Mapping Wall Rock Chemistry on the Ultimate Pit Surface of an Open Pit Mine Utilizing GIS

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Abstract

Knowledge of the composition of the ultimate pit surface (UPS) of a pit mine is essential when predicting the final chemistry of any ensuing pit lake. The spatial distribution and makeup of rocks present in the pit wall directly affects acid-base-accounting (ABA) predictions and are used in planning of post-mining phases. 3D GIS methods afford a simple and effective means of mapping geologic block model data to spatially fit the contours of the UPS and provides a means to “buffer” the intersection using a distance filter in x, y, z space. Due to the uncertainties in the block model, this distance often can range anywhere between 10, 20, 50, or more feet. Values that place the block model closer to the UPS are preferred if they result in a large enough population of the wall being represented by the block model. Once the intercepts are established, kriging or other gridding methods can be used to calculate areas of sparse surface exposure of each lithology. Exposure areas can then be calculated using simple GIS tools and accounting for the average slope corrections for each UPS –Lithology grid node.

Introduction

When building a sound model for the fate and transport of chemical species resulting from the development, mining, and subsequent closure of an open pit mine, there exists the possibility that the waters that impinge upon the excavated pit will be of a different quality than that of the pre-mined, undisturbed groundwater. This water often forms a “pit-lake” that may have a vastly different chemistry than the original waters that existed in the subterranean environment prior to development. Pit lake modeling is required to predict the nature of this water and assist in reducing or eliminating any negative impact on water quality within the lake, as well as any adverse effects on the regional groundwater quality. Shifts in water chemistry and quality are to be expected from pre-mining conditions, as the original groundwater generally is in chemical equilibrium with the surrounding strata. Once disturbed, the exposed strata can be subjected to oxidation and chemical leaching, allowing chemical species to either be mobilized or precipitated until such time that equilibrium is once more achieved.

As a first step in evaluating the direction or tendencies of the chemical evolution of waters that accumulate within a pit lake, one necessarily needs to accurately define the spatial extent of the final pit geometry or ultimate pit surface or UPS, (Hustrulid, et al, 2000) so as to allow for realistic mapping of groundwater flow through the resulting pit surface, as well as anticipate the interaction of atmospheric precipitation and run-off across the pit wall surfaces. Overall pit geometries and depth are also a required factor to consider as evaporative loss of waters will depend on overall pit shape and size. For example, a shallow wide lake, because of its large air/water surface area will tend to undergo evaporative loss faster than a lake of similar volume whose pit is deep, but whose surface area is much smaller.

Typically, the UPS is derived by mine planners using any one of many software packages, but generally, computer assisted design (CAD) software appears to be favored within the industry.
To accurately define this surface in 3D space, one generally converts this design file into a more GIS-centric format and then processes it as necessary in one of several available GIS packages to get it into a format that can be used to calculate surface areas, merge with geologic block models, and determine relative groundwater flow into or out of the pit for each of the “nodes” or wall rock voxels to help predict chemical behavior. A voxel is the smallest distinguishable box shaped part of a 3D space, defined by its x, y, z coordinate of its centroid, or one of its eight corners, (Howe, 2010).

By accurately mapping geologic and geochemical parameters of the UPS, a sound, defensible pit lake model can be developed.

**Process Flow**

When developing a pit lake model, the pit surface is generated for the various phases of the mine development. While pit lake models generally are concerned only with the final or ultimate configuration, often times intermediate phases are also produced to assist in mine planning and evaluate waste rock disposal during the operation. In those efforts, the material being mined (waste and ore) are scrutinized and evaluated to assist in developing waste rock facilities, segregating sub-economic ore for possible future processing should the economics become favorable, and determining volumes of such materials.

![Figure 1: Original CAD drawing of UPS surface](image)

As such, the UPS is mapped in 3D space and all prior phases or surfaces are likewise determined. In the simplest case, the space between two subsequent surfaces can be evaluated for the volume and content of mined materials either from the 3D geologic block model, or, if sampling density is high enough, from the chemical and geologic evaluation of boreholes, blast samples, and cores within the pit proper.
A typical UPS DXF file derived from CAD software appears in Figure 1. This data is imported into a GIS package such as ArcInfo (DenverGis, 2011) or GRASS64 (Grass, 2011) and converted to either line or point 3D ESRI shapefiles. Often, because the contour vertices are somewhat distal, points are added between vertices to assure that the elevations are honored when this data is converted into a grid file for further processing and merging with geology, chemistry, or groundwater flow data. Once the data is in a GIS format, analysis and further processing is performed. It should be noted that the authors realize there are many different software packages available and that any one given method may not be any better or worse than another. What is presented here is a typical job stream of many and each project may follow a slightly different path depending upon data availability and formats

The data, once resampled to in-fill vertices along the contours, is subjected to a surface gridding. The above data after resampling vertices is shown in the ensuing Figure 2. As the original dataset was built in CAD on a 50 ft x 50 ft grid, a resampling on 10 ft intervals was determined to be sufficient to “honor” the original UPS topography.

![Figure 2: UPS contour lines re-sampled to 10 foot intervals](image)

Once the resampled data is deemed “acceptable,” the next step is to regrid the dataset on a finer 3D grid. In this case, 10 ft x 10 ft x 5 ft was chosen. This grid honors the original x, y, z points from the DXF file and provides for a uniformed grid that can easily be merged with other data relevant to creating the pit model. The grid shown in Figure 3 was created in the GIS package GRASS 6.4 using the v.surf.idw. It depicts the UPS elevation where darker grays represent higher elevations and lighter grays and whites are the lower elevations.
Figure 3: UPS contour lines converted to 3D raster grid in GRASS

GRASS has a very useful utility for visualizing data in 3D called NIZ. In Figure 4, pit topography for the example used thus far in this article as well as a proposed adjacent pit just south of this pit are shown in 3D.

Figure 4: GRASS 3D nviz of UPS surface elevations
Once the data has been defined as a 3D x, y, z grid, it can be exported and used to find the intercepts of other spatial data to “paint” the wall surface with geology, chemistry, groundwater flow, etc.

Using customized intercept programs, the geology provided in the block model is queried to find data proximal to the UPS wall. In that grid spacings between the various datasets are not always uniform (i.e. by their very nature, geologic block models are often very large, so grid spacings often are fairly coarse), intercepts are often determined by allowing for a range of distances in 3D space between the wall and the feature one wishes to “merge.”

Figure 5 shows the geology derived from the block model painted on the UPS. By creating this grid with the same interval spacing as the UPS, other values inherent to the UPS can be directly applied to the geology, mapping them grid node by grid node. For example, in a pit lake model, it is often useful to determine the surface area a specific lithology has in contact with the pit lake. The slope angle for any grid node on the UPS can easily be calculated using the GRASS module v.surf.rst. The slope value for each grid node can then be used to calculate a “slope-corrected” area of the grid node exposed on the pit surface. In that all grid nodes are defined as 10 ft x 10 ft for the planar grid, the corrected 3D surface area is obtained by adjusting the area using the relationship of 1/COS(slope) * Area for that node. If the geologic code is also in that same grid space, one can then easily determine the area of that particular geology present on the UPS.

Figure 5: Geology painted on UPS

Figure 5 reveals areas where additional information would need to be obtained to assist in accurately mapping the geology on the UPS as well as where PAG or neutralizing material might exist so one can better predict and plan for ultimate closure.
Conclusions

GIS methods can be very helpful in defining a realistic depiction of wall rock geology whose geochemical character, in turn, is required in designing a closure plan for open pit mining. Accurately mapping the geology and the specific lithology unit areas or volumes on the UPS is generally a good first step required to accurately model groundwater interaction with the exposed wall rock. Applying the compositional and chemical character of the wall material, coupled to the amounts of material present is required to accurately predict wall rock and pit lake chemical interactions. Only by accurately knowing the spatial distribution of wall rock lithologies and coupling that with static and kinetic test data from the same lithologies can one hope to accurately define the likely character of any pit lake waters that will form at cessation of operations. Applying corrected surface area of these rocks in addition to the affected thickness at any given node will yield a volume of rock that may leach or otherwise react with pit lake and groundwater fluids. Further refinements such as including rock permeability and porosity, as well as diffusion coefficients for the chemical species present in the system, allow for a better estimation of the chemistry of the resulting pit lake fluids.

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