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The Rise and Fall of the Coal Industry in the United Kingdom

Although there is evidence of mining in Britain dating back to the Stone Age, the prevalence of wood and charcoal as a fuel source delayed the onset of coal mining. It is widely believed that the Romans began the first commercial scale coal mining, but coal mining did not become established until the 16th and 17th centuries (Younger 2002).

As early as the late 13th century, warnings against the use of coal were issued in London due to the sulphurous smell when it was burnt. It is said that Queen Elizabeth made a concerted effort to avoid London's smog (Doyle 2005). The smog resulting from burning of coal killed many residents of London before and during the industrial revolution. Thick smog in 1880 killed two thousand people in a single week.

Evidence of the first coal mining shows exploitation of coal exposed on riverbanks and on hillsides. One modern mine in the Durham coalfield encountered coal seams that had been mined out previously, presumably by the Roman invaders (Doyle 2005).

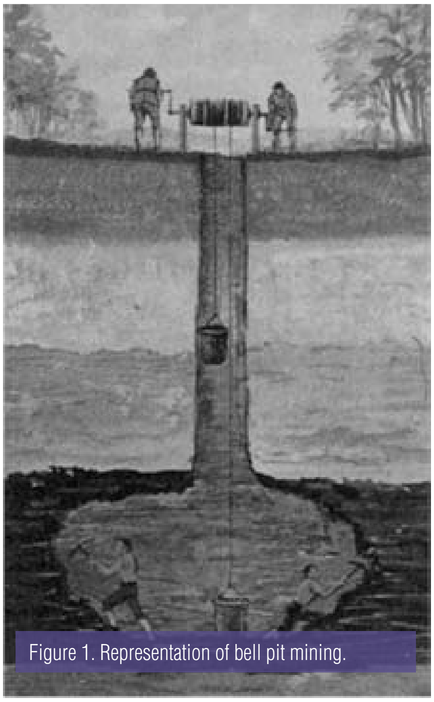

Figure 1. Representation of bell pit mining.

Early coal mining was performed using the bell pit to access near-surface coal seams. Miners would dig a vertical shaft to reach the coal seam, and then dig away from the shaft with no supports until the pit became too unstable or collapsed. Evidence of bell pits dates back to the 13th century. The coal was removed with buckets, similar to a well, as portrayed in Figure 1. This mining method continued through the early 1700s. With the advent of bell pit mining, the export of coal from the River Tyne to London began.

By 1700, two-thirds of the national output of coal was mined from the Tyne and Wear Valleys, part of the Great Northern Coalfield, which consisted of the Durham and Northumberland Coalfields (Figure 2). These coal fields were the greatest producers of British coal and fueled not only the industrial revolution in Britain, but also technological developments in coal mining. The national annual production of coal in 1700 is estimated at 2.6 million tons. The shafts from which coal was mined in this era were 7 feet to 8 feet in diameter and up to 360 feet deep (Fretwell 2004).

The Great Northern Coalfield

Consisting of the coal fields of County Durham and Northumberland, the Great Northern Coalfield was the first to be commercially exploited due to its maritime links with London and other large European cities. The geology and geography of the region have allowed extensive early mining of coal. The coal measures in most of the Great Northern Coalfield were accessible for several centuries before dewatering technology was developed. In the south and east of the Durham coalfield, the Coal Measures are overlain by Permian carbonates, often referred to as the magnesian limestone. For many years, it was in doubt as to whether coal would be found beneath the limestone and, until steam engines for dewatering were developed, whether shafts could be sunk through the water bearing limestone (Doyle 2005).

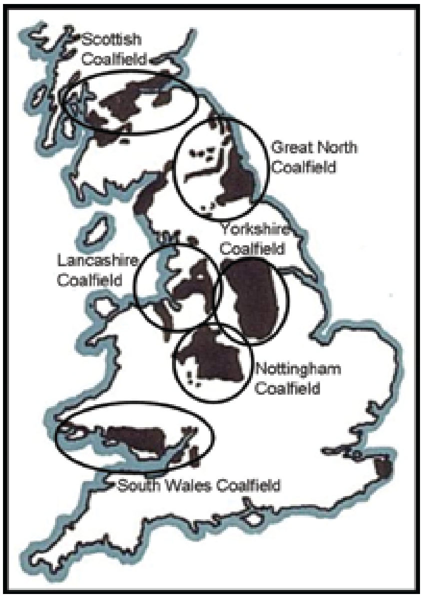

Figure 2. Location of British coalfields.

As early as 1325, there are records of coal export from the Tyne to France. By the peak of production from the Great Northern Coalfield in 1913, coal from the region was fueling cities and transportation industries across Europe. In 1913, over 56 million tons of saleable coal was produced from the coalfield with nearly 200,000 men employed by the mines (Fretwell 2004).

World War I began the downturn of the coal mining industry in Northern England. The raging war effectively cut off Northumberland and Durham's export markets and many miners lost work in the mines. The conditions of the Treaty of

Versailles in 1919 led to further downfall of the Northern industry – Germany was made to make coal reparations to France, Belgium and Italy. The treaty also stated that Germany was not only to forfeit all large merchant ships and many fishing vessels, but also to begin construction of new shipping for the Allies for bare minimum of expense. The shipyards and collieries of Northern England could not compete with the slave wages paid the German employees leading to massive layoffs and a severe depression. Despite an increase in demand for British coal during World War II, the fate of the Great Northern Coalfield was clear and production never again reached the levels of 1913 (Fretwell 2004).

The last deep colliery in County Durham, Wearmouth Colliery was closed in December 1992 and the last deep colliery in Northumberland, Ellington Colliery, was closed in January 2005 (Figure 3). These closures ended an era of coal mining in the northeast of England.

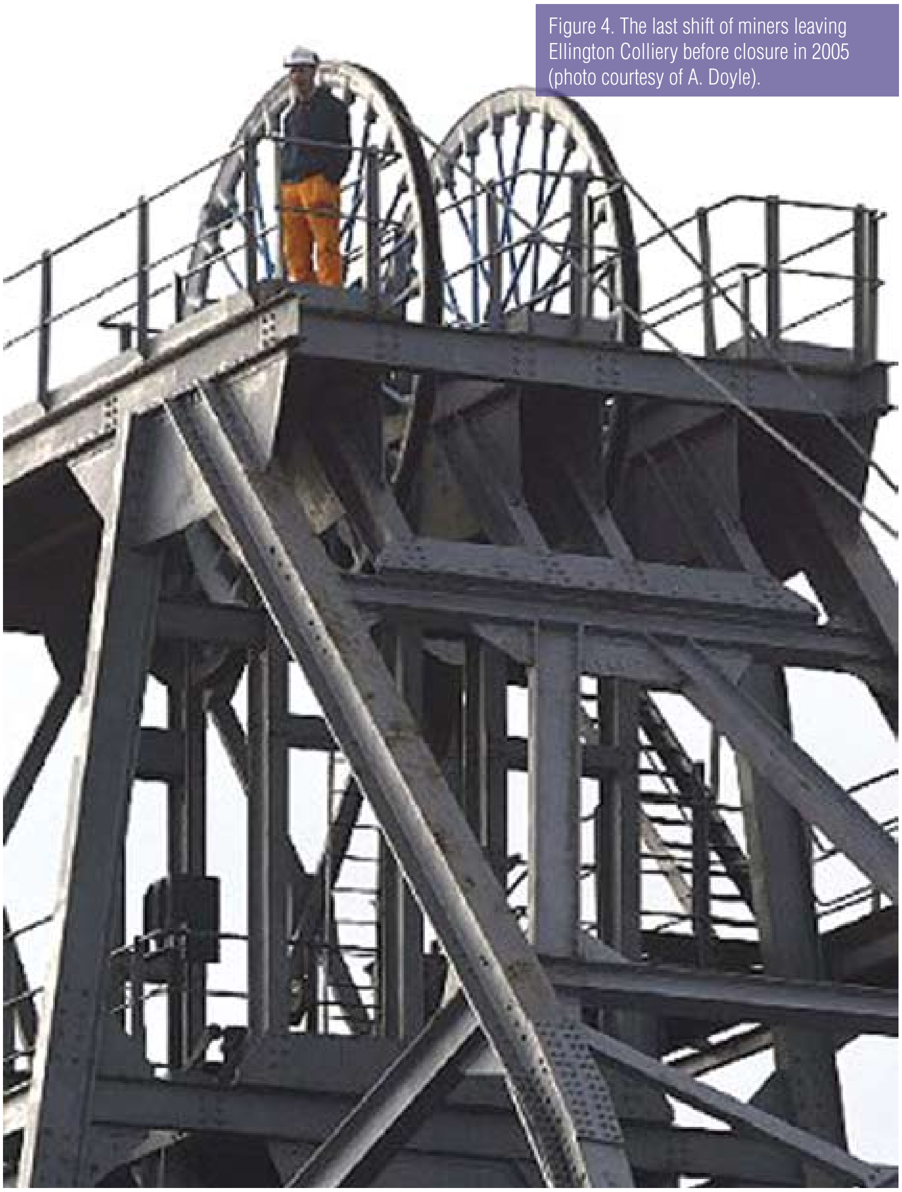

Figure 4. The last shift of miners leaving Ellington Colliery before closure in 2005 (photo courtesy of A. Doyle).

The Yorkshire Coalfield

Mining in Yorkshire dates back thousands of years because the Coal Measures are relatively shallow. Despite the long history of mining in Yorkshire, most of the large collieries were sunk in the late 18th and early 19th centuries. Caphouse Colliery, now the site of the National Coal Mining Museum of England, is shown on plans dating back to the 1780s. This may be the oldest operational shaft in England. Caphouse Colliery was closed as a standalone coal mine in 1985 and subsequently it was converted to an underground museum (Figure 4, Foster 2005).

Woolley and Denby Grange Collieries were opened around 1950 and, together with the two shafts on the Caphouse Colliery site, became part of one of the most productive complexes of Yorkshire mines. In the 1980s, production from the four shafts on the Woolley site totaled to about 13,000 tons of coal per week. Woolley Colliery was closed in 1987 (Glyn 1997).

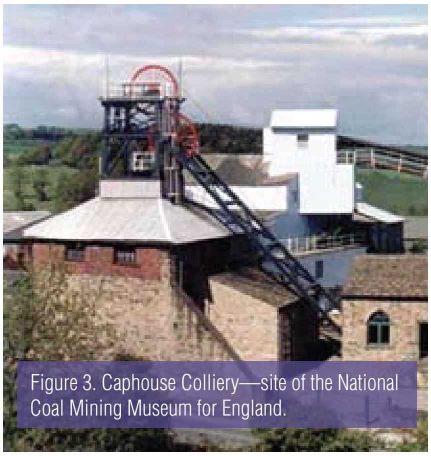

Figure 3. Caphouse Colliery—site of the National Coal Mining Museum for England.

After the mining strikes of the mid-1980s, Denby Grange, Caphouse and Bullcliffe Wood Collieries combined to form Denby Grange Colliery. This amalgamation of three collieries closed in 1991.

Technological Development in the Coal Fields of Britain

Transportation

In order to expand the export and haulage of coal from the Great Northern Coalfield, the steam locomotive was developed. In 1830, worldwide, there were no more than a few dozen miles of railroad. By 1850, this had increased to over 23,500 miles of railway. This technology allowed coal and goods to be transported nationally and allowed ships to travel to the far reaches of the globe. Coal had become not just the fuel of the nation's homes, but the fuel of an empire (Doyle 2005).

Dewatering

Limitations on the depth and location of shafts were often due to water in the mine. Dewatering technology advanced as the need for deeper shafts in wetter environs increased.

One of the original dewatering methods was simple bailing or "winding water" out of bell pits and shallow workings above the local water table using buckets. As mining progressed below the water table, bailing was used on a larger scale to haul water to surface using "kibbles," essentially large buckets. Winding water using kibbles was

Figure 5. An early example of a Davy Lamp.

calculated to only be able to manage about 2 liters to 3 liters per second of inflow into the mine (Younger 2004).

Drainage adits for coal mines dating back to the Roman times have been discovered in Britain during the development of modern open pit mines. Drainage adits were essentially mine roadways that sloped away from the workings to the surface and used gravity flow to under drain the mine. In Cornwall, the Great County Adit and its tributaries totaled to about 55 kilometers (34 miles) of underground roadways that under drained over 33 km^2 (13 mi^2) of mine workings. Although most of the mines drained by this adit have been closed for over a century, it still intercepts about half of the precipitation falling on the overlying ground surface and is a major element of the area's groundwater system (Younger 2004).

The earliest pumps used in dewatering of mines were developed before the advent of steam power. They were usually powered first by horse gins then, later, by water. By the 1600s, evidence exists of rag-and-chain pumps for dewatering. These "drew water up a standing wooden pipe by means of discs mounted on a continuous chain" (Clavering 1994). Water was diverted, sometimes from several kilometers away, to power the pumps. By the mid-1700s, reciprocating engines had widely replaced rag-and-chain pumps. Despite the advent of steam power, many of these continued to be powered by water well into the 20th century (Younger 2004).

In 1712, the Newcomen engine, a steam-powered atmospheric pumping engine, was first introduced to the collieries marking a new era in dewatering technology. The Newcomen engine was used widely for dewatering for nearly 80 years until the Cornish pumping engine, developed by John Watt, was introduced. The Cornish pumping engine was a steam-powered dewatering engine that improved upon the Newcomen engine design by separating the cooling/condensing step from the main piston chamber. This reduced power usage and created a smoother piston movement compared to the relatively jerky motion of the Newcomen engine.

Safety

The extent of industrialization in the northern coal fields of Britain led to a large number of worker injuries over time, which gradually resulted in developments of mine worker safety. In 1816 the first Davy lamp was tested underground at Hebburn Colliery (Figure 5). In 1881, the first breathing apparatus was used underground. The safety helmet, however, was not introduced to underground mining in Britain until 1930 (Fretwell 2004).

Nationalization of the Coal Mines

On Jan. 1, 1947, all privately owned coal mines were nationalized in an attempt to relieve the post-war financial pressures. At nationalization, the workforce in the coal mines totaled 718,400 men and 21,000 pit ponies at 980 pits. Unfortunately, the economic downfall of the British coal mining industry could not be staved off by nationalization and by 1958, an average of 34 pits were being closed each year. By 1992, only 50 pits employing less than 50,000 men remained open. The last underground pit in the North was closed in early 2005; a few collieries in the Midlands and South Wales are all that remain of the industry that built the British Empire.

The Longevity of Mine Water Pollution

With the long history of mining in Britain comes a long environmental legacy (Figure 6). Although the coal fields of Britain have been mined for many centuries, most of the recorded discharges are from more modern mines. These mines have a recorded life of up to two centuries, but most have not been abandoned until the 20th century.

There are both time-dependant and time-independent factors that affect the longevity of mine water pollution. The key time-independent factors are lithological setting and extent of workings. Strata associated with marine environments tend to contain pyrite in the more oxidizable

Figure 6. Ferrous ochre at Shilbottle.

TABLE 1. SELECTED DISCHARGES AND SEEPS IN COUNTY DURHAM, YORKSHIRE AND NORTHUMBERLAND – MINING HISTORY AND DRAINAGE TYPE (ADAPTED FROM YOUNGER 2002).

COLLIERY	LOCATION	START OF MINING	ABANDON-MENT	TYPE OF DISCHARGE
ST HELEN AUCKLAND	SOUTH DURHAM	1831	1926	NET-ALKALINE DEEP-MINE SHAFT OVERFLOW
BOWDEN CLOSE	WEST DURHAM	1845	1960S	ACID SPOIL LEACHATE OR DRIFT MINE DRAINAGE
MORRISON BUSTY	NORTHWEST DURHAM	1927	1974	ACIDIC SPOIL HEAP LEACHATE
SHILBOTTLE	NORTHUMBERLAND	1882	1982	ACIDIC SPOIL HEAP LEACHATE
WOOLLEY	YORKSHIRE	1850	1987	ALKALINE-PUMPED DEEP MINE WATER
CAPHOUSE COLLIERY/ HOPE PIT	YORKSHIRE	1780S	1985	ALKALINE-PUMPED DEEP MINE WATER

framboidal form when compared with strata associated with freshwater depositional environments. Larger mines have greater surface areas available for oxidation and thus pollution production. Time-dependant factors include the transition from juvenile acidity to vestigial acidity, carbonate dissolution, and changes in water flow rate (Wood et al. 1999). The shift from juvenile acidity to vestigial acidity is based on the observation that the first flush of highly polluted water upon flooding of an abandoned mine is due to the dissolution of efflorescent salts. When these so-called acid generating salts are exhausted, quality of discharges tend to improve and reach a long-term baseline level – the decline from the initial highly polluted levels to the lower baseline contaminant levels marks the shift from juvenile to vestigial acidity (Younger and Banwart 2002). Carbonate dissolution can act to buffer acid produced through mineral oxidation; this process occurs at a faster rate than pyrite oxidation and, therefore, the supply of carbonates may be exhausted before that of acid-producing minerals. Changes in flow rates through the mine will result in either the concentration or dilution of pollutants in the resulting discharge.

In County Durham, Yorkshire and Northumberland, there are a variety of net acidic and net alkaline drainages. Most of the highly acidic drainages result from spoil piles and shallow drift mines that have passive natural ventilation. Six selected discharges from the area show some of the variation in mining history, discharge quality, and longevity of drainage (Tables 1 and 2). These sites show the trend found in much of the U.K. of alkaline deep mine drainages and acidic shallow mine and spoil pile drainages. These sites are all treated by passive systems constructed by the Coal Authority, Northumberland County Council, Durham County Council or Newcastle University.

Analyses of drainages in Scotland are available for comparison with the age of the drainage (Table 3). The six sites described here are all abandoned, flooded deep mines with no ventilation – the trends shown in these sites do not apply to drift mines, shallow shaft mines or spoil heaps there passive ventilation will cause different trends. Due to local geology, water pH of the drainages are all circum-neutral and they are all net alkaline. The discharges were observed to reach this circum-neutral state within about 30 years and have high alkalinities for about 25 years. The availability of alkalinity-producing materials is likely caused by the practice in Scottish deep mines of spreading the walls of a deep mine with lime slurry to prevent ignition of coal dust. Long-term trends in iron and sulphate concentrations are likely related to the rate of groundwater rebound within the mine (Wood et al. 1999).

Post-Mining Site Management

Since most British mines were closed after nationalization, the government holds the responsibility for post-closure remediation. This responsibility is shared between several government agencies including the Environment Agency and the Coal Authority. As more is learned about the nature and longevity of mine water resulting from abandoned underground mines, a holistic method of treatment is becoming more common (Younger 2000).

Mining in the coal fields of Britain has spanned many centuries; even the most modern mines were usually highly interconnected with mines of many eras. In order to continue mining until final coalfield closure, large dewatering schemes were undertaken. In County Durham, the dewatering program of the late 1980s and early 1990s cost £2 million annually. Once the pumps were withdrawn, the mines flooded until the water reached a decanting level and discharged into surface waters impacting the ecological status of the receiving water (Younger and Sherwood 1993).

Many remediation projects are being undertaken by several authorities and all attempts are made to use passive treatment methods. The HERO (Hydrogeochemical Engineering Research and Outreach) group at Newcastle University has been at the forefront of pas-

TABLE 2. QUALITY OF DISCHARGES FROM SELECTED MINES AND SPOIL PILES IN COUNTY DURHAM, YORKSHIRE AND NORTHUMBERLAND

COLLIERY	PH	ALKALINITY (MG/L $CACO_3$)	ACIDITY (MG/L $CACO_3$)	TOTAL IRON (MG/L)	MN (MG/L)	AL (MG/L)	SUL-PHATE (MG/L)	SOURCE
ST HELEN AUCKLAND	6.3	500	0	3				YOUNGER 2000
BOWDEN CLOSE	5.0	4	100	20	1.5	8	416	YOUNGER 2000
MORRISON BUSTY	4.5	53	300	10	1	53	631	YOUNGER 2000
SHILBOTTLE	3.5	0	6000	1100	300	700	15000	YOUNGER ET AL. 2006
WOOLLEY	7.5	716	0	3	1	<0.1	722	FOSTER 2005
CAPHOUSE COLLIERY	6.9	362	0	16	1	<0.1	1147	FOSTER 2005

TABLE 3. LONGEVITY OF DISCHARGES FROM ABANDONED UNDERGROUND MINES IN SCOTLAND

(ADAPTED FROM WOOD ET AL. 1999).

DISCHARGE	AGE (YEARS)	FLOW RATE (L/S)	PH	ALKALINITY (MG/L $CACO_3$)	ACIDITY (MG/L $CACO_3$)	TOTAL FE (MG/L)	AL (MG/L)	MN (MG/L)
BLACKWOOD	117	3	7.2	265	3	0.7	0.2	0.3
STAR ROAD	106	3	6.5	173	10	4.0	0.2	0.5
LATHALLAN MILL	100	16	6.1	182	21	10.8	0.1	0.7
ELGINHAUGH	35	55	5.7	207	192	92.8	0.6	11.5
CAIRNHILL	20	1	7.6	80	27	6.7	1.1	4.0
PENNYVENIE #3	18	6	6.9	854	2	0.3	0.2	0.5

Figure 7. Wetlands at Morrison Busty.

sive treatment in Europe. Two examples of treatment systems constructed by the HERO group in the northeast of England are presented here.

In 1995, a pilot scale wetland installed at Morrison Busty (Quaking Houses) in County Durham was the first application of its kind in Europe (Figure 7). In 1997, this was scaled up to a full-scale treatment system treating the drainage from the spoil tip from the abandoned Morrison Busty Colliery (Jarvis and Younger 1999). The system of two wetlands in series cost less than £20 thousand to install and has consistently removed high levels of metals and acidity from the water before discharging into the Stanley Burn. Before the treatment wetlands were constructed, the highly acidic drainage from the spoil tip created a streambed with red and white striped bands of precipitates, known locally as the 'Sunderland Scarf' in relation to a local football team whose fans wear red and white striped scarves to matches.

Shilbottle in Northumberland is perhaps one of the most severe examples of discharge from a spoil heap in Britain; the highly acidic, metal rich drainage emptied into the Tyelaw Burn (Figure 6). Newcastle University installed a permeable reactive barrier (PRB) and settling ponds to treat the leachate from the spoil pile at Shilbottle (Figure 8). The PRB is constructed as an approximately 180-meter-long trench filled with 25 percent horse manure, 25 percent green compost and 50 percent limestone gravel. The effluent from the PRB enters a series of three settling ponds before a final polishing reed bed before discharging into the Tyelaw Burn (Younger et al. 2006).

By contrast, Figure 9 shows the reedbeds constructed in conjunction with Durham County Council to treat the net alkaline drainage from a deep mine shaft overflow at St. Helens Auckland. The reedbeds were constructed in 1999 and continue to remove metals and remediate the high flow discharge.

As more European coal fields are closed, pressure mounts to continue development of low-cost, effective treatment systems. With the rapid closure of British mines after nationalization, the social and environmental legacy of the British mining industry is clear. Both universities and government agencies continue to tackle the seemingly insurmountable environmental problem resulting from mine abandonment, while

Figure 8. Settling ponds at Shilbottle

Figure 9. Reed beds at St. Helens Auckland.

towns and villages that relied solely on mining for their livelihood continue to adapt to post-mining struggles.

Literature Cited:

Clavering, E. (1994), Coalmills in Tyne and Wear Collieries: the use of the waterwheel for mine drainage 1600-1750, Bulletin of the Peak District Mines Historical Society, 12, 124-132.

Doyle, A. (2005), The Great Northern Coalfield: Mining Collections at Beamish Museum, Northumbria University Press, Newcastle Upon Tyne.

Foster, S. M. (2005), Integrated Water Management in Former Coal Mining Regions: Guidance to Support Strategic Planning, Mineral Industry Research Organization, Leeds.

Fretwell, E. T. (2004), Coal Mining - a general history - Timeline, in Durham Miner Project, edited, Durham, England.

Glyn, A. (1997), The economic case against pit closures, in The Mining Industry, edited by T. Boyns, I.B. Tauris Publishers, London.

Jarvis, A. P., and P. L. Younger (1999), Design, Construction, and Performance of a Full-Scale Compost Wetland for Mine-Spoil Drainage Treatment at Quaking Houses, Journal of the Chartered Institution of Water and Environmental Management, 13, 313-318.

Wood, S. C., et al. (1999), Long-term changes in the quality of polluted minewater discharges from abandoned underground coal workings in Scotland, Q. J. Eng. Geol., 32, 69-79.

Younger, P. L. (2000), Holistic remedial strategies for short- and long-term water pollution from abandoned mines, Trans. Instn Min. Metall. (Sect A: Min. technol.), 109, A210-A218.

Younger, P. L. (2002), Coalfield closure and the water environment in Europe, Trans. Instn Min. Metall. (Sect A: Min. Technol.), 111, A201-A209.

Younger, P. L. (2004), 'Making Water': the hydrogeological adventures of Britain's early mining engineers, in 200 Years of British Hydrogeology, edited by J. D. Mather, Geological Society Special Publications, London.

Younger, P. L., and S. Banwart (2002), Time-scale issues in the remediation of pervasively contaminated groundwaters at abandoned mine sites, in Groundwater Quality: Natural and Enhanced Restoration of Groundwater Pollution, edited by S. E. Oswald and S. F. Thornton, pp. 585-591, International Association of Hydrological Sciences, Wallingford (UK).

Younger, P. L., et al. (2006), Coal Mine Sites for Targeted Remediation Research: The CoSTaR Initiative, 4 pp, Newcastle Upon Tyne.

Younger, P. L., and J. M. Sherwood (1993), The Cost of Decommissioning a Coalfield: Potential Environmental Problems in County Durham, Mineral Planning, 57, 26-29. ■