ADVANCE DEWATERING AND CONTROL OF GROUND WATER IN SURFACE COAL MINING

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ABSTRACT

With greater excavation depths and stricter pollution controls affecting surface mining in the U.K. many pits are experiencing considerable pumping problems. Mines are often sited in areas of abandoned deep mine workings which contain large reservoirs of water extending well beyond the site boundary and which do not conform to normal hydrogeological patterns. The paper uses examples from different surface mining environments to highlight the problem of predicting the likely draw-down and flow patterns and the advantages to be gained from borehole pumping in order to depress the water table in advance of working. The main advantages, regardless of the method of mining, are: that the need for more costly sump pumping within the working area is reduced; that there is improved slope stability and vehicular movement; that there is a significant reduction in water pollution and a general improvement in efficient working methods.

INTRODUCTION

With greater excavation depths coupled with an increased rate of digging and stricter water pollution controls many surface mines in the U.K. and especially in Scotland are experiencing considerable water problems. Pumping rates of up to 750 litres per second (14 million gallons per day) are sometimes required to maintain dry working areas. In the past, when pollution laws were less stringent, water was normally pumped from sumps constructed within the working area of the pit and the associated piping restricted machine movement in the working area. Pollution of ground water on entering the pit could be severe and this water required extensive chemical treatment before being discharged off-site.

It is now becoming more important to be able to predict ground water flow as the costs of pumping and treatment are increasing. Furthermore, the legal pollution limits laid down by the local water authorities are becoming increasingly more restrictive and typical limits of a maximum of 5mg per litre of iron and minimum pH of 5 are being rigorously enforced. With the use of submersible electric borehole pumps and advance dewatering techniques at selected locations around the pit perimeter pollution and the cost of pumping can be significantly reduced and in some cases the need for expensive water treatment eliminated. There are also the usual added benefits to be accrued from a dry pit environment of improved haulage, slope stability, reduced blasting costs and reduced moisture content of the coal.

However, many of the surface mines in the U.K. are frequently in areas of ground complicated by the presence of abandoned mine workings which can extend within the strata for up to 10 kilometres from the site and contain a considerable reservoir of water. The ground water flow patterns in this environment are very difficult to predict even when an extremely detailed knowledge of the old workings is known. Unfortunately complete records of abandoned mines only go back as far as the late 19th century and plans prior to this are sketchy and often non-existent. Even when the plans are available it is not known whether the cavities have been backfilled or collapsed with subsequent fracturing of the overlying strata. Interruption to the theoretical type of ground water flow is extreme.

In planning future surface mines it is always necessary to make a reasonable estimate of the volume analyses and flow rates of the body of ground water into which the mine will intrude. From the estimate the probable pumping rates, size of watercourses and lagoons to be constructed to prevent flooding of the workings and surrounding land and pollution must be made. Also important is the draw-down affect on any wells and other industrial pumping stations in the vicinity and the possibility of collapse of shallow flooded old mine workings due to loss of hydraulic support. This last problem is especially important where these workings occur under built-up areas. The method and direction of working the site will also have a bearing on the siting of pumps, lagoons and watercourses.

It is during the initial box cut excavation in retreat mining methods (deep to shallow) or during the final cut in down-dip mining that drainage and stability problems are most acute. With advance borehole pumping close to the box cut or final cut dry workings can be maintained. It is often convenient to place a large pump within deep old mine working cavities close to the high wall rather than a series of smaller pumps within less permeable solid strata. This method is equally useful for strike or diagonal cross cut methods, the essence being that the pumps are installed to the deep of the proposed pit. Where retreat methods are used then pumping will be needed for sometime prior to coaling and this may require a large capital investment on behalf of the mine operator before income can be gained from the excavation and sale of coal.

BLINDWELLS MINE

General

Blindwells Opencast Coal Mine is situated in the Lothian District of Scotland some 8 kilometres east of Edinburgh and about 1 kilometre from the sea (Fig. 1). 5.0 million tonnes are being extracted from nine coal seams in the Carboniferous Limestone Coal Group. Half of them contain from 12% to 35% old deep mine working voids. It is a dragline task site with an overburden to coal ratio of 11 to 1 and with a maximum depth of 64 metres and an average depth of 38 metres. The strata contain a higher proportion than normal of poorly cemented, highly porous sandstone. The geological structure within the mine is basically a gentle syncline with dips of 1:10 and its axis plunging towards the deepest proposed excavation in the N.W. corner of the site. The area for a distance of up to 6 kilometres beyond the site boundary had been heavily worked by interconnected deep mines and has a history of both surface and underground water problems. Some of the wettest pits in Scotland were once within the catchment area to the south and at a higher elevation than the proposed Blindwells Mine. Most of the known workings were up to 100 years old and the reservoir of water they contained was difficult to establish as the degree to which they were backfilled or had collapsed was not known. Also within the strata were a great number of unknown ancient workings some of which go back to the 14th Century.

Hydrogeological Investigation

In 1963 the last deep mine in the area was abandoned and the pumps withdrawn. Almost immediately the water table rose and overflowed from various surface outlets in the vicinity of the proposed mine (See Figure 2) and continued as iron rich acid water with iron content of up to 15 mg per litre and a pH of between 6 and 7. The National Coal Board constructed a drainage pipeline to an outfall on the sea shore in order to prevent flooding of low lying built-up land. Several other springs associated with this water table emanated at a level of 33 metres above sea level from abandoned adits, shafts and natural springs with a total flow of around 250 litres/second.

The proposed excavation was to a depth of 3 metres above sea level resulting in 30 metre head of water above this level and connected to a considerable reservoir which would gain access to the excavation through the porous rock but primarily through abandoned old mine working cavities which were to be exposed in the high walls and side walls. Twelve Casagrande Type B piezometers were installed around the site in order to ascertain the water table gradient and give an approximate indication of the mass permeability of the strata in the vicinity. All available abandoned mine plans were studied in an area of up to 6 kilometres from the site in order to estimate the total volume of water within them. However the amount of unrecorded ancient workings in this area coupled with an unknown amount of collapse, backfilling or other blockages within them made estimation extremely difficult and results for the total reservoir varied between 2,000 million litres and 20,000 million litres. Because of the presence of so many abandoned mine workings it was decided not to conduct pumping tests as the strata did not conform to any normal hydrogeological pattern. Between November 1977 and the commencement of excavation in July 1978 piezometers recorded levels which indicated a hydraulic gradient of approximately 1 in 320 to the north-west towards the sea. Almost no fluctuation due to rainfall was noticed which was probably due to the exceptionally high permeability of the strata within the zone. An investigation of shallow old workings underlying the town of Tranent (population 17,000) about 1 km to the south-west revealed they were not flooded and hence the problem of collapse did not arise. Shallow flooded ancient workings did occur under the main Edinburgh-London railway line and a piezometer (P12) was installed in them to register drawdown. However, the roof of the seam worked is an exceptionally competent sandstone and collapse was considered a remote possibility. Precise survey levelling at regular periods along the railway has to date shown no movement associated with the drawdown. The direction of flow of the ground water was towards the north-west but is probably impeded by a quartz-dolerite dyke running east-west about 0.5 kilometres to the north of the site.

In order to design the off-site drainage to the sea a total possible drawdown pumping rate of up to 1,100 litres per second was anticipated and to prevent throttling and subsequent flooding of the adjacent coal preparation plant and railhead which was constructed at the lowest point on the site, adequate piping was needed under the Railway.

Once drawdown had been achieved it was expected that pumping capacity would revert to a similar volume of 250 litres/second that issued at surface prior to site operations. The local River Purification Board enforced stringent pollution limitations of a maximum of 5 mg per litre total iron, 60 mg per litre suspended solids and a pH between 5 and 9. As these limits were more exacting than the already existing conditions then it was necessary also to design into the off-site drainage scheme a series of settling and treatment lagoons in order to purify a large volume of water which would contain at least 15 mg per litre iron. An area of 4 hectares was set aside for this purpose.

To further complicate matters, incorporated within the restoration of the site is the construction of a Bypass road. The restoration to road formation level needed to be ready by December 1981 and it was therefore necessary to achieve drawdown, successfully excavate the box-cut and Phase I of the operation and then provide a suitably compacted embankment along the line of the road prior to this date. It thus became obvious that whatever method of working was used the deepest part of the site in the north-west corner would have to be excavated at an early stage and hence the most attractive method of working would be a box-cut in this area and retreat mining up-dip.

The most convenient place to install the submersible pumps would therefore be along the west or north-western perimeter of the excavation area which was fortunately also nearest to the discharge to the sea.

Mine Operation

The contract was put out to tender and the successful tenderer, Fairclough-Parkinson Mining Ltd. commenced work in June 1978. Excavation of the box-cut started immediately and proceeded down towards the water table. Two Pleuger submersible electric pumps each developing 180 kW at 2,900 rev/min were installed in 600mm cased boreholes drilled by Foraky Ltd. at the locations shown in Figure 2. The pumps had a working head of 75m and a capacity of about 150 litres/second. Pump No.1 started in March 1979 as the excavation approached the water table (Figure 2). Pump No.2 started later and a significant drawdown was noticed in the associated piezometers. Unfortunately during May and June of that year the highest rainfall on record was recorded at the site and supplementary pumps were needed within the cut to maintain dry operations.

One of the major problems associated with occasional rises of the water table in the working area was an increase of the moisture content of the coal from an acceptable level of around 18% to an unacceptable level of 23%. This extra moisture in the product caused problems of congestion with conveyor belting and screens at the Railhead Disposal Point as well as an increased load factor in transportation of the coal.

At Blindwells, where the water emanates from old mine workings and the volume is high it has been possible to discharge water using settlement lagoons and to expect aeration of the water to precipitate the bulk of dissolved iron present. In actual fact throughout the life of Blindwells no chemical water treatment has been necessary. Table 1 shows the average results to date and as can be seen the stringent pollution limitations have been met. On rare occasions they have been exceeded but this has usually been due to such reasons as storm rain conditions creating high suspended solids from surface run-off or borehole pump downtime due to power failure. Although the local River Purification Board have not relaxed limitations during storm conditions they have still not seen fit to prosecute the operator.

In hindsight, conditions could have been improved at Blindwells if one extra borehole pump had been installed. This would then have eliminated the occasional problems with the water table rising above the excavation depth level. However, to date all the coal has been successfully won from what was expected to be an extremely difficult working pit, the only exception being when an in-rush of water entered the pit along two old mine roadways. This was due to the fact that the water table had not been lowered sufficiently due to heavy rainfall in May and June 1979 and on the 12th September 1979 an in-rush of about 36 million litres occurred which drowned two diesel sump pumps and caused a cessation of coaling in this area for about a week. The incident was regarded as unfortunate as it had been anticipated as the water table drawdown had only reached a level of 126m but the excavation was at a level of 120m. Although the two driveages were not actually intercepted it is reasonable to assume that the ground above them was broken due to the presence of numerous small faults and collapse. The experience served to highlight the importance of the dewatering level to be continually at a lower level than the excavation. Since pumping began in March 1979 a total of 28,000 million litres (6,200 million gallons) of unpolluted water has been pumped from Blindwells with no serious loss in production and it is expected that the site will continue to its conclusion with no further water problems. There is no doubt that if advance dewatering techniques had not been used and 'wait and see' sump pumping had been undertaken then water pollution and interruption to the production rate would have been considerable.

HAYWOOD MINE

Haywood Mine (Figure 3) lies midway between Glasgow and Edinburgh in Scotland and is smaller than Blindwells producing only 453,000 tonnes from seven seams in the Limestone Coal Group at an overburden coal ratio of 16:1. The original mine was for 313,000 tonnes but was later extended to the deep in order to win a further 140,000 tonnes. The mine is surrounded by higher ground for several kilometres which is drained by streams crossing the site which needed to be diverted before work could commence. The strata to be excavated lies on the eastern limb of a fault-truncated syncline and groundwater flow to the north-west down-dip beyond the high wall was therefore impeded.

Again, extensive old mine working cavities exist in the strata surrounding the site. Piezometers were installed and the water table was found to be at about 26m below surface. As the deepest part of the excavation was to be 71m then a considerable head and quantity of water was expected to flow into the mine. Extensometers were also placed on the eastern wall in order to monitor a potential wedge failure which had been identified from geotechnical investigation.

The contract was let in 1977 to Murphy Ltd. and the chosen method of working was by 40 metre wide dip-cuts running in a north-westerly-south-easterly direction and worked by forward reduction truck and shovel followed by dragline. The initial cut contained the deepest part of the excavation and posed considerable problems with water and instability of the eastern high wall. One of the major problems being that the stream diversion could only be constructed along the top of batter and to prevent ingress of water into the strata a number of methods were tried to maintain an impermeable bed to the diversion. Unfortunately, the diversion was subjected to a number of flash floods which severely eroded the bed. In order to surmount this problem a welded steel channel running for some 500m along the high wall was constructed but unfortunately another flash flood occurred prior to its completion and water entered the strata in the already unstable eastern high wall and a small amount of coal was abandoned under a buttress formed to prevent any further failure.

In order to maintain dry workings in subsequent cuts two 430mm diameter Flygt electric submersible pumps were each installed in a 2 metre diameter perforated concrete chamber and as backfilling took place this was connected to surface by a 1 metre diameter concrete column. The pumps each developed 37 kW at 2,900 rev/minute and were capable of delivering 240 litres/second with a 55 metre head. These pumps worked continuously and occasionally the total amount of water pumped off-site rose to 300 litres/second which was quite considerable in comparison to the small size of the mine. Although a filter bed of large graded rock surrounded the pump chamber the water contained a large amount of abrasive suspended solids and was also polluted with iron. Water treatment and settlement was therefore needed in order to comply with the exacting water pollution legislation. (See Table 2).

Three lagoons holding a total of about 25 million litres of water were constructed. The first is to aerate the water, oxidise the carbonate iron and precipitate some of the suspended matter. In the second, lime is added and the water further aerated and finally the third lagoon is used to settle out the finer suspended matter. Water is then allowed into the stream diversion and flows into the natural watercourse where it eventually finds its way into the River Clyde.

A further extension down to 70m depth was added to the site in 1980 and a new pumping column was required. The same pumps were installed in two cased 900m boreholes drilled into the solid strata which was highly fractured in this region and therefore very permeable. Because this water passes through strata rather than backfill then it is less polluted especially with abrasive solids which reduce pump life. Although it is sometimes more convenient to place pumps in backfill the resultant pollution of water is considered to make this method less desirable than installations in solid rock in advance of working.

OTHER MINES

Elsewhere in the U.K. advanced dewatering has been beneficial when large volumes of water were anticipated. At Radcliffe Mine in the north-east of England two 360mm diameter submersible electric pumps were installed in a disused mine shaft below the anticipated excavation level of a large dragline mine. The shaft was situated a distance of 650m away from the final high-wall but drawdown was achieved because of the exceptionally good hydraulic continuity within the abandoned mine cavities. Up to 750 litres/second were pumped continuously to the sea about half a kilometre away in order to achieve drawdown and once equilibrium conditions were reached then pumping reverted to about 350 litres per second for the rest of the life of the site.

In the same region 150mm diameter pumps were installed in adjacent old mine workings next to a 76m deep box-cut where the prime excavator was a 1550W Bucyrus-Eyrie Walking dragline with a bucket capacity of 50 cubic metres. A number of holes were drilled and pumps installed which were abandoned as the pumps quickly ran dry. Finally, a successful borehole was drilled with good hydraulic connection to the underground water in the abandoned mine system. This is often the case when pilot holes for pumps do not prove sufficient connection due to collapse of backfill within the voids. In 1971, again in the same coalfield, at Horsley Mine in an open-pit environment, a submersible Beresford electric pump with an output of 45 litres/second and 71m head was installed in a vertical, steel welded column constructed as backfilling took place in order that an extension to the pit could be worked without recourse to awkward and restrictive sump pumping.

In future, in Scotland, the installation of dewatering borehole pumps is being actively considered at three differing environments. At a large shallow dragline site operated on a dip-cut basis, a pump is expected to be installed in an initial cut backfill. At this site a significant reduction in water pollution is expected as the ground water is exceptionally pure and only becomes contaminated after gaining access to the working area. Stability is also expected to be improved here as the overburden contains a significant amount of peat which poses problems when mixed in the backfill spoil pile and in a wet environment.

Secondly, in another 90m deep pit, hydraulic connection with extensive old mine working has been proved by drilling and detailed examination of abandoned mine plans and the installation of large pumps within adjacent abandoned mine shafts should reduce stability and pollution problems.

At another large open pit pumps will need to be installed in strata where no abandoned mine cavities exist. It is hoped to locate pumps in sandstones which contain individual aquifers especially where they are truncated against large faults. It is also hoped to install pumps within fault gouge material in a large 2,000m downthrow fault plane which is known to have a high permeability compared with the surrounding impermeable strata. Here it will be necessary to drill pilot holes, install piezometers, and conduct pumping tests in order to locate the most permeable strata for installation of the pumps. It is also expected that several small pumps will be needed rather than one or two large ones as is the case when abandoned mine cavities are used.

CONCLUSIONS

Advance dewatering techniques are now being used successfully at various surface mines within the U.K. and the method proves to have many practical advantages. The location and type of pumps is critical and in order for this to be compatible with the mine operation a thorough hydrogeological and geotechnical investigation is necessary prior to installation. Regardless of the excavation method it is essential that the water table drawdown level is maintained in advance of the excavation level.

From the experience to date the proven advantages of advance dewatering are:

(1) Reduction in water pollution by prevention of water entering the working area of the pit and becoming contaminated by contact with carbonaceous material and suspended solids. This in turn reduces the need for costly lagoon and water treatment facilities.

(2) That method is more efficient than in-pit pumping which hinders machine movement and working method with the need for sumps and piping columns within the working area.

(3) Improved stability of excavated slopes due to the lowering of water pressure in advance of digging resulting in safer working conditions.

(4) Electric submersible borehole pumps are less labour-intensive than other forms of pumping as they work continuously with the minimum of supervision.

(5) Reduced haulage costs and problems of congestion in coal preparation due to a lowering of the moisture content in the coal.

(6) Reduced blasting costs with fewer wet boreholes.

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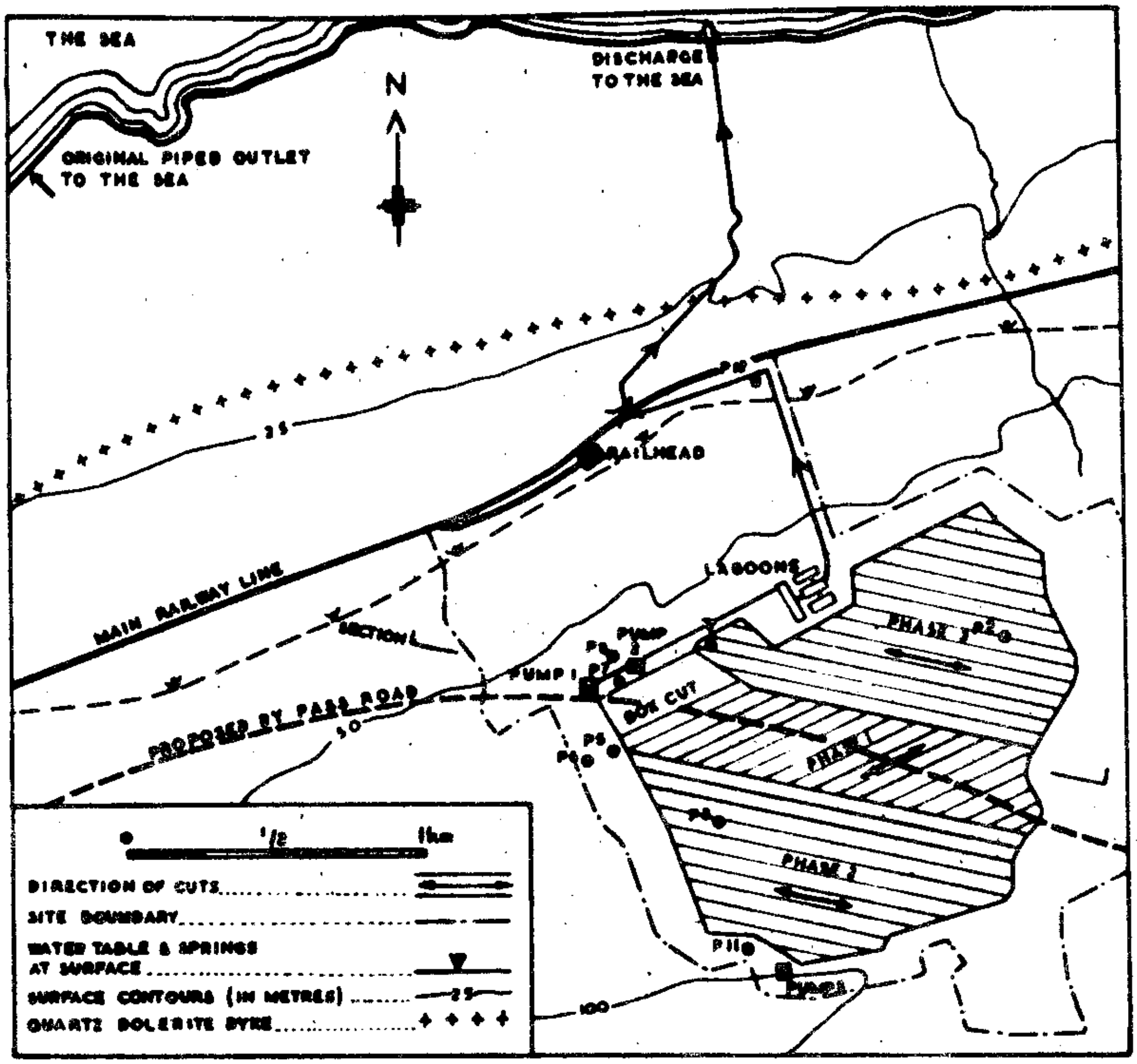
ANALYSIS LOCATION	pH	SUSPENDED SOLIDS milligrams/ litre	TOTAL IRON milligrams/ litre
Stream quality prior to mining	6	30	13
DISCHARGE CONSENT LIMITS	5 - 9	≯ 60	≯ 5
Borehole Pump water quality (Average)	6	20	12
Sump Pumps water quality (Average)	7	54	8
Mine Discharge to Sea (Average)	7	37	5

TABLE 1 BLINDWELLS WATER ANALYSES

ANALYSIS LOCATION	pH	SUSPENDED SOLIDS milligrams/ litre	TOTAL IRON milligrams/ litre
Stream quality prior to mining	7	6	1
DISCHARGE CONSENT LIMITS	5 - 9	≯ 40	≯ 5
Pumped water quality to lagoons (Average)	6.5	28	9
Mine Discharge (Average)	6.5	12	2

TABLE 2 HAYWOOD WATER ANALYSES



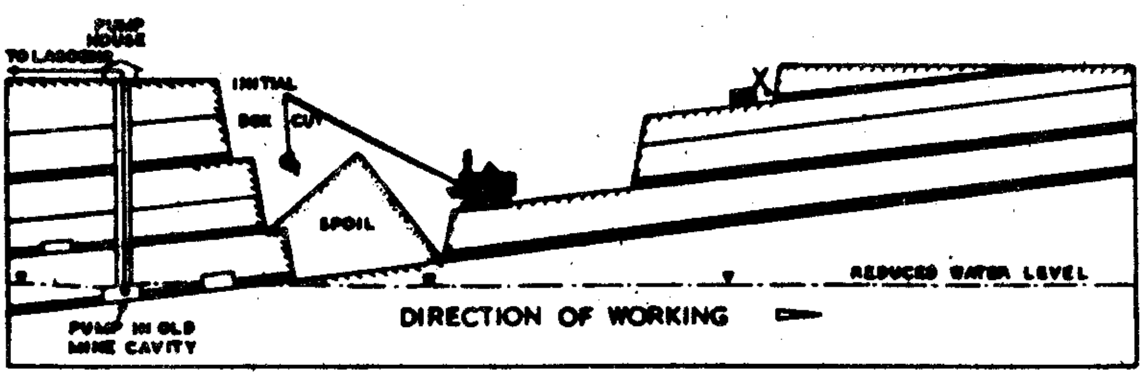


Fig. I. BLINDWELLS MINE LOCATION MAP AND SECTION
(Section not to scale)

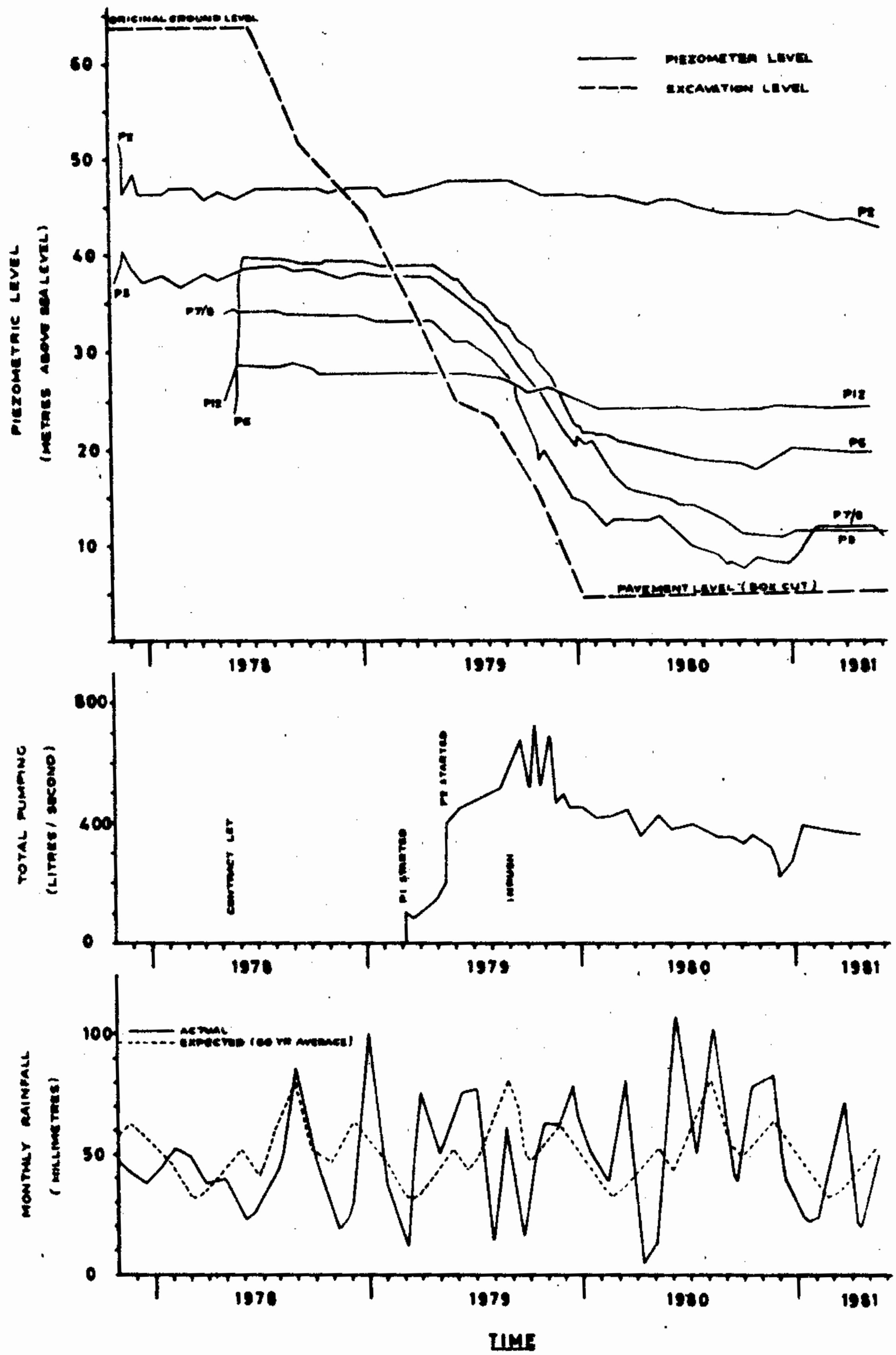


FIG. 2 BLINDWELLS DE-WATERING GRAPH

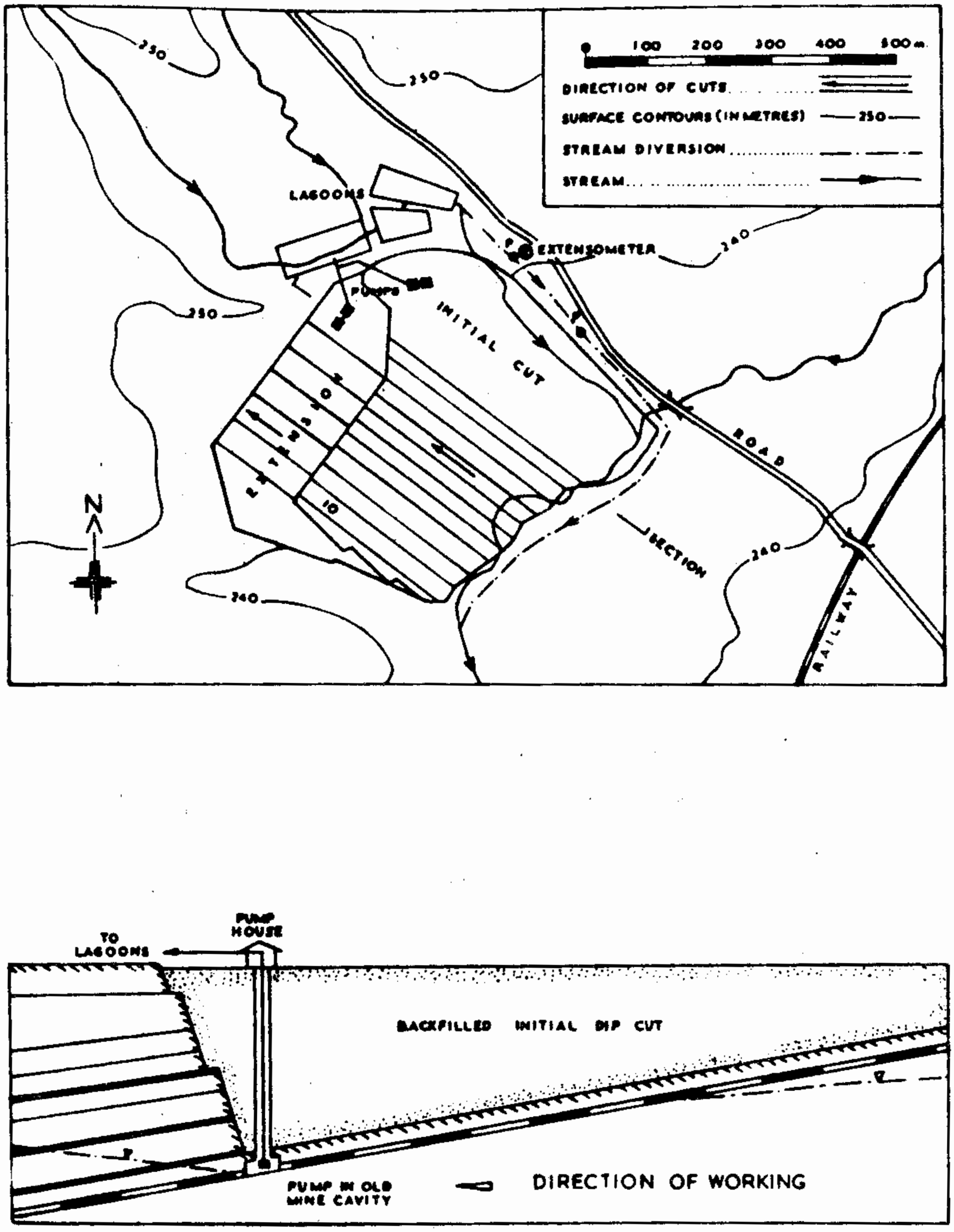


Fig. 3. HAYWOOD LOCATION PLAN AND SECTION

(Section not to scale)

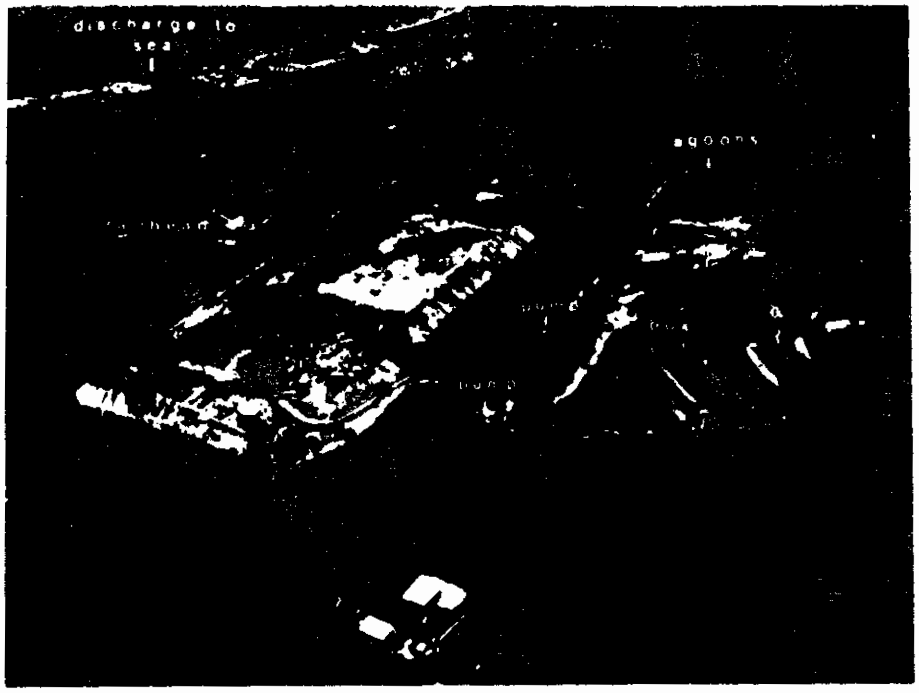


Fig. 4 Aerial view of Blindwells Site, looking North-East

Fig. 5 Aerial view of Haywood Site, looking West