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Evolution in Tidal Related Hydrogeochemisty at a Long-term Coal Mine Water Pumping and Treatment Scheme, Former Frances Colliery, Scotland

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Abstract Pumping and treatment of mine water from Frances Colliery, UK, has been undertaken by the Coal Authority since 2004. Historically, tidal variations in mine water level have been observed, and shaft stratification has also been noticed. However, regular tests on the pumped water started to show peaks in iron concentrations from 2008 onwards. The hypothesis of tidal variations had been suggested in a pumping test in 2000, thus in 2012 and 2014, this theory was put to the test. Measurements of electrical conductivity and water levels obtained using dataloggers indicated a tidal pattern in the chemistry of the pumped water.
Keywords mine water, stratified, tidal, hydrogeochemistry, pumped

Introduction

Frances Colliery is situated in the East Fife Coalfield, Scotland and forms part of an interconnected area of mine workings, some of which extend under the Firth of Forth (fig.1). During the 1990's subsurface mining in the coalfield ceased, with dewatering ending in 1995. Monitoring of the mine water levels and their recovery was commenced by the Coal Authority to aid future predictions for mine water rebound. In conjunction with this water level monitoring, shaft water sampling and logging were undertaken during the recovery period; these data were used to help predict water quality and showed evidence of shaft stratification (Nuttall et al. 2002). Dataloggers were also installed in to Frances, and other shafts in the coalfield, to measure water levels, and these instruments identified a 'tidal' pressure-related pattern was present in the rebounding mine water (Whitworth 2002).

Fig. 1 *Map of East Fife Coalfield (after Whitworth, 2002 (adapted from Sherwood, 1997)).*

In 2004, following various pumping tests and investigations, continuous pumping (initially *c.*50 L/s, progressively increasing to *c.*160 L/s) and semi-passive treatment (periodical chemical dosing was used) was undertaken to prevent risks associated with rising mine water. Shaft sampling and temperature-conductivity logging continued to show stratification within the pumped water column. Through part of the Authority's operational and management requirements at Frances, daily on-site testing was undertaken in conjunction with regular routine laboratory sampling. From 2009 onwards, and following increases in abstraction rate, the chemistry data started to show spikes in some metal and anion concentrations. Following from possible tidal pH variations identified during a pumping test in 2000 (IMC, 2001), it was suggested these spikes may represent tidal variations within the pumped mine water quality. Thus, in 2012 and 2014 this hypothesis was tested, the results of which are presented below.

Methodology

To test for any possible tidal patterns in pumped water chemistry and ascertain how this phenomenon affects the performance of the treatment scheme, the following devices and methods were utilised:

- Pressure transducer and datalogger–Installed in the pumping shaft and set to record water levels at 30 minute intervals. This configuration of datalogger and pressure-transducer has been utilised by the Authority since 1995 to give reliable water level data.
- Electrical conductivity and temperature loggers–In the first test in 2012, one logger was installed within the top of the aeration cascade of the first settlement lagoon. The second logger was installed at the outlet from the first settlement lagoon. During 2012, both calibrated instruments were set to record electrical conductivity every 15 minutes. Temperature was also measured by the dataloggers at the same frequency; temperature is used to compare changes and differences in specific electrical conductivity. In the second test, loggers were installed in the aeration cascade and in the atmosphere above the aeration cascade; the conductivity logger was set to record specific electrical conducted (i.e. corrected to 25 ℃).
- Atmospheric temperature logger–In 2014, a logger was installed in the atmosphere, above the aeration cascade to record air temperature throughout the testing period.
- During the test, the pumping rate was kept constant at 100 L/s (in 2012) and 130 L/s (in 2014). This removed a factor which could potentially cause variations in water levels and chemistry.
- In 2012, pumping was undertaken from two pumps; pump 1 at a depth of 99 m below ground level (BGL) (52 m below Ordnance Datum (BOD)) and pump 2 at 97 m BGL (50 m BOD). On-site chemical testing of the water at regular intervals was also taken from both pumps.
- Discrete shaft sampling and logging–During the test in 2012, a set of discrete water samples and electrical conductivity-temperature surveys were taken at intervals throughout the day, and timed to correspond to low and high tidal water level.
- Tidal records for Kirkcaldy (*c.*2 km SW of Frances) were obtained for test durations.

Results

The results from the tests undertaken in 2012 and 2014 are summarised below:

Iron – For the shaft sampling and on-site testing undertaken in October 2012, total iron concentrations from each pump were measured throughout the day (fig.2A). For pump 1 the concentrations varied between 30 mg/L and 247 mg/L; for pump 2, the concentrations showed little variation with a mean value of 32 mg/L. In 2014, on-site testing was not undertaken for iron.

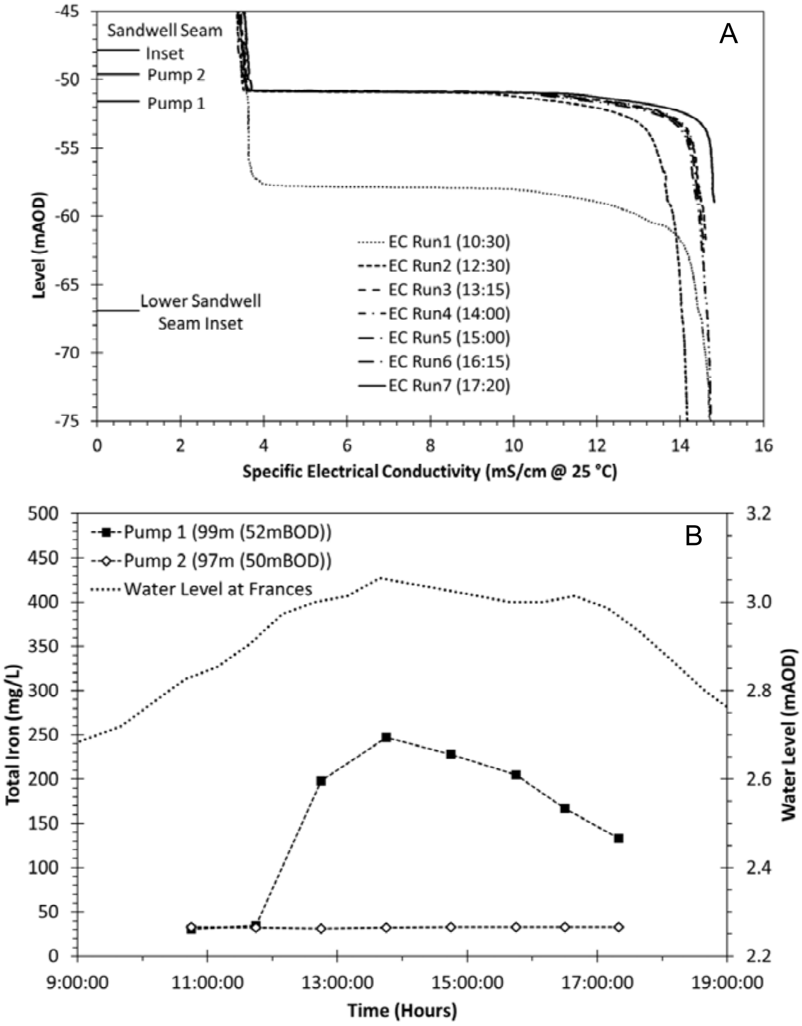

***Fig. 2** A) Graph of on-site total iron concentrations and water level at Frances, 2012. B) Electrical conductivity-temperature logs at Frances shaft, 2012*

Shaft logging – In October 2012, both regular and specific electrical conductivity-temperature logs were taken of the water in the shaft (fig.2B). The results show that the interface between the lower conductivity water (*c.*1.5 to 3.7 mS/cm @ 25 ℃) and the high conductivity (*c.*14 to 15 mS/cm @ 25 ℃) moved through the day, with the interface moving up by 10m corresponding to a rise in water level following the tidal trend. During low water level conditions, the interface was below the pump intakes; as water level rose, the interface rose rapidly to the approximate level of the intake for pump 1, the lower of the pumps. These values of specific electrical conductivity equate to approximately 30 mg/L of total iron and 300 mg/L of total iron for the lower conductivity and high conductivity waters respectively. Note that these concentrations are similar to those pumped from pump 1 and pump 2 in the on-site testing recorded in 2012.

Electrical conductivity – Throughout the test in May 2012 (fig.3A), the mean electrical conductivity was 2.1 mS/cm with a mean temperature of 13.8 ℃. The results show a diurnal tidal pattern where the pulses in electrical conductivity correspond to the rise and fall in shaft water levels. The diurnal trend in conductivity is less distinct in the settlement lagoon outflow. This is considered to be as a result of dispersive mixing processes occurring in the lagoon (which has a nominal residence time of 2.25 days (at 160 L/s)). The electrical conductivity varied between approximately 1.2 mS/cm and 4.2 mS/cm. In the test undertaken in January ~ February 2014 (fig.3B), the mean specific electrical conductivity was 6.7 mS/cm @ 25 ℃, with variations between 4.8 mS/cm @ 25 ℃ and 8.8 mS/cm @ 25 ℃; the mean temperature during this test was 14.1 ℃.

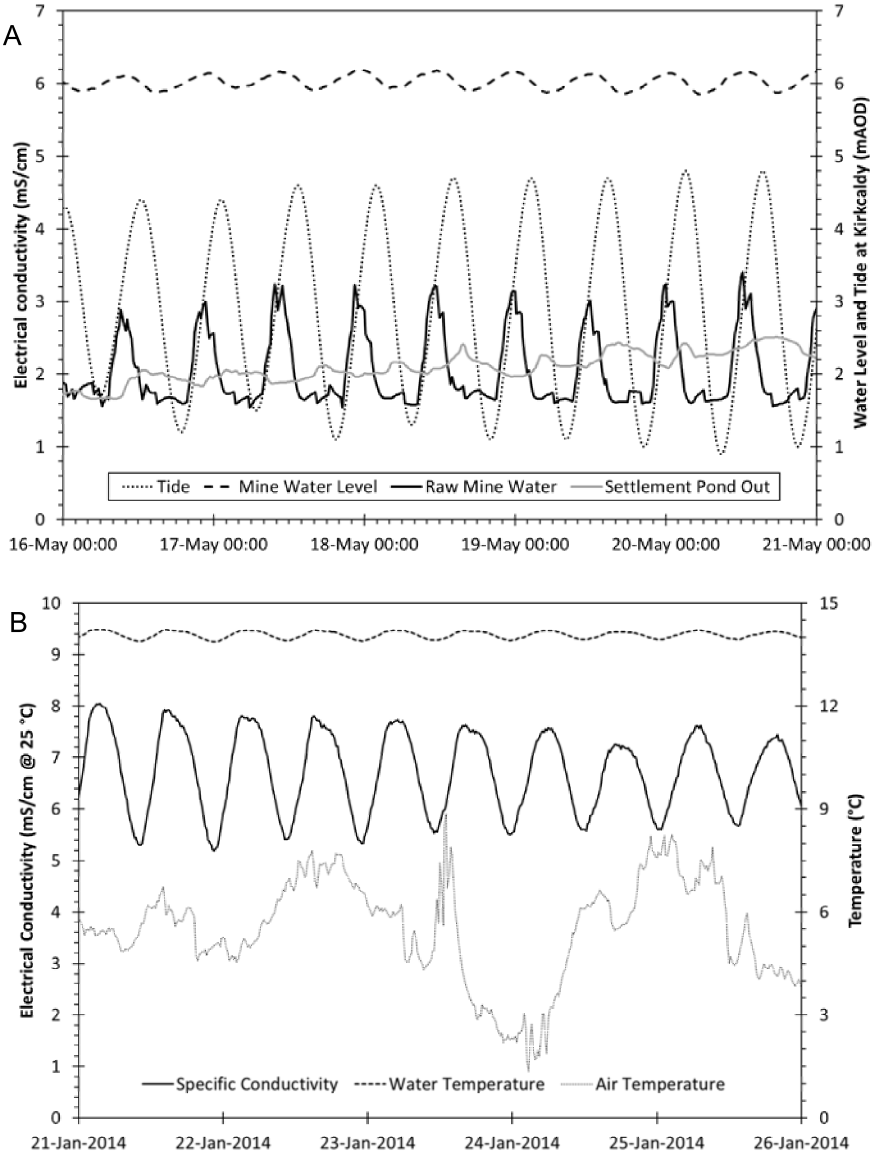

Fig. 3 *A) Graph of electrical conductivity, water level at Frances, and tide at Kirkcaldy, 2012.*
B) Graph of specific electrical conductivity and temperature at Frances, 2014.

Conclusions

Prior to the 2012 and 2014 testing undertaken at Frances, the water level was known to be influenced by the pressure of the tidal water acting on the flooded offshore mine workings. Although a tidal signature was intimated in the chemistry of the pumped water in the 2000 pumping test; it was not until 2008, four years after the scheme became operational, that the tidal signature became discernable in the water chemistry. The results of the tests undertaken at Frances in 2012 and 2014 clearly show that there is a tidal influence to the chemistry of the pumped mine water. This tidal change in the chemistry of the pumped mine water is a result of the interface boundary of the stratified water, moving up and down in response to the tidal pressure acting on the flooded offshore mine workings. The reasons for the 'tidal' chemical signature becoming evident in 2009 is most probably in response to changes in the mine water regime (i.e. rising mine water level), and the resultant need to progressively increase the abstraction rate at Frances shaft. The level of the interface between the lower conductivity and higher conductivity waters was observed to vary by 10 m. This variation in depth is greater than the difference in the shaft water level that occurs in response to the tide (*c.*0.4 m) and is also greater than the tidal range of sea level recorded at Kirkcaldy (*c.*4 m). During the "low" shaft water level period, both pumps abstract the low conductivity, low iron water. However, during the "high" shaft water level period, the upper pump extracts the low conductivity water from the shaft, whereas the lower pump abstracts the high conductivity, high iron water, which has risen up the shaft. The exact mechanism causing the interface to move upwards is not currently well understood, although we consider that it is likely to be due to the different densities of the two types of water, being affected by the on-going pumping and the tidal forcing.

From a practical point of view of efficiently operating the treatment scheme, accounting for the diurnal water quality deteriorations, this detailed monitoring has identified two strategies for improved chemical dosing. Firstly, dosing could be automatically varied according to the pumped water conductivity; since conductivity correlates directly with iron concentrations. Secondly, the location of dosing could be relocated to the outlet of the primary settlement lagoon, at which point most of the tidal signal in water quality has been smoothed out by dispersion; and the secondary settlement lagoon still offers sufficient residence time to fully treat the water.

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References

IMC (2001) Report on frances pump test for the coal authority. Unpublished report 175

Nuttall CA, Adams R, Younger PL (2002) Integrated hydraulic-hydrogeochemical assessment of flooded deep mine voids by test pumping at Deerplay (Lancashire) and Frances (Fife) collieries. In: Younger PL, Robins NS (Eds), 2002 Mine water hydrogeology and geochemistry, Geological Society Special Publication 198, Geological Society, London, p 315-326

Sherwood JM (1997) Modelling mine water flow and quality changes after coalfield closure. Unpublished PhD thesis. Department of Civil Engineering, University of Newcastle

Whitworth KR (2002) The monitoring and modelling of mine water recovery in UK coalfields. In: Younger PL, Robins NS (Eds), 2002 Mine water hydrogeology and geochemistry, Geological Society Special Publication 198, Geological Society, London, p 61-73