# LATEST METHODS OF PREDICITION AND PREVENTION OF THE HYDROGEOLOGICAL IMPACT OF COAL MINING IN THE U.K.

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## ABSTRACT

Because of increasing constraints imposed on the mining industry by recent European and United Kingdom government legislation it has become even more important to be able to predict the hydrogeological impact of mine abandonment. Thorough hydrogeological investigation at the mine planning stage and the subsequent introduction of remedial measures into the operational phase and reclamation of mines and colliery wastes can do much to alleviate the problems of dewatering, pollution and groundwater rebound on mine abandonment. The paper outlines the background legislation and the latest methods developed by the author in the U.K. surface mining environment and uses case studies to illustrate the different methods used where groundwater has been a problem.

## INTRODUCTION

Environmental pressures have placed increasing constraints on the United Kingdom mining industry in recent years. New European Laws concerning the pollution of rivers and inshore waters has meant that the mine operator must be increasingly vigilant regarding pumped minewater and groundwater rebound issues which eventually reach downstream watercourses. Remedial measures must be included in the operational and restoration phases of both surface and deep mines as well as reclamation of colliery wastes. In order to predict and therefore be able to minimize the environmental impact it is imperative that a thorough hydrogeological investigation of the proposed mine site or reclamation area is undertaken as early as possible, preferably during the exploration period. As recoverable reserves are often deeper than in the past it is inevitable that many mines will go well below the water table and the problem is likely to become more acute in the future.

## U.K. BACKGROUND

### Legislation.

Over the last 100 years the U.K. has had a history of increasingly severe legislation imposed on the mining industry with regards to water pollution. However, upto 1951 the only law which concerned groundwater was the Rivers Pollution Act of 1876 and the Water Act of 1945. Both were non specific and were primarily concerned with water supply abstraction.

In 1951 the Rivers (Prevention of Pollution) Act came into force and its main relevant clause stated that a mine operator would be guilty of an offence if he knowingly permitted any pollutant to enter a watercourse. Regional Water Authorities were created to enforce the law mainly by improving consents to discharge water. The most severe limitation on discharge during this period was up to 5 ppm Iron a pH of between 5 and 8 and maximum suspended solids of upto 60 ppm. In some cases the mining company was expected to improve on ambient conditions.

Since 1974 the Control of Pollution Act has introduced much stronger measures and protects both underground and inshore maritime waters. The Government intends to create a new unified Inspectorate of Pollution on 1st April 1987.

Also since 1974, the U.K. has been a member of the European Economic Community (E.E.C.) and several of its directives have an influence on groundwater pumped from active and abandoned mines. Many of these restrictions are based on "The Polluter pays Principle" (1983), whereby it is the operator who causes the pollution who must pay to clean it up with no assistance been given from government sources.

The mining industry must exist within this background of legislation and in order to do so it is becoming increasingly necessary for hydrogeological investigation of the strata to be mined so that a safe and pollution free environment can be maintained. Unfortunately the fact is that mines are going deeper below the water table and as a result larger volumes of water are being pumped to maintain safe working conditions.

### Pumping

Until the early 1970's it was rare for a surface mine to intercept large volumes of groundwater; supplies of coal close to the surface were readily available. If water was encountered, then diesel or electric sump pumps were used on an 'ad hoc' basis. However as more water was encountered the possibility of dangerous inrushes and pollution of the water in the oxidising environment of the pit floor became a problem. Practical research was undertaken (Norton 1983) into the use of advance dewatering methods using electric submersible borehole pumps outside the excavation area. In this way the water is prevented from becoming polluted and the need for costly chemical water treatment and settling lagoons avoided. The cost effectivness of the method is considerable and it is now used at many locations in the U.K., especially where the surface mine is situated in a coal basin which has previously worked by extensive deep mine methods.

The volumes of water pumped in surface mines have increased from around a maximum of 120 litres/sec in 1970 to upwards of 1000 l/s in 1988 and is a significant cost factor in the face price of the coal. In one case over 20 tonnes of water are pumped per tonne of coal excavated.

A thorough hydrogeological and geotechnical investigation of the whole basin is necessary so that the resevoir of water which is contained in the abandoned workings can be assessed. Some of the interconnected voids date back to the 14th Century and many of them are unrecorded and can only be proved by dense drilling patterns. In some basins there are no longer any working deep mines left and because pumps have been withdrawn the water table has risen back to its original level close to the surface. A typical case of groundwater rebound on colliery closure was at Dalquharran in 1979.

The Dalquharran Case Study

The pit was the last to be worked in a confined coalfield (See Figure 1) and pumping ceased in 1977 and by 1979 acid minewater was issuing from the abandoned mine entrance. The quality of water was very poor with a pH of 4.1, Iron content of 1200 ppm, Aluminium 100 ppm and total sulphates at 6000 ppm. The peak wet weather flow was 150 l/ and eventually reached the River Girvan, a popular salmon fishing river. Within a very short time all biological life in the river ceased to exist and the mine operator were fined by the authorities under the Prevention of Pollution Act.

At first, the only remedies appeared to be either to pump the offending water to the sea some 8 km away, or to construct a chemical treatment plant and lagoons (Scottish Development Agency Report 1979). Both schemes were considered too costly and British Coal evolved a more ingenious and far less costly scheme (Goldie 1982) which is summarised below in Figures 2 and 3.

- All open shafts, pitfalls and other entrances whereby surface water and rainfall could gain access to the underground system were sealed.

- A horizontal borehole was driven into the Dowhail Level and a permanent gravity drain installed in order to lower the overall water table level in the system to that at the Dalquharran outfall and draw off relatively clean water from the system.

- A dam was constructed at the Dalquharran outfall so that that the outflow of water could be regulated i.e. releasing water during periods of high river flow and retaining it during low flow periods. This provided a dilution effect with the river water and maintained an iron content of less than 1 ppm in the River Girvan itself. Flow gauges were installed in the river to facilitate this.

The scheme has been an unqualified success and the author is pleased to state that the latest River Inspector's Report (Clyde River Purification Board 1985) shows a full recovery of the biological index to the highest ever recorded in the River Girvan and furthermore that in 1986 a large amount of salmon returned to breed in the water.

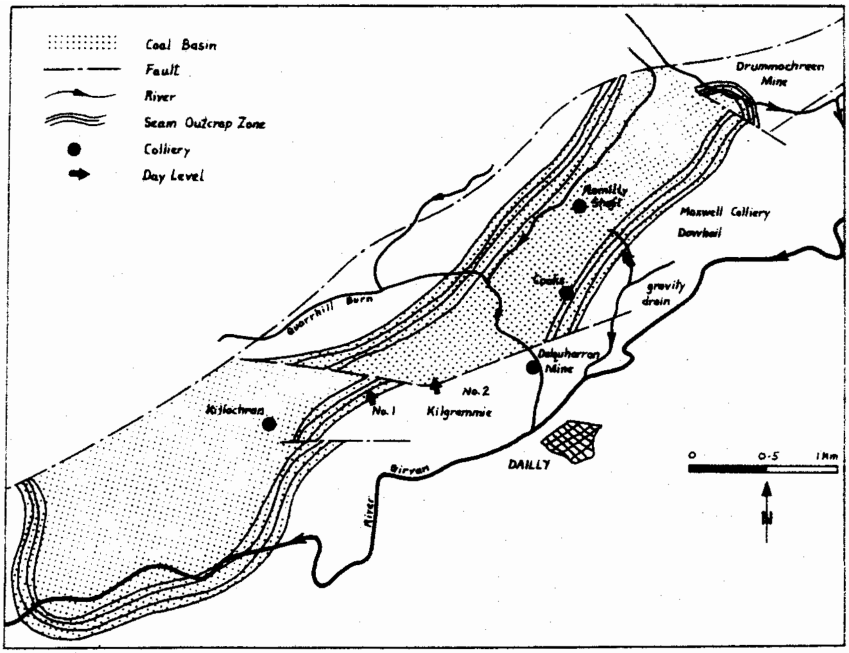


Figure 1. GEOLOGICAL PLAN OF DAILLY COALFIELD.

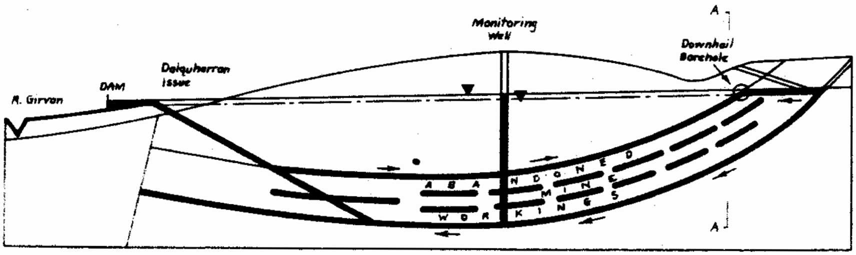


Figure 2. DIAGRAMMATIC CROSS SECTION THROUGH DALQUHARRAN MINE.

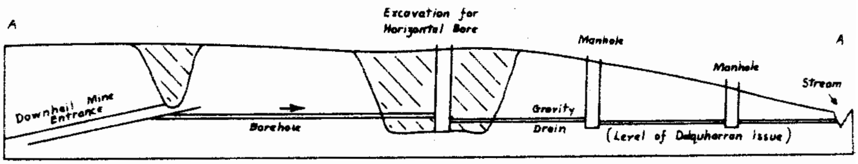


Figure 3. SECTION AA THROUGH DOWHAIL GRAVITY DRAIN.

## HYDROGEOLOGICAL INVESTIGATION

Until about 15 years ago very little hydrogeological investigation was necessary for surface mine development. Most mines were shallow and in areas where deep mine pumping was still active, therefore most surface mines never reached the permanent water table. Now conditions are reversed and the need for hydrogeological investigation has become very important so that remedial measures can be included in the operational and reclamation phases of mining.

Apart from the more obvious techniques using piezometers and pumping tests there are several new methods being used in the U.K. The latest developments in physical and chemical investigation are discussed.

### Physical Investigation

It is important that groundwater monitoring equipment is installed at least one year before the mine plan is finalised. In this way the seasonal fluctuation in the water table can be observed and compared with rainfall and hydrology of adjacent rivers. Even where considerable underground extraction has taken place there will be a small change in level of at least one metre which is limited by the level at which shafts and adits connecting with the voids reach the surface. This may be a considerable distance away from the mine site and the piezometers but because of the high permeability caused by the abandoned deep mine workings the fluctuation in water table is very low in comparison to the normal response to rainfall reflected in areas of solid undisturbed strata.

The graph shown in Figure 4 shows such a response,in this case only 4.5m, where the piezometers and site were located 6 km away from the very variable main surface issue of acid mine water from the abandoned mine workings connecting with the future surface mine. It was found during this investigation that the surface issue was slightly influenced by atmospheric pressure i.e. when pressure was high the flow was reduced and vice versa. In some cases this phenomenon has been known to alter flow rates by as much as 10% for every 10 millibar change in pressure.

In areas of extensive abandoned mine workings it has not been found worthwhile to conduct pumping tests prior to mining because of the extremely large mass permeability caused by the interconnecting voids. The test pumping rate would therefore equate to that necessary for the final working rate in order to indure a significant draw down. Only in areas where a minimum amount of old workings or solid strata exist has it been found suitable to conduct the usual falling head, constant head and well test observations.

The task of estimating the reservoir of water contained in the abandoned mine voids is very difficult (Rogoz 1978) especially, as often happens the workings are so old that no plans of them exist. Once the voids have been located by drilling then a further estimate of the degree and method of extraction, backfilling and collapse must be made. From experience, it has been found that the total reservoir volume that will connect with the pumps can only be calculated with an accuracy of $\pm$ 50%. Also, the strata between the Coal Seams is affected by collapse and the permeability values are thus very variable. In the final assessment it has often been found that only values to the right order of magnitude can be calculated and the only way of achieving this

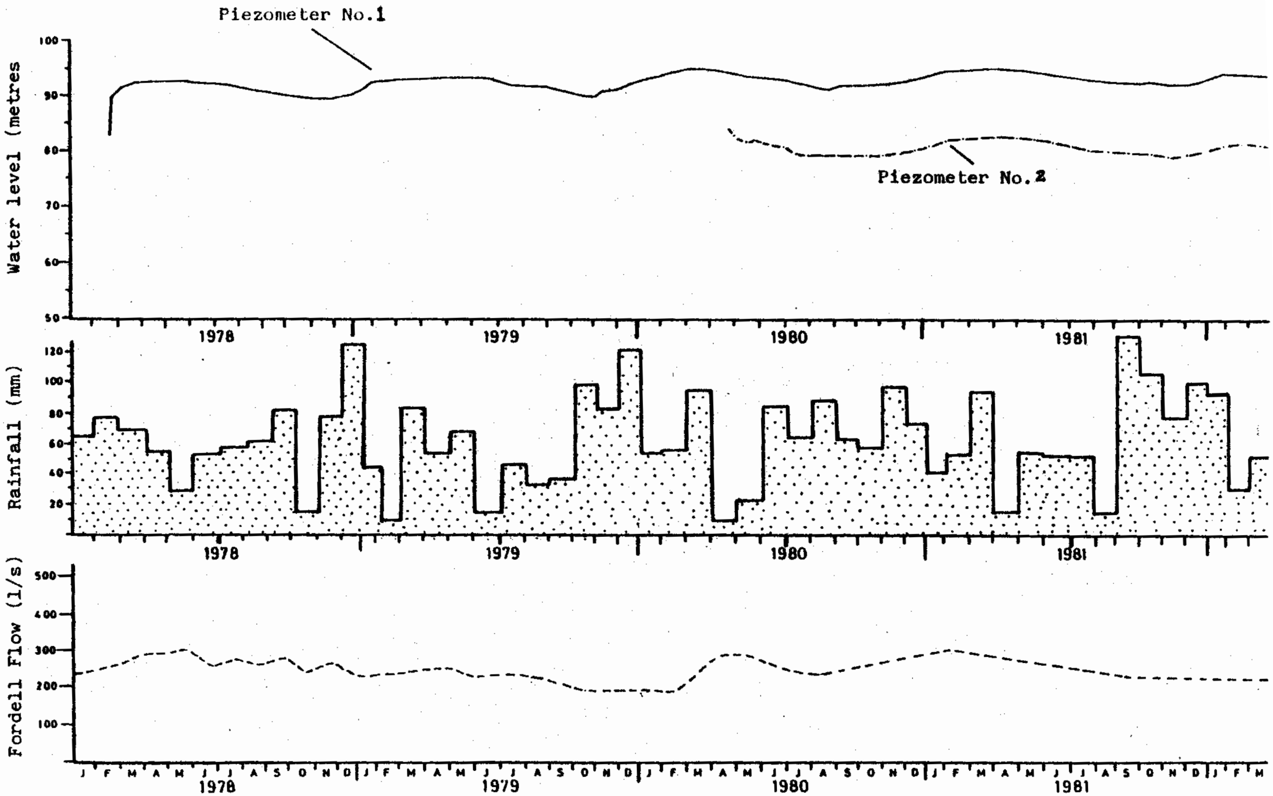


Figure 4. GRAPH SHOWING COMPARISON OF FLOW RAINFALL AND PIEZOMETRIC LEVEL IN A SMALL CONFINED COALFIELD.

is to space exploratory boreholes as close as 30 m apart. The subsequent installation of pumps, lagoons and discharge watercourses must take this into account.

## Chemical Investigation

To complete the hydrogeological picture, it is necessary to also consider the quality of water prior, during and after the mining event. Again the investigation should be at least one year prior to mining so that seasonal fluctuations in the ambient conditions can be recorded. The changes in iron content of the receiving streams in areas of abandoned old workings can be quite large. The level of iron in flood conditions when heavy winter rainfall causes the water locked in the abandoned mine working voids to burst out of shafts, day levels and pitfall. This effect can be seen in the case illustrated in Figure 5 where iron in the form of ferric hydroxide was flushed out of the old workings. The graphs shows the effect of one particular shaft on the quantity of iron in the stream compared with the rainfall figures. The site is located in an upland area with an annual average rainfall of about 1500 millimetres. Experience has shown that the quality of water which is eventually pumped from the advance dewatering boreholes will approach that of the issues during flood conditions. This is assumed to be due to the increased flow of water through the old workings induced by the act of pumping.

Once the coal has been worked, then the old workings can be sealed and the groundwater, if it rebounds and issue at surface after restoration, should not be as polluting as prior to working. However, it may be that the backfill itself is a potential pollution source and the prediction of this has been the subject to much recent research (Henderson and Norton 1984). The method outlined in the reference can also be used to assess any colliery waste or fill material which is used for backfilling abandoned surface mines or used in the construction of embankments and other civil engineering structures. In the latter case it is important to know whether the material is the source for sulphate attack on concrete or acidic attack on metal structures such as soil reinforcement straps.

Continuous cores of the strata to be mixed or samples of the colliery waste are taken to the laboratory. In the case of the cores the strata is split into lithological units and each sample then crushed and dried to minus 3mm reduced systematically to 500 gram samples and further crushed to minus 0.02 mm for analysis. Each sample is then tested for pH, moisture content, organic and pyritic sulphur, and Acid Neutralizing Capacity (A.N.C.). From this the Acid Producing Potential of each individual section of strata or sample of colliery waste can be assessed by subtracting the A.N.C. from the Theoretical Neutralization Requirement (calculated from the potential acid producing sulphur in proportion to the sample thickness). An Acid Producing potential of only 1% represents a potential production of about 9.8 tonnes of sulphuric acid and 5.64 tonnes of Ferric hydroxide per 1000 tonnes of backfill.

It is essential therefore if problems are to be avoided that units of polluting material indentified from the tests are segregated or mixed with other material with a high neutralizing capacity. The technique has now been widely accepted and it has been found that strata with the most acid producing potential are mostly found within argillaceous rocks adjacent to coal seams. Unfortunately, this is the very material which quickly weathers on exposure during the mining process and provides a larger surface area for contact with circulating groundwater. However, it is also gratifying to note that most sites investigated so far in the U.K. show a sufficient amount of neutralzing strata (mainly sandstones and limestone) to counteract this effect. The mine sites and materials to be wary of are those with an excess of 75% of argillaceous rocks in the overall overburden to be excavated and subsequently restored.

## BIOTECHNICAL RESTORATION

All surface mines must be restored in an acceptable manner in agreement with Local government Authorities. In recent years, the restrictions on the type and method of restoration of surface mines and quarries has been increased and been the subject of numerous Government reports and commissions. Mine sites may be restored to agriculture, forestry or amenity use (recreation or urban development). The recent research into biotechnological reclamation methods at sites where groundwater rebound is a problem is discussed below.

For many reasons such as high bulkage factor, low overburden to coal ratio etc. there may be a void left at the end of the mining operation. This void may be simply left and allowed to fill with water,backfilled with colliery waste, or used as a landfill site for domestic waste. The recreational amenity value of a lake has many attractions for restoration but in some cases the water may be acidic after having passed through pyritic backfill. Until recently, it has not been possible to remedy this except by the ad infinitum addition of considerable amounts of expensive chemicals. Recent investigation by British Coal Minestone Services in conjunction with the Freshwater Biological Association has found anew and successful, one-off remedy by the addition of activated sewage sludge to the acidic minewater lake. (See Figure 6). The organic material added to the lake starts a process of eutrophication whereby the high iron sulphate content of the water and other toxic metals are reduced to sulphides in a reducing environment and deposited in the sludge on the lake bed. The resultant deposit prevents any further oxygen getting to the pyrite in the backfill and as a result the lake is neutralized and capable of supporting fish and plant life. The geometry of the lake bed is critical to the success of the scheme.

In order to back up this remedy, it has been found necessary to provide a wetland environment downstream of the lake in order to clean up any other acidic minewater in the vicinity or even lake water should a flood cause the sulphides in the lake bed to be stirred up. The use of wetlands can also be used downstream of any source of acid mine water such as colliery waste heaps. The provision of a marsh environment again reduces sulphates to sulphides in a reducing environment and provides another remedy that requires no further labour or capital investment. The wetland area also finds public environmentalist approval as it will eventually create an 'ecological niche' for wildlife.

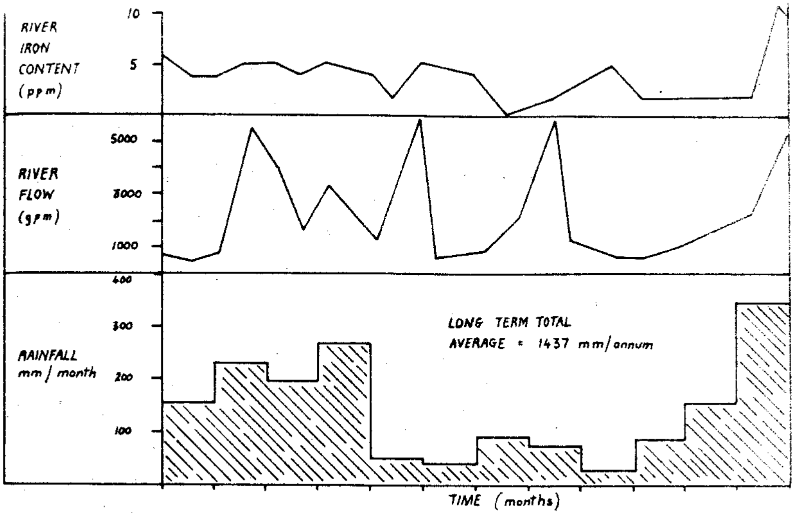


Figure 5. CORRELATION BETWEEN RAINFALL, RIVER FLOW AND IRON CONTENT PRIOR TO MINING.

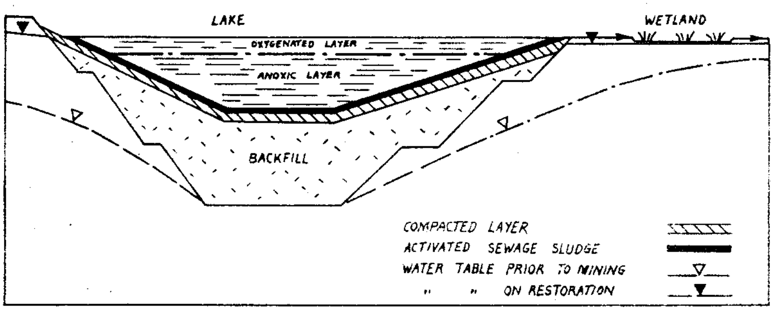


Figure 6. MINE SITE RESTORED TO A CLEAN WATER LAKE BY USE OF ACTIVATED SEWAGE SLUDGE AND DOWNSTREAM WETLAND AREA.

## CONCLUSION

In the space available, it has only been possible to give a brief outline of the latest researches in the hydrogeology of coal basins in the U.K. The most promising developments are in the use of biotechnical remedies for controlling pollution and the research continues in the use of cheap and readily available materials such as sewage sludge and the use of wetland environments. It is hoped in the future to have much more precise prediction of groundwater problems so that preventative measures are successful and cost effective.

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