1

General Report on Mine Drainage

by C. O. Brawner,
Department of Mineral Engineering,
University of British Columbia,
Vancouver, British Columbia, Canada

INTRODUCTION

The requirements for effective control of water in mining are increasing as mines became deeper and larger and as environmental controls became more stringent.

The First International Symposium on Mine Drainage was organized to interrelate theory with practice and to emphasize current procedures being used to solve mine drainage problems. To illustrate this approach numerous case examples are included.

No extensive theoretical treatment has been included in the program since the Conference on Water in Mining in Granada Spain in August 1978 dealt with this aspect in considerable detail.

This program included sessions on investigation and evaluation of surface and subsurface water, drainage control for surface and underground mines and tailings disposal facilities, regulations and typical case examples.

INVESTIGATION AND EVALUATION

Measurements of groundwater conditions may be required on mining projects for the following purposes:

- to develop hydrogeochemical profiles to assist in locating

potential orebodies.
- to determine groundwater levels and groundwater pressure profiles with depth.
- to obtain water samples to assess background water quality levels prior and during exploration, during mining and after mining is complete.
- to establish the three dimensional flow pattern prior to mining.
- to determine the groundwater flow and pressures and their influence on stability in open pit mining.
- to determine deep groundwater flow volumes and pressures and assess this influence on stability in underground mining.
- to assess methods of controlling groundwater flow and stability.
- to monitor ground water seepage and potential contamination from leach dumps, wastes dumps and tailings dams.

The diversity of hydrogeological problems encountered in surface and underground mines is great. If the geology is well understood an evaluation of the hydrogeology may not be difficult. However extensive testing may be required. One of the most difficult conditions to evaluate acquifers or aquitards in most rock is where flow is through fractures, joints, faults, or other openings.

The control of water in mining is a multi team effort. Specialists should typically include the following:

Climatologist - seasonal and peak precipitation conditions
Hydrologist - surface water studies
Hydrogeologist - subsurface water studies
Mining Engineer - influence of water on mining and mine stability.
Drainage Engineer - dewatering studies
Hydraulic Engineer - pump and pipeline design
Reservoir Engineer - gas effect studies (if present)

The two most important factors to interrelate subsurface ground water studies are the influence of geology: faults, fractures, joints, solution cavities and the method and care of mining. Fracturing induced by the mining has major influence on permeability.

The primary tasks of this group are to determine the probabilities and volume of water inflow, evaluate the influence of the inflow and where necessary develop a preventative or control program.

The standard procedures have been generally to install a single piezometer in a number of boreholes in the general area of exploration, around the potential mine site. The cost of the piezometers is only a small fraction of cost of the drilling.

On most mining projects the total depth of mining is such that multi-geologic sequences and multi-aquifers exist. It is obvious to define the ground water profile and flow that the water pressure in each aquifer should be known. A single piezometer cannot possibly provide this information.

Patton has described a "Profiler" which can measure permeability at intervals during the drilling operation so that the best location for piezometers can be established.

Patton suggests that the least number of piezometers required for minimum coverage is 2n + m where n is number of aquifers present with appreciable thickness and m is the number of aquitards below the water tables. For adequate coverage he suggests 4 n + 2 m piezometers.

This density of piezometers can be achieved by (a) several piezometers in separate boreholes (b) conventional multiple piezometers installed in one drill hole or (c) multiple piezometers of the enclosed type in a single borehole. The latter technique is very recent (the Westbay MP System described by Patton). This technique has the advantage of reasonably rapid response, the calibration can be checked periodically, negative pore pressures can be measured, low cost per piezometer point, large number of possible reading points, reduced scheduling problems and capability to obtain water quality samples. The major disadvantage has been the increasing complication of installing many seals. This has recently been overcome with the development of multiple casing packers.

In numerous instances piezometers are necessary when the rock is not competent. The use of special bio-degradeable muds assist in the advancement of the borehole, allow installation of the piezometer without seriously affecting permeability near the borehole. Water samples should be taken during the early part of any investigation to establish the base line water quality parameters. Rouse emphasizes the importance of obtaining representative samples. To ensure this, samples should not be taken until a constant value of pH and conductivity occurs.

Regional long term climatic conditions have a major influence on ground water balance. In hot dry climates the ground water flow may be upward due to the high evaporation influence. In heavy rainfall areas the net flow is obviously downward.

For deep underground mining Halepaska suggests the analyses make use of the reduction in the mine plan geometry to "effective radius". He suggests three methods:

Method 1 entails approximation of the mine plan as a well and uses the constant head Jacob-Lowman equation to calculate flow rates. This method generally yields a pumpage rate that is too high.

For Method 2, the technique of interfering wells is utilized, wherein each drift face of the proposed mine plan is considered to be a well. The cumulative production of the drift "wells", which typically are mutually interfering, is an approximation of the expected production from the mine.

For Method 3, the technique of confined-unconfined theory and the Jacob-Lowman theory are combined to calculate the required pumpage. The effective radius in this method is chosen as the radius at which the aquifer of interest goes from the confined to the unconfined state. Therefore, the concept focuses on fluid entering the unconfined state from elastic yield of the confined state.

Permeability changes in caving ground can be of major importance when the mine is located near or under water courses or bodies of water. Recent full scale by Whittaker on two longwall coal projects indicates that appreciable change in the insitu permeability occurs between the face and 40 meters behind the face and above the extraction horizon. The increase in the permeability is a function of the natural rock jointing and bedding and the thickness of the seam being extracted. Beyond about 40 meters behind the face the permeability begins to reduce due to reconsolidation.

The increase in permeability during the test program ranged from about 40 to 80 times the undisturbed permeability.

Venburg describes the practical requirements of geohydrological evaluations for mining projects with emphasis on pre-drainage. Considerable emphasis is placed on obtaining preliminary data from local sources such as climatological offices, water resources branches, drilling companies, water well developers etc.

With minimal additional expense, exploratory boring can be used to show depths of unconsolidated sediments, classification and lithology of bedrock, location and orientation of discontinuities, zones of caving or heavy mud or water loss and artesian water conditions. The use of geophysical logging is strongly recommended. These should include temperature, flow meter and tracer logs.

Chemical and bacterial analyses of water encountered should be tested for background data, well and dewatering equipment selection and environmental consideration.

Detailed consideration must be given to cost assessments for pre-drainage schemes. Vensburg lists items for a typical well de-watering system:

Drilling costs	Surface casing
Mud pit excavation	Well screen
Well casing	Gravel filter
Grouting	Well development
Test pumping	Fuel, oil and grease

Power
Labor, including supervision
Mobilization and demolization 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.

To evaluate mine ground water problems it is usually necessary to determine the following properties or conditions.

(a) Acquifer Coefficients - Transmissivity and Coefficient of Storage
(b) Boundary Conditions
(c) Local water budget or sources of recharge.

Slayback describes several case examples which illustrate practical investigational programs and interpretation of these programs to solve unusual groundwater conditions.

A typical field test program was used for the Dundee Cement Company to determine whether a sand acquifer might provide a conduit for water from the Mississippi River 4,000 feet away from a planned limestone quarry. A test production well and a pattern of observation wells were drilled between the proposed quarry and the River. No significant recharge was indicated by the plots of the test data. This low cost program indicated that recharge from the Mississippi was manageable at low cost.

A major concern at the Pine Point Mine in N.W.T., Canada owned by Cominco was recognition that the dewatering combined a transition from a confined or artesion aquifer to a water table aquifer. Slayback indicates that in his experience no other single phenomena in hydrogeology has caused more problems in groundwater evaluation. This case results in differences of more than one order of magnitude between the artesian and water-table storage coefficients. This can lead to delay time in pumping between the artesian condition and water table condition which can be devastating. If the delay period were to extend through three log cycles a delay period from 10 to 10,000 days or 27 years could occur. The solution at Pine Point was to promote sufficient pump capacity to drive through the delay barrier early.

In the Athabasca tar sands, conditions have been found to vary greatly. At the Great Canadian Oil Sands project there are no aquifer problems and no ground water control system. On the Syncrude project up to three aquifers were encountered below the feed zone. Aquifer pressures must be dewatered to ensure the water pressure does not cause the mine floor to heave or to pipe where the aquifer sand is directly below the feed. Extensive field tests were performed. The testing & evaluation was complicated by the evolution of dissolved gas, creating a four phase hydrocarbon system. The analysis made use of an oil-reservoir computer model to predict depressurization.

The depressurization program at Syncrude involves over 500 depressurization wells.

At the Alsands project a basal aquifer zone exists which contains clean coarse sand but with no dissolved gas present. As a result more water is likely to be discharged with fewer wells than at Syncrude.

Loofbourrow quotes pumping costs for an efficient design pumping system to range generally from $0.20 to $0.30 per million foot gallons. The key to economy is to reduce the pumping energy. Indirect costs must be considered due to increased production, maintenance and increased transportation costs.

The most effective planning to control water is one that is instituted during the mine design stage. Special consideration should be given to pre-mine dewatering and in underground mines to mining from the bottom up. This planning should also consider normal methods of seepage reduction, such as the use of clay or slimes grouts or plugging with chemical or bacterial precipitates. In addition the planning should include an ongoing program to drill ahead of the working levels, maintain up to date plots of water data and to have repair equipment and tools immediately available.

Hofedank, Consulting Engineer from West Germany states that no other water problem, aside from those having to do with the drainage of mines, needs such a large number of different sciences for its solution. He outlines the programs recommended to evaluate the influence of groundwater, surface water, precipitation and environmental impact on the mine.

He reviews an open pit coal project where two aquifers separated by a clay seam exist. Leakage appears from the lower aquifer when the upper aquifer is pumped. After several years the rate of leakage reduced. The use of Boulton's concepts of a semi-confined aquifer may explain decreasing leakage taking into account the difference in short and long term dynamics. The author would note that as depressurization of the upper aquifer progresses a substantial increase in effective pressure occurs which could cause consolidation of the drainage layers, reduce permeability and leakage.

Careful planning and meticulous field work are required to successfully assess mine dewatering problems. However, it must be recognized that comprehensive programs do not eliminate the risk of unforseen anomalous conditions. Properly designed groundwater investigations will reduce the probability of encountering unforseen conditions to reasonable limits.

DRAINAGE IN OPEN PIT MINES

Surface and subsurface water creates a wide range of problems on surface mine projects. The most important of these include the following:

Surface water-

(a) Pit slope, haul road and drainage ditch erosion.
(b) Haul road softening, frost heave in winter.
(c) Erosion fan deposition.

(d) Water pressure build-up in tension cracks.
(e) Glaciation in winter.

Subsurface water-

(a) Reduction of soil and rock shear strength.
(b) Pit slope instability which requires flatter slopes.
(c) Increase in blasting costs.
(d) Pit slope and floor bottom heave.
(e) Slope seepage and associated erosion and glaciation.

Procedures to control surface drainage are simple and well understood. Control of subsurface drainage has only recently been recognized on many projects as a serious and potentially costly problem. The case examples in this symposium have been selected to provide a cross section of typical problems as well as control and stabilization procedures. Table 1 provides a summary of these examples.

Where the open pit mine extends below the water table the least expensive method of slope drainage usually involves horizontal drains. Specialized equipment and procedures can install drains up to 300-400 feet long. Greater lengths are usually not required. The drains should be installed at an entry gradient of about 5 per cent. If the drain holes collapse, 1 to 2 inch plastic pipe should be installed. The outer sections of the pipe above the water table should not be perforated. The inner lengths should have the perforations down to allow the water in the pipe.

To reduce set up costs and collection costs, 4 to 6 drains can be angled and from one location.

If the rate of drilling is too fast the drill rod will climb above the water table and the program will be ineffective. If the rate of drilling is slow the drain gradient will drop below horizontal. This is not serious as the drain will operate under pressure. For long term operation the drains must be flushed occasionally. The amount of water which flows from the drains is not a good measure of the effectiveness. Piezometers should always be installed to monitor the drop in the water pressures.

Perimeter and in pit wells have been used on many projects to lower the water table. In situ pumping and permeability tests are a recommended prerequisite to the design of the well and pumping system. One frequent benefit of the well system, provided the water level is lowered below all mining levels, is that less expensive explosive can be used. Numerous projects have reported that blasting costs

TABLE 1 - SUMMARY OF OPEN PIT STABILIZATION BY DRAINAGE

Location	Problem	Solution
Cyprus Anvil Mine Faro, Yukon	Surface inflow from Faro Creek causing erosion in summer and glaciation in winter. Subsurface seepage into the mine causing unstable pit slopes, increased blasting costs, glaciation on slopes, increased haul and maintenance, ice build up in truck boxes and shovel buckets. Overly wet ore required stockpiling for drainage. Excess stockpile time lead to oxidation.	Diverted creek and placed water proof lining along high permeability zones. Six thousand feet of horizontal drains were installed with 1.5 inch O.D. slotted plastic pipe. Average drawdown ranged from 7-14 feet. Daily volumes of water averages about 100,000 gal./day. Collector sump in bedrock constructed with pumps and 6-8 inch polyethylene pipes used to remove water from pit. A steamer is used to thaw frozen pipelines.
Pine Point Mines Pine Point, N.W.T.	Extensive seepage into numerous open pits cause difficult and hazardous mining conditions and high explosives costs. Seepage is from acquifers that continuously recharge from mountains to the south. Sinkholes are frequently encountered in the open pit areas.	Installation of deep wells (400-500 ft.) and pumps around the perimeter of the open pits. Design based on pumping tests and analysis methods of Cooper and Jacob and of Thiem. Well design allows for 10 percent loss due to well collapse and 80 per cent effective pumping rate. Well locations selected away from sinkholes. Wells 14-3/4 inch diameter with no casing or screens at depth. Dewatering costs represent 16 per cent of direct mining costs. Volume is 60 million gallons/day.
Bougainville Copper Mine Papua and New Guinea	Very high rainfall region combined with severe earthquake potential would require expensive flat pit slopes to maintain stability unless the water pressures in the rock slopes could be minimized. The rock contained high fracture frequency with a majority of steeply dipping joints.	Development of drainage adits below the orebody developed an extensive zone of depressurization near the adits. Flows increased when semi impervious zones were intersected, i.e. clay filled faults. Field permeability values ranged from 10^{-2} to 10^{-5} cm/sec.
Twin Buttes Mine Arizona	Two large slide zones developed in the pit over a vertical depth of some 600 feet. The movement was largely influenced by high water pressures in the slope. These pressures varied due to numerous clay filled fault and shears in the slope.	An underground adit 3400 feet long was mined and 25,500 feet of drain-holes was drilled from the edit to increase the effective drain radius. PVC slotted pipe was installed in the drain holes. The water pressure in monitoring piezometers dropped an average of 67 percent. The overall permeability averaged 10^{-6} cm/sec. If a risk factor of 12 percent is acceptable the average slope angle can be increased from 27° to 35°.

TABLE 1 (con't)

Location	Problem	Solution
Jeffrey Mine Canadian Johns Manville Quebec	Granular soils overlying the bedrock provide a major ground water supply to develop water pressures in the pit slopes. This lead to a major slide involving about 20,000,000 tons of rock. The slide intersected the ore skipway and came within 75 feet of the primary crusher building. The instability was aggravated by leakage of water from town service mains and mining at the toe of the slope. Considerable water infiltrated tension cracks.	Horizontal drains were installed from the skipway bridge area. Drain holes were drilled upward from a horizontal adit to intersect the failure zone. The adit was used for previous mining and exploration. Tension cracks were filled in. Horizontal drains were installed into the granular layers in the upper overburden slopes to reduce recharge into the rock. Surface interception and diversion ditches were developed.
Iron Ore Company Quebec	High precipitation, very cold winter climate, variable strength rock with considerable folding and faulting led to numerous slope stability problems. The high water table resulted in a high moisture content of the ore and very wet haulage access with high maintenance of roads and trucks.	Surface drainage was installed around the pit to control surface water. 47 in pit and perimeter wells (15-inch diameter) have been installed to lower the water table. Special precautions are required to protect the pipelines from freezing. Problems still exist with operating delays due to blasting, relocation of pipe lines and inspection of pumps.
Konin and Turow Mines Poland	A shallow water table existed where 40 to 150 meters of overburden required removal to expose the coal measures. Depressurization of the overburden, coal and underlying strata was required to maintain slope stability and prevent pit bottom heave.	The zone proposed for initial mining was dewatered by deep wells and drainage galleries in the coal horizon. As mining progresses wells are installed ahead of mining and from the galleries. These latter wells drain by gravity as pressure relief wells. Horizontal drains are installed from the pit slopes. Dewatering trenches and pumping stations are developed in the pit bottom. Pumping systems are designed for 120 per cent capacity.

TABLE 1 (con't)

Location	Problem	Solution
Rhenish Lignite Mining District West Germany	Water bearing sand zones exist between multi layered coal horizons. The lignite extends to a depth of over 600 meters. Some major faults exist in the deposits which usually act as barriers to ground water flow. The topwall aquifers in the pit area must be completely dewatered and the footwall aquifers sufficiently depressurized to maintain stability and control heave. Continued monitoring of groundwater is essential each year. About 82,000 feet of monitoring holes are drilled. Local depressurization of sand pockets is required ahead of the dredgers to control slope blowouts.	Groundwater budgets to evaluate parameters, yields and boundary conditions are developed. Design diagrams based on Dupuit-Thiem and Sichardt are used for design of gravel packed dewatering wells. One and two dimensional numerical aquifer models have been developed. Because of high transmissivities and large areal extent of the acquifer, gravity discharge into vertical tube wells is used with high capacity submersible motor pumps to lift the inflow. Well depths extend to 1650 feet. Drilling diameters range from 48 to 71 inches with well screens and inner casings of 12 to 32 inches. Reverse circulation air injection drilling is used. Vacuum dewatering is used to lower the water table ahead of excavators in the slopes in areas of low hydraulic conductivity.
Morwell Open Cut Brown Coal Project. Australia	Two water bearing aquifers are located below a coal seam up to 400 ft. thick. The water pressure below the base of the pit must be reduced to control pit bottom heave and development of zone of tension near the toe of the pit batters. High water pressures in the slopes partially induced by surface watering to minimize fire potential must be reduced to reduce risk of batter movement. Water pressure reduction to improve stability has increased the effective vertical stress in the coal which is slightly compressible. This has resulted in differential settlement of up to 5 feet near the open cut and some settlement up to 10 miles distance.	Wells have been developed into both aquifers to reduce the water pressure to control pit bottom heave and horizontal movement at the toe of the batters. Piezometers have been installed as control installations. Control elevations have been established at each piezometer to assist in determining the required pumping rates. To minimize differential settlement near the open cut, depressurization wells can be located to develop uniform levels of vertical effective stress. The stability of the batters has been maintained by extensive installation of horizontal drains up to 600 ft. long.

TABLE 1 (con't)

Location	Problem	Solution
Swift Agricultural Chemicals Phosphate Mine, Florida	The major problems to maximize phosphate recovery are pit slope stability, ground-water control and influence on spoil volume to matrix recovery. In cohesive soil the existence of water pressure increases the potential for sliding. In cohesionless soil the slopes tend to flow. Surface water in the pit base can cover the base and make spotting of the bucket for efficient matrix recovery impossible.	Drilling and aquifer water pressure testing revealed a deep aquifer in the Avon Park formation (approx. 700 ft. below surface) had a lower piezometric top elevation then the shallow Hawthorne aquifer immediately below the matrix to be excavated. Connector wells joining the surface sediments and Hawthorne to the deeper Avon Park formation have resulted in a vertical flow by gravity reducing the water levels in the upper formations some 42 feet. This has allowed prestripping with scrapers, steeper pit slopes and increased matrix recovery.
Western Phosphate Field, Idaho	Water resources within the phosphate field exist in complex ground water and surface flow systems. The water has the potential to hamper mining operations by pit flooding and pit and waste dump stability. It is desireable to be able to predict in advance of mining the imput of water on the mine program.	Extensive use of stream flow gain - loss monitoring indicated that certain geologic formations support ground water flow systems while others did not. Structural geologic features have a significant effect on the development of ground water and surface water flow systems. Major surface drainages are generally parallel to fold or fault structures. Geologic sections for various combinations of formation dip, smooth or broken ridges, valley or ridge location were developed to allow a prediction of ground water systems at proposed mine sites.

have been reduced by over $500,000 annually following dewatering.

In deep coal mines and strip mines, water pressures below the base of the pit can cause heave of the pit bottom. The installation of pressure relief wells commonly used to control water pressures below dams is very effective. Usually vertical holes can be drilled with available mine equipment. The depth depends on the depth of the aquifer and weight of the rock. In many instances free flowing wells will be adequate. Where considerable depth or large flows are required to depressurize, pumping wells are required.

Drainage adits have been installed at a number of mines. They are expensive. Provided they are located in the most suitable location and agumented with drain holes from the adit they can be very effective. The drain holes should be directed to intersect as many structural discontinuities as practical. The effectiveness of the adit system can be significantly improved by installing twin bulkheads and a vacuum system to put the adit under negative pressure.

Lowering of the water table will induce weathering in the dewatering zone. The influence of this on the mineralogy and mineral processing should be assessed.

The type of dewatering and design and location of the dewatering system is very site specific. The maximum cost effective benefit can only be achieved when the installation is preceeded by a comprehensive field test program.

DRAINAGE IN UNDERGROUND MINES

The costs of dewatering are increasing due to inflation and mine expansion. Improved knowledge and efficiency to reduce the risk of sudden water inflows, to improve stability and to reduce dewatering and mining costs is a goal at many underground operations.

The most important initial program is to determine the general geologic stratigraphy, water pressure profile and permeability. This program should always be an order of magnitude investigation. The primary purpose being to determine the conditions and parameters which will have a significant bearing on the project. Thousands of dollars and much time has been wasted on many projects in the past in attempting to develop extensive data for factors that are relatively unimportant. By recognizing the important factors there is less likelihood of hydrogeologic surprises. Brown emphasizes that since the accuracy of geologic and hydrologic data is usually low it is inappropriate to use highly sophisticated analytical methods to evaluate conditions and to develop design systems.

Most groundwater problems can be approximated using Darcy's Law, the well equation modified from the Theis equation and the Steady State Leaky Aquifer equation.

Uncertainty of the results relates to inaccuracies of the idealized hydrological model, the analytical evaluations performed by the model and the measurement of parameters for the model.

Once the type and magnitude of the problem is defined the potential solutions to reduce or control the problem can be developed. Most of these programs comprise procedures to reduce the inflow of water. The primary reason being to reduce pumping energy which usually will be required throughout the entire year.

To control ground water during shaft sinking it should be recognized that the problem is short term, until the lining is complete.

It is recommended that a drill hole always be drilled at the shaft location. In addition to determining geologic factors important to rock stability, excavation methods and lining requirements, rock permeability and water pressure head profiles can be assessed.

In small inflows, sumping and pumping from within the shaft will normally be adequate. For larger flows procedures to reduce inflow will usually be necessary.

Typical Methods include:
(a) Installation of dewatering wells around the shaft
(b) Grouting of pervious rock zones
(c) Freezing ahead of shaft sinking

Where several aquifers exist it will be expensive to perform separate pumping tests. One procedure to reduce this cost described by Greenslade involves drilling a well to the lowermost aquifer, installing casing and cement the well to the surface. The well is pump tested. Overlying formations are tested by installing a wire line bridge plug below each zone and perforating the casing over the entire aquifer thickness. Following pumping of the perforated zone a second wireline zone is set below the next overlying zone and the perforating pumping sequences repeated for each zone going up the hole.

The effects of water in underground mining are many. They include:
(a) Large scale rapid inflow can halt production.
(b) Corrosion of steel ropes and members is increased.
(c) Timber rot is increased by wetting and drying.
(d) Machine and labor productivity is reduced.
(e) Maintenance costs are increased.
(f) The cohesive strength of many types of rocks is reduced.
(g) The migration and contamination or rock fines is increased.
(h) Weak ground is washed out of rock discontinuities.
(i) More expensive explosives are required.

Water associated factors outside the mine include:
(a) Moisture in the ore increases the costs of handling, shipping and treatment.
(b) Dewatering may induce weathering and reduce mineral recovery.
(c) Drawdown in and around the mine may deplete regional water supplies.
(d) Dewatering may lead to surface subsidence, or collapse.
(e) Effluent may reduce the quality of surface water.

Loofborouw suggests two methods should be considered where dewatering of underground mines will reduce overall costs. Mining up from the bottom of the orebody will greatly reduce pumping requirements at sites where rock becomes less pervious with depth. There would also be a postponement in the time and rate of depressurization of the near surface water table. The mined and lower area of the mine can be used as a storage reservoir during major inflow or as a settling & clarification horizon.

In fractured and jointed rock, fine grained clay grouts may be effective in reducing permeability. This fine grout is usually quite effective in sand and sandstone. Pregrouting ahead of shaft sinking has proven to be effective on projects in South Africa.

Areas of promising research include chemical and bacterialogical treatment which develop precipitates and reduce permeability.

Methods to control the flow of water include:
(a) Divert or intercept surface water.
(b) Dewater prior to mining.
(c) Minimize water flow by selective shaft location, mining from the bottom up or leaching insitu (where practical)
(d) Develop impervious linings around shafts.
(e) Reduce the permeability of the rock mass.
(f) Protect the work area from inflow. Plug alldrillholes.
(g) Over design the dewatering and pumping system. Maintain an adequate supply of stabilization and control equipment available and operational.

Trexler describes a program to monitor underground inflow at the Bunker Hill Mine near Kellogg, Idaho. The mine has been in operation since 1885 and has many drill holes, drifts, stopes, shafts and one major caving area. Inflow into the mine is controlled by five conditions -
(a) natural ground water seepage
(b) geological discontinuities
(c) diamond drill holes
(d) underground excavations
(e) injected potable and sand fill water.
Some of this water flows through pyrite rich zones and results in production of acid discharge with a pH from 3.3 to 4.7.

Flow studies revealed there was a low time lag, generally less than 24 hours between changes in surface creek flows and discharge volumes. Rhodamine WT dye studies also revealed a short time lag.

The surface recharge contributes to several problems-
(a) additional dewatering.
(b) additional discharge treatment.
(c) wet mining environment.
(d) potential water to flush acid producing water.
Programs to reduce the water inflow included:
(a) relocation of raises and construction of cut-off walls
(b) installation of pipes & flume to bypass water around pervious areas.
(c) Capping and valving drill holes.
(d) Increasing the slurry density for sand backfill.
This example illustrates the importance of site specific studies and design.

A dramatic example of a major water problem is described by Cox for the Friedensville mine. The normal dewatering program discharged about 26,500 gpm. A sudden major inflow of 35,000 gpm developed in one of the stopes. Immediate steps were instituted to establish maximum pumping plant efficiencies. Fortunately the total dewatering capacity was available so the mine was not flooded.

To control the free flow a series of concrete plugs were developed and finally a 30 inch pipe line was installed to carry the water to a pump station.

This example illustrates the desireability for excess pumping capacity in the event that abnormal water flow is encountered.

The selection of the proper pumping system is one of the most important decisions in underground mine design.

Schiele presents a strong case for the use of water filled submersible pumps for depressurization and mine dewatering.

The advantages given are:

(a) Water is an excellent conductor of heat.
(b) Will not fail if leakage develops.
(c) Will operate at a high ambient temperature.
(d) Naturally firedamp proof.
(e) Instant startup characteristics.

To control the ingress of dirt common on mining projects a special system has been developed. The rotor is guided in two radial bearings. The thrust bearing plate is mounted at the lower end of the rotor shaft, and it rotates against a ring of tilting pads which are stationary in the peripheral direction, but which are otherwise free to tilt in all directions.

In underground mines submersible pumps are used in sumps. The trend is toward pumping from one deep location with one pump.

In large pumps operating at high flow rates the double suction design is recommended to balance the hydraulic thrust on the thrust bearing.

Pump sizes up to 1800 KW have been used for several years with heads up to 3300 feet and flow rates in excess of 13200 USGM. In the Rhineland Coal fields 2500 submersible pumps are in use with diameters up to 32 inches and depths to 1700 feet.

For the most efficient design of well dewatering systems Archer recommends the well diameter should not be established until the volume and head of water is reasonably well known.

It is very important to determine the quality of the water to assess if corrosion will be a problem. Special attention to top quality gate and check values is imperative. Flow meters are recommended for all installations so that changes in flow characteristics or pumping problems can be quickly recognized.

SEEPAGE CONTROL FOR WASTE DISPOSAL

Extensive experience is available internationally in the design and construction of earth dams for hydro electric development, commercial and residential water supply and for irrigation purposes. The control of seepage has essentially been for the purpose of maintaining stability. A secondary reason is to reduce storage losses. Seepage control, for these reasons is being incorporated in most of the dams developed for tailings storage. The tailings however usually contain materials introduced in the extraction process which in some instances could lead to some degree of contamination of seepage waters.

When design programs and regulations are developed it should realistically be recognized that it is practically and economically impossible to completely stop all contaminants from being released into the seepage system. A reasonable approach is to require that any contaminants in the seepage water should be controlled by design and location so that regulatory maximum allowable criteria are met with a specified distance from the tailings storage area.

A common assumption made by many people is that the contamination is carried as far as the seepage water flows. It should be recognized that transport of contaminants is a complex function of parameters such as conductivity and dispersivity of the underlying soil and rock strata, hydraulic gradients, ion exchange and buffering capacity of subsurface materials and amounts of precipitation and evaporation. Soil and rock is a better natural filter than usually realized. In general, natural subsoil conditions will tend to remove many heavy metals and radionuclides such as radium and thorium from the tailings seep.

Precipitation will occur primarily as a result of chemical precipitation and sorption processes.* Some heavy trace metals such as selenium, arsenic and molybdenum may form ions which behave similarly to anion contaminants such as sulphates which do not tend to be removed by sorption.

Taylor and Antommaria present an excellent case example where the subsurface seepage courses below a tailings impoundment area were monitored at varying distances. The tailings disposal area had been in operation for about 20 years. The following elements were evaluated:

(a) Uranium
(b) Thorium
(c) Lead - 210
(d) Radium - 226
(e) Polanium - 210

The results of the monitoring program revealed that at short distances below the pond the contaminant concentrations were all within permissible limits. At this site it was concluded that isolation barriers would do little to decrease the detrimental effect of tailings disposal other than to reduce the distance of effects away from the pond.

An important factor which influences contaminant movement is soil alkalinity. Isolation barriers or precipitation media should be considered for non-alkaline soil conditions.

Schubert describes a monitoring program to assess groundwater contamination, around a coal refuse pile that had been unreclaimed for over 50 years. The natural soil conditions at the site comprised glacial till with low permeability. Twenty seven wells were installed at the site to monitor the ground water. Thirteen existing residential wells were also monitored near the pile.

Based on the monitoring program the shallow ground water quality had not been significantly affected at distances greater than 200 meters from the refuse pile. Surface water flowing off the pile and onto the adjacent surface tends to infiltrate and recharge the ground water. This could be the source of some of the local contamination.

* "Generic Environmental Impact Statement on Uranium Milling" (draft) U.S. Nuclear Regulatory Commission, NUREG-0511, Office of Nuclear Material Safety and Safeguards. Washington, D.C., April, 1979.

Control of this surface flow would likely have reduced subsurface contamination. The author concluded that by developing a better understanding of the reactions of contaminants with the soils it should be possible to develop disposal sites with adequate "absorption" capacity to adequately retard contaminant migration.

One of the most effective research programs that can be undertaken in North America would be to measure contaminant movement profiles around waste disposal areas on as many projects at as many locations as possible for as many minerals and industrial wastes as possible.

Considerable time and money has been spent on evaluating seepage flow paths, volumes and areal extent. It is important to recognize that it is the contaminant flow that is the most critical environmental concern. What concern is it if the seepage travels 20 miles but the contaminants are carried along that seepage path only 200-500 feet.

Where there is a likelihood that tailings seepage could contaminate ground water supplies several procedures to reduce this seepage are available.

The use of natural clay liners is the most common procedure and the procedure with which we have the most long term experience. The rate of seepage can be reduced to 10^{-6} to 10^{-8}cm per sec. At these low rates, dilution in the ground water system generally reduces contaminant levels to meet regulatory requirements. In addition base exchange, chemical reaction etc. in the clay reduces contaminant movement.

Recently the use of synthetic liners has become widespread. Provided the problems of seam separation and gas bubble breakage can be overcome liners provide positive seepage control. In very dry areas where the tailings disposal system will dry out the long term disintegration of the liner is not important. However in wetter climates, 15 to 20 inches of annual rainfall or more, the tailings ponds will not completely dry out and disintegration of the membrane could result in a large scale release at a later and unexpected date. In this condition it is suggested it would be better to use a synthetic semi pervious membrane to allow a very slow continued release from day one.

There is some experience to show that peat and glass fiber filters will act as absorption media to reduce contaminant movement. Further research is recommended in this area. If the benefit is significant one or more trenches could be cut across the zone of seepage path and the trench filled with the absorbing media; the slurry trench concept. An alternative procedure would be to drill vertical large diameter holes and fill them with purifying, neutralizing or absorbing materials. In the case of acid water, fill the holes with crushed limestone and for radionuclides, use barium chloride.

In many cases in the past regulatory staff have required contaminant values to meet regulations starting at the toe of the dam. This is not realistic. The area below the disposal area for 1500 to 2000 feet should be considered as part of the decontamination control area. Installation of special programs near the toe of the dam are much easier and less expensive than above or through the dam.

Whatever programs are selected, it is essential that the original background levels of water, soil and rock chemistry be determined before any mining or construction proceeds. There will be instances where background levels will exceed maximum regulatory levels. The mine should not be responsible to reduce these values to legal limits.

Smith has emphasized that most failures of tailings have occurred as a result of inadequate consideration of the influence of surface and subsurface water. The importance of seepage control and methods for this control are summarized effectively by Klohn.

The excellent case examples by Davis and Robinson illustrate a key concern that all investigation design, construction and regulatory programs must be site specific.