Applications of pumping tests in the development of mine water management strategies and remediation schemes

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Abstract Throughout the UK, the Coal Authority has performed numerous pumping tests at abandoned mine sites, lasting between 4 weeks and 3 years. Recent tests have been undertaken at sites in both the South Derbyshire Coalfield: to determine chemistry of a saline mine water; and the Cleveland Iron Orefield: to ascertain chemistry and necessary abstraction rates of a highly ferruginous mine water. These two case studies demonstrate the importance of test pumping in the development of successful and efficient mine water management strategies and remediation schemes, reducing unnecessary risks present in predictive models.

Key Words pumping, test pumping, mine water, abstraction, mining hydrogeology

Introduction

Deep coal mining throughout the UK has taken place for several hundred years, reaching a peak during the late 19^{th} to early 20^{th} Century. Widespread closure of deep mines occurred during the latter part of the 20^{th} Century for political and economic reasons. The Coal Authority was established in 1994, following privatisation of the formerly national coal industry. From its inception it has been tasked with, amongst other duties, managing the mine water legacy of abandoned coal mines.

Since its creation, the Coal Authority (CA) has developed more than 50 mine water treatment schemes. These schemes are implemented to remediate pre-existing discharges from abandoned coal mines, in addition to preventing future pollution from rising mine waters that are resulting from cessation of active de-watering during mine operation. Treatment is provided primarily to remove iron, which otherwise precipitates as ferric (oxy)hydroxides when discharged to the surface environment, causing visual and ecological impacts (Banks *et al.* 1997). The methods of treatment vary considerably, from constructed wetlands where mine waters are of relatively good quality, to process based plants in the case of poor quality water (i.e.: net acid waters with large iron loadings) or where land area for treatment is restricted.

Many CA schemes involve the abstraction of mine water from open shafts or constructed boreholes using submersible pumps, in order to lower and control water levels within mine workings. Until establishment of long-term pumping arrangement, the water quality and necessary abstraction rate to control levels is uncertain. Estimates can be made from available desk study information and modelling, however these are often inaccurate, due to unanticipated flow paths brought about by dam failures and collapses, for example. Spot samples from monitoring boreholes have also been used to determine water quality, although it has long been known that data obtained from such discrete points often suffers stratification, localised effects and interactions (Everett 1985; Humenick *et al.* 1980; March and Lloyd 1980).

In order to resolve this problem, and ensure that mine water pump and treat schemes are developed upon robust data, the CA often commissions pumping tests which aim to simulate the predicted abstraction regime (e.g.: Barnes 2000; Nuttall *et al.* 2002). Water level data from remote monitoring boreholes and shafts is collated, any pre-existing discharges are monitored and the pumped water quality is assessed.

Case Studies

As every coalfield, orefield or isolated area of mine workings is different, both in terms of geology, hydrogeology and nature of mineral extraction; the nature and behaviour of mine waters within also varies. Therefore, bespoke design is required for each individual pumping test.

South Derbyshire Coalfield

Situated in the Midlands of England, the South Derbyshire Coalfield has a long history of open cast, outcrop and deep mining; and with good mining connections between the majority of mines it is considered an isolated hydraulic unit as outlined in figure 1. The last operational deep mine in the Coalfield, Donisthorpe, closed in 1990; with cessation of deep dewatering activities resulting in the commencement of regional mine water recovery. Monitoring data from 2006 has been collated and is shown in Figure 2.

Recovering mine water posed two key risks that were addressed in a study by IMC Ltd (2002), namely surface discharges in low lying areas and contamination of an overlying aquifer used for potable water supply. To assess these risks, the CA made improvements to its monitoring infrastruc-

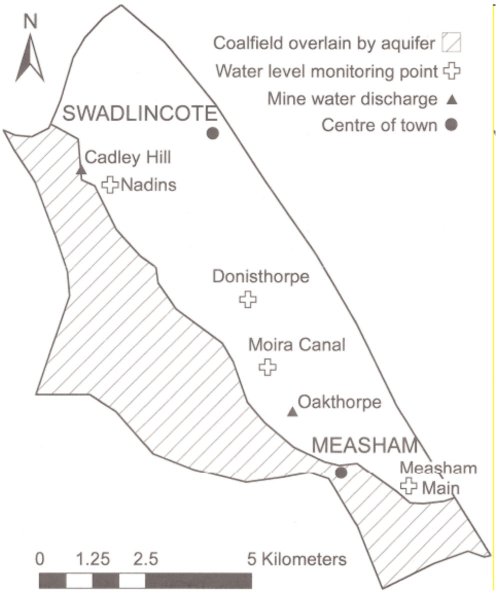

Figure 1 Sketch plan of South Derbyshire.

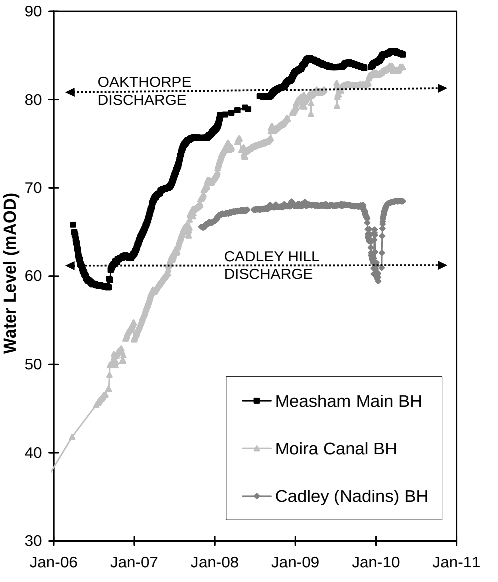

Figure 2 Mine water level recoveryCoalfield.Note lowering of water levels in Cadley HillBH during pump-test around Jan 10.

ture and proposed the development of a pump and treat scheme to the regulator (Environment Agency for England and Wales).

A subsequent report by WYG (2008) considered desk study information, in conjunction with point sampling from monitoring boreholes and newly established mine water discharges across the Coalfield. The report indicated that the mine water at the preferred Cadley Hill abstraction point contains a moderately high salinity (>1000mg/L Cl^-) and moderate iron loading (<10mg/L Fe^{2+}); however results showed significant variability between individual sites.

The lack of certainty as to water quality presented two obstacles for the development of a management strategy: treatment scheme sizing depends principally on iron loading; and salinity of treated water may restrict pump and treat site to less sensitive river catchments.

In order to determine the water quality during long-term abstraction at a proposed treatment site, a pumping test was commissioned by the CA in late 2009. This test comprised abstraction of mine water at Cadley Hill, temporary treatment to remove iron, and discharge to nearby watercourse. Temporary treatment comprised a CO_2 degassing cascade, polymer flocculent dosing and settlement within an above-ground lagoon. Throughout the duration of the test, a detail programme of monitoring was undertaken.

Cleveland Ironstone Orefield

Situated in Yorkshire, England, the Cleveland Orefield comprises a sedimentary basin in which the principal ore is siderite. The Orefield was worked largely for a single Main Seam by deep and drift mines for a period of more than 150 years. Following closure of the last mines in the area in the 1960s, de-watering pumps were turned off allowing water levels to recover. In 1999, a suspected crown hole collapse resulted in the ongoing discharge of approximately 2.5L/s of net acidic mine water with iron concentrations greater than 1000mg/L into the Saltburn Gill, causing severe ecological degradation and visual impact (Younger 2002).

A local community action group was established to tackle the problem, as unlike coal mine water discharges, no party are charged with clean up operations under UK legislation. The CA was tasked with investigating the feasibility and likely cost of developing a remediation scheme at Saltburn, on behalf of the Environment Agency that is a stakeholder on the action group. Following an earlier scoping study, the ability to collect the existing discharges for treatment had been ruled out for a number of logistical reasons, and therefore abstraction of the mine water from a remote location was considered the best approach.

Although regular sampling of the discharge had accurately characterised the water in this location, the mining hydrogeology and geochemical evolution of the water was uncertain, and therefore the water quality abstracted at a remote control point could differ. Furthermore, the ability, and necessary abstraction rate to control water levels below the discharge point from a remote site, relies upon the nature and connectivity of mining void and associated strata. Thus, once a control well and two remote observation boreholes had been established within 0.5km of the discharge, an abstraction test was duly commissioned both to demonstrate that the existing discharge may be mitigated, and to provide necessary flow rate/ contaminant loading parameters for treatment scheme design. The test design was based upon existing monitoring data and desk study information, including a review of mine plans and reports, in addition to geological data. On this basis, an abstraction capacity of up to 10L/s was considered sufficient to lower water levels below the existing discharges over a period of several months.

Results and Discussion

Results from the South Derbyshire Coalfield

Static sampling data, obtained using disposable bailers lowered into the mine workings below the Cadley Hill site, suggested that although iron concentrations were elevated (up to 42mg/L on the 10 June 09), chloride concentrations remained relatively low throughout the monitoring period (up to 186mg/L on the 16 Jan 09). The pumping test commenced at a flow rate of ≈ 5L/s, increasing incrementally to a maximum of ≈ 29L/s for the latter part of the test. Upon commencement of pumping, the water quality rapidly deteriorated, and chloride concentrations immediately rose to more than 4000mg/L, and remained steady at approximately 5000mg/L for the remainder of the test. Iron concentrations initially rose to 50.5mg/L, and then fell to around 35mg/L and remained steady. Note fluctuations in iron concentrations shown in Figure 3, which reflects intermittent pump performance during the course of the test.

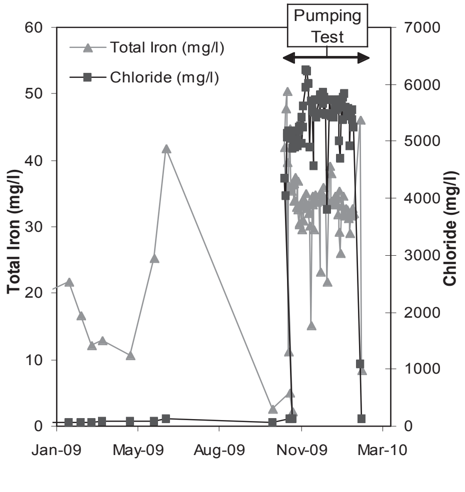

Figure 3 *Iron and chloride concentrations from static sampling of the Nadins Borehole at Cadley Hill, and sample results during pumping.*

Results from the Cleveland Orefield

Sampling results from existing discharging into the Saltburn Gill from the Cleveland Orefield characterised the water as Mg – SO_4 facies, and although had a circum-neutral pH at emergence, is actually strongly net-acidic due to iron concentrations in excess of 1000mg/L (Younger 2002). Spot water samples during 'air lift' purging of both the North Observation Borehole, North OBS BH (Plate 1) and the main abstraction borehole were found to have a very similar hydrochemical signature to that at the discharges (Entec 2009; CA sampling data).

Sampling results upon commencement of the pumping test characterised the abstracted water as Ca-SO_4 dominated, circum-neutral, net-alkaline with moderately high iron loading (up to 186mg/L, on the 17 March). This signature varies significantly from the adjacent discharge into the Saltburn Gill, and is more analogous with the larger, but better quality discharges at Skinningrove, some 3.8km away. The nature of pumped water has highly significant implications upon treatment methods; however it is also the volumes of water needed for control which influence the sizing requirements of a treatment scheme.

Initial pumping rates of ≈ 10L/s showed slow draw down rates, and increased to capacity of ≈ 15L/s for a period of 6 weeks lowered water levels by a modest 2.4m, some 6.0m above the upper

Plate 1 *Air lift purging of North OBS BH.*

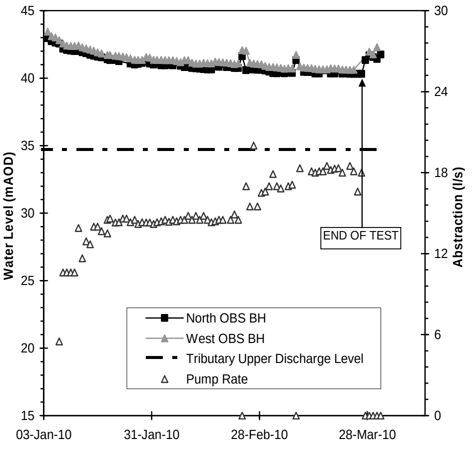

Figure 4 Abstraction rate vs. local water levels.

point of discharge as shown by Figure 4. A larger capacity pump was installed on the 23 Feb, which marginally increased flow rates up to a maximum of ≈ 20L/s (26 Feb), limited by borehole recharge rates.

Conclusions

Water quality obtained during the Cleveland pumping test was significantly better than anticipated, given the quality of the existing discharge, indicating significant input from groundwater recharge. It is this suspected groundwater input and high regional transmissivity that prevented sufficient draw down within the workings to stop the pre-existing discharges. The implications of these findings upon a proposed pump and treat scheme are highly significant, and the difference in anticipated flow requirements and chemistry from pre-test estimates could not be managed on an ad-hoc basis. Projections by Entec (2010) suggest that, based upon the pumping test data, flow rates in the order of 60L/s or more will be required to control the existing discharges, far in excess of earlier estimates.

Data obtained from pumping at Cadley Hill in the South Derbyshire Coalfield showed that results obtained from static samples (i.e. where water in-situ at the point of the borehole is taken) can be in great contrast to that which is drawn through the mine workings once pumping commences. Although, in contrast to the Cleveland test, the iron loading pre-pumping was of a similar order, the chloride concentrations were far higher. This may be attributable to localised recharge from shallow groundwater, or stratification of better quality waters at a shallower depth (Younger *et al.* 2002 pp238).

Lessons Learned

Pumping tests are typically designed to mimic a proposed full scale mine water pumping station, and designs are based upon a detailed review of underground workings, geology and monitoring data. As the case studies presented demonstrate, such knowledge and theory can be fallible. Pumping tests often reveal unexpected mine water facies and regimes, which can have significant impacts upon scheme design and operation.

References

Banks, D., Younger, P L., Arnesen R-T., Iversen, E R. and Banks, S B. (1997) Mine-Water Chemistry: the Good, the Bad and the Ugly. Environmental Geology, Volume 32—3, pp157—174

Barnes, T M. 2000. Treatment of the Gravity Minewater Discharge at Deerplay Mine, Burnley UK. Proceedings of the 7th International Mine Water Association Congress, 344—351.

Entec (2009) Hagg Farm Observation Borehole: Summary of Borehole Drilling and Air Lift Test. Unpublished report for the Coal Authority

Entec (2010) Cleveland Ironstone Hydrogeology Study. Unpublished report for the Coal Authority

Everett L G. (1985). Groundwater Monitoring Handbook for Coal and Oil Shale Development. Elsevier pp 304.

Humenick, M J., Turk, L J. and Colchin, M P. (1980) Methodology for Monitoring Groundwater at Uranium Solution Mines. Groundwater 18—3. pp262—273

IMC (2002) South Derbyshire Minewater Study and Gas Risk Assessment. Unpublished report for The Coal Authority and the Environment Agency

Nuttall C A., Adams, R. and Younger, P L. (2002) Integrated hydraulic-hydrogeochemical assessment of flooded deep mine voids by test pumping at the Deerplay (Lancashire) and Frances (Fife) Collieries, in: Mine Water Hydrogeology and Geochemistry. Geological Society Special Publications 198. pp315 – 326.

Marsh, J M. and Lloyd, J W. (1980) Details of Hydrochemical Variations in Flowing Wells. Groundwater 18—4 pp366—373

WYG (2008) Report on the Potential Impacts of Rising Mine Water on the Overlying Permo-Triassic

Aquifer in the South Derbyshire Coalfield. Unpublished report for the Coal Authority

Younger, P L. (2002) The importance of pyritic roof strata in aquatic pollutant release from abandoned mines in a major, oolitic, berthierine-chamosite-siderite iron ore field, Cleveland, UK (in Mine water hydrogeology and geochemistry) Geological Society Special Publications 198 251—266

Younger, P L.; Banwart, S A. and Hedin, R S. (2002). Mine water: Hydrology, Pollution, Remediation. Environmental Pollution, Kluwer Academic Publishers.