Financial Modelling for Mine Discharge Treatment Options

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Abstract South Africa is faced with the legacy of environmental impacts due to gold mining which have taken place over 120 years. With the depletion of gold ores, considerable changes to the surface and subsurface water flow pathways have occurred. The generation of acid mine drainage as a result of the oxidation of pyrite and other metal sulphides has led to acidic mine water, elevated levels of sulphate and other toxic metals. This paper discusses the development of financial model for selecting the best treatment option in the East Rand Basin considering the results of an integrated model.

Key words Financial modelling, mine discharge, source apportionment, treatment options

Introduction

South Africa is faced with the legacy of environmental impacts due to gold mining activities which have taken place over 120 years in the Witwatersrand gold mining region. Over time, as economically exploitable gold ores have been depleted and progressive cessation of mining operations have taken place. Gold mining over this period has caused considerable changes to the surface and subsurface water flow pathways. This is due to the influence of historical surface operations, shallow sub-surface mining and deep underground mine excavations. The generation of acid mine drainage as a result of the oxidation of pyrite and other metal sulphides associated with the gold ores has led to acidic mine water, elevated levels of sulphate, and elevated concentrations of mobile toxic metals.

The management of the acid mine drainage poses a major challenge and the Department of Water Affairs (South Africa) conducted a thorough investigation in 2013 into various treatment technology options, their associated costs, risks and maturity levels of each technology (DWA 2013).

In 2011, the Council for Geoscience (South Africa) initiated the East Rand Basin Source Apportionment Study. The mine hydrology, hydrogeology and surface hydrology of the area were modelled by means of a surface run-off model, a regional groundwater model and a mine flooding model. All three the aforementioned models were inter-connected to account for the total water balance and produce an aggregated system response in terms of mass and transport modelling, geochemical speciation and kinetic modelling. A graphic representation of the model framework is shown in Figure 1.

This paper focuses on combining the results of the aforementioned studies to develop a financial model for selecting the best treatment option in the East Rand Basin whilst considering the integrated model results and predicted source-term of the mine discharge.

Study Area

The study area is located in the Gauteng Province of South Africa and covers the East Rand area. In mining terms the area is referred to as the East Rand Basin. Mining in the Eastern Rand portion of the Witwatersrand Goldfields started in approximately 1888 with the Nigel Mines and in 1892 the Van Ryn Estates. The mine lease areas in the basin cover approximately 768 km^2. It is important to note that the East Rand Basin is geographically, hydrologically and hydrogeologically different from the other Witwatersrand mined basins (Scott, 1995).

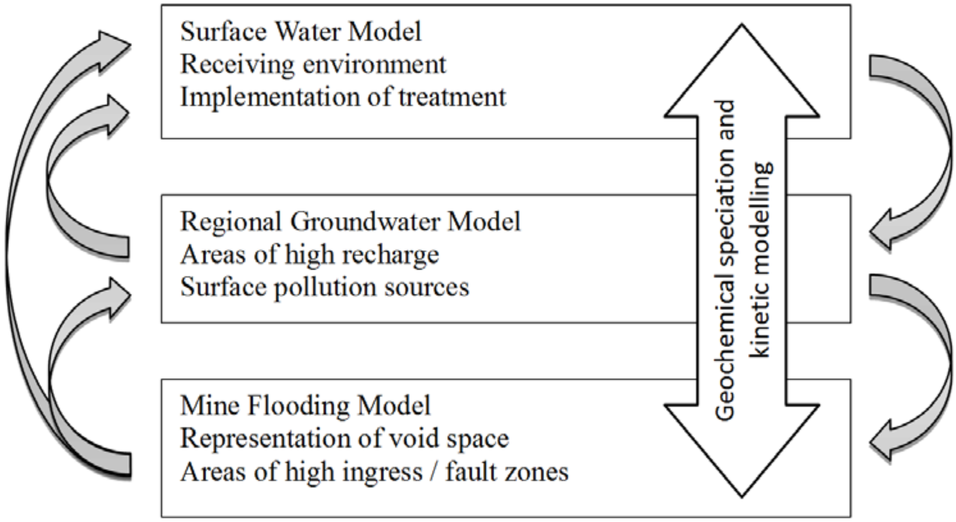

Figure 1 *Integrated model concept for source apportionment study.*

Methodology

DWA (2013) conducted a thorough investigation into various treatment technology options, their associated costs, risks and maturity levels of each technology. The study found that pre-treatment through the High Density Sludge (HDS) process followed by a conventional multistage Reverse Osmosis (RO) would be the most suitable option. To quote DWA (2013): *"The only solution that can be implemented with a low risk is the HDS process followed by conventional multistage RO. The product water by this process train is also the most versatile in terms of re-use options and is most likely to be accepted by the public or industry should it be considered for potable use or re-use. This process train should be analysed in detail, as it is able to address all associated risks, and costs can be assigned to the elimination of the risks."*

To perform financial modelling on various treatment scenarios, the cost of treatment is required for a specific plant configuration. The preferred treatment technology under consideration, is the HDS pre-treatment followed by conventional multistage RO. The HDS has a pre-neutralisation stage (pH 5.5-6.0) making use of a 10% limestone slurry and a neutralisation stage where CaO is slaked and dosed as 10% milk-of-lime slurry into the neutralisation reactor (pH 9). This process train however generates waste product that is stored on a Sludge Storage Facility (SSF) and this should also be taken into account from a financial point of view.

The treatment plant conceptual model is shown in Figure 2. The abstraction volume is assumed to be the capacity of the treatment plant in question. Provision is made in the model to have treated water distributed to water users. All water not distributed to water users are returned to the river for dilution purposes to comply with the desired state of the environment downstream.

Surface water chemistry in South Africa is generally dominated by 3 factors: chemical weathering, chloride salinisation, and sulphate contamination (Huizenga 2011). For the purpose of this study SO_4^{2-} was considered as a conservative tracer in the system. The SO_4^{2-} tracer selection was further motivated by the use of SO_4^{2-} in the field as a tracer next to Tailings Storage Facilities (TSFs), hence the same constituent is used in the financial modelling. A function describing the RO feed SO_4^{2-} versus the RO Permeate SO_4^{2-} was formulated from literature values as a treating function for the proposed plant to illustrate the application of the model based on a dynamic source-term. It is well known that membrane technology is unpredictable in behaviour as it relates to complex water types. It is therefore recommended that pilot studies be conducted with the proposed solution to determine a more accurate treatment function for the model.

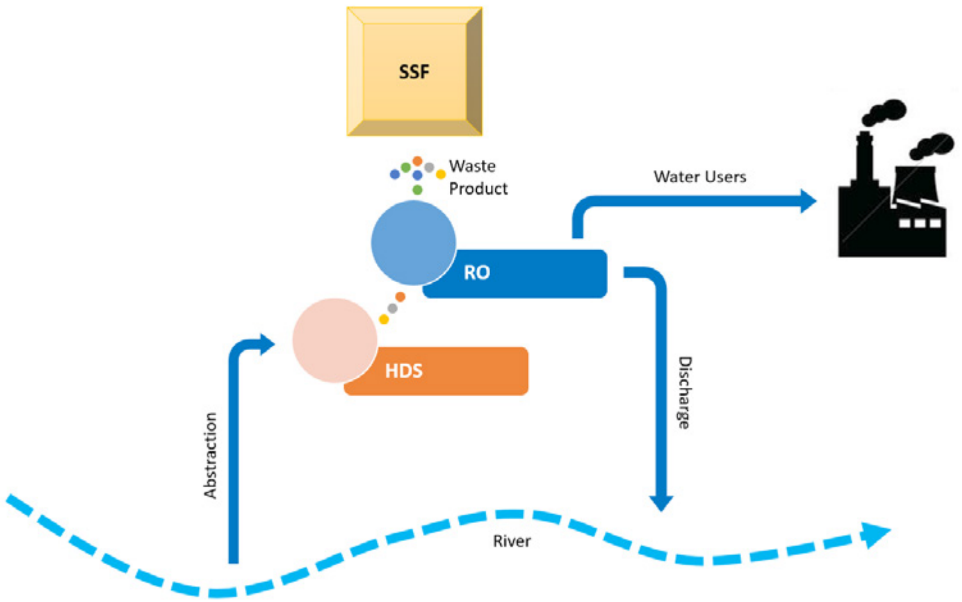

Figure 2 *Conceptual model of treatment plant.*

The DWA (2013) study calculated the CAPEX and OPEX for each of the proposed plant sub-components described in the conceptual model (fig. 2). These cost estimates were conducted for the Western, Central and Eastern basins, with the advantage that each of the aforementioned basins had a different design capacity, feed water composition and the water compositions were reported on the 95th, 75th and 50th percentiles. Analysing the CAPEX and OPEX data, various relationships could be established to formulate the sub-component costs in terms of the required variables. As an example, an excerpt of these relationships for the sub-components are presented in Figure 3 (SSF, electricity and chemical cost relationships omitted). It should be noted that the CAPEX and OPEX data obtained from DWA (2013) is expressed in terms of 2013 Rand values, but the relationships presented in Figure 3 is expressed in 2016 Rand values (2013 values adjusted with a 6.5% inflation rate).

The integrated model already solves for flows and concentrations at various points in an equivalent network, but cannot connect directly to the proposed financial model. In addition to the aforementioned restriction, the integrated numerical model is computationally expensive and requires extended computational time (in the order of a week depending on the scenario), which is not ideal for considering various financial scenarios by decision makers. Hence the selection of base case scenarios based on annual average responses that describe the physical mass-transport network (fig. 4).

The mass-transport network operates on the principal of the conservation of mass as illustrated in Figure 5 (Louck and Van Beek 2005). Note the modelled system represents the steady state solution for the selected base case scenarios and a decay factor k of 0 was assumed, resulting in conservative mass transport. The symbols C_i and V_i denote the concentration and volume respectively for segments i = 1,2,3,…,j of the system (fig. 5).

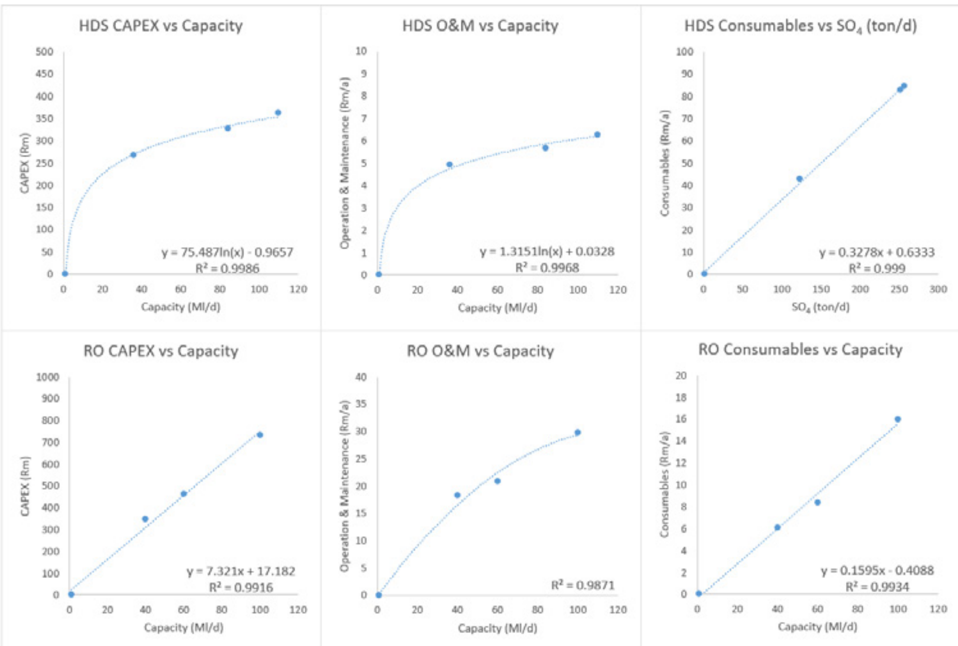

Figure 3 *Example CAPEX and OPEX relationships.*

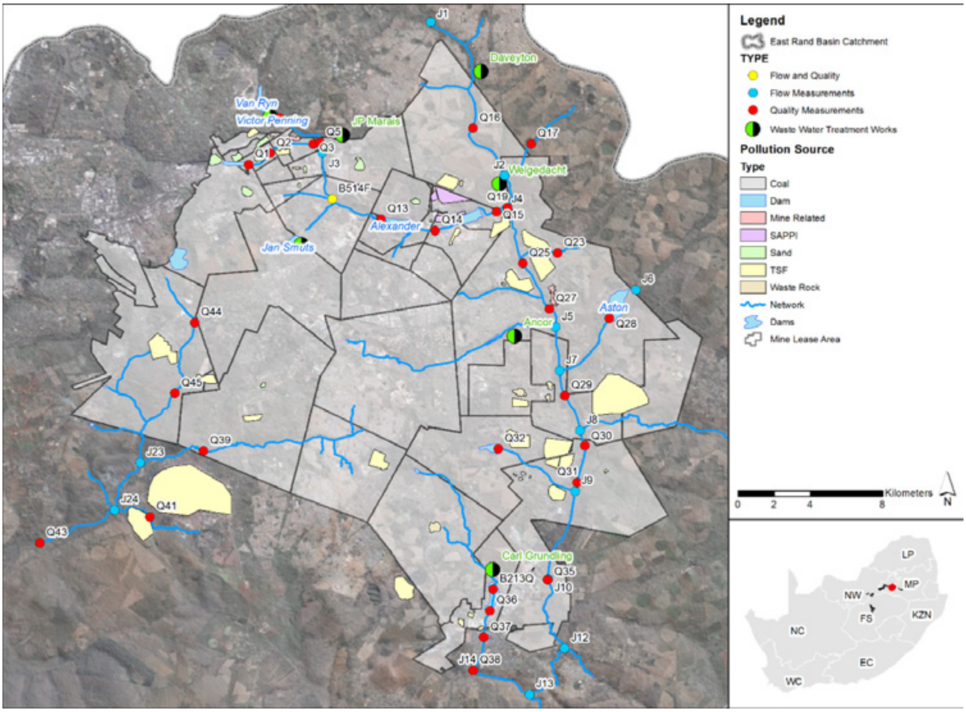

***Figure 4** Physical mass-transport network.*

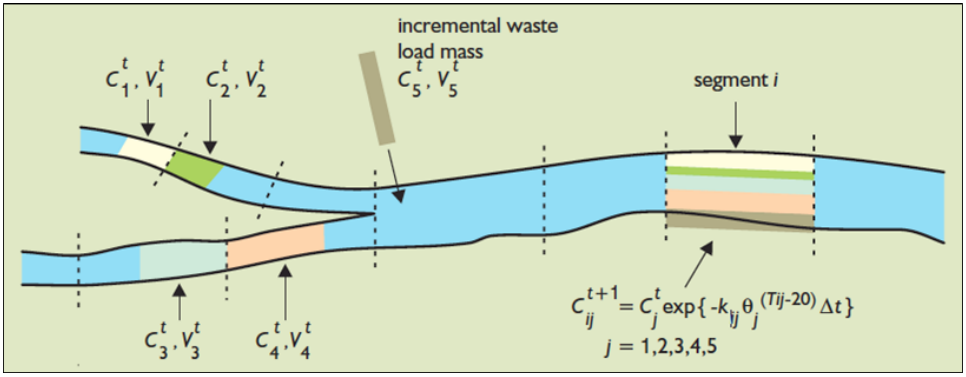

***Figure 5** Water quality modelling approach (Loucks and Van Beek 2005).*

Results

For the purpose of this paper two scenarios are compared based on the desired state of the environment. Each of the following scenarios consider no water sold as well as the maximum amount of water sold without jeopardising the desired state of the environment:

1. Pumping takes place at Grootvlei No.3 Shaft to maintain the Environmental Critical Level (ECL) and pumped water must be treated and discharged in the Blesbokspruit.

2. No pumping takes place in the system and mine discharge takes place at Nigel No.3 Shaft.

Each of the above scenario has a $SO4^{2-}$ source-term and predicted discharge rate associated with it as shown in Figure 6.

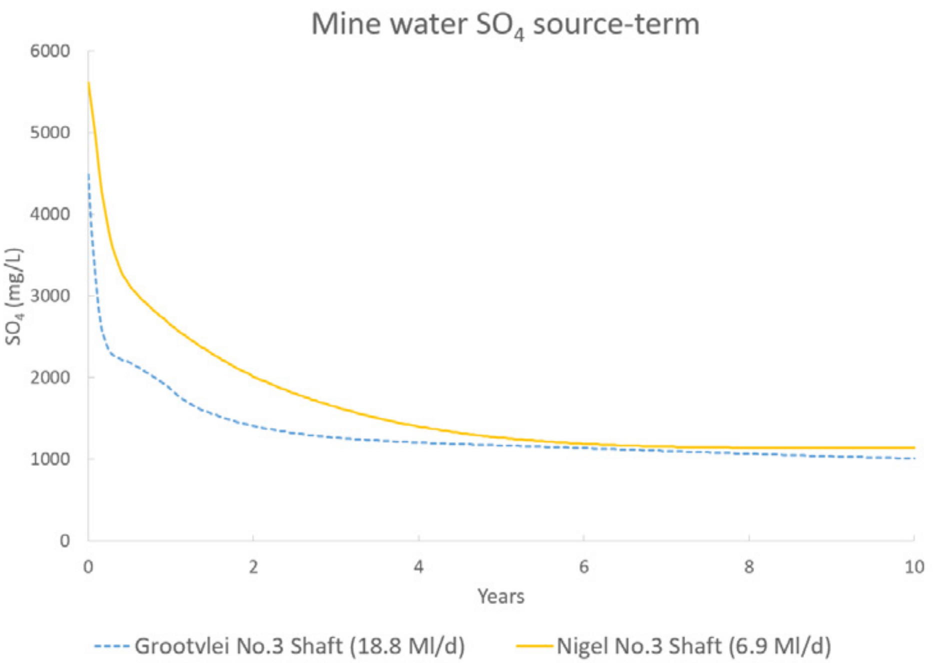

Figure 6 *Water quality modelling approach (Loucks and Van Beek 2005).*

The following inputs were selected for all the scenarios for comparison purposes: general inflation of 6.5%, electricity inflation of 7.5% and an electricity cost of R1.00/kW. The financial modelling resulted in a CAPEX of R1988 million for Scenario 1 and R587 million for Scenario 2. The OPEX expressed in Present Value (PV) per year is shown in Figure 7. A significant reduction in OPEX is achieved in Scenario 1 by selling 18.8 Ml/d treated water at cost. No water is available to sell in Scenario 2 to allow for maximum dilution required to meet the desired environmental state.

Conclusions

Using the base case scenarios obtained from the integrated model and the application of the developed financial model that accounts for a dynamic source-term, various scenarios can be tested to obtain the most cost effective solution. The developed financial model is not area specific but rather technology specific and the same approach can be applied in other areas, but economic indicators must be taken into consideration.

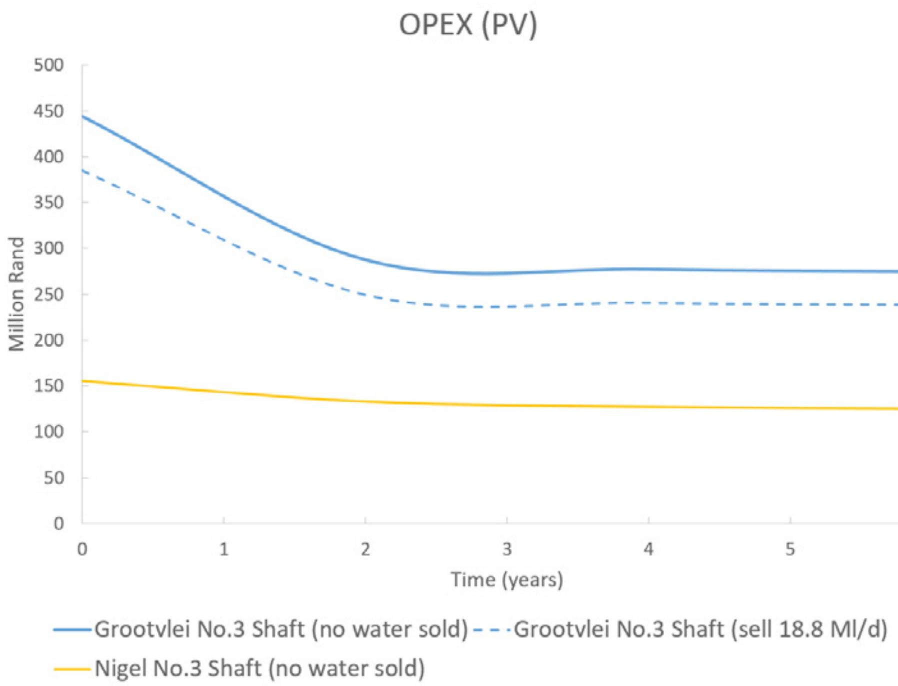

***Figure** 7 Water quality modelling approach (Loucks and Van Beek 2005).*

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