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IMWA INSIGHTS

Groundwater Flow Models in Open Pit Mining: Can We Do Better?

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Abstract When do issues of complexity outweigh the practicality of experience-based judgement? Prior to the arrival of computer-generated flow models, heurism and the application of simple, practical, tried-and-proven techniques resonated at the heart of any mining operation. With the current reliance on overly designed and time-intensive numerical models, are we meeting what the miner needs? As hydrogeological practitioners in the mining industry, we need to be adaptive and possess tools that allow 'on the run decision-making' that can, quickly and effectively, meet the time frames required by the miner, at each stage of mine development. A more appropriate strategy would be to adopt a 'right tool for the job' approach using models that target specific areas or stages of mine development. This will potentially result in multiple models that overlap in time and space. Furthermore, in the process of selecting an appropriate model, the hydrogeologist needs to be cognisant of the levels in accuracy required from the model; it should be commensurate with the detail built into the conceptual model. This should guide selection of the model solution and the complexity of the model. The approach is discussed, using an actively dewatered open pit mine and the application of the analytical superposition modelling method as an example.

Keywords Scientific method · Mathematical models · Open pit mining · Analytical superposition model

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Introduction

The introduction of computer-aided technology into mainstream hydrogeology in the early 1980s revolutionized the way we, the practitioners of hydrogeology, went about our work. Numerical modeling codes such as MODFLOW and FEFLOW (Diersch 1992; McDonald and Harbaugh 1988) enabled us to address complicated groundwater problems where previously we had relied on simpler methods such as flow net analysis or simple analytical models.

Computer-generated flow models were understandably instantly appealing. The development of user-friendly graphical user interfaces linked dynamically to model codes allowed for easy input and processing of large data sets. It also gave us the ability to provide outputs, such as predicting changes in regional flow systems over time, with visually impressive and persuasive figures.

The acceptance and adoption of these new tools has occurred rapidly, over a period spanning less than a generation. Contemporary literature, however, suggests that the process can be improved, particularly in terms of providing a more philosophical context to the development of numerical models Voss (2011a, b). We concur and argue that there is a disconnect in the modeling process due, in part, to the rapid adoption of these new tools, and that there is now an over-reliance on the numerical modeling approach. The loser in all this has been the scientific method, the cornerstone of the scientific process.

The scientific method requires us to observe data, make generalizations through the development of a conceptual model, select an appropriate model solution, test the hypothesis by attempting to replicate the process using the mathematical model and, if we are satisfied, use it to undertake predictive scenarios (Fig. 1). However, in mining,

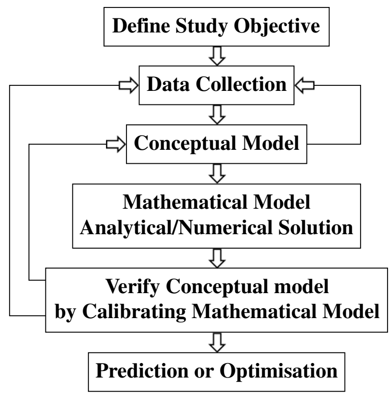

Fig. 1 Scientific method flow chart

this typically manifests as one conceptual model with one accompanying deterministic numerical model. By adopting a one-model-fits-all numerical approach to modeling, we are circumventing the process and not selecting the most appropriate model solution. This paper discusses the implications of this in the wider context of mining, using a superposition analytical model at an operational open pit mine that is being actively dewatered as an example.

Common Shortfalls

There are common and recurring shortfalls in the current approach to models in mining. These can be summarized as:

1. *Insufficient hydrogeological investigation* In particular, a reticence to undertake planned on-going field programs following completion of initial work, due to cost pressures.
2. *Lack of conceptualization* Insufficient resources and time spent in the development of the conceptual model and consideration of alternative conceptualizations.
3. *The one mathematical model approach* Assumes that one mathematical model will meet all the mine's modeling requirements.
4. *Unnecessary complexity in the model* Unwarranted complexity in the model, especially in early models, that do not match the level of understanding.

A Solution

The current approach of using one conceptualization and an accompanying deterministic numerical model to meet all of a mine's modelling requirements is ill founded. Specifically, there are issues of scale; the original model developed for environmental approvals was designed to assess regional impacts. The model is therefore too cumbersome and in terms of running times, unsuitable for smaller-scale modelling projects such as determining a dewatering strategy or assessing progress in a pit that is being actively dewatered.

An alternative for smaller-scale model projects in mining are analytical superposition models, which are based on the superposition of solutions to analytical functions. The potential applications of using these models to the mining industry have previously been highlighted by Kelson et al. (2002). We include models based on the analytic element method (Strack 1989) under the umbrella of analytical superposition models because the principles are very similar. Theoretically, analytical element models are, however, not transient. The advantage of analytical superposition method models are that they can be used to simulate abstraction spatially using multiple bores with variable pumping rates under transient conditions. Also, in addition to analyzing the impacts of multiple pumping bores, boundary conditions can be added, either no flow or constant head, and the model can be calibrated using observed data.

The advantage of analytical superposition models over numerical models are they are generally easier to use and can produce comparable results in a relatively quick timeframe. They, therefore, can be an effective management tool that can be used on-site, removing the reliance on complex, time-consuming, numerical models that are generally managed off-site. Simple analytical (e.g. Theis solution), analytical superposition, and numerical model techniques are compared in Table 1.

In context with the scientific method and selecting the most appropriate mathematical model, application of the superposition method depends on conceptualization. However, if it works and simulates what is happening within levels of understanding, and hence confidence, then why not use it?

Conceptualization

The suitability of the analytical superposition method was tested at an operational open pit mine. The site is an open pit mine approximately 500 m wide and 1,000 m in length that is actively being dewatered. The aquifer is unconfined but there is a very low permeability hydrogeological barrier

Table 1 Comparison of model technique attributes

	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)

located along the 1,000 m length on the southern side of the pit. The mine is located in an arid environment. Rainfall recharge was considered negligible and was not modelled.

Model Construction

The conceptual model was represented in an analytical superposition solution constructed using the AQTESOLV interface (Duffield 2007). The model comprises a single layer in an open infinite unconfined aquifer with a no-flow boundary condition located along the length of the southern edge of the pit. Dewatering was simulated via five in-pit production bores. The mine is operational and so water level and pumping abstraction data were therefore available.

Results

The analytical superposition model was calibrated to transient drawdown levels observed in wells located in-pit and ex-pit. Calibration was achieved by trial and error with just two parameters: hydraulic conductivity and storage. The results of the observed versus modeled drawdown is shown in Fig. 2. 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 the existing bores. The calibration results suggest that the measured groundwater level response is reasonably well replicated by the model.

Additional bores could have been added to test alternative pumping scenarios if required. Two predictive simulations are presented; he results are shown in Figs. 3 and 4.

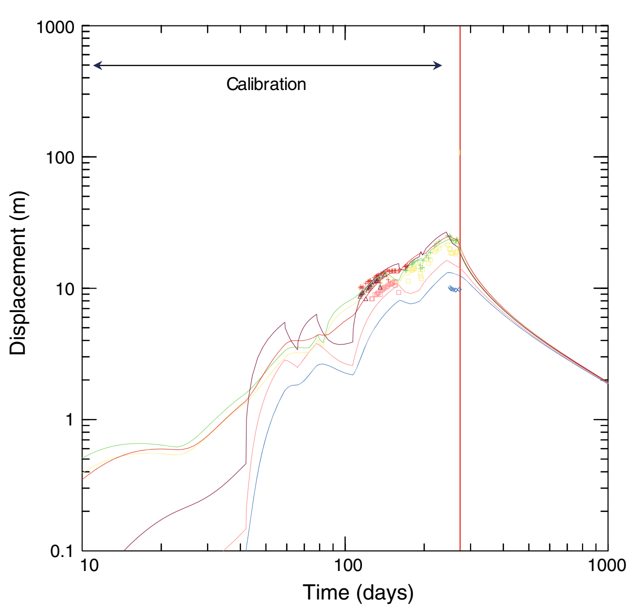

Fig. 2 Model calibration

(1) Simulation 1 was carried out utilizing three production bores with cumulative abstraction of 3 ML/day. The results indicate that a predicted drawdown of approximately 50 m will be achieved by the end of 10,000 days.

(2) Simulation 2 was carried out utilizing five production bores with cumulative abstraction of 5 ML/day. The results indicate that the predicted drawdown of approximately 80 m will be achieved by the end of 10,000 days.

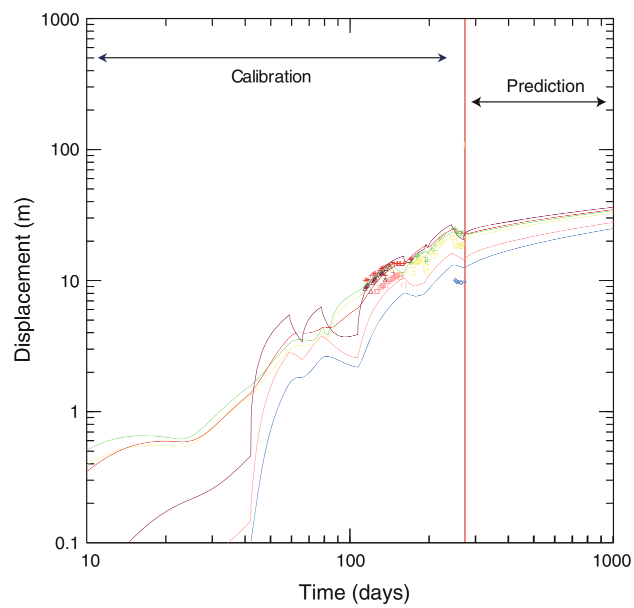

Fig. 3 Predictive simulation 1

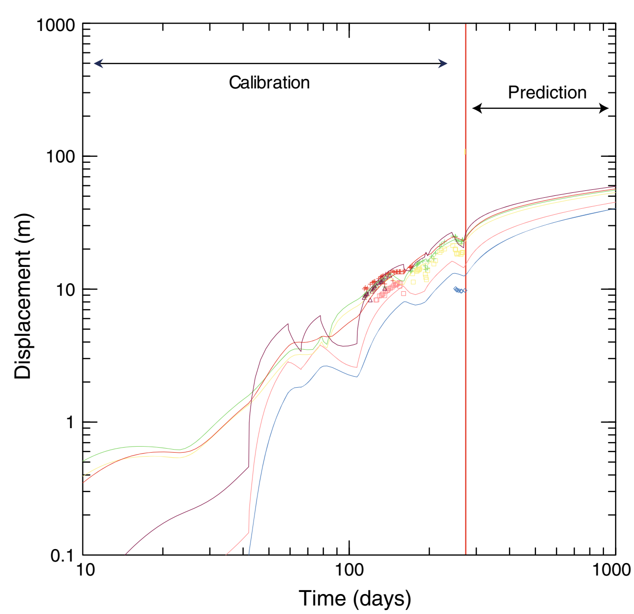

Fig. 4 Predictive simulation 2

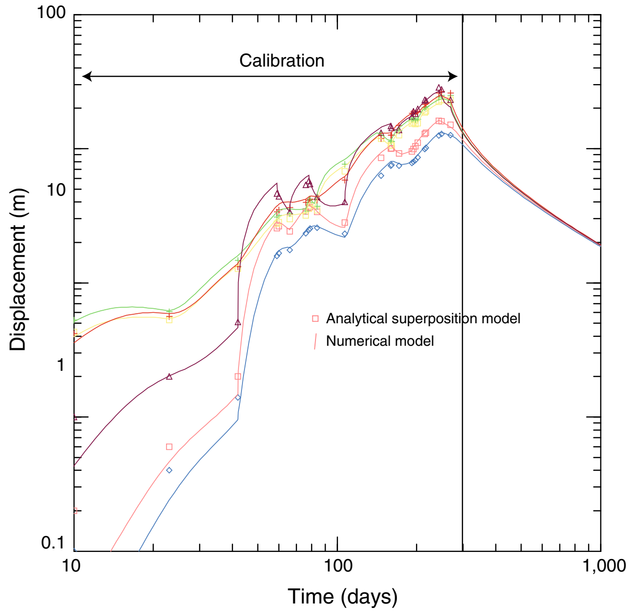

Fig. 5 Comparison of analytical and numerical results

Some Corroboration

A numerical finite difference MODFLOW (McDonald and Harbaugh 1988) groundwater model was constructed using the same conceptualization and design to enable a comparison with the results from the analytical superposition model. The model consisted of 350 rows and 500 columns with a saturated aquifer thickness of 100 m. The numerical modeling results are consistent with the analytical superposition model results, as shown in Fig. 5.

Comparison of the model results shows that the same level of prediction was achievable through analytical superposition models as was achieved by the numerical model. This was not unexpected in this example, since both models were based on a simple hydrogeological conceptualization. For example, there was no vertical flow component (i.e. each model consisted of only one layer).

Discussion

The scope and complexity of water resource problems in mining are generally associated with scale, time, and geometry. But in this example, with limited data availability and a high degree of uncertainty, the analytical superposition modeling method arguably gave outputs that would allow effective management of mine dewatering.

The application of analytical mathematical methods can potentially serve as a useful management tool, particularly at operational mine sites. Such tools allow for quick assessment of dewatering targets and meeting the mine plan. This modelling approach allows site personnel, with minimal training, to run the model themselves using the AQTESOLV interface without the reliance on more complicated, and potentially time-consuming and costly numerical models that are generally run external to the operation by dedicated modelers in lieu of an appreciation of on-the-ground logistics. The argument here is, if it works, then use it.

Conclusion

Delivery of practical modeling solutions can be improved at many, perhaps most, mine sites by implementing the following strategy:

1. Develop an integrated modeling strategy for the life of a mine. This will potentially result in multiple models, each addressing specific groundwater issues. These models may be used in overlapping spatial areas or identical periods of time; that these models result in different sets of 'numbers' is not an unresolvable dichotomy.
2. Closer adherence to the scientific method to ensure that consideration is given to selecting the most appropriate mathematical solution that best matches model objectives.
3. Consider reducing complexity in initial modeling, either through using simpler numerical models or analytical superposition models that are commensurate with the level of understanding.

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