International Journal of Mine Water, Vol. 3 (1), (1984) 1 - 12
Printed in Granada, Spain

GROUNDWATER PROBLEMS IN SURFACE MINING IN THE UNITED KINGDOM

Ngah, S.A., Reed, S.M. and Singh, R.N.

Mining Engineering Department
University of Nottingham, Nottingham, U.K.

ABSTRACT

An outline of ground water problems in surface mining in the United Kingdom is presented. Sources of mine water in surface mining are described together with the operational problems created by adverse groundwater conditions. The effects of groundwater on the stability of excavation slopes, spoil slopes and superficial deposits are described with the aid of case histories.

INTRODUCTION

With the advent of modern excavation technology the surface mining operation has increased both in physical size and efficiency. The availability of new and improved machinery has led to a vast increase in the economic depth of extraction possible. In Great Britain, the extent to which this is occurring is exemplified by the fact that surface mining operators are frequently exploiting near-surface coal deposits which were previously worked by room and pillar mining systems.

The increase in the possible economic working depth has resulted in surface mine workings extending well below the water table. Consequently, groundwater and, occassionally, surface run-off have become factors for major concern. Surface mine excavations in Great Britain are generally quite shallow, the average depth being only about 50 m. However, some surface mine operations do work at significant depths below the water table. For example the proposed extension to the Westfield site, Fife, Scotland is planned to reach a depth of 250 m.

Groundwater problems, often under-estimated, now have a considerable effect on the overall economy of a surface mining project. The aim of this paper is to review the origin of surface mine water and problems associated with groundwater in surface mines, especially the British experience.

SOURCES OF INFLOW TO A SURFACE MINE

The sources of inflow to a surface mine can be classified as follows:

- Inflow from atmospheric precipitation and percolation through the backfill which forms its own water-table.
- Inflow through geological/structural features.
- Inflow from mineral beds and underground aquifers.
- Transmission via disused/abandoned mine workings.
- Inflow via pit floor heave and/or "piping".

Fig. 1 illustrates the main sources of groundwater and surface water inflow to a surface coal mine.

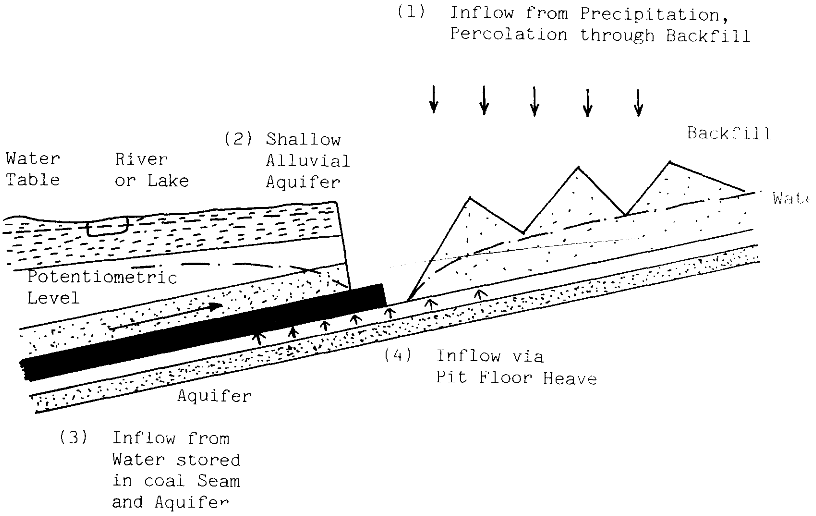


Fig. 1. Sources of Groundwater Inflow to Surface Coal Mines

Inflow from atmospheric precipitation

Atmospheric precipitation acts as a direct natural recharge to a sub-surface aquifer. Surface run-off due to rainfall or snow-thaw can also percolate through the superficial deposits to feed an underground aquifer. The unconsolidated nature of backfill provides an excellent conduit for the passage of water into the pit.

In British conditions, the rate of percolation through consolidated coal measure strata is normally low, due essentially to the presence of numerous semi-permeable horizons of mudstones and siltstones. If however, precipitation falls directly over well jointed and over-blasted slopes, then the rate of percolation becomes significant. At Westfield site in Scotland, the average annual rainfall is 924 mm but the groundwater level behind the slopes was raised by several metres owing to the direct action of rainfall on the well jointed and overblasted slopes.

Inflow from mineral beds and underground aquifers

British Coal measures are generally poor aquifer systems, and so water problems are not generally attributable to these strata, but rather to the adjacent post-carboniferous water bearing strata.

Subsurface aquifers serve to store and transmit groundwater, and when such beds are intercepted by mining activities, inflow may be induced to the excavation. A concealed outcrop of coal measures abutting heavily water-bearing strata may similarly allow a direct yielding of water into the excavation. Inflow to the mine will increase significantly if the aquifer maintains a hydraulic continuity with a large surface water body from where it draws its recharge.

Fossil water contained within more porous lithological units of the mineral bed and which is cut off from the hydrological cycle, can also be liberated into the excavation when disrupted by mine workings. In this case however, unless recharge occurs from an external source - which is less likely - the quantity of water yielded will be finite.

Fig. 2 illustrates the situation encountered at the Morewell Opencut operation in Australia, where a second coal seam, M2 COAL, is sandwiched between two sand-aquifer systems. The configuration was such that to avoid flooding the excavation, it was necessary to dewater the aquifers before the mineral could be extracted.

Transmission via disused/abandoned mine workings

Surface mines in Great Britain frequently work near surface coal deposits which have previously been worked by room and pillar methods. Such abandoned mines can provide highly permeable underground water reservoirs, which when intersected by mine workings provide a high potential in-rush situation. Groundwater stored in abandoned deep mines does not conform to normal hydrogeological patterns and estimation of the quantity of water available for release is often complicated by inadequate knowledge of the local strata stability, porosity and permeability. In situations where complete consolidation has not taken place, the porosity and permeability of the rock are obviously very high. The storage capacity will therefore be high and such water will be liberated into a surface mine if a hydraulic link is established with the old goaves.

Inflow through geological/structural features

Structural features associated with the geological environment of a

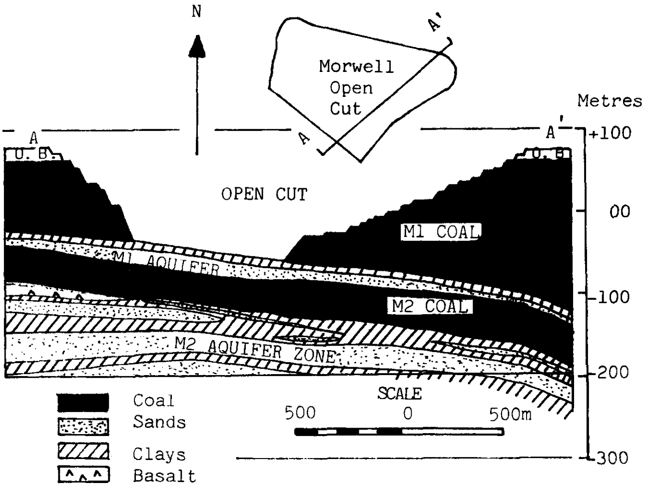


Fig. 2. Morewell Open cut Section (after Fraser and Pitt 1979)

mine can act as pathways through which water can enter an excavation. Such structural features include joints, faults, bedding planes, cleavage planes and dykes.

Faults which intersect the workings, and also penetrate water bearing horizons above and/or below the pit floor can act as excellent pathways along which flow can occur. Flooding can also occur if the faulting has brought a heavily water-bearing rock sequence into close proximity with the mining horizon.

Joints are common geological discontinuities in coal bearing strata. Their orientation and spatial distribution vary and depend, amongst other parameters, on the lithology, the thickness and the geological age of the rock as well as on the geological history of the rock. Where large accumulations of water are available, such discontinuities serve as low resistance routes for the passage of water from the accumulation to the excavation. Dykes penetrating water bearing horizons can also act as channels through which water may flow into a mine excavation.

In a well cemented sandstone sequence, the intact permeability is generally very low but the sequence can act as an excellent aquifer if jointing and fracturing are particularly well developed. If the sequence shows bedding, then flow can also be effected via the bedding planes.

Limestone can also form aquifers by the development of a series of fractures within the rock mass. Water moving through the limestone sequence (often slightly acidic) is capable of dissolving away the rock material forming solution channels and cavities capable of housing and transmitting large quantities of water. If such water bearing strata are intersected by surface mining operations, production and safety are naturally seriously affected. Table 1 illustrates some differences which have been recorded between the permeability of rock samples with reference to pore permeability (pk) and joint permeability (jk).

Table 1. Values of Pore Permeability pk and
Joint Permeability jk
(Blyth 1979)

Rock Type	Pore permeability pk (cms^{-1})	Joint Permeability jk (cms^{-1})	Width of Joint (mm)
Limestone	10^{-13}	10^{-4}	0.1
	10^{-9}	10^{1}	6.0
Sandstone	10^{-11}	$10^{-3}-10^{-2}$	0.4
Granite	10^{-10}	10^{-1}	2.0

Inflow via pit floor, heave and/or "piping"

If an artesian aquifer underlies the floor of an excavation and the confining bed is structurally weak, then flooding of the pit floor can result from a phenomenon termed "heave". Inflow will be rapid if the transmissivity and the hydrostatic head of the aquifer are high.

Floor heave results from the imbalance of forces which occurs when the overburden and mineral bed are removed in the process of mining. Prior to excavation, the weight of the strata above the confined bed provides a net downward resultant force on the bed, which is reduced as the overburden and minerals are removed. At the heave limit line, the downward weight of the remaining overburden is in equilibrium with the upward force acting on the confined bed as a result of water pressure. Further excavation will lead to an overall net upward force on the confining bed and the bed itself will tend to heave upwards. If the confining bed is incompetent, fracturing may occur and large quantities of pressurized water can be released into the excavation.

Floor heave is well exemplified by the case of Neyveli Opencast Mine, India, (Brearley 1964). At Neyveli, the hydrostatic pressure at the top of the confined aquifer before mining was 58,300 kgm^{-2}. The downward force exerted by the overburden, the mineral seam and the underlying confining beds amounted to 145,800 kg m^{-2} - a net downward thrust of 87,500 kg m^{-2}. As stripping progressed, the balancing pressure was reduced to only 9,700 kg m^{-2} leaving a net out-of-balance force of 48,6000 kg m^{-2} which acts upwards on the confining bed. The balance of force was restored by pressure drawdown pumping only at significant extra cost.

This particular problem of floor heave has not been experienced in Great Britain owing, probably, to the lower water pressures and the presence of more competent rock strata or because working has been at relatively shallow depths.

Pit flooding can still occur above the level of pit floor heave, and this is of particular importance in situations where the confining beds do not provide a perfect seal, or where communication exists through geological discontinuities, between the underlying aquifer and the level of excavation. Unsealed boreholes are of particular danger. A small, initial flow of water may occur, which escalates into a larger flow as the action of groundwater erodes its own transmitting channel - a phenomenon termed "piping".

Communication can also be established as a result of a local thinning out or sedimentary facies changes into more permeable material which provides an upward path through which water flows from an aquifer into the pit floor.

To determine the possibilities of "heave" and "piping" at a surface mine, it is essential that the strata should be tested well below the base of the working mineral for the presence of groundwater. To completely protect a mine from these hazards, the groundwater level must be lowered to a level well below that of the pit floor.

PROBLEMS CREATED BY ADVERSE GROUNDWATER CONDITIONS

The problems created by the presence of groundwater in a surface mine can be detailed as follows:

- The requirement for pit drainage.
- The possible need for a chemical treatment plant.
- The reduction in slope stability.
- The increase of costs.

The requirement for a pit drainage scheme

The adverse effect of the presence of groundwater in a surface mine obviously necessitates its removal. In Great Britain, the simple sump pumping method has been used on an "as required" basis. This method allows the groundwater to collect in the base of the pit, (the sump), from where it is pumped, treated and finally discharged into the local water courses. Recently, the use of the advance dewatering technique has proved superior. Using this technique the water table is lowered in advance of the workings, and the groundwater is consequently removed from the excavation area before it comes into contact with the polluting environment of the pit.

The need for pit drainage requires additional capital investment, and on sites with severe groundwater problems, the extra costs may become excessive, drastically reducing the overall profitability of the project.

It is essential that, in order to achieve an economy of scale, initial planning and recognition of a groundwater problem should be accorded its due importance. To design a pumping scheme effectively, estimates must be made of the expected inflow into the mine. A number of mathematical models exist for this purpose, the accuracy of all depending largely on site-specific characteristics. Information from local data such as past and present mines, civil engineering projects and even water wells must be considered when formulating a strategy for determining and combating groundwater problems.

The possible need for a chemical treatment plant

The removal of groundwater from a surface mine requires the discharge of such waters into natural water courses as part of the process. The discharged water is often of much different chemical composition than when it entered the pit environment. In British surface coal mines, the high concentration of pyrite present reacts with oxygen from the air, in the presence of water to produce a highly acidic, highly ferruginous discharge which is capable of severely polluting the local water courses and hence seriously affecting the ecological balance of the locality.

This polluted water requires extensive treatment before it can be discharged. The Control of Pollution Act 1974 seriously legislates against the discharge of polluted water into natural water courses. Treatment for the removal of suspended solids, iron and the restoration of pH value (to between 5 and 9) are generally required.

THE EFFECTS OF GROUNDWATER ON THE STABILITY OF EXCAVATION SLOPES, SPOIL SLOPES AND SUPERFICIAL DEPOSITS

The effect of groundwater on stability of slopes is well documented. Brealey (1964); Brawner (1968), (1982); Sharp, Hoek and Brawner (1972); Sharp, Maini and Harper (1972). Studies by Scoble (1981) showed that in an analysis of 82 case histories of slope failure in British Surface Coal Mines, 51% of these failures involved the presence of groundwater as a significant contributory factor. The consequences of such failures are readily apparent - loss of production, investment and in extreme cases even life.

Two cases reported by Scoble (1981) and Cobb (1981) show two typical failures occurring in Great Britain with groundwater as a significant contributory factor.

High wall instability at an opencast coal site (After Cobb 1981)

Water flow from the overlying glacial drift eroded soft mudstones below the A Seam (Fig. 3), undercutting a hard sandstone band above the A Seam. Sandstone blocks slid and toppled out on joint planes which formed a poorly developed set parallel to the wall dipping at 142°/85°. The component of strata dip into the wall was 10°.

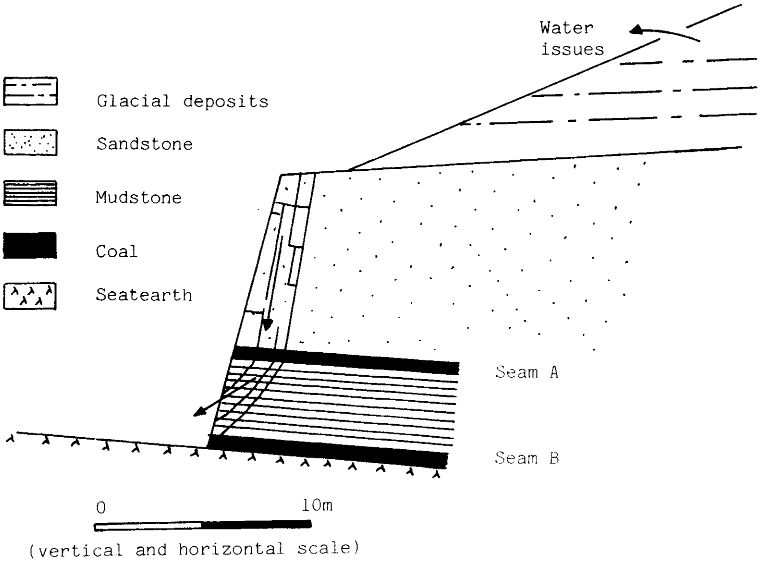


Fig. 3. Highwall Instability at an opencast coal site (After Cobb 1981)

Highwall sliding and wedge failure, (After Scoble 1981).

The highwall suffered a series of minor sliding incidents due to sliding on joint surfaces of 10° wedges, 2-3 m thick, formed by the intersection of the steep face (70-80°) and shallower dipping master joints (70°) striking parallel to the slope crest. (Fig. 4). A more significant 10 m thick wedge failed in the final highwall with its backscar coinciding with the line of the site perimeter ditch cut through the boulder clay into bedrock. Water inflow from this source was indicated as having reduced joint and rock strength by weathering and increased uplift/driving forces in the systematic joints, promoting deeper-seated failure. Fig. 5 shows other failure modes common in U.K. surface mining.

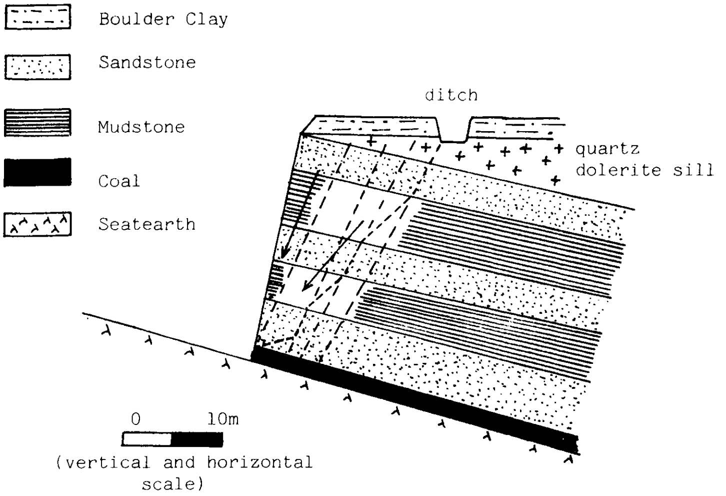


Fig. 4. Highwall sliding and wedge failure at an opencast coal site (After Scoble 1981)

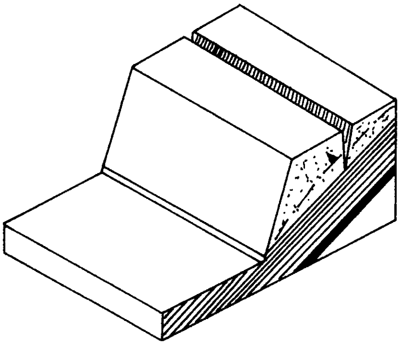
THE EFFECT OF GROUNDWATER ON COSTS

Apart from the possible adverse influence on the stability of excavated slopes and superficial deposits, groundwater affects the overall costs of the surface mining enterprise.

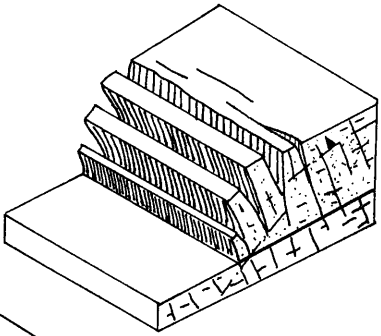
Effect on blasting costs

The cheapest and most effective blasting agent used in British mines is ANFO, ideal for use in dry holes. If wet holes are encountered then the explosive is quickly desensitized and even in blastholes with minor amounts of water, the use of polythene covering bags/tubes may prove impractical. (ANFO is less dense than water). Operators may thus be compelled to resort to the use of more expensive explosives such as opencast gelignite or aluminium slurry explosives. Relative costs of all three explosives are shown in Table 2.

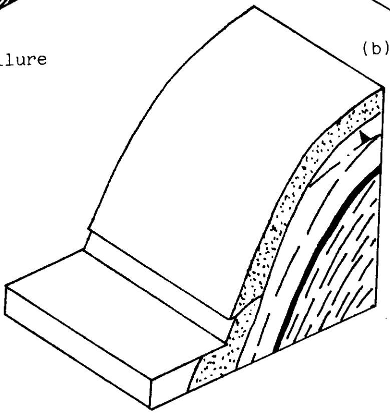
Table 2 well indicates the value in being able to use ANFO in preference to other explosives. As the volume of rock which requires to be blasted is generally in the region of 30-40% of the total excavation, the total extra cost to a contractor using water resisted explosives can be up to £100,000 for an average wet site. (Norton 1983).



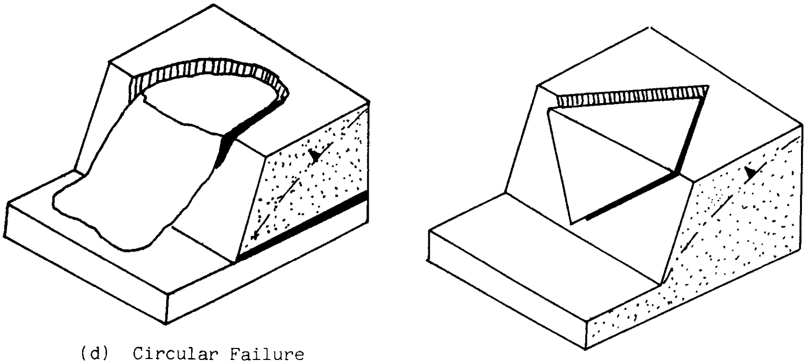
(a) Plane Failure



(b) Toppling Failure



(c) Slab Failure



(d) Circular Failure

(e) Wedge Failure

Fig. 5. Some failure modes common in U.K. (after Norton 1983)

Table 2. Relative Costs of Blasting Explosives (After Norton 1983)

Explosive	£/kg
ANFO	£0.81
Opencast Gelignite	1.28
Aluminium slurry	1.22

Effect on mineral (coal)handling and transportation costs

Coal often contains a high intensity of fractures making its moisture content high. Occasionally coal may act as an aquifer itself within the strata. The adverse problems which arise if the moisture content of the coal is too high may manifest themselves in the form of congestion of conveyors, screens and hopper-bin dischargers, caused by the more cohesive fines within the product.

Colder months may also freeze the coal to the sides of transporters e.g. trucks, railway wagons, necessitating the need for more expensive antifreeze products. (Norton 1983).

If the coal has too great a moisture content, then the net value of a cargo is reduced - unwanted moisture is transported from the mine to the buyer. In the iron ore mines at Knob Lake, Quebec, Canada, an extra 2% moisture in the ore increased the cost of transportation by 12 cents per ton. (Stubbins and Munro 1965). In Great Britain it is estimated that 5% of the load of an average lorry will consist of water, and stipulations are normally laid down by the buyers, specifying a maximum moisture content, and penalty clauses may be inserted into contracts.

Effects on machine/vehicle operation costs

Muddy pit floor conditions cause increased fuel and power consumptions in plant vehicles and machines. Maintenance of wheeled vehicles is high as tyres tend to skid and spin and consequently wear is accelerated.

A wet environment will also accelerate the process of corrosion, leading to a great increase in costs owing to maintenance, repairs and renovation of machinery.

CONCLUSIONS

The main sources and problems of groundwater is surface mines have been presented. It should be appreciated that with the depletion of shallow minerals and the advent of new mining technologies and machines, the economic depth of excavation of most sites and the physical sizes of these mines will continue to increase. Consequently, the problems attributable to groundwater will also increase.

In order to achieve economy of scale, detailed hydrogeologic and hydrologic investigations of mining sites should be integrated into the planning stage of a project. Groundwater monitoring should continue, even after production has commenced, helping to reduce to the barest minimum the choices and consequences of wet operations.

REFERENCES

1. Argall, G.O. and Brawner, C.O. (1979). Mine Drainage. Proc. of 1st Inter. Mine Drainage Symp. Denver, Colorado, USA.

2. Atkinson, T. and Dow, R. (1982). Surface Mine Drainage using Large Diameter Pumpwells. International Journal of Mine Water. IMWA, No. 1. December, 1982.

3. Aston, T.R.C. (1982). Hydrogeological Aspects of Rock Mechanics and Mining Subsidence around Longwall Extractions. An unpublished PhD thesis, University of Nottingham.

4. Brawner, C.O. (1968). Influence and Control of Groundwater in Open pit Mining. Proc. 5th Canadian Symp. on Rock Mechanics.

5. Brawner, C.O. (1982). Control of Groundwater in Surface Mining. International Journal of Mine Water. IMWA, No. 1, March 1982.

6. Brealey, S.C. (1964). Groundwater Control in Opencast Mining. Proc. of Symp. on Opencast Mining. Inst. of Min. and Metall. Nov. 1964.

7. Cobb, Q. (1981). Slope Stability in British Surface Coal Mines. An unpublished PhD Thesis, University of Nottingham.

8. Dow, R. (1982). Mine Water Investigations and Control Aspects. An unpublished MPhil Thesis, University of Nottingham.

9. Norton, P.J. (1982). Advance Dewatering and Control of Groundwater in Surface Coal Mining. 1st International Mine Water Congress, Budapest.

10. Norton, P.J. (1983). A study of Groundwater Control in British Surface Mining. An unpublished PhD Thesis, University of Nottingham.

11. Reeves, M.J. and Hammond, D. (1979). Old Mine Workings and their Influence on Rock Mass Permeability. Qterly Journal of Enging. Geol. Vol. 12.

12. Scoble, M.J. (1981). Studies of Ground Deformation in British Surface Coal Mines. An unpublished PhD Thesis. University of Nottinghan

13. Sharp, J.C., Maini, Y.N.T. and Harper, T.R. (1972). Influence of Groundwater on the Stability of Rock Masses 1 - Hydraulics within Rock Masses. Instn. of Min. and Metall. Jan. 1972.

14. Sharp, J.C., Hoek, E. and Brawner, C.O. (1972). Influence of Groundwater on the Stability of Rock Masses 2 - Drainage Systems for Increasing the Stability of Slopes. Instn. of Min. and Met. March 1972.

15. Stubbins, J.B., Munro, P. (1965). Openpit mine dewatering Knob Lake. The Canadian Mining and Metallurgical Bulletin.

16. Wood, P.A. (1981). Hydrological problems of Surface Mining. International Energy Agency, Coal Research, London. Report No. ICTIS - TR - 17.