MANAGING MINEWATER IN ABANDONED COALFIELDS USING ENGINEERED GRAVITY DISCHARGES

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Abstract
Historically, dewatering adits were engineered by the mining industry to manage mine water cost effectively. A different challenge now faces those tasked with managing mine water from abandoned workings in an environmentally sustainable and cost effective manner. Commonly, pumping has to be employed to provide environmental benefits. Modern engineered gravity discharges provide an alternative to ongoing pumping, and can allow the discharge location to be moved significant distances to a preferred location. Another location may be better suited for managing the mine water if more land is available for passive treatment, or if a dilution and dispersion strategy can be implemented. Two innovative case studies which have been commissioned recently by the UK Coal Authority are summarised here. Engineered gravity discharges have potential to form an important tool in achieving sustainable management of abandoned mine waters.

Introduction
The management of water in mines has been a challenge throughout history, both whilst mines were operational and after abandonment. The historical construction of sometimes very extensive dewatering adit systems to underdrain mining areas is well known (Younger, 2002). These adits can induce regional lowering of the water table, greatly increasing the volume of minerals which can be extracted without needing pumping. The benefits were that the need for dewatering by pumping was reduced, since the engineered adits allowed the mine water to flow out by gravity. During mineral extraction the economics of de-watering, either by driving significant dewatering adits, or by pumping, was limited by the value of the extracted mineral.
Following abandonment of the mines, there generally ceases to be an economic reason to continue pumping. Exceptions might be that the water is used as a resource or coal mine methane extraction is to occur, or there is a heritage, or tourism benefit to the pumping. More often, the reason for continued pumping may be limited to providing environmental protection, for example through pump and treat schemes. In the UK the Coal Authority (CA) manages the legacy of abandoned coal mines and associated minewater issues. At the start of 2007 the Coal Authority actively manages mine water at 52 sites to provide environmental benefits. Table 1 shows the current split of Coal Authority managed sites.

Table1. Coal Authority sites categorised by type of water management and treatment.

Water managed by:	Number	Treatment Type	Number	Costs
Gravity	15	Dilution & Dispersion	9	Low
Engineered Gravity	6	Passive	32	↓
Transfer Pumped	14	Active	11	↓
Deep Pumped	17			High

"Gravity" fed sites are where the mine water is simply collected at the point of issue, e.g. historical dewatering adit, or overflowing shaft, and flows down to the treatment facility. An "engineered gravity" discharge is here distinguished as a site where a new engineering solution has been recently implemented to allow a gravity discharge. It is noted that historical de-watering adits were also engineered, but the classification here is intended to highlight recent examples. "Transfer pumped" water is where the gravity flow cannot be directed onto a suitable treatment area, so it is collected in a pumping sump at the point of issue and transferred via pipe ranges to the treatment area. "Deep pumped" water is abstracted from the abandoned workings via pumps in open shafts or large diameter boreholes. Many of the Coal Authority's deep pumped sites have pumped continuously since the abandonment of coalfields in order to achieve a controlled recovery without surface discharges. Other deep pumped sites have been established over the last decade in order to prevent new pollution occurring as recovery approaches surface discharge levels. It is noted that the source of many minewater discharges is from old dewatering adits which were historically installed to the lowest available topographical level, which minimised the cost of water management during mine operation. An unfortunate result of this is that many current discharges are located in the bottom of steep valleys, so the water cannot be gravity fed to a treatment scheme, and requires transfer pumping. Thus, in order to treat the minewater to comply with modern environmental expectations and legislation, water now has to be pumped where it was allowed to gravitate freely in the past.

Dilution and Dispersion effectively means that the minewater is discharged without formal treatment, and reliance is placed upon the receiving watercourse having enough capacity to dilute and disperse the potential contaminants to less than relevant environmental quality standards within an acceptable distance. Passive treatment is a mixture of aeration, settlement lagoons, and reedbeds principally removing the iron loading in the minewater. Active treatment implies the addition of chemicals to facilitate the treatment process. Most of the dilute and disperse schemes are deep pumping stations which have operated for 50 years or more and have never had treatment added. However, the environmental impact of these is reviewed by the UK regulators, Environment Agency, EA, in England and Wales and Scottish Environmental Protection Agency, SEPA. For example, as controlled recovery proceeded at Kibblesworth pumping station near Newcastle, England, the water quality deteriorated sufficiently that it was worth commissioning the new Lamesley passive treatment site in 2006. Implementing new dilute and disperse schemes is the cheapest long term strategy for the Coal Authority, since there is little maintenance and no ochreous sludge waste to dispose of on a recurring basis. However, experience has shown that there are relatively few sites where this treatment is acceptable.
The Coal Authority is tasked with commissioning treatment schemes for over 100 further prioritised discharge sites. As such, it will be important to seek the lowest cost solutions wherever possible. The preferred solution to providing environmental benefit at minimal ongoing cost is a gravity fed scheme with no formal treatment other than dilution and dispersion by the receiving watercourse. As briefly illustrated above, this is not always possible. However, opportunities have recently been exploited to engineer new gravity discharges where the alternative might be a pumped solution. This paper illustrates two case studies of engineered gravity discharges implemented and operated by the Coal Authority in the UK for a sustainable management of minewater.

Case Study: Glyncastle, Resolven, Neath Valley, Wales

The coal mine at Glyncastle (National Grid Reference SN834028) in the South Wales coalfield was abandoned in the late 1800's. The Tyn-y-cwm drainage adit dewatered the workings in the No 1 Rhondda seam to the level of the valley floor. Minewater flowed from the adit until the 1980's when the adit became blocked, possibly by a roof collapse which propagated to the surface as a crown hole. The minewater then backed up within the workings, and began to overflow out of the crown hole and also an old air shaft some 400 m away. Most of the flow was from the air shaft into the Clydach Brook which became contaminated for 1 km up to its confluence with the River Neath which has much more capacity for dilution. The remaining flow was from the crown hole with some residual seepage from the blocked adit. The Local Authority tried to unblock the adit, but this resulted in a sudden, hazardous pressurised release of slurry, a "blow-out" from the adit mouth. A grout plug was then installed in the adit mouth to prevent further blow-outs. The general situation is illustrated in Figure 1.
In the 1990's the site was prioritised for remediation by the EA, and CA looked at feasible options. A suitable area for treatment was available at the original adit discharge location, but the Clydach brook is a steeply incised valley with no suitable treatment land and no vehicular access. It did not appear practical or cost effective to transfer the mine water overland from the air shaft discharge to the treatment area due to steep topography and multiple landowners en route. A borehole was drilled into the workings near the internal end of the adit. A pump test showed that the discharges dried up within hours. This proved hydraulic connectivity was still very good within the workings behind the crown hole collapse blockage. Thus, the option was available to create a pumped scheme using the borehole to pump minewater out of the workings and down to the treatment area. However, the associated on-going pumping costs were not attractive. Thus, CA decided to install a new engineered gravity discharge, which would in effect do the same dewatering job as the adit performed historically. The strategy was not without risk of failure, but the potential benefits were obvious. Two directionally drilled, horizontal boreholes were drilled and lined entering the adit floor 75 m in from the mouth. The practicalities of the drilling meant that the unfractured rock below the adit floor was the preferred route. In order to remove the difficulty of drilling against a significant head of water, the minewater was pumped out of the existing vertical borehole during the drilling operation. Valves were fitted at the end of the twin pipes to control the discharge rate. In order to maintain the pipes into the future bespoke cleaning equipment was purchased. The new treatment site was commissioned at the end of 2005. The engineered gravity discharge successfully feeds the minewater into the new passive treatment scheme consisting of aeration, two settlement lagoons and three reedbeds (Atkins, 2006). The treated water discharges directly to the River Neath, with the result that the Clydach Brook is remediated. The site has been monitored throughout 2006 (Fig. 2) with the following observations. Initially with high water pressure and high Winter flows, there were some events where significant amounts of ochreous and shaley material came out of the pipes. However, with time the flow appears to have stabilised around 10 l/s, and the workings have been dewatered so there is less head acting on the pipes. The iron concentration is between 20 and 30 mg/l, such that the flow and quality of the minewater is now similar to the former combined flow from the air shaft and the crown hole. The innovative application of the drilling led to Glyncastle being awarded as winner of the New Installation – Small Project category by the UK Society for Trenchless Technology.

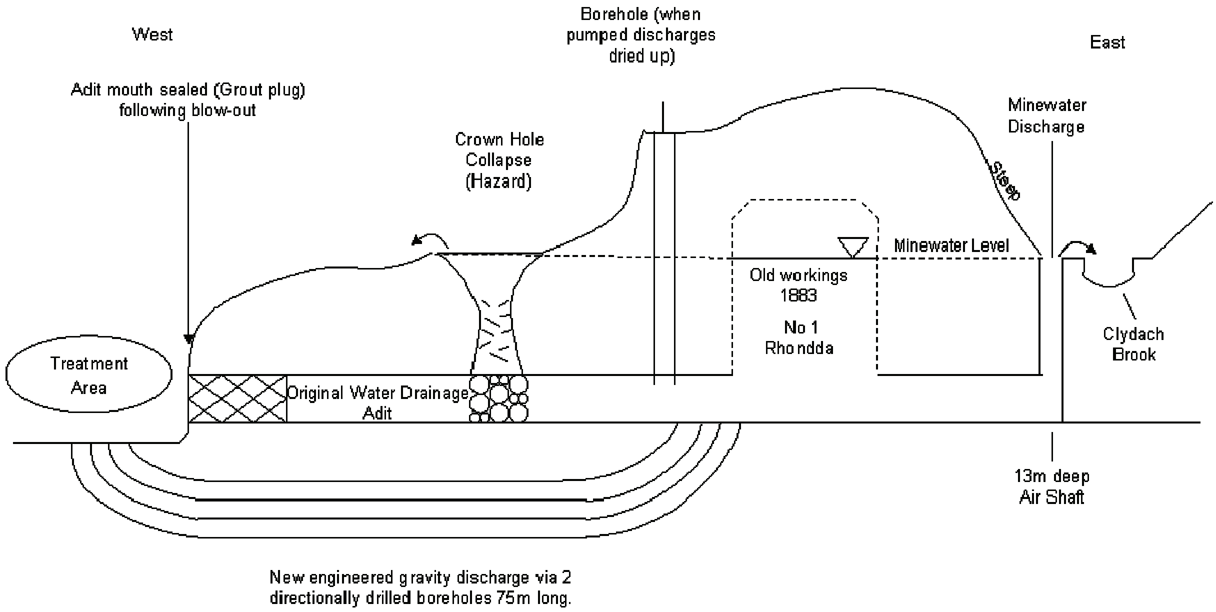

Figure 1. Schematic cross section of Glyncastle case study.

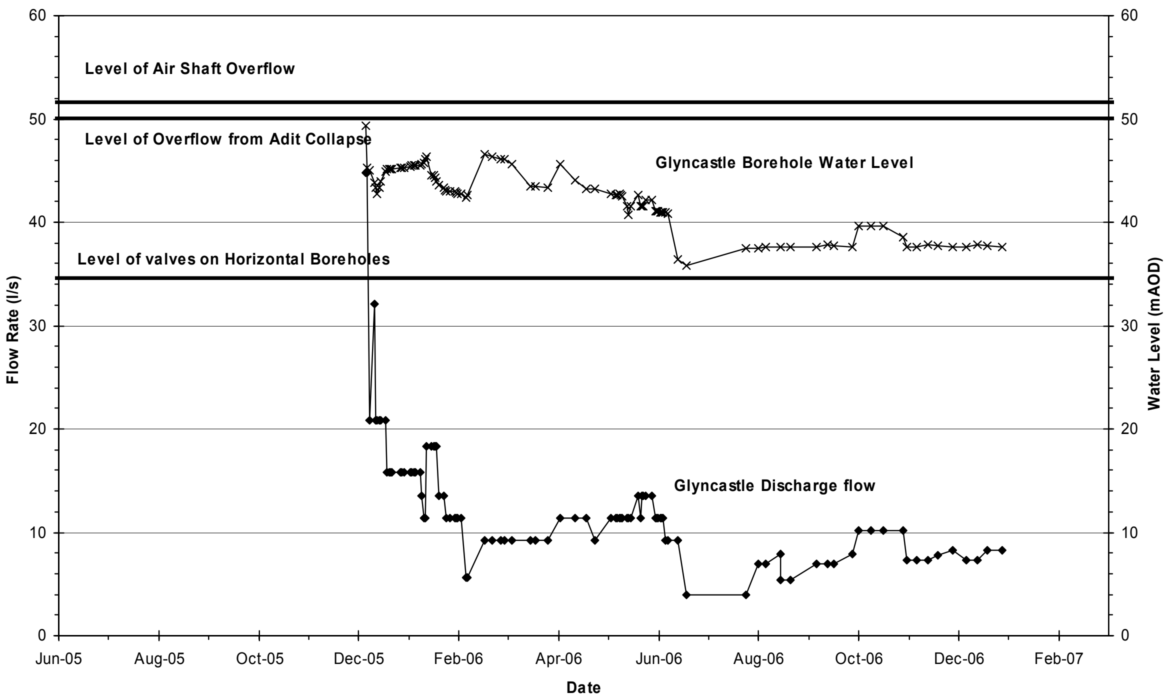

Figure 2. Flow and Water Level monitoring at Glyncastle.

Case Study: Ravenshaugh, Wallyford, Edinburgh, Scotland

This example is located on the former Wallyford coal mine complex to the east of Edinburgh in Scotland. In 2003 grouting of shallow workings along the line of the principal Edinburgh to London railway line, the East Coast Mainline (ECM), led to partial blockage of the minewater pathways. Minewater levels rose locally and Network Rail had to install pumps to prevent the ECM tracks flooding in a cutting. The minewater was discharged into the adjacent watercourse, Ravenshaugh Burn, which became contaminated with ochreous deposits for c.1 km causing concern for the regulator, SEPA. The CA investigated the problem through studying the abandonment plans and interpreting the likely regional hydraulic gradients and flow paths. The study concluded that there was a good chance that a borehole could be drilled to produce an artesian flow, and lower the minewater levels at ECM in a controlled flow test (White Young Green, 2004). The proposed vertical borehole was sited at NGR NT366732 and targeted to intercept workings in the Great Seam 220 m below ground, originally worked in 1913. As the workings were approached an expected artesian head of c.16 m was encountered, although this occurred at conjectured position of the index limestone bed around 170 m depth, which may have been worked with the coal, but is unrecorded. The artesian conditions made drilling difficult, so the borehole was completed c.30 m shallower than planned, at c.190 m depth. Comparison of the piezometric head at the new borehole and existing piezometers by ECM showed similar levels and trends (Fig. 3), suggesting reasonable hydraulic connection over the 1.0 km distance separating the two sites. The flow test commenced in July 2005 with an initial flow of 5 l/s and gave a drawdown response at ECM piezometers within one hour, although the steady state drawdown was insufficient at ECM. The flow was stepped up to around 8.5 l/s near the end of July, giving a steady drawdown of c. 2.5 m. This effectively achieved the objective of replacing the pumping activity at ECM with a new engineered gravity discharge. The previously contaminated section of the Ravenshaugh Burn was remediated.

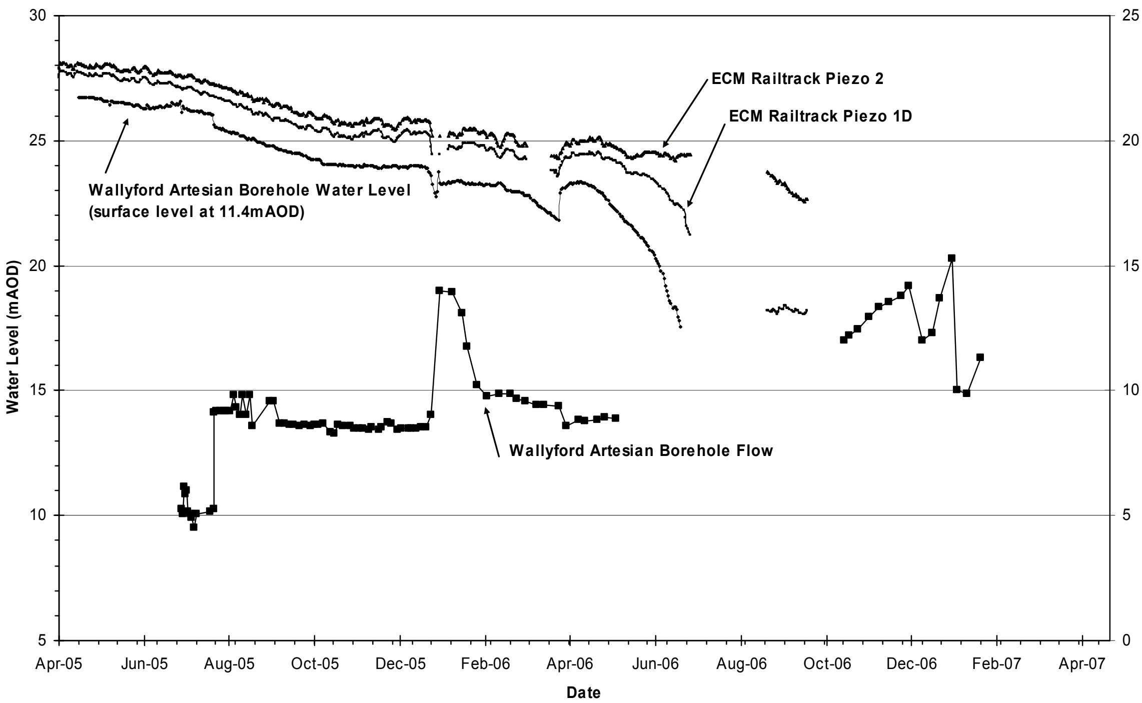

Figure 3. Flow and Level monitoring at Ravenshaugh.

The artesian borehole was sited next to the Ravenshaugh Burn near the point where it enters a culvert which is 400 m long and discharges into the Firth of Forth, a 15 km wide tidal estuary. The artesian minewater is piped directly into the culvert and is initially diluted and dispersed by the small amount of water in the Burn, and then by the large volume of water in the estuary. SEPA are monitoring the situation, and to date it appears that the dilute and disperse strategy is working well, and no impact is observed from the 50 to 100 mg/l iron in the minewater. The minewater has also been observed to have high levels of dissolved carbon dioxide, presumed to be due to reaction of the minewater with limestone strata. The degassing could have led to hazardous low oxygen atmospheres developing in poorly ventilated spaces, so the health and safety risks were addressed, for example by preventing access into the culvert where the minewater was discharging. The minewater was found to be

particularly aggressive to the borehole headworks, which may have been exacerbated by acidity due to the dissolved carbon dioxide, and also silt particles suspended in the artesian flow. Thus, in early 2006 the top of the borehole casing became corroded, and began to leak in an uncontrolled fashion. The total flow (through pipe and leak) may have exceeded 20 l/s and caused a steady dewatering of the mine workings. The repair was completed by inflating a packer in the borehole to stop the artesian flow and replacing the corroded steel casing with a section of ceramic material which should be more resistant. After the leak most of the artesian pressure at the borehole has been removed, as the borehole has effectively de-watered the block of mine workings.
The Wallyford borehole has replaced the need for ongoing pumping at ECM with associated pollution of Ravenshaugh Burn with an engineered gravity discharge which can be diluted and dispersed in the Firth of Forth.

Conclusions

The management of minewater in abandoned coalfields in the UK has a significant cost associated with it. Where possible, pumping is avoided in favour of gravity fed schemes. To date, the Coal Authority has implemented only a few engineered gravity discharges, as illustrated by the two case studies. Although the historical engineering of dewatering adits to provide gravity discharges was commonplace, the use of modern engineered gravity discharges within the context of abandoned coalfields is a relatively new challenge. The two cases given differ in their use of vertical or horizontal drilling, but the similarities are summarised as follows:
Drilling in artesian ground conditions was a significant risk in attempting these projects, and in one case could be managed by pumping from another borehole. Both cases illustrate that the minewater level can be controlled using artesian flow bores. In both cases the discharge was moved significant distances, 400 m and 1 km, which not only avoided the need for ongoing pumping, but also delivered the water to areas where cost effective treatment could be readily provided either through passive treatment or dilution and dispersion. Both the projects will need ongoing maintenance to ensure pipes flow freely, and monitoring to demonstrate that water levels are not rising again towards previous discharge points.
The two innovative case studies demonstrate that in some areas minewater in abandoned workings can be managed in a cost effective and sustainable way through the application of engineered gravity discharges. Table 1 illustrates that in the majority of cases standard gravity or pumped solutions will be required. An underlying reason why engineered gravity discharge solutions will be rare is that historical de-watering adits are already draining recovered abandoned mines to the lowest topographical level available. Despite this often fundamental issue, the Coal Authority has identified other possible applications for engineered gravity discharges. A major example is in County Durham, England, where CA is now finalising a controlled recovery exercise involving moving a >300 l/s pumping station at Vinovium to an engineered gravity discharge at Page Bank 4.3 km away, with the relatively good quality minewater (<2 mg/l Fe) being diluted and dispersed in the large River Wear. This strategy will allow the Coal Authority to decommission one of its most expensive pumping stations, and provide regional minewater management for minimal cost. It is envisaged that engineered gravity discharges will form an important tool in achieving sustainable management of abandoned mine waters.

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