Adaptive mine water treatment: modelling to long-term management

Lee Malcolm Wyatt, Arabella Mary Louise Moorhouse, Ian Andrew Watson

Coal Authority, 200 Lichfield Lane, Mansfield, Nottinghamshire, NG18 4RG, United Kingdom
leewyatt@coal.gov.uk

Abstract

Following the closure of coal mines in the UK, and since its inception in 1994, the Coal Authority manages mine waters in the coalfields of Great Britain. Often the mine water is controlled and treated to either prevent new discharges occurring, or to remediate existing pollution. This paper describes how changes in mine water quality and differences to predicted scenarios result in an adaptive long-term approach to mine water treatment. It gives two case study examples of how mine water treatment schemes have, and continue to adapt to, changes in mine water and the development of new technologies.

Keywords: Mine water, adaptive treatment, long-term management, coal mining

Introduction

Mine water chemistry from abandoned mines in the UK is of variable quality. In most areas, multiple mines and seams form a complex mining system, which can contain mine waters with different chemical characteristics. In contrast to other countries, the mine water in the UK is predominantly net-alkaline or circum-neutral, with iron concentrations ranging from <1mg/L to >200mg/L. The geology and the depths of the mine workings also results in variable salinity throughout the UK, with chloride concentrations ranging between <20mg/L and >20,000mg/L.

In some instances, predictions of mine water quality have been required prior to designing and building treatment schemes. Generally the predictions of chemistry are based on first-flush phenomena and sulfur content of the coal (e.g. Younger, 2000 and Banks, 2004). Over time, however, mine water quality often changes, and this can result in a reappraisal of the most appropriate and cost beneficial treatment methodology.

In addition to mine water quality changing naturally over time, underground changes in mining systems can also result in abrupt changes to the mine water chemistry and/ or quantity. For example, a collapse of a roadway may not only result in a diversion of the flow pathways in the mine system, but may also allow mine waters with differing water chemistry to mix, thereby changing the characteristic of the mine water. Such instances are rare, but the impacts can suddenly manifest at a treatment scheme and can necessitate prompt action, with the possibility of leading to a permanent change in water treatment.

Since 1994, the Coal Authority has amended a number of treatment systems to reflect changes in mine water quality and quantity. This paper presents two examples of how treatment schemes have been impacted by changes to the mine water occurring naturally over time.

Case study 1: Blenkinsopp (multiple changes to treatment)

Blenkinsopp is the collective name for a small group of mines (total area of 5km^2) located in Northumberland (northeast England), south of Hadrian's Wall World Heritage Site. The mines solely worked the Little Limestone coal seam and were abandoned in 2002. Following abandonment of the mines, it was predicted that iron-rich mine water would discharge via the shaft and former treatment ponds to the nearby river, the Tipalt Burn (flows to the River South Tyne 3km to the east) by April 2005 (Younger, 2003). Predictions of the mine water chemistry were also undertaken by Younger (2003 and 2004) to assess the initial quality of the mine water and how this could change over time.

Initial Predictions

Initial predictions of the mine water quality (Younger, 2003 and 2004) were made using a combination of: previous pumped data; water chemistry data collected within the mine (during operation); geological data (e.g. information on the local geology and sulfur content within the coal); the type of mining employed in the area; and comparisons with other similar coal mines located in the region. Based on a review of this information, Younger (2003 and 2004), predicated that the initial (first flush) of mine water would likely be net-acidic (pH ≈3.5), with an iron concentration in the region of 300mg/L, reducing to ≈100 mg/L (with an increase in pH ≈6) after a few weeks following decant.

It was expected that the first flush mine water would be net-acidic, due to pyrite content in strata overlying the coal seam. The majority of the first flush mine water was predicted to be sourced from the older, upper pillar and stall workings. The presence of limestone goaf above the later, deeper longwall workings was predicted to provide sufficient buffering capacity to generate net-alkaline mine water. Over time, and following rebound, this net-alkaline water would mix with the net-acidic waters, eventually neutralising the acidity to allow a net-alkaline mine water to reach surface. Using the behaviour of water recovery at geologically similar nearby mines as a proxy, the long-term discharge was therefore expected to become net-alkaline with an iron concentration in the region of 14mg/L. The estimated timeframes given for this improvement in water quality was predicted to take between 7 and 11 years.

In addition to water chemistry predictions, future flow rates were also estimated for Blenkinsopp by Younger (2003 and 2004). It was estimated that flow rates would be in the order of 21L/s, with some seasonal variation (18L/s in the summer and 24L/s in the winter). These predications were made using a number of factors including: observed makes of water (from the Smallburn Shaft, main sump pumps and Wrytree dip pump); pumping quantities during mining; loss of head-dependant flows; and comparisons with other similar coal mines located in the area.

Observed Conditions

Pumping eventually commenced on 18th January 2005, at a flow rate of 14L/s, later reduced to 10L/s. Predictions made by Younger and Thorn (2006), suggested that overflow of the mine water would have occurred in March 2005 had pumping not started; which was very close to the date predicted by Younger (2003 and 2004). The actual mean pumped flow rate from 2010 to 2018 has been 25L/s. This is similar to the predictions made in 2003, with the minor difference likely due to the water being pumped water in contrast to the predicted gravity overflow conditions. Thus, the predictions made in 2003, for rebound and flow rate, can be regarded as accurate.

Conversely, the same cannot be said for predictions of chemistry, which transpired to be more challenging than expected. While the pH of the water was slightly less acidic to that predicted (the modal average over the first year of pumping was pH4.5), the initial iron concentrations were >1,000mg/L, over three times higher than the expected 300mg/L. With the majority of the iron being present in the ferrous form (typically 98%), the passive treatment scheme was inadequate to treat the mine water to meet the required design limit of 5mg/L, despite the initially low flow rate. Consequently, an active High Density Sludge (HDS) plant, using sodium hydroxide (25%) had to be installed at the site; this remained operational until 2008 due to sustained elevated (>200mg/L) iron concentrations.

In 2003, it was predicted that the mine water quality would improve over time (iron concentrations in the region of 14 to 30mg/L), with an estimated timeframe of 7 to 11 years. After 13 years of operation however, the iron concentrations remain higher than the estimates. Since the start of 2017, total iron concentrations generally range between 70 – 100mg/L, with ferrous iron continuing to account for the greater proportion (97%) of the iron in the mine water. The alkalinity of the mine water has improved however, with a mean concentration of 180mg/L (expressed as CaCO3) recorded since 2017, combined with a circum-neutral pH ranging between 6.0 and 6.5. Although this decrease in iron

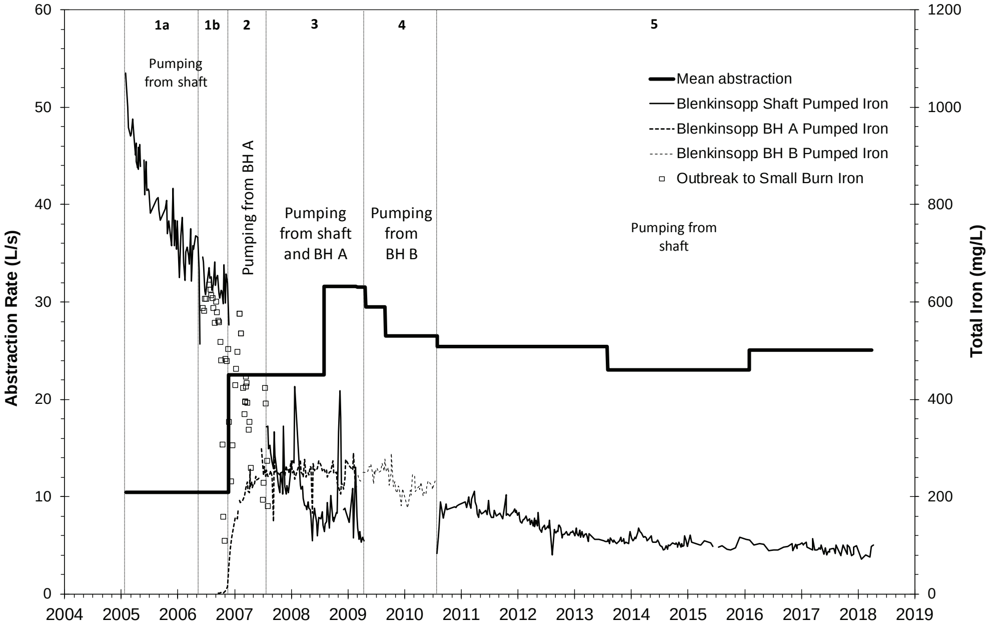

__Figure 1__ Trends in iron and pumping at Blenkinsopp from 2004 to 2018

and increase alkalinity has been more gradual than expected, it has allowed the treatment of the mine water to evolve over time as a result. The trends in iron concentrations and changes in pumping are shown in Fig. 1.

Following the decommissioning of the HDS plant in 2008 (when iron concentrations were generally <200mg/L), semi-passive treatment was used. An overview of the changes to the treatment methodology is shown below. The greatest change has been in recent years however, with the cessation of chemical dosing in 2015. This has resulted in the scheme operating passively for this first time since commissioning in 2005, whilst continuing to comply with its environmental permit (5mg/L total iron and 2mg/L dissolved iron).

An overview of the various changes to have taken place at Blenkinsopp in terms of both the pumping arrangement and treatment of the mine water treatment are as follows:

- 2005 to 2008: Temporary HDS plant, with addition of sodium hydroxide (25%).
- 2006: Pumping borehole (BHA) constructed and operational.
- 2008: Mine water treated semi-passively using the initial scheme, which comprised: Newton aerator; mixing channel, settlement ponds and aerobic wetland augmented with chemical dosing using sodium hydroxide (25%) added in to the mixing channel.
- 2009: Pumping borehole (BHB) constructed and operational.
- 2011: Ochre sludge drying bed added to the scheme.
- 2012: Temporary aeration cascade added after Newton aerator, new longer dosing channel added, with ongoing chemical dosing using sodium hydroxide (25%).
- 2014: New conventional stepped aeration cascade replaced the Newton aerator and temporary cascade.
- 2015: Cessation of chemical dosing, and use of passive treatment.

In summary, when comparing the predictions made for Blenkinsopp, with reality, the following conclusions can be made:

- estimated date of potential uncontrolled discharge was accurate.
- predicted flow rates for a gravity discharge are only fractionally lower than the abstraction rate typically employed in 2018.
- net-acidic nature of the first flush of mine water was predicted.

- modelled mine water chemistry underestimated the iron-concentration by a factor of 3, resulting in requirement for a temporary HDS plant.
- longevity of the iron concentration was under-estimated by a factor of between 2 and 5, requiring longer-term use of chemical dosing.
- initial treatment required use of HDS plant and not the intended passive treatment
- quantities of chemicals used decreased and ceased, and passive treatment was enhanced, but on a much longer timescale than anticipated.

Case study 2: Horden (active to passive treatment)

Horden is located in County Durham (northeast England) on the Durham Heritage Coast; mining in the area ceased in 1992. It forms part of a complex mining block (area of >165km^2), which contains numerous interconnected collieries that worked multiple seams, and includes exposed and concealed Coal Measures; in addition to some offshore workings. Mine water is pumped at Horden in conjunction with the nearby Dawdon active treatment plant, located in the same mining block, to prevent pollution of a regionally important drinking water aquifer (the Raisby Formation [Magnesian Limestone]) in the overlying Permian strata.

After mining and pumping in the area ceased in 1990's, it was identified in the early 2000's, that there was a threat to the aquifer from the rising mine water. In order to provide time to investigate and confirm longer-term pumping strategies to protect this regionally important water supply, pumping was initially resumed at Horden in 2003; this slowed the rate of the rising mine water in the area. As a result of the mine water quality and short timeframe available to deploy an alternative system, the initial treatment at Horden was a temporary HDS plant, to remove the iron. Active treatment was initially chosen for this site due to the reliability of the technology, its versatility in treating a range in iron concentrations, expected during first flush, and salinity conditions, and its ability to comply with a discharge permit of 10mg/L total iron. Following the construction of a permanent active treatment plant at Dawdon, which controls the water levels in the northern area of the mining block, the active treatment system at Horden was replaced by a more sustainable passive system; this became operational in 2011. A reduction in abstraction flow rates at Horden (due to pumping at Dawdon from 2009), with reductions in iron (<150 to ≈75mg/L by 2010) and chloride concentrations (≈30,000 to <15,000mg/L), enabled a passive treatment system to be built. Today, the passive system is treating ≈60mg/L of iron to comply with a revised (as of 2015) loading based permit of 173kg/day; this scheme discharges directly to the North Sea via an outfall pipe. A challenge to the use of conventional passive treatment methods at Horden however, is the elevated salinity of the mine water. These conditions therefore required modelling before a passive scheme could be constructed, to ascertain if the mine water salinity would be acceptable for conventional polishing wetlands.

Initial Predictions

Analysis of shaft samples and pumping data collected during mining, showed high chloride concentrations (>20,000mg/L) were likely in the mine water at Horden. Geochemical modelling was therefore undertaken using the methods described in Waterchem (2007). The modelled results predicted that chloride concentrations at Horden would initially rise from <5,000mg/L, to typical values ranging between 25,000 and 45,000mg/L; taking between 2 and 15 years to reach a peak. Following this, it was predicted that the chloride concentrations would decrease and reach concentrations between 15,000 and 25,000mg/L after a period of 25 to 30 years.

During the feasibility stages of the Horden and Dawdon long-term treatment options, the tolerance to chloride for the various types of reeds typically used in wetlands (e.g. *Phragmites australis* or Common reed) was tested. Initial estimates for an upper limit of 5000mg/L chloride were given for the reeds; although this was later revised to 10,000mg/L. Information presented in Batty (2003) quotes concentrations of up to 20,000mg/L for *P. australis* and *Typha latifolia* (Reed-mace), but suggests that normal growth for *P. australis* is up to 10,000mg/L. Both these species are commonly used for mine water treatment in the UK, with *P. australis* used at Horden.

Observed Conditions

Chloride data collected throughout the operation of the active and passive treatment schemes, in addition with pumping information, are shown on Fig. 2. In line with the predictions from the modelling, Fig. 2 shows that the peak in chloride concentration (≈30,000mg/L) occurred in 2008, after four years of pumping. This timescale is on the shorter end of the estimate, but still falls within the timescales of 2 – 25 years suggested by the model. Furthermore, the peak chloride concentration also fell within the mid-range of concentrations predicted by the model. Following the peak concentration, a gradual decrease in chloride concentrations was observed, to approximately 17,000mg/L. A further stepped decrease in chloride concentrations occurred in 2009, when abstraction rates at Horden were reduced as the Dawdon active plant came online. Since 2009, the chloride concentration at Horden has varied between 5,000 and 15,000mg/L. This variation is influenced by changes in the pumping rate at Horden.

Based on the modelled and observed chloride concentrations recorded at Horden (Fig. 2), during the operation of the active treatment system, it was concluded that the mine water could be treated passively by aeration cascade; settlement lagoons; and aerobic reed bed wetlands. However, it would be necessary to maintain the chloride concentrations, ideally below 10,000mg/L to protect the reeds in the wetlands. The mine water in this region is stratified, with hyper-saline waters being present at depth. If abstraction rates at Horden exceed 50L/s, there is a risk that the hyper-saline waters are extracted at the site. Consequently, pumping at Horden is limited to ≈50L/s. As can be seen in Fig.2, the abstraction rate at Horden is operating near to this level, which at times results is waters >10,000mg/L chloride being treated by the scheme. The total amount of water required to be pumped in the mining block to protect the aquifer is 100 to 150L/s. Hence, there is a need to pump the additional flows at the active Dawdon plant.

In summary, when comparing the predictions made for Horden with reality, the following conclusions can be made:

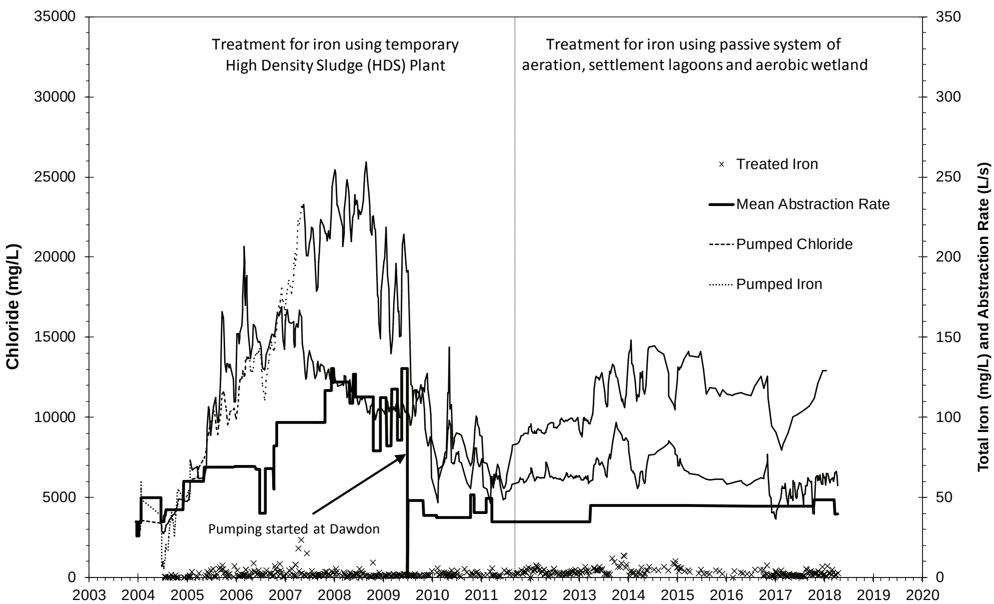

Figure 2 *Trends in iron, chloride and pumping at Horden from 2003 to 2018*

- long-term plan was to abstract and treat mine water at both Horden and Dawdon
- initial treatment required a temporary HDS plant to remove iron from the saline water
- long-term modelled chloride concentrations (>20,000mg/L) were greater than those observed, and the timescales to achieve these lower concentrations was shorter (5 years instead of >20 years)
- observed peak chloride concentration fell within the suggested range and was attained within the timescales predicted
- modelling showed chloride concentration at Horden would eventually reduce to levels close to those acceptable for passive treatment technology
- active treatment switched to passive treatment in 2011, although the reeds do struggle with the higher chloride concentrations
- strict controls of pumping between Horden and Dawdon are needed to reduce chloride and iron loading at Horden

Summary

Prediction of mine water quality and flow rates has proven difficult within complex mine systems in the UK. Modelling of chemistry and mine water flows can provide a high level overview of water quality (e.g. high-iron, low-iron, high-salinity). However, extra information from pumping tests and long-term monitoring is required to assess more accurately how the mine water changes under different conditions, and also how mine water treatment needs to be adapted to these changes. Furthermore, developments in mine water treatment technologies also need to be considered when assessing the potential for evolution of a mine water treatment scheme. For long-term mine water management, all these aspects need to be considered holistically, and where possible, it is advantageous if any future potential changes to treatment are accommodated at, or in, an existing treatment scheme.

References

Banks D (2004) Geochemical processes controlling minewater pollution. In Proceedings of the 2nd IMAGE-TRAIN Advanced Study Course. Groundwater management in mining areas, p 17–44

Batty LC (2003) Effect of salinity on the growth of wetland macrophytes. Prepared for the Coal Authority

Waterchem (2007) Optimization of mine water discharge by monitoring and modelling of geochemical processes and development of measures to protect aquifer and active mining areas from mine water contamination (Waterchem). Research Fund for Coal and Steel RFC-CR-03006, Technical report no.7

Younger PL (2000) Predicting temporal changes in iron concentrations in groundwaters flowing from abandoned deep mines: a first approximation. J. of Contaminant Hydrology 44: 47–69

Younger PL (2003) Report on mine water rebound and likely post-rebound water quality at Blenkinsopp Colliery, Northumberland. Prepared for WS Atkins Consultants Ltd on behalf of the Coal Authority.

Younger PL (2004) Acidic leachate, limestone goaf: hydrogeochemical observations and predictions for remediation planning at Blenkinsopp Colliery, Northumberland (UK). In Young RN and Thomas HR (Eds) Geoenvironmental engineering – Integrated management of groundwater and contaminated land. Proceedings of the 4th conference of the Geotechnical Association, 28-30 June 2004, pp 367–374

Younger PL, Thorn P (2006) Predictions and reality: Generation of strongly net-acidic mine waters through flooding of underground coal mine workings with limestone roof strata, Blenkinsopp Colliery (Northumberland, UK). 7th ICARD March 26-30, 2006, pp2542–2557