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MINE WATER POLLUTION — AN OVERVIEW OF PROBLEMS AND CONTROL STRATEGIES IN THE UNITED KINGDOM

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ABSTRACT

The management of water within the British coal mining industry and the means by which surplus waters are discharged to the environment without serious effect are described. The acquisition, use, treatment and re-use of water is discussed in detail with particular reference to the control of the volume and quality of surplus water generated.

COAL MINING IN GREAT BRITAIN

Coal has been mined in Britain for at least 2000 years. Production was negligible until about 1800 and then rose rapidly with the development of water and rail transport, reaching a peak of 292M tonnes a year in 1913, falling to 125M tonnes a year at the present day. Currently, 211 underground mines of average age 86 years produce 88% of the output, the remainder being from 67 opencast (open pit) mines. The industry's heritage consists of tens of thousands of abandoned mine shafts and 7500 ha of land made derelict by mineral spoil from the former underground mines. (Department of the Environment 1981). In contrast, all completed opencast excavations have been fully restored.

The productive coalfields, occupying a total area of 17000 km^2 occur in Kent, South Wales, Central, Western and North East England and the Scottish Lowlands. The depth of working is between 50 and 1000 m in the underground mines and down to 200 m in the opencast mines. Most of the coalfields lie in areas of high population density and intensive land use. Land surfaces are mainly flat or gently rolling, the steep sided valleys of South Wales being exceptional. Monthly average rainfall in the British coalfields is fairly consistent throughout the year, but irregular seasonal variations may lead to droughts lasting for several months and corresponding periods of exceptional rainfall. Average annual precipitation varies from 600 mm in the eastern counties to 2000 mm in South Wales. Almost all of the precipitation falls as rain. Light frosts are common in the winter months but seldom penetrate more than 0.5 m into the surface of the ground.

Apart from Kent and parts of Nottinghamshire, all the mines have access to a comprehensive surface drainage system of streams, rivers, estuaries and coastal waters for the disposal of surplus waters. River lengths from the point of discharge to the coast average about 100 km, the longest being the River Trent having a length of 300 km from the North Staffordshire coalfield to the sea.

The economic coal deposits are of Carboniferous (late Palaeozoic) age which are exposed in the older coalfields and concealed by rocks of the Permo-Triassic series in the newer coalfields. These latter form important aquifers for public and industrial supply and have hindered access to the underlying coal reserves.

The bulk of the coal output is of low to medium rank; prime coking coals occurring in South Wales, North East England and parts of other coalfields. Anthracite coals are mined in South West Wales and Kent. Over 90% of the coal marketed has a sulphur content in the range 0.8 to 2.5% and a chlorine content of less than 0.5%.

The recoverable coal seams vary in thickness from 0.5 to 3m, the average in current production being 1.5m. The coal seams lie on well-defined seat-earths, the inter-seam rocks consisting of shales and sandstones.

The coal measures are effectively saturated with water and traces of mineral oil in the undisturbed state. The sandstones form significant aquifers, having thicknesses of up to 100 m, porosities in the range 5 to 23% and pore-flow permeabilities in the range 0.01 to 2000 mD.

The coal measures are relatively undisturbed in the Midlands and East Yorkshire coalfields, but distortion and faulting is common elsewhere, particularly in South Wales. The fault planes do not transmit significant volumes of water.

WATER INVENTORY

The total average daily volumes of water involved in the British coal mining industry are illustrated diagramatically in Fig. 1, the sequence from acquisition to disposal indicated in the first column being used as the framework for the subsequent discussion. Volumes shown are approximate and vary seasonally.

ACQUISITION OF WATER

The sources of water to be considered under this heading are the public supply, abstractions from rivers, streams, wells, boreholes, etc., and rain falling directly onto mining operations. Acquisitions of water from the strata into underground and opencast mine workings are considered in the next Section.

A volume of 13 Ml a day of water from the public supply is used in baths, offices and canteens. The relatively low demand for water of the highest quality for personal use (average 70 l a person a day) is insufficient to justify the costs of treatment of locally available water. However, the high cost of this water (15 to 30 pence a m^3) provides an incentive to minimise use, and for secondary purposes such as baths cleaning, alternative local supplies (approx. 2 Ml a day) are used. A further 24 Ml a day of public

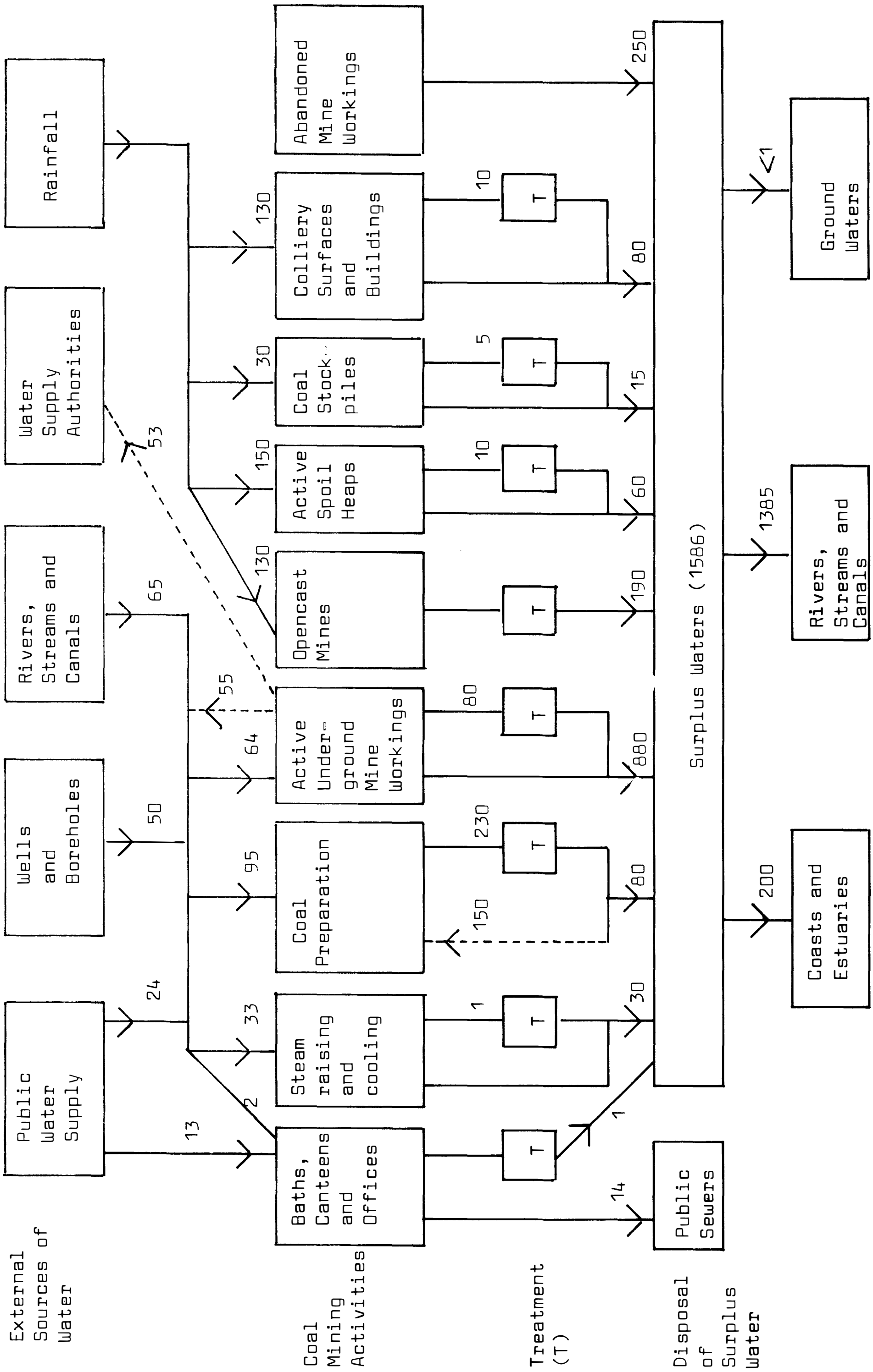

Fig. 1 Water inventory. Average volumes Ml a day

supply water is used for steam raising, the preparation of dilute oil emulsions and underground dust suppression where local supplies are of unsuitable quality.

Abstractions of water from rivers, streams, canals, wells, boreholes, etc., are made on an extensive scale, totalling some 115 Ml a day. Abstractions in England and Wales are made under licence granted by Water Authorities under the provisions of the Water Resources Act 1963. Similar provisions apply in Scotland. Typical charges are a few pence a m^3. Waters taken from rivers and streams are usually chemically soft but often biologically contaminated. Waters from wells and boreholes are normally sterile but may contain higher concentrations of hardness salts.

The estimated total volume of rainfall (daily average 440 Ml) falling on mining operations has been derived from an assumed mean annual rate of 700 mm on the following land areas: active spoil heaps, 8000 ha; coal stock-piles, 1500 ha; colliery surfaces and buildings, 7000 ha, and 1000 mm of rainfall on 4800 ha of active opencast mine workings.

SURPLUS WATER GENERATION

The nine coal mining activities identified in Fig. 1 as producing surplus water will be considered in turn.

Baths, Canteens and Offices

A total volume of 15 Ml a day of waste water is generated. This waste water is similar in composition to domestic sewage but the flows are more irregular.

Steam-raising, Cooling, etc.

About 30 Ml a day of surplus water is created, mostly from once-through cooling systems which induce little change in the water quality. Purge waters from closed circuit cooling systems contain higher concentrations of dissolved solids than were present in the make-up water. Boiler blowdown is highly mineralised and often alkaline but is of low volume since little use is now made of steam operated machinery.

Coal Preparation

Almost 90% of the run-of-mine from underground operations is subjected to some form of wet preparation process, which includes froth flotation in about half of the treatment plants. Internal water recovery and re-circulation is used at all plants, individual return rates being as high as 2 Ml an hour. Although it is possible to design and operate modern plants so that no surplus water is generated, it is sometimes necessary to purge circulating water to limit the build-up of dissolved solids, and due to temporary changes in the quality of the run-of-mine it may be necessary to discharge slurries and tailings for external secondary treatment. Individual discharge rates may be as high as 2 Ml a day with suspended solids contents of up to 35%.

Underground Mine Drainage

A total volume of about 1000 Ml a day is pumped from active mine workings and from adjacent abandoned workings. This corresponds to 3 tonnes of water for each tonne of coal mined. Most of the water flows from shallow unconfined aquifers which are continuously replenished. Significant volumes of water are also pumped from overlying Permo-Triassic strata to protect the shafts and drifts of some of the older mines. In the deeper mines of Central England the relatively low volumes of water flowing from the strata (less than 0.5 Ml a day) are comparable in magnitude to the volume of water introduced into the mine for dust suppression and to the volume of water lost as vapour in the mine ventilation. The qualities of the mine water discharges are shown in Table 1.

TABLE 1 - Examples of the Composition of Mine Drainage Waters and the Relative Abundance of the Classes Identified

Quality	Hard	Alkaline	Moderately Saline	Alkaline and Ferruginous	Acidic and Ferruginous	Highly Saline
Approximate percentage of waters in each class	55%	25%	10%	7%	1%	2%
pH value	7.8	6.8	8.2	6.9	2.9	7.5
Alkalinity mg/l $CaCO_3$	260	850	240	340	NIL	190
Calcium mg/l Ca	75	28	90	190	125	2560
Magnesium mg/l Mg	90	17	40	130	90	720
Dissolved Iron mg/l Fe	0.1	0.5	0.1	25	122	0.6
Suspended Iron mg/l Fe	0.1	2	0.1	21	0.1	0.2
Manganese mg/l Mn	0.1	0.1	0.1	6	7	0.9
Chloride mg/l Cl	180	200	3400	42	50	30800
Sulphate mg/l SO_4	170	210	250	1720	1250	350

The data given in Table 1 show that some 80% of the mine drainage waters are of reasonable quality, although most are moderately hard and slightly alkaline. Salinity is seen to affect a further 10% to such an extent as to make utilisation unlikely, and the remaining 10% are sufficiently mineralised as to create disposal problems. The sources of the dissolved minerals in these discharges are, (a) chloride salts which have accumulated in the strata and been separated by geochemical forces into well defined quality patterns (Chamberlain 1976a), and (b) the mineral iron pyrite (FeS_2) which is ubiquitous in the coal measures and although insoluble in water, oxidises rapidly in air to form a series of acidic products such as ferrous and ferric sulphates and sulphuric acid. These acidic products in turn react with clays and carbonate minerals to form aluminium, calcium, magnesium and other sulphates.

Mineral oils from the strata and spilled oil from machinery occur in some mine drainage waters.

Opencast Mine Drainages

The major sources of water are rainfall, ground water and abandoned underground mine workings. The estimated volume of surplus water generated (190 Ml a day) is liable to considerable variation.

Contamination of the surface run-off or the water pumped from the excavation by suspended mineral particles may occur at any phase of the operation, but is a particular hazard during the initial soil stripping and the restoration operations. Waters from the strata are normally of good quality but the waters from abandoned mine workings are often ferruginous although never saline.

Spoil Heaps

The older spoil heaps constructed by deposition from an aerial flight or tippler were relatively permeable and yielded little or no surface run-off, but low volumes of toe drainage, often ferruginous, were common. Modern compacted spoil heaps are relatively impermeable and yield large volumes of run-off in periods of prolonged or intense rainfall, but no significant toe seepages occur. The surface drainages become progressively more contaminated with suspended mineral particles as the rainfall intensity increases. The iron content of drainages from modern heaps is negligible since pyrite oxidation cannot occur within the body of the heap and exposure is minimised by the rapid build up of spoil and early restoration of the finished surfaces.

Coal Stock-Piles

Run-of-mine and prepared coals are stock-piled for periods of a few days to a few years. The total quantity of distributed and undistributed stocks in Britain in December, 1981, was 42 M tonnes, equivalent to 4 months production. Almost all of this coal stands in the open, yielding surface drainages which are liable to contain suspended mineral particles, chiefly of coal, and a few of the long-term stocks yield acidic and ferruginous seepages. In extreme cases pH values as low as 2.0 and dissolved iron contents greater than 5000 mg a litre (as Fe) have been observed. The chloride contents of the surface drainages and seepages seldom exceed a few hundred mg a litre.

Colliery Surfaces and Buildings

Much of the total volume of rainfall (130 Ml a day) is discharged in an uncontaminated condition in a similar manner to that from other industrial sites. A small proportion of the drainage becomes contaminated with suspended mineral particles.

Abandoned Mines

The discharges to be considered under this heading flow by gravity, in contrast to the waters pumped from abandoned mines which have already been considered. The initial flows from freshly submerged workings tend to be ferruginous, commonly containing 10 to 200mg a litre of dissolved iron. As a rule of thumb, the iron concentration falls by 50% in each subsequent period equal to that taken to fill the workings originally. Flows from unsubmerged workings change little with time and may be acidic, having pH values as low as 3.5 and iron contents of up to several hundred mg a litre (as Fe).

QUALITY CONTROL AT THE SOURCE

An essential feature of the strategy of water management is the control at source of the volume and extent to which surplus waters become contaminated. Such controls improve the possibility of re-use and minimise the disposal problem, but must be cost-effective. Controls are ideally incorporated at the design stage, and often lose their identity as such in the overall system. Examples of the types of controls used in British mining practice are as follows:

Coal Preparation

As far as possible, all water circuits are closed, i.e. no surplus water is generated. Plants are provided with emergency ponds into which process fluids can be dumped and quickly returned to the system and additional lagoon capacity is available at most mines for the receipt of slurries and tailings if necessary. Lagoons which are in regular use are often fitted with return facilities for the re-use of supernate. Non-phenolic froth flotation oils are used where traces of phenols in the surplus water discharge would be unacceptable.

Underground Mine Drainage

In practice little can be done to reduce the volume of water discharged from mine workings. Current policy is to design new shafts and drifts which must be driven through water-bearing strata in such a way as to restrict the ingress of water to negligible volumes. Workings beneath the sea, large bodies of water and major aquifers are set out so as to minimise the risk of water ingress. Quality problems may be classified as: suspended mineral particles, pyrite oxidation products and salinity.

Suspended mineral particles. These are an ever-present problem in an active mine and can only be controlled on an ad-hoc basis. During the sinking and development of new mines such problems may be increased by the presence of grouting materials and may be severe unless strict control is exercised at the point of contamination. Once a mine has been developed, pump sumps and lodgements provide sedimentation, and in older mines complete sections of abandoned workings may be used for this purpose.

Pyrite oxidation products. The oxidation of exposed iron pyrite cannot be prevented in an active mine working, thus the only fundamental control possible is to avoid mining in highly pyritic strata. The physical contamination of the drainage water by pyrite oxidation products can sometimes be controlled by trapping a water-make at the point of entry into the workings. Some workings in pyritic strata are flooded as soon as possible after completion in order to prevent further pyrite oxidation. Air-seals are not normally constructed to control pyrite oxidation in worked-out areas of the mine.

Advantage is frequently taken of the alkaline properties of the strata waters at intermediate depths to neutralise in-situ the more acidic waters from shallow workings. These reactions take place in underground pools and sumps and produce waters of neutral pH value containing dissolved iron as bicarbonate in concentrations from 10 to 150 mg a litre (as Fe).

Salinity. No effective control over the ingress or quality of saline waters into mine workings can be exercised other than by not working in strata liable to yield such waters.

Opencast Mines

The principal controls are aimed at restricting the volume of water flowing into the excavation. Peripheral surface ditches are provided and surface water courses diverted. Ground waters and abandoned mine workings are drained by pumping from boreholes and old mine shafts in the vicinity. Water accumulating in the excavation is allowed to clarify by sedimentation as far as possible before pumping out, and, where necessary, water channels are lined to prevent scour and erosion of solids.

Coal Stock-Piles

Possible control procedures depend on the particle size distribution of the coal. Industrial fuels and coking coals having a particle size range from zero to about 30mm are preferably stored in heavily compacted piles. Such piles achieve a maximum use of land space, eliminate the risk of spontaneous combustion, reduce the loss of coking properties and do not produce chemically contaminated seepages. Surface run-off, possibly contaminated by coal particles occurs in periods of prolonged or intense rainfall.

Graded fuels, on the other hand, cannot be compacted and are highly permeable. The risk of generation of pyrite oxidation products is intensified by the relative absence of the shales and carbonate minerals which would otherwise serve to neutralise the primary oxidation products in the less clean coals. The storage of graded coals of high sulphur content is restricted as far as possible, the guidelines given in Table 2 representing acceptable practice in the British climate.

Table 2 - Safe Coal Storage Times

Total Sulphur Content of graded coals (% S)	Safe Storage Time in open air
Less than 1	Indefinite
1 to 2	6 months
2 to 4	2 months
Greater than 4	1 to 4 weeks

Spoil Heaps

The principal control over the quantity and quality of the drainage is achieved by minimising the area of disturbed land exposed to the weather. It may, however, be necessary to leave the final surface of saline spoils exposed for up to two years in order to leach out salts which would otherwise retard the growth of vegetation. At many sites, the peripheral drains used for the control of pore water pressures in the heap may serve the additional purpose of flow balancing and sedimentation by appropriate design.

Abandoned Mines

Almost no control over the quantity or quality of abandoned mine (gravity flow) drainages is attempted in Britain. Hydraulic sealing to prevent the emission of water is generally impracticable due to the absence of underground coal barriers and the multiple outlets created by small-scale mining in the past. Air-sealing has been used on a few occasions but has seldom had any significant effect on the quality of the drainages.

TREATMENT

Processes to be considered under this heading include treatment of contaminated surplus waters for re-use or disposal to the environment and exclude common industrial processes such as sewage purification, water softening and oil separation. The contamination problems revealed in previous sections fall into three classes: suspended mineral particles, pyrite oxidation products and salinity.

Treatment to reduce the salinity of coal mine surplus waters is technically feasible but is not practised in Britain since the disposal problems can be solved more cheaply by overland transport of the untreated water to an acceptable disposal point.

Excessive concentrations of suspended mineral particles are almost always controlled by sedimentation, usually in earth-walled lagoons. Such mine drainage waters as need treatment usually contain sufficient pyrite oxidation products to act as flocculants, and surface drainages from spoil heaps are often flocculated, presumably by residual polyelectrolytes from the coal preparation process. Lagoon design may be based on settling rates to give a single area parameter. In practice retention times in the range 4 to 48 hours are provided.

Drainages which are completely rainfall-related such as spoil heap run-off cannot be completely controlled in high-flow conditions by sedimentation unless prohibitively large areas of land are set aside for the purpose. Current philosophies are that about 0.4% of the disturbed land area should be provided for the sedimentation of run-off. This provides adequate control in the climate of Central England on all but about 2 to 5 occasions a year, at which times the receiving water courses should be in spate and capable of accepting the drainage.

Treatment to reduce the iron content of coal mine surplus waters is technically feasible (Chamberlain 1976 b) and is used in Britain on an increasing scale, about 16 treatment plants being in operation in 1981. Simple chemical processes are used which remove not only as much of the iron as is necessary, but also associated contaminants such as aluminium and manganese and traces of copper, nickel, zinc, etc. Processes in use are based on the precipitation of iron from solution with subsequent separation by sedimentation and filtration. Precipitation may be accomplished simply by aeration of many of the waters, but others require the addition of alkali. The two types of water may be distinguished by boiling a sample after which the pH value of the latter will be less than 8.3 and the former greater than 8.3 (alkaline to phenolphthalein). The pH value of the raw water does not necessarily indicate the type of treatment required.

Aeration and sedimentation processes are usually conducted in earth-walled lagoons with cascade aeration between stages. Plant design may be based on elaborate studies of the rates of de-carboxylation, oxygenation, oxidation, coagulation and sedimentation, but for practical purposes the guidelines shown in Table 3 are found to be effective in the British climate.

TABLE 3 - Empirical Design Data for Aeration and Sedimentation Treatment Systems

Ferrous content of raw water mg/l Fe	Number of lagoons each providing 24 hours retention time	Number of cascades each providing a 2 metre fall
Up to 30	2	1
30-60	3	2
60-90	4	3
90-120	5	4
120-150	6	5

The sludges deposited from these aeration processes consolidate to 5 to 10% dry solids content within 21 days and then drain easily on gravel beds to a dry solids content of 25%. The iron content of the dry solids is about 40% (as Fe). This sludge may find a market as a pigment.

Alkali treatment is normally conducted with calcium hydroxide, although calcium oxide and the sodium alkalis have been used. Dosage control may be determined by testing samples of the water to be treated or by continuous measurement of the pH value at the point of mixing. Contrary to the practice in some countries, no attempt is made to oxidise or densify the precipitated iron compounds after neutralisation. The sludge from alkali treatment is relatively impure, containing 5 to 10% solids after 21 days consolidation, the dry solids containing less than 20% of iron (as Fe). These sludges may be disposed of directly, for example into opencast mine backfill, or may be further drained on sand beds or by mechanical filters before disposal, for example with colliery spoil.

RE-USE OF WATER

The principal re-use systems are shown by the broken lines in Fig. 1.

The mine drainage waters provide consistent sources and some 53 Ml a day is transferred to water supply authorities for use in the public and industrial supply (Rae 1978). A further 55 Ml a day is used as process water within the coal mining industry.

The rainfall-derived drainages are of reasonable quality but the flow rates are so variable that the costs of storage reservoirs would not be justified. Surplus coal preparation waters are re-cycled from lagoons where profitable, although in the British climate, waters of suitable quality are often readily available, and re-cycling is used as a means of pollution control rather than as a means of water conservation.

DISPOSAL OF SURPLUS WATER TO THE ENVIRONMENT

As shown in Fig. 1 the average total daily volume of surplus water from coal mining activities, including gravity flows from abandoned mines is about 1586 Ml. This volume is negligible compared to the flows in the rivers and streams which form the surface drainage system and is considerably less than the volume of water provided by public supply authorities, which is 13000 Ml a day in England and Wales alone.

The water discharged by the coal mining industry is generated at about 400 sites and flows through about 1500 identified outlets. The mean discharge rate is thus about 1.1 Ml a day. Discharges containing a high proportion of surface drainage vary in flow considerably and may reach 15 Ml a day at a single outlet. However, even these flows seldom present any hydraulic difficulties of disposal since they represent such a small proportion of the surface drainage in the British climate.

Difficulties have in the past been encountered in meeting statutory requirements relating to the quality of discharges to surface waters but these have now largely been overcome by technical developments, appropriate investments and improved management control.

Responsibility for the management of streams, rivers, estuaries and ground waters is vested in Regional Water Authorities in England and Wales and River Purification Boards in Scotland. Discharges of trade effluents to surface waters are subject to consents obtained from an authority under the Rivers (Prevention of Pollution) Acts which will soon be superseded by the Control of Pollution Act 1974. Consents may not be required for the discharge of certain surface drainages but it could be an offence to cause or knowingly permit such discharges if they were poisonous, noxious or polluting. Certain of the waters raised or drained from underground parts of a mine are presently exempt from statutory liability but this exemption will not be maintained in the Control of Pollution Act. Discharges to ground waters by means of well, borehole or pipe are regulated by the Water Resources Act 1963 and further powers to control discharges to ground waters will be obtained by the enforcement authorities under the Control of Pollution Act.

The conditions specified in consents for discharges are based on published environmental quality objectives which will become increasingly controlled by Directives of the European Economic Community.

Typical consent conditions for discharges from coal mining operations to rivers and streams include:

pH value:	greater than 5 (or 6) and less than 9
Suspended solids:	30 to 200mg/l
Iron (total) as Fe:	5 to 30mg/l
Oil:	5mg/l

It is a measure of the success of the industry in dealing with these problems that over 80% compliance with consents is now achieved regularly in most of the coalfields. Outstanding problems are confined to accidental spillages involving the release of suspended mineral particles, and to some of the more ferruginous and saline mine drainage waters which are at present exempt from liability. Additionally, the drainages from abandoned mines, some of considerable age, remain to be controlled.

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