Long-term Mine Water Management of Abandoned Coal Mines in the United Kingdom: Almost 30 Years of Process, Experience, and Lessons Learned

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Abstract

During the closure of the UKs coal mines little consideration was given to mine water risks and management. Since, 1994, the Coal Authority have gained experience and learnt valuable lessons through the efforts made to manage mine water problems and risks. Throughout the history of mine water management in the UK there has been a progression in the process adopted to identify and assess risks and manage long-term legacies of mine water and abandoned mines. Lessons learned and forward looking outlook are essential for long-term mine water.

Keywords: Mine Water, Management, Long-term, Abandoned Mine

Introduction

The UK has a long history of coal mining, with activity in many areas dating back several centuries. The age, depth, and type of mining can vary within an individual mine or mining area. The process of mining creates voids, which, capture, store and transmit water. Excess water in workings presents a challenge for mining and continues to do so post abandonment. Within the UK (and other parts of the world) management of water in mines has been a key part of mining successfully and safely. At present the Coal Authority treat approximately 120 billion litres of mine water per annum (3800 L/s, average of 50 L/s per site). A simplified development history of mine water management in mines and mining areas, based on Younger, 2004 follows:

1. Use of buckets to bail out from shallow workings
2. Under-drainage by adits from mine workings to a valley low point
3. Pumping of water from the mines to surface (or to drainage adits)
4. Installation of barriers to stop or restrict excessive flows of water; or divert water to unflooded abandoned mine workings

During post nationalisation "modern mining" in the UK, various efforts were made to standardise mine water operational management practices with typical approaches outlined below.

Where a colliery (underground coal mine) comprises a simple isolated mining system (well-connected workings, no other nearby collieries or historical workings) – water pumped at a single location or discharged via gravity drainage adits to surface.

In more complex situations where a number of formerly independent collieries were operating water management may have been amalgamated with centralisation of pumping effort. In order for this to function, deliberate connections were made between previously unconnected working sets. Engineered connections may have served multiple purposes such as safety (improved access and egress), transport of coal as well as water management. In addition, investigation and management of "old" (abandoned workings for which records may have been poor and/or unavailable at the time) was undertaken, to understand mining risks (collapse, gas, inrush). These investigation boreholes and connections were in some cases used to drain water from historical workings to manage risk. In some cases connections were made unintentionally or as side effect of mining operations (direct connection or fracture connection). As well as augmenting connections in some cases, the opposite was done, with stoppings and dams constructed

to prevent flows of water between and around mine workings.

Following the privatisation of mining and the associated tranche of mine closures, the Coal Authority was formed in 1994 to manage the legacy and liabilities of nationalised coal mining in the UK. Privatised mines continued to operate around the UK during the late 90s and the early 2000s. Since then, the majority of underground coal mining has ceased, the last major colliery to close was Kellingley in 2015. The original remit of the Coal Authority was related to the management of ongoing subsidence claims and British Coal property interests. Later changes to legislation meant the Coal Authority were given powers to manage and treat mine water – although the Coal Authority do not have any statutory liability for any mine water discharges. The Coal Authority work in partnership with government funded environmental regulators to manage mine water pollution.

Due to the nature of the mines, mine systems and uncertainties about hydraulic connectivity between mine workings (and mines), there are several broad categories of mine water management currently present in the UK:

1. Recovered – mine water is controlled by discharges either to groundwater or the surface. Typically all recharge will discharge, though mining connections, and storage within the mine workings may result in water level variability. In some instances the flow rates of gravity discharges will vary, and under certain conditions may dry completely.
2. Recovered / pumping for treatment – mine water recovered to surface and caused pollution of receiving watercourse. Pumping is undertaken to stop mine water discharge(s), the water is treated to remove iron before being discharged to appropriate surface watercourse
3. Continuation of historical pumping (from before formation of the Coal Authority in 1994) – mine water is pumped to prevent uncontrolled pollution across a wide area and multiple possible surface discharge locations. Mine water can be treated or untreated before discharge to appropriate surface waterbody
4. Resumption of pumping following mine closures – mine water pumping was originally ceased at a mine or in a mine area, the mine workings were allowed to flood (often monitored). Mine water pumping was restarted by the Coal Authority to prevent pollution to surface water and drinking water aquifers
5. Ongoing mine water recovery – mine water pumping ceased and there is ongoing monitoring or assessment of a mine system to confirm if or when mine water management may be needed in the future
6. Unknown mine water status – some mine water systems are considered to have no or minimal risks to the environment, and thus have not been monitored. There are some areas where it is uncertain if mine water is recovered or recovery is ongoing

Coal Authority coal mine water management: progression

In 1994, when the Coal Authority was formed, they were a total of 28 pumping stations abstracting mine water. These pumping stations were predominantly ones operated by mining companies to allow the continued extraction of coal (underground not surface).

Through the 1990's there was a reduction in the number of pumping stations (tab. 1 and fig. 1), this was due to changes in mining operations and centralisation of pumping operations. Throughout the 2000's operational mining decreased, and some pumping stations were transferred to the Coal Authority. During the same time period, proactive management of rising mine water areas (to prevent pollution) by the Coal Authority began. In addition to new mine water management sites, cessation of some pumping stations led to new engineered gravity discharges being implemented. Engineered gravity discharges were a result of a need for cost saving, and actions being taken from assessments of mine water management in parts of the UK. Throughout the 2010's the remaining operational mines ceased pumping, and the Coal Authority added a few additional sites to continue to manage rising mine water.

Table 1 Types of Coal Authority mine water management (1994 to 2023).

Year	Pumped (untreated discharge)	Pumped (treated discharge)	Coal Authority engineered gravity discharge	Sites ceased pumping since previous date	Pumped by underground mine operator
1994	10	1	1	0	17
2004	5	15	2	6	8
2014	3	20	3	8	1
2023	4	21	4	1	0

Note that some operator pumping sites transferred to the Coal Authority for pumping, either a continuation, or at a later date

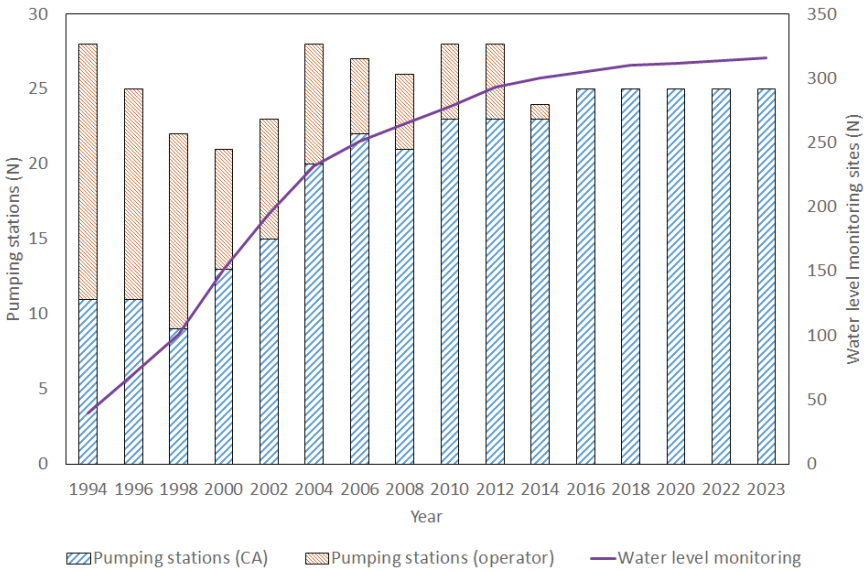

Figure 1 Graph of coal mine water pumping stations in the UK 1994 to 2023. (note there are 548 water level monitoring points across 316 water level sites)

Methodology of progressing mine water management in the UK

In terms of coal mine water management, the Coal Authority work alongside environmental regulators to prevent new pollution, and where feasible to remediate existing pollution. The ethos of the Coal Authority is to promote efficient and sustainable methods for mine water management.

Since 1994, the main aspects that the Coal Authority have adapted to coal mine water management are:

1. Reduce pumping where feasible, yet manage the risks associated with mine water
2. Cease pumping where feasible, and manage the risks associated with mine water
3. Set appropriate pumping control bands to allow for flexibility, whilst managing risks associated with mine water
4. Plan for future mine water management needs and new sites
5. Plan for future changes to existing mine water management strategy
6. Identify possible benefits from mine water management
7. Adapt to changes and requirements for mine water management
8. Evaluate existing mine water management systems

Throughout the early stages of the Coal Authority and mine water management in the 1990s, the main focus was continued pumping at existing sites; followed by strategic reduction in the numbers of pumping stations and centralisation of pumping at fewer locations within each mine water block. Typically this approach was achieved through evaluation of the most appropriate site, based on aspects such as existing pumping infrastructure and site locations for controlling mine water across the area. Much of the early progress in the 1990s was made based on studies done by British Coal (nationalised mining operator until 1994) or other similar bodies, and through pumping and recovery testing (fairly short-term) across different sites.

In the 1990s very little pumped mine water was treated, at best treatment was partial, using settlement ponds. Throughout the later 1990s and into the 2000s, it was recognised that pumped mine water, should be treated where feasible. In 1994, they were a total of 28 coal mine water pumping stations, with only one of them being partially treated. Currently, in 2023 there are 25 coal mine water pumping stations and 21 of them are treated, primarily by passive means. Since 1994, pumping had ceased at some sites, and there have been an extra 3 engineered gravity discharges locations (fig. 2), of which one of those is treated. The ones where treatment is not undertaken have been assessed and are thought to not be beneficial for treatment on the basis they cause very little pollution, and / or are within loading based discharge consents.

Continuing in to the 2000s, regional-scale mine water studies were undertaken to identify the risks of rising mine water to the surrounding environment, including likely timescales and scale of potential risk. Where required, additional studies focussed on areas specifically at risk, and areas where mine water management and treatment could be undertaken. At that time, limited assessment of cost-benefit or long-term sustainability was undertaken.

In certain instances, water level control bands were determined before pumping was started, the bands were based on conservative estimates of mine water gradients. The Coal Authority continues to take a conservative approach to estimated mine water recovery predictions, though the accuracy of predictions is constantly improving as the long-term monitoring dataset grows and the understanding of system behaviours develops.

Through the early parts of the 2010s, the Coal Authority mine water management approach was based on mine water studies undertaken in the 1990s/2000s. Despite limited resources in the Coal Authority the interpretation of monitoring data to inform on the performance of mine water management activities and to plan future interventions was done in-house. To add further challenge to the mine water management approach around

Figure 2 *Photographs of Page Bank, former pumping station left, and gravity discharge right*

this time, much of the operational and early Coal Authority mine water management experience was being lost to retirement.

During the 2010s and 2020s the Coal Authority developed the following process / steps for mine water management.

At existing pumping stations

Determine mine water control bands based type of mine system, mine water gradients between the pumping station and risk area, and long-term monitoring data from a network of water level monitoring sites. The Coal Authority currently use the following control band levels for pumping stations:

a. Overflow / discharge Level: Water level at the pumping station must be kept below this level. Likely or known decant point from the mine workings to the surface or aquifer
b. High Level: Water level at the pumping station needs to be kept below this level. Used as a buffer between this and the Decant level, a pumping station should not go above this level. Buffer based on observed or estimated values for recovery time during pump outages / no pumping
c. Control Level: Water level at the pumping station should be kept to, this allows a for pump maintenance and some flexibility for scheme maintenance and planned pump down-time
d. Too Low Level: The water level should be kept above this level, and ideally it should not go too far below it. This is used to maximise pump efficiency for the chosen pump

Pumping control levels are reviewed on a regular basis to confirm if the control levels are correct, or if they need amending.

Coalfield strategy documents are undertaken and / or reviewed to confirm if the mine water management system for a coalfield, or mine water block is correct, or if it can be improved. A coalfield strategy document can also look at future needs within the block.

Regular liaison and working partnerships with regulator and other key stakeholders confirm if the mine water level management is appropriate, and if any changes are needed.

At future areas requiring pumping (rising mine water areas)

Undertake a coalfield strategy study to review any existing data and reports. The coalfield strategy document will highlight expected timescales of any rising mine water, along with a high-level review of associated potential risks. The coalfield strategy will also help to identify a strategy for future mine water management, and also some future requirements such as pumping tests. The document will also highlight key stakeholders that may be involved or included as a project progresses, typically these will include regulator and water companies, and other internal departments at the Coal Authority.

An enhanced coalfield strategy is used to build upon a coalfield strategy, where it is required. Such a study will also review mining information to determine an initial conceptual model, or improve any existing model. The study will also help to determine appropriate location(s) for mine water management along with gaps in understanding, and where future monitoring can be focussed.

Due to previous experience and lessons learned about predicting mine water flow rates and mine water quality (Wyatt *et al* 2013), the Coal Authority will look to obtain this data from pumping tests. The pumping tests undertaken by the Coal Authority can be variable, and in some instances a site can have multiple parts. To help in the assessment of a site for pumping and along with assessment of mine water risks, the Coal Authority would undertake a selection of the following:

1. Electrical conductivity-temperature profiling, along with grab samples from shafts and boreholes are considered to be representative of potential mine water risks. These may be undertaken at regular intervals throughout the life of a project, and may also be used to continually assess mine water management (Wyatt *et al*, 2021)
2. Purge-test. A short duration pumping test, used to remove the water column within a borehole or shaft, and to obtain water quality data from a purged system In an ideal situation, the purge should be done

until a constant electrical conductivity, although given the nature of the mine system, this may not be achieved in a reasonable time frame.

3. Short-term pumping test: Typically 3 to 6 months long though sometimes shorter. These are used as an initial test to confirm whether further work is needed ahead of future tests. Typically used to establish scale of treatment required during a future longer duration pumping test. In some instances partial treatment may be required. The short-term pumping test is usually at a lower abstraction rate than full scale testing. Often half the estimated full test abstraction requirement is sufficient.
4. Long-term pumping test: Typically these are more than 6 months and may be several years duration. Such a test may require partial or full treatment of the mine water prior to discharge. A long-term pumping test will help improve refine assessments made from shorter-term pumping tests. A long-term pumping test is often required to confirm if a mine system can be fully controlled by the site and for a full range of likely flow rates and water quality.
5. Assessment of any water treatment requirements for pumping tests – based on conservative estimates of water quality and receiving water-courses for dilution and impacts. Done working with the regulators to progress a feasible and viable solution.

Throughout different stages of the process for future mine water management, the Coal Authority will have regular liaison with the regulator and other key stakeholders. These are to confirm things like mine water treatment requirements, appropriate time scales for a pumping test, and other potential benefits of a pumping test.

Conclusions and discussions

Throughout the past 30 years, the Coal Authority have made changes to the way mine water management is undertaken. Improvements have been made in to how water is managed, and the efficiency of mine water management. Improvements have also been made in respect to requirements and desire to treat mine water where applicable and to cause minimal pollution from mine water management. It should be recognised that future changes to current mine water management strategies are likely to occur.

Future issues, challenges, and benefits to mine water management are already being researched and investigated, and include possibilities of improved mine heat schemes (not to duplicate pumping mine water); groundwater flooding; inland saline mine water concerns; better utilising the mine water (such as grey water and for irrigation).

Within a complex mine system, where there are unknowns about the mine system and mine water data, there are ongoing issues, which current mine water management strategies cannot prevent. Primarily, such instances would be issues such as sudden releases of mine water to the environment, or future changes to underground mine water flow paths.

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