SESSION 32

WELL MAINTENANCE AND REHABILITATION I

Dr Amjad Aliewi

House of Water and Environment

Email: amjad.aliewi@hwe.org.ps , Website: www.hwe.org.ps

Objectives

- Well Development has two broad objectives: (1) to repair damage done to the formation by the drilling operation so that the natural hydraulic properties are restored, and (2) to alter the basic physical characteristics of the aquifer near the borehole so that water will flow more freely to a well.

- All new wells (Figure1) should be developed before being put into production to achieve sand-free water at the highest possible specific capacity.

Objectives

- Well development is confined mainly to a zone immediately adjacent to the well, where the formation materials have been disturbed by well construction procedures or adversely affected by the drilling fluid.

- In addition, the undisturbed part of the aquifer just outside the damaged zone may be reworked physically during development to improve its natural hydraulic properties.

Objectives

- Well rehabilitation objectives are:

(1) to reclaim existing wells than simply abandoning them to start over. The main reason usually is sometimes very high cost of finding a new location (getting it approved), drilling and testing, and the logistics of powering a pump and piping water.

(2) A well that is failing was put in that particular spot for a good hydrogeological reason and therefore it is not always possible to identify a successful alternative site, hence rehabilitate such wells.

- Older wells often require periodic redevelopment to maintain or even improve the original yield and drawdown conditions. Maintaining a high specific capacity assures that the well will be energy efficient.

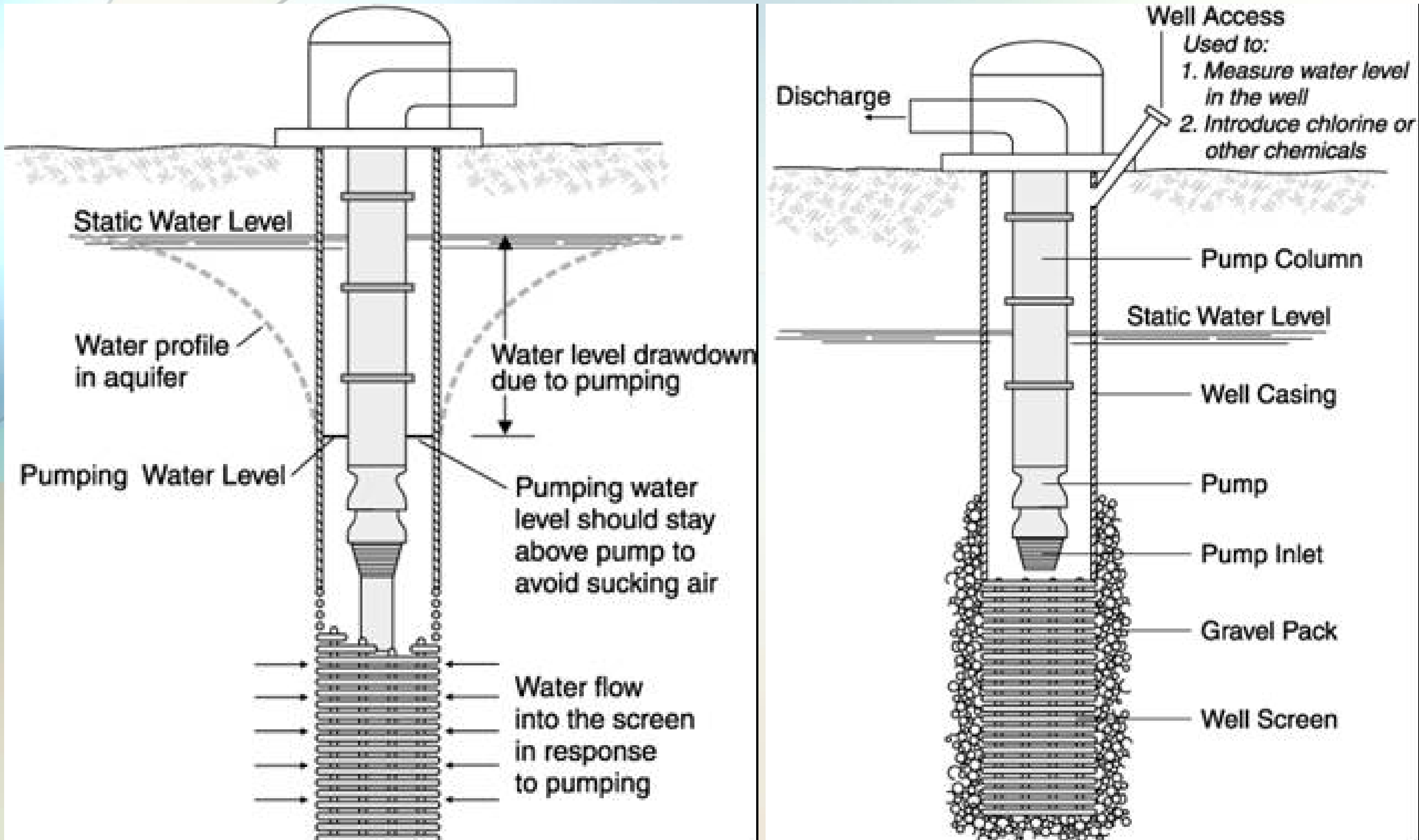

Figure 1: Typical set-up of a well

1. Factors That Affect Development

1.1 Well Completion Method

- There are two major completion methods - natural development and filter packing. In natural development, a highly permeable zone is created around the screen from materials existing in the formation. Creation of this zone is best understood by visualizing what happens throughout a series of concentric cylindrical zones in a sand aquifer surrounding the screen.

- In the zone just outside the well screen, development removes most particles smaller than the screen openings, leaving only the coarsest material in place. A little farther out, some medium-sized grains remain mixed with the coarse sediment.

1. Factors That Affect Development

- Beyond that zone, the material gradually grades back to the original character of the water-bearing formation. Finer particles brought into the screen in this process are removed by bailing or pumping. Development work is continued until the movement of fines from the formation becomes negligible.

- In filter packing, a specially graded sand or gravel having high porosity and permeability is placed in the annulus between the screen and the natural formation.

1. Factors That Affect Development

- By creating this succession of graded zones around the screen, development stabilizes the formation and prevents further movement of sediment.

- After development, water moving toward the screen encounters sediment with increasing hydraulic conductivity and porosity. Improving the hydraulic conditions around the well will increase the specific capacity and efficiency.

- Thus, more water can be obtained from the well, and for any yield the cost of lifting the water to the surface will be minimized.

1. Factors That Affect Development

1.2 Open Area And Slot Configuration

- All development methods work best in wells equipped with screens having both maximum open area and the type of slot configuration that permit hydraulic forces exerted inside the well screen to be directed efficiently into the formation. Both factors are equally important in successful development.

- Screen open areas vary typically from a low of 1 percent for perforated pipe to more than 40 percent for continuous slot, wire-wound screens.

1. Factors That Affect Development

- Screens with high open area can be developed more effectively because more of the development energy can reach the formation.

- Slot configuration also controls how much development energy reaches the formation, and the percentage of the formation that this energy can affect.

- Thus, more fine material can be removed more quickly if all the available energy can be directed at most or all of the surrounding formation.

1. Factors That Affect Development

- Selection of the correct slot size for well screens is essential for successful well development. Slot openings are chosen to permit removal of the fine material from the formation. For naturally developed wells, it is common practice to select a slot width that retains about 40 percent of the sediment in the formation adjacent to the screen. For filter-packed wells, the slot opening is selected to retain about 90 percent of the filter pack material.

- Removal of too much sediment may cause settlement of the overlying surface materials, which can have undesirable effects on the well and produce dangerous conditions for the drilling rig. On the other hand, when well screen openings are smaller than necessary, full development may not be possible and the well yield will be below the potential of the formation. Incomplete development can also lead to cementation or incrustation caused by abnormally high flow velocities and the corresponding pressure drop near the well bore.

1. Factors That Affect Development

1.3 Filter Pack Thickness

The thickness of the filter pack has considerable effect on development efficiency. This happens for two reasons.

First, the filter pack reduces the amount of energy reaching the borehole wall. The thinner the filter pack is, the easier it is to remove all the undesirable fine sand, silt, and clay when developing the well.

Second, a filter pack is so permeable that water may flow vertically in the filter pack envelope at places where the formation may be partially clogged, rather than move into or out of the natural formation. To permit the transfer of development energy to the borehole wall, filter packs normally should be no more than 8 in (203 mm) thick and should be properly sized and graded according to the design criteria.

1. Factors That Affect Development

1.4 Type Of Formation

Highly stratified, coarse-grained deposits are most effectively developed by methods that concentrate energy on small parts of the formation. In uniform deposits, development methods that apply powerful surging forces over the entire well bore produce highly satisfactory results. Other development methods that withdraw or inject large volumes of water quickly can actually reduce the natural hydraulic conductivity of formations containing a significant amount of silt and clay.

2. Malfunctioning of Wells and Reduction in Efficiency

2.1 Well Efficiency and Performance

The reduced efficiency generally determined as a percentage loss in specific capacity based on the specific capacity determined from pumping tests at the time of installation.

The specific capacity of a well should be measured and recorded at the same time each year as shown in **Table 2.1**. August is the best time because it generally is the driest month.

2. Malfunctioning of Wells and Reduction in Efficiency

Table 2.1 Example: Yearly record of specific capacity of irrigation wells.						
Year	**Flow Rate from Well** (gpm)	**Pumping Water Level (PWL)** (feet)	**Static Water Level (SWL)** (feet)	**Drawdown (PWL-SWL)** (feet)	**Specific Capacity**	**Comparison to New Well**
1	900	80	30	50	18	
2	900	73	22	51	17.6	98 %
4	880	85	31	54	16.2	90 %
6	850	89	30	59	14.4	80 %

2. Malfunctioning of Wells and Reduction in Efficiency

As the years pass, the performance of most wells will decrease without some form of maintenance. Increased drawdown often will reduce the flow rate due to the greater lift required from the pump, and it can increase pumping energy requirements. Therefore, having an accurate flow meter on each well and a useable access port to the well casing, **Figure 2.1**, is important.

The access port is used to measure the water level in the well and to add chlorine or other chemicals to the well. It should be at least 1 inch in diameter, but a 2-inch diameter access is preferred.

2. Malfunctioning of Wells and Reduction in Efficiency

Figure 2.1: Measuring the water level in a well with a steel tape.

2. Malfunctioning of Wells and Reduction in Efficiency

Table 2.2 identifies five basic causes of well failure that account for most well maintenance problems. These are: well design, installation, development plus hole stability and incrustation.

2. Malfunctioning of Wells and Reduction in Efficiency

Table 2.2 Definitions of Poor Well Performance and Causes

Problems	Causes
Sand/Silt Pumping: Pump and equipment wear and plugging.	•Inadequate screen and filter-pack selection or installation, incomplete development, screen corrosion, collapse of filter pack due to washout resulting from excessive vertical velocity in the filter pack. •Presence of sand or silt in fractures intercepted by an “open hole”. •Casing/screen break due to settlement, ground movement, or poor installation. •Pumping in excess of gravel pack and system capacity (oversized pump, pipe breakage lowering pumping head, etc.).
Silt/Clay Infiltration: Filter clogging, sample turbidity.	•Inadequate well casing seals, infiltration through filter pack, or "mud seams" in rock. •Inadequate development, or casing-screen break due to settlement, ground movement or poor installation. •Formation material may be so fine that engineered solutions are inadequate.

2. Malfunctioning of Wells and Reduction in Efficiency

Table 2.2 Definitions of Poor Well Performance and Causes (**CONT.**)

Problems	**Causes**
Pumping Water Level Decline: Reduced yields, increased oxidation, well interference, impaired pump performance.	•Area or regional water-level declines. •Pumping in excess of sustainable well capacity, well interference, or well plugging or encrustation. •Sometimes a regional decline will be exaggerated at a well due to plugging.
Lower / Insufficient Yield: Unsatisfactory system performance.	•Pump wear or malfunction, encrustation, plugging, or corrosion and perforation of discharge lines, increased total dynamic head (TDH) in water delivery or treatment system.
Complete Loss of Production: Failure of system.	•Most typically pump failure. Also loss of well production due to dewatering, plugging, or collapse.

2. Malfunctioning of Wells and Reduction in Efficiency

Table 2.2 Definitions of Poor Well Performance and Causes

Problems	Causes
Chemical Encrustation: Increased drawdown reduced output or reduced injection acceptance rate.	•Deposition of saturated dissolved solids, usually high Ca, Mg carbonate, and sulfate salts or iron oxides, or FeII sulfides. •pH > 7.5 •Carbonate hardness> 300 mg/l. •Dissolved Iron concentration > 2 mg/l. •Dissolved Manganese > 1 mg/l.
Pump/Well Corrosion: Loss of performance, sanding, or turbidity	•Natural aggressive water quality, including : -H2S< 1 mg/l. -NaCl-type water. -pH< 7. -DO> 2 mg/l. -Cl> 500 mg/l. -TDS> 1000 mg/l. -CO2> 50 mg/l. •Aggravated by poor engineered material selection.
Well Structural Failure: Well loss and abandonment.	•Tectonic ground shifting, ground subsidence, failure of unsupported casing in caves or unstable rock due to poor grout support, casing or screen corrosion and collapse, casing insufficient, local site operations.

2. Malfunctioning of Wells and Reduction in Efficiency

2.2 Common Causes of Well Failure

A. Design

1. Design does not adequately consider hydrogeologic conditions, including water quality, interference, recharge, screen selection
2. Pumping rate not properly related to well design.
3. Pumping rate and well design not properly related to design life of well

2. Malfunctioning of Wells and Reduction in Efficiency

B. Installation

1. *Failure to accurately identify and locate productive zones*

a. Screens improperly located, not adjacent to aquifer

b. Wrong zones fractured, or "shot"

c. Wrong zone grouted

2. *Improper casing installation*

a. Failure of connection, poor weld or coupling

(1) Accelerated corrosion

(2) Aquifer inter-connection

(3) Casing leaks, well contamination

(4) Casing failure or collapse

b. Failure of grout

(1) Poor grout distribution, too thin, no centralizers on casing.

(2) Segregation during emplacement, improper tremie or pumping procedure

2. Malfunctioning of Wells and Reduction in Efficiency

3. *Drilling techniques*

a. Excessive “mudding” of fractures and voids during drilling by either cable tool or rotary methods

4. *Sanitary protection*

a. Improper surface drainage.
b. Improper surface grouting.
c. Improper well seal.

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C. Development

1. Failure to remove mud embedded or emplaced during drilling operations.
2. Failure to remove fine clay, silt and sand indigenous to formation being developed.
3. Improper application of chemicals:
   a. utilization of phosphates without bio-acid
   b. Oxidation of iron at well interface.
   c. Chemical precipitation of carbonates by diluting acids.
   d. shale hydration.
   e. Corrosion of screens by development chemicals.

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D. Hole Stability

1. Casing failure, grout failure, screen failure
   - a. Corrosion of screen or casing
     - (1) Hydraulic
     - (2) Chemical
     - (3) Galvanic
     - (4) Biological
   - b. Improper installation

2. Uncased hole caving
   - a. failure to case or screen where required (unstable well)
   - b. Shale hydration
   - c. Excessive fluid velocities

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E. Incrustation

1. Chemical

a. carbonate, oxide, hydroxide,sufate deposition on or within the intake structure of the well.

- Well declines exponentially with increase in velocities

2. Physical

a. Particulate plugging

(1) Fine sand, silt and clay slowly migrate toward well

(2) Well declines substantially (apparently), linearly with velocity increase

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3. Biological

a. Bacterial growths in aquifer adjacent to well, in screen openings, or in well bore

(1) Rate of bacterial growth exponential with abundant nutrient, but limited by availability of nutrients in most ground water supplies. Increase in velocity increases amount of nutrient available.

b. Multiple strains of naturally occurring bacteria available to most wells

(1) Iron-fixing (oxidizing conditions), sulphur-splitting (reducing conditions), hydrocarbon- forming (reducing), hydrocarbon-splitting (oxidizing), and other strains may all coexist within close proximity. Balance shifts with nutrient variation

c. Contamination during drilling

(1) Introduction of bacteria from surface into borehole

(2) Introduction of nutrients into borehole via drilling fluid,

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4. *Combined chemical, physical, biological incrustation*

a. High percentage (80% +) of all industrial and municipal well failures result from combined incrustation problems

(1) Chemical-physical

(2) Physical-biological

(3) Chemical-physical-bilogical

b. Physical (particular migration) is common to most well failures

(1) Particulate material migrates to well face where it is commonly bound by chemical/biological cementing mass

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2.2 Impact of Water Quality on Well Operation and Maintenance

Physical and Chemical Quality Although the quality of groundwater is known to influence the operation and maintenance of wells, no theoretical model reliably predicts the performance of wells on the basis of a certain quality of water. The performance of a new well can be predicted by considering the operating histories of similar nearby wells. Nevertheless, a familiarity with the basic factors that influence the quality of groundwater include color, dissolved solids or conductivity, dissolved gases, hardness and temperature.

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Color

White or milky water may indicate pump cavitation or cascading water within the bore of the well.

Concentration of Hydrogen Ions (pH)

Groundwater with a pH from 0 to 6 is acidic and corrosive, although unpolluted groundwater with a pH less than 4.5 is rare. Since a pH of 3.5 seriously inhibits biological activity, relatively weak acids may be used to maintain and redevelop biologically contaminated wells. Pure water has a PH of 7 and is natural. Groundwater with a pH from 8 to 14 is alkaline. The pH in unpolluted groundwater typically ranges from 6 to 8.

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Chlorides

High concentrations of chloride ions (>500 ppm) may quickly corrode the ferrous metals normally used to construct water wells.

The presence of chlorides may also indicate the pollution from industrial sources or oil field brines, the proximity of production units to natural brines or brackish water. In all cases, the increased concentration of chlorides leads to increased corrosion, especially in a neutral (pH=7) or acidic solutions. Good well design and construction, proper selection of casing materials, and good operational practices can improve production and minimize chloride intrusion.

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Sulfates

Calcium sulfate may cause an increasing scale.

2. Malfunctioning of Wells and Reduction in Efficiency

Iron and manganese

Since rocks with minerals containing iron and manganese are so widespread geographically and geologically, groundwater normally contains some of these metals in solution. At pH of 5 or lower, iron and manganese are dissolved as ferrous (Fe++) and manganese (Mn++) inos which may form an insoluble, jelly-like mass in mass in the vicinity of well screens or the surrounding aquifer. As PH increases or oxygen is present, ferric (Fe+++) and magnetic (Mn+++) oxides are deposited as scale, a process which may result from dewatering near the well screen. If calcium and manganese carbonates also precipitate while carbon dioxide is released from water entering the well, a complex scale containing the carbonate salts of calcium, magnesium, iron and manganese may deposited onto well screens, fissures, void spaces, etc… in the aquifer, greatly reducing the efficiency and yield of the well.

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Trace amounts of iron and manganese greatly affect the life cycle of iron and manganese –fixing bacteria like *Gallionella* and *Crenothrix*. In the presence of only minute quantities (.01 ppm) of iron and manganese, minor amounts of trace elements and nutrients, and adequate oxygen, these bacteria quickly multiply and aggravate the plugging problems in the aquifer, borehole and screens caused by chemical precipitation.

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Nitrate

Although small quantities of nitrates may enter groundwater through natural process such as nitrogen fixation, significant quantities normally indicate pollution from industry, feedlots, irrigation, sewage, etc. Besides destroying portability, a high concentration of nitrates may nourish bacteria whose growth could aggravate the maintenance problems already discussed.

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Dissolved Gases

- Three important gases are frequently found dissolved in groundwater: carbon dioxide, oxygen and hydrogen sulfide.

- Carbon Dioxide is a major factor which may accelerate the rates of corrosion and incrustation. Carbon dioxide may dissolved in water as rain falls through the atmosphere, as groundwater percolates through some soils or rock types, or as a result of bacteria producing it in the subsurface environment.

- Under normal atmospheric conditions, carbon dioxide gas is odorless, colorless and soluble in water at 0.7 ppm.

- However, solubility increases rapidly under pressure. Carbon dioxide reacts with water to form carbonic acid.

2. Malfunctioning of Wells and Reduction in Efficiency

- Water with a high content of dissolved carbon dioxide causes the corrosion of metal on casings, screens, pumps, etc.., and the deposition of metallic carbonate scale. Corrosion of metal usually occurs at a concentration of 20 parts per million of carbon dioxide. All chemical reactions involving carbon dioxide (i.e., formation of acid, dissolution and precipitation of carbonates) are reversible and sensitive to the relatively minor changes in temperature and pressure that may be caused by the stress of pumping. An example of this phenomenon is the almost universal precipitation of calcium carbonate within the well bore, presumably caused by the rapid reduction of pressure within the bore relative to the pressure within the aquifer.

2. Malfunctioning of Wells and Reduction in Efficiency

- Within rock wells, where productivity depends primarily upon fractures and bedding planes, precipitation of carbonates occurs only at the intersection of the face of the bore with tight, closed fractures or bedding planes, while large, open fractures (greater than 0.01 inch) stay clean, or even enlarge, in carbonate rocks. These conditions explain the great longevity and very slowly declining yields of rock wells, and point the need for maintenance of the bore at the tighter, generally lower-yielding fractures. Yields may improve with new fracturing or with enlargement of old fractures.

- Field evidence indicates that the precipitation of carbonates caused by reduction of pressure is much less important than the precipitation caused by turbulent flow at high velocities. Wells designed to cause laminar flow within the bore should last approximately 40 years and require low maintenance, other factors permitting.

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Oxygen

- Although soluble at 7 parts per million, dissolved oxygen usually occurs in groundwater at a much lower concentration because of use by micro-organisms and the formation of metallic oxides during the percolation of groundwater to the water table.

- Even at great depth, however, groundwater often contains enough oxygen to support limited microbiological activity. At low concentrations (1 to 2 parts per million), dissolved oxygen speeds the corrosion of iron, galvanized iron, steel and brass. Conditions of low pH accelerate corrosion, but even at high pH (greater than 8) corrosion may be extensive if the dissolved oxygen concentrations are high.

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- Dissolved oxygen, along with nutrients and minor trace elements, controls the level of microbiological activity which may affect corrosion and organic incrustation. Increasing the content of dissolved oxygen by the turbulence and agitation with bubbling air, backflow from pumps, cavitation, off and on cycling, and related phenomena can increase organic and inorganic corrosion.

2. Malfunctioning of Wells and Reduction in Efficiency

Hydrogen Sulfide

- Hydrogen sulfide, also known as the toxic “sewer gas” of wastewater systems, gives the easily recognized “rotten egg” odor to water even at low concentrations of 0.01 parts per million. Hydrogen sulfide originates naturally in groundwater when metallic sulfides dissolve and sulfates are organically or inorganically broken down, or when pollution from sewers, tanneries, paper mills, etc.., invades the water supply.

- Hydrogen sulfide dissolves in water to form the relatively weak sulfurous acid that in the presence of dissolved oxygen or bacteria may be oxidized to form much stronger sulfuric acid. Dissolved hydrogen sulfide corrodes many metals used in well construction, resulting in expensive repairs. Often, metals dissolved from screens, casings, pump columns, etc., reappear close to the site of corrosion as oxides and sulfides.

2. Malfunctioning of Wells and Reduction in Efficiency

Hardness

- Hardness, which depends upon the concentration of calcium and magnesium ions, is measured in milligrams per liter as calcium carbonate, and indicates the tendency of a water to form soap scum.

- In hard water, calcium and magnesium primarily form carbonates, although bicarbonates, sulfates, nitrates and chlorides may also occur. Increases in temperature and decreases in pressure may result in precipitation of carbonate salts. Because of its relatively low solubility, calcium carbonate is the most common type of scale on the screens of wells. Although calcium and magnesium sulfates, nitrates, and chlorides may form scale under some conditions, high concentrations of these ions are more likely to cause corrosion.

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- Since the content of magnesium and calcium is important to hardness, aquifers of limestone or dolomite, or sediments from these rocks, usually yield the hardest water. Hardness is lowest in water from granitic and metaphoric rocks and noncarbonated shades. The degrees of hardness are defined below:

Category	mg / 1 as $CaCO_3$
soft	0-60
Moderately hard	61-120
Hard	121-180
Very hard	> 180

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Temperature

- A variation in temperature of 15 to 200F can significantly affect the type and rate of chemical reactions within the well screen and strongly affect biological activity. Furthermore, even at a constant rate of pumping, variation in temperature, and consequently viscosity, can cause important changes in pressure in the well and aquifer.

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Corrosion and Incrustation

- Corrosion is the removal of metals from well equipment. This can result in enlarged screen openings, perforated casings or pump columns, excessively worn pump parts, and similar damage. Incrustation is the deposition of unwanted material. This section describes some kinds of corrosion and incrustation, their causes, and some quantitative attempts to predict the likelihood of corrosion or incrustation occurring in groundwater.

- Groundwater is part of a dynamic chemical system which continuously adjusts to local changes in equilibrium. Consequently, within a single well, corrosion, incrustation and many other chemical, biological and physical activities can occur simultaneously.

2. Malfunctioning of Wells and Reduction in Efficiency

- The variety of chemical environments within a single ground water system caused some interesting effects on the screens of a radial collector well along the Ohio River near Louisville, Kentucky. In 1966, an inception of the upstream screens revealed a reddish, oxidizes environment consisting of iron hydroxide, carbonate scale, and significant amounts of clay and silt bound to the screens by *Crenothrix* and other iron fixing bacteria. Inception of the center screen revealed almost neutral conditions with little oxidation and incrustation this screen was in good condition, considering its age.

- The screens farthest downstream were chemically opposite to their upstream counterparts. Opening in the screens were enlarged and sulfur-reducing bacteria had deposited hard, black scale typical of a chemically reduced environment.

2. Malfunctioning of Wells and Reduction in Efficiency

- Although analysis of the water surrounding each screen did not account for such wide variations in chemical activity, each screen nevertheless presented very distinct maintenance problems. Similarly, two adjacent wells may require completely different types of maintenance because of a wide variation in local conditions

2. Malfunctioning of Wells and Reduction in Efficiency

2.3 Well performance

To recognize a change in well performance we must monitor:

- Discharge (quantity and quality).
- Pumping water level.
- Regional non-pumping water levels.

These will reflect changes:

- in pump performance
- in well condition
- in aquifer condition

2. Malfunctioning of Wells and Reduction in Efficiency

There are many variations to interpret:

- Higher discharge + higher pumping water level
- Higher discharge + constant pumping water level
- Constant discharge + higher pumping water level
- Constant discharge + constant pumping water level
- Constant discharge + lower pumping water level
- Lower discharge + higher pumping water level
- Lower discharge + constant pumping water level
- Lower discharge + lower pumping water level

Consideration of regional non-pumping water level changes will often aid interpretation of the well performance data.

However, the major causes of reduced specific capacity with time are mechanical, chemical, and biological.

2. Malfunctioning of Wells and Reduction in Efficiency

(1) Mechanical

Most wells undergo some loss in specific capacity probably due to the slow movement of foundation fines into the filter pack with a corresponding reduction in permeability. The process occurs more commonly:

(1) In cases of poorly designed filter packs, improper screen and filter pack placement, or insufficient well development.

(2) When generally fines are introduced into the well by back flooding of muddy surface waters. Normally, back flooding can be prevented by the use of check valves at the well outlet, however if not properly designed and maintained, the valves may not function as intended. These fines materials can find their way into the well through a variety of ways such as holes in the casing from corrosion, migration of fines from over-pumping, poor placement or sizing of the gravel pack, screen openings that are too wide and poor well development

2. Malfunctioning of Wells and Reduction in Efficiency

(2) Chemical Incrustation

Chemical blockage results from the deposition of minerals in the form of scales or incrustation on the well screen, Figure 3. It also cements parts of the gravel pack and aquifer materials on the outside of the screen, Figure 4.

Chemical incrustation of the well screen, filter pack, and surrounding formation soils can be a major factor in specific capacity reduction with time. Chemical deposits forming within the screen openings reduce their effective open area and cause increased head losses. Deposits in the filter pack and surrounding soils reduce their permeability and also increase head losses.

2. Malfunctioning of Wells and Reduction in Efficiency

Most mineral deposits on well screens either are calcium and magnesium carbonates or calcium and magnesium sulfates. They precipitate out of the water where the water velocity is highest and the pressure is lowest -- at or near the entrance to the well screen. Incrustation from precipitation of iron and manganese compounds, primarily their hydroxides or hydrated oxides.

These minerals bond the aquifer materials into a solid mass that over time will plug the well screen openings and cement the materials outside the screen.

2. Malfunctioning of Wells and Reduction in Efficiency

Many ground waters contain iron and manganese ions if the pH is about 5 or less. Reduction of pressure due to well flow can disturb the chemical equilibrium of the groundwater and result in the deposition of insoluble iron and manganese hydroxides. The hydroxides initially have the consistency of a gel, but eventually harden into scale deposits. Further oxidation of the hydroxides results in the formation of ferrous, ferric, or manganese oxides. Ferric oxide is a reddish brown deposit similar to rust, whereas the ferrous oxide has the consistency of a black sludge. Manganese oxide is usually black or dark brown in color.

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A properly designed well screen will have entrance velocities of less than 0.1 foot per second. Water entering the well screen at a rate greater than 0.1 feet per second can contribute to more rapid mineral deposition. The rate of incrustation accelerates with time because as some of the screen openings become plugged, the water enters the remaining slots at a higher velocity, which causes more incrustation.

2. Malfunctioning of Wells and Reduction in Efficiency

Figure 3: Encrusted minerals on the inside of a totally plugged well screen

2. Malfunctioning of Wells and Reduction in Efficiency

Figure 4: incrusted and plugged well screen along with an example of cemented gravel from the aquifer materials outside the screen

2. Malfunctioning of Wells and Reduction in Efficiency

(3) Biological Incrustation

Naturally occurring, common soil bacteria are found in almost all aquifers and are the cause of biological screen blockage. The bacteria are in three main types: iron-reducing, sulfate-reducing and slime producing. Of the three, iron bacteria and slime producing bacteria are the most familiar to irrigators.

Iron-reducing bacteria are a major source of well screen and gravel pack contamination. They consist of organisms that have the ability to absorb dissolved iron which oxidize or reduce to ferrous or ferric ions for energy. The ions are precipitated as hydrated ferric hydroxide on or in their mucilaginous sheaths. The precipitation of the iron and rapid growth of the bacteria can quickly reduce well efficiency.

2. Malfunctioning of Wells and Reduction in Efficiency

The presence of iron bacteria is usually indicated by brownish red stains in well collector pipes, pumps, pipelines and irrigation systems. Often the rotten-egg smell of hydrogen sulfide gas also will be noticeable when the pump is operating. Generally, if the iron amount in the water is greater than 0.3 ppm, iron bacteria problems will arise.

These bacteria form a slimy organic substance on the well screen, pump intake and pump column, and in the water-bearing aquifer materials surrounding the screen, Figure 5. As the bacteria build up, they reduce the open area of the screen and the open spaces in the aquifer materials surrounding the screen, thus reducing well yield. If exposed to air, this buildup hardens and becomes much more difficult

2. Malfunctioning of Wells and Reduction in Efficiency

Evidence exists that iron bacteria may be carried from well to well on drill rods and other equipment and therefore every effort should be made to avoid introducing iron bacteria into a well during installation, maintenance, or rehabilitation operations.

After completion of operations on a well, all drilling equipment, tools, bits and pumps, should be thoroughly disinfected by washing with a chlorine solution (100 ppm) before initiating work on another well.

2. Malfunctioning of Wells and Reduction in Efficiency

Sulfate-reducing Bacteria consume the sulfate in the water and the byproducts are an organic acid and hydrogen sulfide gas (rotten-egg smell). These bacteria are anaerobic in nature (don't need oxygen). They reside behind scale and other low-oxygen environments, thus they are harder to kill than other types of bacteria.

Slime-producing Bacteria coexist with iron and sulfate-reducing bacteria. The byproduct of these bacteria is a slime that often can be seen on pumps removed from a well. The slime can plug screen openings, the gravel pack and sometimes the aquifer materials outside the screen.

2. Malfunctioning of Wells and Reduction in Efficiency

Figure 5: Iron bacteria on pump column riser pipe just removed from a well

SESSION 33

WELL MAINTENANCE AND REHABILITATION II

Dr Amjad Aliewi

House of Water and Environment

Email: amjad.aliewi@hwe.org.ps , Website: www.hwe.org.ps

3. Well development and` rehabilitation

Once the well has been drilled and the equipment is in place, there are several procedures the drilling contractor must complete before the well is ready to use. The drilling contractor is responsible for:

- Well development
- Disinfecting the well
- Conducting a yield test.

In this chapter we are trying to provide details about how to develop or redevelop a well, which is termed as rehabilitation.

3. Well development and` rehabilitation

In general there is a need to understand the processes which cause the following problems:

- Drilling fluid invasion damage.
- Particle redistribution.
- Chemical Encrustation.
- Biofouling.
- Structural/ Material failure.
- Low well efficiency and performance.

Practically all methods of drilling cause compaction of unconsolidated materials of variable thickness in an annulus around a drill hole. In addition, fines are driven into the wall of the hole, drilling mud invasion may occur to a greater or less extent, and a mud cake (if used) may form on the wall of the hole.

3. Well development and` rehabilitation

A quantitative measure of the loss in efficiency is only determined by carefully conducted pumping tests. Should the pumping tests indicate a reduction in specific capacity of more than 20 percent compared to that measured at installation, a detailed study should be made of the consequences of the reduction and what remedial measures should be employed?

There is a need for sufficient information in order to correctly identify the problem before trying to treat the well.

- Discharge/ drawdown date
- Discharge quality data
- Examination of retrieved equipment
- Geophysical logging
- CCTV survey

3. Well development and` rehabilitation

Well development is the process of removing fine sediment and drilling fluid from the area immediately surrounding the perforations. This increases the well's ability to produce water and maximize production from the aquifer. There are several methods for well development:

(1) Over pumping

The simplest method of removing fines from water-bearing formations is by over pumping, that is, pumping at a higher rate up to 1.5 times the design capacity. Over pumping, 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.

3. Well development and` rehabilitation

Problems with over-pumping:

(1) For a given pumping rate, the longer the screen, the less development will take place in the lower part of the screen.

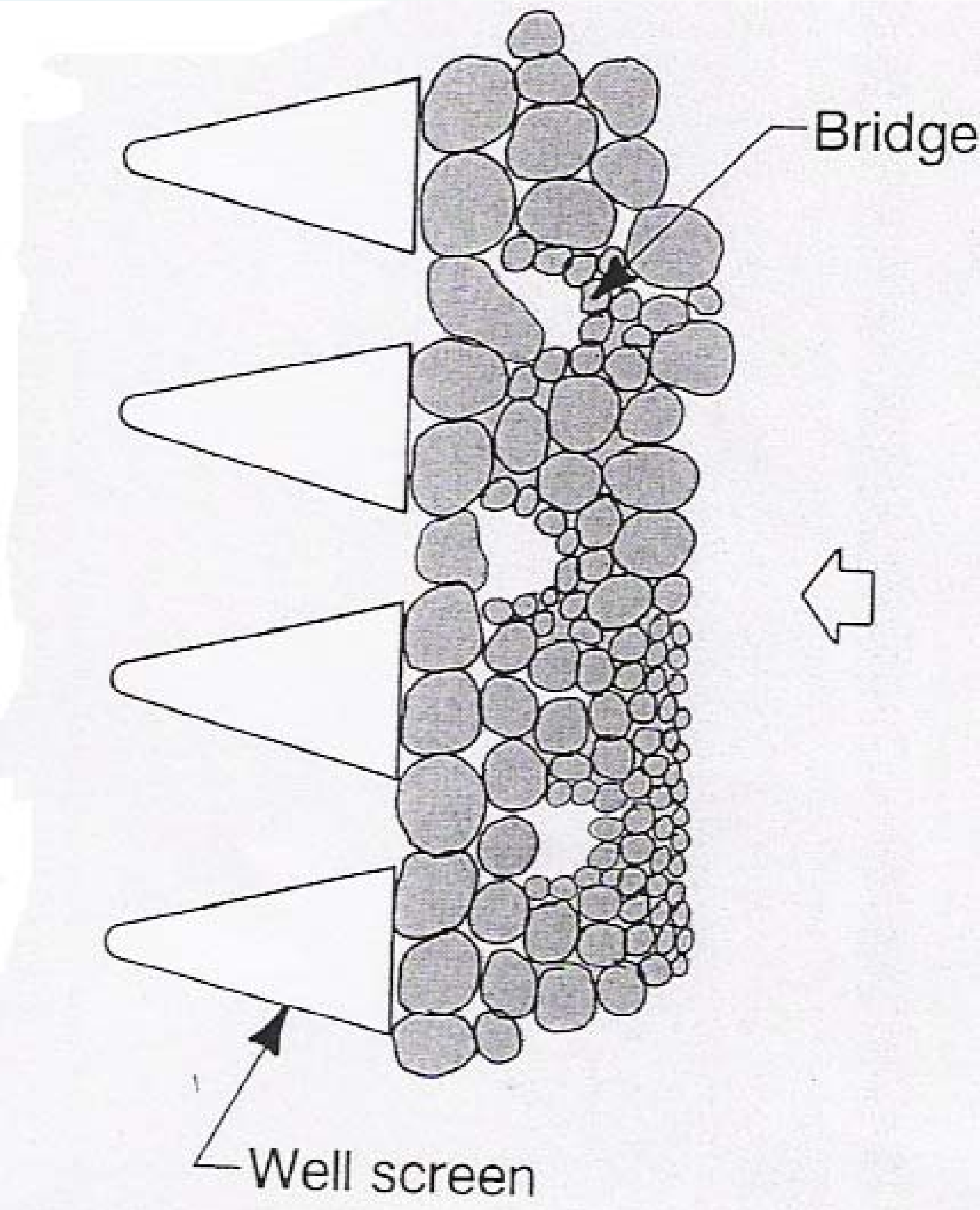
(2) After fine material has been removed from the permeable zones near the top of the screen, water entering the screen moves preferentially through these developed zones, leaving the rest of the well poorly developed and contributing only small volumes of water to the total yield.

(3) In some cases, over pumping may compact finer sediments around the borehole and thereby restrict flow into the screen.

(4) 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 6**. In this condition sediment may enter the well if the sand bridges become unstable and collapse.

3. Well development and` rehabilitation

Figure 6: Sand grains bridge openings because flow occurs in only one direction



3. Well development and` rehabilitation

(5) It may be difficult to obtain equipment of sufficient capacity at reasonable cost for over pumping. 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.

3. Well development and` rehabilitation

(2) Backwashing or hydraulic surging

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 7**. Reversing the direction of flow normally breaks down the bridging between large particles and across screen openings. 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.

3. Well development and` rehabilitation

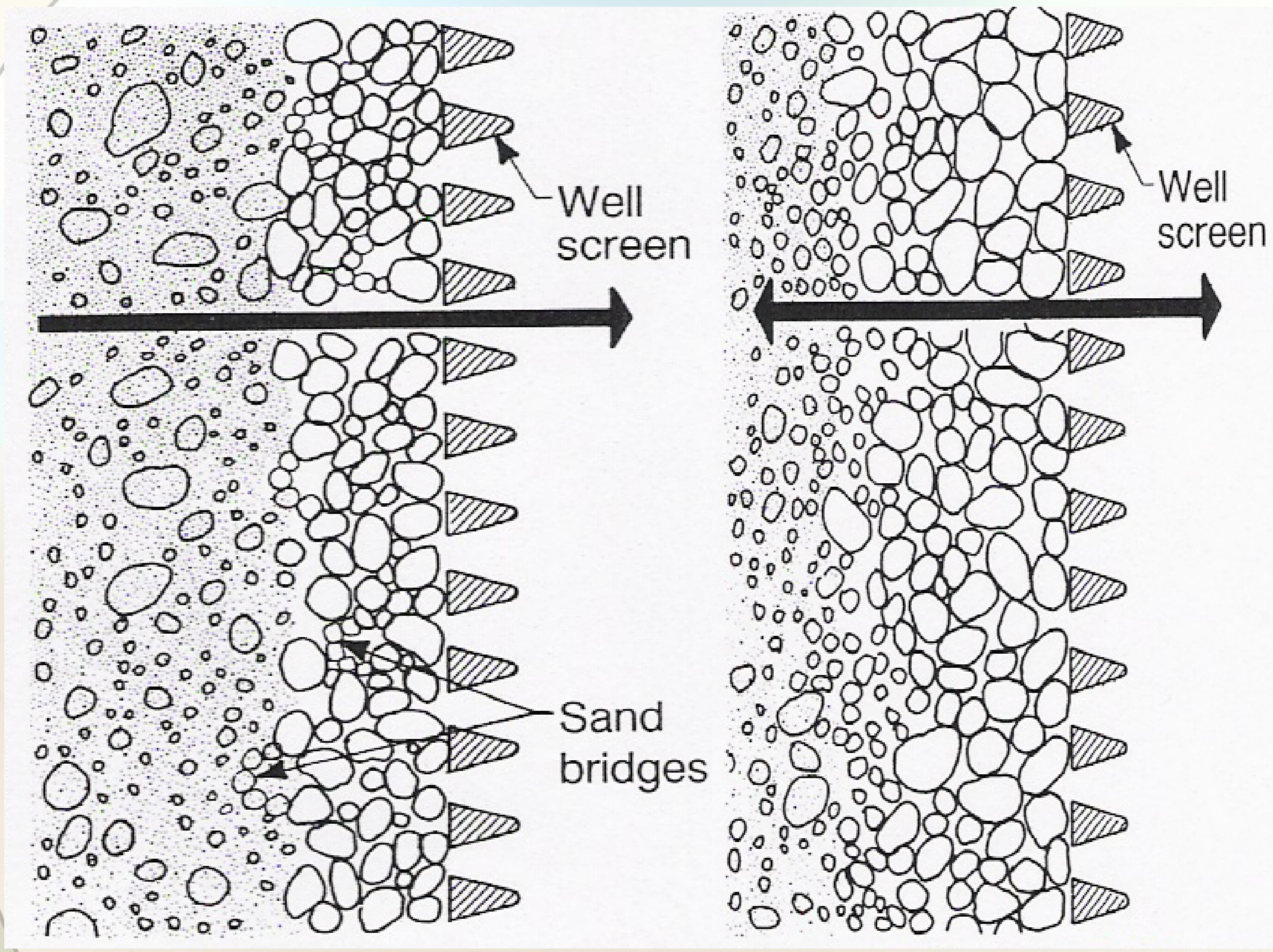


Figure 7: Back washing effect on breaking down bridge of particles.

3. Well development and` rehabilitation

A hydraulic 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.

The pump should be started at reduced capacity and gradually increased to full capacity to minimize the danger of sand-locking the pump. 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 stopped as rapidly as the power unit and starting equipment will permit.

3. Well development and` rehabilitation

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. The well should be pumped to waste occasionally to remove the sand that has been brought in by the surging action. 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. The overall effectiveness of surging in high-capacity wells is relatively limited when compared with other development methods such as below.

3. Well development and` rehabilitation

(3) 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 **Figures 8&9**.

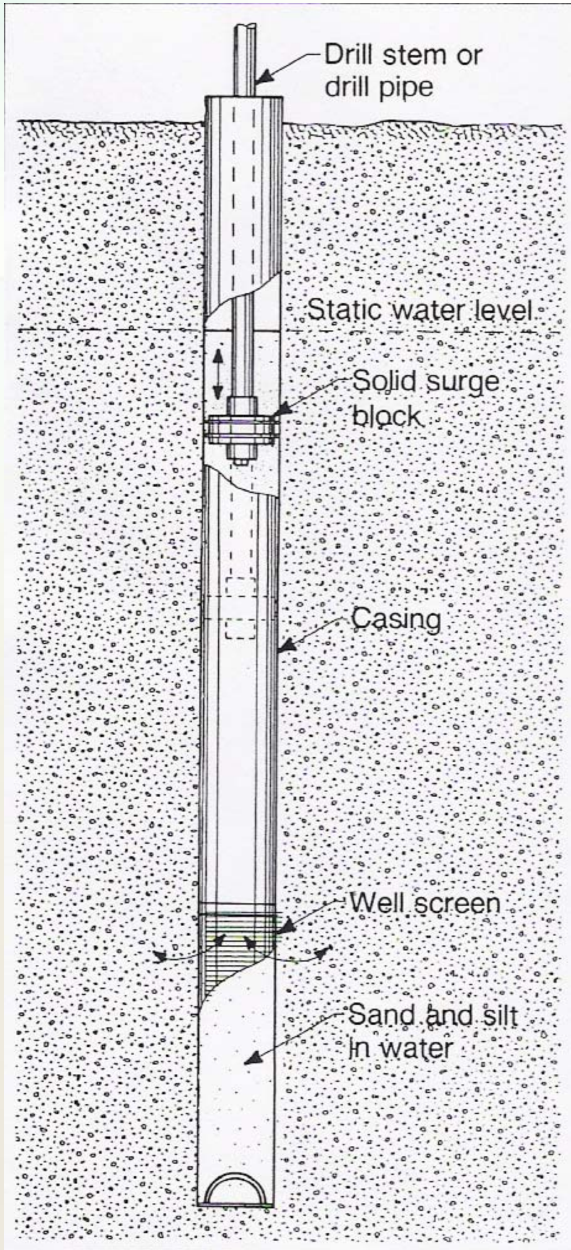
Although some drillers depend on surge blocks for developing screened wells, others feel that this device is not effective and that it may, in some cases, even be detrimental because it forces fine material back into the formation before the fines can be removed from the well. To minimize this problem, fine material should be removed from the borehole as often as possible.

3. Well development and` rehabilitation

Surging is somewhat effective in reaching into the surrounding aquifer, but doesn't provide consistent cleaning throughout the length of the screen. Surging is most effective near the bottom of the screen and progressively less so the closer the surge block gets to the top of the screen. Surging can cause channeling through the screen into the porous formation, leaving layers of silty, finer-grained particle formations undeveloped. **Figures8&9** show the way that surge block acts.

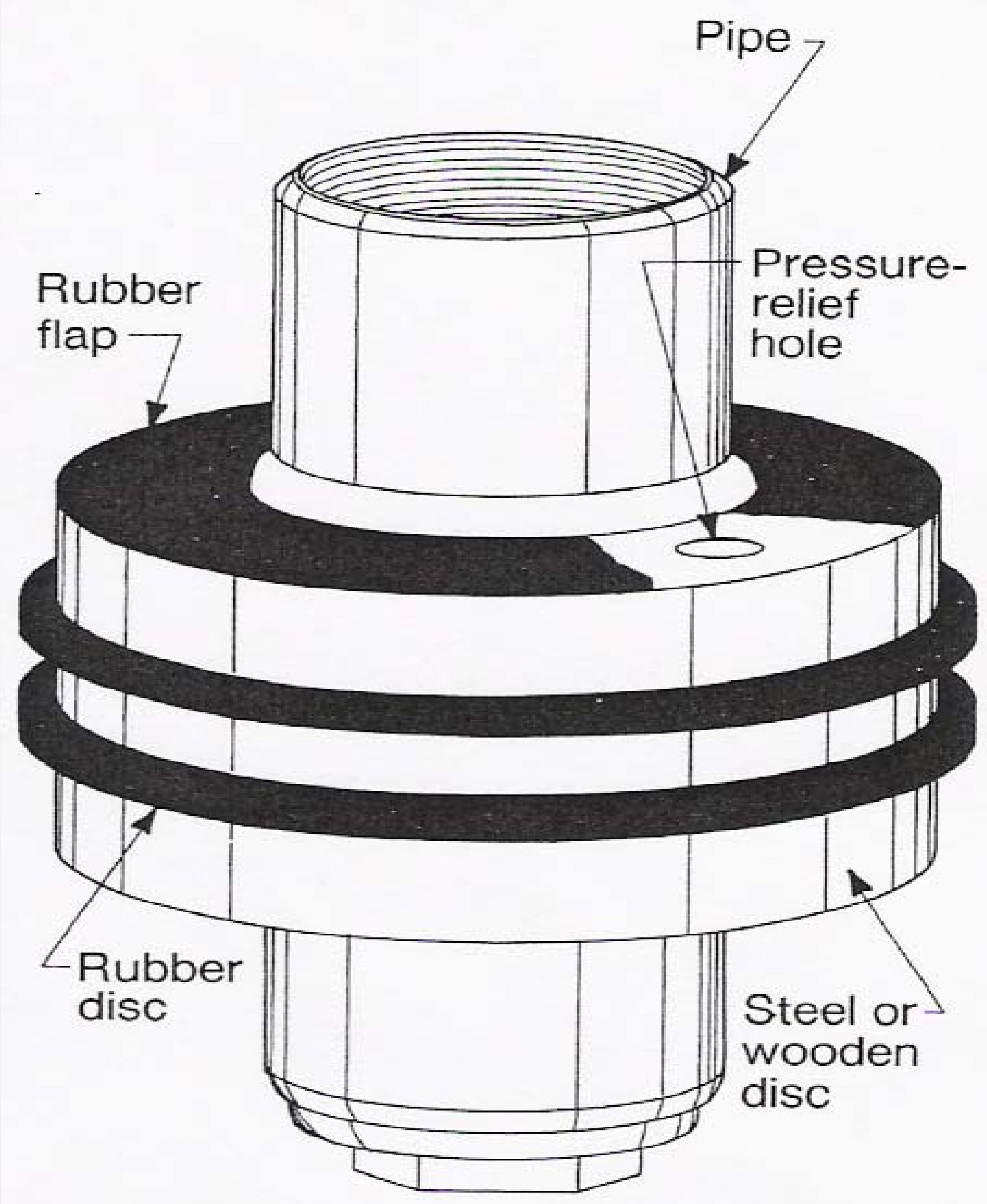
3. Well development and` rehabilitation

Figure 8: Mechanical surging by using solid surge block



3. Well development and` rehabilitation

Figure 9: Typical surge block



3. Well development and` rehabilitation

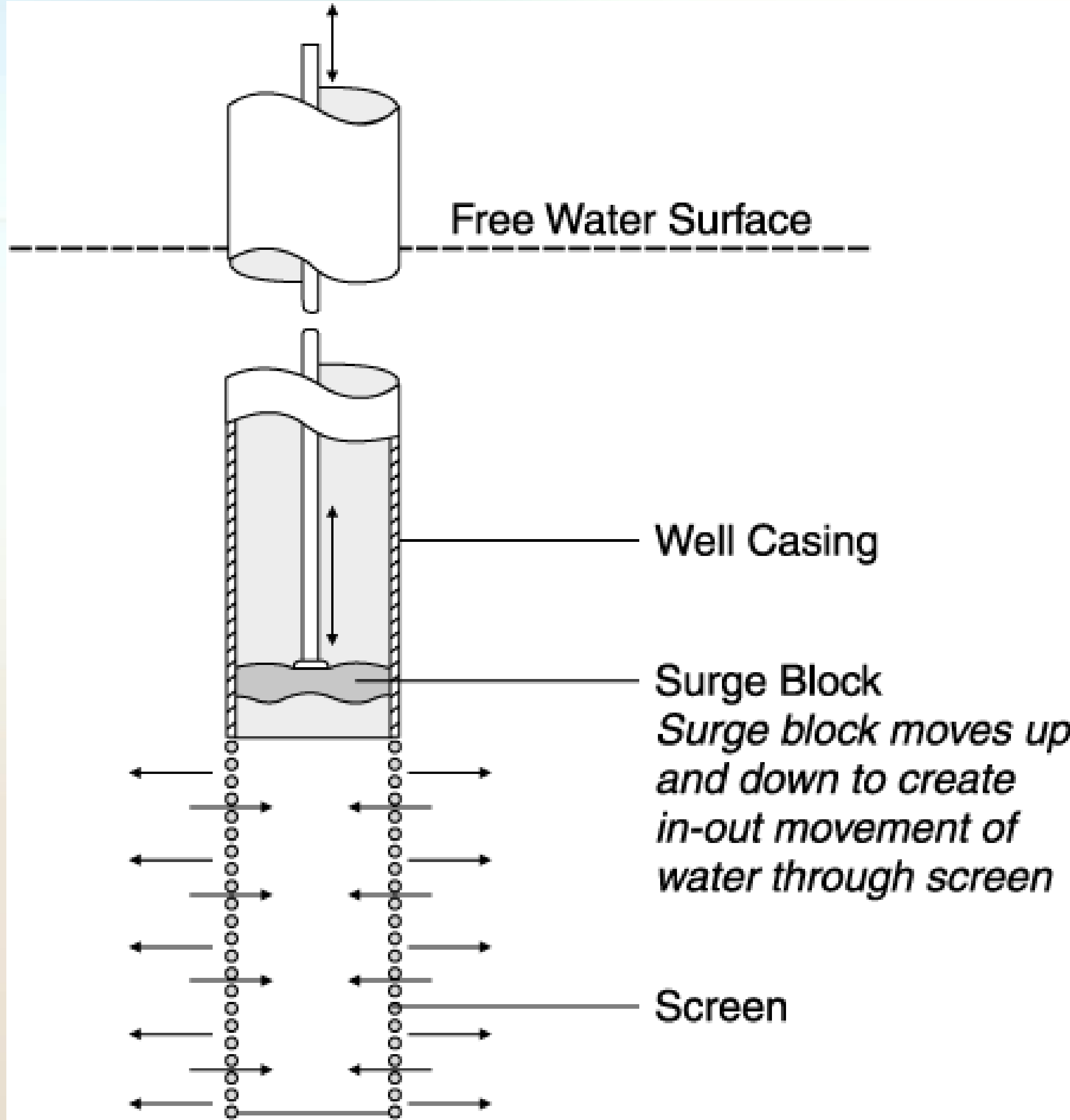
Surging alternately forces water into and out of the formation through the well screen openings, Figure 10. A pistonlike tool moves up and down in the well to create the surging action.

The water surging through the well screen loosens the minerals and fines in the borehole and draws them into the well to be removed by pumping or bailing.

Surging especially is suited to cable-tool drilling. Surging is not very effective with very deep wells (more than 200 feet) or those with multiple screens.

3. Well development and` rehabilitation

Figure 10: Well redevelopment by mechanical surging with a surge block



3. Well development and` rehabilitation

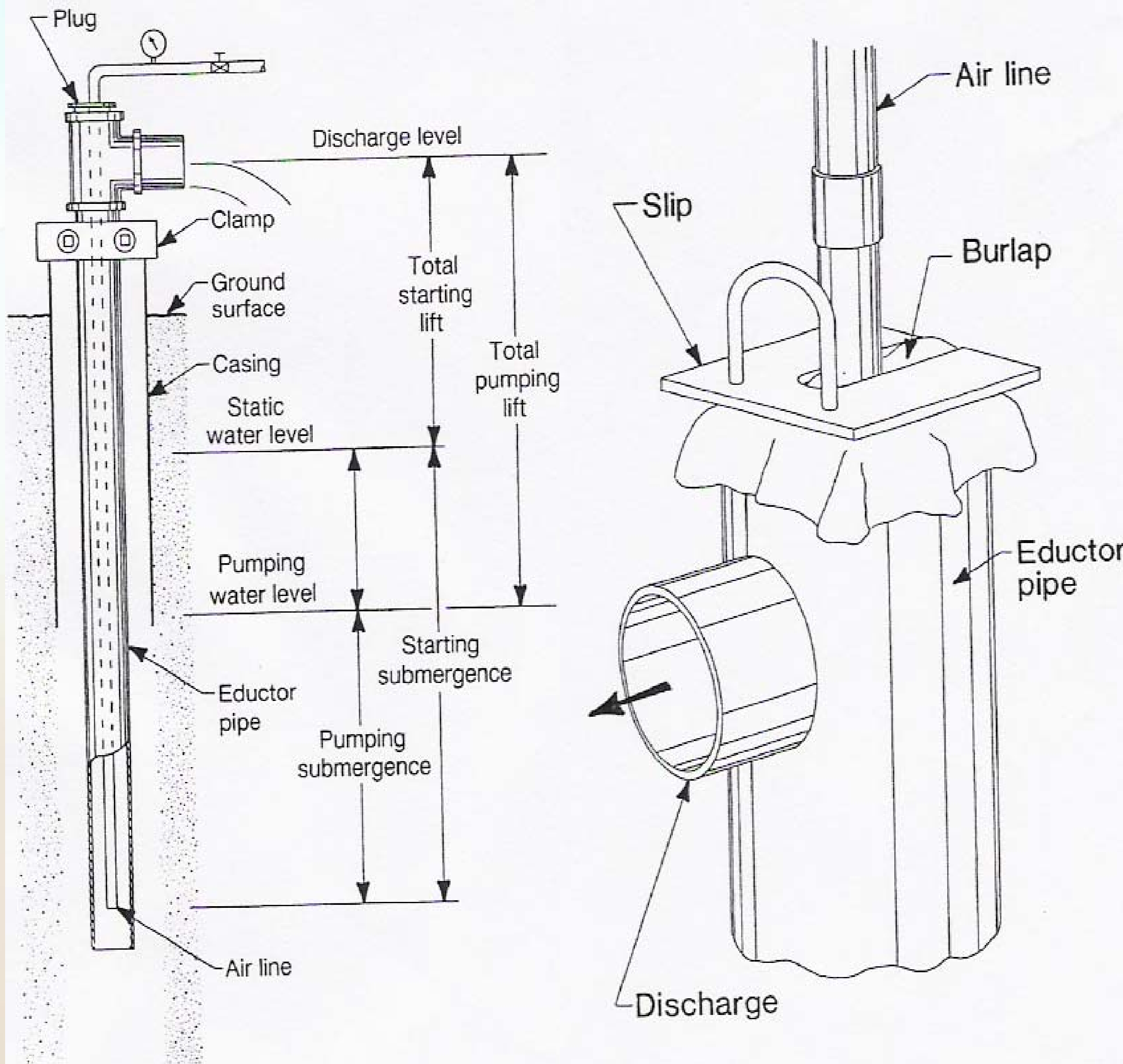
(4) Air Lift Surging

Many drillers use compressed air to develop wells in consolidated and unconsolidated formation. The practice of alternatively 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. **Figure 11** shows the basic layout of an air-lift system and the appropriate terms.

3. Well development and` rehabilitation

Figure 11: Basic layout of an air-lift system



3. Well development and` rehabilitation

Compressors, airlines, hoses, fittings, etc., should be of adequate size to pump the well by the airlift method at l.5 to 2 times the design capacity of the well. Each case is specific in terms of depth, submergence, well diameter, and screen hydraulic conductivity.

For wells less than 90 m in depth, with 60% submergence possible, approximately 5.6 m^3/sec of air per 1 m^3/sec water of anticipated pumping rate.

In practice, a 375-cfm compressor developing 100 psi can usually pump 400 to 500 gpm (approximately 44 to 67 cfm or 1.25 to 2.0 m^3/sec) of water with proper airline submergence **Figure 12** shows that.

3. Well development and` rehabilitation

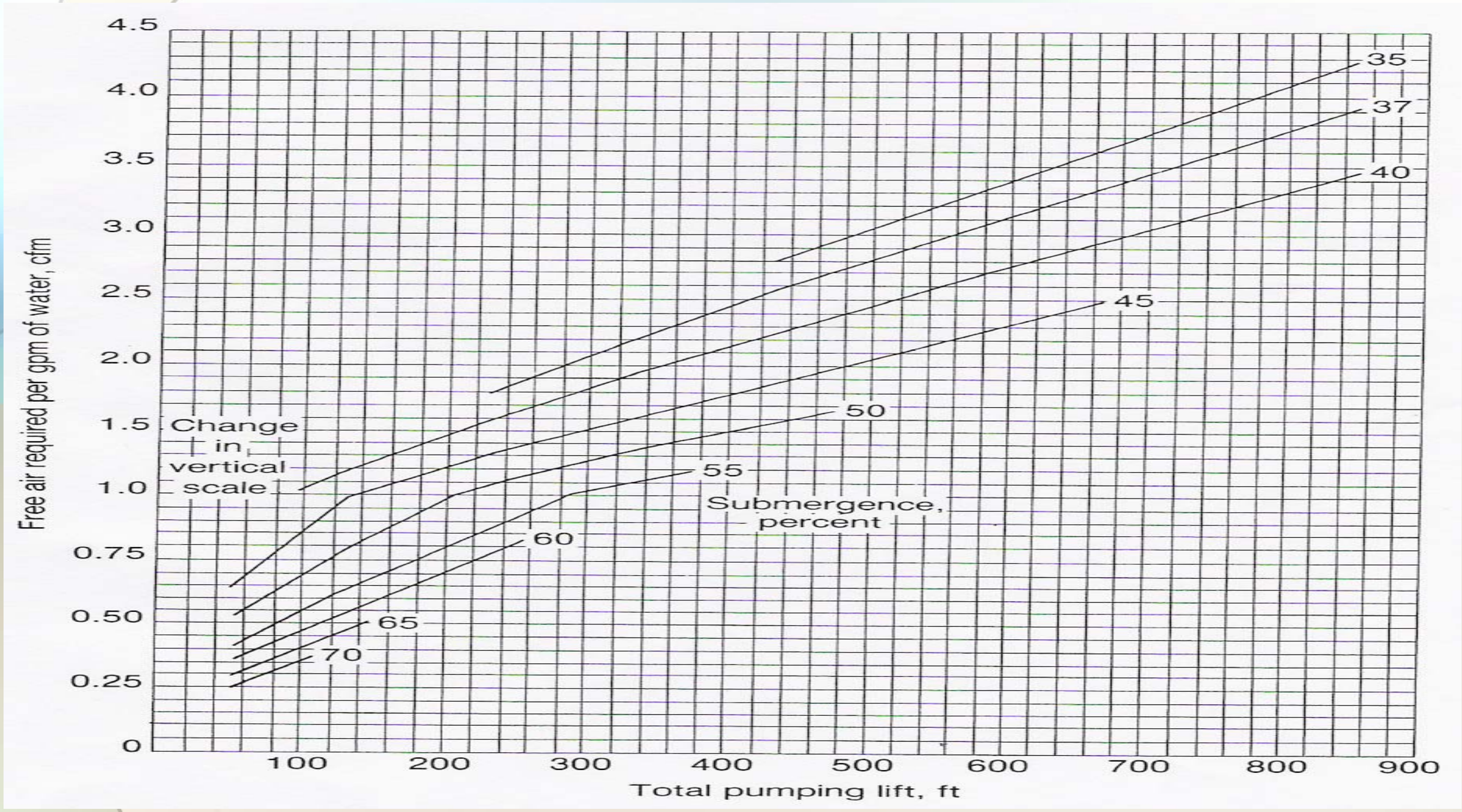


Figure 12: Cubic feet of air required to pump 1 gpm (5.5 m^3/day) for various submergences and pumping lifts

3. Well development and` rehabilitation

The first goal in the development process is to establish a piston effect (surging) and not to conduct airlift pumping.

In surging, sufficient air is fed to raise the water level as high as possible, then it will be released to let it drop. Airlift pumping is then used to pump the well periodically to remove sediment from the screen or borehole.

When the well yields clear, debris-free water, the airline is lowered to a point below the bottom of the eductor line and air introduced until the water between the eductor pipe and the casing is raised to the surface. At this time the airline is raised back up into the eductor line causing the water to be pumped from the well through the eductor line.

3. Well development and` rehabilitation

The procedure of alternating the relative positions of the air and eductor line is repeated until the water yielded by the well remains clear when the well is surged and backwashed by this technique.

Airlift pumping forces compressed air through an air line to the bottom of the well, Figure 13. As air bubbles rise, they create a surging effect that carries water and dislodged materials out of the well. Airlift pumping is alternated with short periods of no pumping, which forces water and chemicals out into the formation to help break up minerals and bacteria lodged in the aquifer formation surrounding the screen.

This method of well development is effective only if the water is deep enough in the well to get the surging action. Airlifting does not work if the lift to the surface is too great.

3. Well development and` rehabilitation

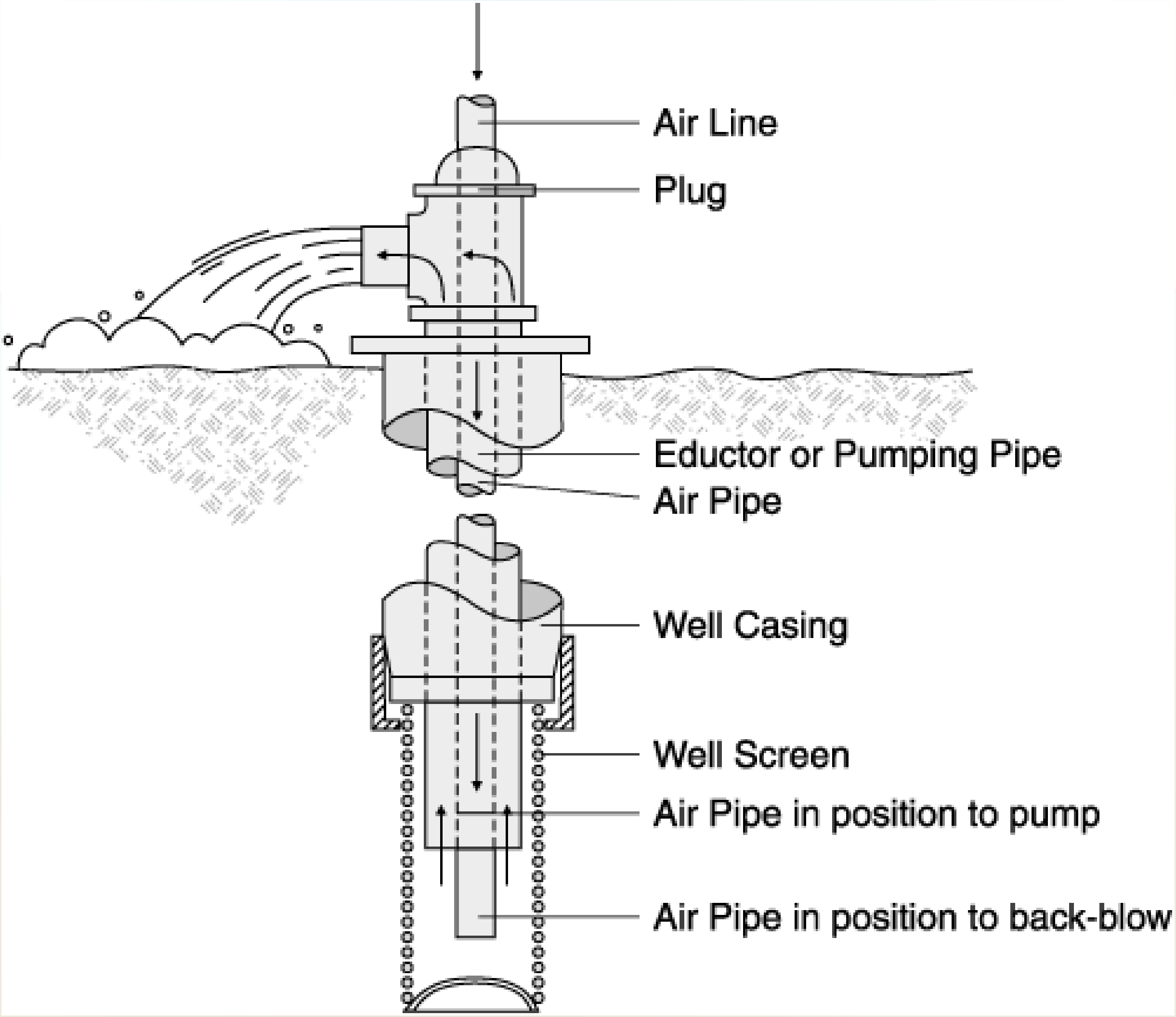


Figure 9: Well redevelopment using airlift pumping and agitation

3. Well development and` rehabilitation

(5) Hydraulic Jetting

Development is accomplished by simultaneous high velocity, horizontal jetting and pumping. The outside diameter of the jetting tool must be 1 inch less in diameter than the screen inside diameter. The minimum exit velocity of the jetting fluid at the jet nozzle should be around 45 m/sec. The tool is rotated at a speed less than 1 rpm and positioned at one level for not less than 2 min and then moved to the next level, which is no more than 6 inches vertically from the preceding jetting level.

Pumping from the well should be at a rate of 5 to 15% more than the rate at which water is introduced through the jetting tool. Water to be used for jetting must contain less than 1ppm suspended solids.

3. Well development and` rehabilitation

Figure 15 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 plugged pipe or coupling will be reasonably effective.

The best well development method is high-pressure water jetting with simultaneous pumping, Figure 14. High-velocity water jets through the screen and gravel pack into the formation to loosen and break down the fine materials. The jetting tool rotates slowly as it moves up and down inside the well screen.

3. Well development and` rehabilitation

Pumping removes the loosened sand and mud as they enter the well screen. The jet stream can be directed at any part of the formation around the well for selective development.

Cage-wound screen is best for jetting because its design allows the jet to impinge directly on the gravel pack or borehole. Well screens that use louvered or bridge openings do not respond to this type of development because the opening design interferes with the jet of water. Jetting often is the most costly development method.

3. Well development and` rehabilitation

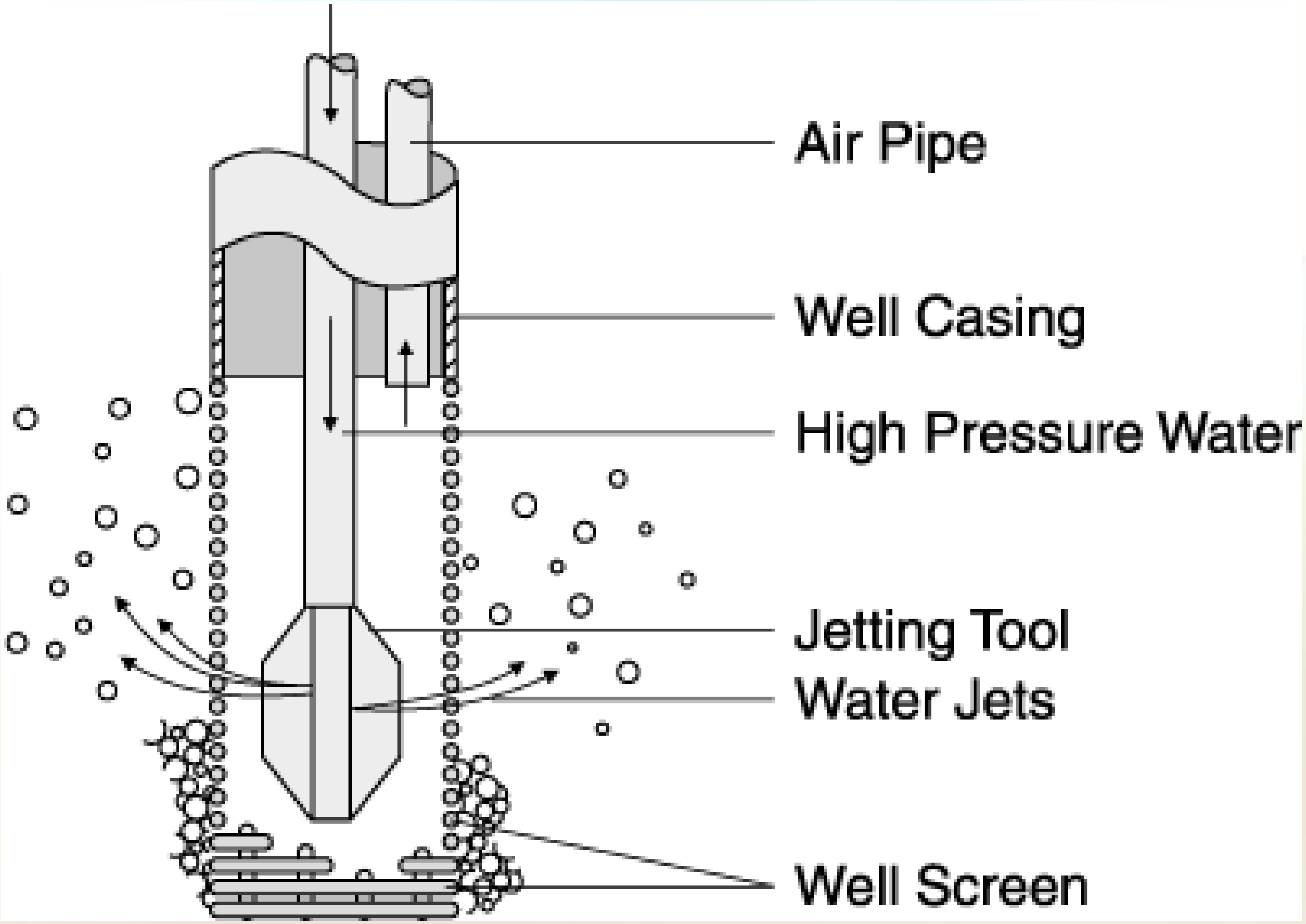


Figure 14: Well redevelopment using high-velocity water jetting

3. Well development and` rehabilitation

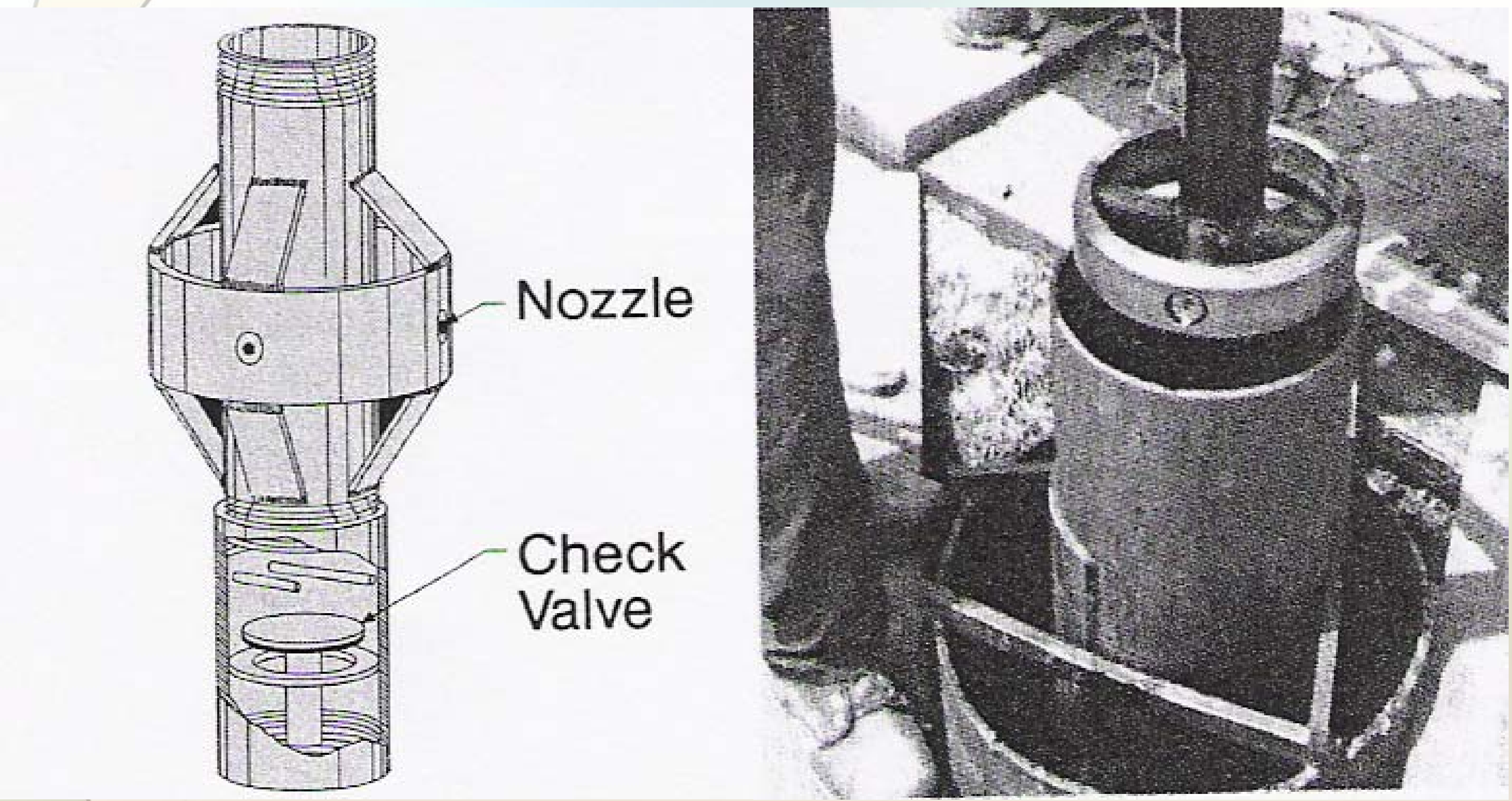


Figure 15: Four-nozzle jetting tool designed for jet development of well screens.

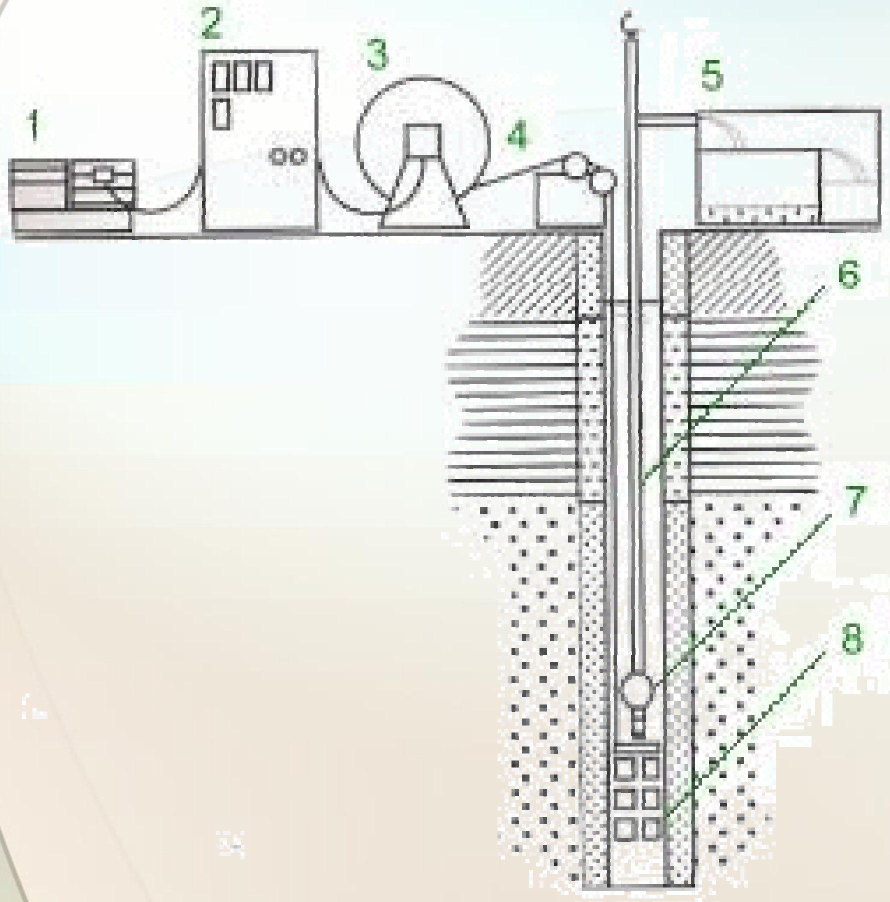
3. Well development and` rehabilitation

(6) Ultrasound

The term ultrasound refers to oscillations of frequency above the audible range of an adult human being, which means it ranges above 16 kHz. An ultrasound device, lifted down into the well, is the essential part of the ultrasound rehabilitation system. The ultrasound generators, transforming the current of the mains supply into alternating current of a high frequency, are installed in a switching cabinet.

The ultrasound transducers are stimulated by this high frequency current. All required control and supervising devices are installed in the same switching cabinet. A special cable on a motor driven cable drum is required to transfer the high energy. **Figure 16** shows the ultrasound device.

3. Well development and` rehabilitation



The main units required are:

1.Power generator*
2.Switching cabinet*
3.Cable drum*
4.Cable*
5.Container
6.Tubes
7.Dirty water pump
8.Ultrasonic device*
•crane
•transport vehicle

*Delivered by SONIC

Figure 16: The ultrasound device

3. Well development and` rehabilitation

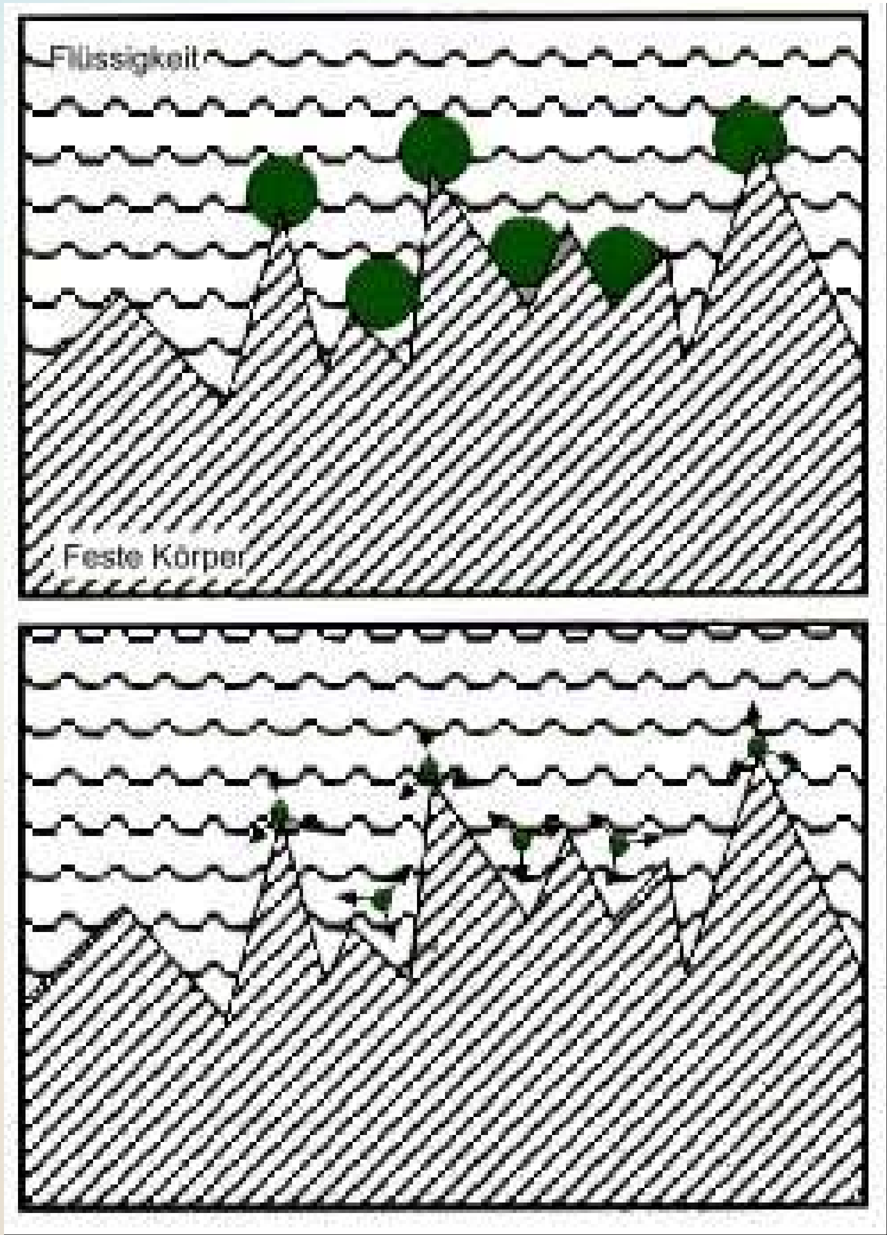
Sound is a continuous series of overpressure and under pressure in a medium. As everybody knows from experience, sound creates a mechanical movement due to the (changing) sound pressure. Even from audible sound levels, which are no health-hazard yet, we know the clinking of windows, the dropping off of plaster.

Contrary to an expansion wave created by an explosion, sound creates a "standing wave". No substance is transported, which could, due to its kinetic energy, cause any damages.

The most popular of the numerous effects of ultra sound is the so-called cavitation effect **Figure 17**, which plays an important role in cleaning technologies. Ultra sound oscillations periodically compress and attenuate liquids. The energy of the ultra sound is such that the cohesion of liquids is reduced (phases of instability).

3. Well development and` rehabilitation

Figure 17: Schematic presentation of an enlarged surface of a solid substance with cavitation bubbles, in the moment of the biggest (above) and lowest (below) expansion.



3. Well development and` rehabilitation

The formation of tiny hollow space bubbles is called cavitation. During the following pressure phase the bubbles collapse at great speed, releasing energy which becomes noticeable as an overpressure of 1000 bar or as a micro-current.

This extremely high current, limited to smallest space, with simultaneously very high temperatures causes enormous mechanical forces.

The high energy of Ultrasonic systems causes high changing pressures and pressure differences in the well, which result mechanical and chemical changes. When rehabilitating a well, there are, besides the cavitation effects, also further other effects.

3. Well development and` rehabilitation

The big energy of the SONIC ultrasound systems leads to high changing pressures and pressure drops, resulting in mechanical and chemical alterations.

The mechanical effect of ultrasound is shown by considerable shearing forces at the border surface of the gravel filling which cause dissolution of mechanical connections in the micro-structure of the filter.

Ultrasound with according output intensity has an adverse effect on micro organisms. This means, that the bacteria, which are in the surroundings of an ultrasound converter, will be deadened.

3. Well development and` rehabilitation

The efficiency of the unit also depends on the special modulation of the emitted sound:

The sound sources do not produce an equal sound power (so-called equal sound), but the sound is pulsated with a frequency of 100 Hz.

Thus the sound power pulsates in shock waves between 0 and 4 kW. Both features (the high energy as well as the pulsation) are decisive for a successful use of ultrasound for well rehabilitation.

4. Aquifer development techniques

In many parts of the world, the only available groundwater comes from bedrock. If the rock is massive, with few joints or faults, the volume of water available is often inadequate.

In this type of aquifer, yields can be increased dramatically by applying one or more aquifer development techniques.

Aquifer development can be thought of as a second level of development which can increase well yields far beyond those obtained through typical well development.

Aquifer development procedures in massive rock are usually cost effective. Under most circumstances, well development techniques are used before any aquifer development methods are initiated.

4. Aquifer development techniques

4.1 Use of acid

Acid can be used for both well and aquifer development in limestone or dolomite aquifers and in some semi consolidated aquifers that are cemented by calcium carbonate. Acid dissolves carbonate minerals and opens up the fractures and crevices in the formation around the open borehole, which is the intake portion of this type of well.

Some of the acid, however, is forced into cracks and fissures much farther from the well bore. The acid dissolves some material naturally existing in the voids, thereby increasing the overall hydraulic conductivity of the aquifer. The use of chemicals, principally, hydrochloric or sulfamic acid, in conjunction with hydraulic jetting as part of a measured programme, has produced significant improvements in borehole.

4. Aquifer development techniques

4.2 Use of explosives

Explosives are sometimes used to "shoot" rock wells in an attempt to develop greater specific capacity. Good results can be obtained if blasting procedures are appropriate for the rock type and the size and depth of the well. Because of the many unknown factors, however, it is difficult to predict whether the shooting operation will produce beneficial results, especially in sedimentary rocks such as sandstone.

Extreme care must be used when blasting a well. If it is located near a home, the owner should be asked to remove breakable objects from shelves and to otherwise take precautions against a potentially significant seismic shock. People in the general vicinity also should be warned in advance of the blast. The explosive charge to be used should be carefully planned.

4. Aquifer development techniques

Many factors must be considered, including:

•Depth of water in the hole. Larger charges must be used as the depth of water increases to overcome the hydrostatic pressure.

•Geologic conditions. Actual or incipient joint systems and faults must be present, or the blasting may be pointless.

•Depth of borehole. For boreholes deeper than 200 m, blasting may not be effective because of the weight of the overburden.

•Desired increase in yield. Larger amounts of explosives will ordinarily produce greater increases in yields when all other factors are equal.

•Environmental considerations. Is the blast site in an urban area or is it relatively remote?

•Legal considerations. These include regulations and special insurance requirements.

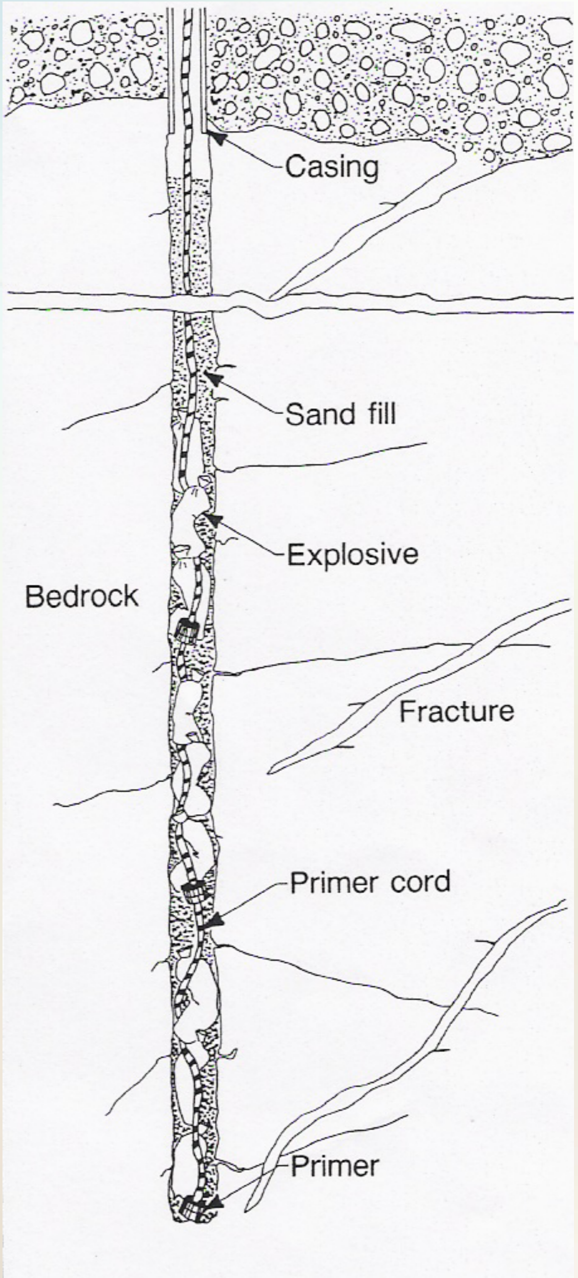
4. Aquifer development techniques

In the past, small explosive charges, usually 14-45 kg, were used. More recently, much lager charges of 454-907kg have been detonated in igneous rock terrains with excellent results.

Figure 18 shows how the explosive agent, sand, and igniting equipment are placed in a well to be blasted. A primer is attached to a primer cord and lowered the bottom of the well, which is typically 91.5-152m deep.

4. Aquifer development techniques

Figure 18: Placement of explosives in the well.



SESSION 34

WELL MAINTENANCE AND REHABILITATION III

Dr Amjad Aliewi

House of Water and Environment

Email: amjad.aliewi@hwe.org.ps , Website: www.hwe.org.ps

5. Disinfection of wells by Chlorination

Provincial regulations require the drilling contractor to disinfect new wells with chlorine.

The objective of well chlorination is to raise the chlorine level in the well to around 500 ppm and hold it there for at least 24 hours to allow the chlorine to attack and kill the bacteria. Getting the chlorine out into the aquifer material surrounding the well screen also is very important.

Chlorine comes in either dry or liquid formulations. Use formulations designed for water wells. Do not use stabilized chlorine products designed for swimming pools because the chlorine's release time is too long. Wells need a quick-acting form of chlorine.

5. Disinfection of wells by Chlorination

5.1 Chlorine Products

Calcium hypochlorite (sometimes referred to as HTH) is a dry, white to yellowish material. It comes in pellets, powder or granular forms. It contains about 65 percent available chlorine by weight. Calcium hypochlorite requires careful storage to avoid contact with organic materials, especially petroleum-based products. If calcium hypochlorite is mixed with petroleum products, it will become hot enough to start a fire. When mixed with water, calcium hypochlorite will create heat.

If preparing a mixture to pour into the well, **never add water** to the container holding the calcium hypochlorite because of the excessive heat and noxious gases that will be produced. Rather, add a measured amount of calcium hypochlorite to a sufficient quantity of water (at least 30 gallons) to control the heat.

5. Disinfection of wells by Chlorination

Sodium hypochlorite is a clear, yellow liquid familiar to most people as laundry bleach. Common laundry bleach sold in stores contains about 6 percent chlorine, but commercially available formulations can be up to 12 percent chlorine.

Irrigators with oil-lubricated, deep-well turbine pumps should be especially careful if they use any dry form to chlorinate their wells. These wells commonly have a layer of oil on top of the water. Mixing chlorine and oil can be explosive. In addition, dry forms of chlorine will collect on the flanges of the column pipe and over time will eat holes in the pipe.

Therefore, if irrigators use a granulated or pellet form of chlorine, they should mix it with a suitable amount of water before pouring it into the well.

5. Disinfection of wells by Chlorination

5.2 Procedure

1. Determine the depth of the water standing in the well.

2. From Table 4, determine the amount of chlorine needed. For example, if your well is 12 inches in diameter and 100 feet deep with a static water level at 20 feet, the column of water is 80 feet or eight 10-foot increments. The amount of chlorine bleach needed is 8 x 2 quarts/10 feet or 16 quarts (4 gallons). The amount of dry 65 percent chlorine product needed would be 8 x 0.4 pounds/10 feet or 3.2 pounds.

5. Disinfection of wells by Chlorination

3. Introduce the chlorine into the well. Use protective gloves and goggles since chlorine solutions this strong can cause skin burns. If you are using the dry form of chlorine, always read the label to make sure you are using the correct amount.

a. When using liquid bleach, mix with at least 50 gallons of water and pour into the well. Add another 100 gallons of water or more to distribute the chlorine mixture throughout the well.

b. When using chlorine granules or powder, dissolve slowly by mixing with 50 gallons of water or more. Pour slowly into the well. Add another 100 gallons of water or more to distribute the chlorine mixture throughout the well.

c. When using chlorine pellets, drop them through the well access port very slowly (about 20 to 30 pellets every minute). When that is completed, pour 10 to 20 gallons of water down the access hole to wash off any pellets that might be stuck in the access pipe or hung up on pipe flanges.

5. Disinfection of wells by Chlorination

4. Wait at least four hours for the chlorine to disperse throughout the water column.

5. Surge the well for one hour (surging is starting and stopping the pump intermittently, but not allowing water to discharge from the well). This action also is called "rawhiding" a well. With deep-well turbine pumps, allow five minutes between starts with no more than six starts in an hour.

Caution: *Don't start the pump while it is rotating in the reverse direction. On some pumps, water flowing back into the well causes the impellers to rotate backward and starting the pump may loosen the impellers from their seats.*

5. Disinfection of wells by Chlorination

6. **Let the chlorine stand in the well for 24 hours. Chlorine needs time to kill iron bacteria.** Don't leave the chlorine in the well during the winter. Concentrated chlorine will attack the metal in the pump, casing and screen and weaken these components.

7. Surge the well at least two more times, then pump the water to waste. The water should be quite dirty and it should smell _ an indication that the chlorine did its job. However, this water might plug sprinklers or pressure regulators on center pivots. If you pump it through a center pivot, remove the sand trap plug. Stand upwind because the chlorine smell could be strong. Pump until the odor of chlorine is gone.

5. Disinfection of wells by Chlorination

Table 4: Quantity of chlorine to use for each 10 feet of water in an irrigation well.

Diameter Well (inches)	**Gallons of Water in 10 feet of Well Casing**	**65% Chlorine per 10 feet of Water** (dry pounds)	**Laundry Bleach 6% Chlorine per 10 feet of Water** (liquid quarts)
4	6.5	0.05	0.25
6	15	0.1	0.5
8	26	0.2	1
10	41	0.3	1.3
12	59	0.4	2
14	80	0.5	2.5
16	104	0.6	3.5
18	132	0.8	4.5
20	165	1.0	5.4
24	235	1.5	7.75

5. Disinfection of wells by Chlorination

5.3 Design and implementation of Acidisation for both well and aquifer

This acid is a most powerful tool to improve yields from chalk and other limestone aquifers.

5.3.1 General Considerations

Objective.

Acids may be used in wells to:

1. Remove debris (from drilling) from test-pump discharge.

1. Remove slurry from the walls or borehole, and to clear fissures at their entry into the well or borehole.
2. Develop and increase the yield.
3. Reduce friction loss to give more economic pumping.

5. Disinfection of wells by Chlorination

Reaction.

If a tank is arranged to mix the test discharge water with a suitable acid, the acid reaction will convert the debris into a soluble salt, carbon dioxide, and some additional water.

It should be borne in mind that the particles of debris are small, and thus offer a large total surface area to the acid. A substantial volume of carbon dioxide will be generated; hence the reaction may be violent.

5. Disinfection of wells by Chlorination

Blockage

Chalk, if left undisturbed for some months in the slurry form will re-harden, and the larger grains of other limestones (filled in with fines) will compact in a shorter period to make fissures difficult to clear. In addition fissures may be filled with fine cuttings as an effect of drilling.

Thus test pumping is advisable to clear a borehole and to develop the yield by scouring fissures. This should be done as soon as possible after the completion of drilling.

Alternatively, the wall of the borehole and the entries of fissures may be cleared by introducing acids throughout the depth of water in a borehole. This acid, by reacting with the finely divided particles by converting them to soluble salts, also ensures a clear discharge.

5. Disinfection of wells by Chlorination

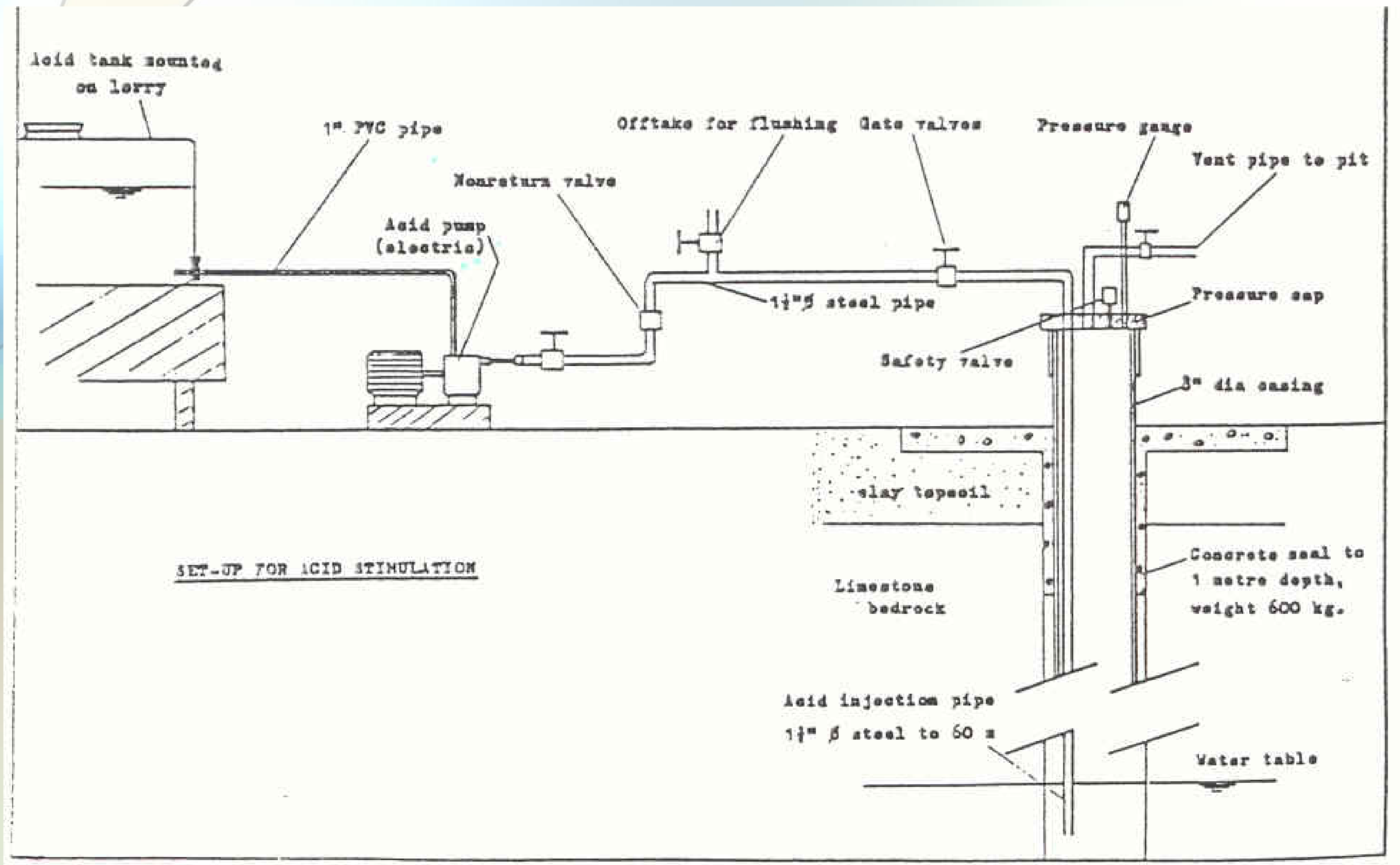


Figure 19: Acid process set-up

5. Disinfection of wells by Chlorination

5.3.2 Increasing yield

The reaction of acids with carbonates may be used to develop and to increase the yield of chalk and other limestone borehole and also, in certain cases, some sandstone boreholes.

The area of entry of the network of finer fissures extending for some distance away from the borehole and supplying the cut fissures should be enlarged.

To enlarge the more remote supply system of fissures it is essential that the acid used should be placed progressively so as to reach to the distance required.

5. Disinfection of wells by Chlorination

In considering the acidizing of a borehole the following information is required:

a)Dimensions of borehole: ***to determine the rate of placing acid***
b)Depth to rest water-level: ***to determine the rate of placing acid***
c)Depth of ground lining.
d)Details of overburden.
e)Geological description of exposed strata: ***to determine the amount of acid and the conditions for placing.***
f)Yield of borehole and draw-down characteristics: ***to determine the amount of acid and the conditions for placing.***
g)Position and size of fissures cut in borehole.

5. Disinfection of wells by Chlorination

h) General direction of underground water flow and approximate velocity: to determine the points for injections, which should be approximately the diameter of the borehole above the points where fissures cut the borehole.

i) Positions of borehole, especially industrial abstraction borehole (and quantities) within ½ mile radius.

j) Facilities for disposal of test-pumping water products of acidizing in solution.

Item (b) and (i) are required to determine precautions and possible effects on other abstractors and on removal of solutes.

5. Disinfection of wells by Chlorination

5.3.3 Placing procedure for hydrochloric acid (Figure 19)

1. Warn owners of neighboring boreholes of the operation and later confirm to them the date and time of placing the acid.

2. If it is not practical to determine item (f) by preliminary test pumping, the slurry should be removed from the walls of the borehole and the fissures entrances, and an estimate should be made of the likely yield and draw-down.

3. To clear the slurry lower a 2 in. pipe (with the bottom reduced to¼ in. diameter) to the bottom of the borehole and place 12.DH Ib. (where D is diameter of borehole, in feet H= depth of water, in feet of 30º Tw acid through this pipe as it is slowly lifted to rest water-level).

4. Items (2) and (3) above may be carried out immediately prior to the main acidizing.

5. Disinfection of wells by Chlorination

5. To carry out the main acidizing lower a 2 in. pipe to a point equal to the diameter of the borehole above the lowest fissure system, and connect this to the tanker delivery with a non-return valve placed at the joint. Draw up a plan of the amount of water to be used to flush the acid into the systems. The larger the amount of water that can be provided the greater the head available and the greater the penetration of acid in unspent condition into the fissures. Where there is no main supply, water for the operation may be stored in surface tanks- including the weir tank- and in surface pits.

The rate of discharge from the road tanker may be taken as 6,000 g.p,h. (or 20 Ib. per sq. in. pressure).

5. Disinfection of wells by Chlorination

The acid valve should be opened and freshwater should be discharged down the borehole. When the planned amount of acid has been delivered, close the acid valve but let the water continue for 30-60 sec. lift the acid pipes to the same distance above the next higher fissure system, and repeat the procedure.

6. Inhibitors may be used at the minimum arte of 0.15 percent, and there is little danger of acid attack on the seal of the lining tubes. The quantity of fresh water flushing down the upper part of the borehole protects the lining tubes and dissolves much of the carbon dioxide which is freely vented, especially when there is the pause in the operations to lift 2 in. tubes.

5. Disinfection of wells by Chlorination

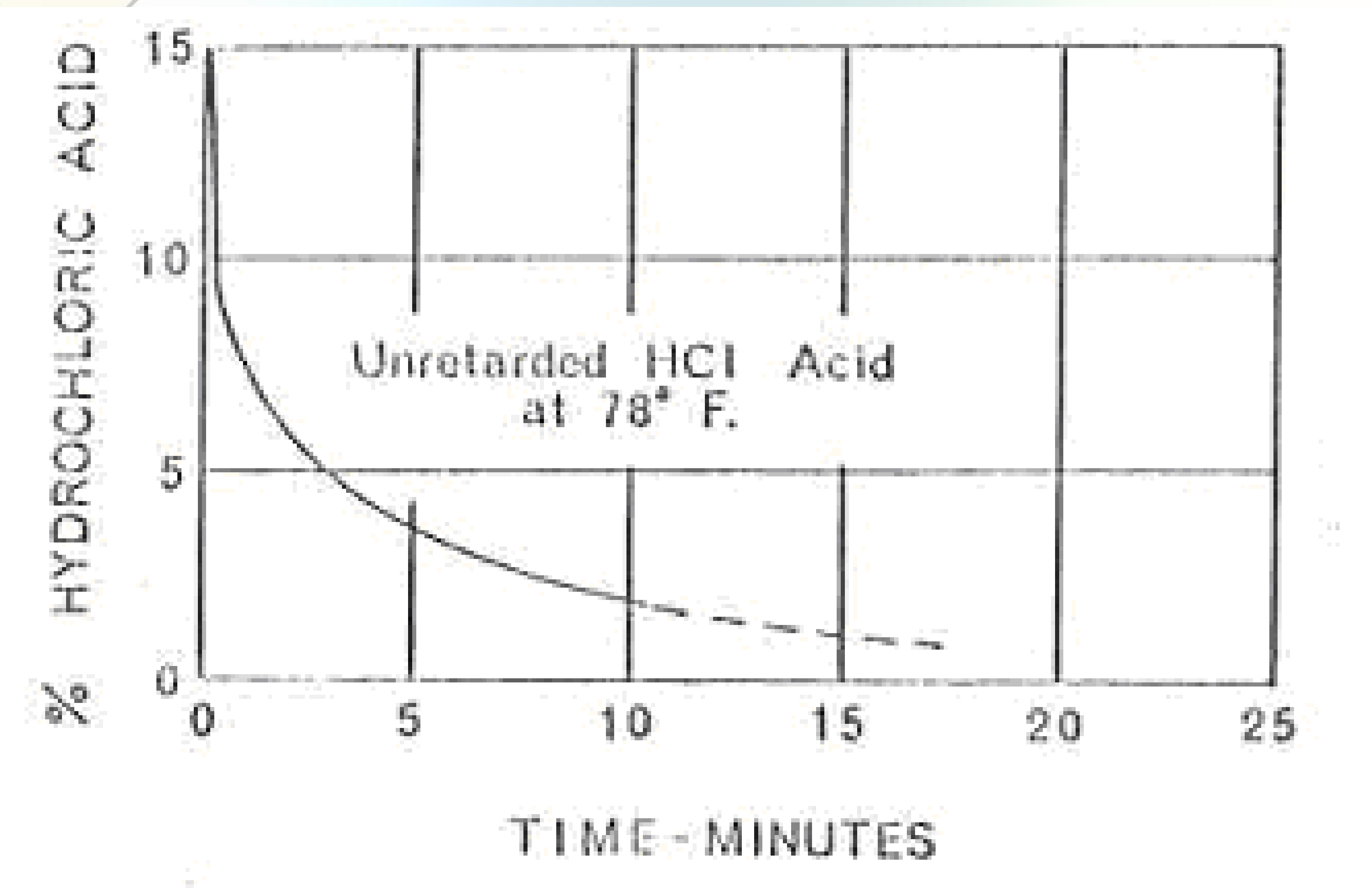


Figure 20: Reaction curve-95-98 per cent acid soluble limestone

5. Disinfection of wells by Chlorination

7. I f the rest water-level is less than 20 ft. below ground there may be overflow due to the reduced density of the water column. To prevent this additional length of borehole casing tube should be fitted to extend some 20 ft. above ground. In such case take special care of the ventilation arrangements and the removal of the carbon dioxide from the site.

8. If apparatus and plans are prepared well in advance, the whole operation should be carried out in the daylight hours of one day, but if there are many levels for discharge, or if there is difficulty in accumulating enough flushing water, there is no reason why the work should not be completed on the following day.

5. Disinfection of wells by Chlorination

As the acid is being discharged from the placing piping a good supply of fresh water should be flushed down the borehole to ensure that the acid is immediately carried away from the borehole into the fissure system to react there. Without adequate fresh water the acid will react on the borehole wall, causing turbulence and spread of acid for further attack, so that much of the acid is spent in enlarging the borehole.

The water flush also protects the grout seal at the shoe of the casing, as only fresh water passes this point. Also, the dilution effect is helpful as it delays the reaction to permit greater penetration (see Fig. 20)

5. Disinfection of wells by Chlorination

5.3.4 Placement under pressure

Acid may be placed in a borehole under pressure by sealing the acidizing pipework through a flange closing the top of the borehole and by pumping the acid in against the head generated by the carbon dioxide discharge.

Freshwater should be pimped in also, at a suitable rate, through a Tee into the borehole lining (with a non-return valve). The acidizing pipework should be lifted to the next higher zone of fissures after the designed quantity has been placed, as described earlier.

The casing shoe is protected by the freshwater, and this method may be recommended for initial acidizing where the fissure are particularly “tight”.

5. Disinfection of wells by Chlorination

The comparatively large quantity of fresh water dissolves much of the carbon dioxide that is generated, but the pressure may rise to 30-40 Ib. per sq, in., which gives some danger, from spread of pressure and strata uplift, unless the quantity of acid for the initial acidizing is not great.

Placement under pressure *without freshwater* is not recommended. The pressure of the free carbon dioxide on the water surface displaces water and acid into the fissures, the pressure obtained varies from 50-90 lb. in a 24 in. borehole depressing the level by 100 ft. would displace 2,000 gal.

Add the volume of the acid, 6, 000 gal. for 30 tons, to give a total displacement rate of 8,000 g.p.h. in the hour needed for pumping down the acid.

5. Disinfection of wells by Chlorination

This is, relatively, a small quantity for the borehole size and gives but slow movement, thus allowing the acid to react and to become spent in and close to the borehole wall.

The pressure is throughout the water column and much of the displaced water will escape in other-higher or lower-fissures. This can give rise to some curious effect, one of which is described later.

The higher pressures generated may be dangerous, and there have been cases where the pressure of gas has been widely distributed under a clay or other impervious bed, to burst out cracks-remote from the borehole- to belch gravel and froth. The cracks-through 30 to 40 ft. of clay, being gravel-filled-may become channels for pollution.

5. Disinfection of wells by Chlorination

But the greatest risk from acidizing *without water flush* is probably that tine of damage to the grout seal to the lining tubes.

The spread of acid the borehole by turbulence is such that the whole borehole may become filled with active acid and the grout may be attacked very heavily.

5. Disinfection of wells by Chlorination

Damage to Grout Seal

The reaction hydrochloric acid with neat cement grout is listed as one of the acid characteristics but the grout as placed in a borehole is rarely neat cement.

When placed the borehole lining tube becomes coated with a thin wash of slurry, the lower section of the receiving wall is more heavily coated, and the water through which the grout falls into place is heavily charged with very small limestone particles.

The grout, when set, contains a large proportion of limestone particles near the casing shoe which progressively lessens for some distance above the shoe.

5. Disinfection of wells by Chlorination

The slurry wash on the tubes, the slurry on the borehole wall and the particles in the grout are eagerly attacked hydrochloric acid, and when the borehole lining tubes pass through and support unstable ground great care is necessary to make sure that acid does not reach the shoe.

If acid reaches the shoe it will digest a pocket and the acid so trapped may digest “pipe” larger at the bottom than the top, or follow a vertical joint to permit an immediate run into the borehole.

More likely, however, is the failure of the borehole some considerable time after acidizing. This may be caused by a space being digested between the grout and the ground for a large part of the circumference, the grout being permeated with acid with it adhesion to the tubes destroyed.

5. Disinfection of wells by Chlorination

The action on the limestone particles in the grout and on the grout itself, continuous until the cohesive strength of the grout is gone and collapses into the borehole leaving a clear space for unstable ground to follow. Possibly an unusually low pumping level or near by boring or other vibration might precipitate such a collapse.

5. Disinfection of wells by Chlorination

5.3.5 General safety precautions

1. Before connecting to the acid tanker ensure that all pipework and joints are in first- rate order. Pressure-test assembly at 150 lb. per sq. in.

2. Never add water to acid-always add the acid to the bulk of water. When water is added enough heat may be generated to cause local flashing to steam, and hence violent patting of live acid.

3. Ensure that there is good ventilation around the borehole, and keep clear of leeward side to both avoid acid and carbon-dioxide discharge

4. Use eyeshields and protective clothing, and keep all people not so protected or not vital to the operations at a good distance and up-wind.

5. Disinfection of wells by Chlorination

Provide adequate first-aid kit open on the site, and ensure that the men carrying out the work understand its use.

5. If skin is in contact with acid remove as much acid as possible by blotting with towels before washing with water or bicarbonate solution.
6. If acid gets into the eyes bend the head forward and open eyelids, wash out eyes with bicarbonate solution and then immerse the head in fresh water keeping the eyes open.
7. Hydrochloric acid will not harm skin surface if it is promptly removed. A hand can be plunged into a bucket of 32 degree acid if promptly washed after removal. But contact with eyes, nose, etc., is painful, and it is important that the way to treat such exposure is known and that the remedy is readily available.

5. Disinfection of wells by Chlorination

5.3.6 General remarks

When a limestone borehole is acidized almost always there is a marked improvement in yield, but often serious damage is done. Sometimes the damage is not realized at the time and sometimes it is considered a natural hazard of acid treatment.

If the borehole needs acidizing then the work of placing the acid is the most important procedure in the whole construction. The water engineers should consider the acidizing procedure in detail, and should discuss it with the contractor and with the authority's chemist. The procedure should be planned.

Often the yield of a borehole is good, but acidizing may be considered to reduce the head loss of entry and in adjacent fissures. In such cases the saving in pumping costs may pay for the acidizing work within a few years.

5. Disinfection of wells by Chlorination

5.3.7 Design quantities of Hydrochloric Acid

Strength of acid in degrees Twaddell	Specific gravity	Percentage acid	Effective acid per ton, lb.
28	1.14	27.65	619
30	1.15	29.37	662
32	1.16	31.52	706
34	1.17	33.46	749
36	1.18	35.39	792

Reaction with chalk (calcium carbonate)

$$2\,HCl + CaCO_3 = CaCl_2 + CO_2 + H_2O$$

Parts 100 137 152 60.3 24.7

5. Disinfection of wells by Chlorination

Products of above reaction, in lb.per ton of acid used:-

Strength of acid used, °Tw	Chalk digested	Calcium chloride	Carbon dioxide	Water formed
28	848	940	373	153
30	907	1007	395	163
32	967	1074	426	174
34	1026	1141	452	185
36	1085	1208	478	195

Reaction with Magnesian Limestone (Magnesium-Calcium carbonate)

$$4\ HCl + MgCO_3 : CaCO_3 = CaCl_2 + MgCl_2 + CO_2 + H_2O$$

Parts 100 126.4 76.1 65.2 60 25

5. Disinfection of wells by Chlorination

Products of above Reaction, in lb. per ton of acid used:-

Strength of acid used, °Tw	Limestone digested	Calcium chloride	Magnesium chloride	Carbon dioxide	Water formed
28	780	465	400	375	155
30	835	500	430	400	163
32	890	535	460	425	174
34	945	570	490	450	185
36	1000	605	520	475	196

Solubility of Products

Expressed as lb. per 1,000 gal. of water:-

		At 10° C.	At 20° C.	At 30° C.
Calcium chloride	$CaCl_2$	6500	7450	10,200
Magnesium chloride	$MgCl_2$	5350	5400	5500

5. Disinfection of wells by Chlorination

Quantity Required to Clarify test pump discharge: QF lb. Where Q is estimated rate of pumping in 1, 000 g.p.h., and F is a factor between 15 and 30 according to the thoroughness of shelling-out during boring, i.e. for a borehole well cleaned during drilling and estimated to yield 30,000 g.p.h., provide 30 $\times$15=450 lb

Quantity required to Remove Slurry from the walls of the borehole: 12DH lb. where D is the diameter, in feet, and H is the depth of water, in feet. This application will also provide a reasonable clear initial test pumping.

Delivery. In road tankers of 6, 9, or 12 tons capacity. Tankers have compressors to exert pressure of 20lb. per sq. in. on the surface of the liquid inside the container; delivery is through a 2 in. rubber hose.

5. Disinfection of wells by Chlorination

Rate of delivery may reach 6,000 g.p.h. with tanker at full pressure and a long column of placing pipes, which, due to acid density will provide a suction effect. Acid action on the placing tubes (and CO_2 generated in the borehole) may cause back pressure and, as the tankers are not able to take a pressure much in excess of 20 lb. sq. in. a back pressure valve must be fitted to the tankers flange. Delivery may also be in Carboys of 112 lb. contents.

Character of Acid. Pale yellow liquid giving off brown fumes. Low viscosity. Liquid and fumes affect the eyes, nose, and throat, will give mild attack on steel that may be prevented by use of an inhibitor, and will attack clothing. Although all safety precautions should be taken when handling this acid a hand may be plunged into concentrated acid without injury if it is promptly washed after removal. Safe to handle under site conditions with proper precautions.

5. Disinfection of wells by Chlorination

Use. May be used for all types of acidizing and the products spread on agricultural land with only slight ill-effect. If extravagant claims for damage are made it would be well to defer settlement until the completion of the harvest.

Action on Cement Grout. Concentrated acid will attack cement grout, giving a violent reaction. When the reaction is completed the grout is left in soft condition and the surrounding water is then a mixture of a gel and acid. Dilute acid reacts quietly to weaken the grout and to leave a gel and acid mixture.

5. Disinfection of wells by Chlorination

5.3.8 Common Well Cleaning Acids

All chemicals to clean wells should be labeled for use in water wells. The amount of chemical added to a well should be based on the quantity of water in the well. Often adding too much acid to a well may not help and actually can hinder the rehabilitation process. With severe mineral incrustation, doing the acidizing in two steps often is better.

Use the first batch of cleaning chemicals to dissolve some of the minerals, then pump them out and add the second batch to dissolve the remaining parts. Wear the proper safety equipment, as recommended by the chemical manufacturer, when handling well-cleaning acids. Equipment should include goggles, masks, rubber gloves and full clothing coverage. In addition, a supply of clean water for eyewash and rinsing spills should be available.

5. Disinfection of wells by Chlorination

Muriatic Acid

Muriatic acid, a common product used for acidizing a well, is an industrial name for a hydrochloric acid solution with about 30 percent concentration -- a very strong acid. It provides a fast chemical reaction to dissolve carbonate scales and incrustation. It is particularly effective against iron and manganese oxides but doesn't remove biological buildup very effectively.

Although good for cleaning wells, hydrochloric acid can be dangerous to handle. Excessive amounts in the well can produce large amounts of toxic fumes. Inhaling these fumes can cause death. Use only the recommended amount of acid for the volume of water in the well. Only professionals with training and access to proper safety equipment should handle this acid.

5. Disinfection of wells by Chlorination

Sulfamic Acid

This is a type of sulfuric acid and comes in a dry form. It is safer to use than muriatic acid, but has a moderate chemical reaction, so it takes longer to dissolve carbonate scales and incrustations. It is not very effective against sulfate mineral deposits. Sulfamic acid doesn't produce harmful fumes and is not very corrosive. It isn't very effective at removing biological buildup.

5. Disinfection of wells by Chlorination

Phosphoric Acid

Phosphoric acid is a mild acid that contains phosphorus, which if discharged into wetlands or water bodies can increase algae buildup. It is less corrosive to metal than muriatic acid. It is somewhat effective in dissolving iron and manganese oxides but is not very effective against biological buildup in the well.

5. Disinfection of wells by Chlorination

Glycolic Acid

Glycolic acid, also known as hydroxyacetic acid, is effective against biological accumulations. It will disperse and help remove biofilms that build up on the screen, pump and casing. The chemical reaction is slow and creates no harmful fumes.

Acid Combinations

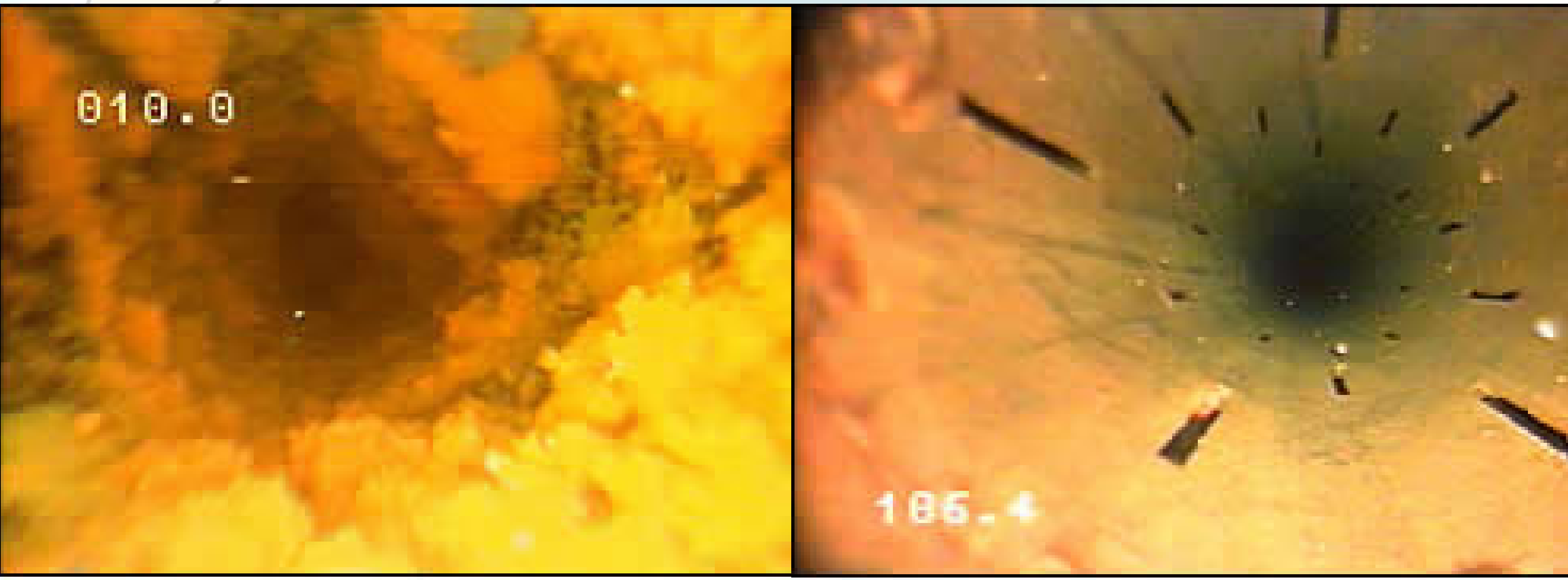
To remove both biological products and mineral incrustations effectively at the same time, well drillers often use a combination of acids when rehabilitating a well. One combination is to mix muriatic and glycolic acid together, with each added to a volume of water at about the same percentage by weight or volume. More often, well drillers will use commercial products that are premixed acid combinations designed to address specific incrustation problems.

5. Disinfection of wells by Chlorination

Chemicals Used for Well Maintenance

	Chemical Name	Formula	Application	Concentration
Acids and Biocides	Hydrochloric Acid	HCl	Carbonate scale, oxides, hydroxides	15%; 2-3 times zone volume
	Sulfamic Acid	NH_2SO_3H	Carbonate scale, oxides, hydroxides	15%; 2-3 times zone volume
	Hydroxyacetic Acid	$C_2H_4O_3$	Biocide, chelating agent, weak scale removal agent	
	Chlorine	Cl_2	Biocide, sterilization, very weak acid	50-500 ppm
Inhibitors	Diethylthiourea	$(C_2H_5)NCSN(C_2H_5)$	Metal protection	0.2%
	Dow A-73		Metal protection	0.01%
	Hydrated Ferric Sulfate	$Fe_2(SO_4)_3 \cdot 2\text{-}3H_2O$	For stainless steel	1%
	Aldec 97		With sulfamic acid	2%
	Polyrad 110A		Metal protection	.375%
Chelating Agents	Citric Acid	$C_6H_8O_7$	Keeps metal ions in solution	
	Phosphate Acid	H_3PO_4	Keeps metal ions in solution	
	Rochelle Salt	$NaOOC(CHOH)_2COOK$	Keeps metal ions in solution	
	Hydroxyacetic Acid	$C_2H_4O_3$	Keeps metal ions in solution	
Wetting Agents	Plutonic F-68		Renders a surface nonrepellent to a wetting liquid	
	Plutonic L-62		Renders a surface nonrepellent to a wetting liquid	
Surfactants	Dow F-33		Lowers surface tension of water thereby increasing its cleaning power	
	Sodium Tripolyphosphate			
	Sodium Hexametaphosphate			

5. Disinfection of wells by Chlorination



Before: severe clogging of slots

After: open area restored

Figure 21: The effect of using Acidisation on a borehole before and after using acid

6. Plugging a well

When a well is no longer being used or maintained for future use, it is considered abandoned. Abandoned wells pose a serious threat to the preservation of groundwater quality. They are also a serious safety hazard for children and animals.

Plugging an abandoned well prevents:

- Downward movement of water in the well or well annulus.
- Surface contamination from reaching aquifers.
- Intermixing of water between aquifers of different water quality.
- Serious accidents from happening.

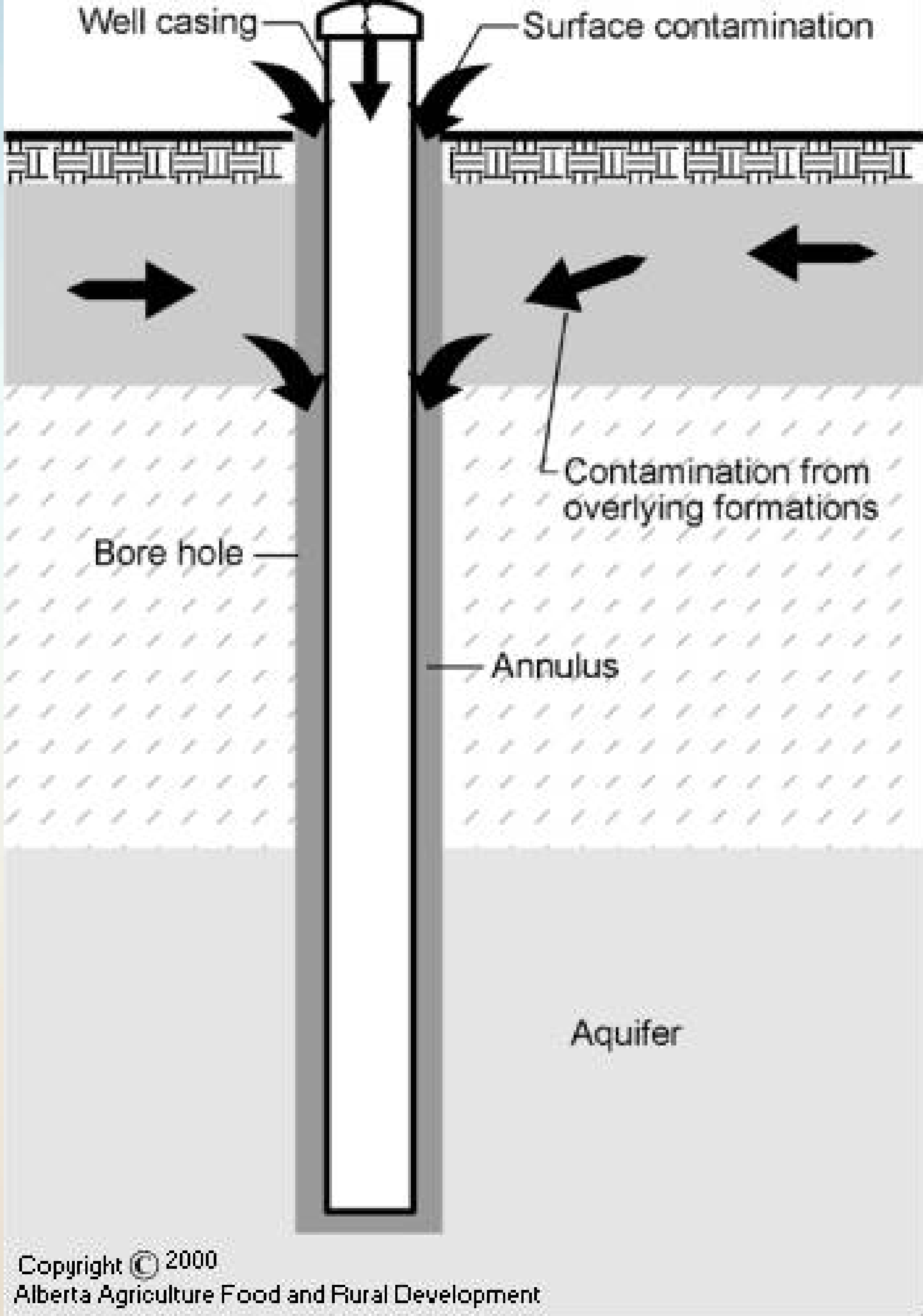
6. Plugging a well

Unfortunately, groundwater contamination and its effects are usually not recognized until groundwater quality is seriously affected and nearby wells have been contaminated. Surface contaminants can enter a well several ways:

- Directly through the surface opening if the cap is loose, cracked or missing
- Through unsealed spaces along the outside of the casing (see Figure 1, Well Contamination).

6. Plugging a well

Figure 22: Well Contamination



6. Plugging a well

When the steel casing of an abandoned well starts to corrode, holes will develop. When this takes place, surface contaminants or poor quality water from shallow aquifers may migrate into the deeper aquifers of nearby operating wells (see Figure 23).

6. Plugging a well

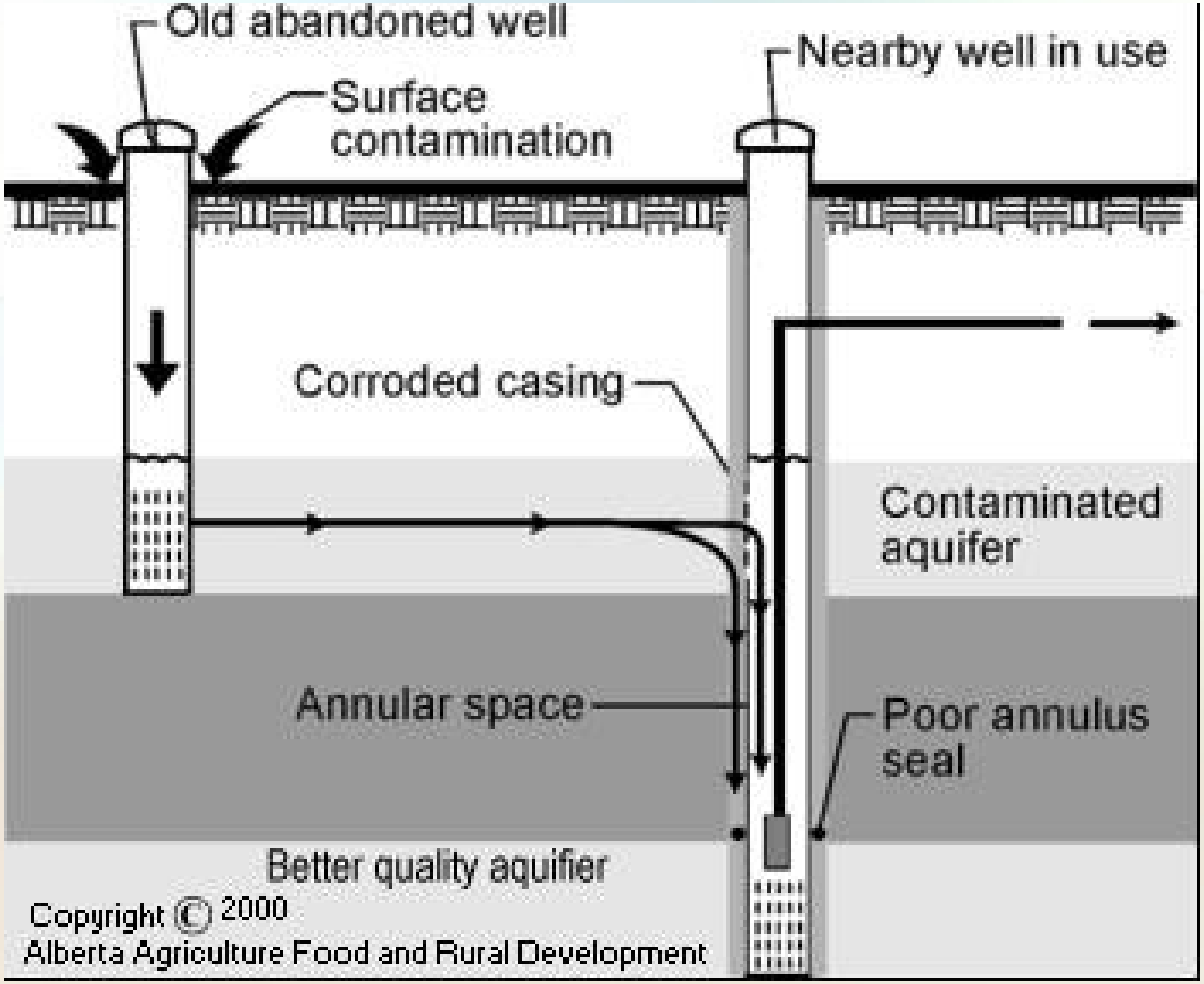


Figure 23: Contamination From an Abandoned Well

6. Plugging a well

Preparation for plugging a well: Ideally the casing should be removed from the well before the plugging process begins. Often only the liner casing is removed and the surface casing is left intact because it is more difficult to remove and it could separate down hole. The older the well, the more difficult it will be to successfully remove the casing. If the casing is left in place, it should be perforated, particularly if there is evidence of water movement in the annulus of the well. Any casing left in place must be cut off 0.5 m (20 in.) below ground surface after the well is plugged.

Materials: Materials that are used to plug a well must be uncontaminated and impervious. They must prevent any movement of water. See the chart below for acceptable and unacceptable materials.

6. Plugging a well

Acceptable Materials	Unacceptable Materials
▪grout ▪neat cement (cement mixed with water) ▪sand cement (cement, sand and water)	sand
▪concrete (cement, sand and aggregate mixed with water)	gravel
▪manufactured high yield bentonite products	drilling mud or fluid
▪clean, uncontaminated clay (for large diameter wells)	

6. Plugging a well

Cement grout and concrete may shrink after setting so may not create as good a seal as bentonite.

Sand and gravel are not acceptable materials. They are not impervious materials because water can easily move through them.

High yield bentonite is a special type of clay that swells when wet to provide a very effective impervious seal. It comes in a powder that when mixed with water produces a slurry that can be pumped into the well. It is also manufactured in pellet or granular form that is designed to pour into the well. This type of bentonite when mixed with water will actually swell to about eight times its original size and will form a water-tight plug.

6. Plugging a well

It is important to understand that bentonite cannot be used as a plugging material in some situations. When the chloride level in the well water is greater than 4000 mg/L, or the calcium level is greater than 700 mg/L, bentonite will not swell properly, so then it is best to use a cement grout.

Large diameter or bored wells pose special problems because of their size and volume of material required to fill them. A lower cost alternative for the plugging material is clean, uncontaminated clay that can be shoveled into the well until it is filled.

This must be done carefully, however, to ensure the clay reaches the bottom of the well and seals off all empty space. The cribbing must be cut off below ground surface and the well topped up with high yield bentonite to make a water-tight seal.

6. Plugging a well

Method

Aside from choosing the appropriate plugging material, the method of placing material into the well is most critical. Regulation requires that the plugging material must be introduced from the bottom of the well and placed progressively upward to ground surface.

If the plugging material is cement grout, concrete or bentonite slurry, special equipment is needed. The material must be placed into the well through a tremie pipe that is usually about 3 in. in diameter. At all times this pipe must be kept below the surface of the plugging material to prevent it from diluting or separating.

It is recommended that you hire a drilling contractor when a slurry is chosen as the plugging material because the drilling contractor will have the proper equipment and experience to do the job correctly.

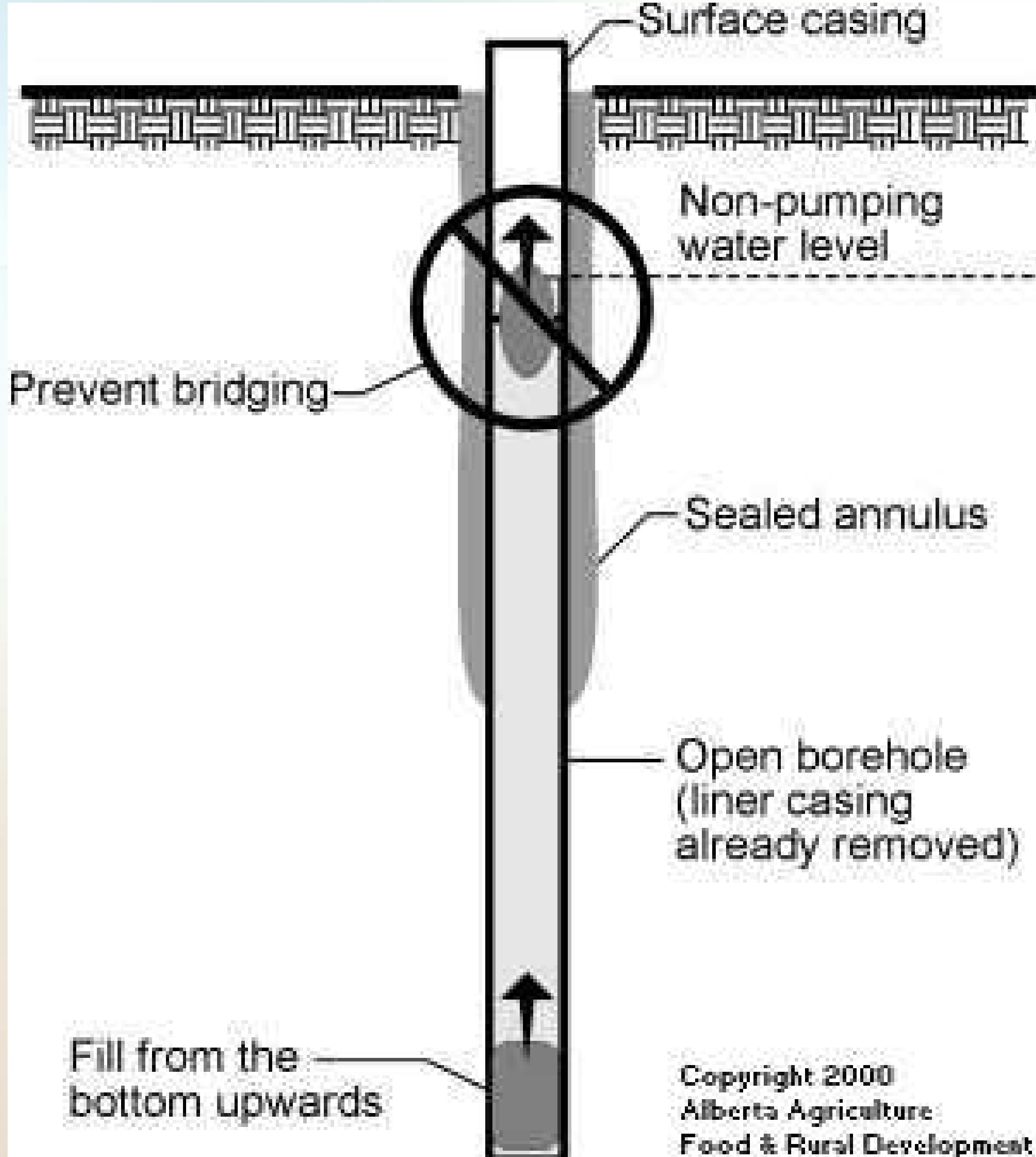
6. Plugging a well

When bentonite pellets are chosen for the plugging material, they can be poured into the well from the ground surface. These pellets have a weight material added to help them sink to the bottom of the hole. They are also coated to prevent immediate swelling on contact with water. When poured slowly, they should reach the bottom of the well before swelling. If you are not careful, however, these pellets will bridge off down hole and the well will be only partially plugged (see Figure 24, Bridging).

Before you pour in the pellets, you can determine how many feet of well casing can be filled with the size of pellets you have chosen. As the well is being filled, measure the depth to the top of the plugging material quite frequently. Then you will know if the plug is rising faster than expected indicating a bridge has formed. If this happens, be sure to break it up before adding more material to the well.

6. Plugging a well

Figure 3: Bridging



6. Plugging a well

By regulation, a well must be filled full length with impervious material. That material must be introduced into the well at the bottom and be placed progressively upward to ground surface.

6. Plugging a well

Steps to Plugging a Well

Step 1 -	Remove all pumping equipment from the well. Thoroughly flush out the well using a bailer or air compressor.
Step 2 -	Measure the total depth of the well, the diameter and the non-pumping water level. If possible, compare these figures with the information on the original drilling report. Confirm whether the well is open to its original depth.
Step 3 -	Use these figures to decide which plugging material is appropriate and how much you will need. Whether or not the casing can be successfully pulled out will also determine which material to use and what method is appropriate for placing it into the well. If the casing cannot be removed, choose a slurry that can be pumped under pressure into the well so that any space around the outside of the casing will also get filled in.
Step 4 -	Disinfect the well.
Step 5 -	If possible, remove the well casing.

6. Plugging a well

Steps to Plugging a Well

Step 6 -	Place the plugging material into the well. It must be introduced at the bottom of the well and placed progressively upwards to ground surface. The only exception to this rule is when the plugging material being used is a bentonite pellet that has been designed and manufactured for pouring into the well from the ground surface.
Step7 -	If the casing was not already removed, dig around it and cut it off a minimum of 0.5 m (20 in.) below the ground surface (see Figure 25, Cutting Off the Casing and Mounding the Clay).
Step 8 -	Backfill and mound this portion of the hole with material appropriate for intended use of the land (i.e., clay) (see Figure 25, Cutting Off the Casing and Mounding the Clay).

6. Plugging a well

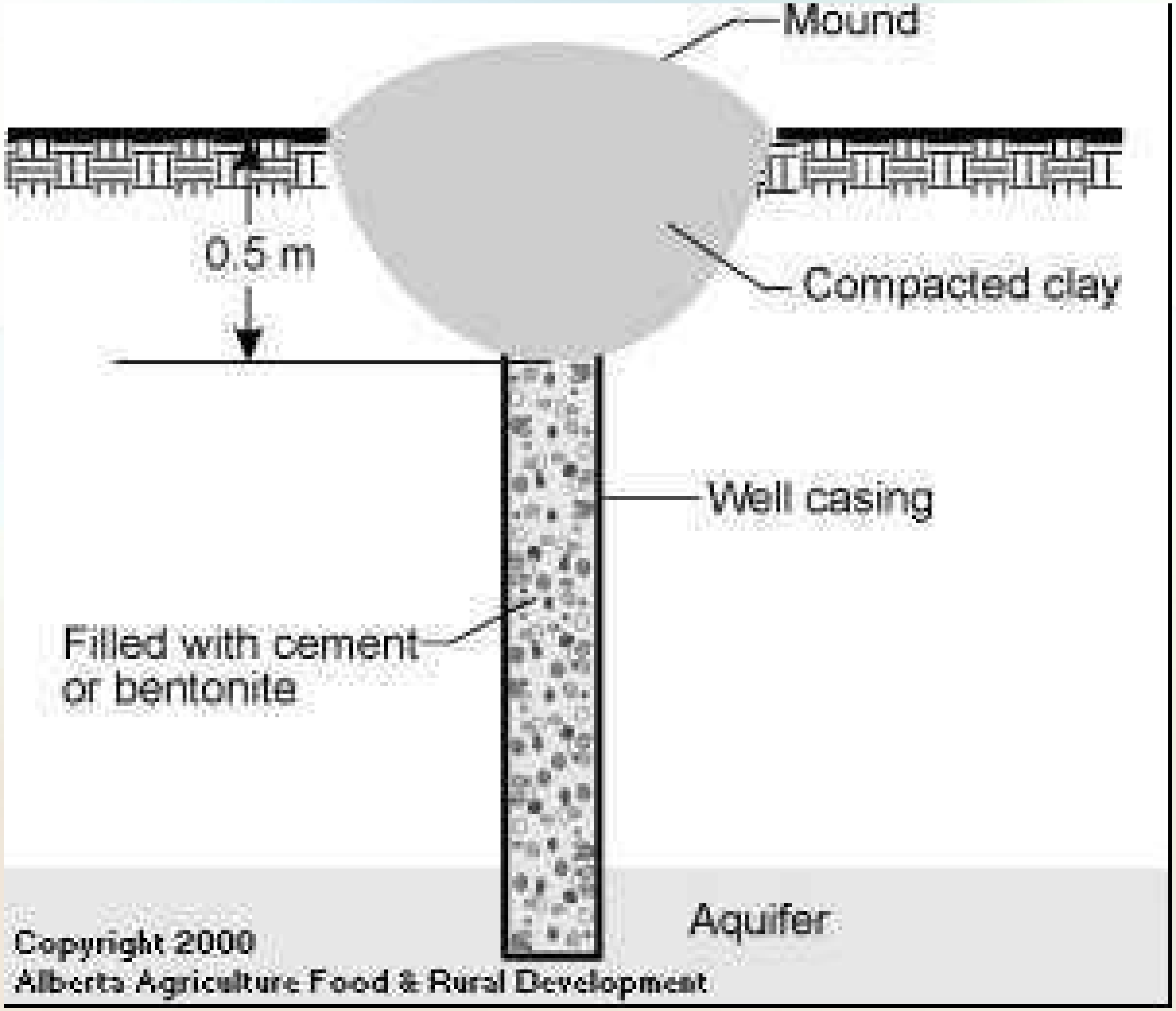


Figure 25: Cutting Off the Casing and Mounding the Clay

7. CASE STUDY

7.1 EXECUTIVE SUMMARY

Within the activities of the water supply project (that the Jerusalem Water Undertaking JWU) with the support of the German Technical Cooperation Agency (GTZ) an assessment of the hydraulic characteristics of the utilized aquifer at Ein Samya Well 2a ESW2a location and assessment the performance of ESW2a which will help determine the maximum pumping rate at the well were carried out.

Earlier test-pumping showed that ESW2a is inefficient as to the average efficiency was less than 35%; quantitative interpretation of the well loss coefficient indicated that the formation around the well had been damaged and analysis of recovery periods showed that the very fast recovery was attributed mainly to the inefficiency of the well.

7. CASE STUDY

Subsequently, recommendations to acidise the borehole of ESW2a were accepted by the JWU and GTZ. 27 tones of hydrochloric acid with 22 wt% concentration were injected.

After washing out the borehole another step drawdown test was undertaken.

The result showed that the specific capacity values for low, medium and high pumping rates had improved 70%, 96%, and 128% respectively.

The results also showed that the efficiency of the well had improved from nearly 35% before acidisation to nearly 90% after acidisation.

7. CASE STUDY

7.2 ASSESSMENT OF WELL EFFICIENCY

The average value of ESW2a efficiency was found 34.5%. For the pumping rate 265 m^3/hr the well efficiency was 26.1% **(Table 5)**.

This is to be expected given that well loses were very high “12.05 m out of a total drawdown of 16.39 m at 60 minutes of pumping” which causes a very fast rate of recovery when the pump is switched off.

It was noticed that 15.63 m of a total drawdown of 16.92 m at 255 minutes of pumping was recovered is about 6 minutes or so during the recovery test which corresponds with evidence already established of the low well efficiency of ESW2a.

7. CASE STUDY

There is a rough rule of thump for recognizing an inefficient well. This rule is based on the observation of the recovery rate when pumping is stopped.

The drawdown of a pumped well recovers very rapidly by great influx of water to the well from the surrounding aquifer wherever the well losses are large. This is because of the great difference in the aquifer water level and the water level of the production well.

Step-drawdown test results presented in Table 5 shows that for steps 1, 2, 3, 4, 5 and 6 the well loss represents 49%, 62%, 67%, 69%, 70% and 74% of the actual incremental drawdown occurred during each test step respectively This illustrates the high percentage of well loss of ESW2a.

7. CASE STUDY

The rule of thump states that ***if the well pump is stopped after 1 hour of pumping and 90% or more of the drawdown is recovered after 5 minutes, then the well is inefficient***. It was impractical to stop pumping after 1 hour, but the following observations presented in Table 4 indicate clearly that it can be concluded that ESW2a well is inefficient.

The results of the step-drawdown test can be used to evaluate the condition of well according to the value of the well loss coefficient. **The value of the well loss coefficient of ESW2a well was found at 0.62 min^2/m^5**. Therefore, and according to **Table 6**, there is a clear sign that ESW2a needs to be developed or rehabilitated. This result enhances that fact that the efficiency of ESW2a needs to be increased.

7. CASE STUDY

Table 5: Results of Step-drawdown Test at 60 Minutes

Step	1	2	3	4	5	6	7*
Actual Drawdown (m)	3.49	6.26	8.35	10.47	11.83	16.39	…
Simulated Draw down (m)	3.33	6.28	8.46	10.51	11.85	16.32	22.47
Absolute Error (m)	0.16	0.02	0.11	0.04	0.02	0.07	…
Relative Error (%)	4.6	0.3	1.3	0.4	0.2	0.4	…
Pumping rate (m^3/day)	2400	3600	4320	4920	5280	6360	7632
Aquifer loss (m)	1.61	2.42	2.90	3.30	3.55	4.27	5.12
Well loss (m)	1.72	3.86	5.56	7.21	8.30	12.05	17.35
Efficiency (%)	46.2	38.6	34.7	31.6	30	26.1	…

* The last step is extrapolated for 20% higher last pumping rate.

7. CASE STUDY

Table 7: Relation of Well Loss Coefficient to Well Condition (after Walton,1962)

Well loss Coefficient (min^2/m^5)	**Well Condition**
< 0.5	Properly designed and developed
0.5 – 1.0	Mild deterioration or clogging
1.0 – 4.0	Sever deterioration or clogging
> 4.0	Difficult to restore well to original capacity

7. CASE STUDY

Table 4: Recovery Data to Indicate the Efficiency of ESW2a

	First Recovery Test	Second Recovery Test	Third Recovery Test
Pumping Rate (m3/hr)	220	205	265
Duration of Test (min)	420	1020	255
Total Drawdown (m)	11.83	11.05	16.92
Recovered Drawdown (m)	11.04	10.01	15.63
Time (min) Required for the above Recovery	5	8	6
Summary	**93% of the total drawdown was recovered in the first 5 minutes**	**91% of the total drawdown was recovered in the first 8 minutes**	**92% of the total drawdown was recovered in the first 6 minutes**

7. CASE STUDY

7.3 THE NEED TO DEVELOP ESW2a

- The average well efficiency is 34.5% (less than 50%).

- The well loss coefficient illustrates that the formation adjacent to the well has been-damaged. Recovery tests show that more than 90 % of the total drawdown was recovered in the first few minutes.

- The drilling method of direct rotary circulation (with air and foam as a drilling fluid) was used in drilling ESW2a. The primary purpose of using air and foam was almost to diminish the damage caused by other drilling fluids such as the bentonite. The above results show that there still a considerable damage to the level that well development can not be avoided. It can be said that regardless the drilling method and the drilling fluid, formation damage is inevitable especially in hard rock formations.

7. CASE STUDY

- The drilling of layered aquifer comprising of marl or clay can cause the marl/clay cuttings to stick to the perforated casing during the casing process of the borehole. Even if clear water is used, the presence of marl/clay content can mix with the drilling fluid and clog the permeable sections in the aquifer. The conditions of ESW2a are similar.

7. CASE STUDY

7.4 Design of acidization stage for ESW2a

The quantity of HCI recommended normally to acidise a borehole equals the amount of water in the screen (or perforated casing) plus additional volume of nearly 50 to 100 percent.

Using **Table 8**, the amount of acid requires per 0.3 m of a 14 inch perforated casing of ESW2a is chosen to be 45.4 liter. The length of the perforated casing is 73 m. Thus the volume of acid required for the perforated casing is 11.05 m^3.

7. CASE STUDY

To allow the acid to reach the formation fissures and fractures, it is recommended that nearly 18.20 m^3 (11.05 m^3 + additional 65% (7.15 m^3) to reach fissures) of HCl acid used to develop the borehole of ESW2a.

Referring to local conditions and with specific gravity of 1.1 for HCI, 20 (18.2 x 1.1) metric tones of commercial 22 wt% is recommended to be used for the development or ESW2a borehole.

7. CASE STUDY

Table 8: Amount of HCl Required to Treat an Incrusted Screen (After Driscoll, 1986)

Screen Diameter (inch)	Amount of HCl Acid in liters (18° to 20° Baume, i.e., 28 t0 31 % HCl) per 0.3 m of screen
1.5	0.42-0.53
2	0.76-0.91
2.5	1.25-1.48
3	1.74-2.12
3.5	2.38-3.48
4	3.07-3.71
4.5	3.94-4.73
5	4.84-5.79
5.5	5.83-7.00
6	6.96-8.36
7	9.5-11.4
8	12.3-14.8
10	19.3-23.2
12	27.8-33.4

7. CASE STUDY

Table 8: Amount of HCl Required to Treat an Incrusted Screen (After Driscoll, 1986) **(CONT.)**

Screen Diameter (inch)	Amount of HCl Acid in liters (18° to 20° Baume, i.e., 28 t0 31 % HCl) per 0.3 m of screen
14	37.9-45.4
16	49.4-59.4
18	62.6-75.1
20	77.2-92.7
22	93.5-112
24	111-133
26	131-157
28	151-182
30	174-208
82	198-237
34	223-268
36	250-300

7. CASE STUDY

On 7 August 1996, the actual acidisation process took place. 27 tones of hydrochloric acid with necessary quantity of retarder, foam and water were injected.

A process of washing out took place over the following few days. Workers from the JWU were spread alongside the disposal wadi in Ein Samya area to prevent anyone and animals from touching the disposed water.

7. CASE STUDY

Samples from the pumped water were sent to the laboratory of Bir Zeit University to make sure that the effect of the acid has diminished. In addition a pH meter was used in site to measure the acidity of the pumped water.

When it was confirmed that the pumped water is safe to drink the washing out process was terminated and the pumped water was connected to the system, also during the washing out process, a step-drawdown test, constant pumping rate test and recovery tests were undertaken.

7. CASE STUDY

7.5 PUMPING TESTS AFTER THE ACIDISATION PROCESS

Table 9 represents the data of the Step draw-down test carried out after the acidisation process

Table 9: Step-drawdown Test after Acidisation

Step	Q		Accumulative drawdown, S (m)	Q/S	
	m^3/hr	m^3/day		(m^3/hr)/m	(m^3/day)/m
1	120	2880	2.47	48.6	1166
2	150	3600	3.19	47	1129
3	195	4680	4.37	44.6	1071

7. CASE STUDY

The above table shows that the specific capacity values for low pumping rate, medium pumping rate and high pumping rate has improved by about 70%, 96% and 128% respectively.

It can be shown that before acidisation and for a pumping rate of nearly 200 m^3/hr the drawdown at 60 minutes was nearly 10m while after acidisation this value was about 4.5 m.

This proves that the acidisation results were positive on the performance of the well.

7. CASE STUDY

The results show that the well's average efficiency is nearly 90% while it was about 35% before acidisation. This means that the efficiency of the well has improved as many as 2.5 times.

Also the well loss coefficient is estimated at 0.0015 min^2/m^5 which is much smaller than 0.5 min^2/m^5 (**see Table 6**).

This means according to Table 6 that the well is well developed.