An alternative approach to managing dewatering in an open pit mine

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Abstract

The application of simple, practical tried and proven techniques resonate at the heart of any large scale mining operation. As groundwater practitioners in the mining industry we need to be adaptive and possess tools with the flexibility to enable 'on the run decision-making' that will meet the timeframes required of an operational mine site. Often it is the proponent's preference to adopt a single groundwater flow model to meet all phases of mining development (approvals, construction and operational) with the view that it will minimise costs and save time. We argue that a multi-model 'fit for purpose approach', while appearing counter intuitive, is a simpler and better option.

Keywords: analytical superposition model, dewatering estimates, open pit mining

Introduction

The arrival of the personal computer, in the early 1980s and the subsequent development of groundwater software codes, into mainstream hydrogeology revolutionised the way that we, the practitioners of hydrogeology, went about our work. Numerical modeling codes such as MODFLOW (McDonald and Harbaugh, 1988) gave us the capability of solving large regional groundwater problems where previously we had relied on simple analytical or empirical approaches. These new tools were instantly appealing. User friendly front ends and back ends attached to these codes allowed us to easily input and process large data sets. More importantly it gave us the ability to communicate results, such as changes in regional flow systems over time that couldn't previously be done easily. This change has occurred in a very short time frame ~ 30 years and we have learnt a lot along the way. Recently published literature, suggests however, we still have some serious thinking to do in terms of context (see articles by Voss (2011a, 2011b) and content with regard to the applications of mathematical models (Hunt and Zheng, 2012).

One area we believe that has suffered through this period is that we have deviated from the cornerstone of scientific process; the scientific method. As scientists in hydrogeology, we are required to observe data, make generalisations through the development of a conceptual model and then test this hypothesis by attempting to replicate it using some form of mathematical modeling. It is our observation that we have become overly absorbed in mathematical modeling and that too little time is spent on, the most important part of the process, the conceptualisation.

Prior to the development of computational numerical modeling methods, groundwater problems in the mining industry were largely solved through analytical and empirical methods or based on experience and the 'thumb suck'. The results generated via these methods were quick but basic and there was generally little effort to quantify the uncertainty in the numbers produced. This, however, fitted well with the requirements of the mine industry at the time. The new age of numerical models has enabled increased hydrogeological complexity to be incorporated into models. But along with it has come additional expectations from the industry. No more is it acceptable to produce a one number result derived from some 'dark art' hydrogeologist. The industry requires quantification, stochastic and subjective, of the uncertainty and we need to be able to deliver.

With increased complexity in a numerical model, however, comes increased cost in its development and longer model run times. These models are generally run by specialist modelers who are located external to the mine operation and in lieu of an appreciation of 'on the ground' logistics.

In Western Australia the highest level of hydrogeological assessment stipulated by the regulator states an appropriate analytical or numerical model should be used to predict impacts (DoW, 2009). The analytical modeling option, however, seems to be given little consideration. This is possibly because we may have become used to doing our work one way and numerical modeling is the only tool we have in our tool box.

We think it is timely to reflect upon the impact numerical models has had on our approach to servicing our clients and in particular those in the mining industry. We are not trying to demonise numerical models. We are, however, questioning where they best fit in the mining process. Questions that we need to consider include: What are we trying to achieve and are we delivering what the industry needs? Are we going about it in the best way? And, are there other tools out there that can help? We do not pretend that we answer any of these questions to any great detail in this paper; we are simply attempting to raise them to create awareness and, hopefully, drive further debate.

One tool that could help in mining is analytical superposition models. They differ from simple analytical methods in that spatial drawdown of multiple pumping bores can be modelled based on superposition. It is a relative newcomer to the mining industry but there are benefits in terms of capability and speed (Haitjema, 2011). The focus of the subsequent discussions in this paper reflects on the application of this method at an unnamed iron ore mine in Western Australia.

Methods

Hydrogeological related works on mine sites can be divided into three pathways; regulatory approval, construction, and operational.

- *Regulatory approvals* works typically include a field program consisting of drilling and aquifer testing; the development of a preliminary conceptual model followed by some form of mathematical modelling, either analytical or numerical. The outputs from which are used to estimate drawdown impacts and pit inflow rates as a result of mining related dewatering operations.
- *Construction works* are a precursor to the mine becoming operational. Hydrogeological works are generally related to suring up the water supply to meet:

    - Water demand for construction of the mine site (rail, roads, dust suppression and camp water supply for example); and,
    - water demand once the mine becomes operational (e.g. water supply borefield).

  Additionally a dewatering strategy will be developed and installed including a reticulation system to remove the dewatered mine water.

- Works on an *Operational* mine site typically involve:
    - meeting mine dewatering targets;
    - managing on-going water demand for the mine site;
    - potentially the discharge of any excess water; and,
    - regulatory governance and reporting.

Regulatory Approval

Hydrogeological works undertaken as part of gaining regulatory approval are aimed at assessing the impacts of mine related groundwater pumping on the groundwater resource, existing bore owners and, arguably, and more importantly, on environmentally sensitive receptors. These works are obviously undertaken prior to the mine site gaining approval to dewater. The hydrogeological conceptual model is at best preliminary and is generally based on limited field investigation. A mathematical model is constructed with the purpose of predicting the likely extent of the drawdown impacts related to the mine activities. The results generated can be conservative. That is, there is a tendency to under estimate drawdown effects rather than over estimate. The aim is, after all, to obtain environmental approval for mining to proceed. There is no judgement of the ethics behind this; the models are based on the available science at the time and are within the limits of uncertainty.

A hydrogeological report is produced detailing the results of the field investigations, conceptualisation, the mathematical model and predictions. The report is submitted to the appropriate regulator as part of the environmental approvals process.

Construction water supply

Whilst awaiting environmental approval, construction works begins. Hydrogeological works typically involve:

- drilling and aquifer testing focussed in the area of the mine footprint itself. The purpose of these works is to better understand the local hydrogeology and to provide parameters to input into the mathematical model.
- by this stage the first (of many) mine plans has generally become available. Modelling continues with the same focus as the field investigation. ‘Bores’ or ‘sumps’ are added to the model to develop a dewatering strategy that will meet the initial part of the mine plan. The dewatering strategy may include in-pit, ex-pit bores, horizontal bores, sumps or a combination of these to name but a few.

Once the main infrastructure is in place and approvals granted the mine starts to pre-strip; removing the non-economic geology. In terms of further hydrogeological field investigations access starts to become an issue. There is competition for space in the mine footprint, for drilling rigs and even camp space amongst others.

There is also competition for money to undertake further hydrogeological works. Mineral exploration drilling to determine the extent of the economic ore zone takes precedent. These works are usually undertaken using RC drilling methods and are considerably cheaper than the cost for hydrogeological drilling works. The hydrogeological costs can, therefore, appear problematic and become more difficult to justify. As the focus is toward mineral exploration drilling of the ore zone there is a general lack of interest in gathering any information other than the ore and, hence, little data is collected proximal to the orebody itself. And in some cases there is a lack of people with the experience in the business to drive the case for increased hydrogeological data collection.

With regard to water related mine infrastructure design much of it may have been based on the earlier initial hydrogeological works. So pumps, pipe diameters, in fact the whole mine water balance could have been based on limited information obtained during the environmental approvals phase. There are numerous examples of this having occurred in the mining industry and the cost to rectify has proved high. There are a number of issues that can lead to this situation; using the initial numerical model results from the environmental approvals process is one, lack of further investigation is another. Poor communication by hydrogeologists in terms of the degree of uncertainty involved in the dewatering estimates, or indeed overselling the estimates is arguably another. The reality is that, in terms of achieving dewatering targets, the estimates could still be an order of magnitude either side of what the science or the 'best guess' is saying.

Operational Mine

If all goes to plan regulatory approval is obtained, construction works have been completed and the mine becomes operational. It is at this point, when dewatering actually begins, there is the realisation that the original dewatering estimates bear little resemblance to what is actually occurring on site. This situation is all too common, and the reasons are many fold. Typically until large scale dewatering begins (i.e. 'suck it and see') no one really knows what is going to happen, particularly the effects of storage. In terms of the model it may have been calibrated against observed transient data but when there is little change in water level over time (i.e. there is no stress on the aquifer) the groundwater level at any point is a function of any combination of hydraulic conductivity, recharge and storage (i.e. the solution is non-unique).

So what to do? After the finger pointing at the end of the day the pits still need to be dewatered. The obvious solution would be to re-run the mathematical model but this is not always practical and may be incompatible with the need to keep the pit dry and the time required to recalibrate the numerical model.

Analytical Superposition Method

Analytical superposition models are based on the superposition of analytical functions and include models based on the analytic element method (Strack, 1989). The advantage of the analytical superposition method is that it can be used in a regional context. The potential applications of using such models to the mining industry have been highlighted by Kelson et al (2002). A comparison of simple analytical (e.g. Theis), analytical superposition, and numerical model techniques are summarised in Table 1. A comparison of analytical (e.g. Theis), analytical superpostion, and numerical model techniques are summarised in Table 1.

Table 1. *Model technique attributes comparison.*

	Analytical	**Analytical Superposition**	**Numerical**
Solution of the governing equation	Exact	Exact	Approx.
Representation of boundary conditions	Exact	Approx.	Approx.
Suitability for complex hydrogeology	Low	Low to Medium	High

Modified after Kraemer, 2007

The analytical superposition method, therefore, has the added capability of analysing the impacts of multiple pumping bores based on the principle of superposition. Boundary conditions can be added, either no flow or constant head; variable pumping rates can be used and bores can be turned on and off. The model can also be calibrated using observation data.

Analytical superposition models are comparatively easy to use and can give reliable results in a relatively quick timeframe. They can be an effective management tool that can be used on-site. Thereby removing the reliance on complex, time consuming, numerical models that are generally run off-site. Strictly from a hydrogeological perspective application of this approach depends largely on the conceptualisation. The argument, however, is that if it works and represents what is happening and communicates what is going on why not use it?

Results

To test the applicability of the analytical superposition method a case study of an operational mine located in Western Australia was constructed using the following conceptualisation.

Conceptual Model

The majority of Western Australia's mined iron ore is associated with three deposits; mineralised Brockman Iron Ore Formation, Marra Mamba Iron Formation and Channel Iron Deposits. These ore deposits, because of the mineralisation are generally permeable and are normally bounded by very low permeability unmineralised basement rock formations.

When mining goes below the water table, and dewatering begins, water inflow occurs from the surrounding formations towards the mining excavation. Understanding the groundwater regime, particularly the hydraulic properties, in and around the mine pit is important to determine water inflows to the mine pit. Thus, hydrogeological characterisation of a mine site is required to determine dewatering rates and to assess potential impacts from the dewatering operation. In general the groundwater studies associated with the mining activity is to achieve the following:

- estimate the pumping rate required to dewater the ore body;
- evaluate the potential impacts to surrounding groundwater systems and other environmentally significant groundwater users;
- increase overall understanding of the groundwater system and the water budget;
- simulate re-injection of excess dewatering discharge;
- estimate a pit filling rates during closure and predict a post-closure equilibrium pit lake elevations and groundwater quality; and,
- evaluate the potential for post-closure pit-lake flow to the surrounding groundwater environment.

Once a mine is operational and dewatering has commenced, the major issue is making sure the dewatering keeps up with the mine plan. This can be achieved using analytical superposition modelling. The dewatering approach for mine deposits is to maintain groundwater levels below the pit floor in advance of mining and throughout the life of mine operations. The hydrogeology of the mine used in this study comprises high permeability mineralised Marra Mamba Iron Formation ore, approximately 80 metres in thickness, bounded by very low permeability basement rock along the southern boundary. The ore zone is about 300 m wide and continues in an east-west direction. To the north the hydrogeology comprises permeable shale and alluvial deposits. Conceptually the area is described as an open unconfined aquifer system with a low permeability hydraulic boundary to the south.

During mining the sources of inflow to the operational pit will be from:

- groundwater storage of the system;
- inflow through surrounding alluvial deposits; and,
- direct inflow from precipitation.

Model construction

To represent the aforementioned conceptual hydrogeological system, an analytical superposition model was constructed using AQTESOLV (Duffield, 2007). The model has one layer, 80 thick, in an open infinite system with a no flow boundary condition at the southern extent of the model domain. Dewatering was achieved via five production bores. The bores were located in-pit. No bores were operational 100 % of the time and to save model running times daily abstraction rates were averaged over monthly time steps. Recharge was not modelled.

Calibration

As mentioned, the mine related to this case study is operational and, therefore, water level and pumping abstraction data were available. The constructed analytical superposition model was calibrated to transient drawdown water levels observed in monitoring wells located in-pit and ex-pit. The results of the observed versus modelled drawdown is show in Figure 1.

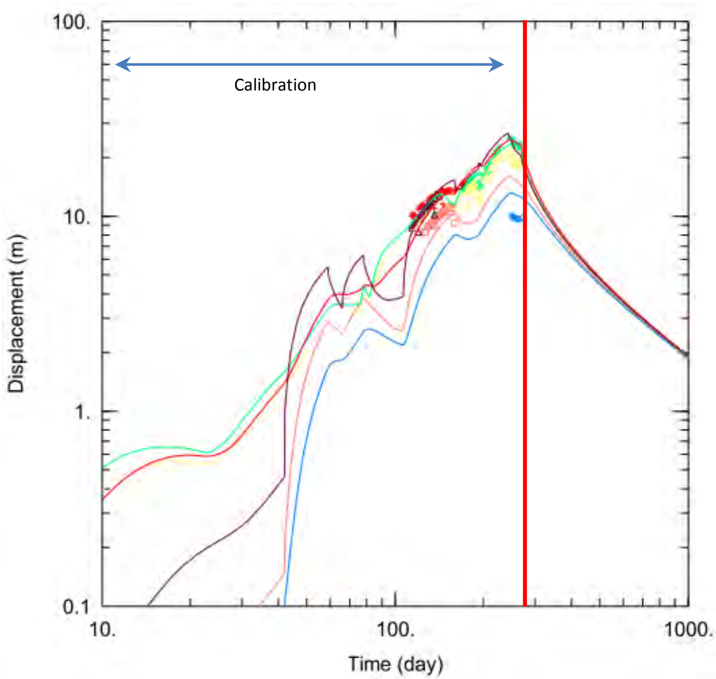

Figure 1 *Model calibration*

The calibration results suggest that the measured groundwater level response is reasonably well replicated by the model. Calibration was achieved using a combination of 'trial and error' and auto-calibration techniques. Once calibration was achieved, the model was used to predict drawdown under various dewatering scenarios. The predictive simulations were carried out by adding pumping stresses to existing bores i.e. by implementing active dewatering in the model. Additional bores could have been added to test alternative pumping scenarios if required. Two predictive simulations are presented and are described as follows:

- prediction simulation 1 was carried out utilising three production bores with cumulative abstraction of 3 ML/day. The results indicate that the predicted drawdown of approx. 50 m will be achieved by the end of 10,000 days.
- prediction simulation 2 was carried out utilising five production bores with cumulative abstraction of 5 ML/day. The results indicate that the predicted drawdown of approx. 80 m will be achieved by the end of 10,000 days.

The results are shown in Figure 2 and Figure 3.

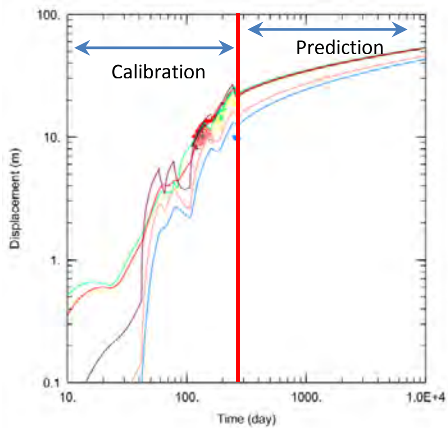

Figure 2 *Predictive simulation 1*

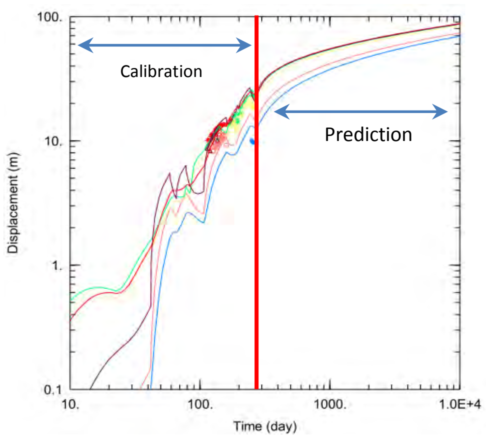

Figure 3 *Predictive simulation 2*

Conclusions

As a comparison of the analytical superposition model results, a groundwater flow model was developed using the numerical finite difference groundwater modelling code Modflow. The model consists of 350 rows and 500 columns with a saturated aquifer thickness of 80 m as per the analytical superposition model. The same conceptualisation and aquifer parameters were used in both models. The no flow boundary condition at the southern extent of the orebody in the analytical superposition model was simulated by low permeability in the numerical groundwater flow model.

The transient calibration simulation was performed to observe the water levels measured in the monitoring wells due to the abstraction carried out in the mining area. The calibration results indicated that the measured groundwater level response is consistent with analytical model results. The results of the observed versus modelled drawdown is shown in Figure 4:

The scope and complexity of water resource problems are generally associated with scale, time and geometry. But in the case of limited data availability and high uncertainties, it has been shown that the analytical superpostion method can give similar results. From the miner's perspective the requirement is reliable estimations of dewatering rates that will ensure a dry pit and to use in the design of the dewatering.

Comparison of the model results shows the same standard of delivery in terms of predictive output was achievable through analytical superpostion models as could be achieved in by numerical modeling. This outcome is not unexpected, as both models are based on a simple hydrogeological conceptualisation. For example there is no vertical flow component (i.e. there are no layers). The purpose of this exercise was not to validate the analytical superposition method but to simply show it could achieve the same result as numerical modeling.

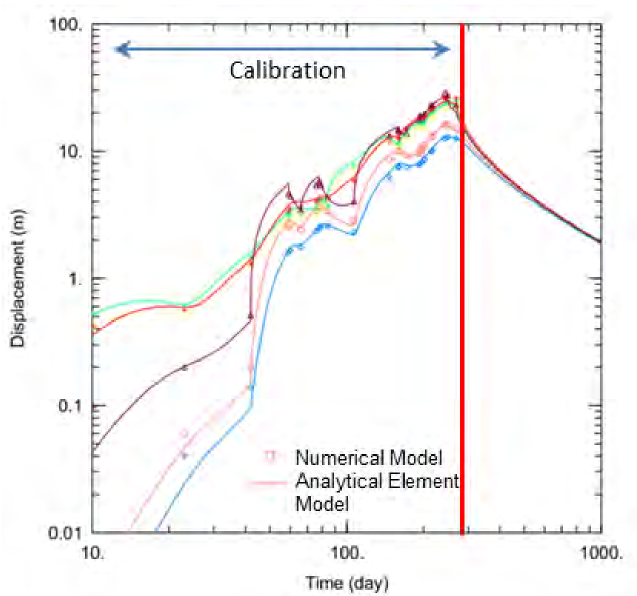

***Figure 4**. Comparison of analytical and numerical results*

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The conclusion here is that the analytical superposition method approach may be a useful tool in mines that are conceptually suitable. The number of analytical superposition software packages available on the market are currently quite small. However, their capability is becoming increasingly more sophisticated and easier to use.

Analytical superposition models can be used on site without the reliance of more complicated, time consuming and costly numerical models that are generally run external to the operation in lieu of an appreciation of 'on the ground' logistics. The argument here is- if it works and is representative; the application of analytical techniques has the potential to serve as an extremely powerful management tool.

We are of the opinion that tools such as analytical superposition models could be of benefit to the mining industry, particularly on operational sites. We also believe that there is an overemphasis in the use of numerical models and as such we are not giving the mining industry what is needs. Delivery could be improved by implementing the following:

- reassess overall hydrogeological requirements for the mining industry;
- hydrogeological works should have a more rounded approach and in context of delivery for the whole life of a mine. That is there is a recognition work is not over just because environmental approval has been obtained;
- consider reducing complexity in initial modeling either through using simpler numerical models or analytical superposition models; and,
- do not automatically assume the regional model used to obtain environmental approval will be useful to assess mine dewatering strategies. Consider using more than one model particularly at the operational phase.

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