - 75.1
20	508	20.4 - 24.5	77.2 - 92.7
22	559	24.7 - 29.6	93.5 - 112
24	610	29.4 - 35.3	111 - 133
26	660	34.5 - 41.4	131 - 157
28	711	40.0 - 48.0	151 - 182
30	762	45.9 - 55.1	174 - 208
32	813	52.2 - 62.7	198 - 237
34	864	59.0 - 70.7	223 - 268
36	914	66.1 - 79.3	250 - 300

dissolve in approximately 4 hours if oversaturation does not occur. Agitation of the water in the screen increases the solution rate of the chemical. The proper quantity of pelletized sulfamic acid required to treat the well is generally determined by the length and diameter of the well screen or by the weight of water standing in the screen. Table 19.3 shows the proper quantities of Nu-Well', a pelletized sulfamic acid, to use for small- and large-diameter screens less than 100 ft (30.5 m) long.

The granular form of sulfamic acid is generally used when acidizing long screens [greater than 100 ft (30.5 m)] or screens separated by casing. It is usually dumped directly into the casing, where it saturates the entire column with acid. The acid goes into solution as the granules descend slowly in the casing. Enough clear water is then added to force the volume of acid standing in the casing above the screen into the formation. For deep wells with high static water levels, granular or powdered acid should be premixed at the surface so it can be piped to the intake portion of the well. A 10-percent solution of granular sulfamic acid is sometimes used for long screens, although a 30-percent solution provides better results.

Sulfamic acid is particularly useful in treating calcium and magnesium incrustants, but is less effective when iron or manganese incrustants are present. The addition of rock salt to sulfamic acid, however, will increase the acid's ability to dissolve iron deposits. Approximately 2 lb (0.9 kg) of rock salt are added to 10 lb (4.5 kg) of Nu-

Table 19.3. Amount of Nu-Well' Required to Treat a Moderately Plugged 1-ft (0.3-m) Section of Screen

Screen Diameter (Pipe Size)		Screen Capacity		Nu-Well Required	
in	mm	gal/ft	l/m	lbs/ft	kg/m
1½	38	0.1	1.2	0.2	0.3
2	51	0.2	2.5	0.4	0.6
3	76	0.4	5.0	0.9	1.3
4	102	0.7	8.7	1.6	2.4
5	127	1.0	12.4	2.6	3.9
6	152	1.5	18.6	3.7	5.5
8	203	2.6	32.3	6.5	9.7
10	254	4.1	50.9	10.2	15.2
12	305	5.9	73.2	14.7	21.9
14	356	8.0	99.3	20.0	29.8
16	406	10.4	129	26.1	38.9
18	457	13.2	164	33.0	49.2
20	508	16.3	202	40.8	60.8
22	559	19.8	246	49.4	73.6
24	610	23.5	292	58.7	87.5
28	711	32.0	397	80.0	119
30	762	36.7	455	91.8	137
32	813	41.8	519	104	156
34	864	47.2	586	118	176
36	914	52.9	657	132	197

The quantities of Nu-Well' are equal to 30 percent of the weight of water in the well screen. This ratio is used for treating relatively short screens that have been affected by moderate incrustation.

Well* (20 percent of the weight of the acid) to create a solution that will treat iron and manganese incrustants.

Sulfamic acid reacts chemically with mineral deposits in the same manner as hydrochloric acid, although at a slower rate. Consequently, longer contact time is usually required to achieve the same results; at least 15 hours is recommended. The effectiveness of the treatment is enhanced considerably if the acid is agitated while and immediately after it dissolves. Forceful agitation is also recommended before the acid is pumped to waste.

Sulfamic acid should not be confused with sulfuric acid. Sulfuric is a strong liquid acid that has been used successfully on rare occasions in well treatment. Its major limitation in well treatment is that when it combines chemically with calcium scale, it forms calcium sulfate which is nearly insoluble in water. Thus, a sulfuric acid treatment may actually reduce the well's performance. In addition, sulfuric acid, even when inhibited, is extremely aggressive in attacking metallic casing and screens.

Hydroxyacetic Acid

Hydroxyacetic acid, also known as glycolic acid, is a liquid organic acid available commercially in 70-percent concentrations. Although not as well known or commonly used as either hydrochloric or sulfamic acid, its use has achieved excellent results in well treatment. It is quite safe to use because it is relatively noncorrosive and produces little or no toxic fumes.

In addition to its ability to dissolve mineral scale, hydroxyacetic acid offers advantages not available with sulfamic or hydrochloric acid. It is an excellent bactericide and therefore may be effective in treating wells with iron bacteria problems. It kills

Table 19.4. Amount of Hydroxyacetic Acid Required per 1 ft (0.3 m) of Screen Length or Open Borehole

Diameter of Well		Amount of 70% Hydroxyacetic Acid per 1 ft (0.3 m) of Screen or Borehole	
in	mm	gal	l
1½	38	0.006 - 0.009	0.02 - 0.03
2	51	0.01 - 0.02	0.04 - 0.08
3	76	0.02 - 0.04	0.08 - 0.15
4	102	0.04 - 0.07	0.15 - 0.27
6	152	0.10 - 0.15	0.38 - 0.57
8	203	0.17 - 0.26	0.64 - 0.98
10	254	0.27 - 0.41	1.02 - 1.55
12	305	0.39 - 0.59	1.48 - 2.23
16	406	0.70 - 1.00	2.65 - 3.79
20	508	1.09 - 1.64	4.13 - 6.21
24	610	1.57 - 2.36	5.94 - 8.93
28	711	2.14 - 3.21	8.10 - 12.1
30	762	2.45 - 3.68	9.27 - 13.9
32	813	2.79 - 4.19	10.6 - 15.9
34	864	3.15 - 4.73	11.9 - 17.9
36	914	3.53 - 5.30	13.4 - 20.1

the bacteria and simultaneously dissolves the bacterial iron deposits as well as other mineral scale.

In addition to its bactericidal properties, hydroxyacetic acid is a chelating or sequestering agent. This means that it has the ability to "surround" metal ions (such as iron, calcium, and magnesium) in solution and keep them from combining chemically with other ions. This insures that all the scale dissolved by the acid remains in solution during the entire treatment period.

Hydroxyacetic acid is placed in the well in the same manner as hydrochloric acid. About 1 gal (3.8 l) of 70-percent hydroxyacetic should be used for every 10 to 15 gal (38 to 56.7 l) of water standing in the well screen. Table 19.4 shows the proper amount of hydroxyacetic acid to use in treating wells of various diameters.

Hydroxyacetic acid is weaker than both hydrochloric and sulfamic acid, and longer contact time is required to achieve the same amount of scale removal. The rate at which an acid removes scale is related to the acid's pH (acid strength). Figure 19.3 shows how pH varies with concentration for the acids described above. Note that hydrochloric acid has the lowest pH and thus will work the fastest, whereas hydroxyacetic has the highest pH and will work more slowly than the other acids.

General Procedure for Acid Treatment

Great care should be taken in placing liquid acid into a well. Only experienced personnel with specialized equipment should attempt to use it in rehabilitating a well. When using any liquid acid, personnel should wear protective rubber clothing and goggles. A breathing respirator should also be used by all personnel handling the acid and by other persons near the well. All mixing tanks, chemical pumps, and piping (tremie pipes) should be constructed of plastic or black iron to minimize reaction to the acid. A large quantity of water, or a water tank with a mixture of sodium bicarbonate, should be available in the event that an accident occurs. Proper ventilation must be maintained because the fumes released from the well during treatment are lethal.

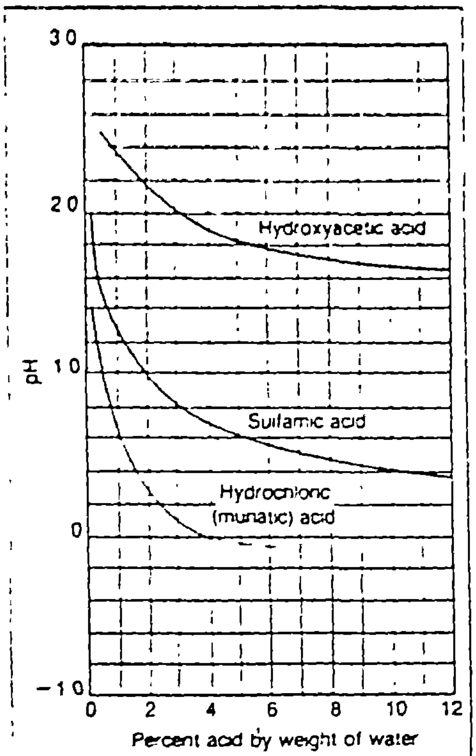


Figure 19.3. Equal concentrations of different acids form solutions with different pH values; pH of an acid-water solution varies with concentration.

Liquid acid should be introduced into the well through a small-diameter pipe. If the screen is more than 5 ft (1.5 m) long, enough acid should be added to fill the lower 5 ft of screen. Then the pipe should be raised and the next 5 ft of screen filled with acid, continuing in this way until the entire screen is full. Pelletized forms of sulfamic acid dropped into the casing will accumulate in the screen where the pellets dissolve. When the granular forms are poured into the casing, they go into solution throughout the entire column of water in the well.

After the acid is placed in the well (or the pellets dissolve), a volume of water equal to that standing in the well screen is poured into the well to force the acid solution through the screen-slot openings into the formation. Some form of mechanical agitation, such as surging, should be employed while the acid is in the well to help break up the incrustation and improve the overall efficiency of the process. This step is particularly important because it exposes the incrustant to the acid, thereby assuring maximum removal.

The use of surge blocks or jetting tools are effective methods of agitating the well. The agitation time will depend on the amount of incrustant in the well. If a surge block is used, the surging effect drives the acid into the formation and brings loosened material into the screen. In the jetting operation, the acid is first poured into the well. The screen or the face of the well bore can then be jetted with clean water from the surface or acidized water from the well (Figure 19.4). A pump pressure of 100 to 250 psi (690 to 1,720 kPa) is sufficient for this type of operation. Circulation of the acid solution may be corrosive to the jetting pump and other equipment, but the wide use of plastic impellers has eliminated most of this type of corrosion damage. If the job requires recirculating the jetting acid at the surface, it is best to call on a well servicing company that has specialized equipment for this work. Great care should always be exercised whenever acid is being pumped in any well rehabilitation operation.

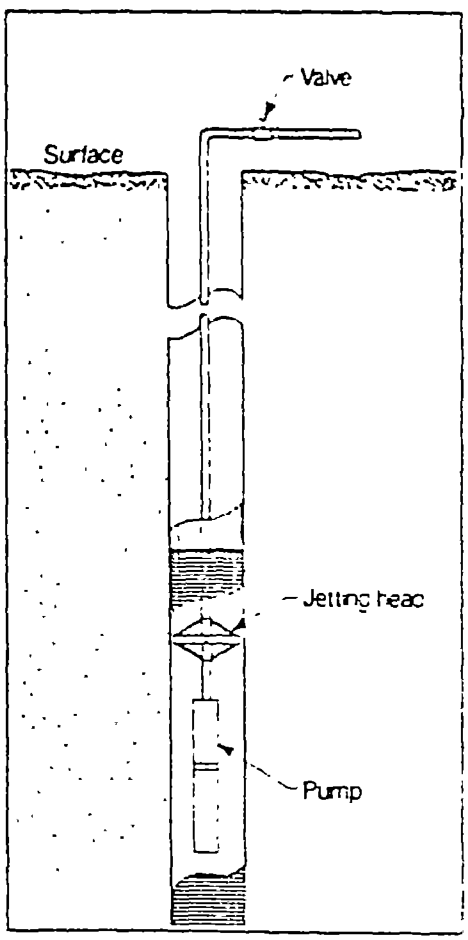


Figure 19.4. To avoid the dangerous practice of pumping acid at the surface, jetting can be accomplished by setting a pump in the well and using the acidified water in the borehole.

An extended zone of the formation around the well screen may be wholly or partially clogged. Thus, it must never be assumed that the chemical solution moves uniformly outward into the voids of the water-bearing materials in all directions throughout the full thickness of the formation. The chemical solutions will flow most readily into those areas where the formation or screen is the most open, that is, where resistance to flow is the least. Therefore, it may be extremely difficult and even impossible to diffuse the chemical solution to all points where it can dissolve or otherwise remove the unwanted deposits.

The use of chelating agents is recommended if iron and manganese incrustants are present and the pH of the treatment solution is approximately 3 or less

At this pH, these cations form insoluble precipitates that settle out and reduce the effectiveness of the acid treatment. Citric, phosphoric, and tartaric acids are three common chelating agents. Four pounds (1.8 kg) of chelating agent are usually added to each gal (3.8 l) of 31-percent (20 degrees Baumé) hydrochloric acid and 1 lb (0.5 kg) of chelating agent to 15 lbs (6 8 kg) of sulfamic (granular) acid.

After mechanical agitation, the solution is left in the well to react with the incrusting materials until the pH is between 6.5 and 7, then agitated again and pumped to waste. The time for the reaction to be completed will vary from a few hours to more than 15 hours, depending on the type of acid used and the amount of incrustants. To minimize disposal problems, the water in the well should be neutralized if necessary before it is removed from the well. In many communities, the water well contractor may be required to haul away the spent acid and dispose of it according to local regulatory agencies. If not, the spent acid should be run onto a sandy section of ground as far away as practicable from the well head. Some contractors neutralize acid wastewater by running it through a limestone-filled container.

Many water well contractors will redevelop the well after it has been acid treated. Solid particles of incrustant can be removed along with any fine sediments that may have entered the zone immediately around the screen after the well was placed in service. In many instances, effective redevelopment of an older, acid-treated well will result in a specific capacity that equals or even exceeds the original specific capacity. The various development procedures are discussed in Chapter 15.

Mechanical Methods to Remove Incrustants

Although removal of most incrustants by acid treatment is extremely effective, several mechanical methods are useful either in preparing for acid treatment or as a primary method of removing incrustants. Wire brushing or other means of mechanical scraping can remove incrustants that have been deposited on the inside of the well screen. The loosened material is then removed from the well by bailing, air-lift pumping, or other means Removal of these incrustants minimizes the quantity of acid that must be used in any subsequent acid treatment, enhances the effectiveness of this treatment, and reduces the time required for the acidizing process.

Controlled blasting techniques are often useful for temporarily improving well yield by fracturing the incrusting matrix so that water can reach the screen. Incrusting materials are sometimes deposited on formation materials several inches or more away from the screen. The incrustant may become so massive that all voids in the formation become filled and little water can reach the screen. Blasting procedures create cracks in the incrustant, allowing water to enter the well. Some fragments of the incrustant will break away and can be pumped from the well. Unfortunately, the opened cracks eventually will also become incrusted and additional blasting or acidizing treatments will be needed to maintain yield. This technique, when combined with acidizing, is particularly effective. Special service companies have formed to provide this type of blasting service.

Incrustation of Rock Wells

Although this discussion has referred only to screened wells in unconsolidated formations, wells in consolidated rock also suffer from incrustation of the borehole wall or the cracks and fissures leading to the borehole. Many rock wells require treatment from time to time to recover the original yield. Both chemical treatments and blasting have proved to be effective procedures and in some cases both are used.

When blasting incrustant, 5- to 10-lb (2.3- to 4.5-kg) shots of explosive are set at 5-ft (1.5-m) intervals in the production zone of the well. More powerful amounts of explosives are sometimes used at different spacings, depending on the experience of the contractor and the nature of the formation and the incrustant. The explosive charges are set off sequentially, beginning at the bottom of the open hole. Do not set off charges within 50 ft (15.2 m) of a shale layer or the bottom of the casing. After blasting, the loosened material should be removed from the borehole and the well redeveloped completely. Samples of sandstone removed after blasting have shown that most of the incrustation extends only about 0.5 in (12.7 mm) beyond the face of the borehole.

Wells constructed in fissured limestone can be successfully treated with acid. An appropriate quantity of hydrochloric or sulfamic acid is placed in the well and the well head capped. A pressure gauge is installed so that the pressure can be monitored. If the pressure build-up is high, the acid is being contained near the borehole. If the pressure does not build substantially, most of the force is being transmitted away from the well bore by means of cavities or enlarged fissures. The solution effect is still beneficial, nevertheless, even if the pressure build-up is low. When the acid stops working, the gauge will indicate a noticeable pressure drop. Work can then begin on redevelopment by jetting, surging, or other means of agitation. All loosened material should be removed before placing the well back in service.

Johnson Division makes no guarantee of results and disclaims all liability in connection with the information or the safety suggestions given for the methods described. Also, it should be understood that not all the acceptable safety procedures are contained herein and that certain circumstances may call for additional precautions. The suggestions given here do not supplement nor modify any state, municipal, federal, and insurance requirements or codes relating to blasting or acidizing.

Acid Treatment of Municipal Wells in Las Vegas, Nevada

A case history from the Las Vegas (Nevada) Valley Water District demonstrates the effectiveness of acid treatment using sulfamic chemicals. The district wells had become heavily incrusted with calcium and magnesium scale, reducing the yields substantially. Both blasting and dry-ice treatment were used to fracture the incrusted formations. A series of small explosive charges were placed in the well and detonated sequentially. In dry-ice treatment, carbon dioxide gases released by dry ice in the well produce extremely high pressures and cause additional fracturing of the incrustant.

The District then undertook an acid rehabilitation program for five of their most heavily used wells. Each of the five wells had been completed with 16-in casing to an average depth of over 900 ft. Length of perforated areas ranged from 278 to 651 ft. The average yield before treatment was 1,870 gpm per well.

A 10-percent acid solution (by weight of water in the casing) of granular sulfamic acid was determined to be adequate to dissolve the incrustant, which consisted primarily of calcium carbonate. This amounts to 0.75 lb of sulfamic acid per gallon of water in the casing. Six 480-lb loads were placed in each well while the pump was still in place. After each 480-lb load was added, the pump was used briefly to surge the well five times to mix the acid and distribute the solution throughout the casing.

When all the acid had been placed in the wells, the wells were surged ten times every 4 hours for the next 24 hours. The wells were then left for an additional 24 hours to guarantee removal of the most firmly imbedded incrustants and then pumped to waste.

During the treatment, silt and sand that were once cemented together by the incrustants were loosened. In order to obtain optimum yields, it was important to remove these materials so the original permeability of the sediments would be restored. To accomplish this, 300 lb of tetrasodium pyrophosphate were added to each well, surged five times, and allowed to stand in the wells for 24 hours. The addition of phosphates helped break up and disperse silt, clay, and other byproducts of the acid treatment. The wells were again pumped to waste.

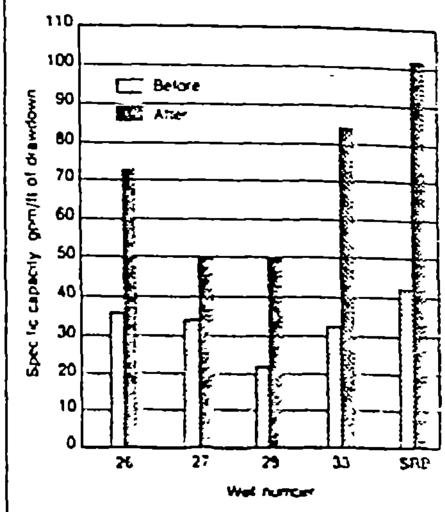


Figure 19.5. Specific capacity of wells before and after acid and polyphosphate treatment.

Before acid treatment, the well characteristics were monitored and recorded as a guide to determine the effectiveness of the treatment. A comparison of specific capacities before and after treatment revealed exceptional results. Figure 19.5 illustrates a range of improvement from 45 to 160 percent of pretreatment specific capacities. After the acid treatment, significant reductions in drawdown resulted in saving the District $16,000 annually in pumping costs alone. The payback time for the investment in materials and labor was estimated to be 1.5 years (Varhol, 1980).

WELL FAILURE CAUSED BY IRON BACTERIA

Iron bacteria occur widely in wells open to the atmosphere when sufficient iron and/or manganese are present in the groundwater in conjunction with dissolved organic material, bicarbonate, or carbon dioxide. Although iron bacteria have been found in wells in all the conterminous United States, the most seriously affected areas include the Southeastern states, the Upper Midwest, and Southern California. In these regions, the principal forms of iron bacteria plug wells by enzymatically catalyzing the oxidation of iron (and manganese), using the energy to promote the growth of threadlike slimes, and accumulating large amounts of ferric hydroxide in the slime (Figure 19.6). In this process, the bacteria obtain their energy by oxidizing ferrous ions to ferric ions, which are then precipitated as hydrated ferric hydroxide on or in their mucilaginous sheaths. Precipitation of the iron and rapid growth of the bacteria create a voluminous material that quickly plugs the screen pores of the sediment surrounding the well bore. Sometimes the explosive growth rates of iron bacteria can render a well virtually useless within a matter of months.

Many other forms of iron bacteria induce the precipitation of iron through nonenzymatic means. Found almost everywhere in both water and soil, these bacteria promote precipitation of iron by four major mechanisms:

1. Raising the pH of the water by (a) metabolizing certain protein or protein-derived materials, resulting in the formation of ammonia, which is alkaline; (b) consuming the salts of organic acids, which can lead to the synthesis of alkaline hydroxyl groups; and (c) assimilation of dissolved carbon dioxide in water by cyanobacteria or algae during photosynthesis.

2. Changing the redox potential of the water by algal photosynthesis. In this process, oxygen given off by plants increases the redox potential, thereby causing the precipitation of iron.

3. Liberating chelated iron by inducing a breakdown in the bond between iron and oxalate, citrate, humic acids, or tannins.

Still other forms of iron bacteria can reduce iron to a ferrous state under anaerobic conditions. Although researchers have not been able to classify many major types of iron bacteria in regard to how they participate in the process of iron deposition, the classification shown in Appendix 19.A provides a tentative guide for enzymatic and nonenzymatic bacteria likely to be found in water wells.

It is unclear whether iron bacteria exist in groundwater before well construction takes place and simply multiply as the amount of iron increases, or whether they are introduced into the aquifer from the subsoil, in mix water during well construction or by backsiphoning from an affected well to an unaffected well. For example, drilling fluid mix water taken from swamps, marshes, or other stagnant surface-water sources may contain high concentrations of iron bacteria. There is also some evidence to show that iron bacteria can be carried from well to well on drill rods, bits, pumps, and water tanks.

Gallionella, a common enzymatic form of iron bacteria, is usually found in water having certain physical and chemical characteristics. Generally the water

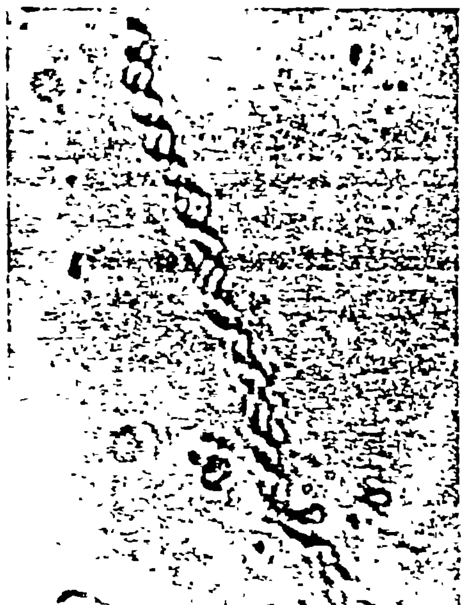


Figure 19.6. Iron bacteria on pump column pipe.

1. Has an iron content of 1 to 25 mg/l and contains only traces of organic matter.

2. Is low in oxygen, typically in the 0.1 to 1 mg/l range.

3. Is usually fresh, although *Gallionella* has been found growing in salt water.

4. Contains over 20 mg/l carbon dioxide.

5. Has a redox potential in the range of 200 to 300 millivolts (mv).

6. Has a pH in the range of 6 to 7.6.

7. Has a temperature from 40 to 60°F (4.4 to 15.6°C).

Presumably, many forms of enzymatic bacteria that could grow in water wells would prefer waters with these same general characteristics. But other forms of iron bacteria, such as *Thiobacillus Ferrooxidans*, *Sulfolobus Acidocaldarius*, *Sulfobacillus Thermosulfidooxidans*, and

Leptospirillum Ferrooxidans can grow in waters having extremely low pH (2 to 6) and much higher temperatures [60 to 185°F (15.6 to 85°C)].

A second classification of iron bacteria generally used in the water-well industry is one based on the physical form of these organisms. This method of classification is helpful in identifying which genus of iron-fixing bacteria is contained in a particular water sample. The three general forms recognized are:

1. The capsulated coccoid form, of which only one genus is known, *Siderocapsa*. This organism consists of numerous short rods surrounded by a mucoid capsule. The deposit surrounding the capsule is hydrous ferric oxide, a rust-brown precipitate. This organism probably produces iron precipitates by breaking down the bond between the iron and the chelating agent.

2. The stalked iron-fixing bacteria, composed of twisted bands resembling a ribbon or chain. The genus of this physical form is *Gallionella*, sometimes called *Spirophyllum*, although *Gallionella* is the preferred name. *Gallionella* can be recognized by the twisted stalk and the bean-shaped bacterial cell at the end of the twisted stalk. The only living part of this organism is the bean-shaped cell at the end of the stalk. *Gallionella* is probably the principal enzymatic bacteria occurring in wells.

3. The filamentous group, consisting of four genera: *Crenothrix*, *Sphaerotilus*, *Clonothrix*, and *Leptothrix*. Species of the genus *Crenothrix* have a thin attached end that gradually thickens toward the free end. The separate cells that make up a thread of *Crenothrix* are rod shaped and lie end to end in a sheath. The free end of the filament contains spherical, nonmotile cells called conidia, which are frequently prevented from leaving the sheath. They germinate within the sheath and thrust their filaments through the walls, giving the appearance of numerous branches extending from the parent filament. Members of the genus *Sphaerotilus* exhibit colorless filaments that show false branching. Another iron bacterium that shows false branching is *Clonothrix* (Figure 19.7). This form differs from others in the filamentous group in that its sheath is tapered. The fourth genus in the filamentous group is *Lepirothrix*, a simple thread form, usually incrusted with iron along the entire sheath. The sheath of this organism is generally the same width throughout its length and contains colorless cylindrical cells that lie end to end (Figure 19.8). *Leptrothrix* and *Sphaerotilus* contain only a relatively small volume of iron in their sheaths and probably do


Figure 19.7. Iron bacteria, genera *Clonothrix*.


Figure 19.8. Iron bacteria, genera *Leptothrix*.

not derive energy from iron oxidation This may also be true for *Crenothrix* and *Clonothrix*.

If the presence of iron bacteria is suspected in a well, samples of the organism can be obtained by a filtering device attached to the discharge of the pump for one week. The water passing through the filter during this period leaves a dark brown precipitate on the porcelain cover which can be examined for iron bacteria by a qualified laboratory.

Another method of sample collection is to examine the material scraped from valves or pump discharge lines from suspected wells, pump shaft seals, water closets, or small steel objects suspended temporarily in the well. However, unless a microscope with a magnification of at least 1,000X is available, it is best to send the samples to a state water laboratory or a private firm familiar with iron bacteria identification. Correct identification of iron bacteria is best accomplished by scanning electron or transmission electron microscopy and phase contrast techniques.

Prevention and Treatment of Iron Bacteria

The water well contractor should use great care to avoid introducing iron bacteria into a well during drilling and repair work. All drilling fluid mix water should be chlorinated initially to a 50 mg/l free chlorine concentration, even if secured from a chlorinated municipal water supply. Because chlorine is not stable in a drilling fluid, more must be added periodically to maintain a 10 mg/l free chlorine residual The drill rods, bits, and tools should be chlorinated thoroughly to eliminate any bacteria remaining from the previous job. Filter-pack material should also be chlorinated before emplacement. This is usually done by adding dry calcium hypochlorite to the pack before it is placed in the well, or chlorinating the water if the pack is pumped into the well. Once the well is completed, it should be sealed immediately to prevent the introduction of airborne bacteria.

Chemical Methods to Control Iron Bacteria

If iron bacteria do grow in a well, they can be controlled by chemical treatments and various types of physical methods (Table 19.5). In general, chemical treatments are more effective and less expensive than physical methods. But for maximum effectiveness, any chemical treatment must be accompanied by physical agitation of the well! Jetting, air surging, air-lift pumping, and valved surge blocks are the principal methods used to agitate the well.

Many effective bactericides are strong oxidizing agents. As this term implies, these

Table 19.5. Methods to Control Iron Bacteria

Chemical	Physical
Oxidizing agents such as chlorine	Heat
pH adjustors such as acids	Vyredox™ technology
Quaternary ammonium compounds	Explosives
	Ultrasonics
	Radiation
	Anoxic blocks

chemicals can oxidize or literally "burn up" organic material. Oxidation is the most common method of killing bacteria, and dissolving and loosening the organic sludge they produce.

Chlorine

Chlorine, a strong oxidizing agent, is used widely to limit the growth of iron bacteria. Chlorine compounds offer significant advantages over other types of bactericides: they are inexpensive, readily available, effective, and generally accepted (actually required in many instances) by health officials as suitable for use in potable water supplies.

The correct chlorine concentration depends on the type of treatment being administered. As little as 50 mg/ℓ free available chlorine is used for routine disinfection of wells and piping following construction, repair, or pump installation, whereas concentrations as high as 500 to 2,000 mg/ℓ are usually desirable for treating wells severely plugged with iron bacteria. A solution strength of 500 mg/ℓ is by definition the strength obtained by dissolving 500 lb (227 kg) of chlorine gas in 1 million lb (454,000 kg) of water. On a smaller scale, this is equivalent to 0.5 lb (0.2 kg) of chlorine gas in 1,000 lb (454 kg) of water [120 gal (0.5 m^3)]. The term "shock chlorination" is reserved for chlorine solutions having a concentration of 1,000 mg/ℓ or more. Table 18.6 (page 621) shows the quantities of chlorine-containing materials necessary to achieve various chlorine solution strengths.

Chlorine gas is the most powerful of the chlorinating agents available commercially. Because it is a gas at normal temperatures and pressures, it must be stored in pressurized cylinders much the same way that propane or acetylene gas is stored. It is extremely corrosive and causes severe damage to human tissues immediately on contact. The use of chlorine gas has generally been restricted to high-capacity municipal and industrial wells because of the skill and equipment required to handle it safely.

During treatment, chlorine gas is usually conducted through a small-diameter plastic tube into the well, where it mixes readily with the water to form the chlorinating solution. A centering device should be used to keep the lower opening of the plastic tube centered in the well screen, because the chlorine gas is so corrosive that holes can form in well screens and casing in a short time, thereby causing sand pumping and ultimately well failure.

After the chlorine solution has been produced in the well, it should be forced through the screen-slot openings into the water-bearing formation by adding water to the well. Then, as with acid treatment, mechanical agitation should be used to enhance the effectiveness of the treatment. As the chlorine disintegrates the organic slime, the mechanical agitation helps dislodge it and move it from the formation into the well, where it can be removed by pumping. Agitation also helps to move fresh chemicals into areas where they may have become expended.

Without some agitation, chlorine may not be effective when treating iron bacteria, because the iron bacteria form a thick, protective slime layer around the cells that is impregnated with oxides and hydroxides of iron and manganese. This layer restricts the movement of chlorine into the cell to the point where the cell may not be inhibited or killed by ordinary lethal doses. In addition, the cells are layered and thus a disinfectant has to penetrate through a series of slime layers, inhibiting and killing the cells as they become exposed. Subsequent disintegration of the dead slime leaves an exposed layer of living iron bacteria beneath which the infestation will continue to grow. Acid treatments are also effective in killing iron bacteria because they generally cannot live at a pH below 2. Figure 19.9 demonstrates that once iron bacteria establish a foothold in a well, they are extremely difficult to eliminate completely by treatment. In this case, the specific capacity of the well is halved in a little over two years.

Agitation can best be achieved by jetting chlorinated water into the formation, because jetting concentrates the greatest amount of energy over the smallest area. Other suitable methods of agitating the chlorine solution include surging by operating a surge plunger in the casing above the screen, or by capping the well and alternately injecting and releasing compressed air, thereby forcing the chlorine solution back and forth through the screen openings. If the pump remains in the well during treatment and there is no foot valve or check valve on the pump, good results may be obtained by pumping and backwashing (alternately starting and stopping the pump). The only requirement is that there not be a net removal of water from the well, because this would

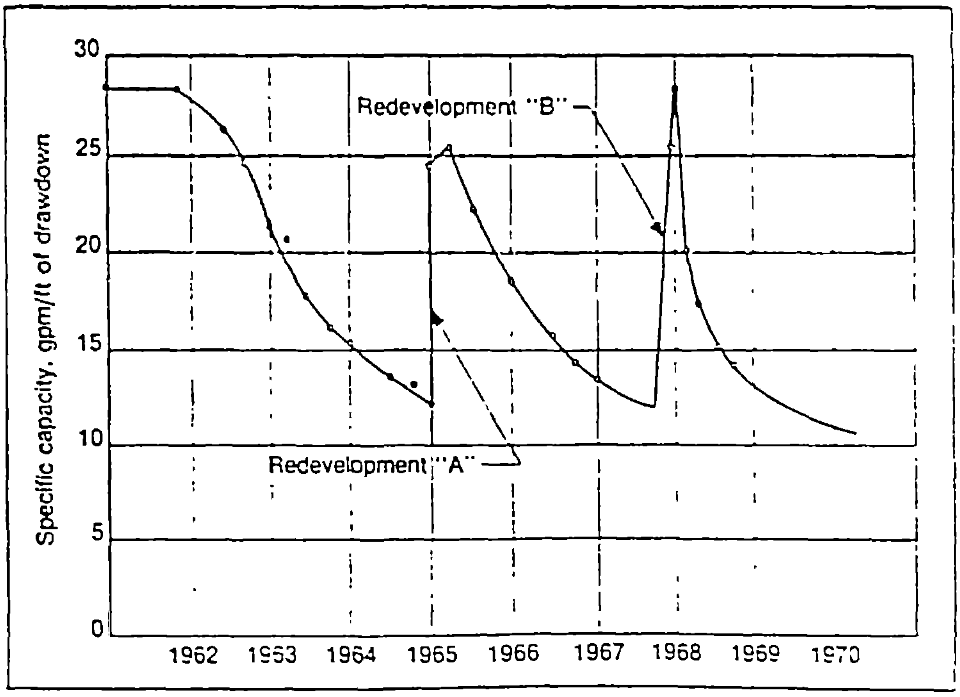


Figure 19.9. Performance record of a well in New Jersey shows declines in specific capacity caused by the growth of iron bacteria, and recovery of specific capacity produced by periodic treatment. Shock treatment with chlorine once a year would help maintain the yield at a satisfactory level. (C. S[illegible] Company)

result in removal and waste of the chlorine solution.

Hypochlorites

A relatively safe and convenient alternative to the use of chlorine gas in well treatment is the use of one of several hypochlorite products. In their commercial form, this family of chemicals eliminates some of the dangers inherent in handling chlorine gas and is easily applied to well treatment.

Calcium hypochlorite is a dry mixture containing about 65 percent available chlorine. It can be mixed with water at the surface and poured or piped into the well. Alternatively, the dry material may be poured into the well or suspended in a weighted mesh container, porous sack, or drive point. This latter method is an efficient way to place chlorine at the bottom of an artesian well. If large quantities of dry material are placed directly in the well, some provision should be made for stirring or agitating the water to help dissolve the chemical. Once the chemical has been placed in the well, rehabilitation procedures similar to those used with chlorine gas should be employed. In isolated instances, so much calcium hypochlorite may be introduced that once it combines with the naturally occurring calcium in the water, a precipitate of calcium hydroxide may form that plugs the pores of the formation. For this reason, rehabilitation procedures using calcium hypochlorite may fail to restore the original yield of the well.

Another hypochlorite chemical, sodium hypochlorite, is available in liquid form, typically in solutions of 5 to 15 percent sodium hypochlorite. Pure sodium hypochlorite is highly unstable, actually explosive, and thus cannot be handled safely unless it is dissolved. Even in liquid form, sodium hypochlorite is somewhat unstable and tends to deteriorate with time. During six months storage, a 10-percent solution of sodium hypochlorite loses 20 to 50 percent of its useful chlorine.

Sodium hypochlorite is frequently used in well treatment for routine disinfection of domestic-size wells because it is readily available in the form of household bleach. In addition, it has been used quite successfully to treat iron bacteria problems. The 5.25-percent solution in household bleach contains 5.25 percent available chlorine. Comparing this with calcium hypochlorite which contains 65 percent available chlorine, 1.7 gal (6.4 *l*) of bleach solution must be used to provide the same disinfecting power as 1 lb (0.5 kg) of calcium hypochlorite.

Chlorine dioxide (ClO_2) is sometimes used for disinfecting drinking water supplies because it produces less trihalomethanes than chlorine except in high-pH waters (Lykins and Griese, 1982). Research has also shown that chlorine dioxide may have stronger oxidative properties than chlorine but its use produces no undesirable organic by-products other than those produced by the use of chlorine. Chlorine dioxide can be used to treat wells or prevent the premature breakdown of drilling fluid made with polymeric additives. In the gaseous form, chlorine dioxide is extremely unstable, and a 10-percent concentration of gas in air is explosive and easily detonated by sunlight. However, in liquid concentrations of 2 to 4 percent, it is relatively stable and can be added to the mix water. The major drawbacks of chlorine dioxide are its relatively high cost and its short lifetime in water (10 minutes).

Table 19.6 contains a list of many of the common chlorinating agents and indicates the amount of each chemical required to provide the same amount of available free chlorine as 1 lb (0.5 kg) of chlorine gas.

Table 19.6. Quantities of Various Chlorine Compounds Required to Provide as Much Available Chlorine as 1 lb of Chlorine Gas

Chemical	% Available Chlorine	Number of lb Equivalent to 1 lb Cl_2
Chlorine Gas	100	1.0
Calcium Hypochlorite	65	1.54
Lithium Hypochlorite	36	2.78
Sodium Hypochlorite	12.5	8.0
Sodium Hypochlorite	5.25	19.05
Trichloroisocyanuric Acid*	90	1.11
Sodium Dichloroisocyanurate*	63	1.59
Potassium Dichloroisocyanurate*	60	1.67
Chlorine Dioxide	4	25.0
Chlorine Dioxide	2	50.0

*Chlorine compounds that incorporate isocyanuric acid stabilize the chlorine against degradation from sunlight. Except for storage, the advantage offered by the addition of isocyanuric acid is less valuable in water wells.

Potassium permanganate, like chlorine gas, is a strong oxidizing agent that is an excellent bactericide. It has been used successfully to control the growth of iron bacteria in wells. Potassium permanganate is available as a dry, purplish-colored crystal that is both inexpensive and relatively safe to use.

In treating wells infected with iron bacteria, dry potassium permanganate is dissolved in enough water to fill the well screen; the solution is then piped into the screen. A solution strength of 1,000 to 2,000 mg/l has been found to achieve excellent results [1,000 mg/l is equal to 0.83 lb (0.38 kg) in 100 gal (0.4 m^3) of water]. Once the chemical has been placed in the well, vigorous mechanical agitation by surging or jetting should be utilized during treatment to promote loosening and disintegration of the organic plugging material and enhance the overall effectiveness of the procedure.

In treating iron bacteria problems, it must be remembered that the clogging of the well screen and aquifer is caused not only by the organic material produced by the bacteria, but also by the oxides and hydroxides of iron and manganese generally associated with these organisms. In addition, it is usually a matrix of these materials in combination with other mineral scales such as calcium carbonate that causes the problem. Because of the presence of inorganic chemicals, better results are nearly always obtained by treating the well alternately with a bactericide to attack the organic material and a strong acid to dissolve the iron deposits and mineral scale. Between each treatment, the well is pumped to waste. The chlorine and acid must never be in the well at the same time.

Longer time intervals between treatments have been achieved by using a three-step treatment consisting of initial shock chlorination followed by acidizing and then a final shock chlorination of the entire water distribution system. Occasionally, acid is applied first to reduce the thickness of the sheath so that the chlorine is more effective in destroying the tubercles. The added cost of applying three separate treatments is almost always offset by the improved results. A more detailed description of the recommended chlorine-acid treatment process is given at the end of this section.

Physical Methods to Control Iron Bacteria

Pasteurization is a physical method that has been developed to control the growth of iron bacteria. Pasteurization treatments have been shown to be quite effective in maintaining well yield in Saskatchewan in spite of iron concentrations of 1 to 8 mg/ℓ in the well water (Cullimore, 1981). In this treament method, hot water [176°F (80°C)] is circulated continuously in the well until the return water reaches the same temperature. The water is kept at approximately 176°F until temperatures from 113 to 129°F (45 to 54°C) have been reached throughout the layer of iron bacteria. At 113°F the bacterial plugging is dispersed, and at 129°F the bacteria are killed. Tests after pasteurization show a significant drop in the iron bacteria concentration, although bacteria that exist in the formation can quickly reinfest the well

The cost of treating small-diameter wells by pasteurization is relatively low, because the equipment and procedures are rather simple. However, generating the necessary heat for treating large-diameter wells requires expensive equipment that may make the pasteurization process infeasible economically. Furthermore, depending on the ambient temperatures of the groundwater, the amount of down time required to perform the process may not be tolerable.

Vyredox™ techniques are sometimes used to control the iron content of water and therefore the growth of iron bacteria (see Chapter 23 for a discussion of this technology). By increasing the redox potential of the groundwater around the production well, iron and manganese will precipitate in the aquifer. If the iron concentration can be reduced in the production well to about 0.1 mg/ℓ, iron bacteria probably cannot survive.

The use of explosives and ultrasonic technology to kill iron bacteria have not been effective. Apparently the slime layers can easily absorb the explosive energy or the sound waves with little damage to the bacteria. Although radiation techniques may prove successful in the future in killing bacteria, the use of this technology in wells may not be acceptable to health departments. The effectiveness of creating anoxic blocks in wells to produce anaerobic conditions and thereby kill aerobic iron bacteria has not been ascertained.

Recommended Procedure for Controlling Iron Bacteria

The procedure given below will control the growth of iron bacteria in a large production well. Less complex treatments consisting of only chlorine applications are suitable for most small-diameter wells. It should be noted that virtually no combination of procedures is effective enough to kill all the bacteria in the well. Normally any procedures used will only control the growth of the iron bacteria.

The recommended chlorine-acid procedure is as follows:

1. Inject a mixture of acid, inhibitor, and wetting agent. The addition of a chelating agent such as hydroxyacetic acid may sometimes be beneficial.
2. Agitate the solution with a jetting tool.
3. Pump to waste a volume of solution equal to the volume of the well bore.
4. Determine the pH of the waste. If it is more than 3, repeat steps 1 to 3. (A pH of 3 or less assures that dissolved iron will stay in solution.)
5. Inject a mixture of chlorine and one or more chlorine-stable surfactants (detergents and wetting agents, for example). The concentration of the chlorine should exceed 1 percent.

6. Agitate the solution with a jetting tool.
7. Pump to waste a volume of solution equal to the volume of the well bore.
8. Determine chlorine concentration. If the value is less than 10 percent of the original concentration, repeat steps 5 to 7.
9. Determine the specific capacity of the well. If the specific capacity has improved by more than 5 percent, repeat the entire procedure until the specific capacity does not improve by 5 percent.

WELL FAILURE CAUSED BY PHYSICAL PLUGGING OF SCREEN AND SURROUNDING FORMATION

Over time, almost all screened wells will undergo some loss in specific capacity. Some of this loss is attributable to the slow movement of fine formation particles into the area around the screen. Depending on the type of screen-slot opening, many of these particles may partially plug the screen itself, or even erode the slot openings under certain conditions. Thus, the invasion of small particles reduces the yield, increases the drawdown, and may damage the screen.

Fine-particle movement results from:

1. Improper well design
   a. Poorly designed filter pack
   b. Improper screen placement
   c. Poor slot selection
   d. Inaccurate aquifer sampling techniques
2. Insufficient or improper development when the well was placed in service
3. Removal of cement holding the sand grains together around the well screen
4. Corrosion of the screen or casing.
5. Increase in the pumping rate beyond the designed capacity (actually over pumping).
6. Excessive pump cycling.

If the well screen becomes plugged with sediment or incrustants, the entrance velocity of the water passing through the remaining openings increases significantly. As a result, fine sediment is entrained that continually erodes the slot openings. As the slots enlarge, more sediment will pass into the screen. Just how much sand must enter a well to cause failure depends in part on the type of well. Experience indicates that up to 1 mg/ℓ is acceptable in a system with many valves and small orifices, such as a drip-irrigation system. Most industrial and municipal systems can tolerate 2 to 4 mg/ℓ and some irrigation systems can handle as much as 20 mg/ℓ. At 20 mg/ℓ, a well pumping 700 gpm (3,820 m^3/day) will yield 168 lb (76.2 kg) of sand per day. Over a period of several weeks or months, many tons of sand pass through the pump. To prevent pump damage, the screen may have to be replaced.

Prevention and Treatment of Physical Plugging

Movement of sediment into the formation around the screen can be largely prevented by thorough development of the well during its completion. As suggested in Chapter 15, certain development methods are more suitable for specific types of aquifers. Application of an appropriate development technique for a sufficient length of time will stabilize the formation materials so that subsequent pump cycling and higher discharge rates will not result in sediment movement.

Not all fine-particle problems result from natural formation materials. Occasionally some clay additives used in the drilling fluids may remain in the formation after development. Thus, over time small amounts of these clay residuals enter the well along with other fine material. To completely remove the clay, a chemical treatment may be necessary in the development process.

Polyphosphates and Surfactants

Silt and clay particles tend to adhere strongly to one another in a viscous state, which makes their removal from sand and gravel aquifers quite difficult. Wells that are plugged with silt and clay particles are most effectively restored to efficient conditions by treatment with dispersing and sequestering (chelating) compounds that belong to the polyphosphate family of chemicals. They have the power to separate clay particles. Dispersing agents cause the particles to repel one another, increasing their mobility sufficiently to allow them to move when water is pumped into and out of the well during the development process. Furthermore, the calcium, magnesium, and iron ions adhering to the fine particles can be sequestered (caused to remain in a soluble state) by the use of polyphosphates. Therefore, particles bonded together by these ions can be removed more easily from the aquifer.

Sodium polyphosphates, a family of white, free-flowing dry materials, have been used widely with great success in treating clay-plugging problems. There are two types of sodium polyphosphates, crystalline and glassy. Crystalline polyphosphates that help remove clays from the aquifer are sodium acid pyrophosphate (SAPP), tetrasodium pyrophosphate (TSPP), and sodium tripolyphosphate (STP). Sodium hexametaphosphate (SHMP) is a glassy phosphate that is readily available and therefore often used in rehabilitating wells. Commercial tradenames for sodium hexametaphosphate include Calgon™, Quadrafos™, and Polyphos™. Weltone™ is sodium hexametaphosphate mixed with a chlorinating chemical and wetting agent.

For treating wells, about 15 lb (6.8 kg) of dry polyphosphate should be mixed with 100 gal (0.4 m^3) of water. It is best to mix the material at the surface in warm water in a small container; then dilute with a larger volume of cooler water, chlorinate to 125 mg/ℓ, and put the prepared solution into the well with a tremie pipe, particularly when using the glassy phosphates. If a slug of dry glassy phosphate material is just dumped into the well, it will sink to the bottom and form a large gelatinous mass that could remain undissolved in the well for some time. This mass may plug a significant part of the formation and be extremely difficult to remove. A small amount of hypochlorite should always be used with phosphates because polyphosphates act as a food source for bacteria. This chlorinates the well and kills any bacteria that may be present. About 1.6 lb (0.7 kg) of calcium hypochlorite should be used for each 1,000 gal (3.8 m^3) of water in the well.

Most surfactants are long-chain organic molecules derived from petroleum products. These agents consist of particles that are attracted to oil at one end of the particle and water at the other. Oil can be pulled into a water solution by these particles and removed easily from the porous medium. The presence of a small amount of surfactant speeds penetration of the cleaning chemical by modifying the surface tension of the materials to be cleaned.

The wetting and soil-dispersing properties of surfactants make them ideally suited for use in well cleaning. Those used for wells should be low foaming or used with a defoaming agent to minimize sudsing. Preferably, they should be of the nonionic type — that is, surfactants that do not form ions when dissolved in water. Ionizing surfactants (anionic and cationic types) often react with other chemicals used in the rehabilitation process to form insoluble precipitates that have no cleaning value.

Surfactants are inexpensive to use because only relatively low concentrations of 250 to 500 mg/l are required. They can enhance the dispersing efficiency of the polyphosphates in the removal of silt and clay. Likewise, acidizing is more effective when a surfactant is used with the acid. This is because the surfactant enables the acid solution to soak into all of the pores and cracks of the incrusting deposit, increasing the total contact area between acid and incrustation and thereby speeding the rate of removal of incrustation.

Physical Agitation

Agitation of the phosphate or surfactant solution is important in removing the maximum amount of fine material from the formation. Agitation of the chemical solution during rehabilitation can be done by using a surge plunger, compressed air, well pump, or high-velocity jet. One of the most efficient methods of redeveloping wells with polyphosphates is high-velocity jetting, where the appropriate polyphosphate solution is used as the jetting fluid. If high-velocity jetting is not used, the polyphosphate solution should be placed in the well, forced into the formation adjacent to the screen, and agitated by one of the development techniques described in Chapter 15. Applying these methods in well treatment, however, requires some minor changes in the details of operation. For example, when compressed air is used for surging the chemical solution, the solution must not be discharged from the well before disaggregation of the particles has occurred.

When agitating with a high-velocity jet, it may be desirable to pump the well periodically at a low rate. In operation, jetting adds water to the well at the rate of 25 to 200 gpm (136 to 1,090 m^3/day), depending on the size of the jetting nozzles and the pump pressure. The water pumped from the well can be recirculated to continue the jetting operation. Movement of water through the screen openings into the well carries with it some of the sediment loosened by the jetting process. Thus material should be settled out in a tank or pit before being recirculated to avoid damaging the screen, pump, or jetting nozzles. Continuous removal of loosened material from the formation will greatly improve the effectiveness of the polyphosphate treatment by allowing the phosphate to reach untreated parts of the formation more quickly. Even though chlorine is used in the phosphate solution, it is good practice to disinfect the well following the polyphosphate treatment to make sure that the well is left in a sanitary condition.

IMPORTANCE OF SCREEN DESIGN ON REHABILITATION

When rehabilitating a well screen, its design will influence considerably the results that can be obtained from various types of chemical treatment and mechanical agitation, particularly horizontal jetting. The force of the jet must be directed through the screen openings. Screens with high open area and uniformly arranged, closely spaced slots that allow direct access to the formation assure the maximum agitation effect from the jetting process. For example, pipe-base and mill-slotted screens offer insufficient open area through the perforations in the pipe. Louver and bridge-slot screens present an almost solid vertical metal surface to the horizontal jet. Continuous-slot screens, on the other hand, have maximum open area and slot configurations that maximize the impact of flow from the jetting tool.

The shape of the screen openings is also important in influencing the effectiveness of the agitation created by the jet. In other words, certain slot configurations will allow the jetting energy to reach deeper into the formation. The best type of opening is a V-shaped slot that widens toward the inside of the screen. When the jet is projected through this V-shaped opening as shown in Figure 15.18 (page 519), the slot opening concentrates the effect of the stream like a second nozzle or venturi. Other slot configurations tend to block or disperse the stream and reduce its force before it reaches the incrusted formation beyond the outer face of the screen.

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CONCLUSIONS

Wells are often allowed to deteriorate for such a long time that their specific capacity may be impossible to restore completely, even when using the best chemicals and rehabilitation techniques available. To guard against such a situation, it is essential that the well owner keep good well records so that any decline in performance will not go undetected. The well's specific capacity should be measured at regular intervals, either monthly or bimonthly. The measured specific capacity should be compared with the original specific capacity. As soon as a 10- to 15-percent decrease is observed, steps should be taken to determine the cause and correct the problem. Rehabilitation procedures should be initiated before the specific capacity has declined 25 percent. Declines greater than 25 percent often require much larger expenditures for chemicals and labor without ever regaining the original specific capacity.

The decision whether to rehabilitate an old well or construct a new one can be extremely difficult. The principal items to consider are the cost comparisons between the rehabilitation program and those for the new well, the time required to rehabilitate an old well or to drill and place a new well into service, the projected life of the new well, the economic life of the old well once it has been rehabilitated, and the costs of continuing to use the old well if no maintenance work is performed. With the exception of treatments for iron bacteria and severely corroded screens and casings, systematic well rehabilitation using proper methods and materials can usually restore or may even increase the original specific capacity of the well for a significant length of time. The important point is that a methodical, long-range program of well inspection and monitoring is required to identify problems so that a regular program of preventive maintenance can guarantee a reliable source of water.

Indian Standard

CODE OF PRACTICE OF REHABILITATION OF TUBEWELLS

1. Scope — Lays down the guidelines for rehabilitation of tubewell.

2. Introduction — The useful life of a tubewell depends upon its design, method of construction, type of acquifer tapped, water quality, discharge and depression at which it is operated and the type of maintenance it receives. With the passage of time and continuous pumpage when the yield falls, it may be possible up to a certain stage to restore the well yield or improve its performance by carrying out suitable rehabilitation programme. A well should normally be taken up for reconstruction when its specific yield falls down below 1/2 to 1/3 of the designed specific yield. Also, a tubewell should be taken up for repairs for improvement of discharge, when its specific yield falls to about 80 percent of the initial value.

3. Cause of Failure — Tubewell failures are generally indicated either by excessive sand pumpage or steady decline in well yield to the economical pumping. The following are the main causes for the failure of tubewell.

3.1 *Those due to Extraneous Reasons not Connected to Well itself* — In this category are included cases where pumping rate may go down due to lowering of water table in the acquifer as a result of over-pumping or due to interference from other wells in the same acquifer. There is nothing that can be done to the well assembly itself to overcome such difficulties, but it is important to recognize these causes.

3.2 *Those Arising from Damage to the Tubewell itself*

3.2.1 *Incrustation and corrosion* — Depends upon the chemical quality of the water. Corrosion is a chemical action of water on metals which results in eating away or removal of material from the surface. It may severely limit the life of a tubewell by enlarging slot openings, leading to sand pumping, reduction in strength followed by collapse of screen and rede-position of corroded products causing blockage of screen openings.

Incrustation results from clogging of the acquifer around the well and openings of the screen, leading to decrease in well capacity.

If *p*H of the well water is more than 7·50, it is indicative of incrustive nature. Carbonate content higher than 300 ppm causes incrustation due to carbonates of calcium and magnesium. Iron content from 2·0 to 3·0 ppm and manganese content higher than 1·0 ppm tend to cause incrustation. If *p*H value of the well water is less than 7·00, it is acidic in nature and may have corrosion effects. If presence of carbon di-oxide exceeds 80 ppm, the water is expected to be corrosive. Presence of chloride content more than 1 000 ppm, hydrogen sulphide 1 to 2 ppm and total dissolved solids over 1 000 ppm is indicative of corrosive nature of water.

3.2.2 *Over pumping* — Over pumping is usually caused due to clogging of well screen or water bearing formations, as a result of accumulation of fine sand particles adjacent to the well screen. This leads to increased draw down and may eventually cause rupture of the strainer. Whenever increased draw down is noticed accompanied with pumpage of fine sand, the rate of pumping shall be reduced down and balanced against rate of replenishment.

3.2.3 *Improper design and gravel placement* — It included failures due to improper design, faulty placement of pack materials and improper development of the well. Gravel pack gradation and screen slot size in many cases are not properly matched to the acquifer grain size leading to formation of voids.

Faulty placement of gravel results into segregations by particle size and also causes bridging or knotting in gravel pack at one or more places. This defect, if left unnoticed, by not ensuring continuity of the gravel pack during development, causes irrepairable failure of the tubewell. As the well is run, gradual development takes place in starta and gravel below and bridged portion moves down, causing exposure of the slotted portion to the acquifer, directly against it. This results in free flow of acquifer material into the well pipe, causing sand filling and consequent reduction in well yield.

Adopted 26 February 1986

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In agriculture strainer type wells incorrect size of mesh openings may either lead to clogging of the strainers resulting in loss of discharge or continuous flow of sand with water followed by cavity formation, which on sudden collapse may cause sinking of the pump house building. Not much can be done to avoid such failures due to faulty design or incorrect size of gravel or mesh openings. However, sometimes formation of cavities around the screen allow the overlying fine material to settle down and get positioned against the screen performations. This reduces the well yield and again, when the so placed material is washed off, the discharge increases. This phenomenon is indicated by erratic performance of the well.

3.2.4 *Faulty construction* — Failures due to deficiences in tubewell construction methods and in construction inspection such as faulty or loose pipe and screen connections or joints are rare. This is indicated by sudden heavy rush of sand into the well pipe. To locate and rectify such defects, it is best to take sounding of the well and compare the sand discharged with the original well logs. The well may be cleared up with a bailer.

If not substantial portion of the slotted pipe or screen is likely to be lost, it is best to plug the portion up to the defective joint. It would, of course, reduce the well yield in proportion to the length of the screen lost.

4. Information to be given by User

4.1 The causes of the sickness of a well shall be diagonaged before any remedial measures are adopted. The condition of the well may be judged from the performance data during its service life. Following information shall be made available by the owner:

a) Initial and present well yield, depression, spring level as observed periodically during the well's service life.

b) Sand content in ppm, if any.

c) Grain size distribution of the strata taped as a result of sieve analysis.

d) Location of screen, its opening size, percentage of screen surface area to the total open area, screen material length and diameter of screen and well pipes, etc, and data of acceptance of the well.

e) Size and quantity of pea-gravel used initially and during its service life.

f) Method used and details of development with results.

g) Method of drilling adopted, name of drilling agency, original pump and well test results and results of sebsequent tests, if available.

h) Results of the initial and present chemical analysis of the well water.

j) Details of any chemical treatment, if ever given to the well and results achieved the refrom.

k) Sounding of the well assembly observed every year.

m) Details of repairs to the pumping equipment carried out every year.

n) Number of electricity units consumed per kilowatt ratings every year during service life of the well.

5. Investigations to be Carried out by the Contractor

5.1 The following data shall be determined for reference when starting rehabilitation on any well:

a) Date of acceptance of well

b) Name of contractor

c) Method of drilling

d) Method of formation sampling

e) Formation log

f) Mechanical analyses of aquifer samples

g) Mechanical analyses of pack material

Screen materials, slot sizes, diameters and depth of setting

j) Present open area of screen, design inflow velocity

k) Depth, diameter and material of pump chamber

m) Method and completeness of development

n) Original pump and well test results and results of subsequent tests, with dates

   1) Static water level
   2) Measured depth to bottom of hole
   3) Discharge
   4) Draw down
   5) Specific capacity
   6) Step tests
   7) Production tests

p) Ground water hydrographs of area

q) Quality of water analyses of well with dates

r) Resume of maintenance, rehabilitation and performance

s) Similar data shall be collected by the electrical division on each pump unit.

5.2 The following investigations shall be carried out and data determined before starting rehabilitation on any well:

a) Ground water hydrographs of the area, if available

b) Chemical and bacterological analysis of the well water shall be carried out and compared with the original one, with regard to its original and the present apparent incrustation potential.

c) If the well is yielding sand, the discharged sand sample shall be collected and compared with the original formation log so as to locate precisely the position of the possible rupture or loose connection, etc.

d) If equipment is available, an under water photographic survey shall be carried out and location of any evidence of incrustation, organic growth or accumlation on the casing and screen recorded. Also, any filamentous algee, iron bacterial or similar organisms floating in the water shall be noted. Any evidence of mechanical damage to the casing and screen shall be carefully inspected with the camera add recorded with regard to its description and depth.

e) The present specific yield at a design discharge rate and draw down low enough to permit continuous pumping for 4 hours, without breaking suction, shall be determined. This will give a qualitative measure of the degree of deterioration and by comparison with the later tests, the succéss of rehabilitation programme.

f) The pump be pulled out and various parts be examined immediately as they are removed from the well. The column pipe, drive shaft, bearing spiders and bowl shall be inspected for evidence of excessive accumulations or deposits of ferric or ferrous hydroxides. If the deposits are present, sufficient samples shall be collected to fully fill a bottle capable of being sealed airtight. This shall be done as rapidly as possible and the samples sent to the laboratory immediately, so to avoid generation of heat in the sample. The samples shall be sent to the chemical and biological laboratories for identification of chemical and biological laboratories for identification of chemical compounds present and identification, if possible, of organism involved.

g) Examine pump parts for evidence of pitting, tuberculations, graphitization, cavitation and wear. Pump bowls and impellers shall be inspected for evidence for graphitization in areas where sulphate bacteria are known or suspected to be present.

h) The static water level and depth of the bottom of the well assembly shall be checked again out of the well when the pump is taken out of the well.

... uses of well failure or sickness are established on the basis of the performance and other data, appropriate remedial measures, as detailed in subsequent para. may be adopted. In case reduction in yield is found to have been caused due to some sort of pump failure, the obvious remedy is to repair or replace the pump. In all such cases, it is a good practice to observe sounding of the well and compare it with the original one.

6. Preliminary Steps for Well Rehabilitation

6.1 Usually a well shall not be rehabilitated until the specific capacity has decreased 15 percent or more. The proposed rehabilitation shall usually involve pulling of the pump

Prior to any field activity, analyses of water from the well as initially completed and at present shall be examined in regard to its original and present apparent incrustation potential If it is high or has increased in time, possibly two acid treatments may be required and provision shall be made to have the required material available, if needed.

If records on the kwh used by the well, the hours of operation, or the volume of water pumped are available, they shall be examined. Other things being equal (which they seldom are), the amount of incrustation or fine invasion of the pack will vary with the volume of water pumped, the hours of operation, or similar measure of well use.

Data on the initial static water level, the present water level the specific capacity at design discharge and the present specific capacity at a discharge rate and draw down low enough to permit continuous pumping for 4 hours without breaking suction shall be obtained. This shall give a qualitative measure of the degree of deterioration and by comparision with later tests the success of the rehabilitation programme. When the pump is pulled, examine the various parts immediately as they are removed from the well. The column pipe, drive shaft, bearing spiders, and bowl shall be inspected for evidence of excessive accumulations or deposits of ferric or ferrous hydroxides. If present, sufficient samples shall be scrapped off for laboratory examination to fully fill a bottle capable of being sealed airtight. This shall be done as rapidly as possible and the samples sent to the laboratory immediately, since the oxidation and loss of original character of such material when exposed to the air, temperature change, and drying is at times of rapid as to generate sensible beat in the sample. Pump parts shall subsequently be cleaned thoroughly and examined for evidence of pitting, tuberculation, graphitization, cavitation, and wear by the machine shop. Any necessary repairs, replacements, or adjustments shall be made while the well is being worked over. The samples scrapped from the pump shall be submitted to the chemical and bilogical laboratories for identification of chemical compounds present and identification, if possible, of organisms involved. Pump bowls and impellers shall be inspected for evidence or graphitization in areas where sulphate reducing bacteria are known or suspected to be present.

The static water level and depth of the bottom of the hole shall be checked again with the pump out of the well.

If equipment is available, a TV camera survey shall be made of the well and the location of any evidence of incrustation, organic growth or accumulation on the casing and screen recorded. Any filamentous iron bacteriol or similar organisms floating in the water shall be noted. Any evidence of mechanical damage to the casing and screen shall be carefully inspected with the camera and recorded in regard to description and depth.

Identification of organisms that contribute to well deterioration is not primarily important initially since it is probable that they may be controlled by presently practiced chlorination or their sterilizing procedures. However, these shall be studied and identified eventially as part of the overall investigation since such knowledge may lead to more effective or less expensive methods of control.

7. Methods of Rehabilitation

7.1 *Glossy Phosphates Treatment* — Polyphosphates are used to disperse clays and silts, and loosen their adhesion to sand and gravel so they may be more readily drawn into the well during development. They are seldom used alone but usually in conjunction with a wetting agent, sodium carbonate and a chlorine compound The wetting agent facilitates the penetration of the polyphosphate solution into the fine grained materials and hastens the operation. The sodium carbonate has a cleaning action towards rust on iron screens and pipe, and also serves to neutralize the effects of oil and other organic compounds that might interfere with the action of the chlorine The chlorine acts somewhat as a catalyst and seemingly improves the action of the polyphosphates as well as acting to sterilise the well and adjacent formations.

However, until more is known of the fabric and composition of the aquifers, it is recommended that wetting agents be omitted from the solutions. Under some circumstances the wetting agents cause too rapid a breakdown of some clays and a drastic breakdown of the fabric. As a consequence, aquifers are sometimes to tightly blocked to be adequately developed by any means.

Also in wells screened with fibreglass-reinforced epoxy, the sodium carbonate may probably be left out of the solution without its losing efficiency.

When first applied to water well development, the use of 13 to 18 kg of polyphosphates per 450 litre of water in the well was used. With experience, this was found to be an unnecessarily strong solution for most wells. On the other hand, it was found that all wells did not respond similarly and that the desirable concentration might range from 2·3 to 9 kg of polyphosphate per 450 litre of water in the well. Initially it is suggested using 3·6 to 4·5 kg hexometaphosphate per 405 litre of water in the wells. Experimental increases or decreases about 900 g each may show better performance with a greater or loss concentration, but it shall be determined only by experiment.

While the percent of chlorine compound in the solution appears to improve its action, if the amount of chlorine present is at least 50 ppm. Larger concentrations do not seem to either impede or improve the effects of the solution. Consequently, chlorine may be used with polyphosphates either as a normal sterlizing agent or in shock treatments designed to oxidize and destroy not only the organisms but the inanimate products of their metabolism that act to block packs and screens.

In view of these considerations and the probable nature of the aquifers and blocking materials in the screen, the initial procedure in rehabilitating any well is as follows:

Estimate the volume of water in the pack and screen between the water table and the bottom of the hole to the nearest 450 litre. On the basis of the following amount of reagents per 450 litre of water in the well, estimate the amount of various chemicals required:

a) For fibreglass reinforced epoxy screens — Sodium hexametaphosphate 3.6 kg; available 100 ppm

b) For metal screens — In addition to the above 900 g sodium carbonate

c) Should experience show use of a wetting agent is helpful 450 g pluronic F68 or equivalent.

Most wells contain between 10 900 to 15 900 l of water. A wooden or black iron tank 1·2 × 1·5 × 3 m is a convenient size for transportation, etc, and holds in excess of 6 360 litre of water. Therefore, two or three batches of solution mixed in the tank shall be required for each well. A convenient but not necessary arrangement that speeds up the operation is to use two tanks in order that the next batch of solution may be mixed while the previous one is being placed in the well.

The solution is poured or pumped into the well through a 38 to 50 mm plastic or black iron pipe that initially is installed from the surface to about 1·5 m above the bottom of the well. Sufficient solution is put in the well to displace an estimated 1·5 or 3 m of the water in the casing and pack. The pipe is then raised 1·5 or 3 m and the procedure repeated until all water in the well and pack are displaced by the solution. The solution has higher specific gravity that the water and displaces it upward and outward from the well. When all the solution is installed in the well, a volume of water equal to about one-half that contained in the casing and screen is pured in at the top to displace the solution from the screen and force it out into the formation (*see* Table 1). A 200 m casing contains about 11 litre and 200 mm screen about 18 litre of water per metre of length. A surge block bail or similar tool is then run from the bottom of the well to above the water table two or three times of the inductor pipe for air surging may be replaced to near the bottom of the well and air bubbled up through the well to thoroughly mix the solution remaining in the casing screen.

TABLE 1 LITRE PER 300 mm OF LENGTH—CONTENTS OF CASING AND SCREEN

(*Clause* 7.1)

Nominal Pipe Size mm	l
100	3·0
125	4·6
150	6·8
200	12·0
250	19·0
300	26·4
350	32·2
400	43·0
450	54·0
500	67·0
550	81·8
600	98·0

Allow the solution to remain in the well for a minimum of 6 hours, overnight is a commonly used period, during which the well is surged about every hour by running the surge block from the top of bottom of the water column in the well three or four times at a moderate speed or by surging with air.

7.2 *Acid Treatment* — One of the most commonly used acids for treatment of well is 27·92 percent hydrochloric acid. The acid is used full strength usually in a volume sufficient to displace 1·5 to 2 times the volume or water in the casing, screen, and gravel pack between the bottom of the well and 3 m above the topmost screen slot. The acid is poured into the well through a black iron or plastic pipe 38 to 50 mm in diameter which extends to the bottom of the well. The estimated volume of acid required to displace the water from 1·5 to 3 m section is poured in. The acid has a higher specific gravity than water. Then the pipe is lifted 1·5 to 3 m and the process repeated until all the acid is added to the well. During pouring of the acid, 900 g of chelating agent per 4·5 litre of HCl shall be poured down the pipe. Citric acid, Rochelle salts, tartaric acid, phosphoric acid, and glycolic acid are acceptable chelating agents. Muriatic acid dissolves iron compounds when at a *p*H lower than 3 but as the acid reacts with the carbonates the *p*H rises to 3 and insoluble ferrous hydroxide precipitates from the acid. The chelating agents tend to keep the iron in solution regardless of the *p*H so the iron can be pumped from the well with the spent acid, rather than remaining as a contaminant to block the pack.

In metallic casing and screen, an inhibitor such as knox gelatine is added to the acid in the amount of 2·3 to 2·7 kg dissolved in warm water per 450 litre of acid to control attack on metal parts. However, there are no such parts in a fibreglass reinforced epoxy well so this is unnecessary when treating such wells.

The acid remains in the well for 4 to 6 hours. At the end of about 3 hours sufficient water is added to the well to displace the acid from 3 m above the topmost slot to the bottom of the well. While the acid is in the well and pack of the well is surged by air or with the surge block for 15 to 20 minutes each hour. At the end of about 6 hours, the acid is bailed or pumped out.

Use of hydrochloric acid is quite dangerous for inexperienced crew members. The acid gives off dangerous poisonous fumes and the reaction with the carbonates in a well is sometimes voilent, resulting in spraying the bystanders around the well. In addition, the transportation of the liquid hydrochloric acid to the field is difficult and sometimes dangerous. For these reasons sulfamic acid is becoming more popular for well rehabilitation Sulfamic acid is more expensive but is easily shipped as a dry drystal or powder. It is not as aggressive or strong as hydrochloric acid and is generally much safer to use. It requires about two times as long to treat a well is does hydrochloric acid.

When using sulfamic acid in a well, the same estimates are made regarding the column of water in the well to be displaced and 1½ to 2 times that volume is poured into the well through a black iron or plastic pipe as described in the discussion on hydrochloric acid. It is available in grannular from and may be poured into the well from the top.

Because sulfamic acid is a milder and less aggressive acid, it is mixed in a black iron or wooden tank at the surface. A tank about 1·2 × 1·5 × 3 m is usually adequate and holds about 6360 litre The tank shall have a bottom valve through which the acid solution is drawn into the well. 41 kg sulfamic acid, 450 g of pluronic F68 and 2·7 kg chelating agent such as Rochelle salts, citric acid, tataric acid, etc, are added and dissolved in each 450 litre of water to be poured into the well. If well is screened with metal, an inhibitor such as knox gelatine shall be used at the rate of 1·8 to 2·3 kg per 450 litre of solution. The acid shall remain in the well for at least 12 hours during which it shall be surged by air or surge block about 15 to 20 minutes every hours. Then it is bailed or pumped to waste.

Hydrochloric acid of adequate strength is readily available at a relatively low price It is used successfully safety precautions that no injuries or casualties have resulted. Under the circumstances, it appears that hydrochloric acid, despite the danger and difficulties associated with its use, shall continue to be used. However, if the programme expands to the point where trained and experienced crews are not available to carry on the acidizing work, consideration shall be given to employing the less dangerous sulfamic acid.

The spent acid is bailed or pumped out of the well using a corrosion-resistant pump for the purpose. In many wells, pumping with a centrifugal pump shall be possible. Close observation of the bailing or pumping discharge and the draw downs during removal of the acid shall give an indication of the success of the treatment.

During acid treatment of a well the crew shall wear protective clothing and respirators One or two 250 litre drums of concentrated sodium bicrabonate shall be available for quick neutralization of acid with which crew members may come in contact during the operation.

During treatment, incrustation is dissolved and the fines incorporated in the agent remain in the pack and base material. On completion of acidizing the well shall be redeveloped using polyphosphates, sufficient chlorine for a shock treatment and one of the methods of surging or jetting.

7.3 *Chlorine Treatment* — In some localities where the bacterial growth or slime have clogged the water bearing formation, the treatment with chlorine has been found effective. The disinfection or burning up of the organism slime is accomplished by hypochlorous and hypochloric acids, which are formed when chlorine is added to water.

The chlorine shall be handled carefully with the aid of suitable containers and piping to ensure proper placement, as it is highly corrosive in the presence of water. When incrusted wells are heavily treated with chlorine. It shall be followed by dechlorination with sulphur dioxide.

For chlorine treatment, a concentration of 100 to 200 ppm of free chlorine is required, sufficient amount of calcium hypochlorite sodium hypochlorite is put into the well either directly or in a water solution so as to give the required concentration of chlorine, alternatively chlorine gas is used in solution with water. The solution shall be introduced in the well through a small diameter plastic pipe. A quantity of chlorine, 14 to 18 kg, added slowly over a period of 12 hours, shall suffice to produce good results in a large well. After adding chlorine solution, it shall be forced out into the water bearing formations by adding considerable amount of water. About 50 to 100 times the volume of water standing in the well shall be used for this purpose.

The well shall be surged or solution agitated as is done in case of acid treatment.

7.4 *Dry Ice Treatment* — The use or dry ice, that is, solid carbondioxide is still in the experimental stage. Dry ice changes from solid to gaseous state rapidly with considerable pressure, when put into well water. The rapidly expanding gas is confined within the well casing and is forced through the screen openings to loosen the clogged material On account of high pressure developed, provision shall be made for the control and relief of pressure to guard against any damage. As dry ice may cause severe burns, if handled with bare hands, heavy gloves or tongs shall be used in handling the ice.

7.5 *Explosives* — These are sometimes employed to develop and enlarge crevices and fissures in tubewells drilled in hard rocks. Charges of 30 to 500 ppm are used according to the hardness of the rock and the depth at which the charge is to be detonated.

8. Criteria for Acceptance

8.1 An increase in yield of the well by 30 percent of the pre-rehabilitated yield of the well or attainment of 75 percent of the initial yield, whichever is more, shall be the basis of acceptance. Alternatives, it may be agreed to between the contractor and the owner.

9. Information to be Supplied by the Contractor to Owner for Future Use

9.1 The contractor shall supply the following information to the owner for future use:

a) Results of the investigations carried out before taking up work of rehabilitation.

b) Result of chemical tests carried out before and after rehabilitation work.

c) Methods used alongwith name and quantity of chemicals used and number of treatments given.

d) Results of rehabilitation, that is, discharge, depression and sand content in ppm at start and after 20 minutes.

e) Sounding of the well after the treatment.

f) Condition of the pumping unit before rehabilitation and details of repairs carried out to it.

g) Suggestions, based on investigations, for future upkeep and maintenance of the well including recommended limit to continuous discharge and depression, that is, rate of pumping in order to avoid harmful over pumping and thereby limiting the entrace velocities.

h) Any other relevant information desired by the owner.

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TABLE 1 ESSENTIAL CHARACTERISTICS FOR DRINKING WATER

(*Clause* 2.1)

Sl No.	Substance or Characteristic	Method of Test, Cl Ref of IS : 3025-1964*	Other Methods of Test	Requirement (Desirable Limit)	Undesirable Effects Outside the Desirable Limit	Desirable, Essential	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Colour, Hazen units, *Max*	5	—	10	Above 10, consumer acceptance decreases	Essential	May be extended to 50 only if toxic substances are not suspected, in absence of alternate sources
ii)	Odour	7	—	Unobjectionable	—	Essential	a) Test cold and when heated b) Test at several dilutions
iii)	Taste	Test at temperature not lower than 20°C. Test at several dilutions	—	Agreeable	—	Essential	Test to be conducted only after safety has been established
iv)	Turbidity, NTU, *Max*	—	Appendix B	10	Above 10, consumer acceptance decreases	Essential	May be extended up to 25, in absence of alternate sources
v)	Dissolved solids mg/l, *Max*	12	—	500	Beyond this palatability decreases and may cause gastro intestinal irritation	Desirable	May be extended up to 3 000, in the absence of alternate sources
vi)	*p*H value	8	—	6·5 to 8·5	Beyond this range the water will affect the mucous membrane and/or water supply system	Essential	May be relaxed up to 9·2, in absence of alternate sources
vii)	Total hardness (as $CaCO_3$) mg/l, *Max*	16	—	300	Encrustation in water supply structure and adverse effects on domestic use	Essential	May be extended up to 600, in the absence of other sources
viii)	Calcium (as Ca) mg/l, *Max*	33	—	75	Encrustation in water supply structure and adverse effects on domestic use	Desirable	May be extended up to 200, in the absence of other sources
ix)	Magnesium (as Mg) mg/l, *Max*	16, 33, 34	—	30	Encrustation in water supply structure and adverse effects on domestic use	Desirable	May be extended up to 100, in the absence of other sources
x)	Copper (as Cu) mg/l, *Max*	36 (*see* Note)	—	0·05	Astringent taste, discoloration and corrosion of pipes, fittings and utensils will be caused beyond this	Desirable	May be relaxed up to 1·5
xi)	Iron (as Fe) mg/l, *Max*	32	—	0·3	Beyond this limit taste/appearance are affected, has adverse effect on domestic uses and water supply structures, and promotes iron bacteria	Essential	May be extended up to 1·0, in absence of alternate sources

(*Continued*)

TABLE 1 TEST CHARACTERISTICS FOR DRINKING WATER — *Contd*

Sl No.	Substance or Characteristic	Method of Test, Cl Ref of IS : 3025-1964*	Other Methods of Test	Requirement (Desirable Limit)	Undesirable Effects Outside the Desirable Limit	Desirable/ Essential	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
xii)	Manganese (as Mn) mg/l, *Max*	35 (*see* Note)	—	0·1	Beyond this limit taste/appearance are effected, has adverse effect on domestic uses and water supply structures	Desirable	May be extended up to 0·5 where alternate source is not available
xiii)	Chlorides (as Cl) mg/l, *Max*	24	—	250	Beyond this limit, taste, corrosion and palatability are affected	Essential	May be extended up to 1 000, in the absence of other alternate sources
xiv)	Sulphate (as SO_4) mg/l, *Max*	20	—	150	Beyond this causes gastro intenstinal irritation when magnesium or sodium are present	Desirable	May be extended up to 400 provided magnesium (as Mg) does not exceed 30
xv)	Nitrate (as NO_3) mg/l, *Max*	—	6 of IS : 2488 (Part IV)-1974†	45	Byond this methnaemoglobinemia takes place	Desirable	No relaxation
xvi)	Fluoride (as F) mg/l,	23	—	0·6 to 1·2	Low fluoride levels are linked with dental caries. Above 1·5 it may cause fluorosis	Desirable	If the limit is below 0·6 water source should not be rejected but suitable public health measures should be taken. Maximum limit may be extended to 1·5, if no better alternate source is available
xvii)	Phenolic compounds (as C_6H_5OH), mg/l, *Max*	54	—	0·001	Beyond this, it may cause objectionable taste and odour	Desirable	May be relaxed up to 0·002
xviii)	Mercury (as Hg), mg/l, *Max*	—	(*see* Note) Mercury ion analyser	0·001	Beyond this, the water becomes toxic	Desirable	No relaxation of this limit is allowed. To be tested when pollution is suspected
xix)	Cadmium (as Cd), mg/l, *Max*	—	(*see* Note)	0·01	Beyond this, the water becomes toxic	Desirable	No relaxation of this limit is allowed. To be tested when pollution is suspected
xx)	Selenium (as Se), mg/l, *Max*	28 (*see* Note)	—	0·01	Beyond this, the water becomes toxic	Desirable	No relaxation of this limit is allowed. To be tested when pollution is suspected

(*Continued*)

Sl No.	Substance or Characteristic	Method of Test, Cl Ref of IS : 3025-1964*	Other Methods of Test	Requirement (Desirable Limit)	Undesirable Effects Outside the Desirable Limit	Desirable/ Essential	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
xxi)	Arsenic (as As), mg/l, *Max*	40	—	0·05	Beyoned this, the water becomes toxic	Desirable	No relaxation of this limit is allowed. To be tested when pollution is suspected
xxii)	Cyanide (as CN), mg/l, *Max*	—	Selective ion electrode method	0·05	Beyoned this limit, the water becomes toxic	Desirable	No relaxation. To be tested when pollution is suspected
xxiii)	Lead (as Pb), mg/l, *Max*	—	(*see* Note)	0·1	Beyond this limit, the water becomes toxic	Desirable	No relaxation being a health parameter. To be tested when pollution/plumbo-solvency is suspected
xxiv)	Zinc (as Zn), mg/l, *Max*	39	—	5	Beyoned this limit it can cause astringent taste and an opalescence in waters	Desirable	May be relaxed up to 15. To be tested when pollution is suspected
xxv)	Anionic detergents (as MBAS), mg/l, *Max*	—	Methylene-blue extraction method	0·2	Beyond this limit it can cause a light froth in water	Desirable	May be relaxed up to 1·0. To be tested when pollution is suspected
xxvi)	Chromium (as Cr^{6+}), mg/l, *Max*	38	—	0·05	May be carcinogenic above this limit	Desirable	No relaxation. To be tested when pollution is suspected
xxvii)	Polynuclear aromatic hydrocarbons (as PAH), µg/l, *Max*	‡	‡	—	May be carcinogenic	Desirable	‡
xxviii)	Mineral oil mg/l, *Max*	—	Gas chromatographic method	0·01	Beyond this limit, undesirable taste and odour after chlorination takes place	Desirable	May be relaxed up to 0·03. To be tested when pollution is suspected
xxix)	Residual, free chlorine, mg/l, *Min*	45	—	0·2	—	Essential	To be applicable only when water is chlorinated. Tested at consumer end. When protection against viral infection is required, it should be *Min* 0·5 mg/l
xxx)	Pesticides	‡	‡	Absent	Toxic	Desirable	‡
xxxi)	Radioactive materials:	—	58		—	Desirable	—
	a) Alpha emitters µc/ml, *Max*			10^{-8}			
	b) Beta emitters µc/ml, *Max*			10^{-7}			

Note — Atomic absorption spectrophotometric method may be used.

*Methods of sampling and test (physical and chemical) for water used in industry.

†Methods of sampling and test for industrial effluents, Part IV.

‡Limits and methods of test are under study.