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GROUNDWATER PROBLEMS IN SURFACE COAL MINING IN SCOTLAND

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ABSTRACT

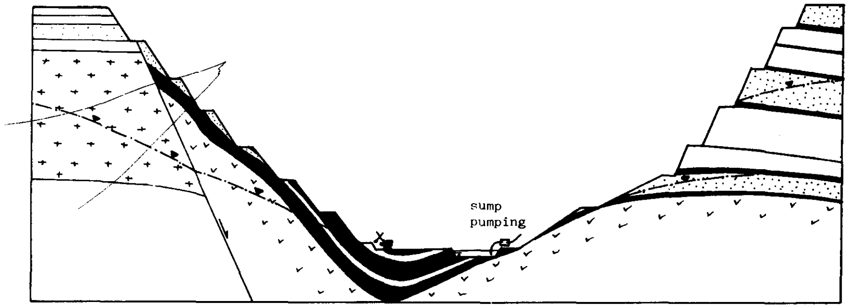
The paper reviews the problems encountered with groundwater in surface mining in Scotland. The problems which occur at various stages of the mining process from initial exploration to mine planning and final restoration are referred to. Special consideration is given to mine drainage and pumping methods.

INTRODUCTION

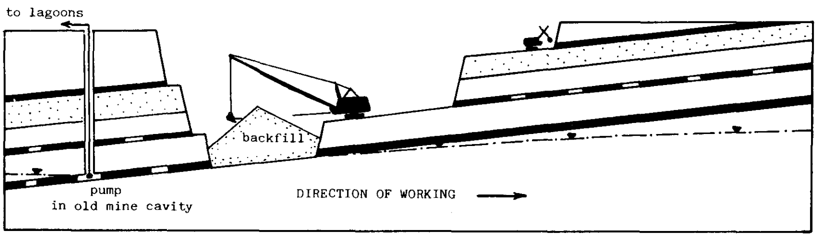
In the year 1980/1981 the total coal production from opencast mines in the United Kingdom rose to a record 15.3 million tonnes of which 2.9 million tonnes came from the ten operating mines in the Scottish Region of the N.C.B. Opencast Executive. A variety of surface mining methods are used in Scotland (see Fig.1) ranging from a 220 m deep open-pit using truck and shovel, to box-cut and up-dip or retreat mining and shallow down-dip or cross-dip strip mining using large draglines. Frequently a site may include several of these methods in different excavation areas. The increasing use during recent years of larger and more efficient machinery has given rise to deeper and larger mines with higher overburden/coal ratios and much faster rates of excavation. As most sites now go well below the water-table there has been a corresponding increase in problems associated with groundwater. Also many of the surface mines are in areas where deep mining activity has ceased and the general water-table has risen as the collieries stopped pumping. These abandoned mine workings become water-logged and often may interconnect with the surface mine for a distance of several kilometres.

The amounts of water encountered in opencast mining have therefore increased and pumped volumes up to 20 m^3 of water per tonne of coal produced are not uncommon. To exacerbate the problem in recent years more stringent pollution legislation has been enforced by River Boards and large sums of money may need to be spent on chemical treatment of the mine water before it can be discharged off-site into the natural watercourses.

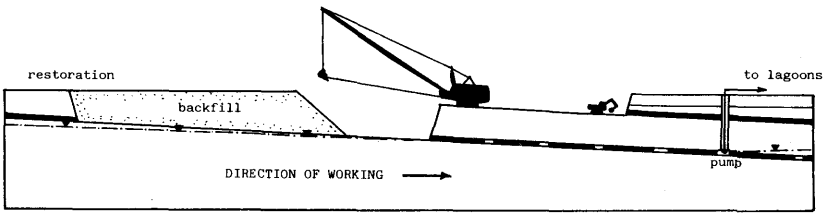
In the past mine operators used simple sump pumping methods on an 'as required' basis which often increased pollution by allowing clean



(a) DEEP OPEN PIT OPERATION USING TRUCK AND SHOVEL METHOD



(b) BOX-CUT AND UP-DIP (RETREAT) OPERATION USING MEDIUM SIZE DRAGLINE AND TRUCK AND SHOVEL METHODS



(c) SHALLOW DOWN-DIP METHOD USING LARGE DRAGLINE

Fig. 1 SOME TYPICAL SURFACE MINING METHODS USED IN SCOTLAND.
(Diagrams not to scale)

groundwater to enter the pit environment and become contaminated with suspended solids and iron. Fortunately these methods are being discarded in favour of more efficient advance dewatering techniques using electric submersible borehole pumps installed at specific locations around the perimeter of the excavation area in order to lower the water-table in advance of working and to collect the groundwater before it becomes contaminated in the aggressive pit environment. The method can be used effectively regardless of the method of surface mining used. The recent improvements in pump design have helped considerably in this matter. To enable these pumps to be installed in positions which give maximum efficiency proper geotechnical and hydrogeological investigations are necessary in order to identify the structural geology, groundwater flow patterns, gradients, likely volumes and quality etc. If the investigation is thorough then it can result in a significant reduction in pumping and water treatment costs.

Also taken into account is the final restoration of the site once coaling has ceased. In such a densely populated country as the United Kingdom overcoming the environmental problems associated with surface mining requires detailed planning and many opencast sites are restored to better conditions than those that prevailed before work commenced. The problem of water-table rebound and possible pollution of downstream watercourses, which in Scotland are often good salmon fishing rivers, must be taken into account before the mine becomes operational.

As will be seen, the problems of groundwater in surface mining manifest themselves at various stages of the mining process, from the initial exploration drilling and hydrogeological/geotechnical investigation through mine development, production and final restoration. The paper intends to show how these problems can be identified by judicious investigation and overcome by efficient pumping and mine planning.

HYDROGEOLOGICAL INVESTIGATION

Exploration

Most of the operational problems associated with groundwater should become apparent during the exploration and planning stage if sufficiently thorough hydrogeological and geotechnical data is collected. The N.C.B. Opencast Executive, who control opencast mining in the United Kingdom, carry out an intensive exploration drilling programme using rotary air-flush drilling in order to prove and quantify reserves of coal. Holes are drilled at centres from 30 m to 60 m apart and detailed information on geological structure is deduced from open hole returns and coring. Aquifers such as sandstones, fault planes, and aquicludes such as faults, impermeable strata are identified. Reset water levels in boreholes are also taken using a dipmeter at this stage. If a water problem becomes apparent further detailed investigation is undertaken to identify individual aquifers and aquicludes, flow patterns and volumes.

Monitoring

This is usually achieved by the installation of piezometers at specific locations in relation to the proposed excavation area so that they can be read both prior to and throughout the life of the mine in order to register drawdown. Simple Casagrande 'Type B' piezometers are usually installed at the required horizon in a bed of pea gravel and isolated with a bentonite seal and cement grout to surface. Access for the dipmeter is gained through a 20 mm tube and readings taken at regular intervals. It has been found best to install the piezometers at least a year prior to coaling so that any seasonal fluctuation in the groundwater can be identified. Because mines are often in populated areas the surface end of the access tube to the piezometer is made vandal-proof using old drilling casing and a padlocked cap and making the surface installation as unobtrusive as possible.

Abandoned Colliery Workings

The normal rules of hydrology apply in strata which is unaffected by old deep mine workings and if necessary the permeability of the strata can be ascertained with reasonable accuracy using conventional falling head, rising head, packer tests etc. However, most surface mines are now located in areas of abandoned deep mine workings where the ground water does not conform to normal hydrogeological patterns and it is here where the greatest pumping problems are encountered by the mine operator.

Often a proposed opencast mine is situated in strata where deep mining has ceased and the water-table has returned to a natural level which existed prior to mining. There may be up to twenty different seams which contain abandoned mine cavities, shafts etc. and a maze of interconnections with the proposed surface mine within the surrounding area for several square kilometres. Plans of the more recent workings will be available, but many of the abandoned workings may have been in existence for hundreds of years. The most common are those worked during the 18th and 19th centuries but cavities dating from the 14th century are not unknown. Plans for such early workings are obviously non-existent and only a very rough estimation of the volume of water retained within them can be made. Even when plans are available it is difficult to decide whether the roof of the cavities have collapsed, whether they have been backfilled and to what extent individual collieries and seams may interconnect with each other and with the proposed new surface mine. In these cases the assistance of officials who have considerable experience of the individual deep mines involved is invaluable. If such help is not available and no other information can be obtained then assessments must be based on good judgement and experience.

GROUNDWATER PUMPING

As a result of the foregoing reasons it is often very difficult to accurately predict pumping rates required to drawdown the water-table in advance of excavation. For example, at one opencast mine in such an environment[1], the assessments made by various contractors' consultants as to the pumping rate required to lower the water-table by 40 metres varied between 45,000 m^3/day and 250,000 m^3/day. After allowing for such contingencies as surface run-off during estimated 10 years storm conditions, the off-site drainage channel was constructed to take up to 68,000 m^3/day and in actual fact the average of groundwater pumped was 40,000 m^3/day with a peak during a period of heavy rainfall and maximum drawdown of 60,200 m^3/day.

In areas where extensive abandoned deep mine workings exist then the drawdown curve is often very flat due to the extremely high overall permeability of strata which is honeycombed with cavities, galleries and shafts. If they extend for many kilometres then the water may be drawn down over a considerable area and the possibility of ground subsidence due to loss of hydraulic support will need to be investigated. Once sufficient drawdown has been achieved the pumping rate can revert to a volume corresponding to the natural equilibrium conditions that existed prior to excavation.

It is an obvious fact, but sometimes overlooked, that the pumping rate must be compatible with the excavation rate. Too much pumping too early will merely waste money. However if the converse of too little pumping too late or if the wrong location or type of pumps are chosen then the following problems may arise, many of which are not immediately apparent but will certainly contribute to increased costs :-

- Flooded excavations requiring expensive and obtrusive sump pumping from lagoons constructed in the working area.
- The possibility of dangerous inrushes where old mine workings exist resulting in loss of coal production until the water is cleared.
- Slope stability problems due to a rise in the water-table behind excavated rock slopes and backfilled spoil slopes, and possibly pit floor heave.
- Increased blasting costs because of wet boreholes.
- Increased pollution if clean groundwater is allowed to enter the aggressive environment of the pit floor.
- An increase in moisture content in the coal product giving rise to handling problems in the coal preparation plant.

Thus it is extremely important to have sufficient hydrogeological data from which a practical estimate of pumping methods and costs can be made prior to the commencement of coaling. Pumping costs can constitute an important part of the "face price" per tonne of coal. In one instance a mine was contracted to produce 12,500 tonnes of coal per week and pumped groundwater at a volume of 40,000 cu.m^3/day with a head of 30 m resulting in 22 cubic metres of water being lifted for every cubic metre of coal produced. When this is translated into energy costs for the power to run the pumps plus the cost of piping, drainage channels, lagoons, etc. then it can be seen that in today's economic climate groundwater can have a considerable effect on the financial success or otherwise of a surface mining enterprise if insufficient attention is given to the problem. If box-cut and up-dip excavation methods are used the pumps will be required at the outset of the mine and hence large capital costs for pumping and associated works may be spent before income can be gained from the excavation of coal.

Off-site Drainage

If large amounts of groundwater are to be pumped off-site then the natural watercourses occurring within and downstream of the mine may be inadequate and may require widening, regrading and often diverting around the excavation area itself.

The hydrology of these streams and rivers will therefore need to be fully investigated by surveying and monitoring in order that diversions and works to downstream watercourses can be designed to accommodate the increased flow. Flow rates, stream profiles, cross sections etc. are required at least one year before work is to commence so that seasonal fluctuations can be taken into account. If temporary diversions are required to cross backfilled areas then an impermeable lining to the bed of the watercourse may be necessary to prevent water gaining access to the backfill and becoming polluted by contact with the disseminated pyritic material therein. If this water is further allowed to enter the working area then increased pollution and instability of backfill spoil slopes become a possibility.

Groundwater Pollution

Legislation under the various United Kingdom Control of Pollution Acts places constraints upon surface mine water discharge quality and have become increasingly more severe during recent years. In Scotland, the local River Purification Boards who have statutory authorities under the Act are, in their Consents to Discharge, applying the following conditions :-

- The mine discharge shall not contain more than 5 mg/l total iron.
- The discharge shall not contain more than 50 mg/l of suspended solids, dried at 105^{o}C.
- The pH value of the discharge shall be maintained within the range 5 to 9.
- The discharge shall not contain any visible signs of oil, tar, grease or any matter poisonous to fish.

These restrictions are being rigorously enforced and the mine operator must be constantly vigilant. In some instances[4] the natural water-courses may already contain issues from abandoned mines and have an iron content of up to 180 mg/l. Thus it is important that groundwater which may be potable or at worst contaminated with iron from abandoned old workings is not further polluted on entry to the excavation area. There is no doubt that the use of advance borehole dewatering techniques can reduce the possibility of this happening by preventing the clean water coming into contact with carbonaceous and pyritic material in the pit and it further reduces the necessity for expensive water treatment and lagoon construction. Lagoons systems, oil-traps, water-courses, pumping columns, cut-off ditches etc. are also required to be incorporated in the overall mine drainage scheme and to be compatible with the anticipated pumping rates.

Groundwater Rebound

Once pumping has ceased and the mine has been backfilled and restored to agriculture there is a problem of water-table rebound where the groundwater returns to its original level prior to surface mining. It has been proved[4] that the major cause of opencast backfill settlement is due to the rise in water-table on cessation of mining and if structures are to be built on such ground then monitoring of the water-table within the backfill must also be taken into account. Where this level is close to surface the groundwater may pass through highly permeable and pyritic backfill and become contaminated and issue at the surface in the form of ferruginous springs. To add to the problem some surface mines are associated with land reclamation schemes where toxic materials contained in such environmental eyesores as old spoil heaps and abandoned railway embankments are to be removed and incorporated in the backfilled surface mine area. To prevent contaminated water from issuing at surface from the restored mine requires careful planning on the choice of location for such waste materials. Suitable contouring of the restored site and diversion of streams from affected areas may also be necessary along with impermeable screening walls and layers surrounding any known toxic materials within the backfill. For example, one spoil heap removed from an old ironstone mine contained material with an acid soluble iron content of 20,000 mg/litre material. Quite often the spoil heaps show no overt signs of contamination such as effervescenses of sulphates or growths of other such indicator minerals and hence require full laboratory analyses during the site investigation stage before being accepted as fill material.

CONCLUSIONS

It is to be expected that the recent trend for increasing volumes of groundwater and more restrictive environmental control in Scotland will continue into the future and that in the process of winning more difficult reserves of coal the excavations will be deeper and go even further below the water-table. The problems concerning groundwater will therefore increase and require even more detailed hydrogeological investigation and monitoring to enable the mine operator to design efficient pumping systems and associated facilities in a cost-effective manner. There is no doubt that the recent improvement in pump design, the use of advance dewatering methods and improved restoration techniques have greatly improved the success rate in dealing with these increasing groundwater problems.

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