Prediction of hydrogeochemical changes due to surface water seepage into 1B Mine Pool of Cape Breton, Canada

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Abstract Since the 1B Mine Pool of the Sydney Coalfield in Nova Scotia was flooded in 1985, the mine water geochemistry has been evolving. The influence of surface water seepage into the colliery voids through the overlying geologic layers may alter hydrogeochemical dynamics and was thus simulated using FEFLOW model. Changes were predicted by time series analyses using weather data as well as different assumed seepage volumes and recharge rates. The preliminary simulation results confirm that infiltration might influence water head rise at the 1B mine pool, the formation and potential flow of contaminants in the 1B Mine Pool.

Keywords Groundwater-flow model, Sydney Coalfields, FEFLOW, mine water

Introduction

To develop an effective mine water management system for abandoned mines, it is necessary to consider all factors contributing to the current hydrogeochemical instability in the mine pools. One of the contributing factors to groundwater of hydrogeochemical dynamics is the interaction of surface water with the groundwater. Mostly the surface waters of concern are those that come from precipitation run-offs. In most cases, precipitation run-off from either rainfall or snow melting dissolve different chemical elements as they infiltrate different soil and geological formations into the groundwater aquifers. Consequently, the geochemistry of the groundwater may change and result into a chain of desorption and dissolution reactions that may lead to an increase in contamination of the groundwater. Further, the pressure exerted by the infiltrations may influence groundwater flow. Similarly, the infiltration of surface water into the mine pools may lead to contamination formations like acid mine drainage. Therefore, the potential influence of surface water on the hydrogeochemical dynamics in flooded mine pools of abandoned mines of Sydney Coalfield in Cape Breton, Nova Scotia need to be considered as an integral component in the mine water management system.

It is in this context, that the project whose preliminary results are reported in this paper was conceived. The aim is to determine and predict the potential influence of the seepage of surface water on the ever changing hydrogeochemical characteristics of mine pools within the Sydney Coalfield. The Sydney Coalfield is located in the Maritimes Carboniferous Basin on the east coast of Cape Breton Island, Nova Scotia, Canada. For the current study, it is hypothesized that the seepage of surface water into the voids of collieries and its contact with the geology of mined region increases contaminant level and results in acid mine drainage. To test the hypothesis, the behavior of groundwater flow and pollution transport in the 1B Mine Pool was simulated using 3D FEFLOW (Finite Element Subsurface Flow system) model. Using geochemical and weather data for Cape Breton as well as different assumed recharge rates of pools with seepage, the potential geochemical changes were predicted by time series analyses. The broader objective was to develop a three-dimensional (3D) model for mine water flow and transport of contaminants with a view to estimate their long-term impact on geochemical stability of the mine pools. Hence, this paper presents the preliminary FEFLOW modeling results of the hydrogeochemical changes and contaminant concentrations in the 1B Mine Pool, which are required for designing effective treatment and management strategies.

Methods

Description of study area

The current study concentrated on colliery No. 5 of the 1B Mine Pool, which is located beneath the communities of Glace Bay, Reserve Mines and Dominion, situated near the east coast of Cape Breton Island (Fig. 1). The 1B Mine Pool was chosen for the preliminary study because it is the largest of the three mine pools, while colliery No. 5 was chosen because it is located on land and has a high probability of benign influence with seepage surface water through the Phalen seam outcrop and into the bootlegs nearby. The No.5 colliery was depillared completely during the mining activities and part of the colliery collapsed accompanied by surface subsidence. The site receives annual precipitation in the form of rainfall and snow accounting for 85 % and 15 %, respectively (Shea 2008, 2009). The recorded mean annual precipitation for the Sydney area is 1504 mm per year (Environment Canada 2013).The study area covers 6.6 km² and the No.5 colliery was extended to a depth of 217.314 m, for the mining activities.

Subsurface profile of study area

The subsurface layers of different coal seams at depths are shown in Fig. 2. The 1B Mine Pool formed following the mining activities of within a gently folded structure, the Glace Bay Syncline and along the northward flanks of the Bridgeport Anticline (Shea 2010; Wolkersdorfer 2011). The mining occurred at three major coal seams namely the Emery, Phalen and Harbour, which are of different depths. The coal measures strata are of Carboniferous age, with the seams separated by sequences of sedimentary rock while the inter seam strata generally consists of mudstone, shale, siltstone, sandstone and traces of limestone. The No.5 colliery was mined only through the Phalen seam and no coal mining was done at the Harbour seam.

Modeling procedure

The conceptual model was developed based on surficial topography and subsurface profile exploration to understand the surface water seepage into the mining ground of the study area. The generated conceptual model is used to simulate a numerical 3D model using FEFLOW Version 6.1. For the FEFLOW simulations, the study area was converted into a polygon,

Fig. 1 Location of study area above No.5 colliery

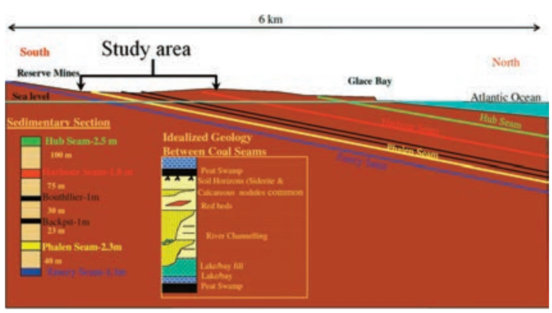

Fig. 2 Location of study area having Phalen Seam outcrop (Shea 2008)

and a mesh containing 23312 triangular-prism elements was generated (Fig. 3). The subsurface profile of the study area was designed to have four layers based on its geological background. The first layer contains elevation data on the topography of the study area, the second layer includes both the over burden and fractured rock layers, the third layer extends to the bottom of Phalen seam, and the last layer contains hard rock stratum.

For the simulation, the model was initially assumed as 3D unsaturated aquifer, which was later saturated variably during the simulation using Richard's Equation (1), which is incorporated directly in the FEFLOW procedure:

$$\frac{\partial w}{\partial t} = \frac{\partial}{\partial y}\left[k(w)\left(\frac{\partial p}{\partial y}+1\right)\right] \qquad (1)$$

where, w is the volumetric aquifer water content changing with respect to time t; k is the permeability or hydraulic conductivity of the aquifer; p is the pressure head variation with respect to vertical elevation y.

Thus, transient flow was simulated based on the surface runoff due to precipitation. The boundary condition assumed absence of flow in and out of the aquifers. The fluid flow was monitored for 365 days, having an initial time step as 0.001 day. The inflow of water head due to the precipitation is assumed as 1504 mm/year and flows into the model from the topographic layer. The assumed permeability in the horizontal direction is 1 m/d and it is assumed greater in the vertical direction due to collapsed roof of No.5 colliery. The porosity of the unsaturated aquifer is assumed as 0.3, since the geological details of the study area includes only sedimentary rock types. The time stepping procedure is based on Adams-Bashforth/Trapezoid rule predictor-corrector, which is incorporated in FEFLOW Software.

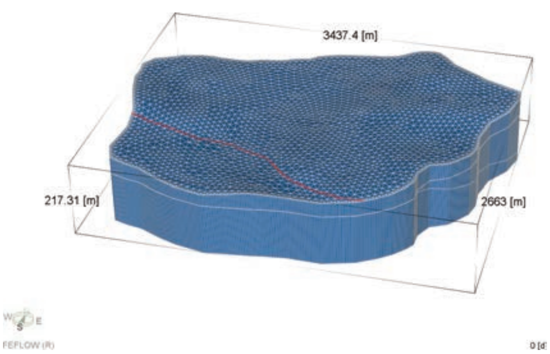

Fig. 3 *The finite elements generated for the study area*

Results and Discussion

Surface runoff and potential infiltration into mines

In order to understand the surface runoff, modeling the exact topography of the study area is important. Based on the topography data and information about the study area, the simulation with FEFLOW predicts the direction of surface runoff to be northwards(Fig. 4 (a)).

The model acknowledges the possibility of surface runoff into the Phalen outcrop, the nearby bootlegs and the watershed of Cadegan Brook. Hence, the model suggests that the source of infiltration of surface runoff into the mine pool is likely to be through surface features shown in Fig. 4.

Saturation and hydraulic head isolines

Fig. 5(a) shows the saturation of the unconfined aquifer model, while Fig. 5(b) shows the hydraulic head isolinesafter365 days simulation. The model predicted maximum saturation locations that coincide with the area known as MacKay's corner. This area contains a natural wetland and is considered the main infiltration point of the 1B Hydraulic System (Shea 2008).

Therefore, this site in particular is suspected to be the source of precipitation run off infiltration into the No.5 colliery. The hydraulic head isolines predicted in wetland and water catchment area are lower because of surface water seepage into the subsurface and colliery (Fig. 5(b)).

Hydraulic and pressure heads

The predicted hydraulic head as well as the pressure created by the water percolation is

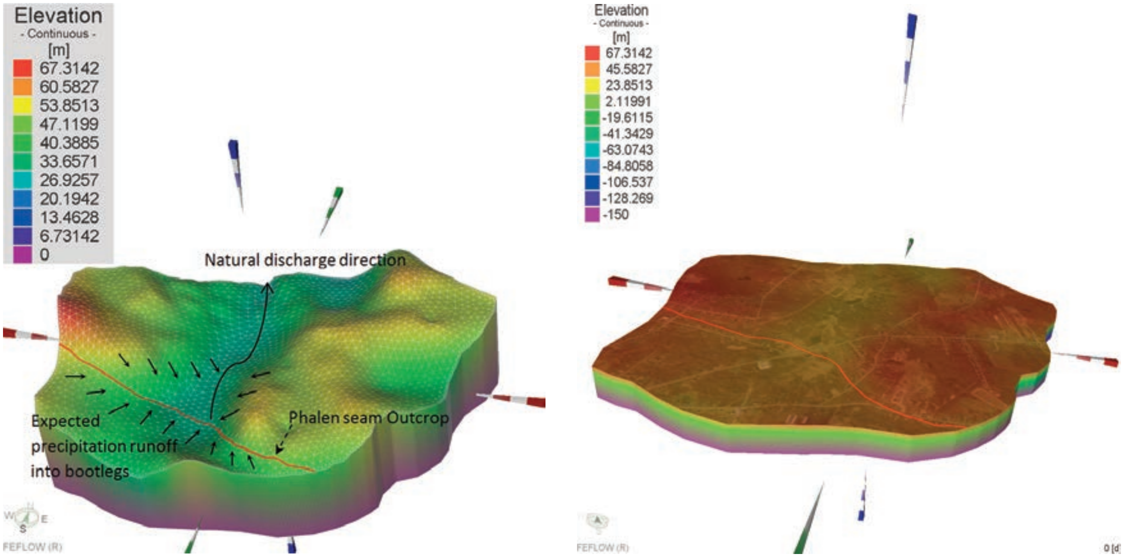

Fig. 4 *The simulated topography (a) showing expected precipitation runoff accumulation near to Phalen seam outcrop and the direction of natural discharge (b) Strata depth details – map layer over the study area and Phalen outcrop*

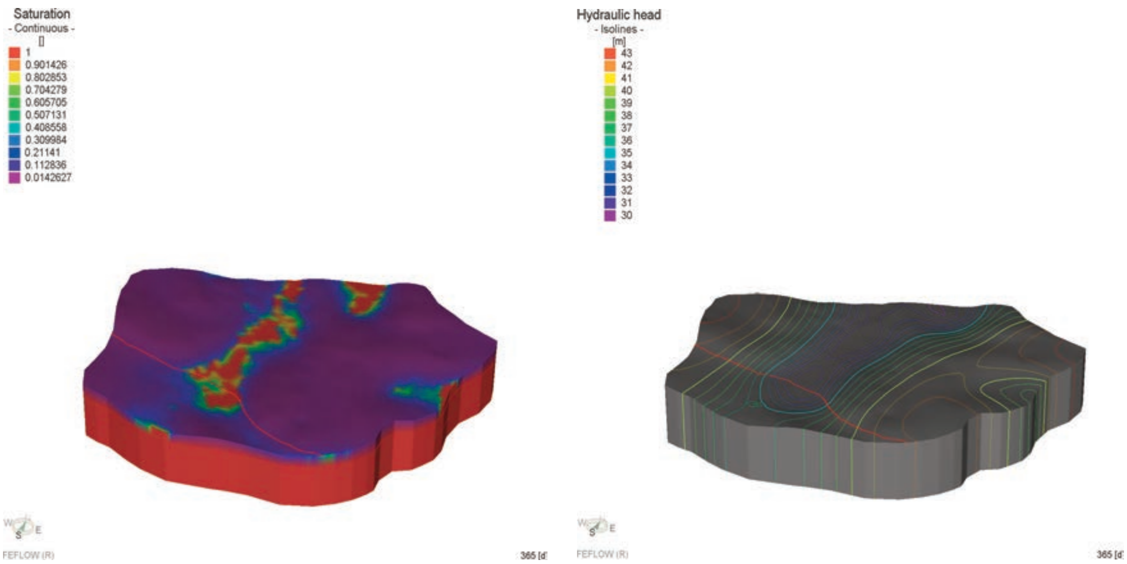

Fig. 5 *(a)Saturation of the model at the end of 365 days (b) Hydraulic head – isolines at the end of 365 days*

presented in Fig. 6. The model has predicted the hydraulic head based on the topographic layer and permeability of rock layers, showing the minimum value within the lowland drainage region (Fig. 6a). The pressure head varies as the water infiltrates into the subsurface layers of the model (Fig. 6b).

Underground velocity flow

The predicted flow direction of the model is shown in Fig. 7. The predicted flow velocity of the percolated water ranges between

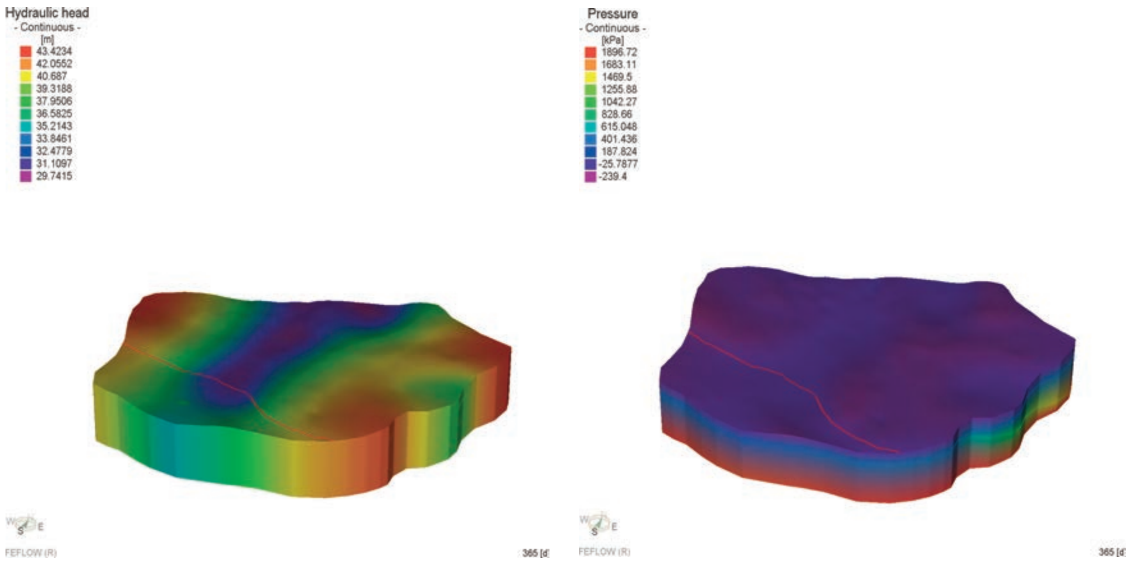

Fig. 6 *(a) Hydraulic head at the end of 10th day – shows surface runoff and head of water percolated into ground; (b) Pressure variation along the layers at the end of 10th day*

0.005730 m/d to 0.68751 m/d. The flow of the percolated water varies based on the permeability of the aquifer and changing porosity during unsaturated to saturated condition. The computed precipitation net inflow rate of the model at the end of 365 days is 25437.9 m^3/d (4667 USGPM). The simulated precipitation inflow of water into the subsurface has not included its loss during surface run off. In future modeling, these limitations will be taken into account when simulating the hydrogeochemical changes of surface water into No.5 colliery.

The preliminary numerical study shows that there is the greater possibility of precipitation runoff into No.5 colliery and nearby bootlegs, which shall increase the mine water head in the 1B mine pool and induces the mine hydrochemistry in the Phalen coal seam.

Conclusion

The preliminary results from the simulation revealed that percolation of surface runoff into the underground seam at No.5 colliery would indeed affect the hydrogeochemical stability of the mine water at 1B Mine Pool. The inflow rate of water is predicted as 4667 USGPM using numerical modeling and it is confirmed with the range of 1B Mine pool water capacity, which fluctuates 450 to 7000 USGPM during the year based on the precipitation events. The percolated water into the siltstone, shale, sandstone, mudstone rock layers and also on the Phalen coal seam may have the hydrogeochemical changes that would cause the acidic mine drainage at 1B mine pool. Further studies will be toward simulation of actual hydrogeochemical changes, including dissolution, desorption dynamics that may take place due to the inflow of precipitation into the rock layers and Phalen seam.

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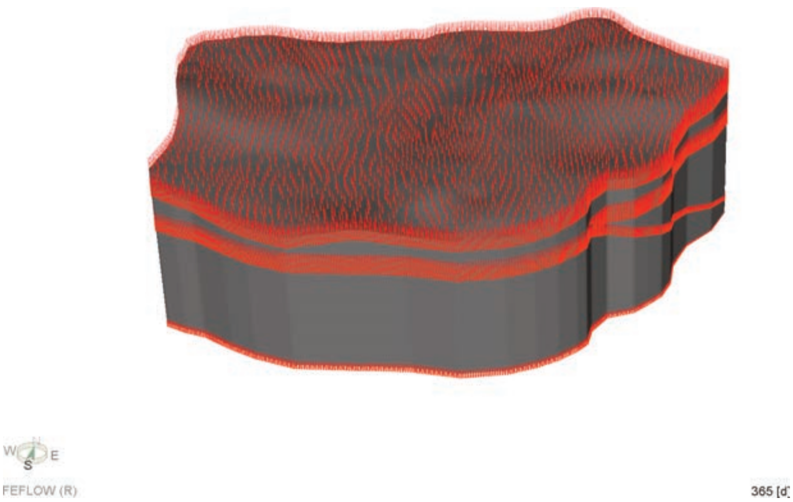

Fig. 7 *Predicted flow direction of the percolated water*

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