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Dewatering of Mines—A Practical Analysis

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INTRODUCTION

Methods of controlling ground water must be devised during the planning of mining activities because ground water in pervious rocks can adversely affect the development of a mining operation. To create an effective dewatering system, the economic, environmental and legal aspects of selected dewatering methods should be investigated concurrent with mine design and planning.

The following benefits may be derived from an efficient dewatering system:

- Slope stability in an open cut mining operation.
- Elimination of caving and upheaval in vertical shaft excavations and reduction of hydrostatic pressure from artesian aquifers, which may underlie mining areas.
- Proper alignment of diversion channels with minimal infiltration of water into mining slopes.
- Fewer legal and environmental restrictions and a reduction in the number of sump pumps, water treatment equipment and other facilities.

USE OF AVAILABLE DATA TO IDENTIFY PROBLEMS IN MINE HYDROLOGY

With minor adjustments in the exploration program, invaluable information can be made available to the ground-water geologist without excessive additional costs. With accurate visual and geophysical logs, recorded water level data and data from the drilling operation, potential aquifers and the extent of ground-water problems can be identified.

The geohydrologist can often determine the extent of ground-water problems by reviewing existing exploration boring logs. Unfortunately, exploratory borings are usually drilled to delineate and evaluate ore bodies, and insufficient attention is given to logging and classifying unconsolidated materials and water-bearing rocks. With minimal additional expense, exploratory borings can be used to show depths of unconsolidated sediments, classification and lithology of bedrock, zones of caving or heavy mud loss and water production from an air drilling operation.

Generally, exploratory holes are also logged by geophysical methods. Ideally, these should include temperature, flow meter (spinner) and radioactive tracer logs in addition to caliper, spontaneous potential, resistivity, gamma ray, neutron and other borehole geophysical logs selected for individual site investigations.

Investigative costs can be reduced if exploratory borings are converted to piezometers. A monitoring network can then be established, with water levels recorded regularly, and water samples can be collected for laboratory analysis.

Supplemental data may be obtained from government documents, private papers, geologic reports, local well logs, pumping records, meteorological and river stage data, maps, seismological reports, environmental investigations, and other bulletins pertaining to the area. The ground-water geologist can use these data to identify possible problems concerning the mine hydrology and to proceed with selection and preliminary design of water control systems while mining feasibility studies are being conducted.

FIELD INVESTIGATIONS, DATA ANALYSES AND OFFICE STUDIES

Preliminary assessments can only be confirmed through field investigations. The ground-water geologist may have considerable data to substantiate the hydrologic characteristics of a formation; however, all potential aquifers, possible barriers, conditions of ground-water occurrence, areal effects of ground-water lowering, piezometric fluctuations, water quality and other subsurface geologic features must be identified. The intensive field investigative program should include pumping tests, water level monitoring, geologic mapping of the area and surface geophysical surveys to define the depth and nature of the bedrock.

A pumping test consists of pumping a well and observing the effect in several piezometers spaced at varying distances from the well. Siting of these piezometers will usually be determined in the field by the ground-water geologist and will be based on assumed transmissivity of the aquifer, planned length of pumping test and other factors such as possible fault zones, the strike or dip of formations, the location of streams and possible ground-water barriers. The effects of barriers on drawdown are illustrated in Figure 1.

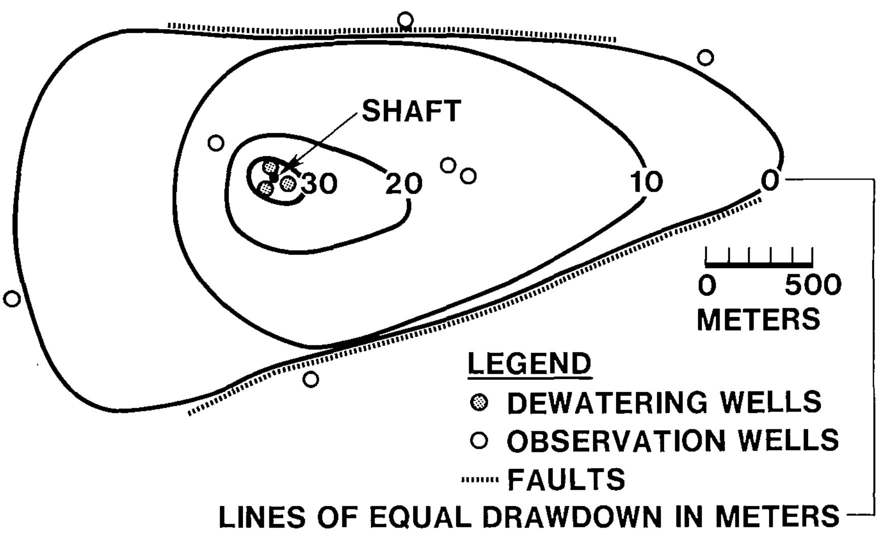
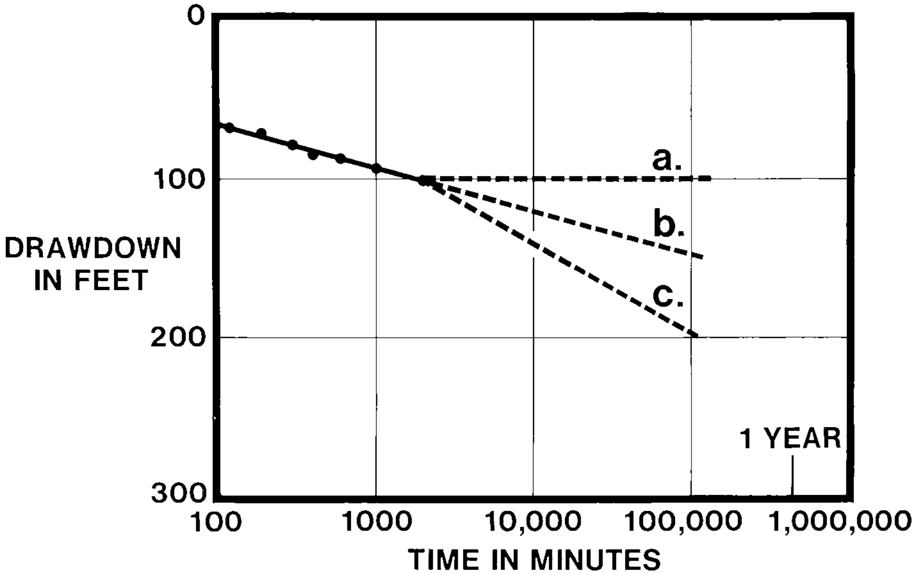


Figure 1. Effect of barriers on drawdown

If an aquifer is pumped at a constant rate, the cone of influence extends outward with time. This cone expands until natural or surface recharge of the aquifer equals the pumping rate (see Figure 2). This may occur within a few hours or days, but, if the aquifer is extensive, the process may continue for years. Precise measurements of pumping rates, water levels in pumping and observation wells and water recovery must be made to produce meaningful data from the pumping tests. The geohydrologist usually conducts several pumping tests early in the mining program to define hydrologic characteristics.



a. Cone of influence intercepts source
b. Cone of influence does not intercept source
c. Cone of influence intercepts hydrologic barrier

Figure 2. Time-drawdown curves

Research has produced usable formulae and analytic methods for evaluating the pumping test results and hydrologic investigations (1). Equilibrium formulae, often modified to reflect site conditions, are used to obtain coefficients of transmissivity and storage if steady-state flow conditions are obtained. More commonly, nonequilibrium formulae are used when equilibrium can not be attained or if radial flow to the well is unsteady on short-term tests.

After data are compiled and evaluated, conceptual designs of dewatering systems can be confirmed or rejected. With relatively complete investigative data, the ground-water geologist can describe the hydraulic characteristics of the aquifer, compute transmissivities and storage coefficients, estimate specific capacities and predict infiltration quantities and drawdown. Also, the viability of water control can be evaluated.

Concurrent with or subsequent to data evaluation, the environmental, legal and economic constraints that may influence the dewatering selection process are studied. Pollution, water disposal, effects of large-scale mining withdrawals of ground water, possible saline water intrusion into potable aquifers, subsidence, the effect of ground-water lowering on domestic and animal habitats and many other environmental aspects of dewatering must be considered.

The ground-water geologist and the engineer must work closely to analyze all factors and to implement the most feasible and economic system. In addition to evaluating the effects of dewatering, the types and availability of the following materials and installation equipment must be considered: drilling rigs, well point systems, pumps, pipe, well screen, bentonite, cement, water treatment equipment, power, sand and gravel and other materials.

WATER CONTROL SYSTEMS

Practical and economical results can be achieved with the selection of one or more of the water control systems that have been used successfully by the mining and construction industries for many years. Pre-drainage may be considered infeasible and mine sumping systems may be installed particularly at open cut mines. Treatment and surface impoundment of sumped water may be required to allow for settlement of suspended solids or precipitation of iron, manganese and other elements.

Conventional and vacuum wellpoint systems are commonly used to dewater unconsolidated sediments. Wellpoints that are 1-1/2 to 2 inches in diameter and 2 to 5 feet in length are attached to riser pipes and installed in a line or ring at spacings generally ranging from 2 to 8 feet. These risers are connected to a common header; they are pumped by one or more wellpoint pumps, which are a combination of centrifugal and vacuum pumps and are generally capable of lowering water levels 15 to 20 feet. For greater lifts, multi-stage wellpoint, jet eductor or deep well systems are effective. Often, well point systems are prescribed to allow placement of compacted earth core or cutoff trenches for diversion or tailings dams, to provide stable slopes along diversion channels or to contribute to ground-water lowering when used in conjunction with a deep well system. A two-stage wellpoint system is shown in Figure 3.

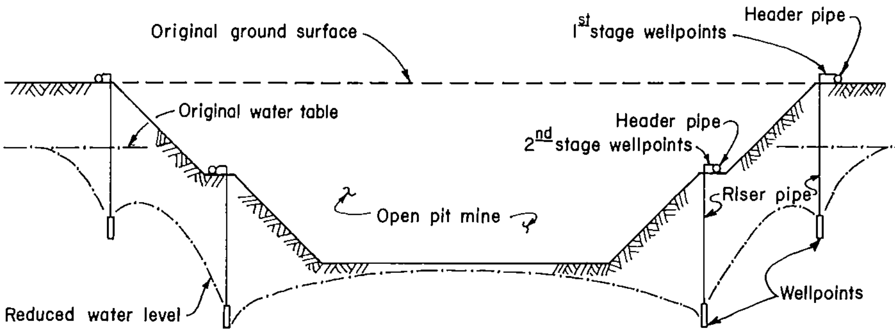


Figure 3. Two-stage well point system

Water control in unconsolidated sediments can also be accomplished by installing slurry trenches. A vertical walled trench is excavated by a backhoe, dragline, trenching machine or clamshell. Bentonite slurry is pumped in the trench to replace the excavated material and to provide support for the trench walls (see Figure 4). The slurry level should not be over 1 or 2 feet below ground level and several feet above the existing static water level. Backfill is usually composed of excavated materials, imported select soils and slurry and consists of a thoroughly mixed, well graded, homogeneous mass that is free from boulders.

Backfill is usually placed by a bulldozer. This method is feasible in areas underlain by silts, sands and gravels; however, excavation may be difficult if boulders are present.

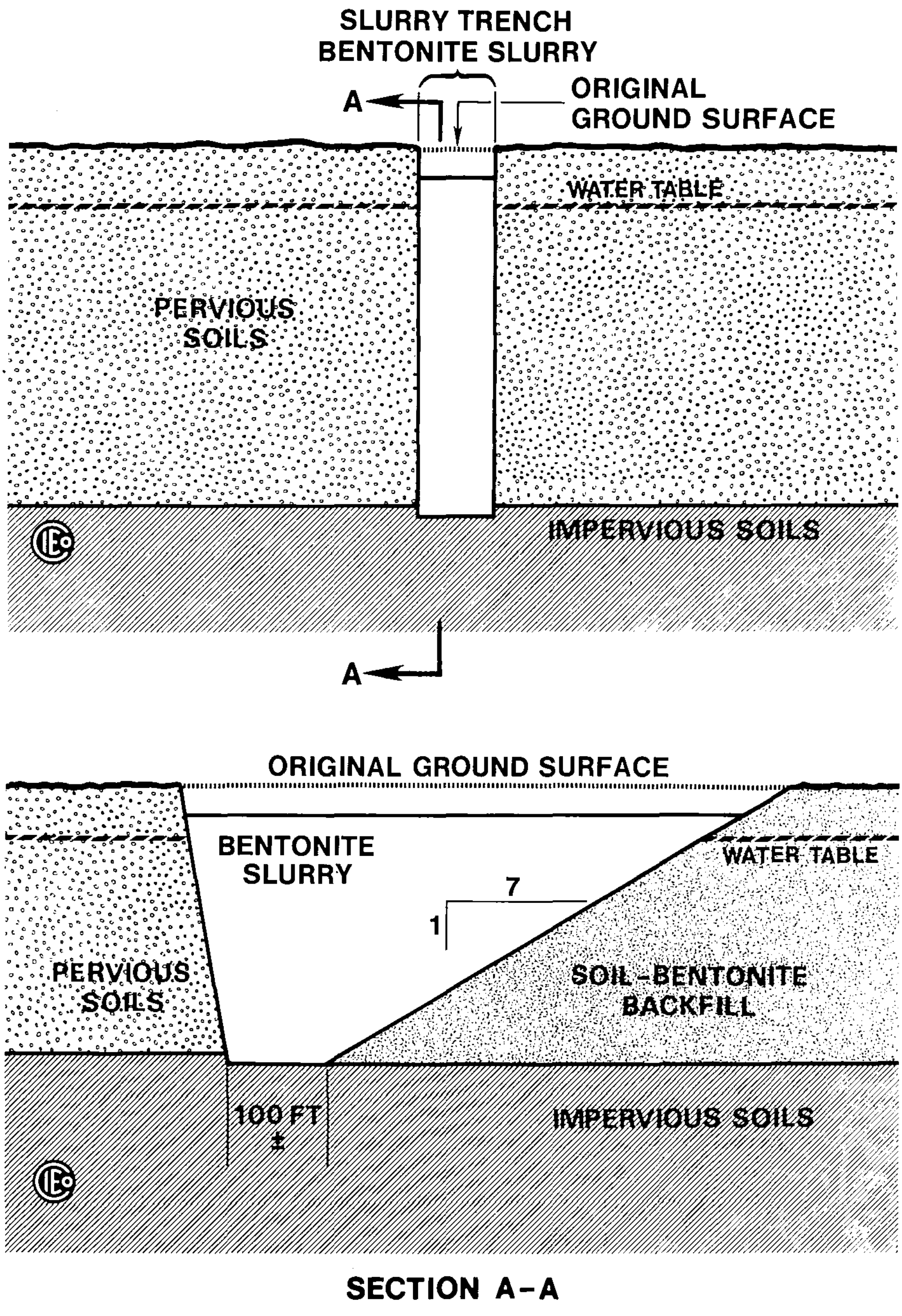


Figure 4. Slurry trench with bentonite slurry

Freezing has been used successfully for many years to stabilize ground for the sinking of mine shafts and to control ground water. This highly specialized procedure requires design, installation and operation by experts in freezing techniques.

Chemical or cement grout is often used to provide an impervious wall in pervious soils and to seal fractured and jointed rock. This method is most effective and economical for water control in localized areas or in mine shaft operations. Extensive grouting may prove uneconomical in a large mining operation.

Wellpoint systems, slurry trenches, freezing and grouting methods, along with sumping systems, horizontal and vertical drains, sheet piling and logging, can be usable and practical procedures for mine water control. Many of these methods, however, are confined to zones of localized seepage, to unconsolidated sediments or for water control along diversion dams or channels or tailings dams (2).

WATER CONTROL SYSTEMS - DEEP WELLS

Installation of deep wells is the most common method for pre-drainage, and properly installed wells and pumps can provide effective water control. Homogenous and free-draining sediments, stratified permeable layers and fractured rock zones can be penetrated by wells from the surface or from working levels in the mine. If pressure relief is of prime importance, relatively few wells may be required. A successful system may include a combination of two or more water control methods, such as deep wells and sumping systems or slurry trenches and pressure relief wells.

Well drilling procedures have advanced from hand excavation methods used over 4,000 years ago to the efficient use of modern equipment. The advantages and disadvantages of current drilling methods are described in greater detail in other documents (3).

Reverse rotary drilling is advantageous in unconsolidated formations containing few boulders because it allows for large hole diameters of 24 to 36 inches. Gravel filters for stabilizing formations can be placed in the annular spaces around the well screens, which usually range from 6 to 16 inches in diameter. Bentonitic drilling muds or other drilling additives that tend to plug formations and gravel filters are not necessary in most cases.

Wells with diameters less than 16 inches are drilled by standard rotary methods, often with roller type rock bits. Bentonite, organic polymers or other additives are added to the drilling fluid to lubricate bits, remove cuttings from the hole, reduce fluid loss and prevent hole cavings; however, time to develop wells increases if these additives are necessary.

Air rotary drilling equipment is commonly used to drill water wells in consolidated materials. These drilling rigs use compressed air in lieu of drilling muds, and many rigs are equipped with conventional mud pumps and air compressors for drilling either unconsolidated or consolidated materials.

The water well industry employs air rotary drills equipped with the down-the-hole or pneumatic hammer. This equipment has a rapid rate of penetration because the method involves both rotary and percussion drilling procedures. Deep wells drilled by air are usually less than 10 inches in diameter as air requirements for large-diameter deep wells are excessive. The ground-water geologist may specify drilling of test wells by this method to measure water production during drilling.

Well design criteria must be carefully established. Well size and depth, casing and screen materials, screen length and slot size, gravel filter specifications, grouting and well development procedures must be determined.

Chemical and bacterial laboratory analyses of water sampled during pump testing should be studied during well design. Water may corrode casings and screens if improper materials are installed and if the water has a low pH or contains hydrogen sulphide, high total dissolved solids, chloride or excessive dissolved gases. Also, well plugging can result from carbonates, iron, manganese and bacteria. Well treatment is necessary to control incrustation, and well construction materials should withstand acidizing, chlorination and treatment with biocides and other chemicals. Stainless steel, plastic, monel or brass are used instead of iron or steel screens and casings to counter corrosion. A typical dewatering well is shown on Figure 5.

Severe abrasion from sand produced by wells can ruin pump impellers and bearings. Screen slot sizes and filter gradation must be specified for unconsolidated or poorly cemented sand formations. If bentonite muds are used, polyphosphates may be required to disperse clay particles. Pumping, jetting and surging methods are used for well development. Completed wells should be sterilized by chlorine compounds.

The geohydrologist and engineer can use information from pumping tests to determine the head and capacity requirements for selecting pumping equipment. A variety of pumps made of various alloys and engineered to meet diverse hydrologic conditions are available in the United States, and manufacturers' performance charts should be consulted prior to choosing pumping equipment. Vertical turbine or submersible pumps are selected for large dewatering projects, and irrigation turbine pump settings of 1000 feet are common in California's San Joaquin Valley.

Capital cost items that are included in the budget for a typical well dewatering system may include the following:

- Drilling costs
- Mud pit excavation
- Well casing
- Grouting
- Test pumping
- Surface casing
- Well screen
- Gravel filter
- Well development
- Fuel, oil and grease
- Power
- Labor, including supervision
- Mobilization and demobilization of equipment, including freight
- Cost of obtaining a water supply, including supply pump and hose
- Pumps and discharge pipe, including installation
- Front end loader, crane, welder, tools, light plant, air compressor and transportation
- Miscellaneous items including taxes, licenses and permits

DISCHARGE SYSTEM

Any large-scale dewatering program must be within the limitations imposed by government and private agencies. Discharging into streams in the area may be illegal or may not be feasible, and selection of alternative methods of water storage or aquifer augmentation may be necessary. These methods may be costly and subject to controls.

If water is impounded, the height and construction of the dam are subject to rigid governmental specifications. Land acquisition, pumping equipment, water lines, roads and construction costs and materials must be considered and budgeted. If water is potable or supports plant life, it may be disposed economically by supplying agriculture or industry with water from the mining operation.

Recharge wells, galleries, shafts, pits or basins can counter the effects of extensive lowering of the water table or can be used to dispose of water. Recharge or injection systems have been used effectively by cities and industry for waste disposal, aquifer recharge and water storage, to prevent salt water intrusion and for disposal of brines.

Injection wells or systems may become plugged due to one or more of the following physical and chemical factors (4):

- Air entrainment, a condition in which gas bubbles are trapped, may plug voids more effectively than silts and clays.
- High levels of suspended solids can plug recharge wells and galleries.
- Chemical changes can occur in water as it is withdrawn from an aquifer; minerals, including iron, may precipitate as a result of aeration.
- Iron or sulfate bacteria and other micro-organisms can be introduced into the aquifer or transmitted by the recharge water.
- Clay colloids may swell in the aquifer.
- Chemical reactions can occur between the ground water and the recharge water; insoluble products may precipitate.

Extensive geologic and hydrologic research of the area must be undertaken before injection or recharge is considered. Geologic structures, aquifers, areal seismicity and possible fracture gradients should be studied. Monitoring networks, bacteriology, the need for water treatment and potential sites and aquifers must be evaluated extensively; and the environmental and legal aspects of reinjection must be appraised. Ideally, recharge or injection systems should be recommended initially on an experimental basis or should be prescribed for areas where injection has proven effective and economical. The chemical, physical and biological quality of the native ground water and of the reinjected water should be monitored regularly at pumping, reinjection and observation well sites. A typical reinjection well is shown on Figure 5.

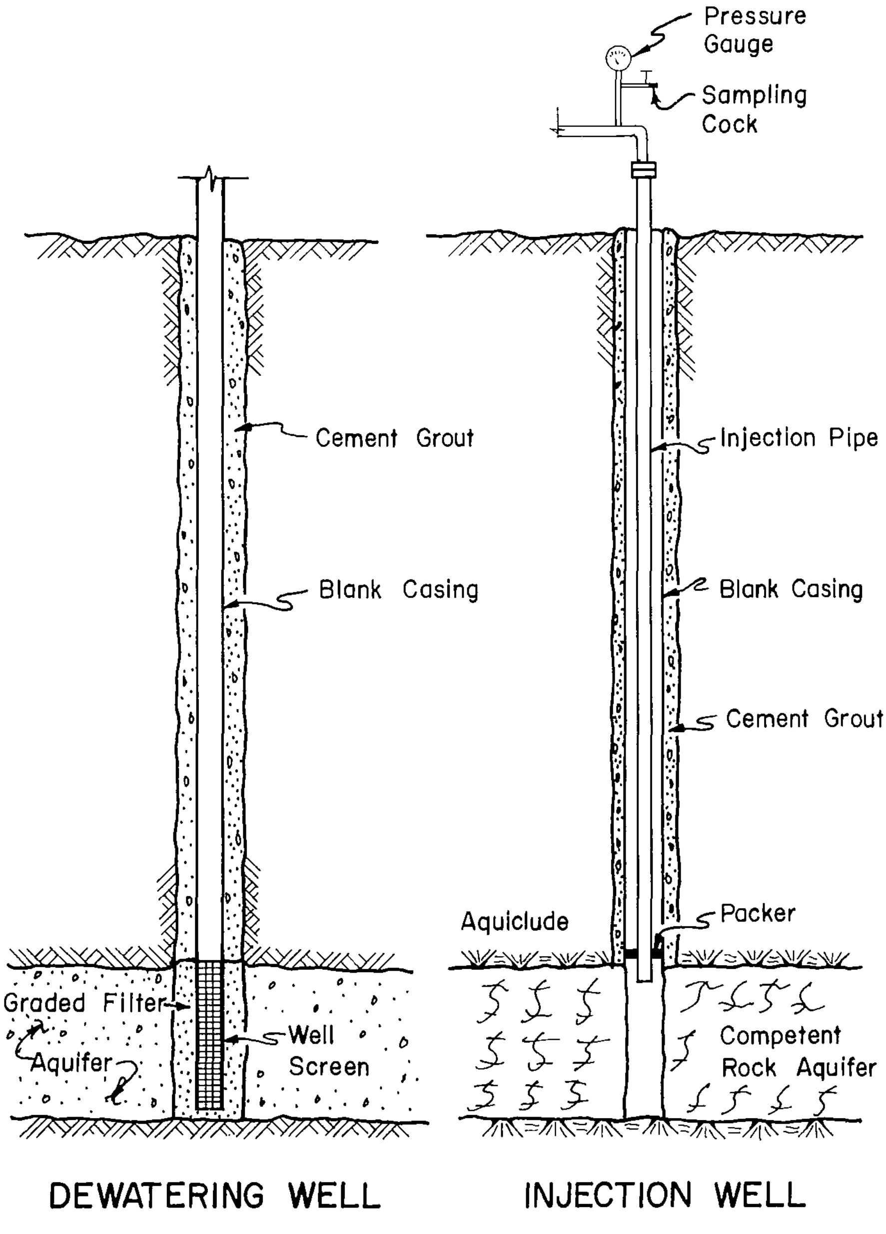


Figure 5. Typical dewatering and reinjection wells

OPERATION AND MAINTENANCE

Costs for operating and maintaining a system of dewatering wells can be budgeted and may include amounts for power, labor, equipment and replacement parts. These can be projected for the duration of mining activities.

Well treatment and rehabilitation costs should also be included because well screens, pumps and formations may be clogged by bacteria, iron, manganese and other elements. If regular inspections and maintenance are not performed, well production declines. Acidization, treatment with polyphosphates, biocides, surging, jetting and over-pumping methods may effectively rehabilitate the well. These procedures are more effective if they are performed by specialists during regular preventative maintenance programs. The ground-water geologist and engineer can devise procedures and suggest schedules for well and pump inspection based on water quality analyses, existing well records and manufacturers' recommendations.

CONCLUSION

Geologic and soil formations at the mine site will dictate the type and application of water control systems. The ground-water geologist can review existing data, prescribe testing procedures and specify methods for dewatering open cut or underground mines. These methods have their respective advantages, disadvantages and limitations; but, with an understanding of the geologic and hydrologic conditions at the mine site, a practical and feasible method of water control can be selected.

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