The monitoring and modelling of mine water recovery in UK coalfields

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Abstract: This paper draws together the information that has been obtained on mine water recovery since the large-scale closure of coal mines in the 1980s and 1990s. The data show that, following cessation of pumping, mine water recovery follows an exponential curve similar to the recovery of an aquifer following a pumping test. Several previously unpublished examples of mine water recovery data from around the UK are included in the paper and there is a detailed assessment of mine water recovery in the East Fife Coalfield in Scotland. The reasons for this type of mine water recovery are discussed and examples are given of the use of the data for both the interpretation and modelling of mine water recovery. In coal mining areas where no water-level recovery data are available, methods for the prediction of mine water inflow and recovery modelling are proposed and the problems associated with mine water recovery modelling are discussed.

The paper concludes that modelling of mine water recovery, based on mine water inflow and estimated void space, can be used to give reasonably accurate predictions of recovery times and flows, but that water level monitoring is essential for precise predictions.

The control of mine water during the period when coal mining was a nationalized industry was generally based on a safety first principle. This meant that when doubt existed about underground connections between modern mines and old abandoned areas of workings, mine water pumping always continued in the old areas. The result of this policy was a general lack of experience of mine water recovery and continuing doubt about underground connections.

The large-scale closure of mines in the 1980s and 1990s mean that in many cases whole coalfields were abandoned and that the pumping of mine water either completely stopped or was greatly reduced. Estimations of mine water recovery made by British Coal at the time of these closures were generally based on a water inflow related to the volume of water pumped from a mine and a residual void-space calculation. The void-space was calculated using roadway dimensions for supported excavations and a figure of 10% of the original extractions thickness for unsupported (total extraction) workings (National Coal Board 1972). Using this principle it was assumed that mine water recovery would proceed as a series of steps, with very little recovery when water was 'filling' a large void, followed by a period of more brisk recovery until the next large void was reached.

The monitoring of mine water recovery by IMC Consulting Engineers on behalf of the Coal Authority (the government agency set up to look after the non-privatized areas of coal mining) has shown that, at least at large scales, mine water recovery follows precise exponential curves that appear to be independent of the distribution of mining voids. These curves are very similar to the recovery curves observed following an aquifer pumping test.

Monitoring of mine water recovery

Since the coal mine closures of the 1980s and 1990s, monitoring of mine water recovery in several abandoned coalfields has shown that, in general, recovery follows an exponential curve with the rate of recovery reducing with time. Figure 1 shows the recovery curves for several mining units in the UK. The units vary from a single small mine (e.g. Whittle in Northumberland; Adams & Younger 2001) to large interconnected areas or whole coalfields (e.g. Sherwood 1997; Sherwood & Younger 1997; Burke & Younger 2000; Robins *et al.* 2002). The data suggest that water inflow rates are probably related to the difference in head between the water in the mine and the source of aquifers and the area that has been dewatered (cf. Banks 2001). It also implies a general interconnection of the mine workings within a block of ground that is governed by the hydrogeology of both the natural *in situ* strata and the changes to that

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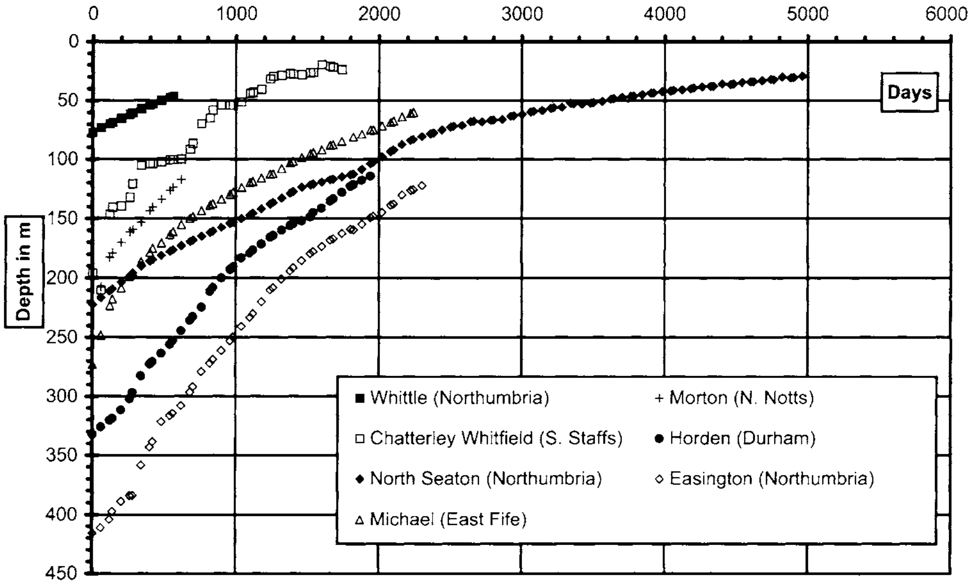

Fig. 1. Mine water recovery curves from a range of major UK coalfields.

strata caused by mining (Sherwood 1997). This interconnection of workings in coal mines could be anticipated from the way both natural and mining-induced permeability gave rise to the rules that governed the way coal can be mined in the UK. The regulations state that the total extraction of coal is not allowed within 60 m of an aquifer (including unconsolidated material likely to flow when wet) or within 45 m of other water-filled mine workings (National Coal Board 1956). These rules were brought in following experience of serious water inflows into mines when working too close to other bodies of water. The results of these regulations was that the active working blocks of a mine were kept 'dry' to avoid sterilization of reserves until all the coal had been extracted. Only where these blocks were isolated from the rest of the mine would old workings be allowed to flood, and then only to a level where the water recovery would not result in a risk of flooding to deeper, active workings. Detailed monitoring of mine water levels during the recovery period did not generally occur; only the start and end of the recovery period would be known, and the recovery 'curve' was assumed to be related to the filling of the void spaces. The occurrence of several major inflows of water into mine workings during the 1970s and 1980s resulted in a renewed interest in water movement around longwall faces. The resulting research tried to link the mechanical effects of total extraction coal mining with the subsidence data recorded at the surface and water inflow monitored underground.

Figure 2 shows how the natural stresses in the ground are altered around a typical longwall panel (National Coal Board 1978). The strains resulting from these stresses cause the opening of fractures and bedding planes, which can significantly increase the vertical and horizontal permeability.

East Fife coalfield

The East Fife Coalfield, situated to the north of the Firth of Forth, has been monitored by the Coal Authority since mine water pumping was abandoned in 1995 and provides a good example of the general principles of mine water recovery (e.g. Sherwood 1997; Sherwood & Younger 1997; Younger *et al.* 1995; Nuttall *et al.* 2002). Mining in the shallow, older areas of workings has been abandoned for a number of years. Initially, mine water had been pumped for safety reasons, but latterly these areas were allowed to recover and overflow to the deeper mines of Michael and Frances. Frances and Michael had closed in the 1970s but were pumped to control water levels up until 1995 (Younger *et al.* 1995). Figure 3 shows the general layout of the coalfield and the current monitoring sites. Since the cessation of pumping, mine water recovery in the workings has followed the typical exponential trend with, as yet, only minor deviations from the trend. These deviations occur on an annual cycle

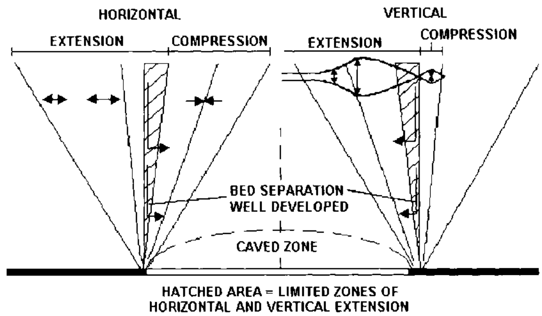

Fig. 2. Strain patterns around a typical longwall panel showing the zone of increased water flow and bed separation (after National Coal Board 1978).

and correlate with annual variations in rainfall. Figure 4 shows that as the mine water recovery reaches the level of each of the shallower blocks, water levels in these blocks take up the same recovery trend. The shallowest areas, monitored at Randolph, Muriespot and Dalginch, have yet to start recovery, although, as with the rest of the coalfield, a hydraulic gradient has developed (see Fig. 3). The hydraulic gradients currently developed in the East Fife Coalfield vary from about 1 in 200 (0.0005) to 1 in 600 (0.0016). Similar gradients of up to 1 in 1000 (0.001) are found in most monitored coalfields in the UK

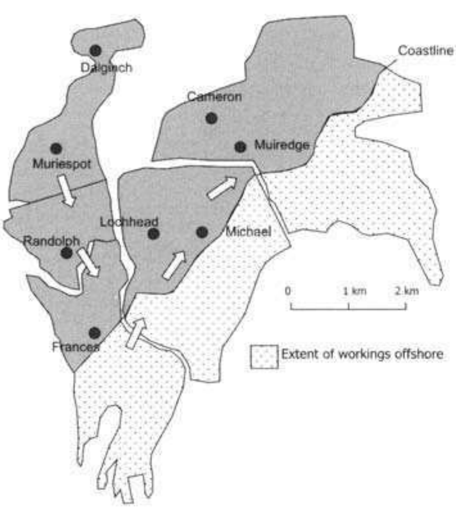

Fig. 3. General layout of the East Fife Coalfield (adapted after Sherwood 1997) showing major bodies of mine workings (shaded grey onshore, stippled where under sea) and positions of mine shafts and boreholes used for water level monitoring purposes, with arrows showing directions of water movement determined from hydraulic gradients and mine plan evidence.

The similar hydraulic gradients in different coalfields suggests that the various coal mines have similar hydraulic conductivities. The range of hydraulic gradients are probably related to the different types of mining and varying lithologies. The low hydraulic gradients will reflect open mine workings or fractured high-permeability strata, such as sandstone, adjacent to the mine workings. The higher hydraulic gradients will reflect workings that have closed or been backfilled and have only low-permeability strata, such as mudstones. adjacent to the workings.

The monitoring of water levels in East Fife is carried out using pressure transducers and data loggers recording a water level every 15 min. This allows very minor fluctuation in water level to be examined in detail. Figure 5 shows the tidal variations in water level monitoring at Frances. These oscillations take some 4 h to travel 2.5 km through the mine workings to Lochhead. The amplitude of the fluctuations of up to 0.4 m are caused by compression of the Coal Measures strata due to weight of water at high tide reducing the storativity of the aquifer by forcing water out of joints. The largest fluctuations of mine water due to tidal compression have been seen at Bates Colliery, Blyth where, during spring tides, fluctuations of up to 2.5 m have been recorded. The varying amplitudes of the fluctuations probably reflect the depth and extent of the under sea workings in an area.

Monitoring and mining connections

Monitoring of mine water recovery, as well as showing interconnection of workings, can be used to confirm the separation of mining units. A mining unit may comprise a single colliery or a group of interconnected collieries isolated from adjacent workings by Coal Measures, by an area where no mining has been carried out or by artificial barriers such as dams.

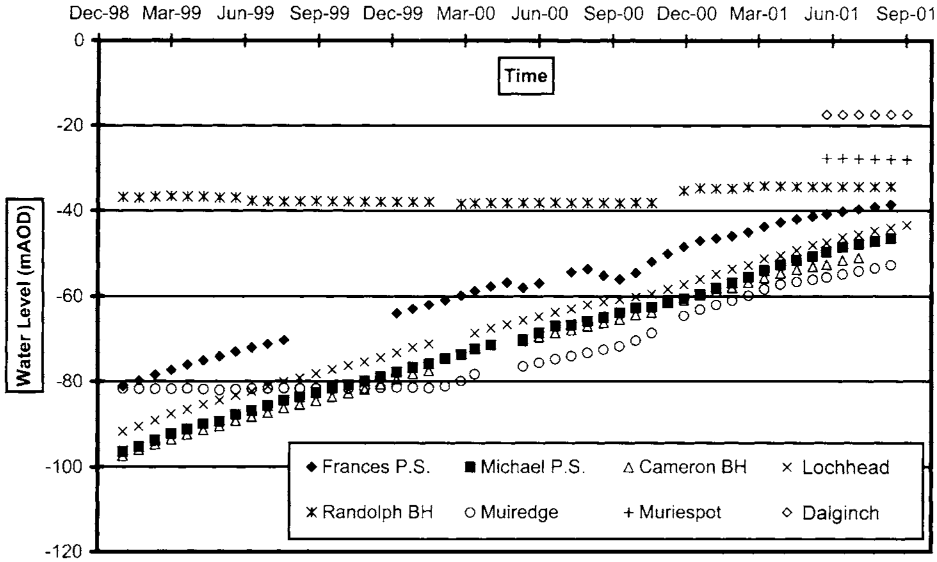

Fig. 4. Mine water recovery in the East Fife Coalfield, as monitored in the shafts and boreholes marked on Fig. 3.

Dams. Where only single roadways connected major mining blocks, dams were sometimes constructed in roadways to separate the mining units and prevent water migration. These dams were generally designed to withstand full hydrostatic head, but were rarely tested because pumping in the abandoned area usually continued and only a limited water head was allowed to build up against the dam. The effectiveness of the dams was therefore only proved with the total closure of mining in an area, sometimes many years after construction. Monitoring of water levels on the rise side of the dams has shown that the British Coal policy of continued pumping was entirely justified, as in nearly all instances where water levels on either side of a dam has been monitored, and a high hydrostatic head has built up on one side of the dam. Figure 6 shows an example from Durham where the mine water recovery in an area isolated by a dam was greater than the rest of the block. The resultant head caused the dam to fail. Since then the water level

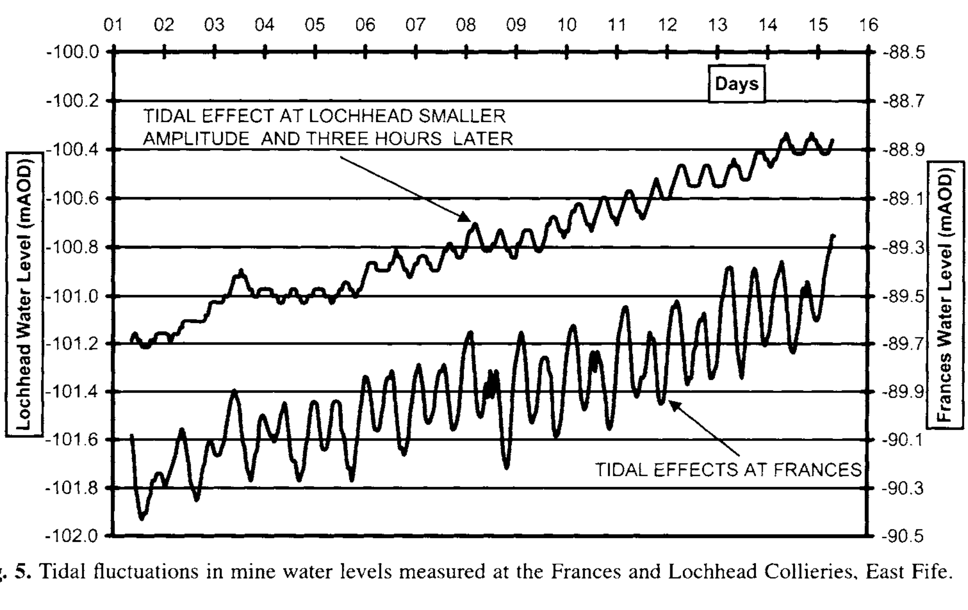

Fig. 5. Tidal fluctuations in mine water levels measured at the Frances and Lochhead Collieries, East Fife.

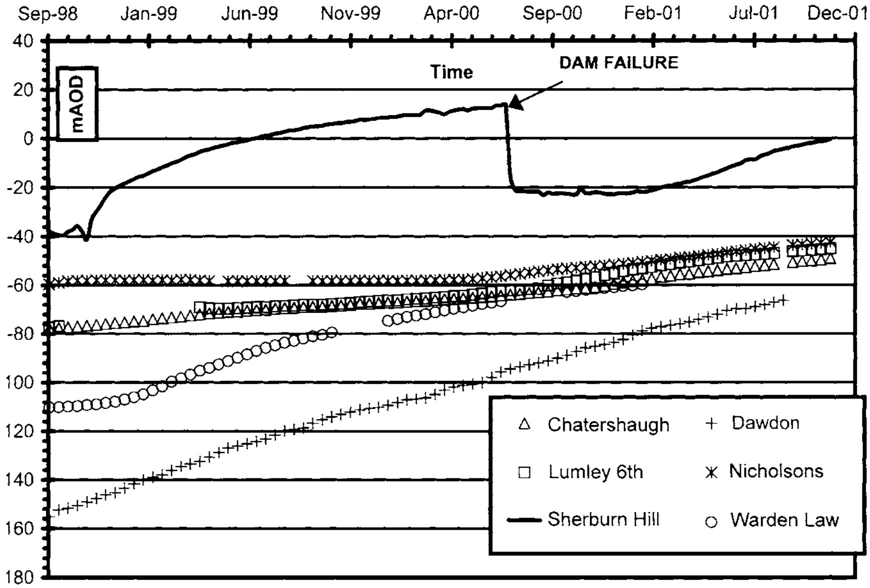

Fig. 6. Mine water recovery records for selected shafts and a borehole (Warden Law) in the Durham Coalfield to the east of the River Wear, showing the effect of failure of a dam on water levels in Sherburn Hill Colliery.

has fallen and harmonized with the recovery in the rest of the mining block.

Permeability of mining connections

The permeability of a mining connection varies greatly dependent on the type of opening, the lithology around the opening and the stresses acting on the opening. In general, mining connections have permeabilities up to several orders of magnitude greater than the permeabilities found in UK Coal Measures. Table 1 shows some typical Coal Measure permeability values obtained from drill stem testing (D.S.T.) in boreholes for the north east Leicestershire project by British Coal (1986). Based on personal observation of changes in flow it is believed that permeabilities in mine workings can revert to near natural permeability where vertical or horizontal stresses, combined with swelling mudstone lithologies, result in closure of a mine opening. In general, these 'closures' only occur in areas of total coal extraction and the edges of these areas usually retain a 'high' permeability. However, examples have been found where major underground roadways have become blocked with a large pressure difference across the blockage. The most striking example of this is the blockage of a 14 × 10 ft (4.26 × 3.05 m) roadway supported by steel arches at 1 m spacing, constructed between Barnsley Main and Monk Bretton Collieries at an elevation of −180 m OD (180 m below Ordnance datum). This roadway was driven specifically for the purpose of water drainage. Water levels were expected to recover at differing rates at Barnsley Main and Monk Bretton until the connection at −180 m OD was reached when the levels should have become harmonized. Figure 7 shows that as the water level at Barnsley Main neared −180 m OD the recovery decreased rapidly, as would be expected from an overflow at a major connection. However, within 6 months there was a sudden rapid recovery, then a return to the exponential curve precisely followed by the mine water recovery below the −180 m OD connection. The original monitoring borehole at Monk Bretton (Lundwood borehole) filled by British Coal in 1994 has been redrilled to confirm that mine water levels at Monk Bretton have not recovered. (This had always been suspected due to a flow of methane from the Monk Bretton mine.) The emission mine gases, either methane or oxygen-difficient air, stop when mine water levels rise above the insets or connections from the shafts to the workings. The new Lundwood borehole shows a static level of approximately −100 m OD, indicating an overflow to deeper workings. These water levels give a minimum of 80 m head difference across the roadway blockage between Barnsley Main and Monk Bretton. A recent borehole drilled by Alkane Energy at Monk Bretton has proved that the Barnsley Seam remains unflooded at a level

Table 1. *Summary of DST results – North East Leicestershire Project*

Strata	Total thickness tested (m)	Assessed permeability	Typical permeability ($m\,s^{-1}$)	(mD)	Maximum permeability (based on assumed uniform permeability) ($m\,s^{-1}$)	(mD)
Sherwood Sandstone Formation (Bunter)	22	High	10^{-5}	1000	2×10^{-5}	2200
Permian	22	Moderate	8×10^{-8}	8	9×10^{-8}	9
Middle Coal Measures above Deep Main (including upper sill)	232	Extremely low with occasional permeable joints	$<10^{-10}$	$<10^{-2}$	5×10^{-8}	5
Main Coal Seams (Deep Main, Parkgate and Blackshale) and adjacent strata	377	Extremely low with occasional low/permeability joints	$<10^{-10}$	$<10^{-2}$	2×10^{-9}	0.2
Lower Coal Measures (including lower sill below Blackshale)	243	Very low permeability	6×10^{-10}	0.06	10^{-9}	0.01
Namurian	50		4×10^{-10}	0.04		

below the connecting roadway level of − 180 OD. Therefore, the Monk Bretton side of the roadway must be unsaturated and the head acting on the roadway is the difference between the level of the roadway (− 180 m OD) and the current water level in Barnsley Main (+20 m OD), i.e. 200 m head of water.

Mine water recovery modelling

The modelling of mine water recovery is important for assessing the risks to aquifers from recovery of contaminated mine water, and for the prediction of the timing and the flow rate of potential surface discharges (e.g. Sherwood 1997; Younger & Adams 1999; Banks 2001; Adams & Younger 2001). It is also very useful in the assessment of coal mine methane (CMM) reserves.

Using mine water recovery curves

Modelling can simply take the form of forward projection of a monitored exponential mine water recovery curve (Younger & Adams 1999). This method has been used in the Northumberland and Durham Coalfields, as well as in East Fife, and has so far proved to be very accurate. Figure 8 shows an example from Easington Colliery in County Durham of a projection compared with the actual recovery curve. A key part of any projection is the source aquifer, and the maximum head of water in the aquifer prior to mining. This information is needed for the project to establish a theoretical maximum recovery level, which gives a more accurate recovery in terms of time.

Monitored mine water recovery curves can also be used to estimate the flow of water into a mine and the likely volume of any surface discharge after recovery. The mining void is calculated by digitizing the area of the mine workings and using recorded extraction thicknesses and roadway sizes. Areas of total extraction and areas of partial extraction are recorded separately to allow the amount of compaction to be varied for the calculation of the residual void. The residual void left in areas of total extraction was generally considered to be 10% of the extraction height (National Coal Board 1972). This figure was based on filling of areas of abandoned workings by known flows. Knowing the rate of recovery and the estimate void space, the volume of water needed to fill this space over a given period can be calculated. Figure 9 shows the calculated inflow for the East Fife Coalfield based on the monitored recovery, and the mine volume derived from the mine plans and recorded

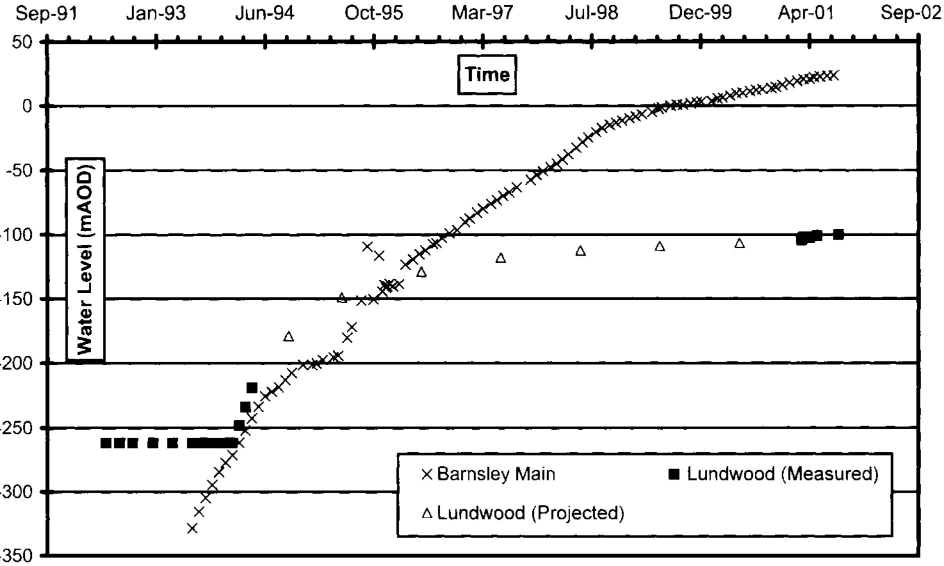

Fig. 7. Mine water recovery at Barnsley Main Colliery and the adjoining Lundwood workings, which were purposely connected by a major roadway at − 180 m OD before abandonment. The lack of harmonization of the two recovery curves above this level demonstrates that the roadway has so thoroughly collapsed as to prevent flow from Barnsley Main to Lundwood.

extraction thickness. The graph shows that the water inflow has reduced exponentially, with a fairly rapid initial reduction followed by a more gradual decrease. The later inflow rates can be used to assess the potential surface outflow after recovery. In this case, the modelling was further refined by using the volume of mine water pumped (30 000 m^3 day^{-1}) as the initial inflow. Using this inflow and a calculated residual mine workings void (based on 10% of the total extraction) resulted in a recovery that was much quicker than actually occurred. Using the 30 000 m^3 day^{-1} inflow and matching the recorded recovery, the best-fit figures suggested that at

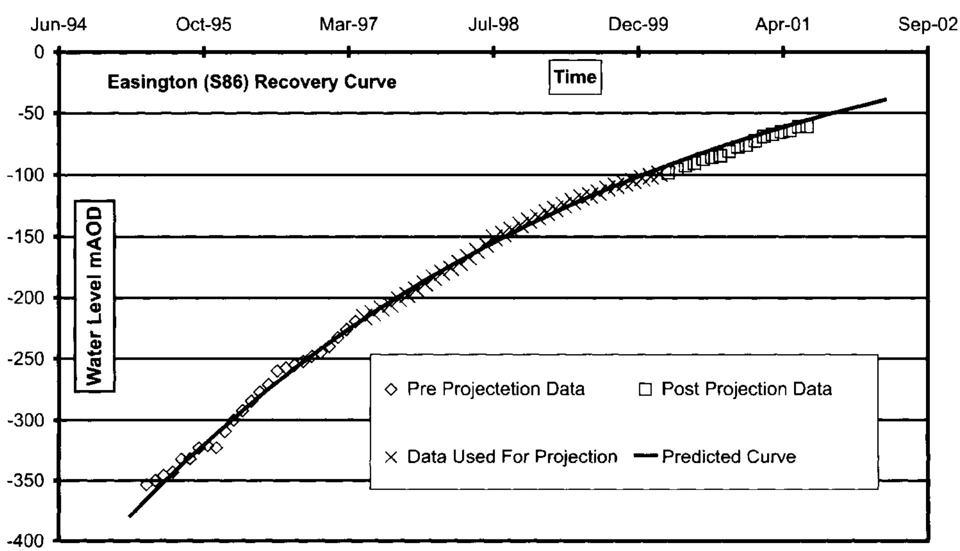

Fig. 8. Projected mine water recovery and subsequently monitored levels at Easington Colliery, County Durham.

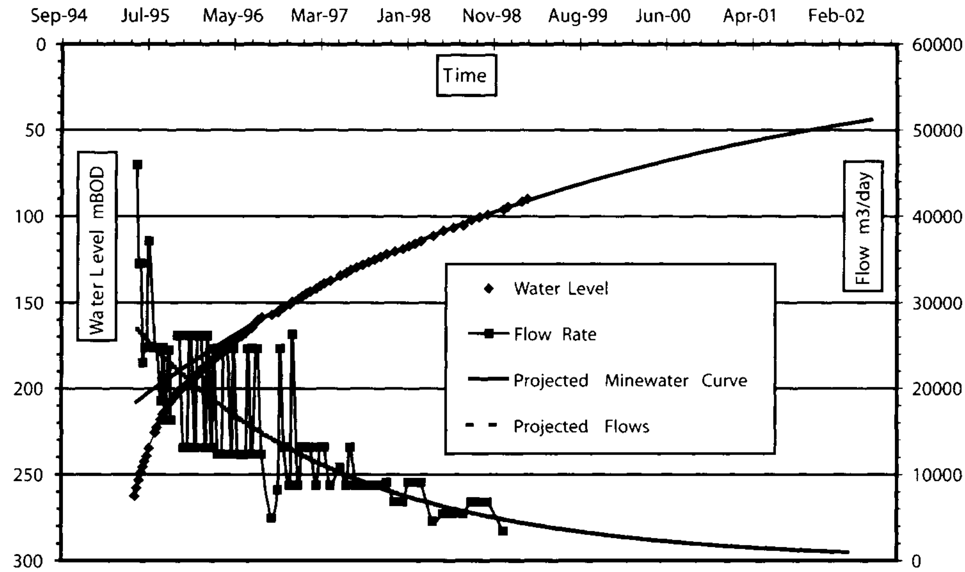

Fig. 9. Measured and modelled mine water recovery and derived values of calculated water inflow over time for the East Fife Coalfield.

300–350 m below OD, the residual void was in the order of 20% of the initial extraction volume. The residual void percentage will vary with lithology and depth, but the East Fife recovery would suggest the British Coal figure of 10% is at the low end of the range.

Monitoring of subsidence above areas of long-wall abstraction would also suggest that the residual underground voids are greater than 10% of the original abstraction. At 100 m depth a 200 m wide longwall panel can result in maximum surface subsidence, which is 90% of the extraction thickness. However, at 500 m depth the maximum subsidence would only be 35% of the extraction thickness, with 65% of the extraction void being underground (National Coal Board 1975). The problem then becomes 'how much of this underground void is hydraulically connected with the mine workings'. Sudden hydraulic connection between the mine workings and bed separation (which form a substantial part of the void above the workings) is believed to be the mechanism controlling the large inflows of water noted both in the South Staffordshire and the Selby Coalfields (Whitworth 1982).

Mine water inflow data

Where there is no monitoring of mine water recovery, an alternative method of calculating water inflow is required. In this case the recorded inflow and pumping data from a mine can be used to interpret the steady state situation where inflow generally equals outflow. The various inflows are then fitted onto a conceptual model for each mine to assess how these inflows will vary during recovery. The water quality of the various inflows can also be assessed at this stage using either actual analysis data or water quality based on the depth in source aquifer (e.g.Adams & Younger 2002). The conceptual model for an individual mine or interconnected block is based on a general model, as shown in Fig. 10. The model is based on the general development of mining in the UK and assumes four basic depth controlled mining units, A–D, which may or may not be interconnected. Water inflows into all the units can then be put into three basic categories.

Shaft water. This water may originate from surface superficial deposits, Coal Measures aquifers or major aquifers, such as the Sherwood Sandstone or Magnesian Limestone. Shafts generally form the only major interconnection between a mine and a major aquifer The use of inclined roadways to access the Coal Measures through a major aquifer is rare due to the increased length of drivage in the aquifer and the related increase in costs to seal the roadway. Water qualities are usually good, as most of the aquifers are at relatively shallow depth and, in many cases, water inflows were collected and pumped to surface separately providing accurate data on these flows. During mine water recovery, shaft

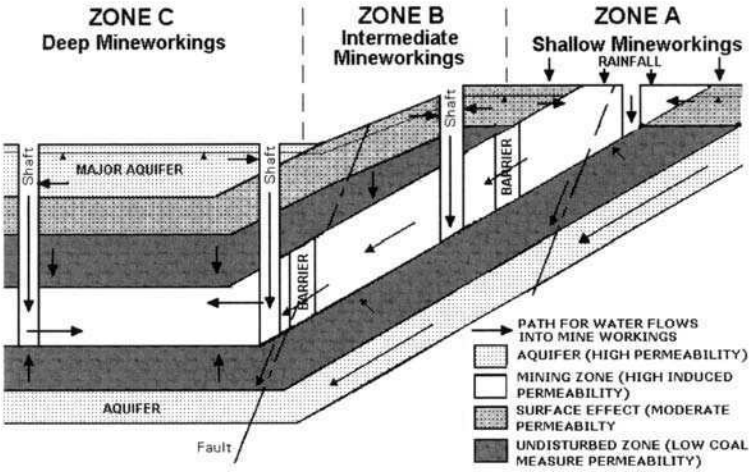

Fig. 10. Schematic diagram of a general conceptual model for water inflow to mine workings.

water inflows from major aquifers will only start to decrease when water levels in the shaft reach the level of the base of the aquifer supplying the water.

Coal measures inflows. Coal Measures inflows are generally small ($<330\,m^3\,day^{-1}$) and originate from minor aquifers. Larger flows may occur from major sandstones both above and below workings and from faulted ground. The rate of water inflow to a mine from these sources will decline once the water recovery in the mine has reached the level of inflow, and the head between the mine workings and the source aquifer starts to decrease.

Water quality from these sources is very variable. Chloride levels, for example, are known to decrease logarithmically with depth, the deeper waters can have chloride values in excess of $200\,000\,mg\,l^{-1}$. (Glover & Chamberlain 1976).

Figure 11 shows a simple conceptual model of inflow to Cronton Colliery in Lancashire based on a small make ($72\,m^3\,day^{-1}$) from Type A shallow workings, and a moderate flow ($459\,m^3\,day^{-1}$) from Coal Measures aquifers.

Shallow workings water. This water will only affect the older shallow Type A workings but can gravitate to the deeper workings via mining connections. The exact course of water may not be known, but inflows are closely linked to rainfall and will have a more dominant effect on water levels in the later stages of recovery when other inflows have decreased. Figure 12 shows an example of shallow mine workings recovery in Yorkshire with annual fluctuations in water level related to variations in rainfall. The quality of shallow workings water can be very variable, dependent on source, the pathway and the length of the pathway travelled by water. Shallow workings water will include shaft water, Coal Measures aquifer water and surface water.

Modelling recovery using mine water inflow data

The simplest method of calculating mine water recovery time is to assume no reduction in water inflows as the water level in the mine recovers (see Sherwood 1997; Banks 2001, for discussions of this point). This approach yields a minimum recovery period for a mine. Any seasonal variations in water inflow to a mine can be addressed by using an average of the long-term pumping rates for the mine. This method of modelling will only be accurate when all the water entering a mine originates at very shallow depth. Where significant volumes of water enter the mine at depth, either from the shafts or from the Coal Measures, a simple linear recovery is likely to be highly inaccurate. In these cases a reduction in water flow is required to reflect the gradual reduction in head difference between the source aquifers and the water level in mine workings.

Data on the piezometric head in the source aquifers may be readily available in the case of the major aquifers, but in many cases there are no data and so have to be assumed. This can be carried out by looking at the topography and geology of the mining area under consideration

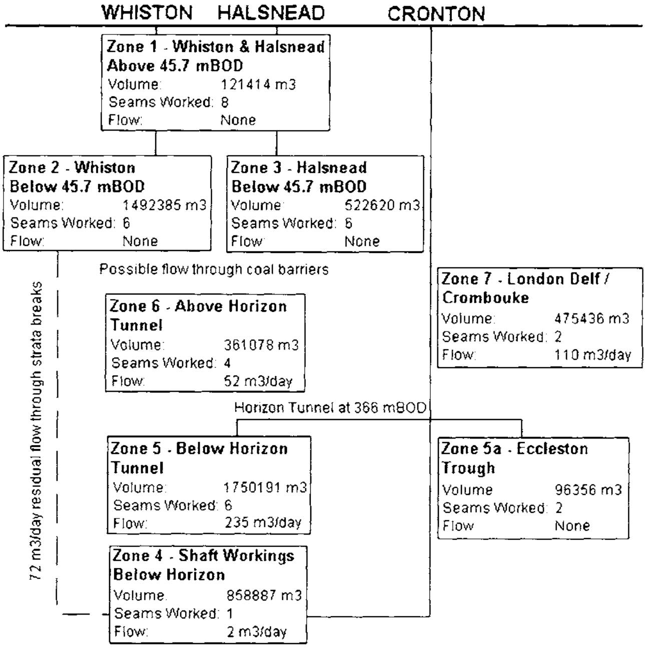

Fig. 11. Simplified conceptual model of mine water inflow to Cronton Colliery.

and estimating pre-mining water levels from springs, water courses and aquifer outcrops. Once the maximum head of the inflow source has been established, several methods of reducing the water inflow between the mine inflow level and the maximum head level can be applied. A straight linear reduction in inflow could be used but the evidence from East Fife suggests that an

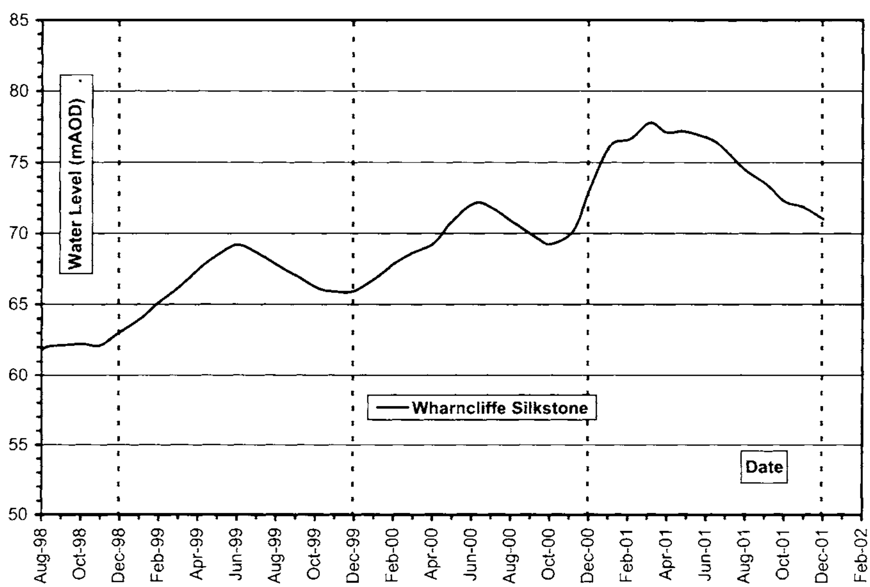

Fig. 12. Mine water recovery in shallow workings in Yorkshire, showing annual fluctuations related to seasonal variations in rainfall.

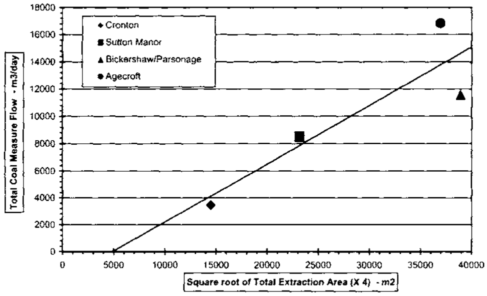

Fig. 13. The relationship between total water inflow from the Coal Measures strata and the area underlain by workings for four mining units in South Lancashire.

exponential reduction in flow, possibly related to the area of the drainage, as in a pumping test, is more appropriate.

Area-related flow model

A simple method for predicting the reduction of the water inflow during recovery was developed by relating the inflow to the area of workings. Plotting of the Coal Measures water inflows against the approximate boundary length of the total extraction area for four mining blocks in South Lancashire shows a general linear relationship (Fig. 13). The boundary is based on the square root of the area of total extraction multiplied by 4, i.e. the working area is assumed to be square. As the mine water recovers the inflows to the workings that originate from the Coal Measures are decreased in proportion to the area or boundary length of workings still to be flooded.

Average permeability model

This method of predicting water inflow reduction is based on an average permeability calculated for a theoretical zone of interaction 30 m above and below the boundary of the total extraction area of workings. The dip of the Coal Measures strata in each mining block is assumed to be constant, therefore, using Darcy's flow equation, the head difference divided by the length of flow path will also be a constant (Darcy's law):

$$V = \frac{K(h_1 - h_2)}{L} \tag{1}$$

where K is the Hydraulic conductivity; h_1 is the maximum hydraulic head (in the source aquifer); h_2 is the minimum hydraulic head (in the mine workings); L is the length of the flow path; and V is the velocity or specific discharge.

Using the total Coal Measures water flow into the mine or mining block and the area of interaction around the total abstraction mining, an average permeability of the Coal Measures strata can be calculated. The Coal Measures flow entering a mine is equal to the flow velocity times the cross-sectional area of interaction:

$$Q = VA \tag{2}$$

where Q is the flow; V is the velocity; and A is the cross-sectional area of interaction.

Using the flow at closure and the interaction area based on a zone 30 m above and below the workings boundary, an average permeability can be calculated:

$$K = \frac{Q}{A} \tag{3}$$

where K is the hydraulic conductivity; Q is the flow from Coal Measures strata at closure; and A is the total area of interaction around the mine workings.

The water inflow to the mine from the Coal Measures is then calculated for various depths using the mining interaction area and the average permeability.

Average Coal Measures permeabilities based on the interaction area around total extraction areas were calculated for several mining blocks in South Lancashire. The permeabilities for each block were generally similar (see Table 2) suggesting that in multiseam workings there is a general relationship between Coal Measures inflow rate and total extraction area.

Table 2. *Permeabilities derived from mine water inflow and interaction areas for five mining blocks in Lancashire*

	Mining block	Average permeability
1.	Bickershaw–Golborn	1.612×10^{-3} m day^{-1} (1.865×10^{-8} m s^{-1})
2.	Cronton	3.92×10^{-3} m day^{-1} (4.537×10^{-8} m s^{-1})
3.	Sutton Manor–Clockface	6.165×10^{-3} m day^{-1} (7.135×10^{-8} m s^{-1})
4.	Ashton Green–Bold	6.55×10^{-3} m day^{-1} (7.581×10^{-8} m s^{-1})
4.	Agecroft	8.82×10^{-3} m day^{-1} (1.021×10^{-7} m s^{-1})

Logarithmic flow model

The area-related and average permeability flow models are methods to reduce Coal Measures flow into the mine. For flows from shallow workings or from aquifers within shafts, the controlling factor is not usually the area of working but the permeability of the mining connection or the shaft lining. Where mine workings extend above the levels of the inflows from shallow workings or shafts, reductions in the flow predictions in the mining area or average Coal Measures permeability can be used once the water in the mine has reached the level of the shallow inflow or the shaft aquifer. However, where there are now shallow mine workings an alternative method of flow reduction is required. In these cases a simple logarithmic scale was applied between the inflow level and the maximum head in the shallow mine workings or the aquifer. A similar technique was also applied to the deeper Coal Measures inflows to give a comparison with area-related and average permeability models.

Results of mine water recovery modelling

The primary aim of mine water recovery modelling has been the prediction of the timing, the site and flow rate of potential future surface mine water discharges. These predictions can then be used to design and correctly place remediation schemes to either prevent or to treat the potential mine water discharge. Where there is no mine water level monitoring and recovery has to be calculated from an estimated inflow and an estimated void, the principal problem is the void-space calculation. The various flow models used (including the simple linear trend) generally give very similar recovery curves except in the late stages of recovery. Figure 14 shows the predicted recovery curves at Cronton, using the different inflow models, based on a residual void-space

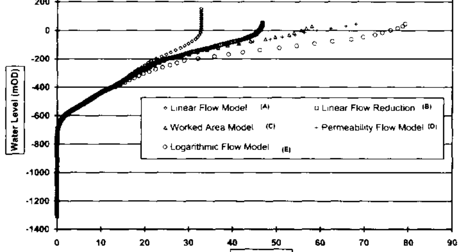

Fig. 14. Predictions of mine water recovery at Cronton obtained using five alternative inflow models.

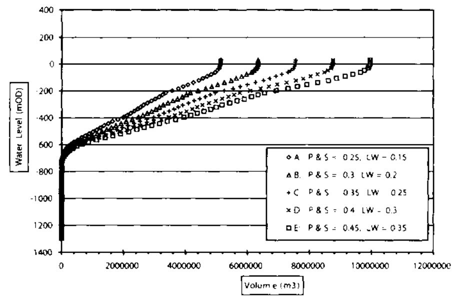

Fig. 15. Variations in predicted mine water recovery times at Cronton Colliery using the linear inflow model for various estimates of residual void volumes.

calculation of 20% for total extraction and 30% for pillar-and-stall workings. However, if the void-space estimation is wrong the recovery period could vary significantly. Figure 15 shows several linear mine water recovery curves based on varying combinations of residual void space for both total extraction and pillar-and-stall workings. There is approximately 30 years difference between the shortest and the longest period.

To date, there has been no monitoring of the actual mine water recovery in a mine or mining block where recovery modelling alone was used to predict recovery. However, of the four major mining units assessed in Lancashire, Agecroft was predicted to have mine water recovery nearest to surface and Bickershaw–Parsonage to have the longest recovery. Recent boreholes have confirmed that mine water levels are still at depth in the Bickershaw–Parsonage block and that water levels in the Agecroft area are close to surface.

Conclusions

The modelling of mine water recovery can be carried out using mine water inflow data and mine plans alone. However, to achieve accurate predictions on timing, this should be coupled with detailed monitoring of the actual water levels especially in the later stages of recovery.

Linking mine water inflow data with void-space calculations and monitored recovery data will give a better estimate of the reduction in water flow during recovery and help in calculating the residual void space in a mine. With this information the timing, site and flow rates of potential mine water discharges can be predicted to reasonable accuracy.

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