New developments on mine planning and grade control at Sishen Iron Ore Mine

by D.J. Steynfaard, W.C. Louw, J. Kotze, J. Smith, and B.H.J. Havenga*

Introduction

Sishen Iron Ore Mine is situated in the Northern Cape Province of South Africa as shown in Figure 1. A high-grade hematite reserve is exploited by open pit mining with a conventional truck and shovel operation. The mine consists of a single large pit subdivided into more than ten small, medium and large pits at varying depths. A bench height of 12.5 m is used with a road width of 30 m and a ramp gradient of 8%. The primary equipment fleet currently consists of:

➤ 45 x 190 t Haulpak 730E diesel electric trucks
➤ 8 x P&H 2300 XPB electric rope shovel
➤ 2 x Demag H485 electric hydraulic shovels
➤ 9 x Bucyrus Erie 49R electric rotary drills
➤ 3 x Caterpillar 994 front end loaders.

The orebody is complex due to folding and sinkhole structures and strikes along a length of 12 km in the north-south direction and dips to the west at about 15 degrees. The orebody consists mainly of massive and laminated ore with about 15% conglomeratic ore and varies in thickness up to 100 m with an average of about 30 m. Due to the complex geological structure, the grades and beneficiation characteristics of the ore differ markedly over short distances. This, together with the fact that the geological information changes continually as the result of new exploration and pit mapping, complicates grade control and ore tracking.

The total ROM production is treated in a heavy media separation plant due to dilution with waste rock on the contact zones and layers of shale included within the orebody.

Synopsis

Sishen Iron Ore Mine is situated 280 km north-west of Kimberley in the Northern Cape Province of South Africa. The mine produces and sells high quality iron ore of various specifications to various national and international clients. The saleable product is derived from the blending and beneficiation of different types and qualities of hematite iron ore.

This paper documents the new developments which were implemented (or are in the process of being implemented) on the mine in the long-term planning, medium-term planning, grade control and material tracking in the beneficiation plant with special attention being paid to the quality of the final, saleable product.

The process starts with the long-term planning where the pit shell and pit optimization is determined by Whittle 4X. New developments include the introduction of a linear programming based scheduling system to enhance the long-term schedule generated by Whittle 4X. The LP route was decided on in order to take into account all the constraining factors of the final product that could not be configured in Whittle.

To complement this the XPAC Auto Scheduler scheduling package was introduced to do the medium-term mine scheduling. This 18-month rolling plan includes cost parameters to enable the planner to extract a detailed operational budget from the scheduling while ensuring that production standards are maintained and grade constraints are met.

The existing grade control system was enhanced with GPS capabilities and a computer system to do material tracking. The high precision GPS system introduced on the shovels allows for the accurate control of the loading procedures at the mining face. Because of the complicated geology and grade composition of blasting blocks it is imperative to accurately differentiate between different materials in the same blasting block and being able to excavate that with the loading equipment. The GPS system on the trucks allows for accurate location monitoring of dumping in order to keep track of specific material types.

The state-of-the-art material tracking system developed for Sishen will enable the grade control officer to keep track and record various parameters of the material from its in situ position in the blasting blocks, through the crusher and onto different stockpiles, in various stages of the beneficiation process and onto the blending beds, into the dispatching trains and eventually into the ships for international distribution.

These developments elevate the Sishen planning and grade control systems to a new level of service excellence from which management can obtain accurate and timely information on product status. It also enables Sishen to maximize resource utilization while still complying with the tough market constraints.

* Sishen Iron Ore Mine, Kumba Resources Ltd, Sishen, South Africa

© The South African Institute of Mining and Metallurgy, 2002. SA ISSN 0038–223X/5.00 + 0.00. The paper was first presented at the SAIMM Conference, Surface Mining 2002, 1–4 Oct. 2002.
New developments on mine planning and grade control at Sishen Iron Ore Mine

Figure 1—Locality map

Long-term mine planning

Scheduling

Sishen uses Whittle 4X as a pit optimizing tool in order to provide an optimum final pit layout with the resultant mineable reserves. Currently about two-thirds of the in situ reserves are economically mineable and included in the final pit layout.

Sishen holds long-term (5-year) contracts with its clients and is known to be a reliable supplier of iron ore. In addition to costs, consistent ore qualities are the main drivers of pit scheduling. The main ore qualities to be controlled are the iron content, as well as the potassium and phosphorous impurities.

Short-comings

The long-term schedule generated with the Whittle nested pits provides a good theoretical guideline as to the optimal pit deployment strategy based on economics. At Sishen however it cannot be closely followed due to the following limitations:

➤ From an equipment capacity point of view the schedule does not take into account limitations due to pit room and for example will require the total loading fleet’s capacity to be delivered from a small pit with loading space for only one or two shovels

➤ The schedule only considers economics based on cost and income and results in high variations in ore quality from one year to the next. This may result in the mine losing market share in one of its important market segments.

The mine decided, in 1997, to implement a linear programming based scheduling system in which these short-comings can be addressed. After investigating the market to see what was available, it was found that most major mining software companies were still in development stage as far as LP scheduling was concerned. It was decided to implement a scheduling system along with a South African firm ‘Large Scale Linear Programming Solutions’ which already had a number of similar implementations on mining sites in South Africa. This firm provided the interface to the LP package (H/XPRESS12), which is the backbone of the scheduling system. The LP package was provided by Haverly Inc. & Dash and is widely used in the mining and other industries. This package is capable of using multiple processors through a network, assisting in solving large LP matrices and cutting down on solution time.

Data preparation for LP scheduling

The data preparation is done in the same manner as for Whittle, using only the portion of the geological model within the final pit limits through the Whittle interface of the general mining package. Block sizes are determined by the working space required by mining equipment. At Sishen block sizes of 50 m in the east-west direction and 100 m in the north-south direction are used in order to provide space for temporary ramps between active mining faces, which have not yet reached final pit boundaries. The LP works on the principle that if a block is to be mined, the nine blocks above it must also be mined. Since only blocks inside the final pit layout are utilized, the schedule results in steep slopes at final pit boundaries with accessible berms at the active mining faces as shown in Figure 2.

Weighted average ore qualities, mining and plant costs and ore and waste tonnages per block are accumulated in separate lists for each pit that can be mined independently. In total about 30 000 blocks are used at the start of the scheduling run. Equipment capacity constraints are provided by subdividing the total mine model into pits, each with a minimum and maximum tonnage to be mined for the next scheduling period. The maximum tonnage is determined by the number of shovels that will fit into the pit, each requiring two blasting blocks with a face length of 200 m each. Although this standard may be increased, it will result in a lower utilization of the equipment as a result of frequent blasting and a lot of time spent on waiting and travelling between blasts. The minimum tonnage per pit can be used in order to force the LP to mine out a specific pit prematurely for example during an investigation into the potential of backfilling of waste rock from adjacent pits. After each scheduling run, normally one-year periods during which the LP has found the optimum combination of blocks meeting the constraints, the following actions are taken:

➤ Remove the blocks mined in the previous period from the model

Figure 2
Subdivide the model into more pit areas, if required
Measure active face lengths where benches have not reached final pit limits. A maximum standard of 10 Mt/a per shovel and 400 m of active face length per shovel is used at Sishen
Adjust required limits for the next period in terms of ore tonnages, qualities and production capacities per pit area
Start the optimization run for the next period.

The above Table is an extract from the LP model used:

### Scheduling results

After completing the scheduling run over the life of the mine, the cash flows from the schedule can be compared to another schedule with different parameters, therefore quantifying the difference in parameters used, such as mining at better qualities than the average of the reserves for a number of years.

The LP schedule mines in each period the minimum waste rock required to expose the ore mined for that period. Since pre-stripping is required to expose the ore on a continuous basis, the additional waste rock pre-stripped during a period is in practice done where the LP schedule has mined waste in the next period. Figure 3 shows the stripping curves for Sishen as follows:

- The maximum stripping curve is the cumulative ore and waste mined if mining is done bench by bench from the top to the bottom
- The minimum stripping curve is the cumulative ore and waste mined if mining is done according to the LP schedule without any exposed ore reserves and pre-stripping
- The planned stripping curve is the cumulative ore and waste mined if mining is done according to the approved stripping strategy, ensuring the required ore exposure and future profitability of the mine without high risks.

In essence the LP schedule follows the same pattern in pit deployment as the Whittle schedule, with the difference that low cost pits are usually mined at a lower rate and high cost pits mined sooner due to ore quality and pit room constraints. It further highlights the possibilities in terms of future ore quality trends and is a handy tool in order to evaluate and quantify different pit deployment strategies.

### Achievements

Sishen Iron Ore Mine now have a long-term scheduling tool based on the following global factors:
- Economics
- Physical pit layout
- Composition of final mined product.

### Medium-term planning

Kumba Resources is committed to add value to its shareholders and therefore continuous improvement is a way of life at Sishen Iron Ore Mine. The iron ore grade variation associated with the product is required to be within a very narrow range, and at the same time impurities within the ore need to be minimized. Costs associated with the mining of the ore and waste had to be integrated into a mine planning system. The main focus is to improve on a rolling 18-month cost plan (every three months) while making sure that production standards are maintained and improved on.

### Identified needs

The following points were identified as being important criteria in a Medium Term Scheduler:
New developments on mine planning and grade control at Sishen Iron Ore Mine

- Controlled final grade of product
- Cost of mining (looking at the whole sequence of drilling, blasting, loading and hauling).
- Different scenarios needed to be evaluated and compared (What if) in an acceptable time.

In order to achieve all of the above-mentioned factors, the need for a specialized medium term, mine scheduling, tool was identified. The criteria were sent to numerous software providers to enquire if such a package existed off the shelf. Figure 5 shows the basic criteria, which had to be met by these software packages.

The only software package at the time, which complied with the criteria, was the XPAC Auto Scheduler, which is a mine planning and scheduling software system developed by Runge Mining in Australia.

**XPAC auto scheduler at Sishen Iron Ore Mine**

**Database functionality**

The database functionality of XPAC provides a user-friendly interface to the mine design system used at the mine. *In situ* data pertaining to grade and tonnage are imported into XPAC. The data are then analysed to indicate preferred areas within the mine (five areas), which may be combined to provide an optimal blend when scheduling is performed. A record in the database represents each mining block, and these records contain information relevant to the mining block.

**The scheduling process**

In order to optimize the scheduling process, mining costs are included for mining blocks. These costs relate to drilling and blasting, loading and hauling as well as secondary equipment costs. The costs for drilling, blasting and loading are computed for each of the seven different waste material types. These costs, dependent on where mining took place, would change from one time period to another. The added ability of XPAC to generate cost plans makes the reconciliation process easier. For the mine-planning engineer it is now possible to know if the production process was effective and efficient. For example the efficiency operating variance can be calculated.

*Efficiency operating variance* equals *‘Actual cost’*(based on actual tonnage mined) minus *‘New budget’*(on area mined)

A prediction of the associated profit for each block or a combination of blocks can be made. Using this technique a cost ranking exercise is completed for each pit to indicate its profitability. During scheduling, the combination of material from each pit is controlled in order to achieve the best blending scenario. It is now possible to do several combinations in a single day. Dependency rules are defined which ensure mining logic and integrity is maintained. Undermining (by the scheduler) is therefore eliminated.

The quality of the blend of material derived from several pits must fall within stringent specifications. These targets apply to iron content as well as impurities like phosphorous and potassium.

XPAC produces mining schedules, which satisfy these criteria, while restrictions pertaining to production rates and logistic limitations derived from the various pits are also adhered to. Production targets are stored in a comprehensive calendar database, which allows for day-to-day scheduling as well as annual scheduling scenarios.

The haul road network within the mine has been imported into XPAC. It is therefore possible to predict hauling distances to major network nodes like primary crushers, stockpiles and waste dumps.

Sishen makes use of a pantograph trolley assist system, which dramatically reduces hauling costs from e.g. R1328.00/h without the pantograph to R508.00/h with the pantograph.

---

**Figure 5—The basic criteria which had to be met by the software packages**

**Figure 4—A three-dimensional view of scheduled blocks for a two-year face advance for a portion of the pit**

**Figure 6—Loading of a 190t haul truck**
pantograph. The pantograph system (shown in Figure 7) has been successfully modelled within the XPAC system.

Detailed haul route profiles can now be simulated to predict the optimal route to use when transporting material out of the pit (Figure 8 indicates a haul road network in XPAC).

In addition, the system is capable of predicting cycle times, truck hours, truck hours per road segment (flat road, uphill with pantoh, uphill without pantoh, total distance for each mining block), litres per hour, tons per litre, tons per kilometre and the number of trucks required on the haul route.

With XPAC, waste dump scheduling is now possible. Each dump position is accurately recorded in XPAC (currently there are 27 dump areas in the mine). The material placed on the dump is recorded and the monthly requirements in dump capacity can be predicted. Using the haul road network, it is possible to decide the best suited dumping position.

The final schedules can be represented graphically. Period progress plots depict the mining operations as it is planned. These plots are three-dimensional, and the mining operations can be animated on the plot to simulate equipment positions and movement. The animation is useful for visualizing and comparing possible mining options. (Figures 9 and 10 illustrate these plots.)

With the XPAC Auto Scheduler the mine produces a rolling 18-month mining schedule optimized within the ore quality specifications and mining parameters and evaluated against mining cost. This ensures that production standards are maintained and improved on at a lower operating cost.

**Grade control**

A culture of continuous improvement is practiced extensively in the modern Kumba Resources, and areas of grade control are no exception. This section of the paper discusses the major improvements that were launched to refine the grade control methods and to develop new methods. In every one of the projects, advanced technological systems and teamwork provided new solutions and insight into the varied grade problems, and helped to re-define the mineable ore reserves.

The main chemical parameters of the high-grade iron ore product produced at Sishen are:

- Iron (Fe)
- Silica (SiO2)
- Aluminum (Al2O3)
- Potassium (K2O)
- Phosphorus (P)
- Sulphur (S).

Numerous ore blocks are blended continuously by a computerized truck-allocation system, which is set to maximize production while staying within the prescribed ore specification. Sishen is one of few iron ore mines in the world where all the ore is beneficiated before being shipped to customers. After beneficiation, 70% of the product is railed to Saldanha Bay for export, whilst the domestic market (Iscor) absorbs the remaining 30% in the manufacturing of steel.

Due to the structural complexity of the geology, the chemical quality of the iron ore varies considerably throughout the orebody. This variability is an important factor in the prediction of ore grades in the geological model, and therefore also in the mine planning, production scheduling, and grade control.

The Grade Control Section utilizes information from a number of sources to control the blending of material from ore blocks in the mine to get the right blend through the plant. Any weak link in this ‘chain’ could contribute to an ore bed falling outside the prescribed specification and being disqualified as saleable product, or the completion of an ore bed could be delayed. A non-conforming product bed represents an income loss of millions of rands.

This section focuses mainly on some of the improvements in technology in the Mining, Geology and Grade Control Sections.

**The problem solving process**

In the iron ore markets of the world, an increasing number of customers are requiring mining companies to comply with the ISO 9002 quality standards set by the International Standards Organization (ISO), which prescribes models for quality management systems in different sectors of industry. The standards can be a valuable tool to companies wishing to reconcile their product characteristics with...
New developments on mine planning and grade control at Sishen Iron Ore Mine

The objectives

In 1996 the following specific objectives were set after brainstorming sessions:

1. A real-time three-dimensional geological computer model would be constructed and would be integrated with the computer systems of the other mining sections
2. Confidence levels had to be stated for all the ore quality predictions in the geological model
3. The blast-hole sampling process had to be automated as far as possible
4. Information on grade control had to include the beneficiation characteristics of the ore types in different areas of the mine
5. Production had to be maximized without any sacrifice of quality.

This portion of the paper will briefly discuss (2), (4) and then (5) in more detail.

Confidence in the prediction of ore quality

1985 to 1995

Traditionally, the modelling of ore quality initially requires extraction of the chemical analyses as weighted bench composites to give an average value on the mid-bench position where each drill hole intersects the bench. This process was carried out with the help of the available computer software. The composite values were used to predict values on a grid 25 m x 25 m x 12.5 m using the statistical technique of inverse distance. Only the identified ore polygons were filled with the predicted qualities.

The shortcomings of this method include the following.

➤ The process of compositing implies that quality prediction of the ore takes place across geological boundaries, whilst geologically homogeneous domains are prerequisite for grade prediction using inverse distance.
➤ There was no method for establishing the most applicable mathematical power and the optimum number of reference samples in the inverse-distance process.
➤ No clear level of confidence could be stated for the predicted values.

1995 to 1998

Research at the mine (C. Lemmer, 1993) showed that geo-statistical concepts were applicable on the site and, if optimized through advanced computer systems, could improve the ore evaluation. A geo-statistical process was introduced.

Homogeneous geological and statistical domains were selected for each material type. A variogram model was constructed for every relevant element in each domain and, after being validated, provides input parameters for the ordinary kriging process. All the iron-bearing material was taken into consideration in the prediction process.

Although the predictions differ significantly from the real values in several individual blocks, kriging provides more accurate average values over several composite blocks than the inverse-distance method.

Post-1998

Sishen utilized the Surpac computer system that gave more information per blast block. The logging and the quality were available on the same screen and one could do the demarcations on screen. The Short-term Geological Office was also implemented to do predictions per blast block using various tools at their disposal.

Short-term geology

The Short-term Geology section was implemented 3 years ago to form a link between geology, long-term planning, short-term planning and quality control.

The ability to predict tonnages and grades is crucial to successful short-term planning and production control. The most sophisticated scheduling process is only as good as the information it is based on. Each day new blast holes and exploration drill holes are drilled. The cores and chips are logged and the information is added to the database. The Short-term Geology section makes use of all the up-to-date
information available to estimate qualities and tonnages for planned mining blocks. This ensures up-to-date information for better risk analysis and decision making for production control.

The statistical methods to estimate the qualities and tonnages are ordinary kriging. This process interpolates values for a given block on the weighted grades of points surrounding it. The kriging weights are based on the variogram model parameters and the anisotropy factors for the search ellipsoid in each homogeneous area. Each blasting block, after being drilled, is kriged again to get a final answer. This is used to reconcile against and eliminates any bias in the predicted estimates. Every second blast hole is sampled every metre.

All the blasting blocks kriged by Short-term Geology are stored on a central database and can graphically be viewed in various configurations (Figure 11). Although the Short-term Geology process drastically improved the continuity and accuracy of the geological estimates and the way it is presented, further improvement will always take place. A project to visualize these 5 m x 5 m x 3.125 m blocks in any given elevation and form is being investigated. This will simulate the tonnages and qualities remaining on a given blast block with the aid of the Global Positioning System (GPS). This development will improve the grade control officer’s ability to make better and more accurate grade blending decisions.

**Information from grade control data**

**Pre-1985**

Up to 1985, proposed mine lines (grade control demarcations) were drawn by hand on the hard copy of a blast block. Colour-coding of blast holes (on this paper copy) indicated only the %Fe in the bench composite sample.

**1985 to 1995**

Since 1985, blast block information had been available on a mainframe computer. The blast holes were colour coded according to %Fe, K₂O, and %P. The mine lines were adjusted on screen, and a final hard copy was produced for production purposes.

The main shortcomings of this process were found to be as follows:

➤ Only one chemical element could be visually inspected on screen at any time
➤ Because there was no integration with the geological computer model, current mine lines from the geological model could differ extensively from the mine lines generated by the Grade Control Section.

**1995 to 1998**

In 1995, Unix operating environments replaced the mainframe system, which was still functioning in the Grade Control Section, and the computer systems of Geology and Grade Control Sections were integrated.
The personnel of the Grade Control Section now had the facility to visualize any of the following attributes on screen:

- The current, applicable blast block with any of its immediate neighbouring blocks
- The above-mentioned plus all the short-term production Geology holes drilled in the vicinity
- (1), and (2), in three dimensions, plus the logging and chemical interpretation (%Fe, %K₂O, and %P) of your choice

- The latest interpretation of the blast block, according to the geological model
- The chemical values, tons, density, and yield for the specific demarcation on a blast block in the following way:
In spite of all the changes results were still unsatisfactory. A mathematical algorithm was developed to simulate the beneficiation process by utilizing the separation density and the beneficiation characteristics of the material supplied to the plant. Currently there is good correlation between predicted grade values and actual product values.

**Grade control in the production process**

**Pre-1990**

Before 1990, the %Fe in the blast holes dictated the feed of ore from every shovel in the mine. Impurities in the ore played a role on rare occasions when they were detected in the sample analyses. Towards the end of the period, impurity constraints per block were calculated manually. It was time consuming and led to unsatisfactory results.

**1990 to 1995**

Since 1990, a computerized truck allocation system (Dispatch) has been used to optimize the operation of the trucks and shovels. This had an impact on the Grade Control function.

The blending functionality of Dispatch involves the control of the optimal production quantities from each block so that the final blend meets the required quality levels.

The Grade Control Section uses the continuous blending by component method. The continuous blending method continuously meet the blending production targets while also meeting the blending requirements. A disadvantage of this method is that it results in under utilization of the loader fleet.

**1995 to 1998**

Although the Dispatch system optimized the production process dramatically, there was still the problem of shovels loading wrong material.

The introduction of a Global Positioning System (GPS) to assist with the control of the digging positions of the shovels in relation to known qualities of the ore was very successful.

With all this in place good control can be applied from the mine to the crusher but the beneficiation plant still presented problems. The plant design resulted in 42 localities in the plant where ore of varying quantity (tons) and quality...
New developments on mine planning and grade control at Sishen Iron Ore Mine

(grade) is in transit. That makes the controlling of the blending beds very difficult. Work was started on a large (10MB) Excel spreadsheet to try and keep tabs of what ore is where at any given time. Sishen Mine investigated various ore tracking systems and decided on the Silag System supplied by Siemens. (Figure 23) The system was customized to Sishen’s requirements and will be commissioned during February 2002.

Closing comments
Sishen Iron Ore Mine is participating in the Information Age. The challenge remains one of continuous improvement of the ability to collect and analyse data quickly, present the data in some friendly visual format, and then to use the results in decision making. Computer technology is essential to the process, but teams of people who are able to apply the technology efficiently are the most important part of the Sishen formula.

The future
To integrate mine planning to such an extent that the short-term planning and grade control are logical derivatives from the medium-term plan which in turn is derived from the long-term plan.

To change the Silag or any other system to make grade control independent from the Dispatch system. (To give the computer onboard the shovel a job list for 24 hours and let the computer control the loading of the blast block with the aid of the onboard GPS.)

To have a system that can track the ore through the process from geology to blasting block, feed to plant, plant, rail, harbour, ship and up to the customer and to have a feedback link from the customer back to the mine.

Acknowledgements
This paper is published by permission of Kumba Resources. The authors express their gratitude to Management for the opportunity to present this paper.

References
1. LEMMER, C. Grade prediction at Sishen Mine. Internal consulting report, 1993, Kumba Resources.
2. CRONJE, P.C. Sishen Mine Internal report.
3. BOTHA, J.J. Sishen Mine Internal report.

Innovative breakthrough in mine water treatment*

A South African consortium has made a dramatic breakthrough in the field of mine water treatment. The Integrated Managed Passive treatment technology, or IMPI, represents the successful outcome of an 8-year collaborative research and development programme and is a world-first.

This research programme has succeeded in improving the efficiency of the technology by a factor of 20 over conventional anaerobic passive reactors, thereby making the technology commercially viable.

The passive treatment process is a system that utilizes naturally available energy sources such as topographical gradient, microbial metabolic energy, photosynthesis and chemical energy and requires regular but infrequent maintenance to operate successfully over its design life.

The South African mining industry is facing major problems with regard to the management and treatment of contaminated mine water. These problems exist with regard to operational mines and, importantly, they also exist for mines which have ceased operations and which have long-term water quality problems.

Currently available effluent treatment technology for dealing with water quality problems is primarily of a chemical or physical nature. Although this technology is generally effective, it typically has very high capital and operating costs and intensive, ongoing, long-term maintenance requirements. This is a particular problem for those mines that have ceased operations and where it is not practical or cost-effective to construct an active treatment plant that requires constant supervision and maintenance.

An urgent need was, therefore, identified to develop low cost, self-sustaining, low maintenance passive treatment systems to address the problems of acidification and salinization (in terms of sulphate) at operating, defunct and closed mines in South Africa that requires constant supervision and maintenance.

To date, three primary phases of research on this topic have been commissioned:

1. PHASE 1: A project funded by the Water Research Commission, Chamber of Mines, Eskom and Sasol and undertaken at Arnot Colliery and Western Areas Gold Mine
2. PHASE 2: A project funded by Anglo coal and undertaken at Vryheid Coronation Colliery
3. PHASE 3: A project funded by the Department of Science and Technology’s Innovation Fund undertaken at Vryheid Coronation Colliery and various laboratories around the country.

The integrated passive treatment technology has been developed and branded as the IMPI technology for Integrated Managed Passive treatment systems designed into three primary configurations as follows:

| IMPIOLUME: Applications where in situ remediation of contaminant plumes is required |
| IMPIIMATE: Applications where reduction of metals and acidity is required |
| IMISURE: Applications where reduction of sulphates, metals and acidity is required |

The final phase in this successful development programme that now needs to be embarked upon is the design and implementation of full-scale systems within the mining industry.

* For further information on the project contact: Dr Ralph Heath, Associate Director, Pulles Howard & de Lange Inc., Tel: (011) 726 7027, Fax: (011) 726 6913