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SURFACE MINE DRAINAGE USING LARGE DIAMETER PUMPWELLS

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INTRODUCTION

Ground water problems in surface mining have increased in size and scope over the past three decades as the economic depth of excavation has increased and as mines have increased in physical size to achieve economies of scale. Surface mines in stratified deposits have reached 300 m in depth, depths of up to 600 m are projected and pumping rates in excess of 70 tonnes of water per tonne of mineral extracted are not uncommon. The design and operation of pumping systems for such duties have a significant effect on capital and operating costs as well as security and their management must be integrated into normal mining operations to avoid interference with mineral production.

Further areas of concern are that the effects of pumping may extend well beyond the boundaries of mining and the regional effects have to be accounted for in water management planning. Water quality is an important aspect and pollution due to mine water discharge into the local streams and rivers of the natural drainage systems, together with the control measures involved, require serious study.

There is no shortage of literature concerning the theoretical properties of aquifers[1 2 3 4 5 6] and the authors have used these authoritive works in planning the several mine groundwater control systems with which they have been associated. There is also no shortage of practical literature concerning water-well construction, pump selection and operation, etc. There is however a paucity of literature concerning the design and operation of surface mine pumpwell systems, particularly for large tonnage mines in stratified deposits. In general the major problems are:

1. Mining above a confined aquifer.

2. Mining within an unconfined aquifer.

GROUND WATER PROBLEMS IN SURFACE MINING

Ground water hazards

These are basically:

- mine floor "heave" and subsequent flooding dangers, due to underlying aquifers.
- "piping" via unsealed boreholes, fissures, cracks and other small area communication channels.
- increased risk of highwall and spoil slope failures.

Detrimental effects of wet operations

Apart from the obvious hazards of flooding and bench failure, excessive water can also cause serious operational delays and increased mining costs e.g.:

- Maintenance costs are increased due to heavy loading conditions with increased wear, and loss of lubricants in propel gear.
- Slope stability is reduced and risk of bench failure is increased with resultant increased re-handling and loss of routine in production operations.
- High moisture content results in increased unit weight of material to be excavated and transported increasing energy costs.
- Haul roads are difficult to maintain and truck rolling resistance is increased.
- ANFO explosives are de-sensitised in wet blast holes and special water proof packing or water resistant explosives are needed with consequent increases in blasting costs.
- Silting of drainage channels and mining areas.
- In cold climates water freezes to some depth and can affect digging performance and blasting costs.

There is no universal method of creating dry mining conditions. Advantage has to be taken of such natural drainage features that may be present to optimise drainage conditions, e.g. permeable layers, fracture systems etc. Where soft haul road conditions exist, any material within the overburden suitable for haul road construction should be selectively mined and stacked for construction use.

At the Bukit Asam mine in South Sumatra a combination of a very wet climate with a high moisture, clay-rich overburden creates particularly difficult conditions for surface mining. The safe slope angle for overburden benching is as low as 15^{o} to 17^{o} which at a future mining depth of 150 meters makes for an excessively wide pit. The clay-rich overburden is difficult to excavate and transport because of stickiness during loading and discharge, and there is poor trafficability on haul roads. Hydrological studies over a long period were however not helpful in providing solutions to improving drainage. The overburden is not free draining, has a general low level of permeability with little open fissuring and high contained moisture.

The best operating compromise arrived at, was the selection of equipment suitable for the wet mining conditions e.g. belt conveyors, bucket wheel excavators, etc. particular emphasis being given to special cleaning devices. Even so with this selected equipment a low operating efficiency of about 30% had to be allowed for in programming.

DETERMINING THE GROUNDWATER HAZARD

An essential preliminary is an adequate knowledge of the physical nature of the mining horizon and information concerning the presence of groundwater. Experience may justify simply letting the water run into the excavation and then pumping it out, alternatively major pumping from wells to depress the piezometric surface may be necessary. Geotechnical investigations are needed to determine slope stability factors relative to the ground water regime.

Whether special groundwater investigations are necessary will depend upon:

- Conditions in similar excavations in the area.
- Results obtained from drilling, e.g. water levels, loss or gain in circulation, stability of borehole walls, etc.
- Behaviour of water wells if any, in the area, particularly flowing artesian or pumped sub-artesian wells.
- The topography, structure and geomorphology of the locality, particularly with regard to recharge areas.
- The nature of the formations and their water bearing potential.
- High rainfall (or snowfall)

The strata must be tested to below the base of the workable mineral for the presence of groundwater, the lower limit being determined by the possibilities of heave and piping from a confined aquifer. Boreholes can provide communication between aquifers and pierce confining beds, (with severe consequences in some mines encountering unrecorded and unplugged wells). It is desirable to seal all boreholes after use, with cement, clay or other impermeable material, unless a piezometer is to be installed for monitoring purposes.

The method of drilling boreholes can mask the potential hazard zones due to sealing of permeable strata by mud flush fluid and from the need to case unstable horizons. Geophysical methods of borehole survey should be used to supplement core and cutting's logging.

Mining Above a Confined Aquifer

Where a deposit is underlain by an aquifer then water may flood the mine due to either floor heave or to piping. Slope failure, particularly in spoil, could be induced by such inflows.

Floor heave results from the imbalance of forces where mine excavation reduces the containing mass of overburden below the up-thrust pressure of the contained aquifer. The phenomena of heave may result in tension cracks developing in the mine floor thus providing a passage for aquifer water to flood the mine.

Flooding may still occur above the level of heave, due to piping. This can occur where communication exists between the aquifer and the level of excavation through geological discontinuities or old boreholes. Possible water seepage from the aquifer into the base of the spoil bank is of special importance. This may also occur in a pumpwell controlled system as the wells are moved forward with the advance of the mining benches, thus allowing the piezometric level to rise under the spoil, with the possibility leakage into the spoil if the confining layer is breached.

The drainage problems can become complex where multiple aquifers and fractured aquitards are present. The piezometric heads can be different for each aquifer under undisturbed conditions and the complexity of the problem increases with the number of variables. A thorough hydrogeo-logical investigation is required to define the problem for practical operational control.

Mining Within An Unconfined Aquifer

Depending on the severity of the ground water problem and on bench stability factors relating to rock type, overburden drainage can be effected by a range of systems:

(a) The water can be allowed to seep into the mine, naturally or via slope toe holes, and be channelled into sumps for pumping from the mine.

(b) The overburden can be drained by pumpwells around or within the mine.

In some special cases localised inflow can be controlled by surface stream diversion and/or lining of waterways and by various forms of impermeable cut-off barriers.

The first option (a) is the most economical solution for low inflows and stable ground and requires little planning control but can have severe slope stability consequences in clay-rich or poorly consolidated overburden.

The dangers of inrush of water and bench failures, etc. must be elim-inated by preplanning, based on systematic hydrogeological investiga-tions and control measures. In limestone formations and in some len-ticular deposits, the localised risk of mud filled cavities or under-ground bodies of water has to be allowed for in mine design and safety planning.

Slope failure due to saturated ground conditions creates a problem since the pore pressure of ground water in overburden reduces the safe slope angle. In a deep surface mine the flatter slope angles needed for bench stability can substantially increase the stripping ratio and mining costs.

The form and extent of ground water control adopted is an engineering design decision based on criteria in which safety and efficiency are the paramount factors. The economic benefits of dry working may however recoup the system cost. The use of pumpwell systems generally provide the best solution where severe groundwater conditions exist. Figure 1 illustrates the typical procedure for the design of a pumpwell system.

MAJOR PUMPING TESTS

It is well known that the field determination of permeability can provide erroneous results and that the design of large scale surface mine de-watering systems using pumpwells should not be based on single pump tests. Nevertheless for large stratified deposits, single pump tests are essential to provide values for T, the transmissibility and S, the coefficient of storage of aquifers, upon which parameters major pumping tests can be designed. These preliminary tests are comprehensively discussed elsewhere[7].

Where a ground water problem is indicated the extent of the mining hazard and the possible adverse consequences of the resultant mine dewatering on the environment has to be evaluated. The extent of such tests has to be assessed on site-specific factors including:

- Mine excavation dimensions
- Aquifer dimensions and areal extent
- Lithologies of the mining horizon
- Hydrological characteristics of each stream

Large-scale multi pump tests have to be carefully planned if they are to be successfully conducted to provide reliable measurements. It is preferable to locate the test site near the projected initial excavation so that the wells may be used later for mining purposes. All the wells must be thoroughly developed and tested and all other preparations completed before the tests commence, then no pumping should be carried out for a pre-test period so that the piezometric surface may resume the "undisturbed" level.

It is useful to carry out tests in progressive stages to verify, that the total drawdown at each stage is equal to the incremental sum of the drawdowns when each pumping well is taken separately, to establish the "principle of superposition" (Figure 2) since this is fundamental to the design of groundwater control systems. The principle of superposition of pumping effect is true in time and space, providing that the aquifer does not suffer a permanent "set" or deformation after pumping has commenced.

The mass of data accumulated during pumping tests can present a formid-

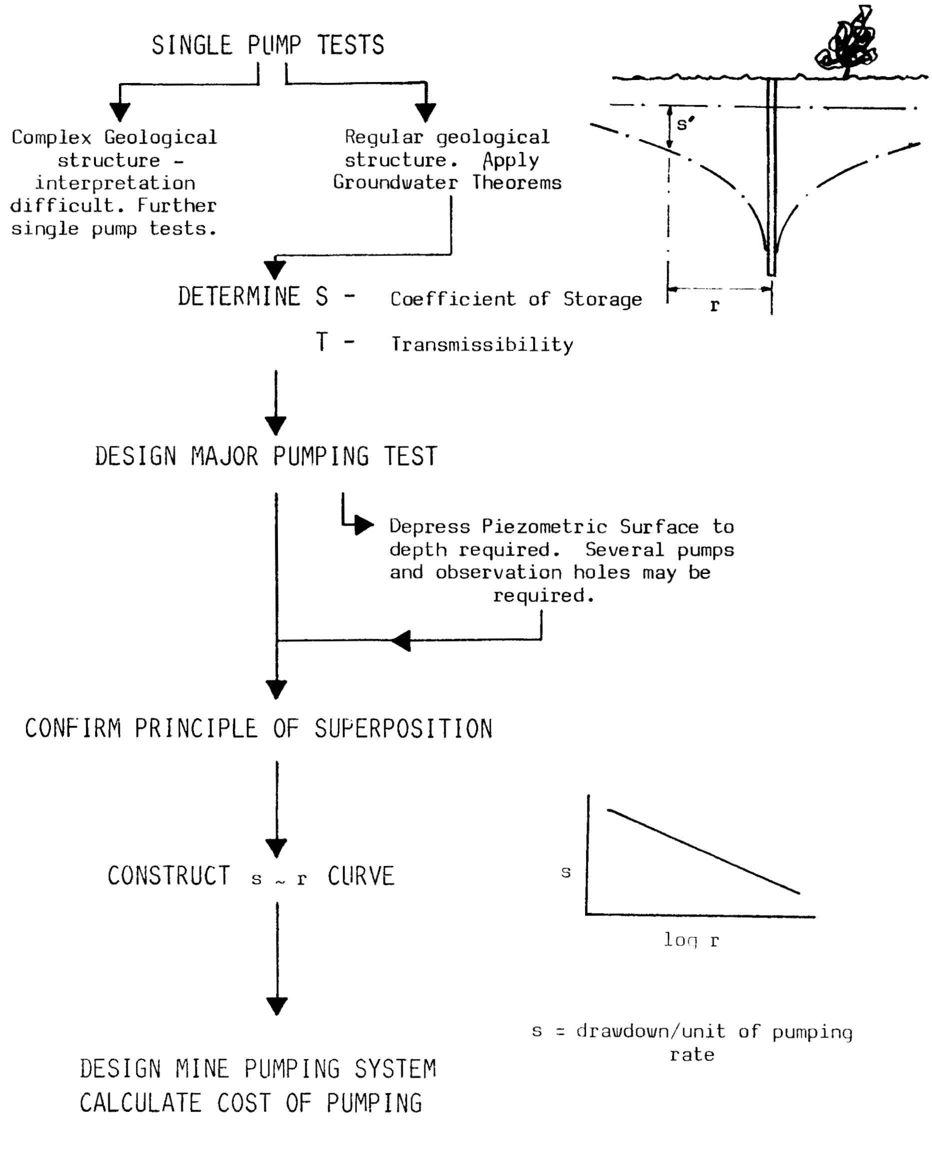


Fig. 1. Pumping System Design Proceedure

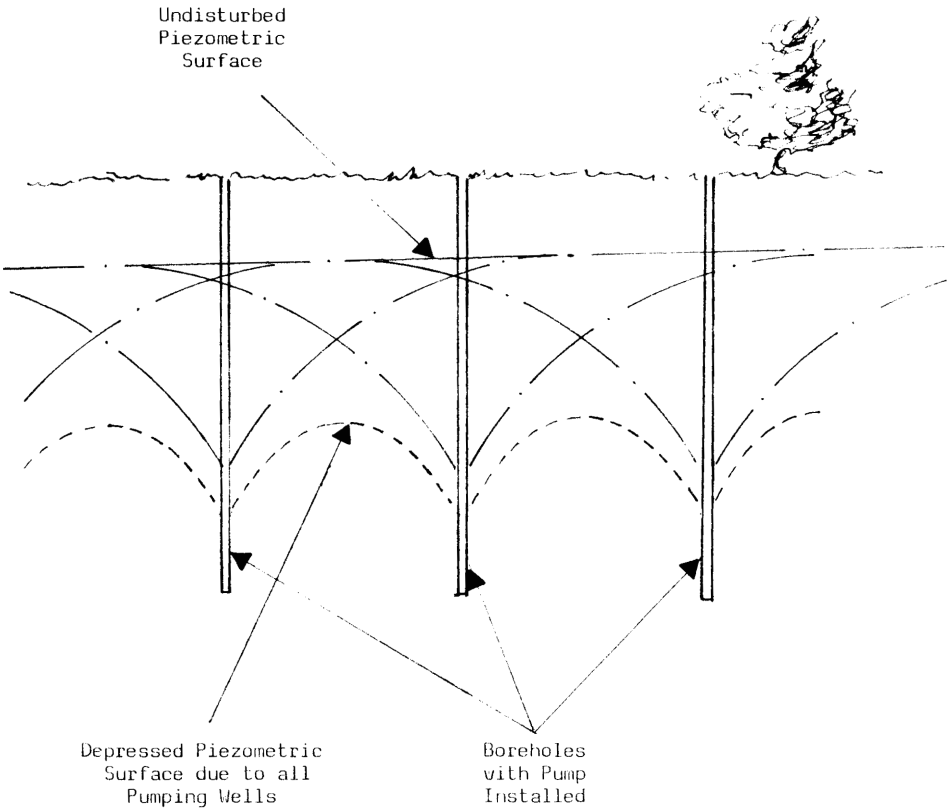


Figure 2. The Principle of "Superposition"

able problem of processing into a convenient form for interpretation and for subsequent use in planning of a groundwater control system. The present day availability of computers however greatly facilitates interpretation of results.

The duration of the test again depends upon local conditions. A single pump test of a confined aquifer will demonstrate conditions within a few hours from the start of pumping although a duration of 2 to 3 days is preferable. A major multi-pump test should be continued for between 10 days and one month to observe any aquifer depletion effects. Water table (unconfined) aquifers usually have slow yield characteristics and tests should be of longer duration than those for confined aquifers.

Pumping Rate and Test Duration

The selection of pumping rate and duration for a test is dependent on the assessment of local hydrological conditions and mining risk factors. In conditions of low permeability, with a limited zone of hydraulic influence and no conflict over water rights, then a drawdown of about 20% of the required depression may be considered an adequate test. For deep surface mines in highly permeable zones, having an area of influence far exceeding the mining area, a major test simulation to the final drawdown may be needed. Such conditions could require evaluation for possible aquifer anomalies over say 70% of the area of drawdown influence for a full control system to ensure that extrapolation of results would be within an acceptable range of accuracy.

Regional Aquifer Flows

A general understanding of the aquifer structure is needed to assist in hydrological impact planning. Several techniques are available including radioactive tracer, chemical tracer, temperature profiling and conventional water table mapping[7].

Observation Wells for Major Pump Tests

A selected number of exploration boreholes should be developed, and installed with piezometers or stand-pipes for water level observation. For a major test the well locations should be selected to provide a full circle cover of 6 to 8 radial lines of observation around the pumpwells. Each line should have 2 to 3 boreholes. For smaller tests at least one observation well should be located up flow and a further well down-flow of the test site. Where pumpwells only partially penetrate an aquifer then observation wells closer than a distance equivalent to about half the full aquifer thickness are likely to be influenced by non-linear flow to the pumpwell. This results in a localised increase in drawdown near the pumpwell which invalidates the readings within the zone. In general observation wells within 10 to 50 metres from a single pumpwell give satisfactory readings. For a multi-pump test 100 metres from the nearest well may be more appropriate.

For thick multi-layered aquifers it is important to measure any effects of partial penetration of the aquifer by the pumpwell. The localised pressure loss in the upper stratum can be incorporated into the mine control scheme to reduce overall pumping. For such conditions the obser-vation wells should be installed to measure pressure changes at two or three depth horizons in the aquifer.

A number of observation/exploratory bore holes should be designated as monitoring holes, located in key areas where they can continue to function throughout the life of the mine.

The location for observation wells should be selected to take account of:

Type of aquifer:	Confined aquifers react quickly to pumping and effects can be measured over a wide area. Unconfined aquifers react slowly due to storage yield effects and the cone of depression propogates slowly.
Transmissibility:	A highly-permeable aquifer will produce a wide flat cone of depression while an aquifer of low permeability will have a deeper smaller radius cone of depression.
Planned Pumping Rates:	The extent of the cone of depression is proportional to pumping rate on a log ratio.
Stratification:	This can create vertical changes in pressure loss due to pumping. Observation points should be located at a range of depths to measure this vertical gradation.

Test Arrangements

The location of pumpwell tests has to take account of site-specific conditions. In relatively low permeability areas a number of single pump tests over the initial mining area may be required to determine lateral changes in permeability and variations in the vertical permeability profile. For highly permeable conditions, requiring a multi-pump test to attain a representative drawdown, the main test should be preceeded by single pump tests to determine test design factors (Figure 1). Pump tests other than small scale proving tests conducted during exploration, *are normally pump-out tests at constant flow. An exception may be in low permeability zones where constant drawdown tests* can be more easily controlled to avoid the borehole water level dropping to the pump inlet level.

In confined aquifer conditions an important proportion of total drawdown is achieved during the first few hours of pumping.

This initial test period provides a base for the analysis of subsequent aquifer anomalies and needs to be carefully recorded. To adequately measure the intial rapid drawdown phase a number of key observation holes near to the pumping grid should be equipped with continuous recorders and observers should also be stationed around the pumping grid at as many wells as possible to measure water levels at short intervals. The time interval for reading key observation holes should be approximately:

Elapsed time	Reading Interval
0-10 mins	30 secs
10-30 mins	1 minute
30-60 mins	5 minutes
1 to 2 hours	10 minutes
3 to 4 hours	15 minutes
4 to 8 hours	30 minutes
9 to 16 hours	1 hour
17 to 24 hours	2 hours
Day 2	4 hours
Day 3	8 hours
Day 4 onwards	Daily

When the pumping phase of a multi-stage test is complete a simultaneous switch-off of pumps provides a positive check on results by measurement of the recovery of water levels. The schedule of water level observations should be similar to the start-up programme.

Electricity Supplies

Power supplies can be a problem for large tests in remote areas. In the case of the Neyveli groundwater investigations, South India, a 5 MW packaged power station was erected for the tests; this station later provided power for initial mine development.

Water Quality Sampling

Water samples should be collected both during the tests and at intervals of not less than 3 months during exploration activities. Analysis of these samples permits the quality of discharged water and its effects on natural surface waters to be examined, as well as influencing pump selection and well equipping.

Flow Rate Measurements

The accurate determination of the pumping rate during a test is essential. Usually the flow rate is measured from each pump and with multi-pump tests the aggregate total flow is also measured to serve as a check.

The following methods can be used[7].

1. Vee notch and horizontal weirs for open channels.

2. The Dall Flow Tube

3. Orifice Plates

All may be fitted with recording devices.

Items 2 and 3 are used in pipe systems. Both are extremely portable and useful where a large number of single pump tests are to be carried out.

PUMPWELL CONSTRUCTION AND INSTALLATION

Well capacity and design depend upon the following interactive factors,

- Well yield tests
- Rock type and degree of cementation
- Sand particle size distribution
- Optimum pumping rate for groundwater control
- Water quality/well screen corrosion factors
- Thickness of the saturated horizons
- Pump selection
- Well location, temporary or permanent?
- Well filter or gravel pack construction?

For major dewatering schemes in large mines in stratified deposits, well diameters range from 0.30 m to 1.80 m and depths can be as great as 500 m.

Well Drilling

Most major aquifers in stratified deposits occur in relatively weak formations. For the large diameter wells required for effective groundwater control, *reverse circulation drilling is most effective*. For stronger formations and for wells of less than 0.30 m diameter standard rotary methods are used.

The depth limit of typical reverse circulation rigs using a centrifugal pump and a 150 mm diameter drill pipe is 125-175 m. For greater depths air injection ("Air Lift") is used and wells as deep as 500 m can be drilled, using drill pipes of 0.15 m dia. (shallow holes) to 0.30 m dia. (deep holes) with water circulation rates varying from 75 ℓ/s to 300ℓ/s. Drag and roller bit types are used with drill collar stabilizers. The volumetric ratio, circulating water to free air delivered, is 1.4 : 1 to 1.7 : 1, with average velocities in the drill pipe from 3-4 m/s. The solids content is about 7%, equivalent to 130t of cuttings/h, requiring a 200 kW compressor (20 m^3/min at 20 bars). The compressed air is conducted down the drill pipe through a separate air pipe, and is injected just above the bit. For deep wells compressed air may be injected at several horizons.

The advantages of reverse circulation drilling are:

- Large wells can be drilled in one pass. A high ascending velocity is maintained in the drill pipe to raise the cuttings regardless of well diameter.

- Untreated water can be used as the drilling fluid in sub-artesian conditions, though a densifying medium is needed for full artesian conditions, e.g. barytes.

- The borehole walls are supported by the drilling fluid and the low downward velocity does not erode the borehole walls. Except for a surface stool pipe, casing of the well during drilling is not required.

- Cuttings as large as 150 mm can be raised through a 0.30 m. dia. drill pipe.

- Sampling of drill cuttings is accurate as the material reaches the surface quickly with very little mixing.

Drilling Fluid

For conventional rotary drilling it may be necessary to use drilling mud. Imported muds usually cause minimal aquifer penetration, thereby reducing well development problems.

The circulating water of wells drilled by the reverse circulation method is re-cycled through settlement pits and is returned relatively free of solids to the well, although some mud contamination from the cuttings can occur. In general this contamination does not seriously affect the permeability of the zone of the aquifer surrounding the well.

Difficulties can arise in some clay formations which tend to swell with water absorption and to cave during well construction For such conditions natural or synthetic polymeric additives may be used to increase viscosity and reduce water penetration of the clays. In some special cases the use of bio-degradable muds can be required and the use of polyphosphates may be needed to disperse clay particles.

In special conditions such as in fractured rock aquifers where no well stability problems exist, it is sometimes possible to drill with aquifer inflow water. This avoids contamination of the aquifer but is only applicable in stable ground.

Foam drilling is not generally applicable in water well drilling

WELL INSTALLATION

Pumpwell construction must ensure that aquifer sands are not transmitted into the well and its surrounding zone, to avoid damage to the pump and to reduce permeability. The two main types of well construction are:

1. Filter Wells

   - graded gravel pack with a slotted screen pipe
   - resin-bonded gravel filter screen
   - wire wound screens

2. Non-filter wells with a large diameter where the flow velocity at the aquifer interface is sufficiently low to avoid disturbance of in-situ sand particles. A simple slotted screen pipe surrounded by a coarse gravel pack is used for support of the walls of the well. This system can be very successful in weak formations for large diameter wells and is most economical for short life wells, e.g. within an advancing pit.

Well Casing

Asbestos cement casing, which is easily cut by excavators is preferred, but in remote areas up to 30% of asbestos cement casing pipes can be damaged in transit and steel casing is then preferred. This is generally most economically manufactured on site from flat sheets, using bending rolls and a seam welder.

Asbestos cement casing must be fitted with special couplings for suspended installation. In deep submerged wells the casing may be wrapped with styrofoam to create buoyancy and reduce tensile stresses in the couplings during installation.

Well Screens

Severe abrasion from sand particles can cause serious damage to pump trim and bearings. Screen slot dimensions and gravel filter grading must suit local site conditions as determined from particle size distribution tests.

Well diameter and depth, screen length, and well development procedures, etc. must also be decided from site conditions.

Chemical and bacterial analyses of water sampled during pump testing is needed in some areas. Water may corrode casings and screens if improper materials are installed where the water has a low pH factor or contains hydrogen sulphide, high total dissolved solids, chlorides or excessive dissolved gases. Also, well plugging can result from carbonates, iron, manganese and bacteria. Treatment may be necessary for long life wells to control incrustation, and well construction materials may have to withstand acidizing, chlorination, treatment with biocides and other chemicals. In long life well installations stainless steel, plastic, monel or brass are used instead of steel screens and casings, where required, to counter corrosion.

Steel is commonly used for well screens where corrosion is not a problem or for short life wells. The screens may be open slotted or bridge slotted, slot openings ranging from 3 to 6 mm width depending on gravel pack size grading. The percentage opening in the screen is approximately 25%. A bonded filter is formed by resin-bonding gravel to the screen, a graded gravel pack is formed around the screen in mesh baskets and wire wound screens are formed by winding suitable wire sections around the screen. These are usually manufacturers proprietary items.

Non-filter wells are formed by placing a loose, graded-gravel pack in the annulus around the screen. The gravel size is based on a screening factor which will retain 80-90% of the aquifer sands, i.e. a screening factor of 4-5. This gravel is placed through a 50 mm diameter conductor pipe lowered from the surface and progressively withdrawn as the gravel is poured. The gravel, typically 2 mm to 5 mm size is flushed down the conductor pipe with water to prevent bridging.

Before placing the gravel pack the well has to be cleaned of cuttings and cement pumped down a small diameter pipe to seal the base of the well. After completing the placing of the gravel pack, a further cement seal is pumped in above the pack to prevent loss of permeability from clay infiltration from above the pack. The screen is fitted with centralisers.

For filter wells the annular space between the borehole and filter is filled with washed sized gravel as for the non-filter well.

Asbestos screens are used in West Germany, these consist of a pierced asbestos-cement casing of the same diameter as the well casing, coated with a 30 mm thick resin-bonded, graded filter.

In the Australian brown coal mines, wire wound screens with 3mm slot openings are used, back filled with 4 to 5 mm gravel. The use of mild steel casing was discontinued because of corrosion problems and asbestos cement casings are now used. Difficulties were also encountered in developing wells with resin-bonded filters and wire wound screens are now used.

Well screens made with polyethylene have been manufactured in recent years but are limited in use due to the low strength of the material, rigid P.V.C. is a further alternative. A current development is the use of glass fibre screens. Many types of glass fibres are hydroscopic and if severed ends are exposed from cutting or damage during emplacement, well collapse could result. Further development of fibres and moulded screen designs are being made.

Scope exists for further improvement in well stabilisation and screening techniques.

Pumpwell Development

During well development the aquifer is induced to flow into the well carrying residual drilling mud and fine sand to establish a permeable and stable interface between well and aquifer. This flushing procedure is required since drilling disturbs the structure of the immediate aquifer around the well circumference and tends to block channels through which water would flow and may be compounded by drilling mud contamination.

Methods commonly used for well development are[7]:

- Surge plunger
- Compressed air backwashing
- Air lift pumping
- Intermittent pumping

Some wells are unable to yield the projected pumping rate after drilling for reasons of mud seal, filter damage or localised low permeability etc. Surge development using clay dispersants or acid injection may improve yield but allowance should be made for 10 to 20% spare wells in a mine dewatering system.

Well Completion Schedule

The drilling rate for a 1200 mm diameter well is about 50 m per 8 hour shift. A typical schedule for completing a 300 m deep well is:

	Shift No.
Site Preparation	0 - 8
Well Drilling	9 - 22
Well Installation	23 - 25
Gravel Packing	25 - 30

Well complete in 30 shifts

Observation Wells

A prerequisite of pumping test evaluation and the operation of a mine dewatering system is the provision of an adequate number of observation wells around the pumping wells. Such boreholes are installed with a variety of piezometers for single and multiple measurements of aquifer(s) pressures. Discontinued pumpwells may also be used where available.

Diameters of observation wells vary from 75 mm to 200 mm, the larger sizes being needed for automatic recorders or multi-piezometer installation.

The drilling of observation wells can be carried out by rotary drills using air, water or mud flush. *It is important that the wells are cleaned after drilling to ensure good hydraulic communication with the aquifer.* The methods employed need not be as refined as for pumpwells.

Observation wells may be left uncased in competent strata, installed with piezometer pipes then gravel filled. Packer tests of individual horizons may be carried out on unlined sections of boreholes, where required for permeability profiling.

Where friable ground necessitates casing as drilling proceeds, the well completion procedure must isolate the aquifer test horizon from the rest of the borehole. A number of options are:

- Unlined test section, cased above
- Gravel filled test section cased above
- Perforated casing in the test section, cased above
- Fully cased borehole, open at bottom (cavity well)

Observation wells in low permeability zones should be fitted with small diameter piezometers to reduce response lag (time to drain borehole).

In tests of multiple aquifers when water level (pressure-levels) are required from a number of horizons this can be achieved by installing piezometer pipes to each horizon in the borehole. It is possible to install two pipes in a 150 mm diameter well and up to six in a reverse circulation drilled well. It is important that each horizon within the borehole is sealed from adjacent horizons.

PUMP SELECTION

To minimise pumping capacity there could be considerable advantage in using pumps of different head and capacity in each borehole, but standardisation of pump type and capacity has obvious overwhelming advantages in limiting spares, maintenance costs and well preparation. The decision on head and capacity must be made after the results of the major pump test are known. There are advantages in using a few large capacity pumps but these usually require larger diameter wells and result in excess drawdown close to the pumps. Invariably some compromise is necessary.

There are two pump types in use for borehole installation:

(a) submersible pumps, and

(b) shaft-driven turbine pumps.

The submersible pump is a multi-stage centrifugal pump coupled to an electric motor in the same assembly and operates under water. It is a very compact unit and supplied with power through a cable from the surface. The shaft-driven turbine pump consists of a centrifugal pump down the pumpwell, which is connected to a shaft driven at the surface, the shaft column can be either oil or water lubricated.

Submersible Pumps

The submersible pump has advantages in mining operations where pumpwells have only a short useful life, the comparative ease of installation and removal enabling pumps to be transferred from one pumpwell to another in a matter of hours rather than weeks. Pumphouses are not required on the surface with this type of installation and little maintenance is necessary. Periodic overhauls are required but these may be phased to coincide with the time when the pumpwell is to be abandoned. A common problem is the abrasion of the pump working parts due to particles in pumped water. Excessive foreign matter in the water can also cause bearing and insulation failures. Other causes of insulation failure are high water temperature requiring special insulation, and frequent switching.

Well pumps require no priming since the suction is continually submerged and automatic operation is possible, this is an advantage in regions where power failures are common as stand-by power supplies can be switched on and the pump will start immediately.

The submersible type is not as robust in construction as the shaft-driven pump and requires greater care in transportation and installation. The period between overhauls is shorter and the units usually have a shorter working life. The capital costs of submersible units, including the pumping system and installation costs, are generally lower than for a comparable shaft-driven type.

Particles of sand suspended in the water to be pumped from a well may damage the impellors of the pump in time and this material should not be allowed to enter the pump chamber. A possible solution is to construct a circular, open-ended shroud around the inlet to the pump which will lower the water velocity into the pump, reducing the entry of the larger particles.

The pumps normally used are of small diameters multi-stage centrifugal design. In the majority of cases no special linings are required as no abrasive material should be present in the water. The chemical content of the water may however influence the type of linings required. The non-return valve may be installed at the top of the well to simplify maintenance.

The motors are of three phase, squirrel cage, induction motor design, having a small diameter and a long core, with a star connected winding to reduce the number of joints. The insulation is specifically designed for underwater operation. Both plug couplers and vulcanised joints may be used for connecting the supply cable to the motor. Plug couplers have obvious advantages where pumpwell life is short but the authors experience is that vulcanised joints are more reliable. The insulation resistances of submersible pump motors, measured from the surface, are often unacceptably low by normal standards but still operate satisfactorily.

Shaft-Driven Turbine Pump

Oil-lubricated shafting is usually preferred to the water-lubricated system being superior in both lubrication and stability. In extreme cold climates the use of water-lubrication is further limited by the necessity for pre-lubrication prior to starting. This requires a tank of water which must be kept from freezing to be permanently sited close to the well. When oil-lubrication is employed the drive shaft is enclosed within an oil-filled tube which runs from the top of the pump to the discharge head. Every 1.5 m approximately the tube is connected by bronze bushings which serve as bearing surfaces for the shaft. The shaft is lubricated in these sections by the addition of oil when the pump is installed. Oil is added at a rate of approximately one drop per second to the column so as to cover losses and provide a constant oil bath for the shaft.

Closed pump impellors are usually used but for cases where abrasion is high semi-open types may be preferred. These tend to be less efficient and difficult to adjust. When little abrasive material is present in the pumped water, relatively cheap bronze pump impellors can be used. If abrasion is a problem cast-iron, enamelled impellors may be used to increase life. These are higher in cost and there is a tendency for the enamel to flake. Special alloys and wear resistant features are provided by most manufacturers to deal with specific problems.

It has been found by experience that the inclusion of extra-strength diffuser cones, bowl stabilisers and impellors with extra long skirts help overcome some of the problems associated with abrasive material.

Shaft-driven turbine pumps are best suited to long life wells.

Maintenance Facilities

Where large numbers of pumps are in service, especially in remotely-located mines specialised pump maintenance and test facilities are needed. These include pump rebuild facilities, which often must be carried out with the pump shaft in the vertical position; submersible pump motor rewind facilities involving a long shop as each phase of the motor winding must be "pulled" through tunnel slots in the stator; facilities for load testing of the pumps and specialised handling facilities.

Pumps awaiting installation or servicing must normally be stored vertically and must not be exposed to sunlight as this can damage the motor windings.

The whole area of pump maintenance, testing and handling requires detailed attention and the personnel involved must be carefully trained otherwise serious damage to both pumps and motors can arise.

PUMPWELL SYSTEM DESIGN AND OPERATIONS

The basic requirements of a pumpwell system are:

1. To depress the piezometric surface (or the water table) to the required safe level. Over-depression at any point results in increased pumping costs.

2. To have the facility to advance as the mine excavation advances.

3. Provision of additional pumping capacity to cover individual well failures, yield deficiencies, etc.

4. Provision of stand-by power to cover electricity supply outages.

The s~r Curve

From the major pump test a drawdown distance per unit of pumping rate against radial distance from the pumpwell curve (s~r) can be plotted (Figure 3). The unit of pumping rate is usually taken as the pumping rate of the selected pump. For preliminary exercises to locate pumpwells the authors found a scale calibrated in drawdown to be most convenient. Additionally to reduce arithmetic, groups of pumpwells can be considered as a single well as follows:

4 pumpwells on a 30 m square grid with one observation well 100 m from corner well, pumping rate for each well 4500 ℓ/min.

Well 3	Well 2	
Well 4	Well 1	Observation 0

measured radius

$$r_1 = 70\text{ m},\ r_2 = 62.5\text{ m},\ r_3 = 98.7\text{ m},\ r_4 = 93.7\text{ m}$$

Weighted mean radius (r_m)

$$Q \log r_m = Q \log r_1 + Q \log r_2 + Q \log r_3 + Q \log r_4$$

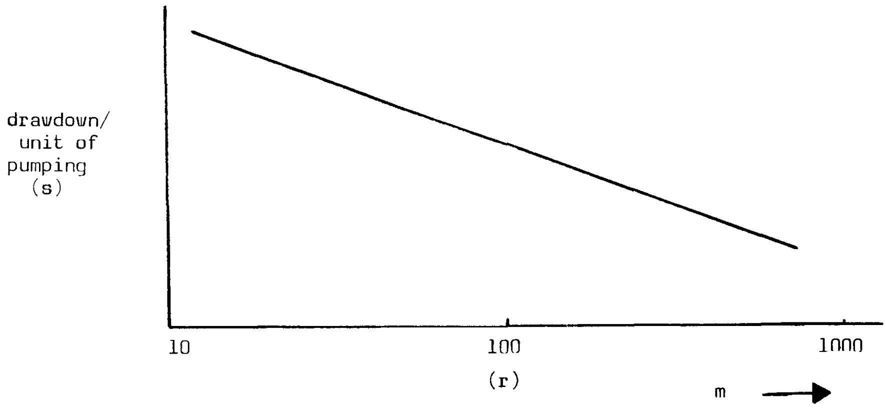


Figure 3. The s ~ r Curve

r_m = 79.7 m at a pumping rate of 4 x 4500 = 1800 ℓ/min.

For small projects in relatively uniform aquifer geometry, analytical and/or semi-graphical solutions can be used, but for more complex conditions and particularly where the effect of mine pumping has to be forecast for aquifers of large areal extent, computer prediction can be used.

Models are available in two basic types, the finite-element model and the finite-difference model, e.g. Aquifer Finite Element Model (AQUIFEM) developed by Massachusetts Institute of Technology and a Finite Difference model (GW) developed by Rheinbraun, Braunkohlenweke. Many other models exist.

In one frequently adopted approach to the problem the aquifer is assumed to be subdivided into linear non-uniform spaced acute triangles (a system which allows for irregular oriented anomalies to be incorporated). Darcy's law or a derivation is applied to calculate partial flow rates in the network. Continuity equations describe node to node water transfer rates and hydraulic parameters. Results are presented as equi-potential lines (contours of piezometric surface). Such programmes can simulate one, two and three dimensional projections of drawdown conditions. The continuing drawdown with time effect of pumping is represented by a discrete series of quasi-steady state flow conditions.

The use of such models enables the planning engineers to observe the optimum development of the cone of depression due to pumping by simulating the effects of varying pumpwell patterns and rates of pumping. However the more sophisticated the programme the higher the quality and quantity of data required, which increases the extent and cost of investigations. A full study is not always justified as order of magnitude estimates are often adequate for many mine hydrological systems. A desk top computer is usually sufficiently adequate facility for day to day control.

Pump Location

To achieve the most economic pumping rate the pumps should be located as near as possible to the points of maximum drawdown. The maximum drawdown for a confined aquifer is invariably required at the lowest point of the excavation, but the choice of this location is constrained by:

(a) the pumpwells would impede mining operations,

(b) the life of the wells would be very short, and

(c) if catastrophic flooding occurred, the pump electrical control equipment would be inundated, rendering the pump useless.

It is usually necessary to compromise by drilling wells and installing pumps on upper benches (with less resultant drawdown at the points where maximum depression is required). As the bench face advances the pump is withdrawn and the well blanked off just below the level of the next lower bench. The internal diameter of the casing may be reduced to locate the blank. A marker of distinctively dyed soil is dropped into the well for easy identification and the upper part of the well back filled (Figure 4).

Asbestos cement casing may be left in-situ and cut down in the normal excavator operation, but steel casing must be cut just above the blank by a casing cutter fixed to the end of a drill rod, and the casing withdrawn for future use. The well is then re-established on the next lower bench when excavation has sufficiently advanced, by excavating around the casing, extending it to above the bench surface, removing the blank and re-installing the pump.

End bench wells are generally less effective in avoiding excess drawdown but have much longer life and do not impede mining operation. Because of this it is often advantageous to use large numbers of end bench wells.

The amount of depression of piezometric surface must be determined by:

- rate of recovery of the piezometric surface when pumping is interupted

- the "limit line of heave" below the pit floor

- plus a suitable allowance usually 20 per cent.

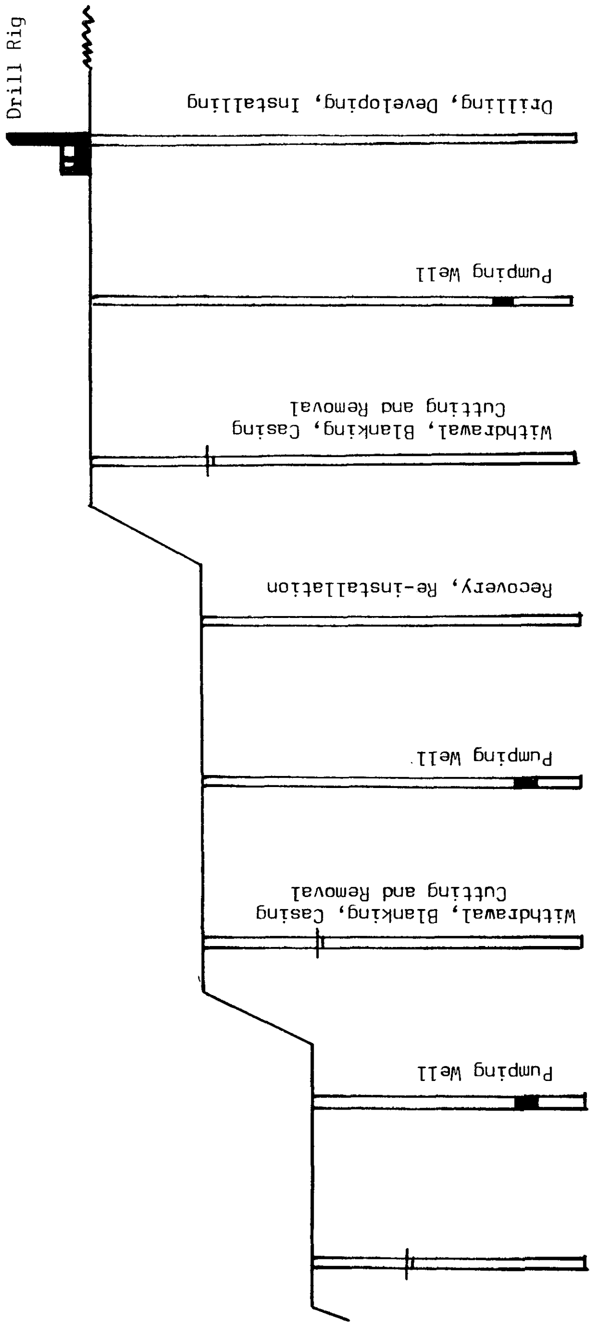


Figure 4. Method of re-use of pumpwells

Where the piezometric surface must be depressed below the upper surface of the aquifer, i.e. the upper part of the aquifer will be dewatered, it is important that the s ~ r curve be obtained from pump tests that achieve the full required drawdown.

The conditions in an unconfined aquifer are more complex as the formation is dewatered during pumping and a longer time scale applies. The pumpwell system capacity is that required to lower the water table to the base of the permeable zone but this cannot be achieved in practice. Doubling the pumping rate of a well may more than double the drawdown close to the well due to local reduced saturated thickness but at larger distances from the well the depression of the water table proceeds more slowly. Overburden drainage wells should be located ahead of the mining benches with a pattern and spacing that allows adequate time for dewatering.

Spoil Bank Drainage

Where the nature of the spoil from the overburden excavation is not free draining the spoil bank design must minimise ground or rain water infiltrating the bank and provide drainage relief to avoid build up of hydraulic pressure within the bank. Severe bench failures and substantial liquified mud flows can occur from poorly drained banks leading to loss of production and in some cases loss of life. The following factors are necessary for stable bank conditions.

- Water should not be trapped in the bank by the dumping layout.
- The floor of the dumping area should be kept free of water by channels and pumping stations where necessary.
- *Underlying aquifers where present must be depressurised within the current and recent dumping zone,* by spoil bank pumpwells where practical.
- Overburden aquifers should be sealed to prevent ingress of water into the spoil bank by selective dumping of clay or other means.
- Installation of adequate main and auxiliary pumping stations on the floor of mine.
- Provision of an underbank or core of bank rock drains where appropriate.
- Draining and/or removal of any weak floor material, if required.
- Selective dumping to provide the most suitable spoil material for the base of the spoil bank.
- Surface drainage should divert water away from the dumping area, the spoil surface to be graded to allow quick run-off of rain falling within the spoil area. Spoil shrinkage cracks should be dozed over at routine intervals.

- Natural clay may be dumped to prevent seepage or to re-establish an aquiclude. This is a basic requirement where mining removes the aquiclude of an aquifer.

The use of spoil bank pumpwells depends on the nature of the spoil, the method of dumping and consolidation rate. Spoil bank pumpwells have been successful in Neyveli, South India. The authors have observed massive spoil failures in Greece, U.K. and elsewhere due to failure to depressurize under-lying aquifers of spoil banks.

Pipe Systems

The water discharge pipe systems are relatively simple but even with high flow velocities large diameter pipes (up to 400 mm dia) are common. These pipes require adequate handling and welding facilities. The main collector pipes are fitted with "Christmas tree" valve manifolds and the availability of closure pieces, bends, "quick" couplings, etc. ensure that pumps can be connected into the collecting system with a minimum of cutting and welding.

Standby Electricity Supplies

Standby electricity supplies should be located as near as possible to the equipment to be supplied. Diesel-generators are usually the most convenient method of providing such supplies. Standby diesel-generators located on mine benches impede the movement of mining equipment. The best alternative is to locate the diesel generators as near as possible on the surface with cable connections to the pumps. Each group of pumps is supplied separately and also connected to the standby supply. Cable systems are inherently reliable and introduce little extra risk. The standby generators are normally started by an under-voltage relay after a time delay of about five seconds. The pumps would also trip on under-voltage and are arranged to re-start at intervals not less than 10 seconds apart to avoid the total starting current inrush being imposed on the generator. When mains power is restored, automatic changeover can be effected. Figure 5 shows a typical system.

THE EFFECTS OF MINE DRAINAGE

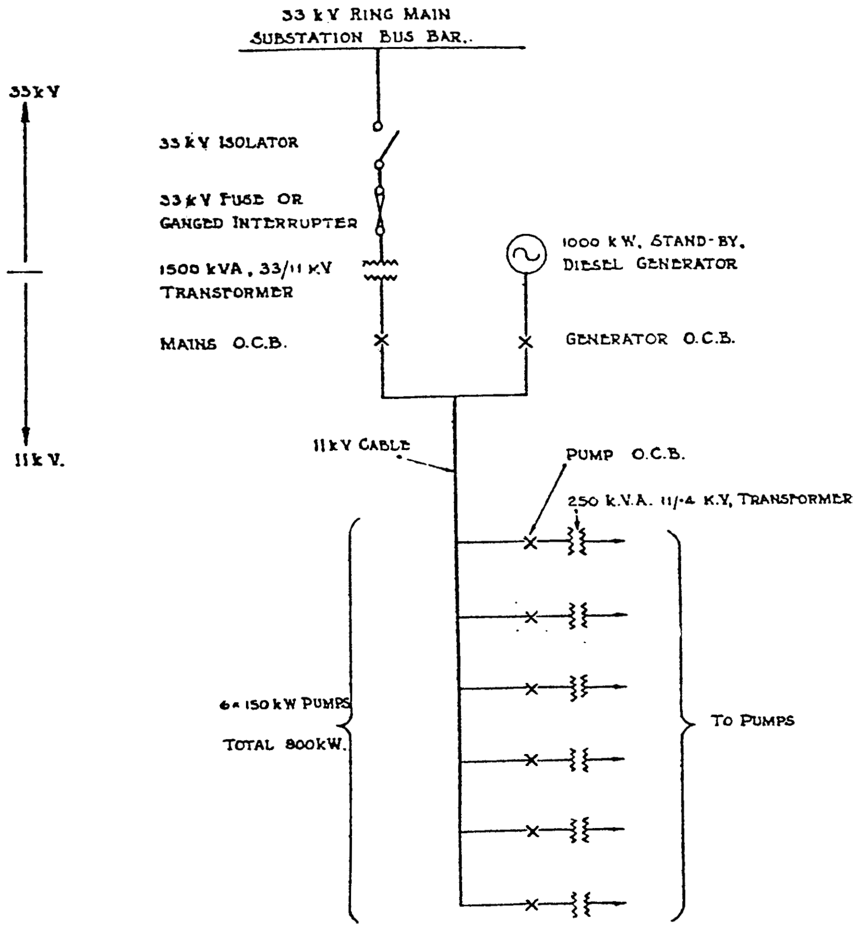
Regulations governing the abstraction of groundwater and the use of surface waters or their diversion are intended to protect the hydrological balance within a region. An environmental sensitivity has developed over the past few decades to the impact of mining on water resources. These problems are dealt with in detail elsewhere[8,9] but the main consequences are briefly:

- severe changes to the groundwater regime
- discharge of contaminated mine water
- erosion and sedimentation problems
- subsidence due to groundwater extraction

FIGURE 5.

PUMPING ARRANGEMENT.

SCHEMATIC DIAGRAM OF ELECTRICITY SUPPLIES.



- surface water drainage pattern changes.

These items require detailed consideration.

CONCLUSIONS

Pumpwell drainage systems used in large surface mines involve considerable investigation and engineering design if they are to be economically effective. Such systems must be compatible with the method of mining adopted and must be fully integrated with mining operations at the planning stage. The security of the mine is often largely dependent on the continuous and effective operation of the pumpwell system and extremely reliable systems are essential.

Often this involves large capital and operating expenditures that can have a significant effect on the viability of a project, thereby justifying the in-depth considerations that are needed. The organisation of the operations requires high levels of technical competence and managerial skill. Often innnovation and occasionally improvisation are essential ingredients in the design and operation of pumpwell mine drainage systems. The whole subject crosses the boundaries of geology, hydrology, mechanical and electrical engineering as well as mining engineering.

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