Environmental risk assessment as the basis for mine closure at Iscor Mining

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Synopsis

This paper discusses the principles and application of risk assessment and management as the basis for environmental management within the mining industry. Unlike in other industries, mines are required to obtain closure certificates in terms of section 12 of the Minerals Act, which should ultimately release them from further environmental responsibilities. It is emphasized that the concept of environmental risk assessment and management, when applied correctly will mean that the mine will be identifying and managing environmental issues beyond those set by current legal requirements and management strategies. The focus shifts from conventional minimum legal compliance management to management of real environmental risks. The advantage of this approach is that the perceived 'shifting of legal and management goalposts' due to changing environmental laws or management principles, will not influence or dictate the mine's short or long-term management objectives or actions, mine closure funds can be more accurately determined and mine closure should become a relatively simple procedure.

The risk assessment approach has been applied to the planning of mine closure at Iscor's Durban Navigation Collieries (Durnacol) in Kwa-Zulu Natal and certain key risk issues such as the long-term risk of water pollution from coal discard dumps have already progressed to fully quantitative risk assessment. This paper will discuss the process, which has been followed to date, with particular emphasis on the most recent phase, namely quantitative risk assessment and management of pollution from coal discard dumps. It is believed that the approach that is being pioneered at Durnacol and which overcomes some of the more obvious deficiencies of both the EMPR and the traditional IEM process will ultimately serve as the model for all responsible mines in South Africa. It is also believed that this approach will enable the authorities to issue closure certificates with the confidence that there will be no unforeseen surprises in the years after closure.

Principles of environmental risk assessment and management

Environmental Risk Assessment and Management (ERAM) is an approach, which is rapidly gaining popularity in South Africa. However, there are many different interpretations of the concepts and principles of ERAM and, unfortunately, a number of prevailing interpretations and wrong applications undermine the essential strengths of the risk-based approach. Examples of these misapplications are the application of the risk-based approach to:

- propagate the viewpoint of 'limiting the risk of being prosecuted by the regulating authorities'. Applying the risk-based approach only to drive minimum legal/regulatory compliance management will most probably not cover all the uncertainties and associated risks, which will ultimately determine the granting of final closure. This mutation of the risk-based approach cannot be seen as the proper application of ERAM and is merely minimum compliance with the law under a different guise. It is also important to note that this approach does not protect one against common law claims which may be successfully pursued despite compliance with all regulations
- persuade regulators to accept lesser action than dictated by minimum standards, by arguing that the lesser action reduces the site-specific risk to an acceptable level. Caution should be taken in the application of the risk-based approach for this purpose. The focus should not be on obtaining relaxed standards, but rather to identify, quantify and manage the real risks ultimately prohibiting mine closure. Should site-specific standards be changed in the process, this should be viewed as a spin-off and not the aim. Mutating the risk-based approach has the inherent danger that regulating authorities could perceive all risk-based approaches as techniques supporting operators in doing less than is required to responsibly protect the environment on a sustainable basis.

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The approach towards the understanding and application of ERAM, which the authors advocate, differs significantly from the two interpretations just given. The most important concept of our interpretation is that ERAM is used to identify, quantify and then manage an operation's real environmental risks—irrespective of whether or not the issues at risk are covered by law, or whether it could lead to the relaxation or tightening of site-specific environmental standards. Diligent application of this approach will mean that all those risks assessed as obstacles to obtaining closure will be known, quantified and managed with funds that will be provided for timeously.

The advantage of this approach, which recognises that laws and regulations are continuously changing, is that it makes the operator independent of changing laws and perceived 'shifting goalposts'—a common complaint voiced all too often by operators whose focus is one of minimum legal compliance. A second advantage is that it allows the company to focus its resources on the real risks, which need to be addressed to enable a closure certificate to be granted. Importantly, the interpretation of ERAM as put forward by the authors would, in their view, be a pre-requisite for any company which is serious about implementing the ISO 14001 management system.

This interpretation removes the sensitivity to 'shifting legal or management-related goalposts' and also gives all relevant Interested and Affected Parties (I&APs), be they the company, authorities or stakeholders, the confidence and peace of mind that there will be no unpleasant, costly and time-consuming surprises later on. This is particularly important for mining operations which, having a finite life, will need to obtain a closure certificate at the end of their productive life.

The authors believe that the ERAM approach, which is being advocated here, will prove to be the only sensible way for mines to plan and manage their operational environmental obligations and the closure process.

Background to mine closure at Durnacol

Coal mining activities commenced at Durban Navigation Collieries' (Durnacol) No1. mine in 1904 and at a later stage extended westwards to No. 2 and No. 3 mines. Production at No. 1 and No. 2 mines was discontinued in 1945 and 1954 respectively. The No. 3 mine continued expanding westwards and a series of service shafts were established to form what is now termed No. 5 and No. 7 mines. A variety of mining methods were used, from hangot development (bord-and-pillar), mechanized bord-and-pillar, mechanized pillar extraction to mechanized longwalling. Some surface settlement is experienced due to longwall exploitation and extraction of large areas of pillars. Durnacol contains numerous washed coal stockpiles, waste dumps and slimes dams which could all impact directly and indirectly on the environment. Waste dumps from the No. 3 and No. 7 plants suffer from spontaneous combustion and have been burning since their existence.

Durnacol is situated in the Chelmsford dam catchment. Since no opencast mining has been done, there is no major surface damage. Various rivers cross the mine area and drain into the Chelmsford dam. Due to exhaustion of reserves, the mine is projected to cease operations by 2003 and detailed planning and implementation of mine closure activities is currently under way.

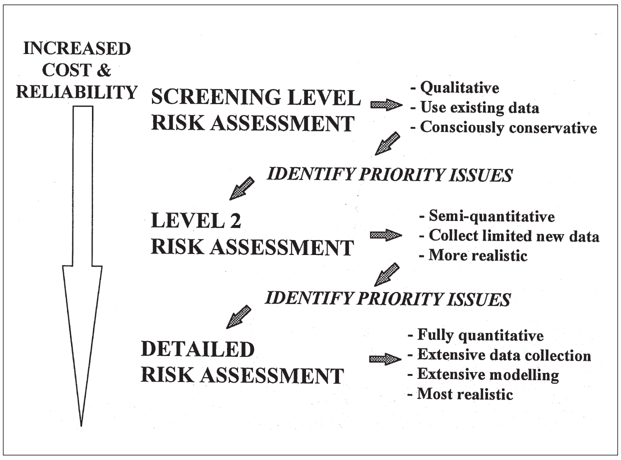


Figure 1—Schematic representation of the Risk Assessment Process

The risk assessment process applied at Durnacol

The ERAM process starts with an all-encompassing, conservative screening-level risk assessment, moving towards a detailed quantitative risk assessment of issues agreed as being critical by a multidisciplinary team consisting of all I&AP's (including all regulatory authorities involved with closure). Apart from being objective, the process has also been designed to be robust and transparent. In this context robustness is interpreted to mean that all potential environmental risks are adequately and demonstrably addressed, and transparency to mean that all decisions are reached by consensus, that they are clearly and fully justified, documented, communicated and agreed to with the I&APs. This approach is shown schematically in Figure 1.

The risk assessment process was started at Durnacol at the beginning of 1996 and has been applied by Iscor's Environmental Management Services in conjunction with the consulting company EnviroRisk Assessment (Pty) Ltd. The process is still ongoing and to date, the following components of the risk assessment and management process have been undertaken:

- initial internal screening level risk assessment
- initial I&AP's meetings to discuss risk assessment approach
- preparation of detailed screening level risk assessment documentation
- initiation of following detailed studies aimed at supporting full quantitative risk assessments:
  - development of scoping catchment management plan
  - detailed monthly water and salt balances and detailed water quality monitoring
  - specification, design and construction of major water monitoring weirs
  - initial geohydrological studies
  - detailed legal /regulatory risk and compliance assessment

- detailed socio-economic and post-closure land use assessment
- detailed kinetic geochemical modelling of dump 7 to quantify long-term (200 years) pollution potential of the dump and to specify appropriate dump rehabilitation measures.

Kinetic geochemical modelling as a quantitative risk assessment tool for Durnacol discard dump 7

The risk assessment process at Durnacol indicated that long term pollution of ground and surface water through contaminated seepage from the coal discard dumps constituted a major risk. Accordingly it was decided that accurate prediction of acid generation and metal leaching should be undertaken with the aim of reducing the uncertainty to a level at which the potential liability can be quantified and to enable selection of the appropriate monitoring, rehabilitation, mitigation and contingency plans. The only effective procedure currently available for the quantitative prediction of metal leaching and acid generation from a coal discard dump is based on kinetic geochemical modelling.

As the No 7. discard dump is the current operational dump and extensions to the dump needed to be designed and implemented, it was decided to apply the first geochemical modelling exercise to this dump.

General principles of geochemical modelling

The selection of geochemical modelling scenarios is based on the results emanating from a physical rehabilitation modelling exercise. Geochemical modelling of a coal discard dump provides long-term estimates (+100 years) of the possible changes/trends of the quality of seepage from these dumps. The results of such modelling improves the understanding of interactions between geochemical processes and enables the mine to make informed decisions when comparing different design, operating and decommissioning scenarios for coal discard dumps. Kinetic geochemical modelling also provides a basis for comparison of the possible long-term water treatment costs for each option.

Kinetic geochemical modelling programmes simulate the generation of acidic drainage in a discard dump. This is a superior modelling approach, since the model considers the kinetic rates of biological and chemical oxidation of sulphide minerals present as fines and rock particles, as well as chemical processes such as dissolution (*kinetic or equilibrium controlled*), complexation (*from equilibrium and stoichiometry of several complexes*), and precipitation (*formation of complexes and secondary minerals*). Through mass balance equations and solubility constraints (e.g. pH phase equilibrium) the model keeps track of the movement of chemical species through a discard dump and provides estimates of the quality of seepage (pH, sulphate, iron, acidity, etc.) leaving the dump. The model also includes the dissolution (thermodynamic and sorption equilibrium), adsorption and co-precipitation of several metals.

The model can be adapted to include the simulation of timed events or site-specific activities such as placement or removal of discard lifts, incorporation of slurry dams within the dump, recontouring of the dump, and installation of a cover. These models could be used in engineering assessments to provide long-term predictions of acidic drainage for application of several different covers on acid generating dumps, e.g. reclamation with a cover (compacted clay, semi-compacted clay, non-compacted clay), re-profiling the dump into an extension and mixing the relocated waste with lime, removal, mixing with lime, and placement at the bottom of an open pit, flooding, and bactericide treatment. The results of the geochemical modelling programme provide crucial information regarding rehabilitation, replacement of material, closure stormwater control, final shaping and end land use.

Geochemical modelling of durnacol No. 7 discard dump

The kinetic geochemical modelling of the Durnacol coal discard dump included three main tasks, which are described below.

Phase 1. Sampling programme for geochemical modelling

The essential data for the geochemical characterization of a discard dump include:

- ➤ the age and method of construction
- ➤ measurement of seepage flow and quality for at least several months
- ➤ an estimate of the volume and dimensions of the dump
- ➤ an estimate of the average sulphide content within the dump
- ➤ identification of buffering minerals plus an estimate of the possible quantity of these within the dump
- ➤ determination of the particle size distribution of the discard material.

The accuracy of the model predictions depends on the amount and quality of the data available.

Phase 2. Data assessment and base case simulation

This task involved a review of the available data for the purpose of preparation of inputs for the geochemical model named ACIDROCK. This task could include some or all of the following steps, depending on the amount and quality of data currently available:

- ➤ assessment of chemical and/or mineralogical analyses of coal discard solids
- ➤ interpretation of Acid-Base Accounting (ABA) testwork on coal discard solids to characterize the acid generation potential
- ➤ review of water quality monitoring data for heap seepage and samples from field installations (e.g. boreholes)
- ➤ examination of the field measurements (e.g. oxygen, temperature) from the instrumented boreholes, and preliminary physical modelling of the dumps
- ➤ examination of particle size data to characterize the reactive surface area, and review of observations on weathering of the spoils to characterize the possible increase in fine particles (and therefore the reactive surface area) over time.

A separate model called CONVECT was used to estimate the convective airflow rates, and heat generation and transport within the dump. These parameters were used to prepare inputs for the geochemical modelling. There are several detailed (non-chemical) models that could be used to simulate the physical processes occurring inside the dumps; however, none of these consider geochemical or biological processes. Detailed physical modelling is expensive, and does not provide any information on the effect of decommissioning options on quality of the seepage, and the potential treatment costs. Also, the typical coupled flow-chemical equilibrium models cannot be used to examine convection or heat generation.

The ACIDROCK model is a deterministic model (i.e. it is currently not contained within a probabilistic framework). Validation of the model would be demonstrated through our ability to accurately predict the current conditions observed for the modelled dump at the site.

The base case scenario was an extended (200-year) simulation of discard dump No. 7, assuming that the dump was left in its end-of-life condition (i.e. current state, after 5 years operation and uncovered). The minerals/precipitates considered in the ACIDROCK geochemical model include pyrite, calcite, gypsum, iron hydroxide, aluminium hydroxide, sericite, mica, jarosite, (plus others). It should be noted that the buffering provided by the carbonate minerals is under equilibrium control, but the buffering provided by the aluminosilicates is under kinetic control (i.e. depends on flow, as well as pH conditions). The typical coupled flow-chemical equilibrium models do not consider kinetic controls on the dissolution of buffering minerals, whereas the kinetic geochemical model does. This important feature allows one to observe the potential buffering provided by various minerals under the different (flow) conditions that could result from various closure options. The buffering provided by aluminosilicates significantly influence the long-term quality of the seepage under the low flow conditions resulting from placement of a cover on the dump.

Another significant consideration at the Durnacol site was the creation of fresh reactive sulphide due to physical disintegration of the particles (i.e. weathering). Since parts of the dumps are burning, the extreme temperatures accelerate weathering. The ACIDROCK geochemical model does not simulate the burning process directly, but does consider several processes associated with burning, such as:

- generation and transport of heat
- effects of extreme temperatures on sulphide oxidation kinetics
- presence of organic carbon
- partial pressure of carbon dioxide; and
- changes in the particle sizes as a result of weathering.

Phase 3. Simulation and assessment of various closure options

The ACIDROCK model was used to examine the effects of the following three (3) cover options on the predicted quality of seepage from the dump:

- placement of a poor cover
- placement of an intermediate cover
- placement of a good cover;

with the key characteristics of these covers being as shown in Table I below. The cover material options were assumed to be increasingly effective in reducing air, oxygen and water movement into the heap. The infiltration rates were based on a model of the physical characteristics of the Durnacol No. 7 discard dump. The selection of oxygen diffusivity coefficients were based on air inlet values for the various available soils to be used as cover material, taking into consideration the effect of particle size, moisture content and temperature on diffusive transport.

The main effect of cover options is a reduction in the extent of sulphide mineral oxidation due to a reduction in the oxygen flux into the discard dump. This is illustrated in the concentration profiles given in Figures 2 to 9 and is most evident in the profiles for sulphate, acidity and total iron for the base case simulation which are much higher than predicted for all three cover options. While the concentrations of these three constituents are similar for the cover options, the pH profiles demonstrate the benefit of intermediate or good cover material versus the poor cover material. The effect of higher pH levels with the cover options is also evident in the trace metal predictions. The arsenic, cobalt, copper, nickel and zinc levels are considerably higher in the base case options than in the cover options. Strontium and manganese show a similar difference between options, though not as pronounced. In general, the trace metal levels for the intermediate and good cover material options are seen to be lower than for the poor cover material option.

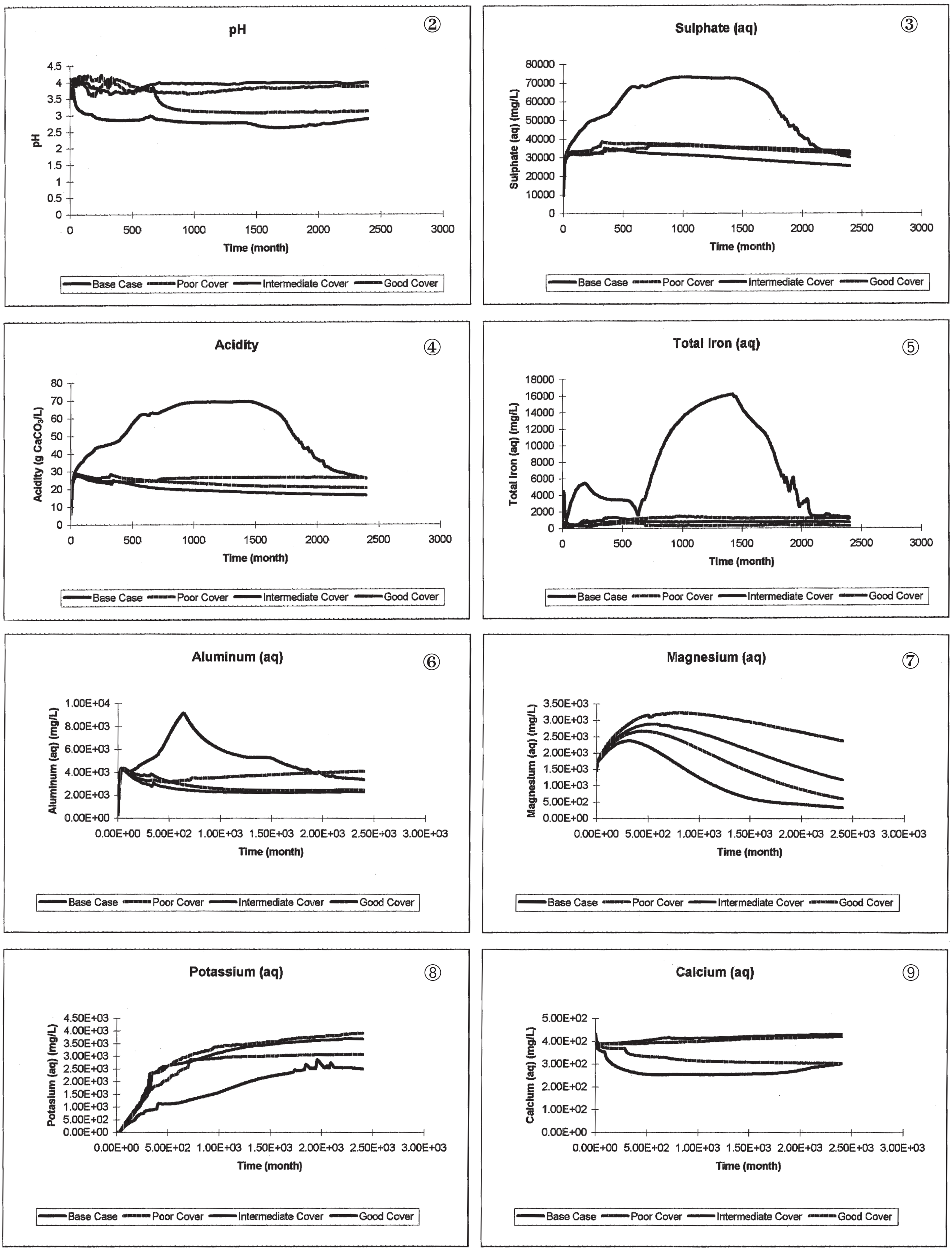
With respect to several of the major cations (calcium, magnesium, potassium and sodium) concentration profiles for the base case are seen to be lower than for the cover material options. The lower levels of calcium, magnesium, potassium and sodium in the base case are attributable to the formation of secondary mineral precipitates caused by the predicted high sulphate level (i.e. gypsum, magnesium sulphate, potassium and sodium jarosites, respectively). The predicted lower magnesium and sodium profiles may also be attributable to simple dilution effects once the available buffering minerals have been depleted. The effect of reduced infiltration rates for the four options is most evident for these two constituents. In contrast, the aluminium level is seen to be higher in the base case scenario. This is due to a higher rate of consumption of the aluminium hydroxide buffering mineral in the base case option. The decrease in the concen-

Table I

Air, oxygen and water transport properties assumed for cover option simulations

Simulation scenario	Infiltration rate as a per cent of total precipitation*	Convective airflow rate (m/month)	Oxygen diffusivity coefficient (m^2/s)
Base case	25% (0.22 m/y)	2.0	5×10^{-6}
Poor cover	15% (0.132 m/y)	0.4	5×10^{-8}
Intermediate cover	10% (0.088 m/y)	0.1	1×10^{-8}
Good cover	5% (0.044 m/y)	0.0	5×10^{-9}

* Note: Total precipitation equals 878 mm/y



Figures 2–9—Concentration profiles as predicted by the ACIDROCK model for Durnacol cover option

tration profile in the base case option coincides with depletion of the aluminium hydroxide mineral.

Cumulative loading data indicate that the cover material options are more effective in reducing the loading of some constituents than others. In particular the sulphate, arsenic, aluminium, cobalt, copper, nickel, zinc, total iron and acidity loading are reduced to a greater extent than the proportional reduction in flow. For example, the flow for the good cover material options is approximately equal to 20% of the base case flow, while the cumulative arsenic loading after a 200-year period equals only 2% of the loading estimated for the base case. Similar observations apply for cobalt, copper, nickel and zinc in the three cover material options although the intermediate and good cover material options are seen to be relatively more efficient than the poor cover material option. The reduction in the loading of other parameters such as aluminium, strontium and sulphate are less dramatic but nonetheless greater than the reduction in the flow in all cover material options. As could be expected, the reduction in the loading for the more soluble and less reactive species (e.g. calcium, potassium, magnesium, manganese and sodium) are the least affected.

Practical implications of geochemical modelling

The purpose of the geochemical modelling exercise was to provide a rational and defensible basis for designing the rehabilitation cover for the No. 7 discard dump. Although the seepage from the dump is currently highly saline but neutral, the modelling clearly shows that the seepage will become acidic in future and that an appropriate cover will be required. Clearly a good cover has benefits over a poor cover, although, depending on the available soils, this may be at a substantially higher cost. The final step in the process (which had not been completed at the time of submission of this paper) is to undertake a cost benefit assessment of the three different cover options, considering the following factors:

- predicted long-term seepage quality and loads and the ability of the receiving environment to assimilate them
- cost of construction and maintenance of different covers
- cost of construction, operation and maintenance of water treatment plants required (if any) to deal with long term seepage.

The most cost effective cover will then be placed on the dump and the predicted long-term residual pollution will determine what provision, if any, will need to be made for water treatment.

Implications and benefits of the ERAM approach

The risk-based mine closure process which is being adopted at Durnacol is a novel approach which is aimed at breaking the stalemate which currently exists with regard to the granting of walk-away closure certificates by the authorities. In particular, it is viewed as very important that regulating authorities and the mining industry adopt a process which is capable of giving the necessary confidence that the mine has accurately predicted its long-term (+100 years) impacts and has made the necessary resource and financial provisions to address these impacts. The authors believe that this assurance can be given and demonstrated by the ERAM approach which is widely used and accepted by environmental authorities around the world. It is proposed that if the regulatory authorities and the mining industry in South Africa use this approach as the basis for granting closure certificates, there will be no risk of identifying further unknown problems after closure has been granted and the authorities will know what liabilities they are accepting when granting closure —albeit after an appropriate monitoring period to demonstrate the accuracy of impact predictions.

Adopting the proposed ERAM approach has the following fundamental implications for a mine.

- Conventional planning and commissioning of new developments and the day-to-day environmental management actions shifted to focus on the identification, quantification and management of the real environmental risks, as opposed to perceived risks.
- The mine may have to go beyond minimum legal compliance to be able to adequately address and eliminate the real risks preventing closure.
- The conventional mine closure cost estimation process, usually dictated by individual role-players' perceptions of risk and the legislation of the day, are adapted to include the real risk concept and become independent of the shifting goalpost syndrome.
- Interpretation of the proposed ERAM approach, as put forward by the authors is a prerequisite for any mine which is serious about implementing the ISO 14001 management system.
- Developing and using a uniform systematic documentation and database management system within a mine throughout the life of the mine results in openness and transparency about environmental management.

Apart from the benefits of the risk-based approach to Iscor Mining, it is truly viewed as the ultimate challenge to the mining industry and regulating authorities in South Africa to initiate and jointly develop a responsible environmental management approach which ensures mine closure—an approach which is sufficiently flexible to accommodate changes in legislation and management policies and strategies, but which ultimately meets the confidence level of regulating authorities by proving that no unknown or hidden environmental risks will appear after mine closure has been granted, thus relieving the company from future legal as well as moral environmental responsibilities.

With more than 15 years of direct hands-on experience and more than 10 years development experience, SENES Consultants Limited (SENES), a Canadian company with their head-office in Toronto, can determine which programs are most suitable to your project needs. Pulles Howard & de Lange Incorporated (PHD Inc.) has a formal association with SENES and the two companies have been working together in the fields of risk assessments, environmental impact studies (including radiological hazard assessments), and in particular kinetic geochemical modelling, for the past two years. All the mathematical (computer) models mentioned in this article are proprietary software developed by SENES. More information regarding these modelling programs and their capabilities are obtainable from Dr Rudy Boer (Tel 011-726-7027; Fax 011-726-6913). These models have been applied in the prediction of long-term geochemical behaviour of tailings (acid-generating or alkaline), waste rock, and entire mining regions (open pits, underground mines, backfill, etc.) ◆