Coalfield closure and the water environment in Europe

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Synopsis

Some of the negative consequences that coalfield closure can have for the water environment are now well documented in Western Europe, providing a useful check-list for possible eventualities during the restructuring of the coal industry in Eastern Europe. As individual mines have closed over the years the burden of dewatering has been passed on to ever fewer remaining collieries, until the last working mines in a coalfield may have to carry economically insupportable pumping rates—approaching 15 t of water pumped from the workings for every tonne of coal raised.

The final closure of an entire coalfield is usually accompanied by the termination of decades (or even centuries) of regional-scale dewatering, which can have diverse consequences, including: (i) relief from some of the negative side-effects of dewatering, such as where the dewatering effluents were too saline for cost-effective treatment prior to disposal; (ii) loss of some former benefits of dewatering, such as the dilution of other surface water pollutants by mixing with less contaminated dewatering effluents; (iii) flooding of the mine workings and surrounding strata, possibly causing geotechnical problems, such as accelerated mine gas emissions and/or renewed subsidence; and (iv) discharge of water from the flooded workings to adjoining surface and subsurface water bodies, which can cause localized surface flooding and (if the mine water is of poor quality) aquatic pollution.

As more and more European coalfields are closing European Commission research projects are now addressing some of the more pressing of the above issues, such as the need to develop long-term, low-cost methods for the remediation of mine-water pollution (see www.piramid.org) and the development of environmental regulation strategies for mine waters that take full cognizance of the social and economic needs of both EU member states and accession countries (see www.minewater.net/ermite).

The growth and decline of European coal mining

The antiquity of the European mining industry is well known, some mine voids dating back to the Neolithic era.[1,2] Coal mining, however, does not date from the earliest days of mining as wood and bone charcoal long held sway as the principal fuels for domestic and metal-working purposes. Apart from sporadic evidence of small-scale coal usage in the Roman era and subsequent centuries, records of organized coal mining at industrial scales do not occur before the seventeenth century in most of Europe. Because it is crossed by two navigable rivers a short distance from the coast of the North Sea, which provided marine access to the markets of London and other European cities, the Great Northern Coalfield of England was the first coalfield to be developed to serve export markets and thus to produce coal in quantities well in excess of those which could be consumed by local demands.[3] Following the birth of railways in this region in the early nineteenth century other coalfields became able to develop export trades of their own, such that industrial-scale coal mining was well established by the second half of the nineteenth century in nearly all areas of Western and Central Europe with appropriate geology (Fig. 1), such as northern France, Belgium, Germany and Poland.[4,5,6] Coalfields of greater structural complexity, such as the Donbass in the

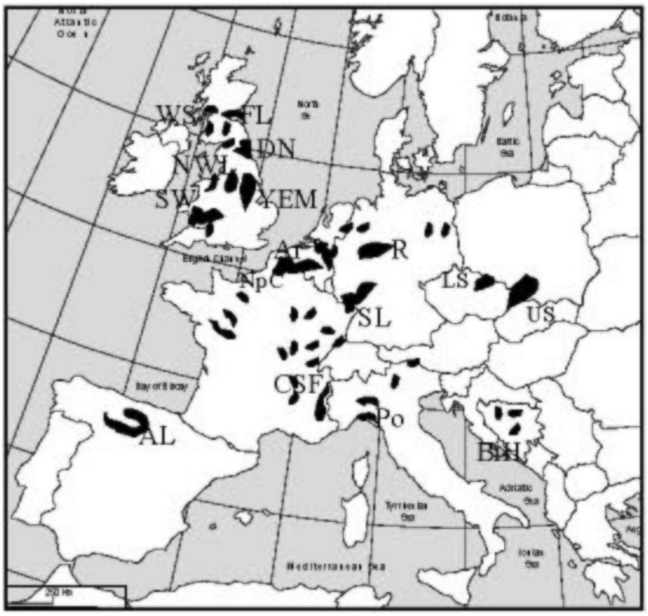

Fig. 1 Sketch map showing principal Carboniferous coalfields of Western and Central Europe mentioned in text. AL, Asturias/León, Spain; Ar, Ardennes, Belgium and southern Netherlands coalfields; BiH, Bosnia–Herzegovina coalfields; CSF, central and southern French coal basins; DN, Durham and Northumberland coalfields, northeast England; FL, Fife and Lothians coalfields, Scotland; LS, Lower Silesian coal basin, Czech Republic; NpC, Nord–Pas-de-Calais coalfield, France; NWL, North Wales and Lancashire coalfields, northwest England; Po, Po Basin coalfields, Italy; R, Ruhr coalfield, Germany; SL, Saarland coalfield, Germany and France; SW, South Wales coalfield; US, Upper Silesian coal basin, Poland and Czech Republic; WS, West of Scotland coalfields; YEM, Yorkshire and East Midlands coalfields, England

Prepared as a contribution to the conference 'Confronting change: North East England and East European coalfields' organized by the North of England Institute of Mining and Mechanical Engineers in collaboration with the University of Sunderland and the Institution of Mining and Metallurgy and held at Neville Hall, Newcastle upon Tyne, on 12 and 13 November, 2001. First published in the conference volume produced by the University of Newcastle and reproduced in edited form as a professional paper in *Trans. Instn Min. Metall.* (*Sect. A: Min. Technol.*), **111**/*Proc. Australas. Inst. Min. Metall.*, **307**, September–December 2002.

Ukraine and the Central Asturian basin in northern Spain, were brought into production a little later than the others, once appropriate and economically viable techniques for mining in steeply dipping strata had been devised.[7]

In most of Western Europe coal production peaked in the first two decades of the twentieth century and after the conclusion of the first world war in 1918 most coalfields experienced a decline in demand, which was particularly marked during the depression of the 1920s–30s. The second world war then disrupted international trade in coal to such an extent that coalfields that had previously been economically marginal in global terms (e.g. the Central Asturian coal basin)[7] gained a new lease of life. By the mid-1960s, however, decline became the dominating trend once more in most of Europe, manifest in widespread closure programmes in the coalfields of the United Kingdom, Belgium and France.[8] Despite occasional periods of optimism, the underlying trend in all the coalfields of Western Europe has been downward ever since, although the pace of closure has varied dramatically from one country to the next, depending on the willingness of individual national governments to implement policies of production subsidies and employment replacement. The United Kingdom government has generally been the least disposed of any of the Western European governments to either of these policies, with the result that the decline in the fortunes of the coal sector has been considerably more rapid here than in neighbouring countries—even those with substantially poorer coal reserves.[8]

Until the collapse of the Soviet Union in the early 1990s the coal industries of most Eastern European countries had been substantially immune to the pattern of decline experienced in Western Europe. Indeed, production increased as much as fivefold between 1946 and 1989 in the former U.S.S.R., former Czechoslovakia, former Yugoslavia and Poland.[9] However, restructuring of the coal industry is now under way throughout Central and Eastern Europe as the economies of former Soviet-bloc countries are brought into line with international markets.[9,10,11] In all cases this has meant full or partial closure of some major coalfields. These closures provide the context for the present paper, in which lessons learnt about the impact of coalfield closure on the water environment in Western Europe are summarized in the hope that they might serve as a guide to what might be expected during the partial or total closure of major coalfields of Eastern Europe, such as those of Silesia[9,10] and Donbass.[11]

'Devil take the hindmost': how dewatering burdens multiply for the last working mines in a large coalfield

With such a long history of extraction many of the larger coalfields of Europe have eventually been transformed into vast honeycombs of interconnected workings, which in many cases are known to be interconnected over linear distances in excess of 50 km.[12] The scale of these interconnections is particularly important in the context of water management during the closure of mines in large European coalfields, as is discussed below. The vast areal extent ensures that, despite the presence of low-permeability roof strata in many cases, the overall water makes of these coalfields are often substantial, averaging 290 m^3/day per square kilometre underlain by workings (in a range from 100 to 600 m^3/day/km^2).[13] It has been recognized since at least 1858[3] that most coal mines raise substantially more water than coal. Table 1 summarizes some estimates of the mass of water raised per tonne of coal produced. The figures quoted in this table vindicate the contention that the mass of water pumped to bank exceeds the mass of coal raised.[14,15]

One problem with expressing water make in this way is that it tends to imply that to cancel the water make only requires the cessation of coal production. This is, of course,

Table 1 Estimates of mass of water raised per tonne of coal mined

Locality	Year to which estimate relates	Mass of water, tonne pumped/tonne coal mined	Comments
Wylam colliery and Percy Main colliery, Northumberland	pre-1858	30	Albeit rough estimates, these high values are consistent with the present substantial discharge from the flooded Wylam workings and many historical accounts attesting to the numerous inrushes that beset Percy Main[3]
Other collieries in northeast England	pre-1858	7–8	A generalized estimate, but the source was a leading authority on mine drainage of his period,[3,19] who was well used to calculating mine pumping requirements[3]
Ruhr coalfield, Germany	1920	1.8	Estimate made in 1994 using substantial archive data[22]
Mean figure for Nord–Pas-de-Calais basin, France	1958	2.4	Mean estimate for the collieries of Nord–Pas-de-Calais operated by the French state coal company, Charbonnages de France; strikingly similar value to the previously mentioned United Kingdom estimate[14]
Average figure for all collieries in England and Wales	1962	2.44	Estimate obtained by the United Kingdom National Coal Board's leading specialist in mining beneath water. Remarkably similar to the contemporaneous figure for French coalfields[14]
Scottish deep mines	1980	6.3	Estimate at a time when Scotland's deep coal mines produced 8 000 000 t/year[15]
Scottish opencast mines	1980	13.2	Estimate at a time when Scotland's opencast mines produced 3 000 000 t/year[15]
Ruhr coalfield, Germany	1990	3.1	Total water make was quite similar to that measured in 1920; the apparent increase in mass of water per mass of coal mined reflects the drop in coal production over time[22]

nonsense as although the cessation of coaling is usually soon followed by a cessation of active dewatering (at least locally), the water make does not halt at the same time. Rather, the workings flood until the rising waters reach some 'decant level',[16] at which point the mine water begins to migrate to another mine, an adjoining aquifer and/or a surface water body.

Where water from one abandoned mine can decant to an adjoining, working mine the net result for the latter is an immediate increase in the water make and, therefore, in its fixed costs without any compensating increase in coal production. The anticipated average increase in water make for a typical deep mine working by longwall techniques can be estimated by combining the previously quoted water-make data[16] with the average annual coal production rate for deep mines. In the United Kingdom output averages about 1 020 000 t/year for each of the 17 large mines still in production in 2000–01 (estimated from government statistics[17]). Assuming that a 2-m thickness of coal is worked (as a total of one or more seams) and given a mean specific gravity for coal of 1.3, a rough mean figure of only 0.15 l/tonne of coal mined results. For a typical mine this means that its own coaling activities are unlikely to result in an increment in the dewatering burden of more than 160 m^3/day in any one year. By contrast, if this working mine receives the entire water make from an adjoining, recently abandoned mine, the step-increase in total water make can exceed the growth in water make anticipated as a consequence of its own coaling activities by more than an order of magnitude. Table 2 summarizes some real cases of increased water make due to migration of water from adjoining abandoned workings. For the few examples given, the step increase in water make due to migration of water from an adjoining abandoned mine ranges from 620 to 13 700 m^3/day with an average of 6400 m^3/day, which is 40 times the 160 m^3/day increment that might be anticipated from the coaling activities of the 'average' mine.

For all but the most economically robust of mines a sudden fortyfold increase in water make is likely to pose significant problems for the continued viability of the operation. In some cases the available compartment space in the mine shafts may be insufficient to accommodate the extra pipe ranges that will be required to handle the increased pumping. Under these circumstances the mining company will be faced with either the major expenses associated with enlarging existing shafts or sinking a new service shaft or else losing the battle with the extra water and closing the mine altogether. The problem is not new, of course, for as early as 1708 J. C. Loudon wrote of the collieries of the mid-Tyne coal basin: 'If there is this and that invention found out to draw out all great old Waists [*sic*] or Drowned Collieries ... there are several good Collieries which lye unwrought and drowned for want of such Noble Engines or Methods as are talk'd of or pretended to.'[18] Within a few years of these words being written the Newcomen engine was invented (1712) and soon enjoyed wide uptake for the dewatering of deep coal mines.[3] The availability of suitable pumping engines did not in itself solve the problems of systems of interconnected, flooded collieries as the location of a pumping operation is at least as important as the mechanical pumping capacity. Thus in the mid-nineteenth century debate continued to rage over the feasibility of an integrated system of pumping shafts to achieve common dewatering of thirteen major Tyne collieries (Whitley, Percy Main, Willington, Wallsend, St Lawrence, St Peters, Heaton, St Anthony's, St Hilda, Jarrow, Manors, Oakwellgate and Hebburn).[19,20] Centralized dewatering systems have remained integral to the operation of major European coalfields ever since, with well-documented examples in the coalfields of northeast England,[19] Nottinghamshire,[21] the Ruhr[22] and the Upper Silesian Basin in both the Czech Republic[23] and Poland[24] (Fig. 1).

As the dewatering burdens of individual, adjoining mines coalesce little by little in response to local closures the last few

Table 2 Selected cases of water migration to operating coal mines from adjoining, recently abandoned mines

Name and location of working mine	**Total water make of working mine before migration of water from adjoining abandoned mine**	**Name of adjoining abandoned mine**	**Year of water migration**	**Quantity of water that migrated to working mine**
Craghead, Durham, England*	3035 m^3/day	Morrison Busty	1973	3074 m^3/day
Frances, Fife, Scotland†	7860 m^3/day	Randolph Coliery	1986	11 200 m^3/day
Maltby, South Yorkshire, United Kingdom‡	<100 m^3/day	Silverwood	2000	620 m^3/day
Mina Figaredo, Asturias, Spain*	Not documented	Santa Bárbara	§	13 700 m^3/day
Shildon Lodge, Durham, England*	1693 m^3/day	St Helen Auckland	1926	2000 m^3/day
Sósnica, Upper Silesia, Poland[52]	Not documented	Gliwice	§	7920 m^3/day

*Unpublished notes in the author's collection.
†Total quantity of water that migrated includes that which entered active workings at Frances (1200 m^3/day) plus the amount that migrated to the adjoining dewatering station in the old Michael Shaft (10 000 m^3/day); the source data are old British Coal records, subsequently processed and published.[53]
‡Personal communication from mine staff, referring to quantities predicted in earlier modelling work.[54]
§Likely migration of water in 2001 was prevented by renewed pumping in abandoned mine, to avoid overwhelming installable pump capacity in working mine.

working mines in a given coalfield can be left with a huge pumping burden, well in excess of the water make that these working mines could themselves induce. Two examples are very instructive in this regard: the Ruhr coalfield, Germany, and the Durham coalfield, England.

In the Ruhr coalfield[22] (Fig. 1) the total quantity of water pumped from active and abandoned mines has remained fairly static over the period 1920 to 1990, averaging some 344 000 m^3/day. However, the amount of coal production has declined over time, from around 70 000 000 t in 1920 to only 40 000 000 t/year by 1990. This means that the amount of water pumped has increased from 1.8 t of water per tonne of coal in 1920 to 3.1 at present (Table 1). Just under 40% of the total dewatering burden is actually raised by the remaining active mines (some 16 at the time of writing), the remainder being pumped from a dozen disused mine shafts.

In the case of the Durham coalfield, by the time the last mine closed in 1994 the total pumping burden averaged 163 600 m^3/day, of which about 100 000 m^3/day was pumped from nine abandoned mine shafts in the exposed coalfield many kilometres to the west.[12,13] For purposes of comparison, if this water make is averaged over the four collieries they are seen to have been carrying a mean pumping burden of 40 000 m^3/day, which is more than thirteen times greater than those of even relatively wet collieries formerly worked inland (cf. Craghead and Morrison Busty collieries, Table 2). In the final year of full production this amounted to about 14.9 t of water per tonne of coal mined, which is about six times greater than the rates associated with modern deep-mined coalfields and even exceeds the rate of the large, wet opencast mines operating in Scotland in the 1980s, which received substantial in-pit precipitation in addition to groundwater inflows[15] (Table 1). It is known that the high pumping burdens associated with the last four working collieries in the Durham Coalfield combined with the unwillingness of potential buyers to inherit the liabilities associated with the eventual cessation of regional dewatering[25,26] contributed materially to the failure of the government to find a private buyer for these four mines during the privatization of the United Kingdom coal industry in 1992–94.[25]

Mine-water rebound and its consequences

The closure of the last few mines is synonymous with the final closure of the entire coalfield, and this is usually accompanied by the termination of decades (or even centuries) of regional-scale dewatering. The consequences of a cessation of large-scale dewatering have been catalogued on several occasions within the last decade[13,26,27] and are now known to include the following.

Relief from some negative side-effects of dewatering

Drawdowns in surrounding aquifers

Among the possible negative side-effects of dewatering are drawdowns in surrounding aquifers. For instance, the abandonment of coalfield dewatering south of the Butterknowle Fault in County Durham in the mid-1970s resulted in a rise of some 10 m in the water-table in the overlying Magnesian Limestone aquifer,[28] an important source of public water supply. This arguably means that the cessation of dewatering restores resources to an important aquifer, although (as seen below) water-quality concerns cloud the issue substantially.

Contamination of surface waters by dewatering effluents

While dewatering effluents are commonly treated to prevent them from contaminating receiving watercourses, highly saline mine waters[29] (some of which, in Poland at least, are also radioactive[30]) may not be amenable to sufficient treatment to prevent them from degrading receiving watercourses.

Loss of some former benefits of dewatering

Dewatering effluents have frequently played valuable roles in sustaining flows in surface watercourses and in diluting other, more noxious pollutants associated with sewage effluents etc.[31] A cessation of dewatering usually results in the abrupt loss of these benefits.

Geotechnical problems relating to land subsidence and mine gas hazards

The reactivation of void collapse and seismicity, sometimes leading to land subsidence, has been causally linked to the flooding of mine voids in the United Kingdom,[32,33] France[34,35] and the Ukraine.[11] The physical mechanisms responsible for these processes are varied and include the erosion of mine voids by rapidly flowing waters, the slaking of seatearths and other incompetent strata[11,32] and the lowering of effective stress in fault planes due to the increase in pore pressure.[33] On the other hand, in the coalfields of the southern Netherlands flooding of workings has caused 'upsidence' (i.e. the raising of the ground surface),[36] presumably due to physico-chemical expansion processes as strata containing swelling clays are flooded. The process of flooding can also temporarily accelerate mine gas emissions as gases are pushed ahead of the rising water-table. This process has been documented recently from mines in Italy[37] and the United Kingdom,[38] fatal incidents being recorded in the latter.

Discharge of water from flooded workings to adjoining surface and subsurface water bodies

Overall, discharge of mine water to other bodies of water is the most common,[27] most sustained[39,40] and most environmentally[41] and economically damaging[42] consequence of the cessation of coalfield dewatering. Problems associated with mine-water discharge from abandoned workings are of two basic types (both of which may result from the same discharge): surface flooding and aquatic contamination. Because of their pre-eminence in the array of problems associated with abandoned mine waters each is considered in some detail below.

Surface flooding

Surface flooding from abandoned mines can result in the loss of valuable agricultural land and damage to residential and business premises. An interesting case study is provided by the St Helen Auckland colliery (United Kingdom grid reference, NZ 199268), in southwest County Durham. This colliery worked from 1830 until the cessation of dewatering during the General Strike in 1926. Although pumping from this colliery never recommenced, the St Helen mine water was not destined to reach the ground surface for another 50 years because mining recommenced in the Chilton (NZ 283303) and Mainsforth (NZ 315312) areas to the east and water began to be pumped from a number of shafts to the west of Bishop Auckland to ease the dewatering burdens of these working mines. It was only with the closing of Fishburn colliery (NZ 361317) in the mid-1970s that dewatering in the area was finally discontinued. By this time the old pit yard of St Helen Auckland had been converted into an industrial estate, with the cap of the old Engine Shaft (NZ 199268) incorporated into the foundations of a button factory. In 1979 the factory employees turned up for work to find a large mound in the middle of the workshop floor, like a huge circular blister in the floor. Not realizing that the shaft cap was present beneath the factory floor, factory staff contacted officials of the local gas and water suppliers to see if they could explain the 'blister'. Within a few hours the 'blister' began to strain at the edges and then burst, releasing an outrush of highly ferruginous mine water that immediately flooded the factory floor. To facilitate work on the site, which ended in the demolition of the factory, the mine water (now flowing at about 2000 m^3/day) was diverted to the nearest drain. This drain led on to adjoining farmland, where the large quantity of water overwhelmed the capacity of the one small drainage ditch and led to perennial flooding of what had previously been a hay meadow (NZ 195265) belonging to Brusselton Farm. It also flooded out a farm access track, rendering other fields inaccessible for much of the year. The flooding thus caused significant loss of revenue for the farmer. Twenty years were to pass before a water diversion and wetland treatment system was finally installed to remedy the problem.

Flooding associated with abandoned mines is not always so detrimental, however. For instance, mine water emanating from the Hazard Shaft of Blaydon Main colliery (NZ 191628), which worked from 1837 to 1921, led to the flooding of an adjoining surface depression, itself formed by mining subsidence. The flooding gave rise to a substantial water body, which came to be known as Shibden Pond (NZ 194628). The pond and fringing wetlands that developed around its margins are now a wildlife habit of national importance, with protected conservation status as a Site of Special Scientific Interest. Although the mine water coming from the Hazard Shaft is moderately polluted with iron (varying between 1 and 2 mg/l Fe in 2000–2001), any detrimental impacts are limited to the immediate vicinity of the discharge, and the pond as a whole is rich in aquatic life and bird species.

Intermittent discharges from flooded workings are a particular nuisance, especially where houses have been constructed downhill from the old mine entrances. For instance, long-abandoned coal drift mines in each of the villages of Spittal, Northumberland (NU 005514),[43] and Jackson Bridge, near Holmfirth, West Yorkshire (SE 16450737), normally discharge only modest amounts of water, but occasionally give rise to torrential outflows that flood residential and commercial properties and cause substantial damage. Similar problems can also arise where mine waters are culverted through urban areas, if ochre deposited from the water clogs the sewers, causing a backwater head to build up and localized flooding. (Since the best-documented examples of this phenomenon relate to ironstone mines rather than coal mines,[44] the phenomenon is not discussed in any further detail here.)

Water pollution

Water pollution by abandoned mine discharges is one of the most widely documented forms of aquatic pollution.[13,15,26,30,45] Although much of the literature focuses on 'acid mine drainage', it is important to realize that many alkaline coal-mine water discharges are still sufficiently rich in iron to be highly contaminating.[13,45] Indeed, biological studies have revealed that the damage caused to benthic invertebrate faunas by alkaline, ferruginous discharges is generally as severe as that caused by acidic mine water discharges.[41] This is because the smothering of the benthos with iron hydroxide precipitates prevents photosynthesis and therefore locally removes the foundations of the trophic web (i.e. the 'food chain'). There is as yet no Europe-wide compendium of the damage caused to surface waters by abandoned-mine discharges. The most comprehensive national data-set currently available is that for the United Kingdom, which indicates that some 400 km of watercourse is currently degraded by abandoned coal-mine discharges[45] (around a further 200 km is similarly contaminated by abandoned metal-mine discharges). By extension, it is likely that the equivalent figures for the whole of Europe will prove to be 2000–3000 km of watercourse contaminated by abandoned coal-mine discharges.

While most documented instances of aquatic pollution from abandoned mines relate to surface waters,[46] polluted mine waters can also migrate into adjoining, freshwater aquifers, jeopardizing their utility as water resources. Examples of aquifer pollution by migration of mine water from abandoned coal mines are surprisingly sparse, probably owing to a lack of investigation. One of the few documented examples concerns Mainsforth colliery (NZ 315312) in the southwestern area of the Durham Coalfield.[16,28,47,48] After the cessation of pumping in 1975 water levels recovered over the following 8 years both in the mine workings and in the overlying Magnesian Limestone aquifer.[28] Contaminated mine water migrated into the Magnesian Limestone during this period, producing the changes in groundwater chemistry summarized in Table 3. As would be expected, buffering of pH by limestone dissolution neutralized the acidity of the mine water and also precluded the persistence of elevated iron concentrations in the limestone groundwater. However, limestone dissolution alone does little to counteract the persistence of high sulphate concentrations and high conductivity in the aquifer water, and the down-gradient migration of a major plume of highly mineralized water has now been underway in the aquifer for about 20 years. A recent rigorous analysis of all available data[48] suggests that this contaminant plume is now perilously close to a public supply well belonging to Hartlepool Water Company. Given that the SO_4 concentrations in the plume considerably exceed the drinking water limit of 250 mg/l, the endangered well may in future have to be taken out of service or used for blending with purer waters. Similar instances of aquifer contamination by migrating mine waters are anticipated to be one of the most important environmental consequences of the recent and future closure of large coalfields concealed beneath major aquifers, such as the Permian dolomites and Triassic Sandstones of the English East Midlands coalfield[49] and the Cretaceous Chalk aquifer that overlies the Kent coalfield in southeast England and the Nord–Pas-de-Calais coalfield of northwestern France.[34]

Table 3 Changes in selected chemical parameters in Magnesian Limestone aquifer overlying Mainsforth colliery, County Durham, 1975–83

	1975	1976	1977	1978	1979	1980	1981	1982	1983
SO_4, mg/l	50	40	80	197	270	340	377	463	491
Conductivity, μS/cm	536	715	705	818	910	970	1150	1250	1400
pH	7.9	7.7	7.6	7.5	7.7	7.6	7.7	7.6	7.7

Data collated from Environment Agency archives.

One issue of particular importance in relation to aquatic pollution from abandoned mines is the longevity (i.e. long-term persistence) of this form of pollution.[39] Whereas contaminant concentrations are usually highest shortly after the mine completely floods to surface and the quality generally improves over a period (the 'first flush') about four times as long as the time that it took the mine to flood,[40] long-term concentrations of Fe, Mn and SO_4 are often still unacceptably high.[50] Hydrogeochemical modelling typically suggests that these levels of pollution may endure for hundreds of years until the pollutant-source minerals are finally exhausted.[50] The development of appropriate, sustainable engineering responses to mine-water pollution requires that this temporal persistence be taken fully into account when remedial works are planned.[50,51]

European research on an Europe-wide problem

As more and more European coalfields are closing, the European Commission has funded research to address some of the generic issues arising from the cessation of dewatering. In view of the long-term persistence of mine-water pollution just noted, one particular need is for technological development of low-cost, sustainable methods for the treatment of polluted mine drainage. This topic is the focus of the European Commission's PIRAMID project. In addition to the practical aspects of developing new technologies, the management framework for polluted mine waters demands better integration of environmental regulation strategies across the EU and in states that are currently candidates for membership (the so-called 'accession states'), such as Slovenia, Poland and the Czech Republic. In view of the importance of mining and coal-fired power production in the accession states[5] it is necessary that any harmonized regulations find ways of respecting not only the natural environment but also the social and economic needs and future prospects of the various member and accession states. The development of integrated technical/socio-economic guidelines for the future management of mine waters within the context of the new European Union Water Framework Directive is the focus of the European Commission's ERMITE research project.

PIRAMID

The PIRAMID project ('Passive In-situ Remediation of Acidic Mine/Industrial Drainage') aims to promote innovation in, and facilitate wider uptake of, passive treatment technologies for mine waters, building on the successful pioneering of the technology in the U.S.A.[55] and its subsequent widespread implementation in the United Kingdom.[51] With a total budget of 1 500 000 euros, PIRAMID is running for the three years until 28 February, 2003. The project is concerned with both hydrogeological[56] and engineering[51] aspects of passive treatment and the research team, which comprises representatives from the United Kingdom, Sweden, Germany, France, Spain, Poland and Slovenia, is therefore multi-disciplinary.

Key elements of PIRAMID research include the following: the identification and mitigation of hydrogeological and institutional obstacles to the wider use of passive treatment in areas with particular constraints—namely, Eastern Europe (underdeveloped economies), southern Europe (semi-arid climates) and northern Europe (cold climates); further development of existing methods, and the evolution of new techniques, to facilitate passive treatment of the full range of European mine-water types (including arsenic-rich waters, cyanide-rich gold processing effluents and uranium mine drainage); and development of engineering guidelines to foster uptake of 'state-of-the-art' passive treatment technologies for both polluted groundwaters and surface mine-water discharges.

The dissemination of PIRAMID outcomes is primarily via the project web-site, www.piramid.org.

Progress made to date that is particularly relevant to coalfield closure has included the following. (1) Completion of a major database (on the MS-Access platform) with details of location, layout and performance for all known passive mine-water treatment systems currently operating in Europe; of the 56 systems currently included, all but seven are receiving coal mine drainage. This database is available for free downloading from the PIRAMID web-site. (2) Initial object-oriented programming of a process-based computer model of passive treatment system performance, which integrates models of flow and solute transport in surface and subsurface zones of wetland systems, as well as in permeable reactive barriers in the subsurface; it is hoped that this code, when complete, will provide the basis for improved interpretation of performance data gathered from passive treatment systems, facilitating better understanding and more robust designs in future. (3) Experimental investigations of the following aspects of passive treatment technology: hydraulic and geochemical performance of compost wetlands and permeable reactive barriers receiving acidic, metal-rich mine waters; heavy-metal attenuation in abandoned mine/pit lakes using sulphate

Table 4 Overview of potential future applicability of passive treatment in European coalfields

Country	Potential for future passive treatment implementation at coal-mine sites	Comments
Albania	Low	Some deep-mine waters and many spoil heaps may benefit from passive treatment in future
Bosnia–Herzegovina	High	Numerous small coal-mine discharges likely in wake of industrial contraction
Bulgaria	Medium	Some deep-mine waters and many spoil heaps may benefit from passive treatment in future
Croatia	Low	Few sites likely to require this kind of treatment; much limestone in the region aids natural attenuation
Czech Republic	High	Closures under way in Upper and Lower Silesian Basins likely to lead to significant pollution problems
France	Medium	Major coalfield (Nord–Pas-de-Calais) is confined beneath Cenozoic aquifers, so surface mine-water discharges unlikely there, but some passive treatment is already being implemented in other, smaller coalfields
Germany	High	Major potential in Saarland and the exposed portion of the Ruhr coalfield in the future
Macedonia	Medium	Current large-scale opencast operations likely to require backfill leachate treatment in the distant future
Poland	High	Closure of Upper Silesian Basin collieries likely to lead to polluted discharges requiring long-term treatment
Romania	Medium	Some coal-mine discharges likely in the wake of planned closures
Ukraine	High	Substantial coal-mine discharges likely in the wake of Donbass restructuring
Yugoslav Federation	Low	A few coal-mine discharges likely in the wake of recent mine closures
United Kingdom	High	Passive treatment already well established with more than 15 full-scale systems in operation, and four or five new systems being installed every year[51]

reduction; assessment of the efficacy of preventing sulphide oxidation by submersion of mine wastes; aerobic pond treatment for As and Fe precipitation; and the role of macrophytes in polishing Fe and other contaminants in wetland treatment systems. (4) Completion of a reconnaissance evaluation of the potential applicability of passive treatment technology to major mining regions of Europe; Table 4 summarizes some of the findings of this reconnaissance specifically relating to coalfield waters.

ERMITE

The ERMITE project ('Environmental Regulation of Mine Waters in the European Union'), which runs for the three years to April, 2004, seeks to provide integrated policy guidelines for developing European legislation and practice in relation to water management in the mining sector. These guidelines need to be coherent with the catchment management approach defined by the Water Framework Directive and the sustainability principles enshrined in the Amsterdam Treaty. To deliver such guidelines the ERMITE team is addressing the multiple facets of the problem by integrating across national boundaries (i.e. by examining a variety of regional and national conditions in EU member states and in countries from Eastern Europe involved in the EU enlargement) and across discipline boundaries (encompassing mining engineering, environmental technology, institutional and social policy and European law).

The specific objectives of ERMITE are: to analyse the different environmental, social, technical, economic, institutional and legal issues involved in the regulation of mine waters through several representative case studies; to provide an overview of these issues for the whole of the EU and the accession states of Eastern Europe; to establish a network for stakeholder dialogue and evaluation of institutional arrangements and policies; to assess different technical and managerial options for mine-water management in a catchment context, including methods for economic evaluation; to propose avenues for the integration of the European policies that influence mine-water management, taking into account the existing ecological and legal principles of EU environmental legislation; and to develop a coherent set of guidelines for use by the European Commission.

The ERMITE consortium includes academic partners in Spain (where the overall coordination of the project is provided by the Oviedo School of Mines), the United Kingdom (whence technical direction is provided by the University of Newcastle), the Netherlands, Sweden, Germany, Poland, Slovenia and Bosnia–Herzegovina. The project also includes the European Commission itself as a partner, through the office of the Institute for Prospective Technological Studies (Joint Research Centre, Seville).

Crucial to the work practices of ERMITE are the activities of national and European 'stakeholder networks', which bring together mining companies, relevant industrial and environmental regulators, local community organizations from the mining districts and other interested parties. By means of open dialogue with these stakeholders ERMITE is developing so-called 'STEPS' analyses, i.e. integrated analyses of the

Table 5 Anticipated water-related impacts of recent and forthcoming closure of some major European coalfields

Coalfield	Country	Impact Main	Secondary	Other	Comments
Ardennes	B	ACM	RS	GE	Coalfield underlies Chalk aquifer; some geotechnical problems already detected
Cuenca Central, Asturias	E	SWM	LFS	GE	Major multi-seam coalfield with very high water makes, but seams have extremely low total sulphur content; total Fe in waters so far has not exceeded 12 mg/l (HUNOSA data). Heavily populated narrow valleys may provide conditions vulnerable to flooding from forgotten drifts etc.
Durham	UK	SWS	RS	ACM	Most of current dewatered area is below Permian cover and controlled at present by Coal Authority pumping stations
Nord–Pas-de-Calais	F	ACM	GE	RS	Coalfield underlies Chalk aquifer; some geotechnical and gas emission problems already detected
Northumberland	UK	SWM	GE	RS	Coastal discharges most likely; these will have less ecological impact than inland river discharges of other coalfields
Nottinghamshire	UK	ACS	SWM	RS	Mainly concealed coalfield underlying public supply aquifer with mapped interconnections
Ruhr	D	SWM	ACM	RS	Mainly concealed coalfield underlying public supply aquifer; in south of basin surface discharges are likely, but mainly to large rivers with high dilution capacities
Saar	D	SWS	RS	GE	Area of relatively high topographic relief likely to provide driving head for surface discharges; some geotechnical hazards in densely populated areas
Selby (North Yorkshire)	UK	ACM	–	–	Modern concealed coalfield with very little water make; some upflow from earliest of Wistow colliery workings to overlying Permian aquifer may eventually be possible
South Netherlands	N	ACM	RS	GE	Coalfield underlies Chalk aquifer; some geotechnical and gas emission problems already detected, including 'upsidence' near Limburg[36]
South Yorkshire	UK	GE	SWM	ACM	Gas emissions already controlled, and even exploited commercially, in several places; highly urban area makes vulnerability to this risk quite high

Impact: ACS, aquifer contamination—severe; ACM, aquifer contamination—moderate; GE, exacerbation of gas emissions; LFS, localized flooding at ground surface; RS, reactivation of subsidence/seismicity; SWS, surface water pollution—severe; SWM, surface water pollution—moderate. Countries: B, Belgium; D, Germany; E, Spain; F, France; N, Netherlands; UK, United Kingdom.

social, technical, economic, political and sustainability issues surrounding issues of mine-water management. In this context 'political' is taken to include both institutional and legal matters and 'sustainability' refers primarily to environmental matters (the issue of the 'sustainability of coal production' in the sense of exploitation rate to reserves ratio etc. being addressed under the 'economic' heading).

While the ERMITE work is still in its early stages, it is possible to abstract from the early findings a few insights relevant to the theme of this contribution. These are summarized in Table 5, which lists the major issues perceived to be associated with present or future cessation of dewatering in some of the major coalfields of Europe. The subtle differences in emphasis are instructive and will colour the nature of both management and debate in the different countries. For instance, in the Nord–Pas-de-Calais basin, which is concealed beneath younger strata, surface water pollution is never likely to be an issue, whereas it is of top priority in most of the United Kingdom basins. Table 5 will undoubtedly require substantial expansion and qualification in the future, but it serves to give some impression of the diversity of water-related issues arising from coalfield closure.

Conclusions

Coal mining was the single greatest driving force behind the industrial development of Europe. In most Western European countries, however, the twentieth century has seen coal mining in decline. In some cases (e.g. the Netherlands and Belgium) coal mining has now ceased altogether and it will cease in other countries (such as France) within the next decade.[8] After more than 300 years of mining in many areas the larger coalfields of Europe are now vast, hydraulically interconnected systems of underground voids, from which water has had to be pumped continuously to facilitate sustained working, frequently at rates of 2–3 t of water per tonne of coal mined. As individual collieries have closed over the years these burdens of dewatering have been passed on to ever fewer collieries, until the last working mines in a given coalfield can carry pumping burdens as high as 15 t of water per tonne of coal produced. While such high water makes exact costs sufficient to spell the end of mining, the end of mining does not switch off the water make. Water continues to enter the abandoned workings long after the dewatering pumps are withdrawn, gradually flooding the mine voids and surrounding rock, with a range of possible negative consequences, such as temporarily accelerated mine gas emissions and renewed subsidence. Once inundation of the voids is complete (or substantially complete) the discharge of water from the saturated workings to the land surface can cause localized flooding. If the mine water is of poor quality, the migration of water into adjoining water bodies can also cause pollution, either of aquifers or, more commonly, of surface watercourses.

As more and more European coalfields are closing the European Commission has funded research to address some of the more pressing issues arising in relation to the water environment, such as the need to develop long-term, low-cost methods for the remediation of mine-water pollution (see www.piramid.org) and the development of environmental regulation strategies for mine waters that take full cognizance of the social and economic needs of both EU member states and accession countries (see www.minewater.net/ermite).

Acknowledgement

The financial support of various projects by the Environment Agency (England and Wales) and the Scottish Environmental Protection Agency is gratefully acknowledged, together with two grants from the European Commission's Fifth Framework programme—PIRAMID (EVK1-1999-000021) and ERMITE (EVK1-CT-2000-00078)). Innumerable stimulating discussions with academic and industrial colleagues helped form the concepts presented in this paper. The author wishes to thank, in particular, B. Banwart (University of Sheffield), R. Adams, J. Sherwood, C. Nuttall and A. Jarvis (University of Newcastle, past and present); and A. England, D. Laine and K. Whitworth (IMC Ltd).

The views expressed in this paper are not to be construed as the official views of the European Commission.

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