Pit lake modelling – The total system approach

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Abstract

Building an accurate and defensible model describing the geochemical character of water that collects in a pit lake after the cessation of surface mining activities involves integrating geochemical, hydrologic, and climatologic data with the lithologic units of the area surrounding the ultimate pit surface (UPS). Such a total system approach often involves developing a coarse regional groundwater model framework which is then refined into a finer-scaled localised groundwater model in the area of the pit. The groundwater model results are integrated with a detailed geologic and geochemical model of the UPS, the chemistry of the groundwater, and other factors such as climatic conditions and surface run-off. The total system approach considers temporal as well as spatial variability. GIS methods coupled to finite element (Feflow), or finite difference (Modflow) groundwater flow models allows to apportion the interaction of groundwater model nodes with geologic nodes on and adjacent to the UPS. This apportionment is used to calculate chemical mixing models using geochemical modeling softwatere of the leachates derived from the pit wall with the groundwater composition, pit lake water chemistry, run-off, and precipitation both spatially and temporally to model the character and behavior of the pit lake. The required life-span of such a model can often exceed several hundreds to even a thousand years.

Keywords: ultimate pit surface, pit lake model, geochemistry, GIS, mine closure, groundwater

Introduction

Surface mining operations often result in an excavation that breaches the water table. At the cessation of mining activities groundwater and surface water are allowed to infill the pit and with exception where evaporative loss exceeds inflow, a pit lake will form. The geological units adjacent to the ultimate pit surface (UPS) are subsequently in disequilibrium with the groundwater, potentially causing water and oxygen to be introduced resulting in the formation of acid rock drainage and metals leaching (AMD). In areas that are devoid of metal sulphides and/or contain relatively robust amounts of acid neutralising material such as limestone and to a lesser extent, dolomite, the ARD/ML generation may be minimal. In areas where the sulphide content exceeds the acid buffering capacity of the system, and sufficient oxygen is present, sulphuric acid will form, lowering the pit lake water pH and release metals from the UPS material. This can occur locally even if the overall system tends to not be acid prone. In the process of modelling the pit lake chemistry, certain information is required that defines the interaction of the existing ground water chemistry, surface water chemistry, wall rock chemistry, and ultimately, the pit lake. In addition to chemical considerations, knowledge of the temporal and spatial interactions among these entities must be well defined and understood.

Specifically consideration include:

- Ground water node locations (Spatial)
- Amount of flow through each groundwater cell (Spatial and Temporal)
- Geologic cell node locations on the pit wall (Spatial)
- A knowledge of which groundwater cells have an effect on which geology nodes (Spatial)
- Evaporation rates of pit lake (Temporal)
- Precipitation rates (Temporal)
- Chemistry of ground water (Spatial and possibly temporal)
- Chemistry from static and kinetic tests of representative rock materials (Spatial)

The discretisation of data in a 3D grid provides for localised chemical nuances to be realised that might otherwise be overlooked when applying bulk chemistry in models such as is commonly done using spreadsheets.

This data allows one to calculate the apportionment of water chemistry that interacts with the wall rock to form solutions that enter into the pit lake. Further, as the lake grows, not only is ground water interacting with the wall rock, but the lake waters impinging on the wall rock can drive chemical reactions as well. The apportionment and spatial distribution is a 3D GIS process that is used to help build the chemical mixing model. The model is then solved using geochemical mixing software.

In that such an approach often is data intensive, input and output data from the geochemical modelling program, as well as all pertinent GIS data relationships are stored in a POSTGRES database and extracted utilising customised scripts for use in the model. Depending upon the complexity of the groundwater model and the size and nature of individual geologic cells, the model may involve several hundreds of thousands to millions of calculations that are better suited in customised computer programs rather than the traditional spreadsheet approach.

Results and Discussion

In setting up a pit lake model, the UPS must be well defined in space. In addition to that, the location of groundwater cells must be identified. The flow of water into or out of the pit over time needs to be available from the groundwater model. Note that at any given time, each cell will show flow into the pit, no flow, or out of the pit. Figure 1 shows a configuration where using a program such as Groundwater Vistas or ModFlow defines groundwater nodes in proximity to the UPS.

From the groundwater model, one can derive a curve that defines the pit lake level curve over time. This in conjunction with the elevation profile of the UPS is required to estimate the volumes of water entering or leaving the pit at any point in time. It is not unusual for such an infilling curve to span several decades or even hundreds of years before equilibrium will be achieved. A typical infill curve for a pit lake is shown in Figure 2.

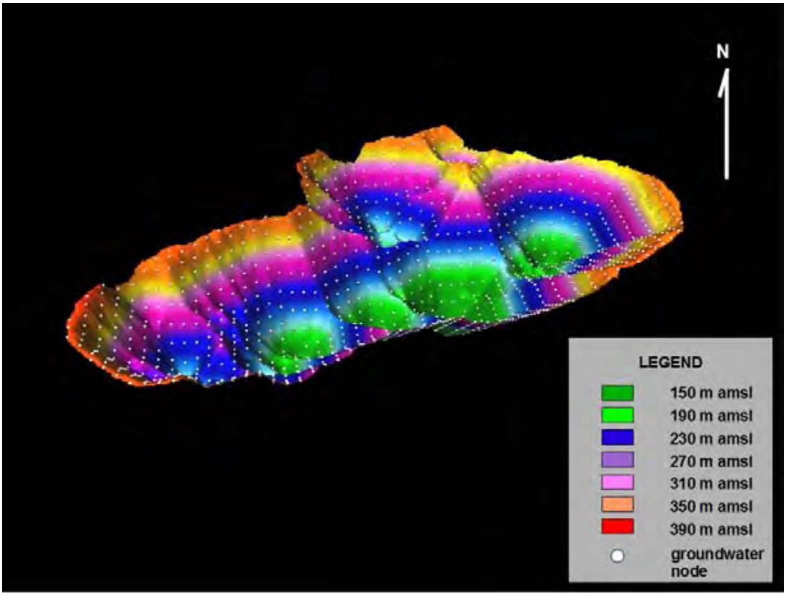

Figure 11 *UPS shell with groundwater node locations*

Once the UPS and the groundwater nodes have been defined, it is necessary to map the geology of the wall material to the UPS and determine the apportionment of the contribution of the groundwater flow to each of the geology nodes. This will vary over time and geomodeling software is used to perform the mixing of the appropriate groundwater chemistry with the chemical release functions determined from the laboratory analysis of each of the appropriate rock types. Figure 3 is a depiction of the geology as derived from a geologic block model "painted" on the UPS. Quite often the block model is statistically derived from evaluating many thousands of lithologic picks in 3D space and applying an appropriate 3D kriging model. Performing random spot checks of the interception of the UPS with mapped drill holes and getting input from geologists familiar with the mine property is an important sanity check to assure that the model is accurate. In that the pit lake calculations require modeling the interaction of specific lithologies, accuracy in this regard is paramount. This map is then used to correlate the chemical results of representative samples utilising static chemical tests, kinetic tests, or both. It should be noted that the assignment of the chemical results of the formation sample that most closely matches the UPS geology node is required. It is not unusual for a given formation to exhibit acid generating character at one location and show a completely different character at another location. Having sufficient geochemical samples to track this reduces either being overly optimistic or conversely, overly conservative in predicting the final pit lake chemistry.

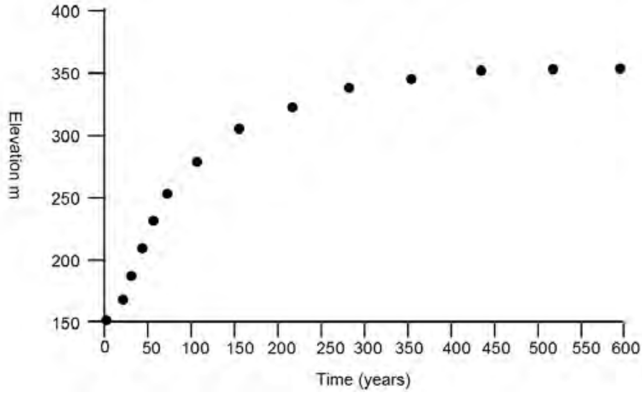

Figure 12 *Typical infill curve for a pit lake*

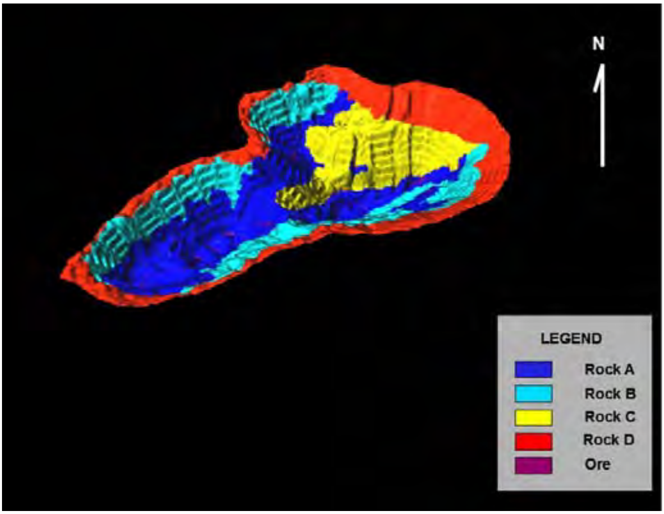

Figure 13 *Geology on the UPS*

The geologic nodes are then assigned the appropriate groundwater node to define the composition and volume of groundwater that impinges on them. This is based on an inverse distance weighing function where geologic nodes proximal to a groundwater node are assigned a proportionally higher influence from a groundwater node than a distal geology node. The sum of all apportionments for any particular groundwater node at that point in time should equal 100% of the flow from that node. It then becomes a simple mixing model, node by node. At the end of any given time period, the output derived from the PHREEQC runs are mixed according to their proportions and the result is remixed with the chemistry of the actual pit lake composition from the previous time step.

Previous studies (Richers et al, 2012) show that one of the major controlling factors in predicting the chemical character of a pit lake is the composition of the groundwater. While it is not uncommon in pit lake models for the investigators to utilise limited and rather homogeneous groundwater chemistries, it should be noted that once the pumps are turned off at the end of mining, groundwater will tend to enter the pit from all directions until time that the regional groundwater flow is re-established. Hence, the chemistry of the waters entering the pit may be quite different depending on where they are derived. Further, it was shown empirically that by Richers et al (2012), that a subtle change in groundwater chemistry can have a large effect on the final character of the lake as equilibrium is re-established. While short term pit lake chemistry can be substantially different than the regional groundwater chemistry, eventually (over perhaps hundreds of years) the pit lake will often tend towards the groundwater composition.

The following is a table showing changes in final pit lake composition where geology was held constant with differing groundwater compositions for rocks from a mining area in Nevada, USA. As shown in all cases, the final pit lake chemistry does not stray too far from the groundwater chemistry although it may take decades or even centuries to reach equilibrium.

Table 1 *Comparison of varying groundwater compositions on final pit lake composition (Richers et al, 2012)*

Groundwater Chemistry	Spring	Pit Lake
Acidic Example		
pH	4.000	4.006
Mg	0.025 mg/L	5.06 mg/L
Ca	48.00 mg/L	45.33 mg/L
Raised Springs		
pH	6.710	6.571
Mg	1.77 mg/L	1.86 mg/L
Big Springs		
pH	7.480	7.317
Mg	5.78 mg/L	5.83 mg/L
Ca	34.70 mg/L	34.43 mg/L
Cedar Cabin Springs		
pH	8.170	7.931
Mg	21.40 mg/L	21.32 mg/L
Ca	60.10 mg/L	60.00 mg/L

Conclusions

Pit lake modeling involves considering the interaction between groundwater and the mineralogy present on the UPS. By utilising 3D grids in GIS to merge geologic, groundwater flow, and chemical compositional data that affords a means to model pit lake chemistry over time. Because of the potentially large volumes of data that may be utilised when looking at the life of a pit lake that might span centuries, modeling in the context of GIS along with a relational database affords an efficient means to track input and output data from geochemical modelling software. The discretisation of data in a 3D grid provides for localised chemical nuances to be realised that might otherwise be overlooked when applying bulk chemistry in predictive models.

References

Richers DM, Richardson, CD, and Moran, P. (2012) Impact of groundwater chemistry on wall rock chemical leaching and pit lake character, SME Proceedings, Seattle, WA.