Hydrogeological and Hydrochemical problems relating to the Smotherfly Opencast Coal Site: An Integrated Approach to the Granting of a Discharge Licence.

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ABSTRACT

In 1989, British Coal Opencast were granted planning permission to develop and extract over 1.6 million tonnes of coal from the Smotherfly Opencast Site at Alfreton in Derbyshire. The proposed mine, which was planned to excavate both solid and room and pillar workings in the Deep Soft and Deep Hard seams, was partly on the site of an abandoned acid and tar works with associated shallow surface and groundwater contamination. The site was also situated some 600m down dip of a previously excavated opencast mine used as an industrial landfill with an unknown 'cocktail' of potential contaminants. The planning permission could not be fully implemented until a discharge licence from the National Rivers Authority was obtained, a licence obtained for the safe burial of shallow surface contamination, and approval of both a temporary and permanent diversion of the River Erewash to allow mining to proceed. The consenting procedure for the discharge licence was technically extremely difficult to achieve as the site contained a considerable number of extremely complicated and interrelated hydrological, hydrogeological and hydrochemical problems that were in urgent need of resolution.

The paper describes the integrated approach adopted by British Coal Opencast to successfully acquire the discharge consent. It describes how a multi-disciplined team of geologists, hydrogeologists, civil engineers, process chemists and mining engineers worked together with engineers and scientists from the NRA during an extensive period of site investigation that included hydraulic insitu testing, comprehensive water quality sampling and long term pump testing. Also discussed is the construction of a multi-layered numerical model designed to simulate the measured groundwater heads and then quantify the inflow characteristics with various containment options in place. The paper finally outlines the groundwater treatment system and the process controlled systems that were established to successfully treat the contaminated groundwater system.

INTRODUCTION

Aim and Objectives of the Paper

The aim of this paper is to present the approach adopted by British Coal Opencast in tackling a complex hydrogeological and hydrochemical issue which crucially impacted on the exploitation of a low cost, high quality coal reserve. The paper will demonstrate how an integrated approach by a multi-disciplined team of geologists, hydrogeologists, civil engineers, process chemists and mining engineers worked together with engineers and scientists from the National Rivers Authority to achieve an acceptable solution for both parties.

The paper briefly reviews the level of existing information, summarising the scope of the problem and the programme of detailed site investigation. Finally, the paper describes the test interpretation, groundwater modelling and contaminant assessment that formed the basis for the successful acquisition of a discharge licence from the NRA.

BACKGROUND INFORMATION

Details of Proposed Mining Operation

The proposed Smotherfly Opencast Site straddled the River Erewash and the Derbyshire/Nottinghamshire border between Somercoates, Pinxton and Jacksdale, about 4 kilometres south-east of Alfreton, (see Figure 1). The site was divided into three areas by the main Sheffield - Trent Junction railway line and the B600 road. Each area had its share of dereliction and/or contamination. Area A, west of the main railway line, contained at least two known waste tips filled in the 1950's, 1960's and 1970's. Area B, east of the railway and north of the road contained contaminated land associated with a former acid and tarworks. The south-easterly portion, Area C, included the surface of the former Pye Hill Colliery and adjacent derelict pipeworks. The rest of the site was predominantly in agricultural use either side of the meandering course of the River Erewash.

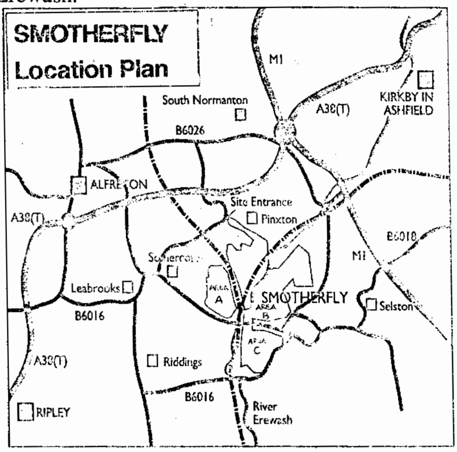

Figure 1 - Location Plan of the Smotherfly Opencast Site

In 1986, the Opencast Executive applied for planning permission to mine 2.3 million tonnes of low cost good quality coal in the three areas described above. The application was not accepted by the two Mineral Planning Authorities, and an appeal was made and a Public Inquiry held in 1988. In March 1989, the Secretary of State for the Environment granted planning consent but excluded area A, west of the main railway line, on the following grounds:

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"So little is known about the waste deposited on site and that the hazards of disturbing any Dioxin contaminated waste are so great and technically complicated that planning permission should not be forthcoming for such an area until a complete investigation has taken place".

The planning permission could not be fully implemented until the following matters were concluded:

a) Identification of the nature of the acid and tar-works waste and securing of the necessary waste disposal licence for its excavation and safe burial.

b) Investigation of the pre-mining hydrogeological regime and designing of any mitigating measures required to control the potentially contaminated groundwater during excavation.

c) Obtaining a Land Drainage Act Consent for the temporary diversion of the River Erewash around the western side of Area B.

d) Obtaining a Land Drainage Act Consent for the permanent restoration of a sinuous River Erewash.

e) Bringing the geological and geotechnical assessment up to date and production of a detailed specification and drawings for the mining contract.

With Area A deleted from the scheme, the tonnage within the Smotherfly site was reduced to 1.68 million. The proposed mining method involved excavation of an opening void in the south of Area C. Overburden would be hauled under the B600 to the designated dump space on agricultural land restored from earlier opencast mining to the east of Area B. Once the initial void was decoaled to the basal seam over a sufficient cut width, work could commence on a series of compacted clay cells to receive the estimated 120,000 cubic metres of acid and tarworks waste which was situated on the alignment of the temporary diversion of the River Erewash.

Mining would progress northwards in Area C with waste cells butressed within the backfill by overburden stripped from the advance.

Once the contaminated land in Area B was cleared to acceptable standards, the temporary river diversion would be installed and excavations for Area B opening void would commence in the south with overburden going to backfill in Area C final void.

Area B would then be progressively coaled out in east-west oriented cuts travelling in a northerly direction. The final void at the northermost part of the site would be backfilled using

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the initial overburden from the adjacent dump. All soils would be restored, the sinuous course of the River Erewash would be redug in alluvial materials, and the temporary channel backfilled.

Geology and Previous Mining

The geology of the Smotherfly Site is summarised in Figure 2. The proposed mine was planned to work a sequence of Middle Coal Measures from Deep Hard to the Roof Soft seam. The whole area had been heavily undermined by deep long wall mining. The main coal reserves were present in the Deep Hard and the Deep Soft seam. Both seams contained significant areas of old deep mine room and pillar working and adjacent shallow opencast workings. A map showing the location of the old workings is given in Figure 3. Two former opencast sites were present in the immediate area, the Cambro Site and the Somercotes Site, both sites being situated 'up dip' to the West of the site.

The lithology of the Coal Measures proved by the main exploration programme confirmed a standard sequence of cyclical sediments. The floor of the Deep Hard was characterised by a moderately weak mudstone seatearth. The immediate roof of the Deep Hard Seam was generally composed of weak mudstones that graded quickly into a series of more competent beds of sands and silts that formed the floor of the Deep Soft Seam. With the exception of its immediate roof the strata above the Deep Soft was composed of a quite competent series of locally fractured sands and silts. Throughout the site immediately overlying this stronger sequence, a split sequence of Roof Soft coals and associated weak mudstones and mudstone seatearths were present. This group divided the competent measures of the Deep Soft roof with a higher sequence of highly fractured interbanded sands and silts.

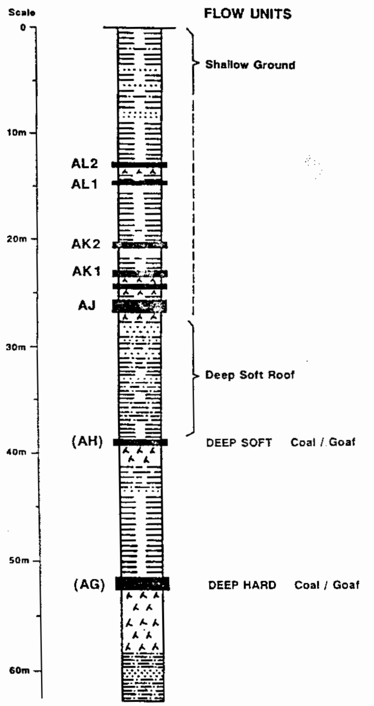

Figure 2 - General Geology of the Smotherfly Site

Hydrogeology

Although good geological information was available from the main exploration phase, the level of hydrogeological data prior to the investigations described below, were minimal and suspect.

The general groundwater flow direction was understood to be irregularly from the Cambro Waste Disposal Site, generally south-easterly to the River Erewash. Throughout the area much of the ground had been observed to be saturated to ground surface during winter months but no information existed about permeability distributions or preferred groundwater flow pathways.

In natural, undisturbed ground the Coal Measure sequence present, would contain groundwater under fairly uniform conditions, it would exhibit a very low permeability and storage. However, because of the past mining, current mine dewatering and material disposal operations at the surface, it was clear the natural ground must have been disturbed to create substantial heterogeneous groundwater conditions both at depth and in the shallow ground. Therefore, detailed hydrogeological studies were considered necessary to define groundwater flows and contaminant pathways.

Potential Sources of Contamination

Potential sources of contamination are shown in Figure 3.

Both opencast mines west of the site had been backfilled with various waste materials, often of a toxic nature. Information was available from the Waste Regulatory Authority on the waste licence conditions for the landfills together with the likely nature and source of contaminants deposited here. Earlier landfills had not been carefully monitored.

CAMBRO waste disposal site is located adjacent 600m W and upgradient of the proposed opencast mine. The landfill was in operation from 1948-1978. The main chemicals tipped which could achieve significance in the aquifers were phenols, chlorinated phenols, chlorinated solvents, ammonia, heavy and trace metals, cyanides and aromatic compounds. Of particular concern was the possible presence of demolition rubble contaminated with dioxin arising from the Chemstar factory explosion at Bolsover in 1968. The restored site is domed with a steep valley running down its western front to a stream.

SOMERCOATES landfill 400m W of the excavation edge only operated from 1968-1971 but is believed to contain toxic materials including coal tar and phenols.

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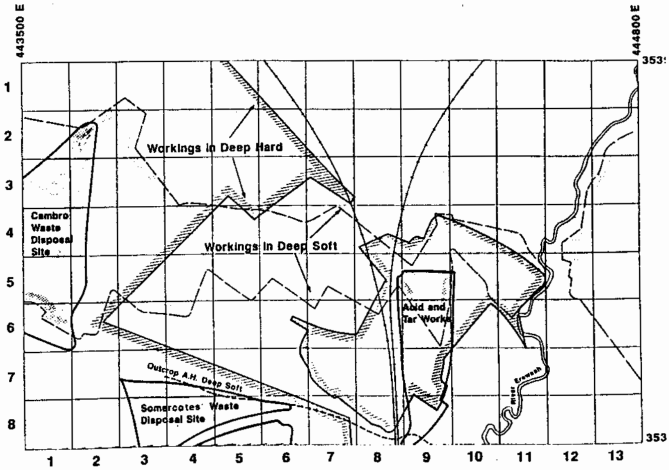

Figure 3 - Plan Showing the Distribution of Old Workings and Potential Sources of Contamination adjacent to the Smotherfly Site.

ACID AND TAR WORKS: In addition to waste disposal, operations of the derelict Pye Bridge Acid and Tar works on the western edge of the site had produced gross contamination of the surrounding land. Previous investigations by Scott, Wilson and Kirkpatrick for British Coal Opencast showed groundwater to be contaminated below the Acid and Tar Works.

GASWORKS: A further potential source of contamination is a former gasworks located adjacent to Somercoates waste disposal site.

Disused shafts in the region continue to be used for waste disposal, but none of this activity occurs within the study area.

SCOPE OF THE PROBLEM

The proposed mining operation in Area B involved excavating solid and room and pillar workings in the Deep Soft and Deep Hard Seams. Initial investigations had established a potential conduit for ground water entering the Area B workings and bringing with it a possible contaminated plume from the landfill sites within and adjacent to the excluded Area A.

The newly formed National Rivers Authority were concerned about the possible movements of contaminants and revoked British Coal Opencast's existing Consents to Discharge in April 1990 explaining that they were not satisfied with limits only being placed on the typical opencast mining determinands of suspended solids, visible oil and pH when there were prospects of a wide variety of organic and inorganic chemicals reaching the River Erewash through trade effluent from the pumped void. Furthermore, account needed to be taken of improved water quality objectives for the River Erewash bearing in mind the already significant pollution load of the river.

During negotiation with the NRA, progress was being made on the Waste Disposal Licence application to Notts County Council. It was accepted by the NRA that the river was already being polluted from uncontrolled surface water run off from the acid and tarworks. The NRA who were a major consultee on this matter were broadly satisfied that British Coal Opencast's proposals to bury contaminated soil within clay lined cells were satisfactory.

British Coal Opencast was therefore faced with the challenge of obtaining new Consents to Discharge with workable limits which took account of the practical limitations inherent in an opencast coal site.

TECHNICAL APPROACH

Introduction - Team Approach including NRA

It was necessary therefore for British Coal to identify what skills it would need to obtain new consents to discharge. In addition to its own geological, geotechnical and chemical sampling resources, the team was supplemented by outside expertise to provide groundwater modelling and expert advice on the chemical treatment.

It was clear that further advice was needed on chemical treatment of any effluent reaching the working void and that the ability to treat diverse pollutants linked closely with the need for specialist skills in negotiating Consents to Discharge. Anglian Water (Engineering and Business Systems) were selected to lead the negotiation with the NRA, their laboratory capability particularly in the field of organic chemistry also dovetailed well with British Coal's inorganic expertise at Bretby.

British Coal's new team could not work in isolation as trust had to be built with the National Rivers Authority to ensure that all their concerns were properly addressed from the start of the site investigation programme.

Field Investigations

Programme of Site Investigation

In an effort to resolve the technical problems of the site, it was necessary to undertake a further major programme of detailed site investigation, which included the drilling of 40 surface boreholes. The aim of the programme was to quantify the detailed hydrogeology of the site and to assess the level and extent of any groundwater contamination present within the abandoned old workings or adjacent to the acid and tar surface tips. An additional requirement of the site investigation programme was to assess the feasibility of reducing the permeability of the abandoned Deep Soft old workings by surface grouting.

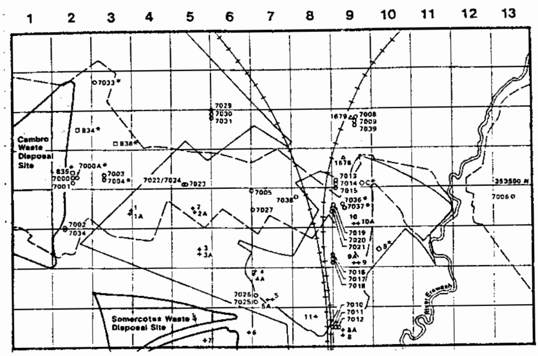

Figure 4 - Plan showing the Location of the Site Investigation Boreholes

From the original programme of 40 boreholes, 13 boreholes were fully cored, photographed and geophysically logging. These boreholes were also hydraulically tested using either 'short duration' straddle packer tests or long term pump tests. The grouting characteristics and the local insitu permeability of the strata adjacent to the borehole were measured using a Lugeon Test. This insitu measurement is a stepped injection test conducted under 3 increasing and 2 decreasing levels of injection pressure. In general the boreholes were drilled in nests of 3. First, the deepest borehole was fully cored, hydraulically tested and geophysically logged to Deep Hard, prior to being completed as a piezometer using 50mm slotted UPVC pipe, gravel packs and bentonite seals. On completion, 2 adjacent boreholes were open holed and completed as piezometers in the Deep Soft seam and in the shallow aquifer. A plan showing the distribution of the boreholes is presented in Figure 4. The programme of boreholes were planned to measure the degree of contamination adjacent to the Cambro site, (boreholes N-S 7034-7033), the degree of attenuation and dispersion of the contaminants within the Deep Soft old workings (E_W boreholes 7000-7037) and the feasibility of grouting the worked Deep Soft and Deep Hard (boreholes N-S 7008-7012). In addition, further groups of boreholes were drilled to assess the effective recharge into the flow systems, the difference in hydraulic parameters between mined and unmined sections and to measure the hydraulic performance of intact pillars of coal between the Somercoates Opencast site to the south.

Sampling

The groundwater sampling programme was designed to characterise the quality and contamination of those groundwaters with a potential to be drawn into the opencast excavation. Particular attention was paid to the Deep Soft and Shallow flow units thought to have the most significance for contaminant transfer. The sampling also investigated lateral, vertical and temporal trends in groundwater quality.

Groundwaters from a grid of 29 boreholes were pumped with a view to sampling. Not all boreholes yielded enough water for sampling purposes. No boreholes were drilled into the waste disposal sites for reasons of safety, occupational health and land ownership. Several boreholes did penetrate through the contaminated land around and under the Acid and Tar Works. Vertical groundwater quality profiles were examined by nests of boreholes, each open against individual flow horizons.

A detailed sampling protocol was adopted to ensure adequate health and safety and to prevent cross contamination of samples. Sampling was carried out by British Coal chemists under the supervision of Anglian Water and British Coal Opencast personnel. All samples were pumped from 50mm and 100mm submersible borehole pumps. Time series sampling was also carried out on key boreholes.

On site quality measurements provided immediate indications of quality changes to trigger extra sampling. A total of 20 sets of groundwater samples were taken and despatched to 5 laboratories for comprehensive analysis of indicator determinands, ionic profiles, strength and treatment parameters, contamination and toxicity. The full analytical suite is given in Table 1.

All discharge water not sampled went to on site lagoons by pipeline or steel tanker. The waters in these catchment ponds were analysed several times to provide information on overall contamination and the effect of simple lagooning on the water.

RESULTS AND ANALYSIS

Groundwater Flow Units

The results of the site investigation programme defined three groundwater flow units separated by low permeability units. The groundwater flow units are:

The Shallow weathered and made ground

The Deep Soft mined strata and overlying collapsed strata

The Deep Hard mined strata and overlying collapsed strata

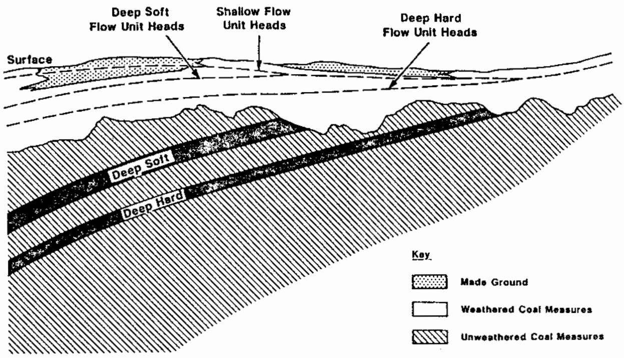

Figure 5 - Conceptual Diagram of the Hydrogeological System at Smotherfly

The shallow groundwater unit is lithologically controlled and contained primarily in weathered material but locally lies in reworked natural materials and various types of made ground. By the nature of its ground environment it is clearly very hydrogeologically heterogeneous.

The Deep Soft coals and associated overlying strata would normally have very low permeabilities and storage, but have been subjected to two mining operation effects. Firstly, deep mining will have induced minor subsidence throughout the area resulting in general permeability and storage enhancement, particularly in the more competent strata such as the coals. Secondly, local shallow "pillar and stall" mining has created a "cave-like" system in the Deep Soft and Deep Hard Seams.

Groundwater Head Distribution

On completion of the site investigation, the programme of completed piezometers were monitored on a weekly basis to establish the 3 dimensional distribution of groundwater heads. The results of the study are presented below. Recharge occurs chiefly to the shallow ground unit, as this unit is present over much of the studies area. Recharge does, however, also occur to the very limited outcrop areas of the Deep Soft and Deep Hard directly. It can also occur to these units via the shallow ground flow unit. The head inter-relationship between the units is shown conceptually in Figure 5.

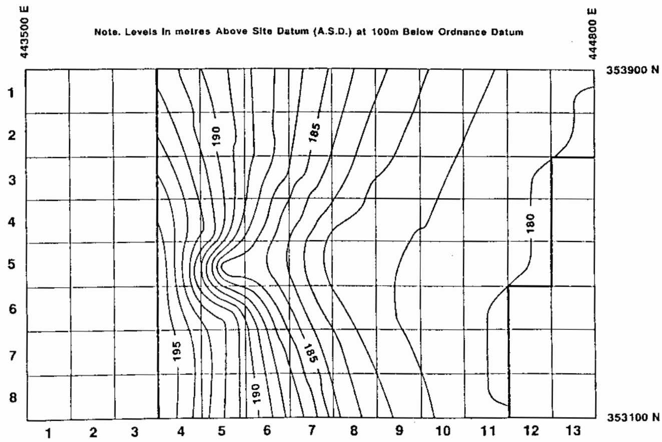

Figure 6 - Initial Groundwater Level Distribution for the Shallow Groundwater Flow Unit

Figure 6 shows the groundwater head distribution for the shallow ground flow unit with a general easterly flow. Topographical effects on the flow systems are indicated by head inflections in the west. Time-variant heads have been measured in the unit with a range of at least 3m.

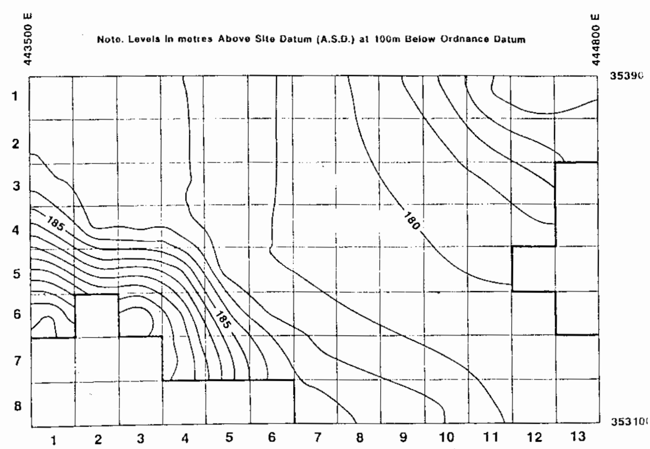

Figure 7 - Initial Groundwater Head Distribution for the Deep Soft Flow Unit

On Figure 7 the head distribution for the Deep Soft flow unit is shown and is at variance with the shallow ground unit distribution. The north-easterly vector of flow is caused by dewatering of deep mines in that direction.

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Hydraulic Parameters

The Deep Soft unit was subject to pumping tests with one test carried out also in the shallow ground flow unit. Additionally, the large suite of packer tests provided an indication of very localised permeabilities, which were significantly lower than those obtained from the larger scale pumping tests. The latter values were considered to be representative of the bulk groundwater flow controls.

The Deep Soft unit pumping test data were analysed using radial flow modelling techniques. Representative results are shown in Figures 8. The model representations were good although the early data in some tests do not accord. Full details are given in Table 2.

The results show hydraulic conductivities substantially above those that would be expected for Coal Measures strata and confirm the observations concerning man-created permeability. Surprisingly, the range of storage coefficients was not particularly large, although it has generally high for the confined conditions tested. As most of the testing was concentrated in the "pillar and stall" mined part of the Deep Soft unit, the results substantially relate to the main disturbed zone. 9 packer tests were conducted within the Deep Soft Seam, 5 of which were over goafs and 4 over unworked sections. Values of unworked Deep Soft hydraulic conductivity from 4.3 E-^{4} to 0.155 m/day and for the goaf from 0.027 - 20 m/day.

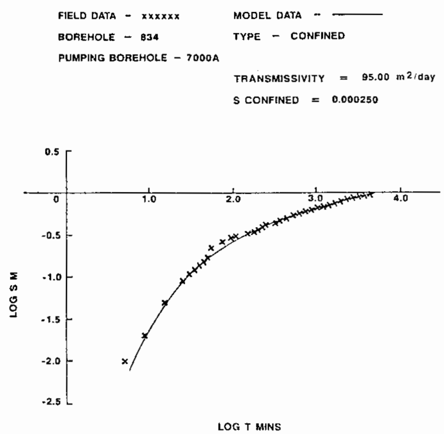

Figure 8 - Pump Test Interpretation for Borehole 7000A

Only packer testing was carried out with respect to the permeability of the Deep Hard Seam where 19 tests were conducted over intact coal seam and goafs. Values of hydraulic conductivity for unworked Deep Hard Coals varied for 0-0.07m^2/day and for worked sections 0.01 - 0.8m^2/day. The results confirm that due to increasing depth of burial and the presence of a weak mudstone seatearths, the hydraulic conductivity of the Deep Hard Seam was significantly lower than the Deep Soft.

Unfortunately the data from the shallow ground flow unit pump testing could not be accurately analysed. However 11 packer tests conducted over the zone confirmed that the level of hydraulic conductivity was mainly lithologically controlled with hydraulic conductivities ranging from 0.9 - 7.5 m/day for the more permeable sandy horizons.

Finally, the packer testing and the large scale pump testing confirmed the original hypothesis that even over worked sections of coal, the intervening beds of mudstone and mudstone seatraith would effectively isolate each of the individual flow units.

Chemistry and Contamination

The analytical results identified pockets of significant pollution close to the derelict Acid and Tar works, Cambro waste disposal sites and, to a lesser degree, Somercoates waste disposal site and the nearby derelict gasworks site. Pollution was defined as contamination of toxicological significance - primarily Red List and List II compounds but also other substances. The pollutants identified are listed in Table 3. No dioxin was detected. Only the highest level found is reported in the tables.

There was evidence of several contaminant plumes emanating from the contaminant sources towards the excavation in the direction of groundwater flow. The plumes only contained pollutants in the immediate vicinity of contaminant sources. Away from the immediate vicinity, the plumes only contained slightly elevated total dissolved solids and contaminant indicators. The plumes were much more extensive than the 'hot spot' pollution zones.

The Cambro plume was a phenolic lime rich water with heavy metals and high pH. It was 400m wide and extended 500m ESE. The Acid and Tar works plume spread up to 300m S and was a magnesium, sulphate and chloride rich water of low pH with PAH's, monohydric phenol and heavy metals. The Somercoates plume was of minor extent but contains lead and PAH's. This plume may owe its origin more to the derelict gasworks than to the waste disposal site.

GROUNDWATER FLOW ANALYSIS

Model Simulation

A major uncertainty with regard to the hydrogeology was the estimation of inflow characteristics from the highly permeable Deep Soft workings and to assess the effectiveness of a grout curtain constructed from surface with the Deep Soft Seam.

Because of the hydrogeological heterogeneity of the system it was not possible to determine a definitive groundwater flow for the area studied. Further, the complexity of the system did not justify any analysis other than a steady-state calculation with estimations for seasonal head variations. Despite the overall complexity a systematic analysis of the flows was made to provide a basic insight.

The system did not readily suit analytical techniques so that the flow assessment was carried out using a mathematical groundwater flow model to represent the shallow ground and the Deep Soft flow units, and the intervening aquitard.

Modflow (McDonald and Harbaugh, 1988) was used for the modelling as it has been substantially verified and allows a layered system representation.

Using Modflow, the procedure that was adopted was to firstly simulate the layered steady-state head distributions under current flow conditions, and secondly, to simulate the flow to the proposed excavation.

The model grid adopted is shown in Figures 8 and 9. For the shallow ground flow unit, no-flow boundaries were imposed in the west at the unit edge and to the north and south where it was assumed that the boundaries equate to west-east flow lines. Along the River Erewash a fixed head was imposed, uniformly at 180 metres above site datum (A.S.D). For the Deep Soft unit a no-flow condition was imposed at all the boundaries.

Due to the variability of the surface geology a classical recharge analysis was meaningless. The recharge to the system was therefore varied on a trial and error basis to simulate the groundwater head distribution. The values established are discussed below.

The output flows are to the River Erewash, in the shallow groundwater unit, and to the mine dewatering in the Deep Soft unit. There are not control data for either of these flows.

The absence of control data for the flows means that the model calibration was heavily dependent upon head distribution and hydraulic conductivity distribution.

By adjusting flows within the system the simulated heads shown on Figures 9 and 10 were obtained within the errors shown in Table 4.

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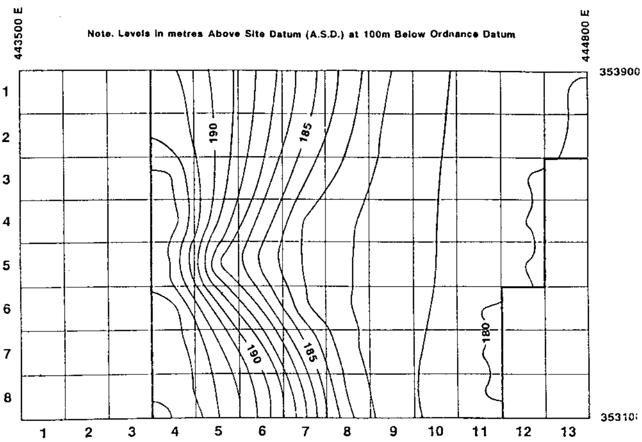

Figure 9 - Simulated Groundwater Head Distribution for the Shallow Flow Unit

To obtain the calibration a recharge of 0.56 mm/day was imposed on the shallow ground unit to the west of the River Erewash. The final simulation for the Deep Soft unit required both recharge and the mine dewatering abstraction.

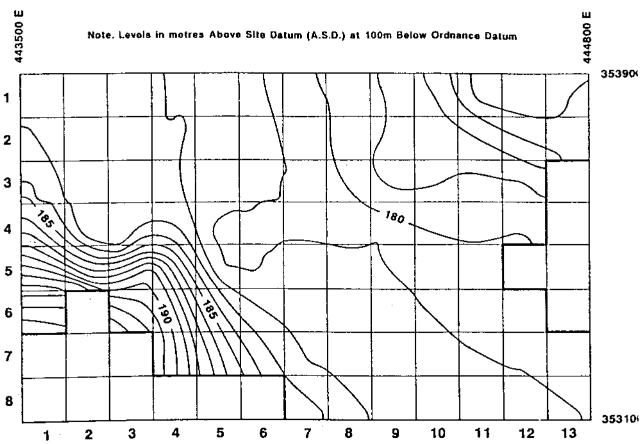

Figure 10 - Simulated Groundwater Head Distribution for the Deep Soft Flow Unit

Permeabilities generally accorded between the model and field results for the Deep Soft. For the shallow ground a range of 0.1 to 23 m/day was used with 0.01 m/day for aquitard materials.

The flow balance for the system with the finally accepted simulation is shown in Figure 11.

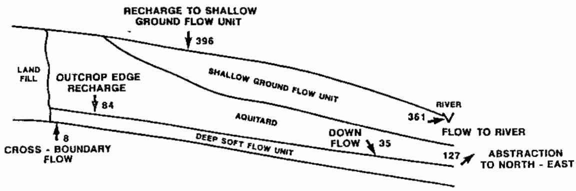

Figure 11 - Flow Balance for the Calibrated Model

Excavation Simulation

In order to assess possible inflows to the open-cast mine the initial simulation model was modified with excavation to 174m ASD over the area shown in Figure 12. A simulated grout wall in the Deep Soft was introduced immediately west of the excavation with a transmissivity of $1m^2$/day. The resultant flows are shown in Figure 13 indicating 380 m^3/day of water entering the excavation.

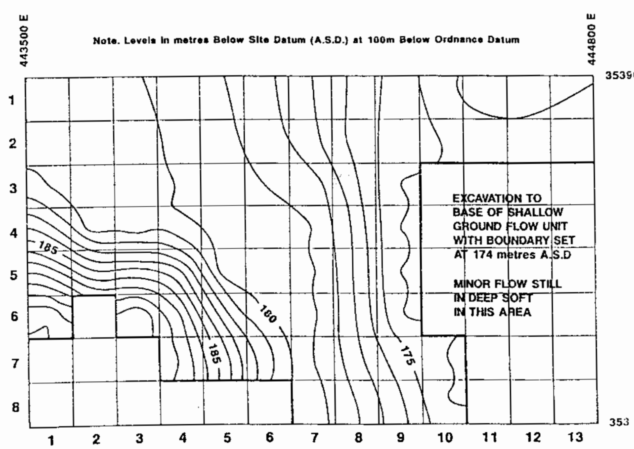

Figure 12 - Modelled Groundwater Head Distribution in the Deep Soft Flow Unit with an Excavation to 174 Metres A.S.D

For excavation to the base of the Deep Soft at 150 metres A.S.D the modelling adopted was unable to provide a reasonable representation because under steady-state conditions much of the areas of both flow units appear dry. For excavation to this depth therefore the total groundwater flow would sensibly be assumed to enter the excavation at the rate of about $400m^3$/day, which equates to the total recharge to the two units. With higher head conditions (transient range 2-3 m) flows could reach 500 m^3/day.

The above estimates do not account for flows to the proposed excavation from the north east and south, nor from the Deep Hard.

Away from the area studied the groundwater conditions in the shallow ground were unknown so an additional flow element to the proposed excavation was therefore allowed.

In view of the hydrogeological conditions in the area modelled, and the fact that this area constitutes only part of the catchment that may contribute flows to the proposed excavation, albeit the most significant part, a substantial safety factor was introduced to the flow estimates made above. It was proposed therefore for initial management purposes, that the total flow to a completely open excavation, at fully mined depth, be anticipated to be of the order of 1000m^3/day. For site water handling this flow would be considered on a per metre width basis of open face.

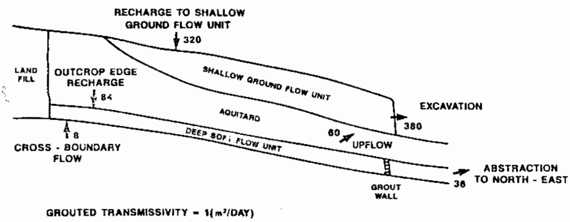

Figure 13 - Flow Balance for the Simulated Excavation to 174 Metres A.S.D

Contaminant Transport

Modelling of the contaminant transport was not considered possible mostly due to unknown hydrochemical parameters, such as dispersivity, porosity distribution and diffusion constants etc. Several interpretive hydrochemical tools were applied to the results.

Significant attenuation and decay was seen in the plumes with concentrations decreasing rapidly away from the contaminant source. The attenuation trends in the major ionic plume components are demonstrated on the Durov plot, Figure 14. Processes, such as, cation exchange complexing and adsorption, precipitation onto rock surfaces, biodegradation, dilution, dispersion and pH re-adjustment are contributing attenuation mechanisms.

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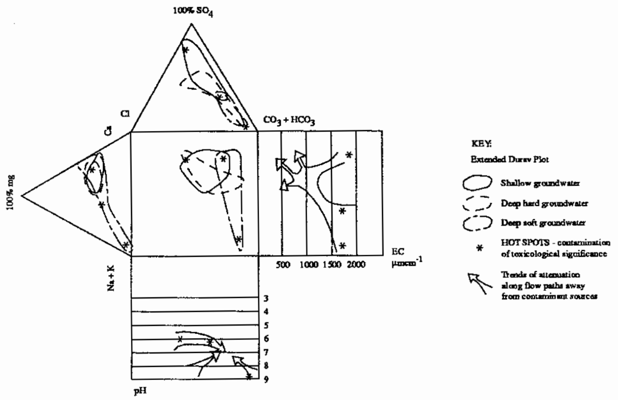

Figure 14 - Durav Plots describing the Contamination Mechanisms throughout the Site

The extent of the plumes differs markedly in the different flow units. The Cambro plume was more developed in the Deep Soft unit, mostly as a result of the lower permeabilities of the Deep Hard but also due to vertical attenuation processes. The Acid and Tar works plume is primarily developed in the Shallow flow unit, but entered the Deep Soft and to a much lesser extent the Deep Hard flow units.

Contaminant velocities were very much retarded with respect to groundwater flow. Retardation factors for individual components of the plumes were calculated empirically and used to predict movement of contaminants.

Much of the contaminated Shallow and Deep Soft groundwaters underlying the Acid and Tar works was east of the grout wall with no low permeability retardation layer between. These contaminated waters were expected to discharge virtually instantaneously into the excavation as it progresses.

The plumes from Cambro, Somercoates and the gasworks were expected to be mobilised towards the opencast when excavation commences. Under a number of assumed conditions including the installation of a grout curtain, estimates of the travel time for a number of contaminants are equal to or greater than the life of the mine. The toxic contaminants in particular were unlikely to enter the opencast within the working life of the mine. The installation of the grout wall would provide further attenuation to Deep soft groundwaters.

Permeabilities and groundwater velocities for the Deep Hard flow unit were so low that the volume of flow and hence contaminant loads were deemed insignificant in relation to the overlying Deep Soft and Shallow units.

TREATMENT AND DISCHARGE CONSENT

Negotiated discharge Consent

The information from the site investigation reports provided the National Rivers Authority with a strong database from which to consider what determinands were appropriate to consent at Smotherfly. The discharge consent was issued following negotiations between NRA and British Coal. British Coal were advised by Anglian Water in the negotiations. It was noted that the River Erewash is already contaminated with some of the identified pollutants and it was probable that discharge of treated effluent and uncontaminated effluent would improve the quality of the river, eg Ammonia and iron. The principle of BATNEEC and in particular, the desirability of avoiding exotic treatment processes was also discussed. NRA did not impose a condition requiring a grout curtain to be installed but this requirement was met by an exchange of letters between British Coal and NRA.

The NRA consent conditions were related to:

- legislation - references 1-6.
- maintenance of Environmental Quality Standards as a minimum
- environmental sensitivity of the recently restored Erewash canal and an aquatic SSSI downstream
- North Sea Directive (Hague Convention) which requires a 50% reduction in metals discharging to the North sea
- EIFAC, EC Fisheries limits
- The pre-existing River Erewash pollution leaving no available capacity for further pollution
- Smotherfly with its contamination is different from other opencast sites and required tighter controls.

The discharge consent issued under Section 88 of the Water Resources Act 1991 was a combined consent for trade effluent consisting of contaminated site drainage and contaminated groundwater. This paper focuses on the latter. Consent conditions are summarised in Table 5.

The consent was legally held by British Coal and will not be transferred to the Contractor operating the site.

Treatment

In view of anticipated Acid and Tar works pollutants in the groundwater and in the absence of available dilutions in the River Erewash, maintenance of the River Quality Objectives created a potential need for a high level of treatment. The treatment strategy was linked to the Discharge Consent and the extent to which flows in the Deep Soft would be limited.

Provision was made in site water management plans for drainage design mechanism to pick up and isolate potentially contaminated groundwater.

The treatment strategy adopted was flexible with a contingency for the 'worst case' scenario in which all contaminants of toxicological significance at the maximum measured concentrations arrive in the opencast excavation. It was recognised that not all pollutants were present at levels which require treatment prior to discharge to the River Erewash and some pollutants will remain below statutory surface water limits and fishery protection limits without effluent treatment. Contingencies are to be phased in as determined by results of groundwater quality monitoring.

The treatment plant design objectives were:

- to achieve the NRA Discharge consent absolutely without recourse to uncontaminated effluent or River Erewash dilution.
- to utilise well established treatment techniques that are easily controlled to remove identified pollutants
- to be flexible and operate in batch or continuous operation.

The key element in the treatment design was long term retention in a series of 6 lagoons of varying depth. These lagoons provided much of the required treatment. An associated package treatment plant fulfilled a polishing task. A schematic diagram of the treatment plant is presented in Figure 15.

It was expected that a relationship between BOD, COD and other parameters could be derived with sufficient confidence to ensure the water quality was acceptable before it was pumped into the river. A facility to recycle from any of the discharge lagoons if final water quality was not to specification was included in the treatment process design. Treatment sludges will be disposed on site after drying in prepared reception areas.

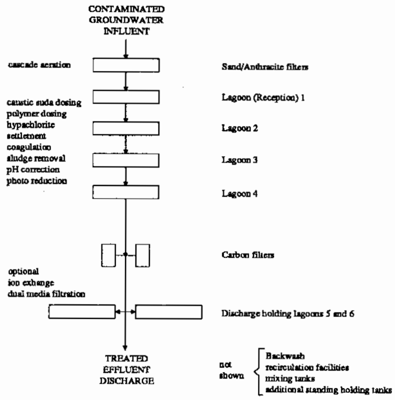

Figure 15 - A Schematic Diagram of the Treatment Plant

PRESENT SITUATION

The Smotherfly Opencast Site mining contract was let to Kier Mining in March 1993. The Contract provides for groundwater monitoring west of the Area B void, the separate collection of groundwater, the installation of a grout curtain across the worked section of the Deep Soft Seam to inhibit transmissivity to no more than $1m^2$/day and provision of a water treatment plant to process up to $1000m^3$/day of contaminated water in order for it to meet consent conditions on discharge to the river.

Kier Mining have engaged CPL Miller to design and construct the "hardware" of the water treatment plant to link with the lagoon infrastructure designed and constructed by Kier Mining. Construction of temporary lined lagoons, modular dosing plants and a process control unit was largely complete in June 1994 in time for the installation to handle any contaminated water from the imminent waste transfer operation.

British Coal Opencast continue to take advice from Anglian Water on the establishment, commissioning and operation of the water treatment plant.

CONCLUSIONS

The approach adopted by British Coal in resolving the technical and legislative issues was based on negotiation, team work and the application of cost effective, high quality field work and laboratory testing. The programme of work was at all times fully integrated to satisfy the competing requirements of all specialist groups involved in the study. This not only required effective project management, but also a detailed awareness on behalf of all parties on the aims of the site investigation programme and the technical issues it had to resolve.

ACKNOWLEDGEMENTS

The authors would like to thank British Coal Opencast for their support and permission to publish this paper. The views expressed in this paper are strictly those of the authors and need not reflect those of British Coal.

LEGISLATION REFERENCES

1. Pollution caused by certain dangerous substances discharged into the aquatic environment 76/464/EC.

2. Surface Waters (classification) Regulations 1989.

3. Drinking Water Regulations DOE.

4. Circular 7/89 DOE.

5. SI 2286 The Surface Waters (Dangerous Substances) Regulations 1989 and 1992.

6. Water Resources Act 1991.

Table 1 - Analytical Suites

On Site Analysis
Continuous measurement during pumping with 15 minute subsamples for:
*pH, Electrical Conductivity, Eh, Ammonia and TOC
*Visual examination
*Sampling with oil-water interface probe
Laboratory Analysis
*Major ions, Nitrate, Nitrite, Sulphide, Phosphate, Total Alkalinity and Total Hardness
*COD, BOD, Ammonia, TOC
*Iron, Lead, Chromium, Copper, Nickel, Zinc, Cadmium, Mercury
*Cyanide, total and free
*GCMS scan for quantitative determination of pesticides and semi-quantitative general organic contamination indicators
*Purge and trap examination for quantitative determination of volatile organic contamination
*Total and mnohydric phenols, PCB's, PAH's
*Organotin, PCSD's, Hexachlorobutadine, trifluratin, Trichlorobezene
*Oils
*Dioxin
Analytical Laboratories
British Coal on site laboratory
British Coal Laboratories
Anglian Water Services laboratories
Stevenage analytical Consultants Laboratory
British Rail Laboratories

Table 2 - Transmissivity (T) and storage coefficient (S) interpretation for the Deep Soft Flow Unit.

PW	OW	T	S
836	834	78	0.015
	835	90	0.006
7000A	7004	55	0.011
	1A	90	0.0014
	834	95	0.00025
	835	95	0.0005
	836	82	0.0004
7036	7014	230	0.0001
	7017	200	0.003
	7020	270	0.016
	7027	210	0.00035
7033	1A	160	0.0005
	834	78	0.0005
	836	80	0.0001
	7004	80	0.0001

T = m^2/day, PW = pumping well, OW = observation well

Hydrogeological and Hydrochemical problems relating to the Smotherfly Opencast Coal Site: An Integrated Approach to the Granting of a Discharge Licence.

Table 3 - Analytical Results - Pollutants

Pollutant	Max Conc	No BHS	Limits
Red List Substances			
Mercury	$0.9mgl^{-1}$	2	$1mgl^{-1}$ $0.15mgl^{-1}$
Cadmium	$6.4mgl^{-1}$	12	$5mgl^{-1}$, $1.5mgl^{-1}$
Pentachlorophenol	$110mgl^{-1}$	1	$2mgl^{-1}$
List II Substances			
Zinc	$0.41mgl^{-1}$	11	$0.25mgl^{-1}$, $1mgl^{-1}$
Copper	$0.04mgl^{-1}$	4	$0.01mgl^{-1}$
Nickel	$0.18mgl^{-1}$	8	$0.15mgl^{-1}$
Chromium	$0.05mgl^{-1}$	7	$0.2mgl^{-1}$
Lead	$0.28mgl^{-1}$	All	$0.25mgl^{-1}$
Iron	$108mgl^{-1}$	All	$1mgl^{-1}$
pH<6	acid	2	6<pH<9
Sanitary Determinands			
BOD	$35mgl^{-1}$	7	$9mgl^{-1}$, $5mgl^{-1}$
Ammonia	$3mgl^{-1}$	5	$0.54mgl^{-1}$
Other determinands of toxicological significance			
Cyanide (total)	$12mgl^{-1}$	9	$0.01mgl^{-1}$
Free Cyanide	$0.3mgl^{-1}$	1	$0.01mgl^{-1}$
4-Chlorophenol	$0.27mgl^{-1}$	1	$0.1mgl^{-1}$
Phenols	$1.88mgl^{-1}$	4	$0.7mgl^{-1}$
Aluminium	$5.95mgl^{-1}$	1	$0.1mgl^{-1}$
PAH's	$5.6mgl^{-1}$	2	$0.2mgl^{-1}$
Napthalene	$17.73mgl^{-1}$	8	$0.7mgl^{-1}$
Benzene	$1.41mgl^{-1}$	1	$3.1mgl^{-1}$

Notes to table 3

1. Limit values of Red List substances are those of SI 2286 for surface waters.
2. $0.15mgl^{-1}$ limit recommended for fishery protection.
3. $1.5mgl^{-1}$ cadium limit recommended for fishery protection.
4. Limit values of List II substances are those of DOE Circular 7/89 for hardness of $250mgl^{-1}$ and presented as annual average and, if appropriate, as 95 percentile.
5. Where not stated, fishery protection limits are served by the limit quoted.
6. BOD limits as absolute and annual average.

7. Ammonia limit is EIFAC toxicity limit, expressed in mgl^{-1} as N.
8. Cyanide limit for fishery protection.
9. 4-chloriphenol limit derived by AW from fish toxicity testing.
10. Phenols are total monohydric phenols and include the PCP and 4 chlorophenol.
11. PAH limit is drinking water quality standard.
12. Napthalene limit presented is that for phenol which is considered to have similar toxcity.
13. Benzene limit is US water quality limit.
14. Aluminium limit based on stickleback toxicity tests.

Table 4 - Degree of Error between Input and Simulated Heads as Percentages

Metres	Shallow Ground Unit		Deep Soft Unit	
	%	Cum %	%	Cum %
0 - 0.1	14	14	25	25
0.1 - 0.2	16	30	17	42
0.2 - 0.3	24	54	28	70
0.3 - 0.4	16	70	9	79
0.4 - 0.5	5	75	10	89
0.5 - 0.6	17	92	2	91
>0.6	8	100	9	100

Table 5 - Summary of Discharge Consent Conditions for Contaminated Groundwater

Consented Substance	Consent Limits
BOD	$7mgl^{-1}$
Suspended solids	$30mgl^{-1}$
Ammoniacal nitrogen	$0.75mgl^{-1}$ summer, $2mgl^{-1}$
Mineral oils and Hydrocarbons	$5mgl^{-1}$
pH	6 - 9
Free cyanide	$0.01mgl^{-1}$
Aluminium	$400mgl^{-1}$
Chromium	$1000mgl^{-1}$
Copper	$40mgl^{-1}$
Iron	$2000mgl^{-1}$
Lead	$200mgl^{-1}$
Nickel	$200mgl^{-1}$
Zinc	$500mgl^{-1}$
Mercury	$1mgl^{-1}$
Cadmium	$5mgl^{-1}$
Phenolic Compounds	$1000mgl^{-1}$
Pentachlorophenol	$2mgl^{-1}$
PAH	1mgl-1
Max discharge	$1000m^3d^{-1}$, $11.61s^{-1}$