Incorporating 2D Analytical Results into 3D Graphical and Multidisciplinary Mining Models

Hannah Redfern, James Catley, Grace Yungwirth

Golder Associates (UK) Ltd., Suite 9.10, 20 Eastbourne Terrace, London, W2 6LG, UK,
hredfern@golder.com, jcatley@golder.com, gyungwirth@golder.com

Abstract

Front end mining studies inform the project development process by assessing key risks and developing an increased understanding of the available site data. 2D analytical models can be appropriate to support hydrogeological assessments during early studies given the level of data available, and the level of confidence required. Incorporating these results into a 3D model can transform a simple methodology into a visual representation which can be integrated with other aspects of multi-disciplinary studies. This methodology incorporates groundwater flow analyses into a 3D surface within standard industry software, Leapfrog Works™, to support an assessment for a proposed open pit mine.

Keywords: Mine water, Pit Inflows, Groundwater, Geotechnical, 3D Visualisation

Introduction

To support Pre-feasibility Studies (PFS) for open pit mining projects, simplified 2D analytical groundwater flow analyses are often used to estimate the potential seepage into the pit, as well as the extent of the cone of depression of the phreatic surface around the pit which is used to inform the understanding of water management measures needed during mining. The results may be incorporated into preliminary geotechnical slope designs as well as used to indicate the likely water management measures needed to stabilise pit slopes. During a recent Golder project, a simple analytical solution, developed by Marinelli and Niccoli (2000), was used to calculate pit inflows and steady state drawdown at representative sections around a proposed open pit. A workflow was created to incorporate these 2D results into a 3D surface for use in the project's Leapfrog model (Seequent Limited 2021), to show the mined out phreatic levels in relation to the topography and pit shell, allowing a cost-effective and visual approach with an appropriate degree of certainty to support the PFS. It is important to note that the appropriateness of this methodology should be assessed on an individual basis dependent on the site condition, hydrogeologic complexity, and level of risk related to groundwater control at the site.

Methodology

The following steps present the high-level methodology created to incorporate 2D analytical results from representative hydrogeological sections, into a 3D surface showing the expected phreatic surface based on pit shells provided by the client.

1. Select representative cross sections around the pit in each of the key domains and to allow appropriate spatial coverage. Multiple conceptual pit geometries may be required due to the site-specific conditions.
2. Calculate the pit inflow and pore pressure profiles for each of the identified cross sections through the conceptual pit geometries using the Marinelli and Niccoli's solution.
3. Using a drafting software, from the calculated drawdown profiles for each conceptual pit or domain, produce a series of circles using the calculated radii and water level elevation to produce a 3D representation of the drawdown profile around each conceptual pit or domain.

4. Export the representative profiles as .dwg files and import them into Leapfrog as polylines.
5. Created a triangulated mesh from each profile, to generate a cone for each domain.
6. Translate the cones so that they lined up with the toe of the pit in the relevant domains.
7. Extract a set of vertices from each cone and filter for the proportion of the cone required to build the final surface.
8. Within Leapfrog create a new surface showing the pre-mining phreatic level, extending to a reasonable distance away from the pit.
9. Added the filtered pointsets into the surface created in Step 8.

Application of the 2D Analytical Solution

The Marinelli & Niccoli (2000) solution is a closed form solution which assumes simplified steady-state 2D flow conditions, **Figure 1**. The solution also assumes a generalised and uniform circular pit geometry, in order to represent a planned pit with an irregular shape and spatially variable hydrogeological and geotechnical conditions the method was modified to consider several representative sections of the planned pit.

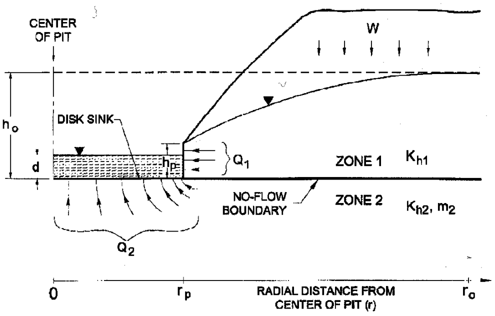
Where W is the distributed recharge flux, K_{h1} is the horizontal hydraulic conductivity in Zone 1, K_{h2} is the horizontal hydraulic conductivity in Zone 2, K_{v2} is the vertical hydraulic conductivity in Zone 2, h_o is the initial (pre-mining) saturated thickness above Zone 1, h_p saturated thickness at the pit wall, r_p is the effective pit radius and d is the depth of the pit lake.

For the purpose of the inflow analysis for this project, the pit geometry was generalised to be represented as three circular conceptual pit - 'east', 'west' and 'satellite'. These were chosen following analysis of the geotechnical and hydrogeological data collected during Golder's site investigation and discussed with the geotechnical engineers. The representation of the west pit geometry was further divided to account for the large variation in pre-mining water levels around the pit as these have a significant impact on the inflow calculations (see Figure 2 for pit geometry conceptualisation).

From the hydrogeological conditions for the site, the total pit inflows and radii of influence were calculated for each of the generalised pit approximations (see Figure 3 for example radii of influence). Each pit conceptualisation was weighted to reflect the proportion of inflow the actual pit geometry would receive from each of the approximated circular pits, given in Table 1.

Converting the data into Leapfrog

From the calculated drawdown profiles, a series of 16 circles were produced in AutoCAD for each of the conceptual pits. Each circle had a calculated radius and elevation to represent increasing distances from the pit to provide a visual representation of the drawdown profile. These were exported as .dwg files and imported into Leapfrog as polylines. From the polylines a triangulated mesh was created to generate a cone for each domain, an example is provided in Figure 4. Each of the cones were



$$h_o = \sqrt{h_p{}^2 + \frac{W}{K_{h1}}\left[r_o^2 \ln\left(\frac{r_o}{r_p}\right) - \frac{\left(r_o^2 - r_p^2\right)}{2}\right]},$$

$$Q_1 = W\pi\left(r_o^2 - r_p^2\right),$$

$$Q_2 = 4r_p\left(\frac{K_{h2}}{m_2}\right)\left(h_0 - d\right),$$

$$m_2 = \sqrt{\frac{K_{h2}}{K_{v2}}}$$

Figure 1 Pit Inflow Analytical Model (from Marinelli & Niccoli 2000).

Table 1 *Percentage weighting of calculation totals.*

Pit Geometry	West Pit (A)	West Pit (B)	West Pit (C)	East Pit	Satellite Pit
Percentage of pit geometry contributing inflows	25%	25%	25%	60%	100%

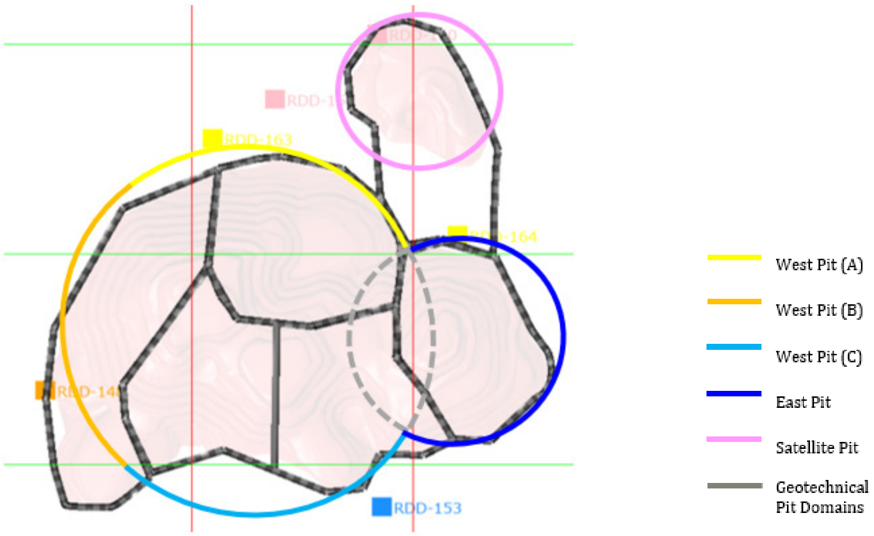


Figure 2 *Conceptualised Pit Geometries.*

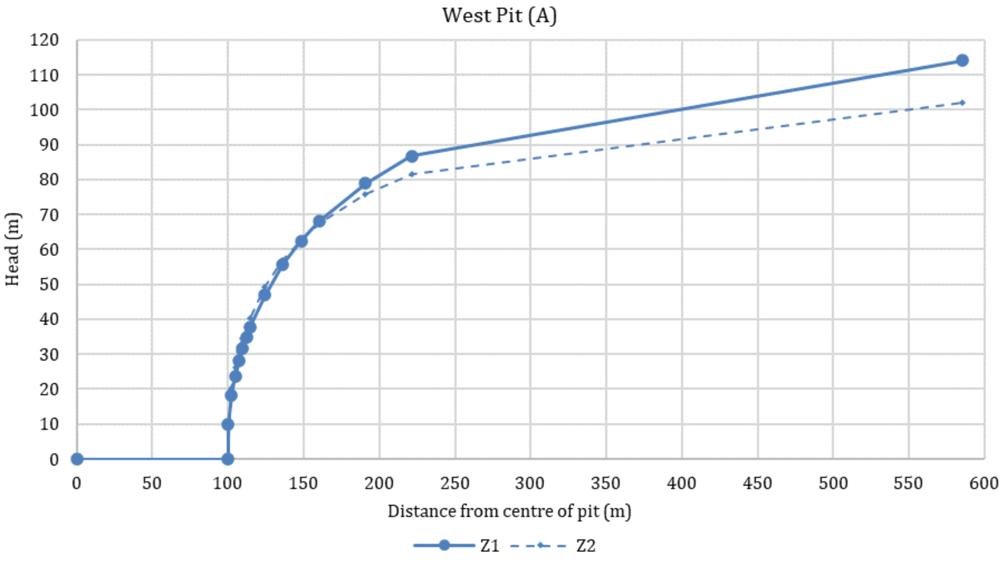


Figure 3 *Example calculated drawdown profile.*

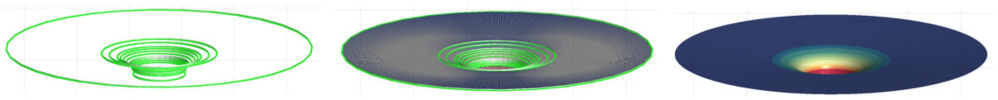


Figure 4 *Imported polylines and triangulated mesh Leapfrog surface created for one of the conceptual pits.*

manually translated to ensure they line up with the toe of the pit in the relevant domains by visually comparing them to the pit shell within the Leapfrog model.

Recombining the Conceptual Pits

For each of the cones created above, a set of vertices were extracted and each point "categorised" within Leapfrog to reflect the conceptual pit they represent. The "query" filter within Leapfrog was used to choose which points were required in the final surface to reflect the planned pit geometry, the points chosen were consistent with the conceptualisation shown in Figure 2.

A pre-mining phreatic surface was created from existing site water levels, extending to a reasonable distance away from the pit to be outside the radius of influence. The mining induced phreatic levels will be cut into this surface, by adding in the pointsets created above.

The project used for this example was located within a mountainous region with steeply dipping topography around the pit. Adding the mining induced water levels into the pre-mining phreatic surface allowed the final surface to be aligns with the cone segments in each domain whilst reflecting the topography at the extents of the surface away from the pit area (Figure 5).

Integration with Geotechnical Slope Design

Being able to incorporate the post mining phreatic surface into the Leapfrog model allowed geotechnical engineers to visualise and assess the expected pore pressures against other key surfaces (Figure 6). The geotechnical slope stability analysis incorporated the expected pore pressure to determine the design slope angle.

Conclusions and Application

For front end mining studies, the level of data available is often not sufficient to support development of complex 3D hydrogeological models. The results provided by 2D analytical calculations provide a cost-effective solution and often produce suitable results to support

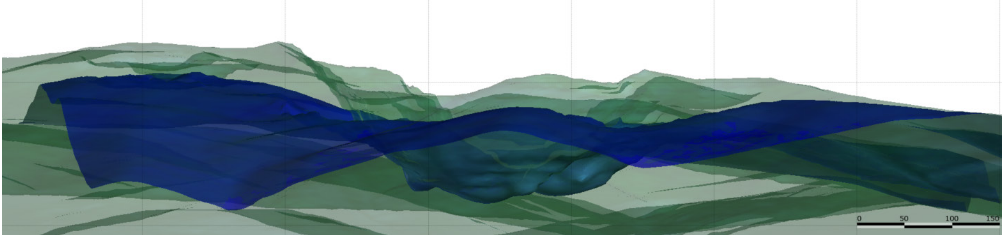


Figure 5 *Topography showing mined out pit shell (Green) & Mined out phreatic surface (Blue).*

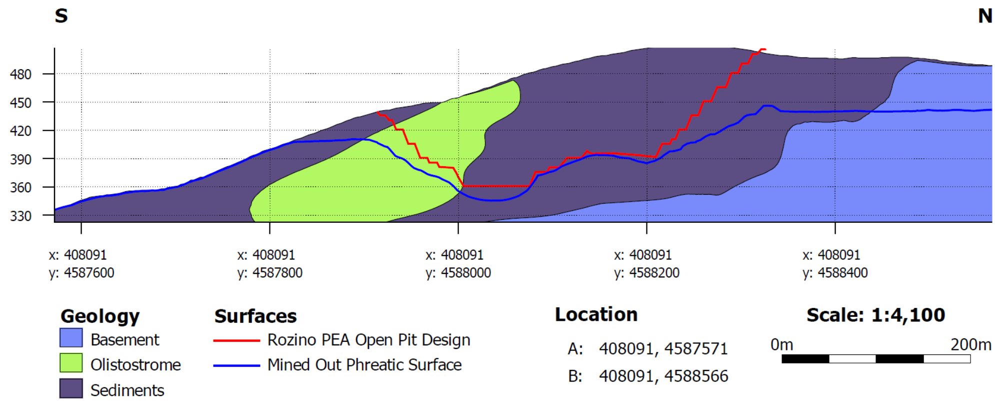


Figure 6 *Section showing the geology, pit shell and mined out phreatic surface.*

the level of study required, dependent on-site condition and level of risk related to groundwater control at the site. This example used Marinelli & Niccoli's solution however the methodology could be applied to the results of other 2D analyses. As Marinelli & Niccoli's calculations assume a generalised and uniform pit geometry. The calculations can be undertaken for several sections or domains to represent changes in pit geometry, domaining, and hydrogeological conditions.

Transferring the results of the 2D hydrogeologic study into 3D Leapfrog software allows greater collaboration between study disciplines and provides a valuable visual representation of the study results, such as the effect of pit dewatering and geotechnical slope stability considerations to be more easily calculated and visualised by the client and stakeholders. As the project progresses, a more comprehensive hydrogeological modelling should be undertaken once such sufficient data and hydrogeologic understanding is developed.

This workflow was created and executed collaboratively by hydrogeologists, geotechnical engineers, geologists, and technicians within Golder's UK based mining team. It is recognised that this process could be streamlined and assisted by more comprehensive templates and CAD documents.

References

Marinelli, F., and Niccoli, W.L. (2000). Simple Analytical Equations for Estimating Ground Water Inflow to a Mine Pit. Ground Water 38 (2), pp. 311-314.

Seequent Limited. (2021). Leapfrog Works (3.0.1). [Software]. [Accessed 10 October 2019].