THE MIDLAND INSTITUTE OF MINING ENGINEERS

GENERAL MEETING,

HELD AT THE DANUM HOTEL, DONCASTER, THURSDAY, 1ST APRIL, 1948.

MAJOR H. J. HUMPHRYS, D.S.O., O.B.E., M.C., PRESIDENT, IN THE CHAIR.

ELECTION OF MEMBERS.

The following gentlemen were elected to membership of THE MIDLAND INSTITUTE OF MINING ENGINEERS:

MEMBER (TRANSFER FROM ASSOCIATE MEMBER)—

GROUP D (*Other Professions*). SUB-GROUP D.2 (*Research Workers*).

GEORGE STANLEY HASLAM, Chief Scientist, N.E. Division, N.C.B., Ridgeholme, Bawtry Road, Bessacarr, Doncaster.

ASSOCIATE MEMBER—

GROUP C (*Engineers*). SUB-GROUP C.1 MECHANICAL (*Mining*):

REGINALD LESLIE CLARKE, Assistant Sub-Area Mechanical Engineer, Area 1A, N.E. Division, N.C.B., 110 Bocking Lane, Woodseats, Sheffield, 8.

GROUP A (*Mining Engineers*):

THOMAS POLLARD, Mining Adviser and Development Engineer, 5 Roman Mount, Leeds, 8 (*Transfer from Student*).

ASSOCIATE—

JAMES ALBERT STEWART, Chief Electrician, 25 Arlington Avenue, Aston, Sheffield: JOHN FYFE WILKIE, Assistant to Area Electrical Engineer, No. 1 Area, N.E. Division, N.C.B., 89 St. Lawrence Road, Tinsley, Sheffield, 9 (*Transfer from Student*).

[No. 3220

MINE WATER

BY H. SAUL, *Member*.

Introduction.—It is hoped that the following account of findings in the course of seventeen years' work on the incidence of water in coal-mines may to some extent assist mining engineers to recognize in their own mining reserves problems potentially similar to those here considered.

MAGNITUDE OF THE PROBLEM OF MINE WATER.

(a) As to Cost.

It will no doubt be possible to obtain accurate figures in the near future under the standard system of accountancy adopted since the mines were nationalized. From the figures so far available, however, it appears that the cost of pumping in South Yorkshire, including power, wages, and maintenance of plant and roads used only for pumping, is of the order of 2d. to 2½d. per ton of annual output, or a total cost of little less than £250,000 per annum. Pits dealing with large quantities of water will probably incur a cost of the order of 5d. per ton, and costs as high as 8d. have been recorded in temporarily unfavourable circumstances. The cost of power (in view of the still common use of compressed air) is difficult to arrive at, but if all pumping were carried out by electricity, the power expended on pumping would cost ½d. per ton. The actual cost must therefore be in excess of this.

In comparing the cost of mine pumping incurred by water-supply authorities, there must be borne in mind the fact that public-supply stations are put down to produce a given quantity of water, regardless of what greater quantity may, in fact, be available. On the other hand, mine pumping-stations must deal with all the water available as it becomes available. A load-factor of 10% is therefore not unusual, accounting for a cost of 10d. to 1s. per million gallons raised 1 ft. as against a cost of 4d. to 5d. on a similar basis for a public-supply pumping-station before the war. From the seasonal variations referred to below, it is clear that a better load-factor is unlikely to be obtained at many mine pumping-stations without incurring undue risk in wet seasons.

(b) **As to Quantity.**

The average quantity of water now being pumped from working mines in the South Yorkshire coalfield is 19,000,000 gal. daily, or about 1⅓ tons of water per ton of coal drawn.

To obtain a more complete account of the water available as percolation there should be added the feeders formerly, and presumably still, available to abandoned mines which have been allowed to fill with water, after proper deductions for water now leaking from such abandoned mines to contribute to the figure of present pumping. A likely figure in the case of South Yorkshire would be 3,000,000 gal./day.

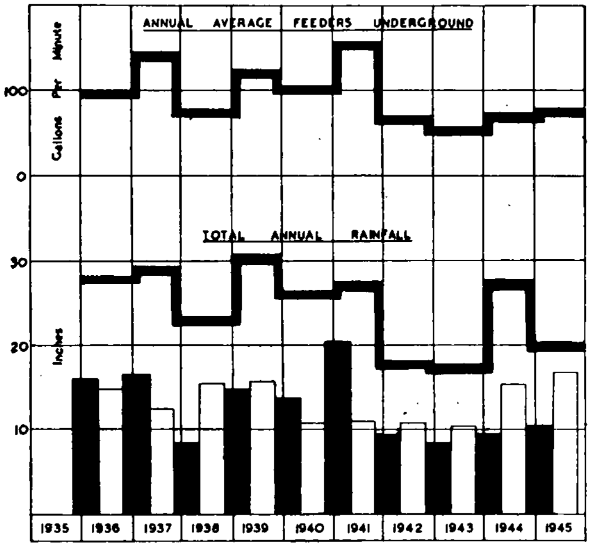

FIG. 1.—RELATION OF RAINFALL TO INFLOW OF MINE WATER, 1935-45. SOLID BLACK COLUMNS ARE FOR NOV.-APR. PERIODS, AND WHITE FOR MAY-OCT.

Seasonal Variation.

In mines subject to direct vertical percolation in appreciable quantity, as opposed to those being fed by leakage from adjacent waterlogged mines*, the seasonal variation is considerable. While the average quantity of water entering the mines is of the modest dimensions already given, peak feeders in a bad winter may reach serious proportions. For example, one pumping-station dealing with an average quantity little in excess of 300,000 gal/day, dealt with over 5,000,000 gal. on each of five days in March 1947. This was certainly an extreme case, but there were many instances of peak feeders out of all proportion to those used for computing the annual average.

RATIO OF PERCOLATION TO SURFACE RAINFALL.

Since surface rainfall must be disposed of as evaporation, run-off, or by percolation, it follows that the factors affecting percolation into a given exposure must include:

(1) Rate of precipitation.
(2) Slope of the surface and height above the nearest surface stream of the exposure in question.
(3) Surface temperature and humidity.
(4) State of the surface in regard to the utilization of land as between plantation, pasture, arable land, and building.
(5) Seasonal state of vegetation.
(6) Geological characteristics of the strata concerned.

* Outcrop Water in the South Yorkshire Coalfield," H. Saul, *Trans. Inst. Min. E.*, 1936-7, **93**, 64.

Other things being equal, the steeper the ground the greater the run-off. The lower limits of the exposure being at a level higher than that of the nearest surface stream will increase this difference.

It is well known that evaporation is greater in summer than in winter from a given amount of rainfall. In order to examine, to some extent quantitatively, the effect of seasonal variation in rainfall on the quantity of water reaching a mine, the percolation of water into the Barnsley Seam at an average depth of 80 yds. from the surface was observed for a period of 10 years, against simultaneous measurements of rainfall on the catchment area. The results of this investigation are shown graphically in Fig. 1. It will be observed that there is no direct relationship between the total quantity of rain falling on the catchment in any year and the quantity of water to be pumped in that year. On the other hand, when rainfall is subdivided into summer and winter periods it will be observed that there is a marked correspondence between the total quantity pumped in any year and the winter rainfall.

Figures quoted by Molesworth of average loss of rainfall *from the surface* in this country by infiltration are as follows:

Winter	33%
Spring	35%
Summer	2%
Autumn	48%
Total Annual ...	42%

The ground water-table having risen during winter, there must be a continuation of percolation at winter rates to the mine until the table falls. On the other hand, the

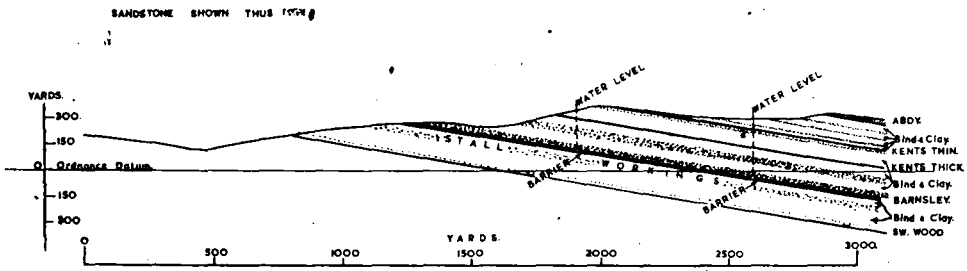

FIG. 2.—CROSS-SECTION OF CATCHMENT AREA REFERRED TO IN FIG. 1.

autumn infiltration from the surface will not result in percolation to the mine at winter rates until the water-table rises again, and a lag of from 1 to 5 weeks is common in this coalfield. Thus the mine figure for spring could be expected to be more than 33% and the autumn figure considerably less than 48%. After due allowance in this fashion, the figures indicate that the two periods used in the graphs have a relative value for percolation of at least two to one. It would appear from a study of the graph that in the example illustrated the ratio is even higher. So far as the actual percentage is concerned, however, the figure for the whole year 1939 was 30%, and for 1945 24%, in the present case, as compared with 42% for the country as a whole in the figures just quoted.

In order to facilitate comparison with any other study which may be available, an average cross-section of the catchment is given in Fig. 2. It will be noted that the factors likely to have a major effect upon the ratio percolation to rainfall are:

(i) Moderate slope on the surface which is mainly arable land.
(ii) Little building.
(iii) Sandstone above the seam which outcrops at the surface quite close to the area in question.
(iv) Extensive mine workings by partial-extraction methods still standing open.
(v) Free drainage from the workings preventing any tendency to accumulation or backing up of water in the measures.

DISTRIBUTION OF UNDERGROUND WATER.

(a) In Area.

Omitting for the moment consideration of the effect of extensive undermining, underground water is encountered in large quantities where coarse sandstones overlie the seam in question. The normal Coal Measure succession of sandstone, shale, coal, fire-

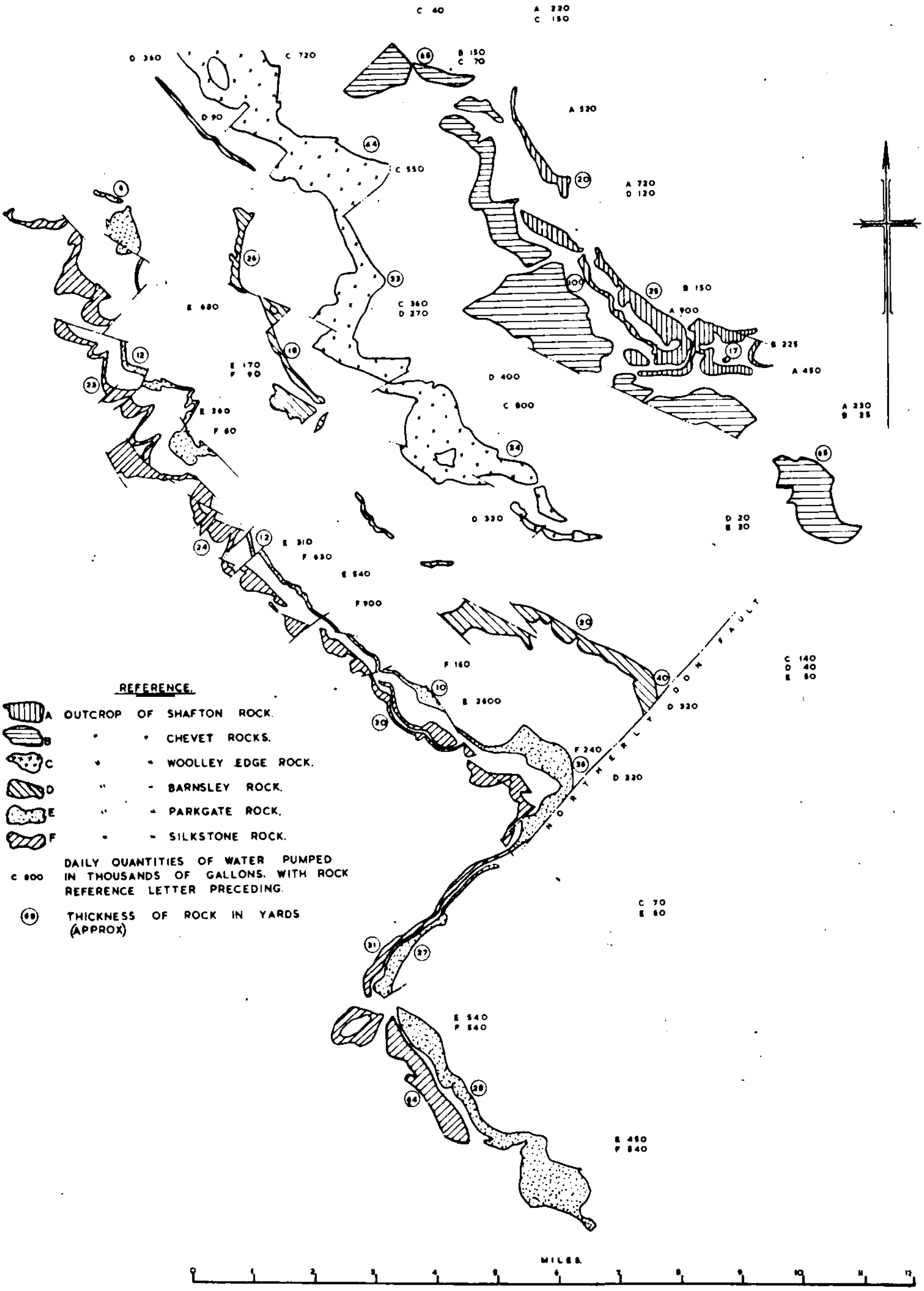

FIG. 3.—SOUTH YORKSHIRE COAL MEASURE ROCK EXPOSURES, THICKNESSES, AND WATER FEEDERS.

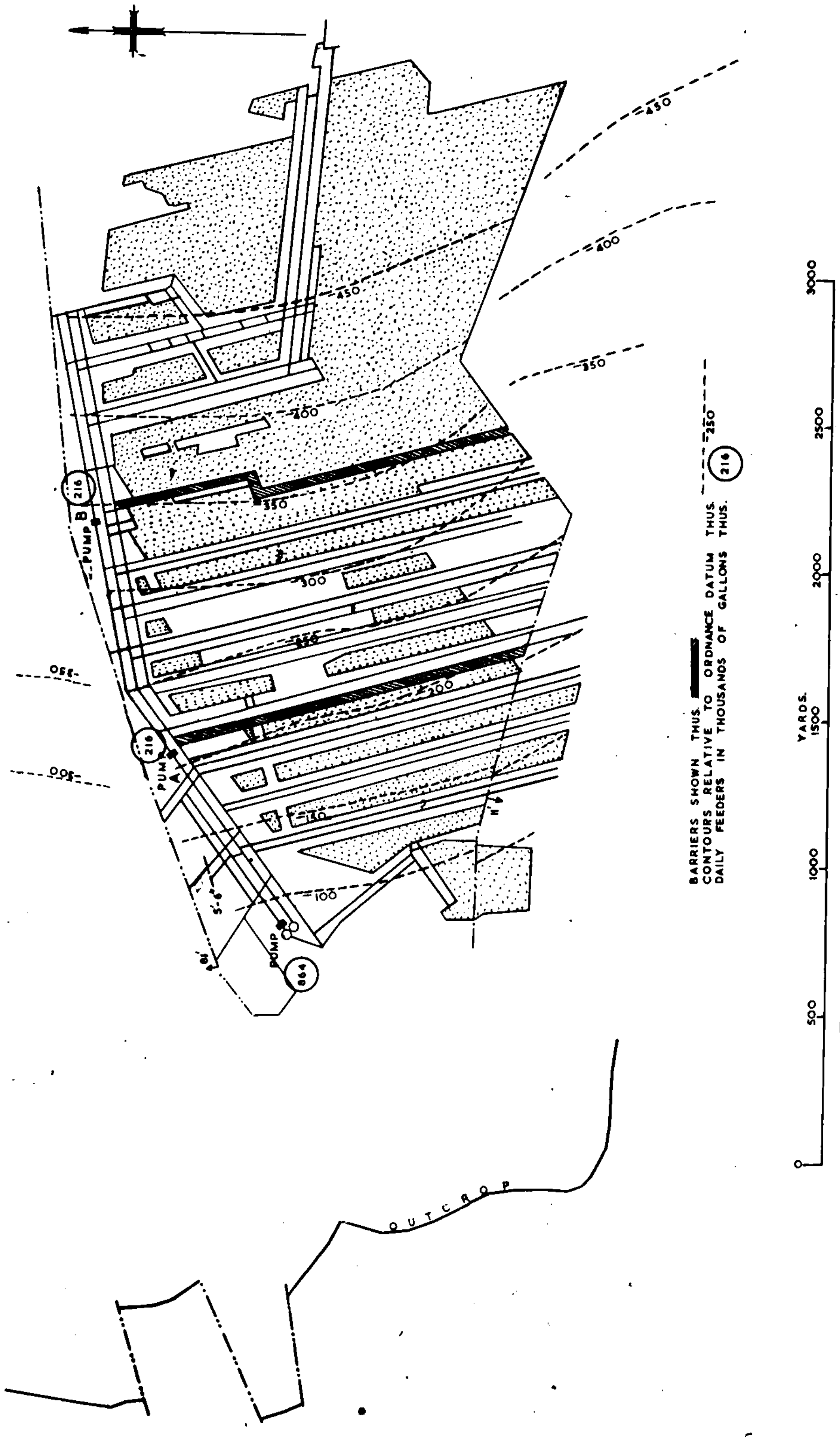

FIG. 4.—SPACING OF WATER-LEVELS AND CATCHMENT BARRIERS.

clay tends, in average conditions, to confine water infiltrating into any porous stratum at its surface exposure to that stratum, as it passes under the cover of the superincumbent beds. The water encountered in a mine working its first seam, remote from old goaves, usually originates therefore in the porous strata occurring within quite a modest distance of the seam. For example, although the Parkgate and Silkstone seams are rather less than 100 yds. apart in the Sheffield district, the water encountered in the two seams is dealt with separately and originates in the rock above the respective seams which, by chance, is of great thickness in both cases.

On the other hand, between Hasland and Boythorpe, south of Chesterfield, the Deep Hard rock is so thick as practically to reach the Deep Soft Seam, and the Deep Hard

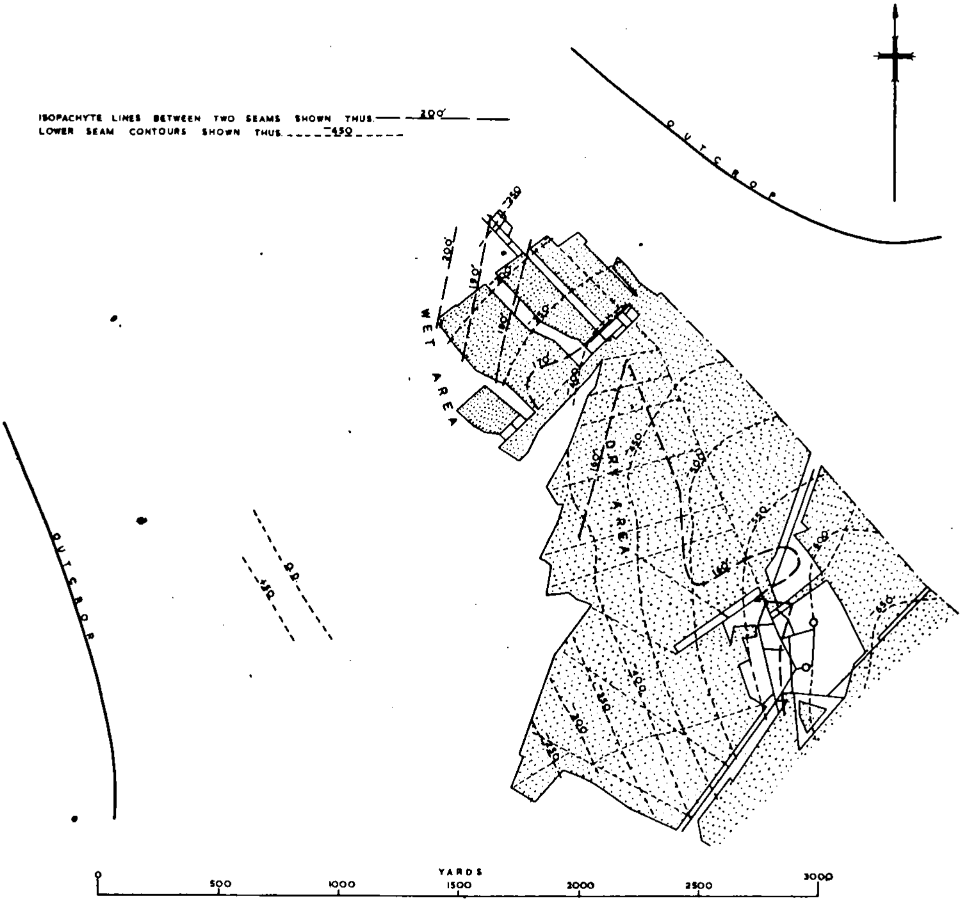

FIG. 5.—VARIATION OF ROCK THICKNESSES AS AFFECTING INCIDENCE OF MINE WATER.

and Deep Soft waters are hardly to be separated one from another. The Piper Seam, however, which is only 70 ft. below the Deep Hard Seam, has been worked under waterlogged Deep Hard workings with so little incidence of water that uphill boring has been necessary to run off a feeder of less than 20 gal./min.

It appears that, generally speaking, under Coal Measure conditions a thickness of fireclay or comparatively impervious bind or shale of only 30 or 40 ft. may be successful, if undisturbed, in preventing the downward passage of appreciable quantities of water from a very permeable stratum.

Fig. 3 shows the approximate distribution of the outcrops of the South Yorkshire sandstones and the overall daily quantity of water pumped from the underlying seam in each case. When these figures are added together little remains of the coalfield total already given.

A study of the extent of the cone of depression produced by drainage from a borehole or adit in a given water-bearing stratum should enable some forecast to be made of the extent to which the rise side rock can be similarly de-watered under mining conditions. Some collieries already have arrived at a rough estimate of this, and Fig. 4 shows how a large feeder is dealt with by pumps at the shaft-bottom; a subsidiary adit runs from a pump-house, *A*, along the strike at 600 yds. to the dip of the shaft and another from a pump-house, *B*, at 800 yds. still farther to the dip, dealing, except for a few very minor feeders, with the whole of the water encountered in the workings. Workings not so laid out often require numerous inbye pumps, and an appreciable cost is incurred in labour to operate and maintain them.

A consequence of the lenticular formation of sandstones is the variation in the thickness on lines, the position of which cannot always be determined. This leads to difficulty in planning a lay-out intended to provide for dealing with the water at as few points as possible, while obtaining the maximum area of work in dry conditions.

It may be possible, however, to arrive at some definition of the limits of the sandstone where a seam above and below it has been worked. Fig. 5 shows a case in which pumping from a shaft at the deep end of the royalty allowed the seam to be worked to the rise under comparatively dry conditions for a distance of 1,500 yds. Roof water was then encountered in quantities so large as to make the remainder of the seam unworkable. Levels being available in an upper seam also, it was possible to plot iso-pachytes of the intervening strata, and these showed a sudden increase in thickness at the point where the roof water was encountered in the lower seam. It is not an unreasonable assumption that so sudden an increase must be accounted for in the coarser grained strata. Then, in the absence of old workings or faults, the explanation of the incidence of roof water must lie in easier flow down the measures from the outcrop to that point than was available below it. A simple analogy is that in which water flows down a uniformly sloping pipe reduced in size at some point from 2 in. dia to 1 in. The initial de-watering at the pit-bottom represented the free flow from the 1-in. open-ended pipe while the increased water represented that available from a broken joint at the increase in diameter.

In such a case it may be possible to obtain reasonable freedom from roof water at the working-face over the remainder of the area by driving a winning face or headings along the maximum iso-pachytes, drilling upwards at intervals if necessary, and conducting the water so made to a central pump.

The Influence of Faults.

A fault on or near to the line of full dip has normally only a direct effect on the incidence of water in one or both of two ways, namely, by reducing the area of rise coal liberated for work by drainage at a given level, or by bringing into line with the working seam a water-bearing horizon of old workings or rock. The latter is the more important.

In laying out workings it is necessary to ensure that otherwise careful protection against water is not negatived by such a juxtaposition, either immediately or, in the case of workings in another seam, at some future date. The Shafton Seam in Yorkshire is unusually difficult in this respect, having sandstones above and below it, so that either an upthrow or a downthrow fault may bring trouble.

Strike faults are very helpful from the point of view of drainage, as more often than not they cut off rise water fairly effectively. In laying out workings it is desirable to see not only that roads through such faults should be as few in number as possible, but also that provision is made for sealing them when they cease to be of use. A corollary of this may not be foreseen. Where such faults prevent rise water from passing farther to the dip it is to be expected that the strata immediately to the rise of the fault will be heavily waterlogged if within a reasonable distance of the outcrop of the measures concerned. A road piercing the fault from the dip side must, therefore, be expected to encounter initially heavy feeders. Even where the fault is such a distance from the outcrop that the permanent feeder is inappreciable there may be a heavy feeder until the rocks have been drained. As a case in point the Parkgate rock, 1,000 yds. deep, yielded a feeder of 200 gal./min. for a fortnight on piercing such a fault, as shown in Fig. 6.

It will be observed that the throw of the fault in this case was only 2 ft. The seam was over 4 ft. in thickness, a reminder that the sealing of the strata is not always by juxtaposition of another stratum but by the intercalation of the "leather bed" on the fault-plane. Herein lies the explanation of two phenomena in connexion with fault flushes, namely, the time-lag of up to 24 hours and the failure of a borehole in certain cases to draw water from a fault which yields a flush when subsequently encountered by a heading. There must be some slight yield in the fault slip before this, previously a seal, can become a conduit.

An exaggerated case arises in a catchment area formed by two faults meeting at an angle, being either a dip fault meeting a strike fault or two faults at intermediate

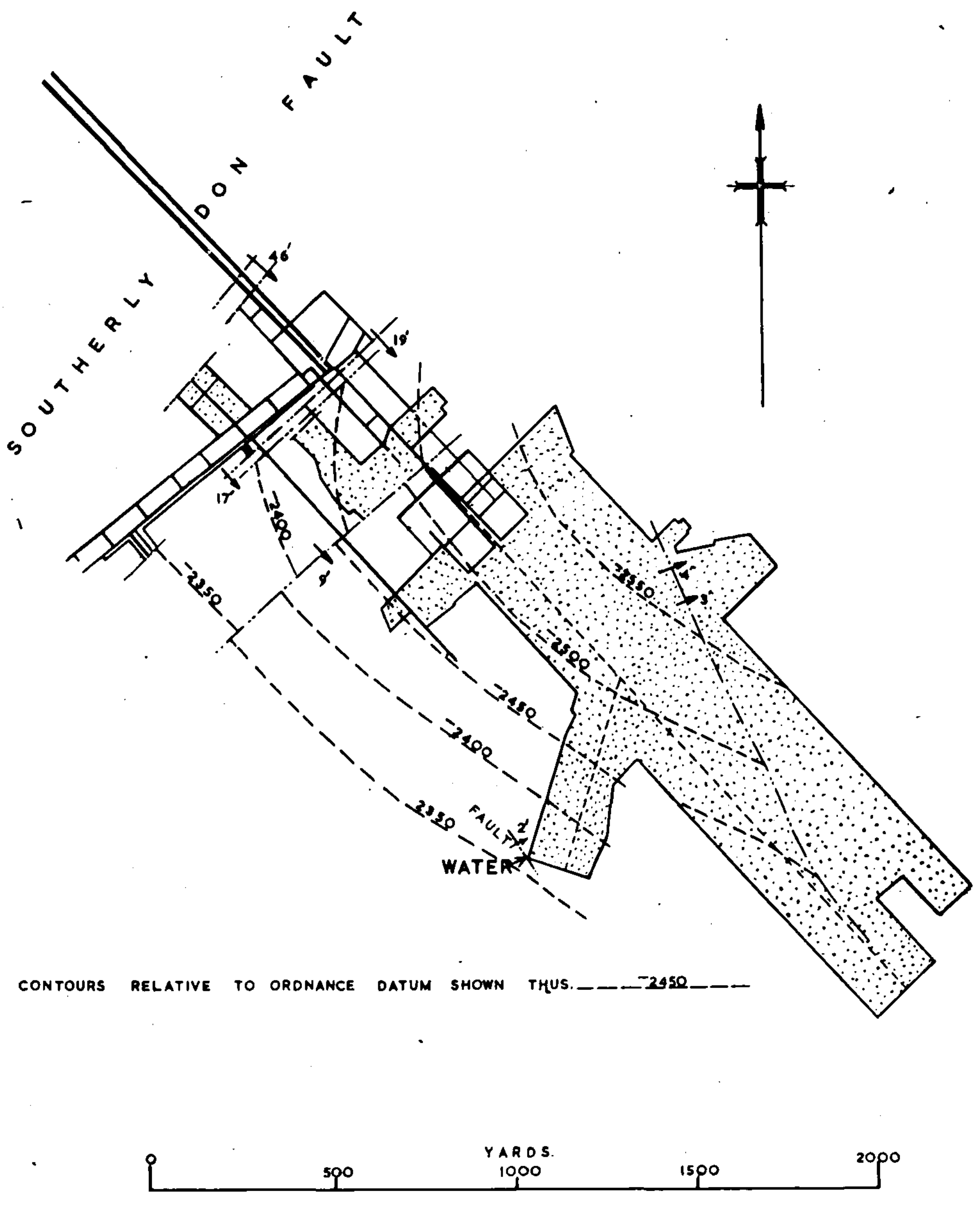

FIG. 6.—INCIDENCE OF WATER AT STRIKE FAULTS, EVEN AT GREAT DEPTH.

angles. The point of junction resembles the neck of a funnel which, if within a mile or so of the exposure of a permeable stratum, is very likely to be heavily charged with water. Fig. 7 illustrates an example in which fairly heavy permanent feeders continued to run even after very heavy initial feeders had been dealt with.

(b) In Depth.

Heavy feeders in the Yorkshire Coalfield are not often found at greater depth than 150 yds. in Coal Measure strata, and even when so deep usually result from a steep dip shortening the normal distance between the outcrop of the rock concerned and the point of incidence. The resistance to flow laterally through the rock is such that the feeders available to workings quickly fall off once the water-bearing stratum is covered by a less permeable stratum.

This is exemplified in the case of the Woolley Edge rock, which is about 100 ft. thick in the Barnsley area. Shaft pillar roads in the Meltonfield Seam below it encounter permanent feeders of 350 gal./min. in the area of the rock exposure at the surface. Half a mile to the dip of the exposure, the available feeder, even to wide workings causing roof collapse, has fallen to 200 gal., and 3 miles from the exposure the available feeder is 50 gal./min. in similar workings.

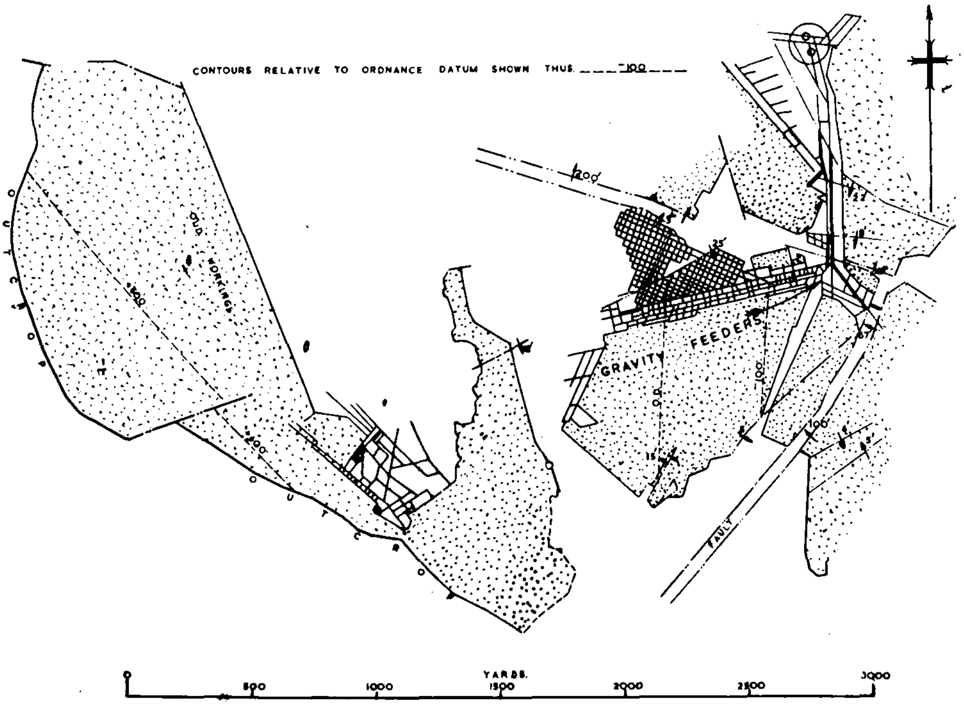

FIG. 7.—INTERSECTING FAULTS FORMING A CATCHMENT FOR OUTCROP WATER.

On the other hand, when a seam has been worked out under the rock and the workings have become waterlogged, not only do the workings provide an easier path to the dip but what amounts to a new rock exposure has been made. The manner in which this may result in the transfer to great depths of water problems normally encountered at depths less than 150 yds. has already been described.

These observations apply only to Coal Measure strata, and in connexion with the Permo-Triassic measures it must be borne in mind not only that the rate of lateral percolation is often much greater, but also that the occasional marl beds which tend to restrict vertical percolation, are neither so frequent nor so effective as the impervious binds and fireclays of the Coal Measures. The greater significance of this point lies in its bearing upon possible feeders awaiting indiscreet approach to the base of the Permian by workings east of Doncaster. The incidence at a fault of an appreciable feeder, approximately 300 ft. below the base of the Permian, is a reminder to planning engineers to provide for a first approach to known faults by a narrow heading in order to test the necessity or otherwise of leaving a little coal at the fault side.

QUALITY OF MINE WATER.

This subject will be considered from the following aspects:

1. Its effect upon the plant and materials used for dealing with it.
2. The consequences of discharging it into (*a*) sources of colliery or public water-supply and (*b*) surface streams.

Generally speaking, and not unnaturally, the larger the feeder and the nearer the point of collection to the point of issue from the source rock, the better the quality of the water. Representative analyses of appreciable feeders from various rocks in South Yorkshire are given in Table I. Feeders which have travelled some distance through old workings on the contrary are occasionally corrosive, and a feeder of 15 to 25 gal./min. may be more expensive in plant replacement and maintenance than in power, notwithstanding its occurrence at depths exceeding 250 yds.

TABLE I.

Probable Composition.	SHAFTON ROCK.	CHEVET ROCK.	KENTS ROCK.	PARKGATE	SILKSTONE ROCK.
Silica	—	0·82	—	0·9	0·4
Alumina and Iron oxide	—	0·20	0·84	—	0·26
Calcium carbonate	9·3	8·99	15·13	14·0	9·5
Calcium sulphate	—	—	—	—	12·65
Magnesium sulphate	—	—	23·74	25·29	21·6
Sodium sulphate	15·9	18·83	15·66	71·76	—
Sodium chloride	3·6	6·23	6·46	9·74	12·52
Magnesium carbonate	8·3	6·85	5·97	2·06	—
Sodium carbonate	—	8·25	—	—	—
Sodium nitrate	—	0·014	—	—	—
Sodium bicarbonate	9·4	—	—	—	—
*p*H value	8	7·3	7·5	7·3	7·0
Permanent hardness	10·5	6·0	37·0	25·00	150·2
Temporary hardness	18·6	17·2	23·0	16·45	20·0

Analyses of two such waters are given in Table II.

TABLE II.

(A)

Probable Constitution.	*Grains/gal.*
Ferrous chloride	7·7
Ferric chloride	1·6
Calcium carbonate	0·8
Calcium chloride	3,346·5
Magnesium chloride	783·9
Ammonium chloride	22·4
Sodium chloride	9,311·2
Organic matter	1,399·5
*p*H value	7·1

(B)

Analysis. Acid Pump-water.	*Grains/gal.*
Acidity as H_2SO_4	84
Ferrous sulphate	282
Calcium sulphate	0·735
Magnesium sulphate	0·833
Sodium sulphate	764
Sodium chloride	25
Total solids	1,474
*p*H value	4·8

In Case (A) the water drips from the roof of the Parkgate Seam at a depth of 700 yds.

In Case (B) the water leaks through a barrier against old workings at a point quite close to a colliery pump-house and is so corrosive in quality that only a pump made completely of stainless steel gives an appreciable life.

Larger feeders in the South Yorkshire Coalfield are rarely so corrosive as to have an appreciable effect on cast iron and in some cases, such as that of the analysis in Table III, the corrosive quality would not be observed except for this action at such points as the mild-steel bolts in the foot-valve joint.

TABLE III.

Calculated Results.	*Grains/gal.*
Silica, Alumina, and Iron oxide	1·12
Calcium carbonate	16·11
Calcium sulphate	11·25
Magnesium sulphate	48·43
Sodium sulphate	20·78
Sodium chloride	4·26
*p*H value	8·2

In some cases chemists appear to have a little difficulty in forecasting the precise action of a water on metals, although usually able to indicate where caution is necessary. There have been suggestions based on research by the DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH that bacterial action may be involved. It may, therefore, be worth while in case of doubt to immerse a sample of the metal concerned in the water, and to weigh and measure it carefully before and after immersion. It is desirable that the exposed surface should be large in relation to the mass and that at least a portion of it should be machined. Such a method could be applied before a change over from cast-iron mains to mild steel, a machined section of smaller diameter mild-steel pipe being suspended on spiders in the cast-iron main during use. Table V gives the result of such a test in the case of water (A) in Table II.

The possible effect of the water upon structural materials, such as the culverts and sumps by which it is collected, should also be considered. In some cases there is a notable effect upon concrete linings, which should be allowed for either by coating to above the water-line or by allowing an increased thickness of cover over reinforcement.

POLLUTION.

More often than not it will be necessary or desirable to utilize water pumped from the mine for colliery consumption. Sampling of the water issuing from the rising main at the surface is not a sufficient test for this purpose unless it prove the whole of the water coming from the mine to be of satisfactory quality. In the contrary event, it may be found that, by dealing separately with one underground feeder, the remainder can be made potable or suitable for boiler-feed or at worst suitable for coal washing. Three samples from the same colliery together with the sizes of their respective feeders are given in Table IV.

TABLE IV.

	A.	B.	C.
Feeders, gal./day	86,000	200,000	70,000
Probable Combination of Mineral Constituents.	*Grains/gal.*	*Grains/gal.*	*Grains/gal.*
Silica	0·665	0·854	0·952
Alumina and iron oxide ..	0·210	0·112	0·126
Calcium carbonate	20·762	8·792	6·587
Sodium carbonate	—	19·138	27·286
Calcium sulphate	13·055	—	—
Magnesium sulphate	27·174	—	—
Magnesium carbonate	—	6·573	5·369
Sodium sulphate	25·025	36·092	44·751
Sodium chloride	4·270	3·234	3·171
Sodium nitrate	0·112	0·231	0·168
*p*H value	7·8	7·8	7·6

TABLE V.

Corrosion Tests. (Water (A) in Table II).

The figures are losses in mgm./sq. in./day.

Cast iron	1·08
Mild steel	1·09
Staybrite F.D.P.	0·05
Monel metal	0·25
Phosphor-bronze	0·62
Bearing bronze	0·64
A.G.M.	0·65

Pollution of surface streams to which mine water is discharged has recently been given some publicity. Water has been discharged from coal-mines in this country, and certainly in Yorkshire, for 200 years, and before discussing the general remedy for pollution from this cause it would be desirable first to go into the question of how many of the cases considered to be those of pollution by mine water are, in fact, pollution by the effluent of preparation plant, water-softeners, and chemical works. These having been eliminated it may be considered that surface streams may be affected in two ways: (1) By acidulation on admixture or (2) by the passage of ochreous water.

Having regard to what has already been said about the small size of acid feeders, it may be believed that the trouble from this cause is not great, at any rate in Yorkshire, if the stream into which the pit-water is discharged is of such a size that its pollution would be a serious matter. It is possible to envisage a case in which a small feeder is allowed to accumulate over several days and is then discharged at a high rate for a short time, in which event there might be temporary trouble. The remedy for such an extreme case is obvious and probably inexpensive.

Ochreous waters are more difficult to deal with, but here again it is suggested that the pollution arising from them is over-estimated by reason of the fact that a little ochre goes a very long way. The ochre, mainly hydrated iron, arises from the aeration of water which may issue from the strata in a clear and sparkling stream, and often results also in increased acidity of the water, after precipitation, as shown by the analysis in Table VI. The action appears to continue after discharge from the mine and thus, even where great care is taken to provide settling-pits, tumbling bays, and the like at the surface of the mine, there may still occur the offensive staining of the banks of streams which probably gives rise to more complaints of pollution than anything found on analysis. Possible approaches to this problem are by an attempt to inhibit or delay the precipitation or by an attempt to accelerate it so that precipitation may be complete before discharge at the surface.

TABLE VI.

Chemical Examination.	*Grains/gal.*
Chlorides in terms of chlorine	2·24
Equivalent to Sodium chloride	3·70
Nitrates	Nil.
Nitrates as nitrogen	0·11
Poisonous metals (lead, etc). ..	Nil.
Total solids (dried at 180° C.) ..	49·0
Total hardness	40·6
Temporary hardness $CaCO_3$ ..	1·75
Permanent hardness	38·85
*p*H value	5·0
Oxygen absorbed in 4 hours at 80° F.	0·04
Ammoniacal nitrogen	0·02
Albuminoid nitrogen	0·003
Free Carbon dioxide	8·4

The dosage of mine waters with chemicals in order to improve their quality on discharge is rendered difficult by the wide and rapid variation in the quantity flowing in the larger feeders. An ochre-bearing feeder, which varies at short notice from 100 to 1,500 gal./min., is not an easy subject for treatment on lines similar to those adopted with rust-forming supply-mains carrying a constant flow containing 10 or 20 parts per million of the offender. Little encouragement can be derived, moreover, from a recent experience in which a public authority proposed to utilize for domestic consumption the pit-waters referred to in Table IV, after treatment much more simple than that required for an ochreous water. Water (A) has had to be omitted entirely because it is said that by reason of the variation in quantity the cost of automatic dosage provision would be prohibitive.

An ochre water commonly gives a great deal more trouble to the mine-owner before it leaves his premises than it does to anyone else subsequently. The cleaning of several years' deposition of ochre from a watercourse 2 or 3 miles in length is a very expensive matter. The settling-out of further ochre on discharge gives rise also to trouble owing to the difficulty of drying and disposing of the ochre. After a rapid initial loss of 10 to 20% of moisture it is found very difficult indeed to dry ochre in any quantity to a less moisture-content than 60%. A shortage of pigments during the recent war provided a ready market for such material, and a great deal of trouble was taken to devise a means of drying ochre to a moisture-content of 20% or less. These failed.

Finally, particularly in the case of larger feeders, any discussions on pollution should have regard to the size of the stream if the mine water were not flowing. It is suggested that that may, in some cases, diminish the importance of the matter, for there is often no stream in summer when the mine pumps are not running.

THE LAW AND UNDERGROUND WATER.

In considering this aspect of mine drainage there must be borne in mind the oft-quoted adage that "a man who is his own lawyer has a fool for client." What can usefully be done in a paper of this nature is to indicate doubtful circumstances in which legal advice is desirable.

Case law on this subject appears to a layman to be based mainly on two fundamentals, namely, the general obligation of the subject to use his own rights so as not to interfere with those of another, and a refusal to assign a course to underground water and, therefore, property in it, in the absence of a specific artificial channel.

A reminder that what follows assumes that the mining activity giving rise to complaint is itself otherwise legally in order may not be out of place.

Damage of Surface-water Rights by Mining.

The owner of land containing a surface stream is, *prima facie*, presumed to be entitled to the rights as to quality and quantity of water which would naturally be flowing in that stream, apart from human agencies. Hence the need for compensation water in the case of waterworks dams, and the remedy for pollution.

The question of pollution by mine discharges has already been dealt with, and, generally speaking, it would appear that any riparian owner on the down-stream side of the discharge would have ground for an action for an injunction and damages if such, in fact, could be shown to have occurred. Reasons for the present state of some of our streams and rivers may be found in the lack of concern of some individual riparian owners and the reluctance of others, on grounds of public policy, to bring an action which might result in impairing or even terminating the activity of some large industrial undertaking.

It is not clear to the lay observer what necessity there is for the proposed "strengthening" of the law in this respect except against prescriptive rights. It is admitted, of course, that the grant of power to require by an Order in Council may be as effective in speeding up action against pollution as it may be in preventing due consideration in an extreme case.

In the case of a reduction in quantity of the water-supply, subsidence fractures or other interference by underground works, the rights of the riparian owner may conflict with the principle of the lack of property in underground water. The House of Lords decision in the case of *Chasemore* v. *Richards* (1859) is a commonly quoted authority. The owner of an ancient watermill was then held to have no right of action against an owner of adjacent land who put down a deep well, thereby diverting underground water, not known to be formed into a stream flowing in a defined channel, which otherwise would have percolated into the river. The fact that the water from the well was pumped and piped to people who were not riparian owners did not affect the result.

Here again in certain areas orders under the Water Act, 1945, may now modify the effect of this judgement to some extent. In such areas Section 14 of the Water Act requires any person—

> "applying any new boring for the purpose of searching for or extracting minerals to give notice to the Minister of Health and to take such measures as may be required by the Minister for conserving water, being measures which in the opinion of the Minister will not interfere with the winning of minerals."

On the other hand, it is not an offence to run water to waste—

> "where underground water interferes or threatens to interfere with the execution or operation of any underground works if no other method of disposing of the water is reasonably practicable."

Right of Support from Underground Water.

Several decisions appear to indicate what may be the legal risk in a proposal to de-water old workings. In the case of *Popplewell* v. *Hodkinson* (1869) the owners of buildings on spongey land were held to have no remedy against persons who, in building a Church, excavated to a considerable depth, draining the spongey soil and causing subsidence damage to the earlier property.

An attempt to apply this decision to the case of *Jordeson* v. *Sutton Southcoates and Drypool Gas Company* (1896) was unsuccessful. In that case the defendants, who had made a deep excavation for a gasometer in quicksand were held to have removed, not dirty water, but wet sand, this being a portion of the plaintiff's adjacent land, in respect of which he had a title to support.

In the case of the *North-Eastern Railway Company* v. *Elliott* (1860) a mine had been abandoned and allowed to fill with water under land which was subsequently purchased by the Railway Company for the construction of a bridge. Support both by the remaining coal-pillars and the water was claimed, but it was held that the mine-owner was entitled to drain the mine, and that the Railway Company were only entitled to an injunction against the working of the coal-pillars, notwithstanding the possibility of a collapse of hygroscopic shales and clay roof when exposed to air after de-watering.

Flooding of Adjacent Mines.

Since nationalization this question has lost much of its importance although it is not impossible for circumstances to arise necessitating its consideration. The position appears in general terms to be that a mine-owner is not liable for what may happen as a result of water entering his mine in the normal course of skilful working and subsequently gravitating into another mine. He may well incur trouble, however, if by means of conduits, pumping, or other artificial means he take any part in the directing of the flow of the water towards the other mine.

Notwithstanding the general principles on which a layman may conclude the law to be based, the importance of the factor that damage of any kind shall be readily capable of proof to have arisen in the normal course of skilful mining, should be emphasized. It cannot be assumed that, if the damage is occasioned by taking advantage in spurious innocence of natural factors known to exist or to arise in certain eventualities, this plea will be successful in protecting the operator against legal action. Although there is no suggestion of spurious innocence, the risks involved in the borderline case are well illustrated by the results of the case of *Lockwood and Elliott* v. *W. J. Cardwell, Ltd.* (1934). This example may be a suitable reinforcement on leaving this subject, of the warning given in opening it.

CONCLUSION.

Little has been said here on the question of water from old workings but the incidence of water from that source has been discussed in the previous paper already referred to. Planning new work in the vicinity of impounded water appears to be more suitably allied with the practical question of dealing with mine water, an ample subject for a future paper.

The President (Major H. J. Humphrys, Doncaster): Mr. Saul has a deep knowledge of his subject and has carried out exceedingly good work during the 16 years in which he has had charge of mine drainage in this coalfield. It must be information to a great many of us that in a comparatively dry coalfield like South Yorkshire a greater weight of water is pumped than weight of coal is produced. His references to the impervious strata between the coal-seam worked and the waterlogged waste above are interesting. There are cases in this coalfield where coal has been worked under such wastes with only 30 yds. of ground between.

I wonder whether Mr. Saul recommends that water-mains should be lined or treated with bituminous paint, and also whether he has any opinion as to the relative advantages, or disadvantages, of pumping as against leaving water-barriers?

Mr. J. G. Bond (Wakefield): I particularly welcome this paper as in West Yorkshire water has always been one of our difficulties. We have in No. 7 Area places where we are lifting as much as 10 tons of water to every ton of coal. I remember one pit, now closed, where 28 tons of water were raised for every ton of coal.

Mr. H. A. Longden (South Milford): In the extreme northern end of the coalfield we have a water problem, in that there is a large number of small pits (mostly abandoned) which are very old and information about their workings not only scanty but unreliable, and in consequence we have to leave ample barriers. In the north-east corner we have the conditions, which Mr. Saul has mentioned, where there are various seams outcropping at the base of the Permian which lies on top of the Coal Measures. We are considering certain shallow workings, as there are very large quantities of coal which, we hope, have been untouched in the past because they have been more difficult to reach. Could the author give us some help on the possibilities of working very close to the Permian on a definite percentage extraction of these seams without incurring extensive water difficulties?

Mr. A. H. Booth (Chesterfield): Would Mr. Saul care to say what he considers should be the minimum cover, underneath the Permian, with longwall working? Does the base of the Permian invariably carry water? Mr. Saul has referred in his paper to the part played by faults, and I am wondering whether, under the above conditions, with post-Permian faulting, he would treat all faults as being equal danger points or only those above a certain size?

Mr. G. A. Corden (Outwood): Can Mr. Saul give us any information about the flow of water in abandoned goaves? I am thinking of places that have been standing a great number of years and where consolidation of the ground can be assumed to have taken place. There are in some parts of West Yorkshire considerable areas of goaf presumed to be flooded, and in considering the working of seams fairly close underneath these areas it is necessary to take into account the possible difficulty of flow in the abandoned goaf when considering measures to drain it.

Mr. J. S. Hayes (Crofton): Can Mr. Saul give us any data as to the rate of corrosion of iron and steel by mine waters in Yorkshire? Many years ago, in the mountain mines of New Zealand, I saw a case of very rapid corrosion of the cast-iron pipes of a long 4-in. syphon range. After filling afresh, the syphon soon failed to function owing to the accumulation of gas at the highest point, and a strong acetelyne smell was present. On analysis, the gas proved to be mainly hydrogen. The floor of the old workings through which the water flowed was covered with a soft white deposit assumed to be alum, and wire nails placed in a bottled sample of the water from the vicinity caused bubbles of gas to rise. As one would expect, the pipes were soon riddled with holes and rendered useless as a syphon.

Mr. S. J. Temperley (Doncaster): Mr. Saul has been of great assistance to us in disposing of large quantities of water. Now we are seeking his aid to find water. A borehole, suitable for installing a borehole pump, was put down at some considerable expense, and water was not found in sufficient quantity. I wonder what course he would suggest being adopted to prove a site before proceeding with the boring and lining of a borehole suitable for a pump.

Mr. N. Hulley (Doncaster): I think we should be interested in this problem today, particularly as in some areas where outcropping is done it is approaching areas which may be considered easy to work from shallow mines. Is it likely to lead to the seeping of water by reason of disturbance of the ground in the area of outcrops and so cause difficulty in the future? Has Mr. Saul any information as to the possibility of such occurrences?

Major N. E. Webster (Sheffield) wrote: I should like to express to Mr. Saul my own interest in the figures and information which he gives regarding the cost of pumping and collection of feeders, though I am surprised at his statement that plant is so much above normal requirements that a load factor of 10% is usual. This may be the case with shaft pumping-stations, but the small inbye set is usually much more fully loaded. Our experience at Nunnery with rate of percolation confirms the points mentioned by Mr. Saul, but I would raise one issue, i.e. his analysis of their composition as given in the table. Whilst the figures for the Parkgate and Chevet appear correct, those for the Silkstone, Kents, and Shafton seem wide of the mark. Taking the first as an example, he gives temporary hardness as 20 whereas it would appear to be 9. Even wider variations exist in my determination of permanent hardness.

The reference to impervious strata could helpfully be expanded to give us an indication from Mr. Saul's exceptional experience in this sphere of the almost unpredictable effects of barriers. In heavily-watered ground in North Wales we frequently found coal-barriers entirely useless, whereas with complete extraction an almost impervious seal was often, though not necessarily always, obtained. Under Mr. Saul's able guidance the South Yorkshire drainage Committee exercised great care in selecting the sites for barriers, dams, etc., and some of the points arising therefrom would appear extremely interesting.

Mr. Bond: I should be grateful if Mr. Saul would explain a little more why water runs in rock-beds, and also whether the chemical composition of the rock has anything to do with it? Does he mean to infer that something in the composition of the rock makes it run more freely in one rock than in another? Would he give us a little more clear definition of iso-pachytes and water-table? He referred to the distance that it was possible to work a seam below a waterlogged goaf without getting water through. The most outstanding case I have known is that of the Old Hands Seam, about 17 in. thick of high quality, which we worked 26 yds. below the Flockton Thin goaf which was waterlogged completely. We never had a drop through.

On the question of ochre, we have a very bad case in No. 7 Area and there is something unusual about it. We completely cleaned a 4-in. cast-iron rising main with acid five months ago and today it is again completely blocked. Alongside it, and through which exactly the same water runs, there is a 3-in. steel main which we did not clean out five months ago and which, to the best of my knowledge, never has been cleaned out but is still running freely today. Can Mr. Saul offer any explanation why the cast-iron pipe becomes blocked but the steel one does not?

Mr. Hulley: With regard to the question of leaving barriers in seams at various levels, can you give us any indication of the size of barrier to be left in the lower seams, assuming that the barriers in all seams are more or less vertically above each other? Has the size of barrier to be left in to be in accordance with the depth of seams? Suppose you had a barrier in the Barnsley Seam of 50 or 100 yds. and were leaving one in Parkgate, is there any rule whereby that barrier should be of a greater or only the same width.

Mr. T. Gledhill (Doncaster): Mr. Saul mentioned the possibility of leaving coal alongside a fault as extra precaution against water. What would be the effect, or the requirements, of working subsequent seams which might have to be protected at lower depths if faults persisted through those seams? With the complication of the faults running parallel to a barrier, I should like Mr. Saul to give us some information or advice in these circumstances.

Mr. Hayes: With a view to ultimate total extraction of a seam below a waterlogged area would Mr. Saul recommend working by longwall or by bord-and-pillar methods?

Mr. H. Heap (Darton): How many water-barriers have been left in the Barnsley Seam, and how many have proved to be successful?

Mr. H. Saul (Crofton): With regard to the lining of mains, I think before a pipe-line is installed an analysis of the water should be submitted to the proposed supplier of the pipe for his consideration. His chemist could then give advice on the possible consequences. I find bituminous lining very satisfactory indeed, better now than originally because it seems more flexible than it used to be. It is necessary to see that the joints are effective and that the bituminous lining is taken around until sealed by the joint-ring.

Test figures in Table V, kindly given to me by Mr. Earnshaw, indicate that the water of which the analysis is given in Table II wasted mild steel at the rate of 1 mg./sq. in./sec., but with the most acid water, starring of the bituminous lining resulted in perforation in a fortnight.

With regard to the question raised by several speakers of pumping versus water-barriers, I think much depends on circumstances. If a mine is in an isolated area and likely to stand for many years before other workings in the same seam approach it, there is no point in keeping it pumped out. I should like to put this point of view, however, if you fill up old workings with water you cannot expect them to seal. While I agree the value of barriers I suggest that subsidence should be complete before water-logging commences. The workings will then, at least, hold less water. There is a lot to be said, particularly where work in another seam is to follow, for keeping workings de-watered. If full, it may even be desirable to de-water them before such working, as it is more than likely that the old workings will then seal fairly compactly.

I am asked what is the number of successful barriers. In a number of cases large quantities of coal have been locked up and leakage has been such as to involve the pumping of water on as large a scale as would have kept the pit empty in the first instance. Barriers may leak at the time they are worked to but they may not leak two years after leaving them. A barrier leaked at 100 gal./min. in 1932-3 when formed; now the leakage is from 10-15 gal. Presumably the breaks have settled down and, in addition, there will have been a silting action.

I am very interested in Mr. Longden's "north-east corner." The "old men" considered the water first. Pumping-stations were expensive, and they laid out the pit for work according to water-levels. In these days of mainly drier pits and cheaper pumps that is, in general, no longer a major point, but at Garforth there is an old-type site, with the modern method of development, taking large quantities of water to great depth.

With regard to safe minimum thickness of cover, I suggest the practical approach, which is to "go and see." With shales above the coal and in the absence of a rock of more than, say, 4 yds. in thickness, then 80 to 100 yds. below the Permian should be safe. Trial headings should be driven to test for "drippers" before the limiting cover is decided at any less figure. In this case it would be unwise to work by longwall methods.

In view of the few cases in which the Permian base has been approached from underground it is difficult to answer Mr. Booth's second query. The rest water-level in a borehole will not, by itself, give much idea of the quantity of water available and, having regard to the expensive consequences in the few cases experienced, it is well to assume in planning that water is there.

I have mentioned the case of a 2-ft. fault. A fault of 2 ft. is less likely to be foreseen than one larger, but I would not put any limits. The major faults are those to fear most, because they are likely to bring the water-bearing strata in juxtaposition. Any fault with a throw approaching the distance from seam to rock is obviously one to give rise to apprehension. I rather think that the possibility of a fault bringing Permian down to Coal Measures should be tested in initial prospecting.

Mr. Temperley's question with regard to boring for water is answered to some extent by my remarks about the diminution of the quantity of water available with increasing distance from the exposure of the rock in question. Quite frequently a borehole apparently unsuccessful, has been made moderately so by shotfiring at carefully chosen points in the hole itself. If there happened to be a coal-seam close to the bottom of the hole it might be possible to head from an adjacent mine under the hole to form a reservoir on the subsequent damming of the heading.

I was alarmed to hear Mr. Hulley say that no precautions were taken against percolation of water from opencast sites. That is not the case. A key-plan of every proposed opencast site is submitted and an objection is lodged if any such difficulty is likely to arise. If the management of a mine likely to be affected make serious objection, which can be substantiated, the site is not worked. There are other cases where damage might result if precautions were not taken. Such precautions take several forms. In a recent case a 24-in. concrete drain was laid for over 1,200 ft. along the last cut to an outfall, and in wet weather it runs more than half full. In other cases there is a mixture of shale and sandstone. The clay is segregated and put back to form a bulkhead in the last cut. It is desirable to do this in layers of not more than 6 in. after first cleaning the floor of the seam.

Although it may be thought that a mixed overburden should consolidate shortly after replacement, difficulty arises from the fact that with drag-line excavators the large material rolls to the bottom of the backfill heap. This may result in the natural formation of a "rubble drain" on the floor of the seam. Several such natural drains were, in fact, cut in re-excavating an old opencast site for the entrances of the new Wentworth Mine, and water issued in quantity into the new excavation. It is hoped to make further tests in this direction by boring from shallow mines into old opencast sites.

I should like to refer to the protection given by fireclays and shales. I have recently heard that in some opencast sites the fireclay has been removed after the coal. If there is any known proposal to do this it should be resisted, because it allows percolation not only down to seam level but also below it, and there may be water where there was none before.

I agree with Major Webster that 10% is a very low load-factor for pumping equipment, but in the case I quoted the factor should have been less for safety. I agree entirely that inbye pumping-stations can generally be run at a higher figure more safely by reason of the installation of additional pumps and of rising mains being commonly a simpler matter, and also because seasonal variation in feeders inherent to the seam is less extreme in most cases.

Major Webster quarrels with my analyses. These were taken from my files. I will check the cases to which he refers and adjust them if necessary.

I cannot agree that the effects of barriers are unpredictable, but certainly a detailed knowledge of local conditions is necessary.

I think, among others, Mr. Corden referred to the size of barriers left in the Parkgate and Barnsley seams. My own view is that an effective barrier in the Barnsley Seam would rarely run serious risk over a barrier of similar size in the Parkgate Seam. It should be borne in mind that most barriers of 100 yds. are not left entirely because that width is necessary to stop water but also for the reason that there may be a mistake in surveying, and/or subsequent movement. It is worth a reasonable margin to prevent a long length of barrier being completely ruined by one weak point. Theoretically, barriers in the lower seams should be rather larger than those above them, but I do not think there is any need for barriers of double width.

Mr. Gledhill asks if coal should be left in lower seams under coal left to seal a fault, and in reply I should say "No," because the coal is left there to keep intact the fault material. If a borehole can be run into a fault dry then a subsidence crack should involve little risk under normal circumstances.

I should like a few more particulars of the ochreous waters before I deal with Mr. Bond's question.

A sandstone is more porous than a shale, but I think the joints and bedding-planes more significant with Coal Measure rocks. Shales and fireclays are not only less porous, in fact practically impervious, but a fissure when wetted tends to seal by the swelling of the material.

Iso-pachytes are lines of equal thickness of stratum. "Water-table" is the level of the water near the surface. It rises and falls seasonally and in evidence it has been said that the water behind the shaft-tubbing at Darfield varied in level in this manner by as much as 40 ft. in 1 year. Another case of observed rise and fall has been in Triassic sandstone where there has been a rise and fall of 4 to 5 ft. between a dry summer and a wet winter.

Further discussion on the paper was adjourned.