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Surface water-groundwater interaction in the fractured sandstone aquifer impacted by mining-induced subsidence: 1. Hydrology and Hydrogeology

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ABSTRACT

Mining-induced subsidence under surface waterways enhances surface water-groundwater interaction due to the enlargement of existing fractures, development of new fractures and the separation of bedding planes. Fracturing of streambeds and rockbars causes surface flow to divert to subsurface routes. The surface water-groundwater interaction in an undermined stream in the Southern Coalfield of New South Wales (NSW), Australia, has been assessed by analysing hydrological data including flow measurements upstream and downstream of the longwall panels. The data suggests leakage of surface water to the subsurface through fractured streambeds and rockbars. Mining-induced fracturing across the catchment is likely to have caused increased rainfall infiltration, reduced runoff, and reduced baseflow discharge, resulting in streamflow reduction and possibly loss, particularly during low flow conditions affecting the catchment's water balance. During medium and high flow conditions, the streamflow loss is relatively small in comparison to the total volume of flow in the stream, as the capacity of the subsurface system limits the volume of water that can enter subsurface routes. Streamflow reduction in mining-impacted catchments is likely to be an effect of the spatial distribution and density of fracture networks, changes in porosity and permeability of the subsurface rock mass, changes in groundwater storage capacity, modification to baseflow discharge and alteration of the hydraulic gradient near streams.

INTRODUCTION

The importance of water resource protection and the maintenance of stream function has increased following the observed surface water-groundwater connectivity in areas where mining-induced subsidence has led to declines in baseflow discharge to streams. There have been various studies undertaken above active longwall mines, providing some insight into mining-induced subsidence on the temporary or permanent impact on streamflow, however, relatively little is known about flow losses as a result of longwall mining. Some of the published papers which cover this aspect of impacts of mining on surface water flow were investigated in the Appalachian Coalfield, USA (Dixon, Rauch, 1990; Tieman et al., 1987), Utah Coalfield, USA (Slaughter et al., 1995); East Midlands, England (Shepley et al., 2008); and Southern Coalfield, Australia (Jankowski, 2007, 2009; Jankowski et al., 2008).

SURFACE WATER-GROUNDWATER INTERACTION

The stream-aquifer system can be classified based on the predominant local groundwater flow component for:

- underflow-component with groundwater flow longitudinal to a stream;
- baseflow-component with groundwater flow lateral to or from a stream;

or a combination of both.

The above three groundwater flow types are postulated in the Waratah Rivulet catchment, Southern Coalfield, NSW, Australia, impacted by longwall mining, through the development of new fractures, enlargement of existing fractures, separation of bedding planes and the modification of stream topography (Jankowski, 2007, 2009). The conceptual lateral and longitudinal flow model of surface water-groundwater interaction in a mining-impacted area was described by Jankowski (2007). The inflow of surface water into the subsurface mainly occurs along vertically outcropping fractures, joints, and veins that provide dominant pathways for surface water to infiltrate an aquifer. Depending on the opening, length, and position of fractures, the surface water-groundwater interaction can be permanent or temporary. Streamflow may be permanent or temporary based on the following scenarios:

Permanent flow occurs when the:

- stream is connected-gaining and there are baseflow contributions from an aquifer in the local groundwater flow system;
- size and distribution of the surface fracture network is small, limiting surface water infiltration;
- capacity of the subsurface system to store water is lower than the streamflow infiltration rate.

Temporary flow occurs when the:

- baseflow contribution is small and unreliable;
- size and distribution of the surface fracture network is large, allowing increased surface water infiltration;
- capacity of the subsurface system to store water is higher than the streamflow infiltration rate.

The location of surface water inflow depends on the interconnectivity of vertical fractures and horizontal bedding planes. Some fractures and bedding planes are well connected and others are not, which can result in complex flow patterns, with flow in part of the stream and a lack of flow in another part, particularly during low flow conditions. Several recharge-discharge zones can be present along a streambed, causing surface water to recharge the subsurface and reappear downstream as surface flow. Cracks in rockbars further complicate the system. Vertical flow can extend to substantial depths depending on the fracture network and whether there is low permeability material present, such as claystone or shale. Horizontal inflow of surface water depends on the extension of bedding planes and their opening. Some large opened bedding planes can be used as preferential pathways for groundwater flow (Jankowski, 2007).

In the Southern Coalfield, for example, observed maximum subsidence may be up to 2.2 m and observed maximum upsidence in the Waratah Rivulet may be up to 197 mm. Mining–induced subsidence causes topographic and structural modifications to streambeds and the drainage basin, generally bounded by the angle of draw (subsidence to 20 mm). Fracturing of streambeds (Fig. 1) and rockbars (Fig. 2) causes surface water to divert to subsurface routes and interact with groundwater. In the Southern Coalfield, surface water typically flows vertically through fractures and horizontally through bedding planes. Recharge to the shallow sandstone aquifer also occurs through joints, veins and large cavities, with baseflow discharge occurring through fractures (flow is often under artesian pressure) and bedding planes.

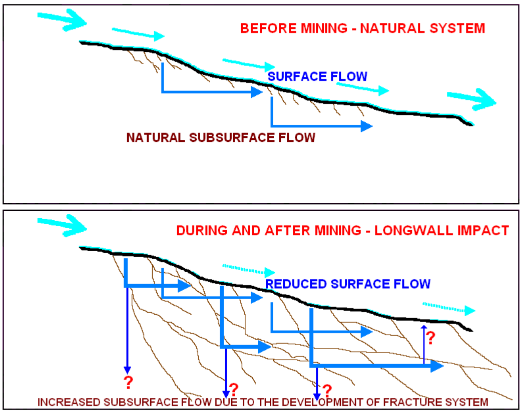

Figure 1. Diversion of surface flow into the subsurface due to fracturing of streambeds — natural versus impacted systems.

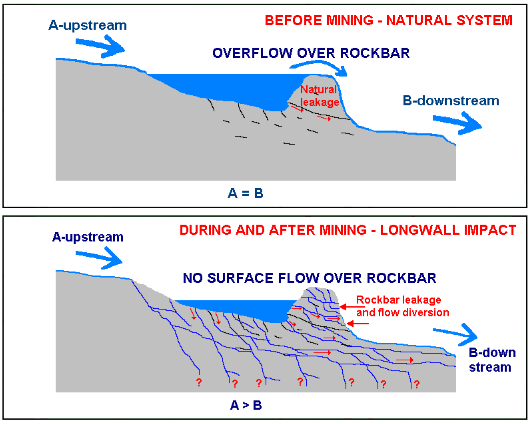

Figure 2. Diversion of surface flow into the subsurface due to fracturing of rockbars — natural versus impacted systems.

STREAMFLOW REDUCTION/LOSS

A lack of detailed baseline hydrological monitoring data is the main obstacle to adequately assessing the impact of mining on catchment hydrology, however a range of methods have been used to assess streamflow. Figure 3 shows the streamflow data from the main stream in the Waratah Rivulet catchment impacted by longwall mining. Although there is no pre-mining data, one method used for assessing the streamflow data is based on subtracting the upstream streamflow from downstream streamflow, which has been used by others, such as Tieman et al. (1987).

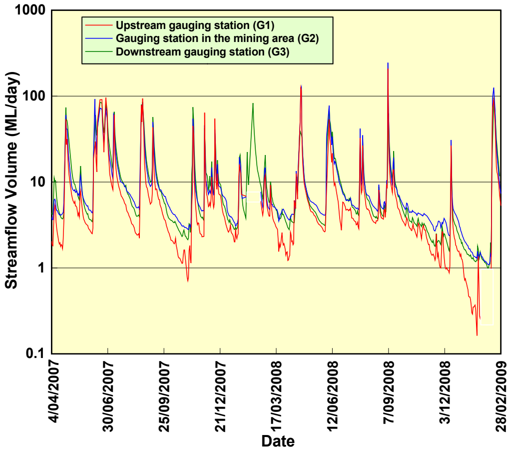

Figure 3. Comparison of streamflow upstream (G1), in the mining area (G2) and downstream of the mining area (G3).

As shown in Figure 3, the upstream gauging station (G1), which is located on the upstream edge of the mining affected area and is likely to represent close to natural flow conditions, has lower flow during dry periods compared to the other gauging stations (G2 is located on the downstream edge of the mining area and G3 is located downstream of the mining area). This lower flow is expected, as the catchment area increases downstream and there is likely to be increased volume contribution to G2 and G3 from additional runoff, flow from tributary creeks and baseflow discharge. During periods of prolonged dry weather, the reduction in surface flow becomes visually evident as streamflow is diverted into the subsurface and there are sections of the stream which are dry.

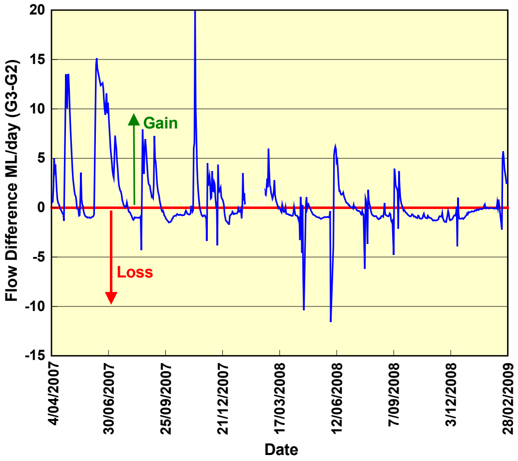

Figure 4. Flow difference between downstream (G3) and mining area (G2) gauging stations.

When the flow data from G1 is subtracted from the flow data from G2, it appears that typically the low flows at G2 are higher than the low flows at G1. Increasing flow downstream is due to incremental contributions from the catchment and baseflow discharge to some or the entire stream length between these two gauging stations. When the flow data from G2 is subtracted from the flow data from G3, the volume of water at the downstream location is lower than the volume of water at the upstream location (Fig. 4). The sharp losses shown in Figure 4 typically occur just before large rainfall events and may represent a lag in travel time.

A number of representative low flow days have been selected from the record and normalised per unit of area for each drainage basin in Figure 5. This figure indicates that the flow on these days is greater at G2 than G3. As these low flows are expected to be dominated by baseflow discharge, baseflow discharge was calculated for each drainage basin bound by the gauging station, by subtracting flow upstream from flow downstream and dividing by the drainage basin area. For G1, baseflow was calculated by dividing the flow at G1 by the drainage basin area bound by G1.

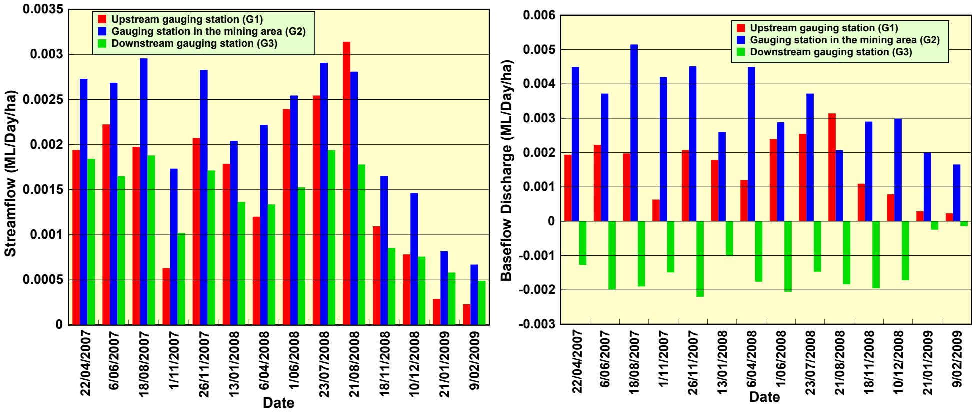

Figure 5. Normalised streamflows during low flows (baseflow discharges) at each gauging station (left) and normalised baseflow discharges at each gauging station (right).

As shown in Figure 5, G1 and G2 have positive baseflow discharge and baseflow increases downstream, except on 21 August 2008, which may be due to rock movements associated with subsidence and the rapid recharge of the shallow aquifer. However G3 is showing negative baseflow during all representative low flows presented in Figure 5, indicating that baseflow may not have discharged between G2 and G3 or streamflow loss is higher than baseflow discharge.

CONCLUSIONS

The following conclusions can be made concerning the impact of longwall mining-induced subsidence on the hydrological flow regimes in the Southern Coalfield catchment discussed in this paper:

- The streamflow changes described in this paper suggests that longwall mining-induced subsidence has enhanced the surface water-groundwater interaction, both laterally and longitudinally;
- A vertical and horizontal extension and enlargement of fractures and bedding planes resulting from the longwall mining activity could explain the loss of flow due to a more inten-

sified surface water-groundwater interaction, and to a greater depth, than would have occurred prior to mining;

- The flow system is both connected-gaining and disconnected–losing over various segments of the main stream;Streamflow losses due to mining dominate during very low to low flow conditions, whereas streamflow losses during medium to high flows are masked by the large volume of streamflow;Surface flow which has been redirected to the subsurface may reappear further downstream or be permanently lost from the drainage basin.

REFERENCES

Carver L., Rauch H., 1994: *Hydrogeologic effects of subsidence at a longwall mine in the Pittsburgh coal seam.* In: Peng S.S. (Ed), Proc. 13th Conference on Ground Control in Mining, West Virginia University, Morgantown, WV, USA, August 2-4, 1994, pp. 298–307.

Dixon D.Y., Rauch H.W., 1990: *The impact of three longwall coal mines on streamflow in the Appalachian Coalfield.* In: Proc. 9th International Conference on Ground Control in Mining, West Virginia University, Morgantown, WV, USA, 1990, pp. 169–182.

Jankowski J., 2007: *Surface water-groundwater interactions in a catchment impacted by longwall mining.* In: Li G. and Kay D. (Eds), Proc. 7th Triennial Conference on Mine Subsidence, Wollongong, November 26–27, 2007, pp. 253–262.

Jankowski J., 2009: *Hydrological changes due to longwall mining in the Southern Coalfield, New South Wales, Australia.* In: Milne-Home W.A. (Ed), Proc. IAH, NSW Branch Groundwater in the Sydney Basin Symp., Sydney, NSW, Australia, August, 4–5, 2009, pp. 107–117.

Jankowski J., Madden A., McLean W., 2008: *Surface water–groundwater connectivity in a longwall mining impacted catchment in the Southern Coalfield, NSW, Australia.* In: Lambert M., Daniell T., Leonard M. (Eds), Proceedings of the Water Down Under 2008, Adelaide, SA, April 14–17, 2008, CD-ROM, 12 p.

Shepley M.G., Pearson A.D., Smith G.D., Banton C.J., 2008: *The impacts of coal mining subsidence on groundwater resources management of the East Midlands Permo-Triassic Sandstone aquifer, England.* Quart. J. Eng. Geol. Hydrogeol., 41, pp. 425–438.

Slaughter C.B., Freethey G.W., Spangler L.E., 1995: *Hydrology of the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, before, during, and after underground coal mining, Water Res.* Invest. Rep., 95-4025, USGS, 56 p.

Tieman G.E., Rauch H.W., 1987: *Study of dewatering effects at an underground longwall site in the Pittsburgh seam of the northern Appalachian coalfield.* Proc. U.S. Bureau of Mines Technology Transfer Seminar, Pittsburgh, Pennsylvania, Information Circular 9137, pp. 72–89.

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