Using a Novel Reactive Transport Model to Determine Flow Distribution between Major Roadways in a Partially Flooded Abandoned Underground Metal Mine

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Abstract

Understanding the hydraulics of an abandoned underground mine is a necessary step in developing a management plan. Although exhaustive in-situ measurements of flow and water chemistry would be the ideal way to gain such an understanding, this is rarely achievable. Hydraulic models may be able to add some insight into the situation, but may not provide a solution that agrees with the chemical data. POSSUM (Pollutant Sources and Sinks in Underground Mines) is a novel reactive transport model created specifically for hydrogeochemical simulation of partially flooded abandoned underground mines. POSSUM simulates varying flow through multiple interconnected mine roadways, mineral weathering reactions, precipitation of insoluble phases, linear reversible sorption, and dissolution and precipitation of acid generating salts. One of the main advantages of a model that combines both the hydraulics of mine systems with their geochemistry is the flexibility of solutions; some of the key applications include determining the longevity of polluting drainage from a site, verifying pollutant sources and sinks and quantifying the flow regime based on chemical data. A good example of the third application of POSSUM is the determination of flow distribution between three main roadways in Rampgill Horse Level, an abandoned lead/zinc mine in Nenthead, Cumbria, UK. Although a comprehensive survey of water chemistry has been conducted by Newcastle University, accurate flow measurements are difficult to take due to the irregular cross-sectional shape of the channels. POSSUM has been used to iteratively simulate the geochemistry at several main junctions and the outflow of the mine using different flow combinations; these were adjusted until the simulated water chemistry was equal to that measured in 18-months of distributed underground sampling. The simulated flow rates were then used to model the sources and sinks of various pollutants, including zinc and sulphate. This application of POSSUM has been deemed successful, with a percent error between simulated and measured chemistry ranging from 0.7% to 14% (depending on the species). The applications of computational models to mine land management are numerous and a complex yet flexible model like POSSUM can give important insight into decision making.

Introduction

Abandoned underground mines create problems for practical understanding of the system due to problems of access, measurement and safety (Younger et al., 2002). Hydraulic regime is often very difficult to determine in underground workings. This paper details the use of a reactive transport model to develop an iterative numeric solution to the flow distribution between major mine roadways using known geochemical values.

Reactive transport models can help to answer many important questions about the fate and movement of water and solutes in the subsurface (Younger, 1997). Modelling allows us to assess the credibility of theories to explain field observations and measurements and to gather knowledge from the past to better understand the present situation and to predict future developments. Improved understanding of the mechanisms acting in current and past environmental systems will allow better management of resources and amelioration of past, present and future environmental impacts (Younger, 2007).

In this context, the **Po**llutant **S**ources and **S**inks in Abandoned **U**nderground **M**ines (POSSUM) model has been developed (Kruse, 2007). POSSUM is a reactive transport model that simulates geochemical reactions and hydraulic changes over the lifetime of drainage along an underground flow path, such as a mine drainage adit.

Field Site

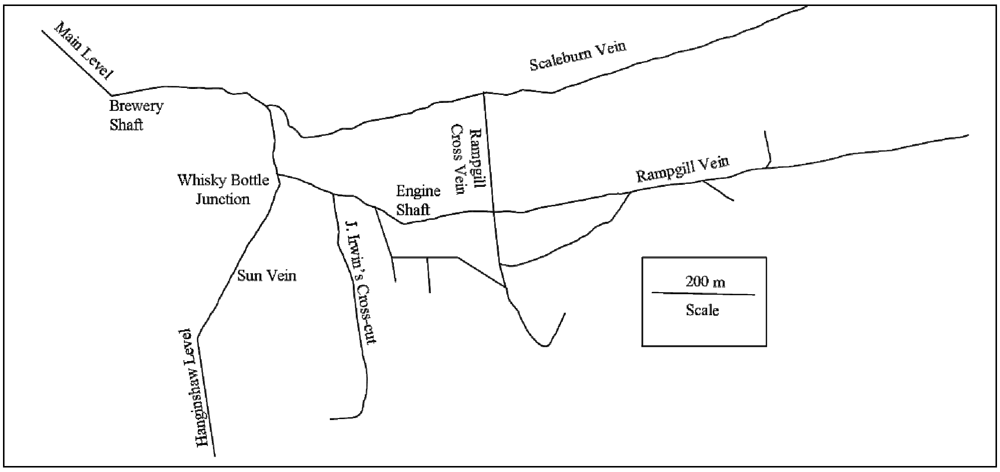
The portal of the Rampgill Horse Level is located in the village of Nenthead in Cumbria in Northeast England. The level drains into the River Nent, a tributary of the River Tyne. The three main veins accessed via the Rampgill Horse Level (the Hanginshaws, the Rampgill, and the Smallcleugh, see Figure 1) each have distinct chemistry. The underground investigations performed by Nuttall (1999) characterized the underground water chemistry specifically in reference to zinc contamination. The Hanginshaws and Rampgill veins were found to contribute most of the zinc to the flow (5.6 mg/L and

10.5 mg/L, respectively), while the Smallcleugh vein contributed significantly less zinc (2.9 mg/L) to the system (Nuttall, 1999). Accurate flow measurement is difficult due to back-water effects; an initial estimate can be made visually to be confirmed through modelling.

POSSUM Model

POSSUM is created in two modules—a hydraulic solver and a geochemical solver. The hydraulic solver (called NOAH in its stand-alone form) uses the St. Venant equations (calculating conservation of mass and momentum) to solve for flow rate and depth of water in channels with varying cross-sections (e.g. rectangular, irregular, trapezoidal, semi-circular) in various network types, including dendritic, branching and looped networks. The geochemical solver models weathering reactions for 28 different minerals, contaminant transport, reversible sorption, dissolution and precipitation of acid generating salts, and inflow from both distributed inflows or drippers and secondary roadways or feeders.

Figure 1 *Map of underground workings on the Rampgill Horse level (after Critchley, 1998).*



Modelling of Rampgill Horse Level

To calculate an iterative solution of the flow distribution between the main roadways in Rampgill Horse Level, first, the geochemistry of the site is characterized. This is based on field work conducted over nearly two years (Nuttall, 1999). The mean flow rate from the Rampgill adit is known, so several simulations with differing flow distributions are run with the geochemical conditions kept constant.

Based on a geological description of the system given by Nuttall (1999, Nuttall and Younger, 2002), the geochemistry in the Rampgill Horse Level was described by oxygen-based sphalerite oxidation, calcite weathering (both dissolution and precipitation) and smithsonite precipitation; although hydrozincite has been observed on site, it is not included in the suite of minerals modelled by POSSUM, so it has been neglected. Sphalerite oxidation by ferric iron was neglected due to the low iron concentrations in the system. Based on underground observation, the cross-section of channel has been represented as a rounded rectangle to take into account sediment buildup in the corners of the nominally rectangular roadways. The hydraulics (flow and depth of water) and geochemistry of the water flowing through the abandoned Rampgill Horse Level was simulated using the POSSUM model for a period of 700 days to correspond with the period of field sampling conducted by Nuttall (1999). Flow distributions were adjusted iteratively between simulation runs to produce results that most closely reproduce the adit geochemistry.

The flow distribution that most accurately reproduced the mean adit chemistry was 4 L/s contribution from the Rampgill Vein and 7 L/s each from the Hangingshaws and Smallcleugh Veins. Figures 2 and 3 are two representative plots of the adit geochemistry. The solid line is the modelled geochemistry (the variation is due to numerical dispersion and small timesteps) and the open circles are the measured geochemistry over the 700 day sampling period (Nuttall, 1999).

Figure 2 *Modelled vs. observed alkalinity.*

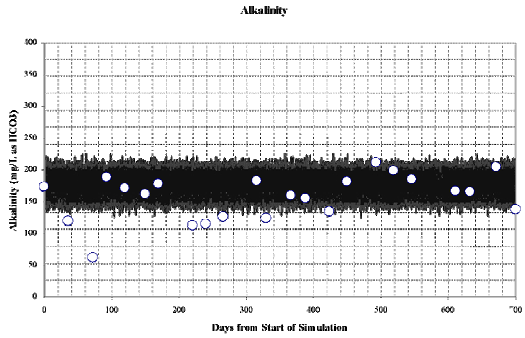
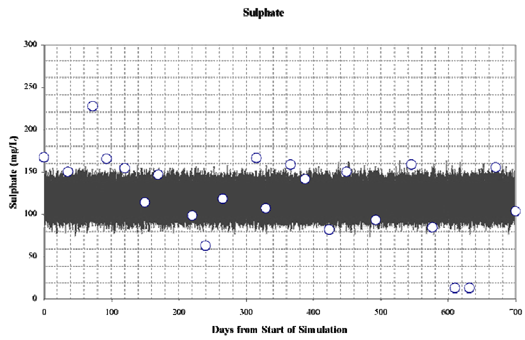


Figure 3 *Modelled vs. observed sulphate.*



Conclusions

Although limited data has been presented here due to space limitations, iterative simulation of Rampgill Horse Level has provided a defensible estimate of flow distribution between the three main roadways on the main level. It must be recognized, however, that this is a method of estimation of flow rather than a single solution. This work has shown the adaptability of reactive transport models for the management of abandoned underground mines.

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