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Modelling the hydrogeochemical evolution of mine water in a decommissioned opencast coal mine

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ABSTRACT

A method for the geochemical modelling of transient contaminant release from rehabilitated opencast coal mines, including calibration against existing data, is proposed. The need for such a methodology is illustrated by a directive received by a decommissioned opencast coal mine in Mpumalanga, South Africa. Groundwater monitoring data, geochemical analyses, numerical flow modelling and geochemical modelling are used to model the hydrogeochemical evolution of mine water over time. Models presented in this study are based on a conceptual model detailing groundwater levels and flow directions, hydraulic conductivities, groundwater chemistry, precipitation, evaporation, surface water bodies and potential sources. Additional to this, mineralogical analyses, leaching tests and acid-base accounting were performed to obtain a better understanding of the site geochemistry. A geochemical model was constructed which was used to obtain a statistically representative mineral assemblage based on laboratory data which was calibrated against leaching test data. This assemblage was simulated in field conditions as input to a numerical flow and transport model. The transport of sulfate was modelled accordingly and sulfate concentrations from monitoring data were used for chemical calibration. Following this, long term contaminant release was simulated. Calibration graphs from the transport model indicated concentrations within a 20 mg/L error margin, showing that the proposed methodology can be used to calculate contaminant concentrations in an aquifer over time within an acceptable range. This approach could provide an improved estimate of the duration of the first flush which, upon completion, will transform decommissioned collieries into large scale reservoirs of utilisable groundwater.

1. Introduction and previous investigations on mine flooding

With coal resources steadily becoming depleted, opencast coal mines in South Africa will approach a period of mass closure, inevitably impacting on groundwater resources (Stacey et al., 2010; Vermeulen and Usher, 2005). Post-mining management and predicting the mine water quality after backfilling opencast coal mines therefore becomes imperative. Although most of the trace elements in the Highveld coals (e.g. Sb, As, Cd, Cr, Co, Cu, Pb, Mn, Hg, Mo, Ni, Se, V and Zn) are considered toxic (Wagner and Hlatshwayo, 2005), they can also be considered an asset and the prediction of their concentrations in discharging mine water, therefore, can be used to identify metal or semi-metal enrichments. Often, the minimum screening method for the potential contamination of groundwater by mining residues in South Africa is acid-base accounting (Wimberley et al., 2007). This method is particularly employed in Mpumalanga, South Africa, where most of the country's coal reserves are mined (Pinetown et al., 2007). However, this method is purely an indication of potential acidity in mine water with no estimate of leachate chemistry or temporal variation (Younger and Sapsford, 2004). Therefore, this study focuses on developing a conceptual model based approach to a long term transient numerical quantification method for the evolution of the hydrogeochemistry from decommissioned opencast coal mines. The need for this type of quantification will be highlighted in this study for a decommissioned opencast coal mine near Carolina, Mpumalanga. There, the local regulatory authorities required the quantification of the first flush from this decommissioned opencast mining operation, as well as the ARD potential of its backfill material.

Various authors already studied the prediction of post-mining water quality in underground mines (Appelo and Postma, 2005; Banks, 1994; Gzyl and Banks, 2007; Wolkersdorfer, 1996; Younger, 2000, 2001; Younger and Robins, 2002). Also the flooding scenario of opencast coal mines has been the focus of scientific studies (Ardejani et al., 2003, 2007a; Dumpleton et al., 2001). However, the focus of these studies was either on abandoned, deep underground mines or metal mines. To date, the quantification of the "first flush" phenomenon (Whitehead

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and Jeffrey, 1995) in backfilled, decommissioned opencast coal mines has not been studied in detail. As the duration and magnitude of the "first flush" in opencast coal mines is assumed to exceed that of underground mines, it is essential to study this effect in more detail. This longer duration is attributed to higher reactive mineral surfaces, slower groundwater flow rates as well as the absence of mine water stratification as it is present in underground collieries (Younger and Sapsford, 2004).

Flooding of rehabilitated opencast mines depends strongly on the type of backfill and how well the backfill has been compacted and the top soils levelled. These before mentioned factors influence the porosity and consequently the recharge rates as a function of the climatic conditions (Hodgson and Krantz, 1998; Reed and Singh, 1986; Singh et al., 1985). In South Africa, the most common practice is concurrent rehabilitation, which is the backfilling and rehabilitation of a previously mined strip, with the overburden of a currently mined strip (Department of Mineral Resources, 2002). This is especially useful in terms of accelerated initial flooding in areas where evaporation supersedes rainfall (Annandale et al., 2001). According to Younger (2000), the flooding time of a mine is one of the factors that controls the duration of its first flush. Consequently, the longer the flooding time of a rehabilitated opencast mine, which is controlled by the hydraulic parameters of the backfill and topsoil, the longer the duration of the first flush.

Based on Webster et al. (2006), the type of pit-lake that may form after cessation of mining is determined by the pit location within the landscape as well as groundwater behaviour within the pit. An adapted classification including the recharge volumes (Hodgson and Krantz, 1998) has been used for this study. When the recharge volumes are relatively high, this results in: recharge pits, flow through pits, discharge pits and drainage pits (Fig. 1).

Pits receiving inflow from the surrounding aquifer, filling and flushing backfill void space, as well as discharging seepage from the rehabilitated pit to the aquifer could potentially become flow through pits or discharge pits, if discharge and high levels of evaporation take place on surface (Fig. 1).

Relatively accelerated flushing may take place in discharge pits and drainage pits, while slower flushing may take place in seepage pits, recharge pits and flow-through pits. Based on the discharge rates, these scenarios will most likely determine the duration of the first flush from a backfilled opencast mine, similar to underground mines (Gzyl and Banks, 2007).

As the backfill material is highly heterogeneous, its hydraulic conductivity will vary substantially and will generally supersede the hydraulic conductivity of secondary porosity aquifer systems (du Plessis, 2010). It can range between 1 m/d and 100 m/d, which is typically 3 to 4 orders of magnitude higher than that of the surrounding bedrock (Younger and Sapsford, 2004). A study by Hodgson (1984) at a rehabilitated colliery near Kriel, Mpumalanga, revealed hydraulic conductivities ranging between 50 and 360 m/d. Additionally, the higher porosity of the material allows storage coefficients in the material likely to exceed 0.01 and could reach values up to 0.25 (Younger and Sapsford, 2004). Due to this heterogeneous nature of the backfill material, preferential flow zones can occur and will cause increased or decreased flow in the backfill material, thus affecting the residence times (du Plessis, 2010).

Younger and Sapsford (2004) stated that "[*essentially*] *all of the environmental problems associated with opencast coal mining* (*including the disposal of the lithic wastes to which it gives rise*) *can be attributed to a single cause*: *the incompatibility between naturally* 'reduced' *coal-bearing strata and the strongly oxidising surface/near-surface atmosphere*". Therefore, Stumm and Morgan (1996) already called pH and Eh the "master variables", which regulate the release of contamination from mining wastes to the largest degree. While "pH (proton activity), which will be determined by the balance between amounts and rates of proton generating reactions and proton consuming (alkalinity generating) reactions",

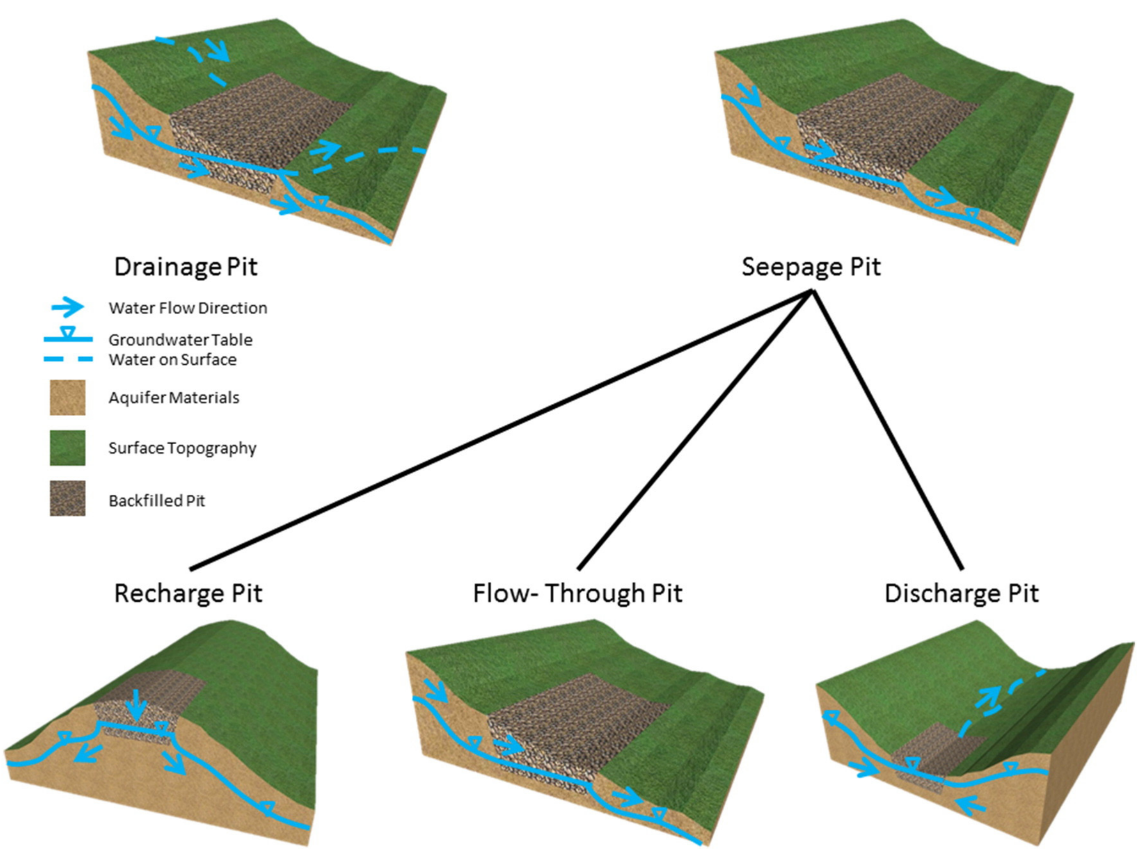

Fig. 1. Potential rehabilitated pit types (modified after Webster et al., 2006).