APPLICATION OF GEO-ENVIRONMENTAL AND BIOTIC LIGAND MODELS IN THE LIFE CYCLE OF MINE DEVELOPMENT – A FLOWCHART FOR INTEGRATION[1]

Ron L. Schmiermund,[2] and James Ranville[3]

Abstract. The traditional sequence and pace of events that occur following discovery and through mine permitting is increasingly unacceptable in light of global communications and heightened environmental and social sensitivity. Local and international NGOs can readily capitalize on corporate failures to be sufficiently environmentally and socially proactive. Eleventh-hour impact assessments are likely to be deemed inadequate and may cause significant financial losses. A flowchart has been developed to illustrate how geo-environmental and biotic ligand models (BLMs) might be used to promote timely, fiscally-responsible assessments of future environmental impacts. The approach parallels accepted methods of mineral resource assessment and mining property valuation.

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[2] Knight Piésold and Co., Denver, CO 80265-2011. [3] Associate Professor, Colorado School of Mines, Golden, CO 80401

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Introduction

The procession of events and stages in the development of an exploration target into a property ready for construction are well known as is the non-linearity of the process and the enormous complexity. Lord et al. (2001) describes the major stages through feasibility with their associated goals, focusing primarily on geologic challenges. She proposes a re-evaluation of the expected value of a prospect at the transition from each stage to the next, including an examination of the probability of successfully moving to the next stage and the associated costs. In this way, prospects might be quantitatively ranked and exploration dollars directed to the best prospect sooner. Similarly, fatally flawed prospects might be identified and abandoned sooner, thus reducing overall exploration/development costs. Using the same conceptual approach, the rapidly growing pressures, costs, and risks associated with environmental and social issues might be realistically incorporated into decision making in a timely manner.

Richards (2002) addressed the new reality of mine development in the 21st century and the requirement that environmental and social sustainability – and the many ways people interpret those concepts – be understood and addressed by mining companies. The current president of the Society of Mining Engineers (Barbara Filas; see SME, 2005) acknowledges the importance of these issues and the huge impact that non-government organizations (NGOs) can have on mining projects due to global communications facilitated by the internet. The number of well funded mining projects conducted by major mining houses that have been shelved, delayed, or made more costly by the local citizenry and NGOs is growing.

It is imperative that mining companies take aggressive proactive measures to secure the confidence of all stakeholders associated with a new project and thus preserve their option to proceed should geologic, engineering, metallurgical, logistical, and economic conditions indicate continuance. Similarly, the earliest possible recognition of environmental and social risks is a fiscal responsibility of mining companies so that the quantification of a prospect's value (as proposed by Lord, op. cit) can be realistic.

The authors propose the early application of various modeling tools to the normal stages of mine development to provide timely environmental information and thus allow proactive measures to be taken.

Proactive Modeling in a Flowchart of Prospect Development Stages

A flowchart is introduced here to illustrate, in a very simplistic manner, the conventional stages in prospect development (Fig. 1). Economic geology (ore deposit) models combine with corporate objectives to direct exploration. Once a prospective target is acquired, additional geologic input via drilling and mapping is applied to upgrade knowledge of ore deposit and its contained resource. As engineering and metallurgical studies are wrapped in, the project evolves through pre-feasibility and feasibility, eventually culminating in a bankable feasibility study necessary to secure financing. Environmental and social studies are typically introduced via environmental impact assessments (EIAs) associated with permitting and feasibility studies.

It is important to acknowledge that by the time an EIA process is initiated, a significant amount of money has already been invested in the project. By the time an EIA is completed, significant additional money has been invested on many fronts, and it is common for the permitting process to be pending review of acceptable/manageable impacts as portrayed in the

EIA application. In this situation, considerable pressure exists to provide an assessment of potential environmental impacts that is acceptable to the entity granting necessary permits. Increasingly, this pressure is compounded by the desire for very rapid development and production within very short timeframes. It is not uncommon that time does not allow for collection of traditionally required data upon which the EIA should be based.

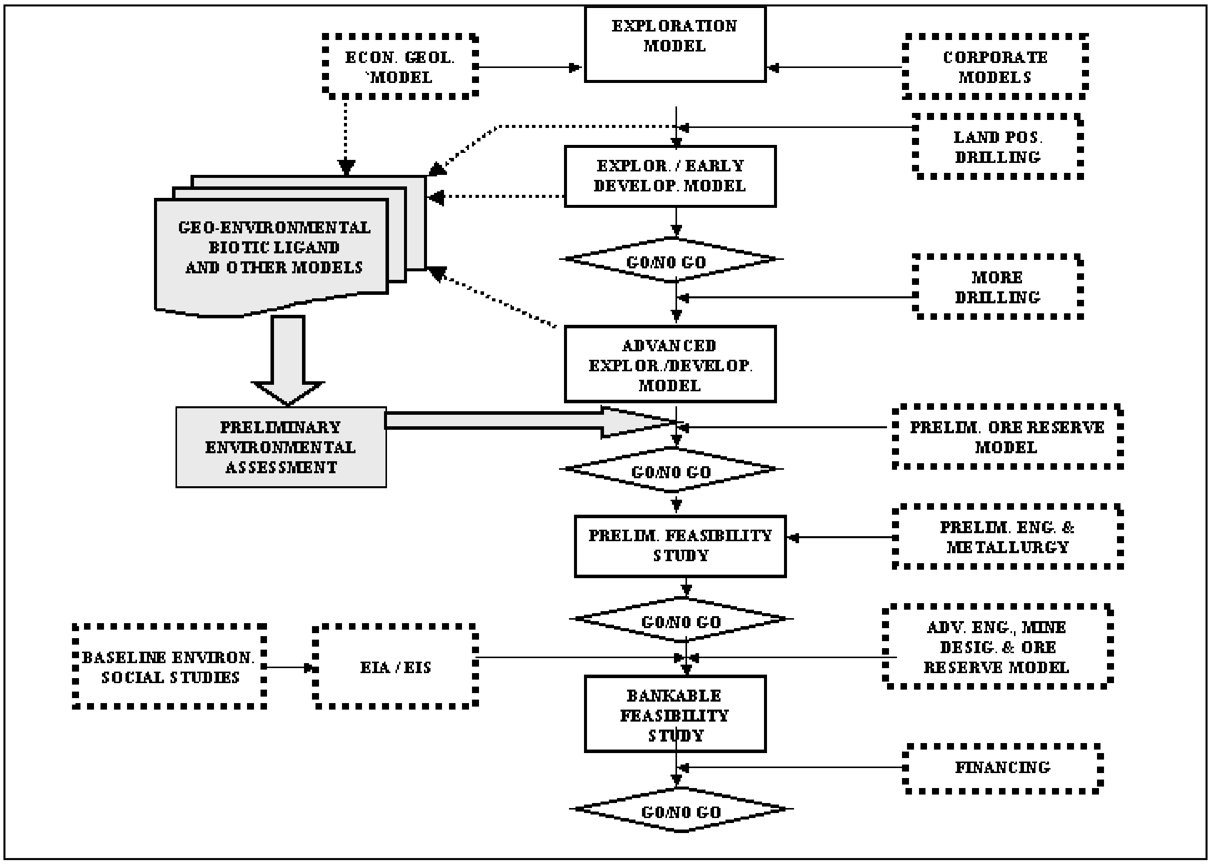

Figure 1. Major prospect development phases through bankable feasibility (center), traditional information inputs (dashed boxes), and applied proactive models including geo-environmental and BLMs resulting in a preliminary environmental assessment. Dashed arrows indicate input to the various models.

The above scenario can clearly lead to compromises that may well contribute to poor economic decisions. Injection of additional information, early in the sequence of events shown in Fig. 1, can be helpful in anticipating future developmental costs and assessing a project's expected value. These models can lead to a preliminary environmental assessment that allows environmental cost estimates to develop in parallel with estimates of the available resource. Two such contributing models are briefly discussed below.

Potential Models to Contribute to a Preliminary Environmental Assessment

Two models are suggested here as having application to the formulation of a preliminary environmental assessment. These are geo-environmental models and the biotic ligand model. The latter is less familiar and will be explained in greater detail.

Geo-environmental models (GEMs) of ore deposits have been thoroughly discussed elsewhere (Plumlee and Nash, 1995) and can be readily understood as "analogue ore deposit-based environmental predictions" (ADEPs). The concept draws upon known environmental characteristics associated with mining operations exploiting mineral deposits of similar type to that being explored or developed. It incorporates not only economic geology but also mining techniques, waste handling methods, and metallurgy. The application of GEMs and ADEPs can provide early predictions of elements of potential environmental concern, waste rock behavior, and typical wastewater compositions. Such data can be applied to preliminary pit lake models, downstream dilution predictions, and estimates of water treatment options.

If GEMs can provide estimates of metal loadings to receiving water bodies from a mining operation, it would be beneficial to anticipate the toxicity of that loading. The water quality criteria for metals that are currently enforced by the U.S. EPA are designed to protect aquatic life and generally employ a hardness-based correction to incorporate the role of water chemistry in aquatic toxicity. The EPA has published updated freshwater and saltwater aquatic life criteria for copper in the form of a draft document entitled "2003 Draft Update of Ambient Water Quality Criteria for Copper" (EPA-822-R-03-026). These freshwater criteria incorporate the use of the BLM in the criteria derivation procedures in addition to incorporating new data on copper toxicity (U.S. EPA, 2003).

The BLM was developed to better interpret the acute toxicity of metals to aquatic organisms in relation to water chemistry parameters. Metals have been found to be most toxic to fish and other aquatic organisms in the free ion form (M^{z+}) in which they are able to bind to sites on the fish gills, termed the biotic ligand (Paquin, et al. 2002). Computational chemical speciation programs such as MINEQL (Westall et al., 1976) and MINTEQA2 (Brown and Allison, 1987), among others, have been created to determine the chemical speciation of metals under varying water chemistry conditions. The BLM incorporates the speciation computation and relates this to observed metal toxicity, presented as the LC_{50} (metal concentration lethal to 50 percent of the exposed organisms).

Inputs into the BLM program include temperature, pH, concentration of the metals of concern, dissolved organic carbon (DOC), percent humic acid, Ca, Mg, Na, K, SO_4^{-2}, Cl^-, alkalinity, and sulfide concentrations. Only DOC and percent humic acid might be considered unusual in a credible baseline program, but both are important to the BLM. Together, these water chemistry components define the inorganic and organic metal interactions that control the concentration of metal present in the free ion form. This concept is based on the free ion activity model (FIAM) (Morel, 1983). The BLM computation for metal interaction with organic carbon is based on the Windermere humic aqueous model WHAM, Version 6.0, (Santore and Driscoll, 1995), and all chemical interactions are simulated by the chemical equilibrium speciation in soils and solutions model CHESS (Santore and Driscoll, op. cit.).

The BLM also considers the competition between the metal of concern and other cations (e.g., Ca^{+2}, H^+, Mg^{+2}) for biotic ligand binding sites. This is done to determine the actual amount of metal that will accumulate on the gill. The model relates mortality to a critical concentration of metal bound to the biotic ligand (LA_{50}) that results in mortality (Di Toro et al., 2001). The BLM computes the speciation of a metal based on the water quality conditions and the amount of metal that has to be present to cause toxicity due to the metal's affinity to the binding sites on the gill. In this way, it may be applied to individual water bodies to determine water quality criteria (WQC) that account for the specific nature of the water composition.

By combining the information that can be derived from the GEM and BLM models, a reasonable understanding can be formed of the likely impacts a mining operation might have on the local surface water resources. These and other predictions, as part of a preliminary environmental assessment (see Fig. 1), can bring early realization of environmental-related costs likely to be incurred and thus contribute to a better pre-feasibility assessment.

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