Practical Applications of Groundwater Modelling for Dewatering Management in Open Pit and Underground Mining, Didipio, Philippines

Anna Kluza[1] and Lee Evans[2]

[1]*OceanaGold Philippines Inc., Didipio Operations, 2nd Floor, Carlos J.Valdes Building, 108 Aguirre Street Legaspi Village, 1229 Makati City, Philippines, Anna.Kluza@oceanagold.com*

[2]*GHD 2 Salamanca Square, Hobart, Tasmania, 7000, Australia*

Abstract

Groundwater modelling has been used to inform dewatering management decisions at the Didipio mine. The modelling approach benefited from the scale and pace of mining, particularly the rapid vertical development of the open cut mine. In addition to this, ongoing data collection and hydrogeological involvement allowing refinement and validation, has resulted in a tool that can be practically applied to the mining geometry and schedule to predict the relative differences between mining and dewatering approaches. High groundwater inflows have been successfully predicted in advance of mining, providing justification to adequately resource the dewatering efforts required for successful mining.

Keywords: Groundwater modelling, dewatering management, predictions, open pit, underground

Introduction

The OceanaGold Philippines Inc. (OGPI), Didipio project is located in Nueva Vizcaya Province, on the island of Luzon in the Philippines (fig. 1). Didipio is a high grade porphyry copper-gold open pit and underground mine. Production is in the range of 150,000 – 160,000 oz gold and 18,000 – 19,000 t copper per year with an estimated mine life to 2032 (OceanaGold 2018).

The regional geology comprises late Oligocene volcanic, volcaniclastic, intrusive and sedimentary rocks overlying a basement complex of pre-Cenozoic age tonalite and schist (Griffiths et al. 2014). The Didipio deposit is hosted within the Didipio Stock, which is in turn part of the larger Didipio Igneous Complex (Griffiths et al. 2014). The deposit has been identified as an alkalic copper-gold porphyry system that includes at least four intrusive igneous phases (Wolfe and Cooke 2011).

The project entered construction in 2011, mining commenced in August 2012 and commercial production was declared in April 2013. Mining of the open cut was completed in May 2017. The open pit extends 220 m below its access, which lies in a valley at approximately 670 m above sea level at the foot the Mamparang Mountains, which locally peak at 987 m above sea level. The development of the underground mine commenced in March 2015 and extends 450 m below the open pit. Beyond the mine area, the area is populated and/or cleared for farming with adjacent areas heavily forested, particularly in the elevated mountainous terrain (fig. 1). The area receives a high rainfall with an average of 3.4 m based on the last 10 years of data (Medidas and Kluza 2016). High runoff results in large flows in the Dinauyan, Surong, and Didipio rivers (Figure 1).

Pre-mining Hydrogeology at Didipio

Initial hydrogeological assessments (Dames and Moore 1995) included packer tests resulting in 16 estimates of hydraulic conductivity as well as pumping and flow recession tests resulting in 29 estimates of transmissivity. A significant baseline hydrogeological dataset is documented in Coffey (1998a and 1998b) including: temporal hydrographs for groundwater levels at 9 locations (13 bores) and flows in 8 artesian drill holes over time; 68 drawdown and recovery test hydrographs including data for a 33 day pumping test; groundwater bore logs; 72 estimates of hydraulic conductivity; and 27 estimates of storage. RDCL (2008) conducted packer tests resulting in 8 estimates of hydraulic conductivity. With these data as background, MWES (2011) produced a groundwater flow model for mine dewatering and site water supply.

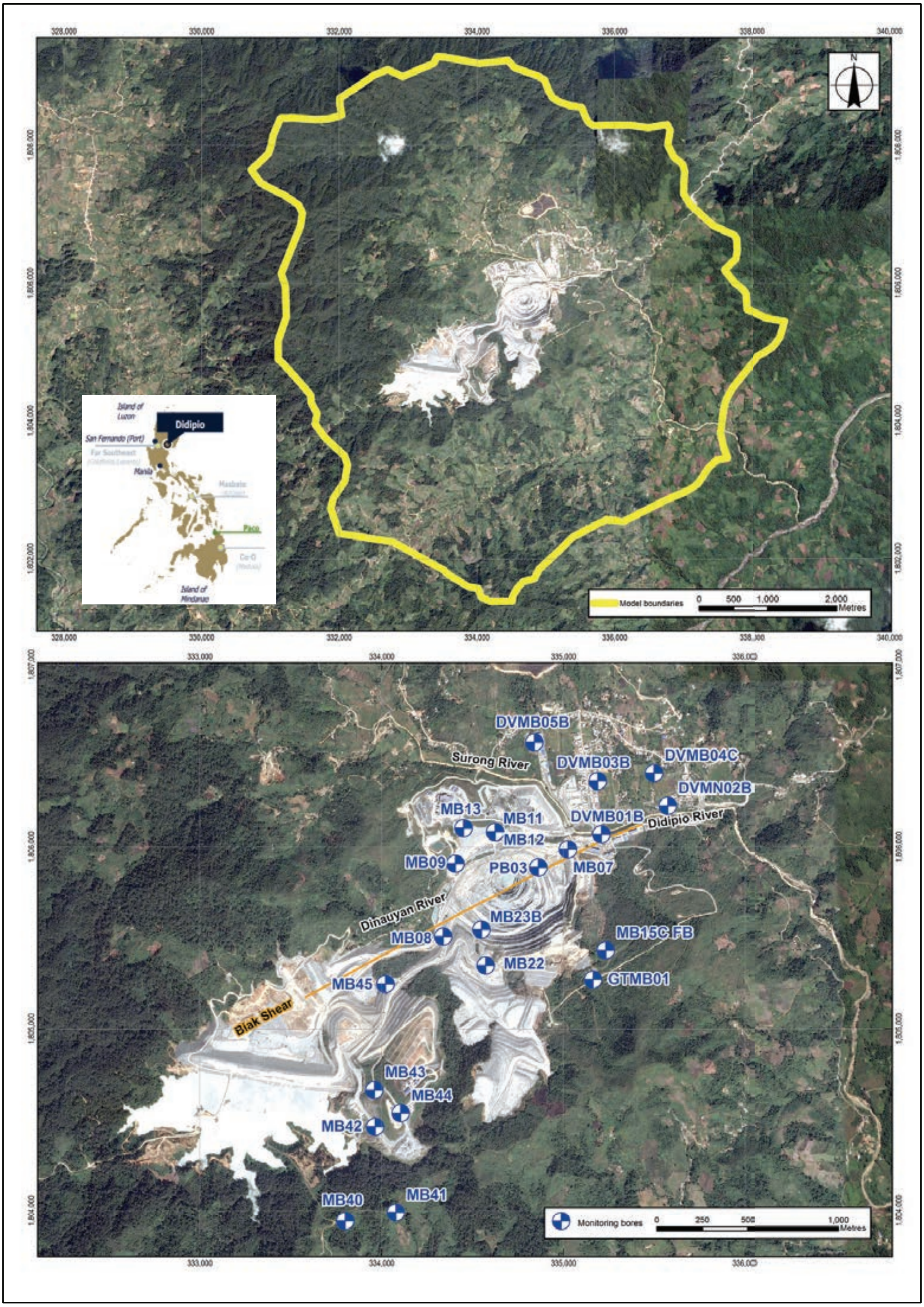

Figure 1 *Location map, groundwater model boundary, monitoring bore locations and local rivers*

The above works established the conceptual hydrogeological model of a highly hydraulically conductive regional scale fault zone (the Biak Shear), in a relatively low hydraulically conductive basement.

Optimisation study: Didipio Mine Hydrogeology and Groundwater Model (2012-2014)

GHD has been involved in hydrogeology during the mining stages at Didipio, initially as part of an optimisation study documented in Griffiths et al. (2014). The hydrogeological work of this study involved the following phases:

- Phase 1 Site Hydrogeological Assessment (December 2013)

With all groundwater monitoring bores destroyed in the period between 1999 and 2013, the first phase of the contemporary works oversaw the drilling of new groundwater monitoring bores, as well as the initiation of open pit and bore pumping data collection by OGPI site staff.

- Phase 2 Hydrogeological Modelling For Open Pit Mining (2014)

With an acceptable calibrated model resulting in reasonable predictions of mine water inflows, defendable results about the relative benefits of different dewatering approaches were demonstrated and informed management decisions were then able to be made based on the model results. At that stage this included demonstration of the relative benefits of perimeter bores, in-pit bores and sump pumping in this unique hydrogeological setting. Thus, OGPI focussed its open pit dewatering resources on in-pit sump pumping approach.

- Phase 3 Hydrogeological Modelling For Underground Mining (2014)

The initial GHD groundwater model predicted the underground inflows at rates at 450 L/s. At this stage the confidence in the model was limited due to the lack of hydrogeological data in the underground mining area, and that the calibration of the model was primarily based on a single 33 day pumping test stress.

- Phase 4 Validation and Calibration Hydrogeological Modelling (2014)

The influence (stress) of the open pit mining on the groundwater regime provided a local but rapid drawdown at a scale that could be replicated in the groundwater model, improving the level of confidence in the model in a relatively short time frame. This presented an opportunity to validate the model with the outcomes demonstrating that the groundwater models predicted groundwater inflows were inline with the measured open pit inflows.

Key to models design were accurate monthly pit shells provided by OGPI, which provided the dominant model stress when applied to model as drain elevations changing over time. The study also demonstrated the value of both groundwater monitoring infrastructure and well co-ordinated and prolonged data collection by OGPI site staff.

- Phase 5 Final Mine Design Hydrogeological Modelling (2014)

Phase 5 took the validated and recalibrated groundwater model and produced predictive inflow simulations for numerous mine designs and schedules as part of the optimisation study. The final mine design and schedule from the Didipio Optimisation Study was then incorporated into the groundwater flow model. Over the underground mining life, the modelled flows rise sharply with the vertical advancement of the decline and peak at approximately 450 L/s. Whilst key hydrogeological data remained sparse at depth, the mine geometry and schedule were able to be incorporated into the model at a higher degree of fidelity increasing the confidence in the model outputs. This work increased the confidence for OGPI to design and procure infrastructure at the scale of the predicted dewatering requirement.

Continued groundwater data collection (water levels and in-pit sump pumping) coupled with collecting data from the early underground development was recommended. These data were expected to provide validation and recalibration opportunities for the hydrogeological model, to further increase confidence in predictive flows and aid in the decisions associated with the detailed design of underground dewatering infrastructure.

Recent Groundwater Modelling at Didipio

Since the initial optimisation study work (2015 onwards), GHD has remained involved with the site, providing a combination of hydrogeological advice, ongoing groundwater modelling support and training for on-site staff. Additional works undertaken by OGPI has involved modelling different mining approaches and schedules (both underground and open pit); the relative benefits of different underground and open pit dewatering strategies; increasing the layering to allow analysis of flows by both time and by mine pit and underground level.

In 2017, GHD and OGPI collaborated again on a second major stage of validation and calibration of the groundwater model. The recent work benefited from: continued regular monitoring of pumping and water level data by by OGPI site staff; an increased dataset of hydraulic conductivity interpretations within the orebody and surround country rock (n=158) from slug and packer; and an external review of the groundwater modelling works to date (Dodson 2017).

- Current Didipio groundwater model inputs

The Didipio groundwater model is constructed in the Groundwater Modelling System (GMS) interface and uses MODFLOW NWT. The model is divided into 30 vertical layers that allow the underground mine geometry and schedule to be inputted in detail using linear drains. Transient TINs of the mine pit at a monthly resolution provide drain elevation inputs. The WELLS package is used to model existing extraction bores and the RIV package represents the rivers. General heads are applied only on the Biak Shear, otherwise no flow boundaries are applied to surface topographical divides (fig.1). Recharge is applied at 10% of rainfall which also corresponds to OGPIs chloride mass balance calculations.

The latest work comprised of: increasing the model boundaries to a distance beyond the influence of the mine dewatering (backed by the external review recommendation) to a model grid of 7.5 by 7.5 km (fig. 1) with a base cell size at 15 m, and simplifying the complexity of the model (reducing from 17 geological and hydraulic parameters (fig. 2) to 3 key hydrogeological units, namely hard rock, Biak shear and oxidised/alluvial material) whilst not increasing model residuals in the observation bore network (fig. 1). This enabled the application of hydraulic conductivity properties at approximately the geometric mean of the large testing dataset of 0.33 m/day (applied as 0.5 and 1 m/day) for the Biak Shear and 0.026 m/day (applied as 0.03 m/day) for all hard rocks. All cells are convertible from confined to unconfined with specific yield assigned at 0.01 for the Biak Shear; and storativity values assigned at 0.00005 and 0.000001 (1/m) for the Biak Shear and hard rocks respectively.

- Current Didipio groundwater model outputs

With the open cut now finished, the primary objective for the groundwater model is to predict underground inflows. The model is capable of replicating observed underground inflows (fig 3.) with a scaled root mean squared (RMS) residual of 11% for underground flows. The modelled peak inflows range from approximately 450 to 475 L/s. This gives increased confidence in the model predictions going forward, however, it has always been recognised that the groundwater flow model is not designed for, nor capable of predicting mine inrush conditions and these need to be considered separately.

Despite the inflow calibration success, overall the groundwater model currently is not calibrating as well for groundwater levels (based on standard scaled RMS measures, although this is significantly improved if pit and underground induced and observed levels are included in the statistics). It is assumed that this is in part due to the complexities in the overlying oxidised/alluvial material, which appears to have little impact on mine inflows, but do impact shallow groundwater levels. Some bores, however, in key areas adjacent to the mine, are calibrating very well (i.e. MB23B on fig. 1) especially considering the very large drawdowns observed. Improved calibration of groundwater levels represents an area for improvement and would be required if the groundwater flow model was intended to be

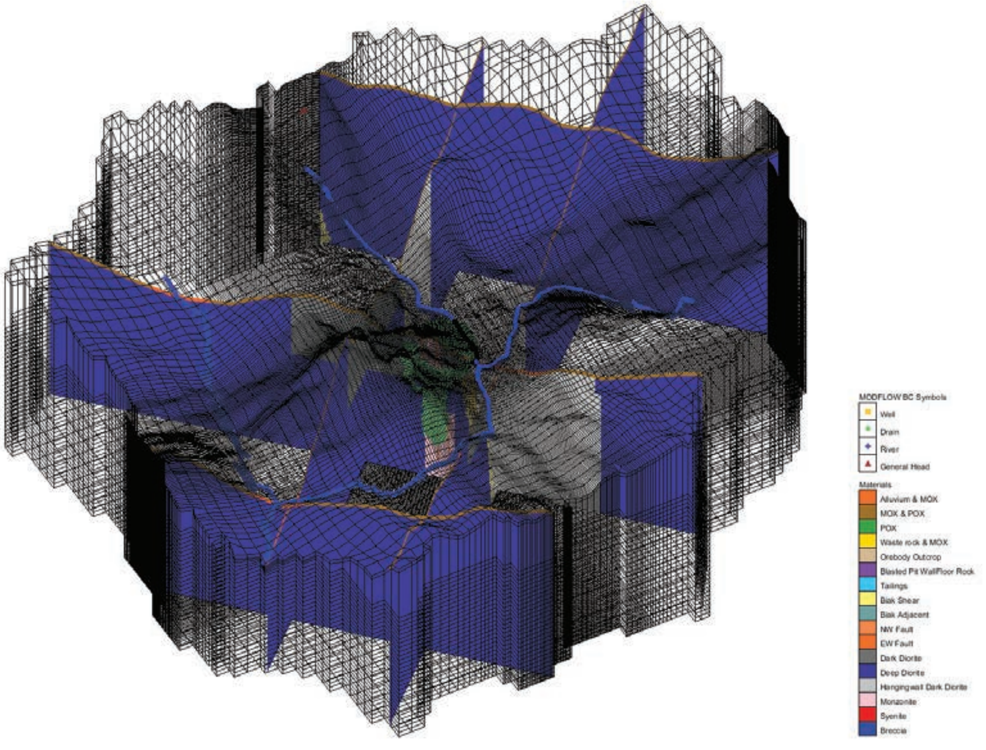

Figure 2 *3D representations of the Didipio groundwater model looking west at a dip of 45 degrees*

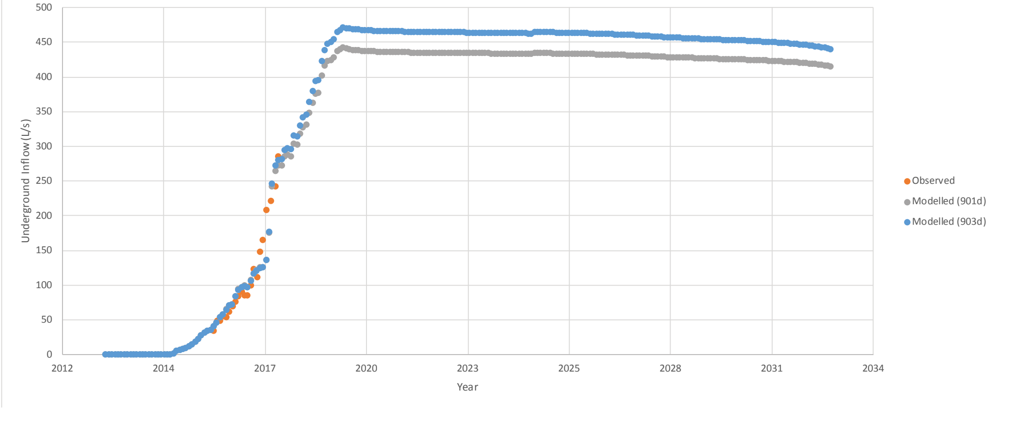

Figure 3 *Observed vs modelled underground inflows and predicted inflows*

used for alternate uses, i.e. for the accurate consideration of the aquifer drawdown from an environmental perspective.

Summary and Conclusions

Groundwater modelling for mine dewatering management is an important tool to aid management decisions to ensure that dewatering approaches are appropriately sized, funded and implemented. This paper presents the groundwater modelling journey undertaken at the Didipio mine.

Mining progressed at fast pace and the resultant influence on the groundwater regime provided a local but rapid drawdown at a scale that was able to be replicated with the groundwater models and at a pace that enabled a higher degree of confidence to be obtained from the models in a relatively short time frame. Installation of groundwater monitoring infrastructure and ongoing groundwater level and pumping monitoring acted as a thorough calibration dataset. This allowed the dewatering drawdown associated with the open pit mine development, which was an order of magnitude greater than that from bore pumping alone, to be included as a known stress in the model. Thus pumping and open pit mining were the inputs to the model as stresses and the subsequent model level and flow results were able to be compared with the monitored groundwater levels and mine pumping.

With a model resulting in reasonable predictions of mine water inflows, defendable results about the relative benefits of different dewatering approaches were demonstrated and informed management decisions were then able to be made based on the model results. This includes for example: the relative benefits of perimeter bores, in-pit bores and sump pumping in this hydrogeological setting; the scale of the predicted dewatering required based on different mining approaches and schedules (both underground and open pit); and the relative benefits of different underground dewatering strategies.

Likewise, the relatively large scale of the predicted dewatering rates, and their rapid and ongoing validation, for both the underground and open pit mine, provides the ongoing justification for funding: appropriately engineered dewatering systems; recruiting and retaining appropriately skilled staff and resources relative to the scale and importance of the dewatering task; ongoing assessment of performance and refinement of the groundwater model; and continued use of the groundwater modelling to aid management decisions.

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