A NEW APPROACH TO HEAP LEACH MODELING AND SCALE-UP

By

Mal Jansen and Alan Taylor,
International Project Development Services Pty Limited

Presented by

Mal Jansen

CONTENTS

1. INTRODUCTION

The roles and limitations of heap leach modeling and various models available are reviewed. The new IPDS model and how it fits in with heap performance projection is discussed.

Heap leach models have been developed as important aids in the application and scale-up of laboratory and/or pilot plant testwork to the design of commercial heap leach/SX/EW plants and the prediction of commercial heap performance.

Inputs to be considered in modeling include the mine plan and schedule, ore types, variations in acid soluble copper head grade, ore crush size, heap percolation rate, type and height of heap, number of lifts, test column copper recovery and kinetics, need for rest-rinse cycles if sulphides present, SX/EW plant design flow rate and cathode copper production rate and values to be used for heap leach scale-up factors.

Outputs from modeling can include a wide range of parameters such as projected commercial annual copper production rate, percentage copper recovery and pregnant leach solution grade versus time.

Variables in the models can include ore type, head grade, particle size, input leach kinetics, kinetic scale-up factors, heap height, wetting rate, heap and lift configuration and design SX/EW cathode copper production rate.

The models can ideally be used to determine the economics of a proposed mine plan, and the changes that are needed to optimize profitability. They can also be used to confirm the adequacy of the design to cope with varying ore grades, multiple lifts, changing cut-off grades, different rest-rinse cycles and heap dimensions.

Topics discussed in this paper include heap types, leach model types, performance forecasting, and steps in the development of the IPDS heap leach model.

2. HEAP TYPES

Heap types can be characterized in a number of ways. For convenience, they have been arbitrarily characterized below by the physical geometry of the heap and surrounding land-form structure, the physical and chemical characteristics of the particulate components making up the heap and the solution handling system in the heap and the plant area:

- Physical Geometry:
  - Run of Mine (ROM) dump – usually deep heaps of low grade waste material
  - On-Off Pads – re-useable pads for shallow to medium depth heaps
  - Permanent single/multiple lift heaps – medium height
  - Planar or valley fill heaps and/or dumps – medium to deep heaps and deep dumps
- Particulate Characteristics:
  - Split leach – coarse crush material to heap leach and fines to agitation leach
  - Oxide, sulphide or mixed oxide/sulphide ores
  - Ore agglomeration and/or acid cure

- Solution Characteristics:
  - In-situ or external aerated bacterial leach
  - Pregnant leach solution (PLS) and intermediate leach solution (ILS) ponds

Fig 1 shows a schematic example of a multiple heap or fixed heap leach system. This includes an intermediate leach solution (ILS) pond that allows two stage counter-current leaching and permits low-grade leach solution recovered from towards the end of the leach cycle in Heap 1 to be advanced and built up into high-grade pregnant leach solution (PLS) in Heap 2. Copper is recovered in solvent extraction and electrowinning (SX/EW) from the high-grade leach solution. Raffinate returns to Heap Leach 1 until the completion of the secondary leach cycle when it is switched to Heap 2. The ore delivered to each heap stays there for the rest of its life. The raffinate applied to each heap moves forward to a new heap at the end of each secondary leach cycle. Intermediate leach solution moves forward to a new heap after the end of the primary leach stage on each heap.

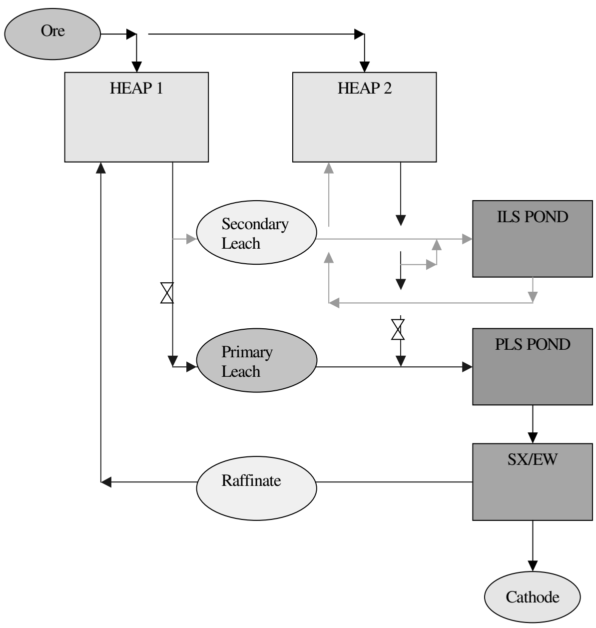


Fig 1: Multiple Heap or Fixed Heap Leach System

Fig. 2 shows a single (on-off) pad leach system where ore has only a limited time for leaching before it is moved off and replaced with fresh ore. Leach residue from the pad can go to either a residue disposal stockpile or to a subsequent fixed heap for secondary leaching.

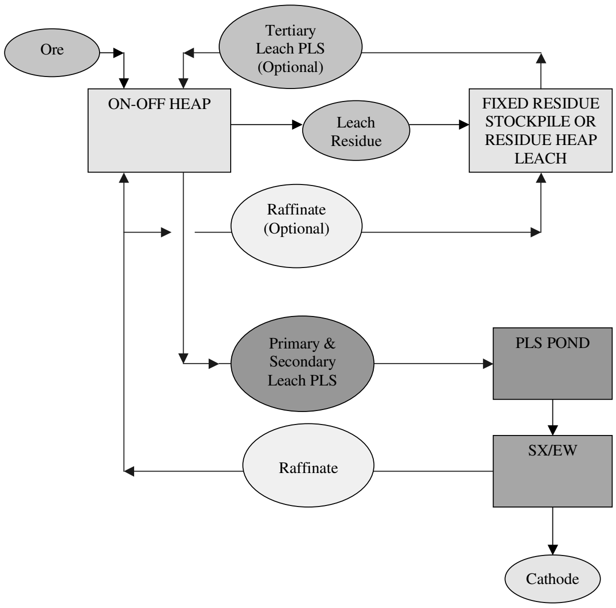


Fig 2: Single Heap On-Off Re-useable Pad Leach

3. MODELS AVAILABLE

Model Types: Models known to be available and briefly reviewed by IPDS on the basis of limited literature references include the following:

- Shrinking core model
- Metsim model
- Ansto models
- IPDS model
- Hand scaled recovery and/or time models

Other models with which the authors are not currently familiar may also be available.

3.1 PARTICLE SHRINKING CORE MODEL

This is a commercially available model that has been developed by Leach, Inc. of the USA. It uses the reaction kinetics of a single particle, as proposed by Octave Levenspeil in Chemical Reaction Engineering (e.g. 3rd Edition, John Wiley and Sons, 1999), to assess the effects of variable particle size on particle leach recovery versus time. Reaction rate constants are fitted to experimental data. The reaction may be either chemical reaction controlled or liquid diffusion controlled. Whilst the model addresses the effects of changing particle size on leaching rates, it is not clear whether it addresses bulk heap leaching parameters such as heap depth and wetting rate or the constraints imposed on leaching rate by the SX/EW plant design.

3.2 METSIM HEAP LEACH MODEL

This model is part of the general Metsim model for modeling of metallurgical reactions, mass balances, heat balances and flowsheets. It is designed for a large-scale multi-lift heap that is treating multiple ore types for gold, silver or copper leaching. Kinetics are handled as a two-step process for each ore type. Ore block spatial xyz coordinates need to be specified for each ore block delivered to the heap from the mine plan. The heap takes ore covering the full mine life and can accommodate wet and dry leach cycles. It takes into account the water balance including rainfall and evaporation to determine whether storage ponds are adequately sized for extreme conditions. Test columns are used to generate leach data provided as input to the model. Model outputs include overall heap leach recovery versus time.

The model would appear to be especially suited to large valley fill heap leach projects, where ore blocks are located in specific zones of the heap. Data input would appear to be relatively extensive and the flexibility to readily change grade, heap depth or leach kinetics rather limited, without re-entering the complete set of model data. The model would also appear to be unconstrained by the production capacity of the SX/EW plant, although this may be less of a problem for low-grade sulphide heaps where leach kinetics are slow.

3.3 ANSTO SULFIDE SOLUTIONS

Ansto Sulfide Solutions is a new business unit of Ansto offering increased general knowledge of sulfidic materials and their management. A suite of advanced programs is said to be available to model the oxidation of sulfidic materials, especially for acid mine drainage control. Programs include:

- Sulfidox, a two-dimensional finite difference heap leaching model that models waste rock dumps and heap leaching operations of any dimension. It describes and models a three phase system consisting of a rigid solid porous phase through which gas and water phases flow, allowing for:
    - oxygen transport and depletion, heat transport and production and reactant depletion in the solid phase (Ansto Fidhelm model)
    - oxidation of minerals such as sulfidic material and the dissolution of other phases such as carbonate and silicate minerals
    - mass transport in the aqueous phase and equilibrium by inclusion of a geochemical speciation module which allows secondary reactions to be considered (Ansto Kemist and GMT3D Models)
    - output parameters as a function of space and time including:
        - gaseous oxygen concentration
        - mass fraction of the oxidizing reactant or reactants remaining
        - temperature
        - gas pressure
        - sulfide sulfur oxidation rate
        - air flow velocity
        - load of each chemical in the aqueous phase
        - global oxidation rate and global oxidation

- Aquarisk, a desktop ecological risk assessment tool for the aquatic environment, using a cost effective tiered evaluation methodology directly in line with the proposed changes to the Australian Water Quality Guidelines

Ansto also offers a consulting capability to assist with bio-oxidative heap leaching for recovery of metals such as copper, lead, zinc, nickel, silver, gold and uranium by:

  - optimization of heap design by recommending suitable heap geometries, material permeabilities and irrigation rates
  - in-depth computer modeling of heaps to predict the time evolution of leaching rates prior to heap construction and to thereby allow optimization of heap design and subsequent management
  - definition of target loads and concentrations in effluent and the development of management options to meet these targets
  - design and management of cover systems applied to sulfidic waste rock dumps, and tailings (Swim^{HeapCov}, a joint Ansto and CSIRO model)
  - design of waste rock dumps to achieve particular pollutant release rates
  - prediction of effluent quality from sulfidic piles
  - optimization of the design and operating conditions of bio-oxidation heaps
  - ecological risk assessment

The service for optimization of heap design by recommending suitable heap geometries, material permeabilities and irrigation rates and the modeling of heaps for prediction of copper recovery would appear to be similar to services available from other consulting groups, although with the added benefit of being able to apply sophisticated mass transfer and geochemical speciation models if required.

The key advantage of the Ansto model suite would appear to be that it can take into account chemical equilibria, which other models currently do not. The draw back of the Ansto model suite for heap leaching of copper would appear to be that it does not take into account the constraint on copper production imposed by the design capacity of the SX/EW plant.

3.4 IPDS MODEL

The IPDS heap leach model is a semi-empirical model based on the application of an Excel spreadsheet to what was formerly a more tedious manual calculation of leach kinetics in successive multiple horizontal slices of a single lift in a heap. The leach kinetics are assumed to be two step, with the first step being at a high constant primary rate and the second step at a slow constant secondary rate. Test columns are used to generate kinetic data and laboratory rate constants.

Scale-up factors are based on experience. The SX/EW production constraint is applied to the copper production output from the model.

Key inputs to the model include:

- copper head grade,
- ore receival rate onto the heap,
- lift height,
- bulk density,
- solution specific flow rate,
- heap scale-up factors for total recovery and for primary and secondary rate periods,
- copper extraction before application of scale-up factors,
- kinetic factors derived from test columns or from raw test column results such as ore weight, diameter, height, primary leach days and secondary leach days.

Other inp s include:

- the number of days represented by each unit leach time interval in the model,
- commercial cell planar geometry such as width and length,
- maximum pregnant leach solution (PLS) flow rate,
- SX percent copper recovery,
- target commercial PLS copper grade
- plant availability.

Key output parameters include projected PLS copper pick-up concentration and projected copper extraction versus time profiles for the commercial heap. The projected PLS copper pick-up concentration may turn out to be less than target PLS copper concentration due to leach kinetics being too slow, head grade too low, or heap height insufficient.

The leach behaviour of individual horizontal slices within the heap can also be seen in the model output.

Other output parameters include:

- primary and secondary commercial extraction rates derived from the test column input data
- primary, secondary and total percentage extraction of copper from the commercial heap
- primary, secondary and total leach cycle times for the commercial heap, both with and without SX constraint
- commercial copper production per m^2 of heap area per heap time interval corresponding to primary, secondary and maximum leach rates, both with and without SX constraint.

Additional output parameters include projected commercial performance parameters such as:

- copper extraction rate in g Cu/m height/day/m^2 area for primary and secondary leaching, both with and without SX constraint
- copper production as g/m^2, g/m^2/m and tpa/m^2 over the complete leach cycle life
- ore throughput tpa and tpm,
- solution flow rate m^3/h and copper production tpa, both with and without SX constraint
- tonnes ore per leach cycle
- and cell area parameters such as cell length filled per unit leach period, cells completed per unit leach period, cells completed per month, primary leach area m^2 and primary leach length for the specified cell width.

Multiple heaps can be simulated with varying lag times between the start of each successive heap showing how the projected PLS grade and percent leachable copper build up with time during start-up of up to 5 successive heaps.

Issues such as the time at which a heap should be cut-off from leaching have also been evaluated in a preliminary way by looking at incremental copper production revenue versus capex payback, organic loss costs and incremental acid consumption costs.

Other more complex issues such as for example how much surplus ore to ideally have available on a leach pad at a time and when to switch from one heap to another when newly arrived higher grade ore is available for leaching could also be simulated but have not been attempted to date.

Key features:

1. The model operates as a simple Excel program which builds up the behaviour of the heap in horizontal slices
2. The model is based on column leach experimental data with a reproducible method for scale up of kinetics and overall copper recovery
3. Leach kinetics are assumed to approximate a two stage model, allowing for a high constant rate initially to say 50-60% copper extraction followed by slow constant rate period to say 80-90% copper extraction, depending on the shape of the leach recovery versus time curve
4. Other kinetic models can be simulated if required, such as an acid cure system
5. The model integrates heap leach copper extraction performance with the constraints imposed by SX/EW design copper production rate and PLS design solution flow rate.
6. The model output is provided in both tabular and visual format. Graphical forms of output can include, for example:
    - PLS copper pick-up gpl Cu versus time
    - Cumulative acid soluble copper percent extraction versus time
    - Area under primary and secondary irrigation versus time
    - Copper leached per day versus time
    - Cumulative t Cu leached and cumulative plant design t Cu versus time
7. The model shows whether the period of a selected PLS grade is likely to be easily sustained throughout the leach cycle for key ore types and grades or whether the period may be too short and the design needs to be changed.
8. The effect on copper recovery and PLS Cu grade of varying heap heights can be readily simulated
9. The model can predict PLS copper concentrations from re-usable pad leaching and from single lift heap leaching
10. Multiple heaps (up to 5 to date) starting at varying lag times can be evaluated to determine likely start-up copper production versus time profiles
11. The production of copper from a complete mine schedule can be simulated by taking the copper recovery profiles for each ore type from the Excel simulation and spreading them with time in another Excel simulation. This allows for mine scheduling of different ore types, and the timing of ore placement in heaps and commencement and cessation of leaching on each heap to be incorporated.
12. The model shows visually how the leach is performing with time and thereby assists with a better understanding of what may be physically happening inside the heap as the leach progresses
13. Actual or proposed commercial heap performance can be simulated by trial and error to extract rate coefficients and scale up factors applicable to the commercial heap and for use of those coefficients to predict probable performance under different heap configurations and/or leach conditions
14. Copper leach recoveries for primary and secondary years for a given grade and lift height can be extracted from the model for each ore type and then used in a separate spreadsheet to model year by year copper production performance for a complete mine plan. Appropriate lags can be also be allowed for between the start and completion of primary and secondary years, depending on the heap wetting plan, dry and wet cycle durations and the relative location of one lift above another and any imposed delay between start of primary and start of secondary leaching on each ore block.

Limitations

The IPDS heap leach model is designed to address basic heap leach and SX/EW plant design issues so that integrated heap leach and SX/EW plant design conditions are selected for commercial operations. From the scale–up of results obtained from leach tests on representative ore types in small scale test columns, the model allows a suitable type of heap to be determined, its height, particle size and agglomeration regime established and an annual copper production rate appropriate to the mine plan established.

The model does not currently take into account spatial locations of individual ore block tonnages and their associated attributes such as ore types, ore mixture, head grade, particle size, acid consumption, oxygen consumption, impurity generation and percolation rates, as would be appropriate to a given mine plan for a multi-lift heap. The model also does not track mineral leaching, solution speciation and mineral precipitation within the heap or sulphide heat generation; allow for the possibility of different percolation rates and different leach-rest cycles over different times, different areas and different lifts; or develop correlations between leach rates and particle size. The model relies on column testwork for selection of optimum particle size.

The SX constraint in the IPDS model does not allow the primary leach rate to exceed the copper plant production rate nor does it keep track of any temporary or long-term build up of soluble copper inventory in the heap with time.

Potential future model developments,

IPDS is holding discussions with a copper mining group on the potential for further co-operative development of the model for the group's in-house modeling needs. More flexible modeling could be used to handle geographic placement and leaching of different ore tonnages and different grades and ore types as specified in a mine plan. The model could also be adapted to allow for varying leach start and stop times for re-useable pads or permanent heaps. In the opinion of IPDS, the model allows realistic plant design criteria to be readily established from column test data and a mine plan for each resource. Separate models could conceivably be developed for plant design, commercial heap recalibration and ongoing plant optimization.

3.5 MANUAL MODELS

Manual models have been used and are still being used for projecting commercial leach/SX/EW performance according to rules of thumb established by different leaching groups.

One manual model is understood to project a commercial copper recovery of the order of 90% of the final lab column copper recovery in the same time as the column test conducted at full lift height. The remaining 10% is assumed to be achieved by extending the time by 50-100%. Other formulations may provide similar manual projections of commercial leach performance.

3.6 SYSTEMATIC SCALE –UP FACTORS

The IPDS model allows leach performance projections to be reconciled to leach kinetics from column tests and the following three scale-up factors for each ore type and to thereby permit a more systematic methodology to be adopted for leach performance comparison:

- a safety factor on copper recovery, which might be say 95% of the final acid soluble copper recovery in column tests,
- a scale-up factor on the column primary leach rate, which might be say a divisor of 1.5 on the lab rate
- a scale-up factor on the column secondary leach rate, which might be say a divisor of 1.25 on the lab rate

It is believed that the adoption of a more systematic scale up methodology would assist the industry develop a more readily comparable set of factors for comparing actual and expected heap performance. At present a systematic approach to comparing actual leach performance with test column performance would appear to be lacking.

4. IPDS MODEL OUTPUT SAMPLES

The following figures show samples of IPDS heap leach model outputs for copper pickup and copper recovery versus time with variations in PLS flow rate, rate safety factors and heap height, whilst all other variables are held constant. The effects of the SX/EW plant capacity constraint and the removal of that constraint are also included in Figs 4.3-4.6:

Fig 4.1 - PLS Cu Pick-up versus Time: Variable PLS flow rate

This figure shows the effect of an increasing PLS flow rate on the form of the PLS copper concentration versus time profile for both the test column and for the projected commercial plant at PLS flow rates of 875 to 3150 m^3/h, all other factors being constant.

Primary rate period: Compared with the column test results showing a primary copper concentration of 12.5 gpl Cu for approximately one leach period at 10 days per period during the initial primary rate period, it can be seen that as the PLS flow rate increases the corresponding projections of primary copper concentration in the commercial plant drop to approximately 3.5 gpl Cu at 875 m^3/h for approximately 5 periods, 1.8 gpl Cu at 1575 m^3/h for approximately 9 periods and 0.8 gpl Cu at 3150 m^3/h for approximately 20 periods.

Secondary rate period: Compared with the column test results showing a secondary copper concentration of approximately 0.3 gpl Cu for approximately 7 leach periods at 10 days per period during the secondary rate period, the corresponding projection of secondary copper concentrations in the commercial plant all drop to approximately the same concentration of 0.3 gpl Cu, whether at 875 m^3/h for approximately 14 periods, 1575 m^3/h for approximately 14 periods or 3150 m^3/h for approximately 14 periods.

Fig 4.1: PLS Cu Pick-up vs Leach Time Intervals for Lab Test and Varying PLS Flow Rates

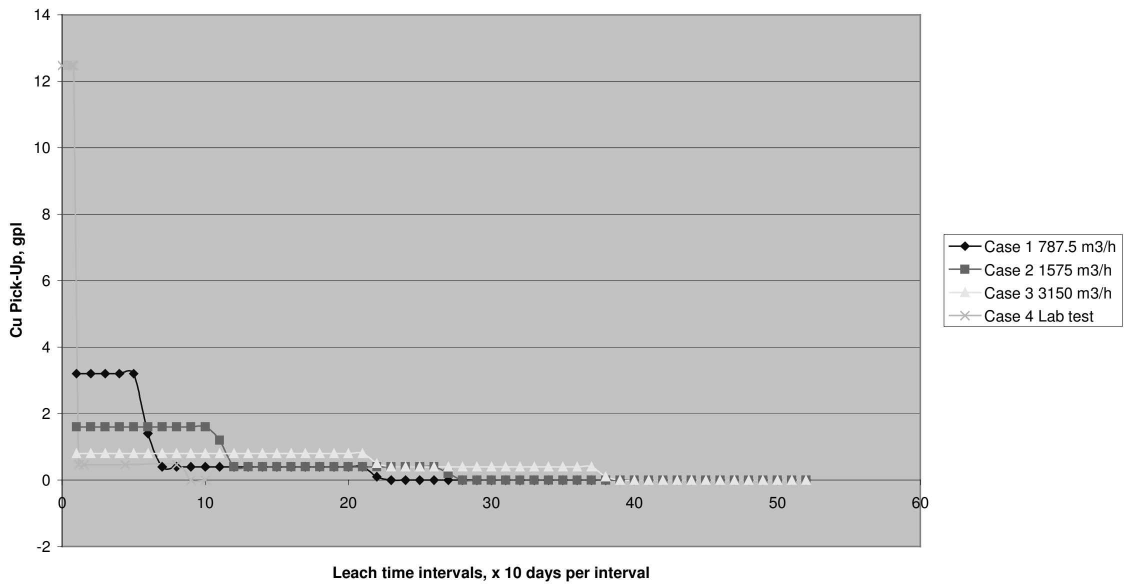


Fig 4.2 - % CuT Recovery versus Time: Variable PLS flow rate

This figure shows the effect of PLS flow rate on the form of the percentage total copper recovery versus time profile, for both the laboratory column and projections of commercial plant performance at the same conditions as Fig 4.1. The difference between the column and the commercial plant performance projections is that the commercial plant performance becomes stretched out in time and reduced in total copper recovery versus the lab. Although the ore under leach increases in direct proportion with PLS flow rate at a fixed wetting rate, the PLS copper concentration has simultaneously dropped in order to hold the copper production rate constant (see Fig 4.1).

Primary rate period: Compared with the column test results showing termination of the primary rate period at 65% copper recovery after one leach period, and termination of the secondary rate period at 90% copper recovery after approximately a further 6 periods, it can be seen that as the PLS flow rate increases, the projected time taken to reach the end of the primary rate periods in the commercial plant increases to up to 5-22 periods. In particular the primary rate period ends after approximately 4 periods at 875 m^3/h, 11 periods at 1575 m^3/h and 21 periods at 3150 m^3/h.

Secondary rate period: Compared with the column test showing termination of the secondary rate period at a copper recovery of 90% at approximately 6 periods, the corresponding secondary rate periods in the commercial plant terminate at 85% copper recovery at approximately 20 – 36 periods, as the flow rate increases from 875 to 3150 m^3/h.

Fig 4.2: % CuT Recovery vs Leach Time Intervals for Lab Test and Varying PLS Flow Rates

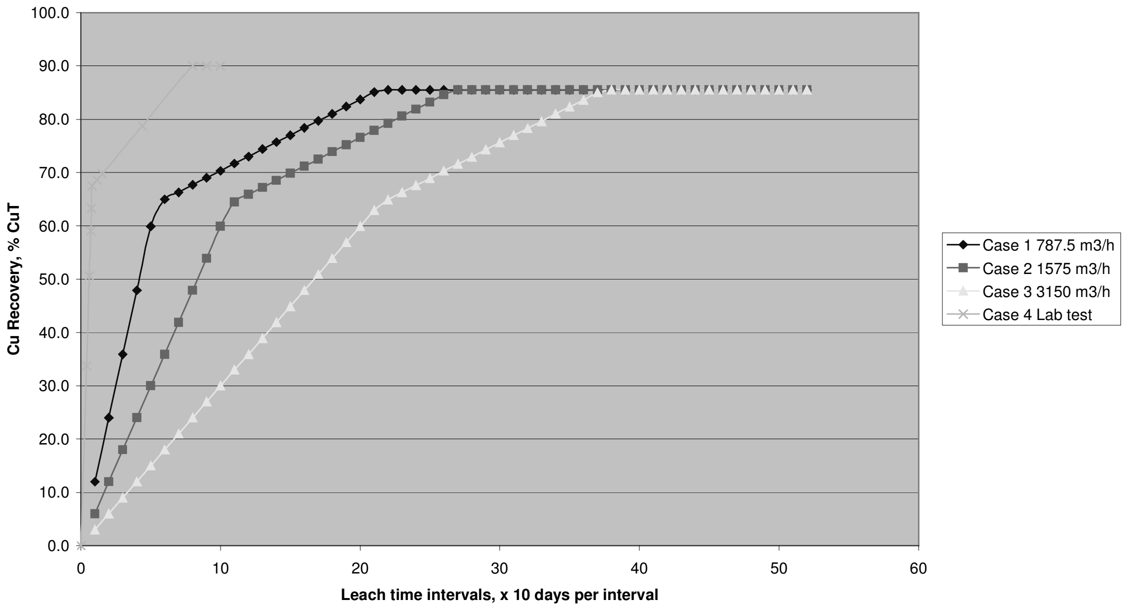


Fig 4.3 – PLS Cu pick-up versus time: Variable Rate Safety Factors and SX constraint

This figure shows the effect on PLS copper pick-up concentration versus time of variations in the primary rate safety factors between 1.5 and 3.0 and variations in the secondary rate safety factors between 1.5 and 2.25. These effects are shown both with and without an SX constraint. PLS flow rate is 1575 m^3/h. Cases 1-3 are with an SX plant copper production constraint and Cases 4-6 are without an SX plant copper production constraint.

The removal of the SX plant constraint allows the initial copper PLS concentration to increase markedly, reaching 5-10 gpl Cu for a very short period but then falling rapidly to the order of 0.2-0.4 gpl Cu. By contrast the corresponding initial PLS value is only 1.6 gpl Cu but over ten leach periods when the SX constraint is in place. Thus, as soon as the heap output is not constrained by the SX plant capacity, the copper concentration can increase to an extremely high level be it only briefly, before it satisfies the primary rate recovery condition and falls back to a very low value set by the secondary leach kinetics. This initial short-term high-copper concentration would not appear to serve any useful purpose, if it simply results in a high raffinate copper concentration recirculating back to leach in a fixed single lift heap. However, it could be useful for a re-usable pad leach, where a smaller pad might be used for the primary leach and the slow residual copper still recovered in a subsequent permanent secondary heap leach.

The secondary leach phase in Fig 4.3 shows a PLS copper concentration of the order of 0.2-0.4 gpl Cu for 18- 26 periods when the SX constraint is in place and 27-35 periods when it is not in place.

It was found that the primary rate safety factor does not appear to have any affect on the PLS copper concentration when the SX constraint is in place but can influence the PLS copper concentration when it is not in place. The primary rate safety factor also has no affect on leach time for the primary or secondary leach.

The secondary rate factor appeared to be the only factor to affect the overall leach time. In this particular case it increased the leach time by roughly 8 periods or 30 to 50% when it was increased 50% from 1.5 to 2.25.

Fig 4.3: PLS Cu Pick-up vs Time: Primary and Secondary Safety Factors 1.5 - 3, with SX constraint and with no SX constraint

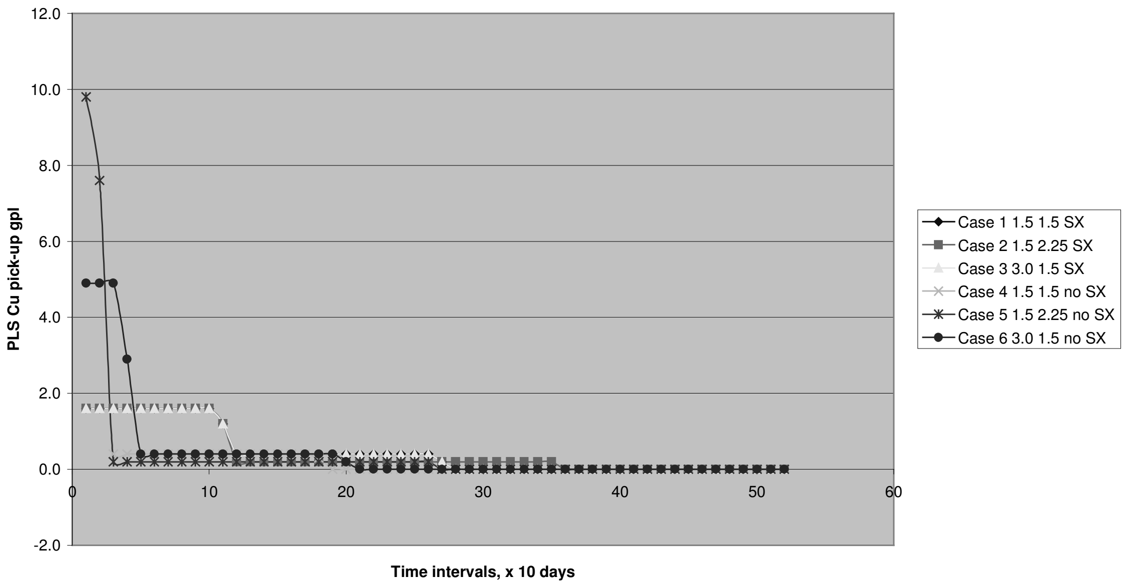


Fig 4.4 – % CuT Recovery versus Time: Variable Rate Safety Factors and SX constraint

This figure shows similar results to Fig. 4.3. Where the SX constraint is applied, the primary recovery profiles are coincident, no matter what the primary rate safety factor. Only the secondary recovery profiles differ.

Where there is no SX constraint, leach recovery occurs more rapidly, with the primary rate and secondary rate periods ending much earlier than when the SX constraint is applied.

Fig 4.4: %CuT Recovery Vs Time: Primary & Secondary Safety Factors 1.5 - 3, with SX Constraint and with no SX Constraint

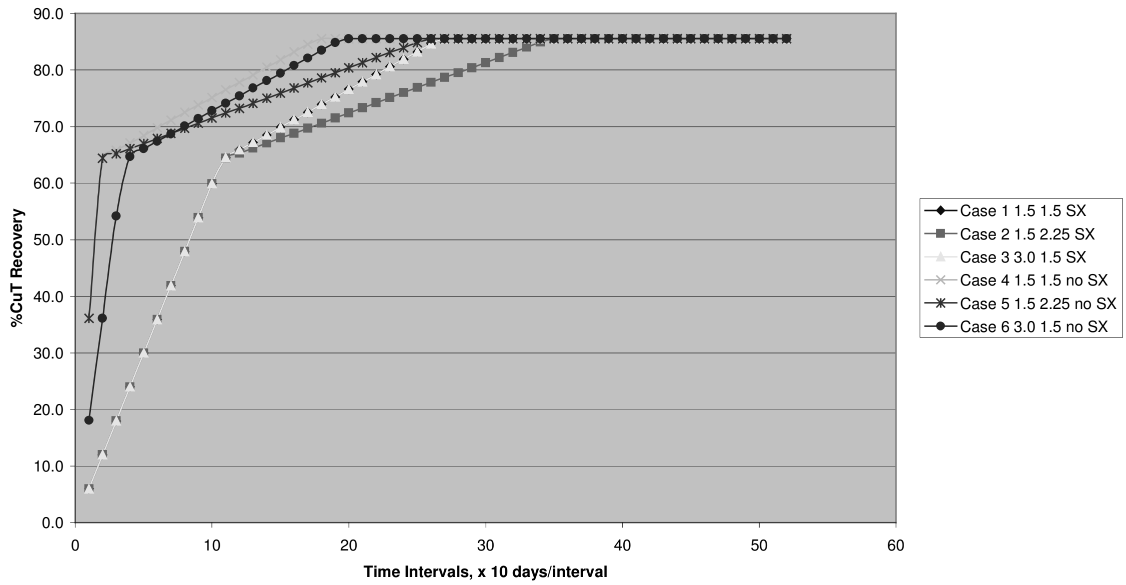
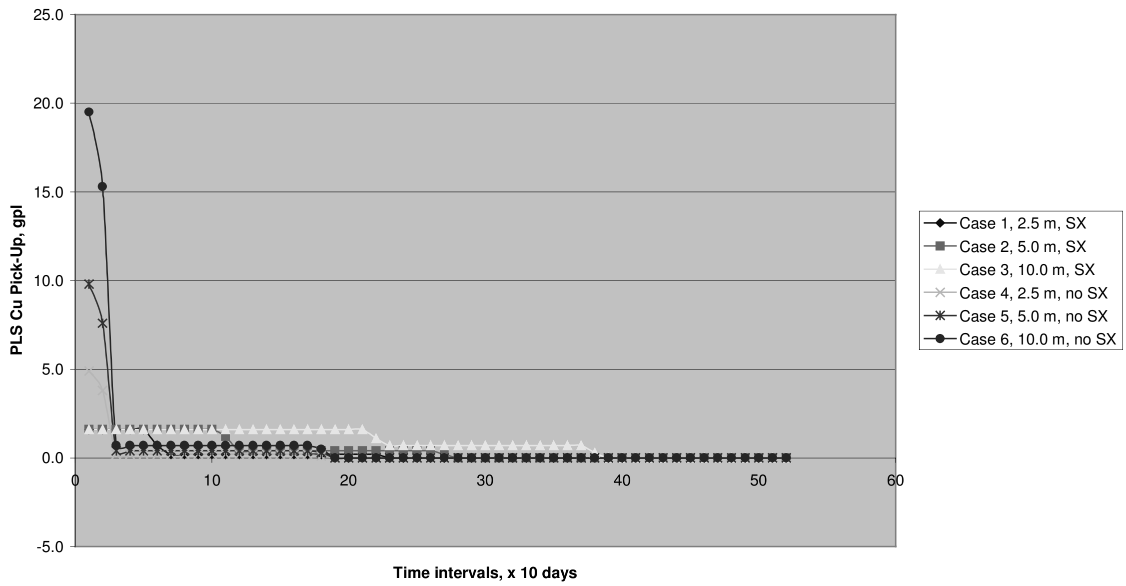


Fig 4.5 – PLS Cu Pick-up versus Time: Variable Heap Height and SX Constraint

This figure shows the effects of heap heights varying from 2.5 to 10 m on the copper concentration versus time profiles, both with and without an SX constraint. All other factors remain constant, with the PLS flow rate remaining at 1575 m^3/h and the primary and secondary rate safety factors remaining at 1.5. When the height changes, the tonnage under leach changes.

When the SX constraint is in place, the PLS copper pick-up is the same for all heap heights and holds at 1.6 gpl Cu until the end of the primary rate period at approximately 5, 10 and 20 periods for 2.5m, 5m and 10m heap heights respectively. The secondary leach periods end at 23, 28 and 39 periods respectively.

Fig 4.5: PLS Cu Pick-Up vs Time: Heap Heights 2.5-10m, with SX Constraint and with no SX constraint



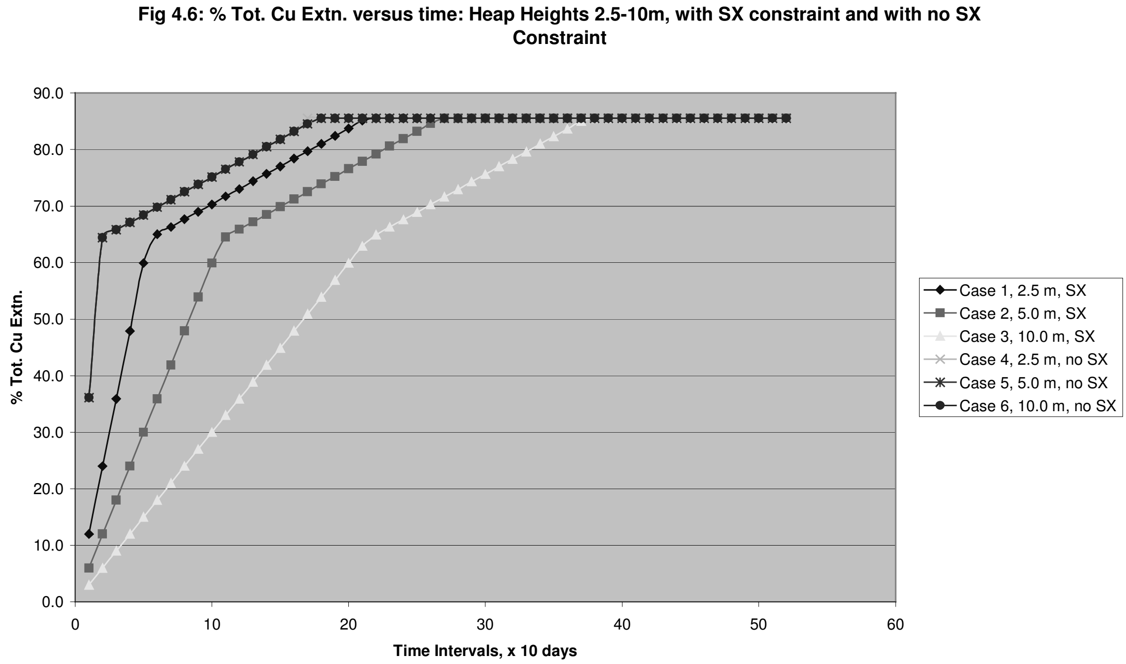
When there is no SX constraint, the initial PLS concentrations increase in proportion to the heap height from 5.0 to 20.0 gpl Cu, but then rapidly diminish to close to zero for the duration of the secondary leach period.

Fig 4.6 - % CuT Recovery versus Time: Variable Heap Height and SX Constraint

This figure shows the effect of heap height variation from 2.5 to 10 m on the percent total copper recovery versus time, both with and without an SX constraint.

When the SX constraint is in place, the percentage copper recovery versus time slows down with increasing heap height due to the greater tonnage of ore under leach at increased height but with the output constrained by the SX plant.

When there is no SX constraint, the % recovery versus time curves are coincident.

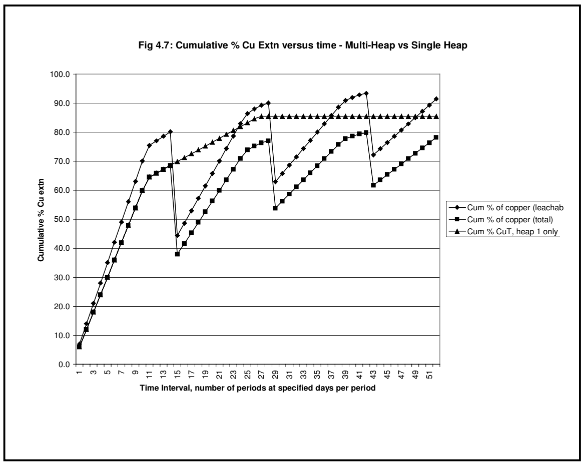


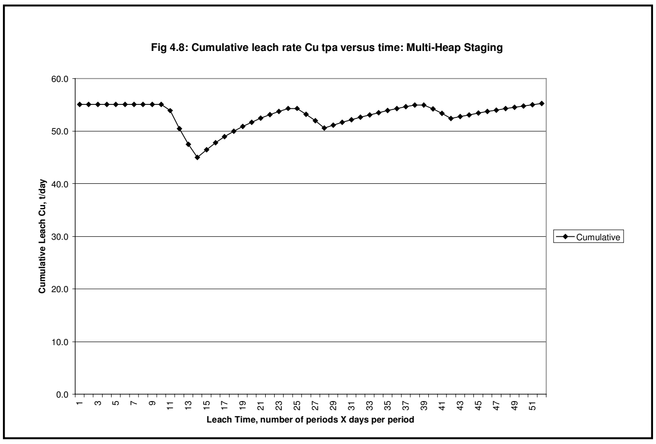
Other sample graphical outputs

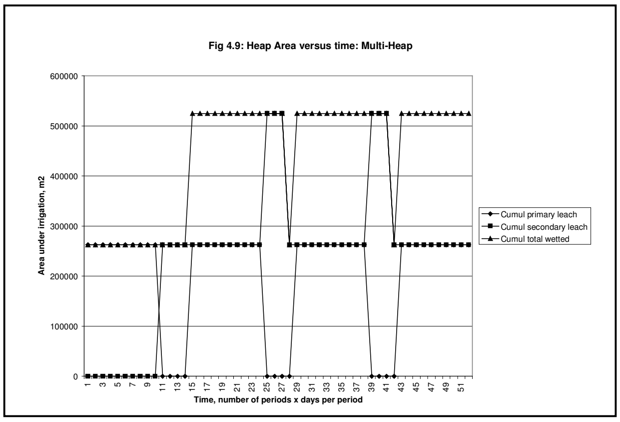
Further sample outputs are shown by the following figures:

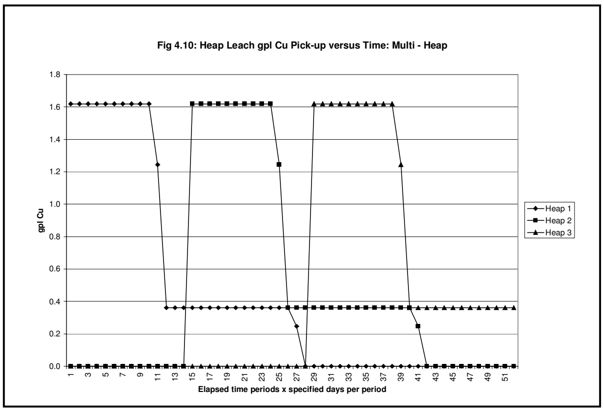
- Fig 4.7 shows the change in % Cu leachable and %CuT recovery versus time for multiple heaps versus a single heap
- Fig 4.8 shows the cumulative annualizes copper output with time as new heaps are brought into production
- Fig 4.9 shows the heap area under irrigation versus time for primary and secondary leaching and for combined both areas combined, where an intermediate leach pond is used to collect the intermediate liquor
- Fig 4.10 shows PLS pick-up versus time for multiple heaps started one after the other
- Fig 4.11 shows cumulative copper leached and design copper production versus time for a multiple heaps
- Fig 4.12 shows percent leach extraction versus time profiles for various two step leach models and safety factors and a model proposed by another company
- Fig 4.13 shows copper pick-up concentration versus time for two sequential heaps with the start-up of the second heap lagging the first by a fixed number of days

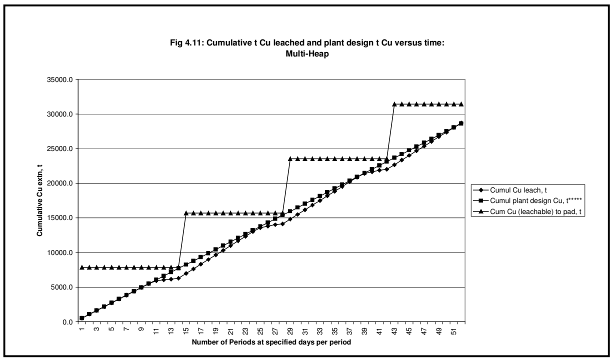
- Fig 4.14 shows daily copper production versus time for two heaps where the second heap is started as soon as the first leaves the primary rate period and the production from the second heap is constrained to maximize total copper production at the design rate

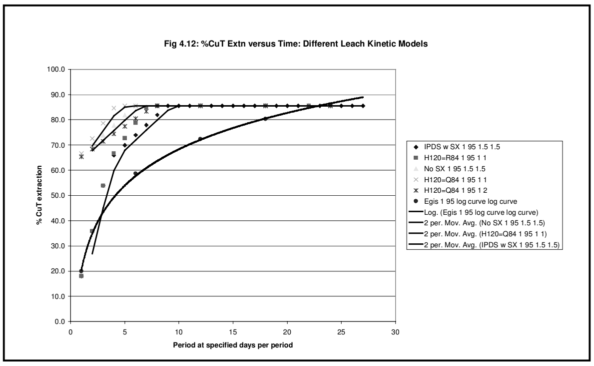


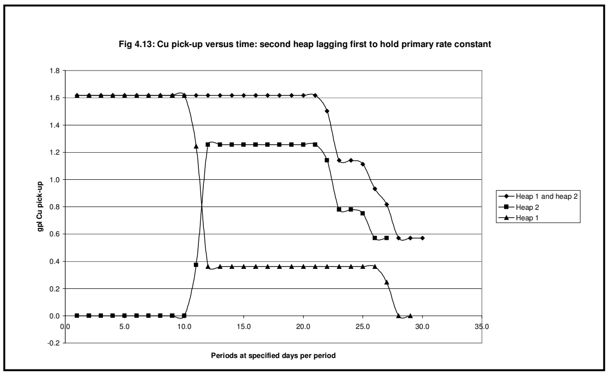


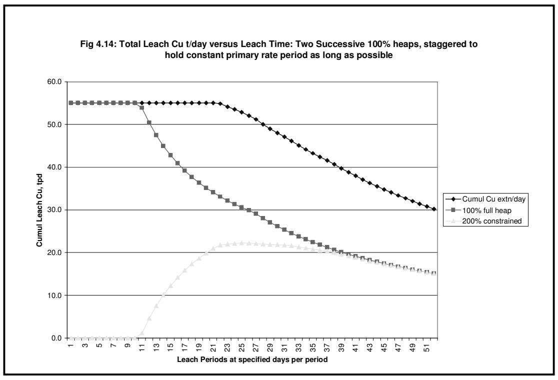












5. COMMERCIAL APPLICATIONS

The IPDS heap leach model has been applied to the design of a number of heap leach SX/EW studies and projects in Australia and overseas including Girilambone and Mt Cuthbert in Australia, Puthep in Thailand and several confidential overseas projects. In all cases, it has helped to highlight key issues in the selection of the most appropriate SX/EW plant capacity, the PLS copper concentration sustainable from the resource and improvements needed to the mine plan and schedule to improve project profitability. It has also been helpful in reviewing projects at feasibility stage, including calibrating the model to projected commercial leach performance and determining whether the proposed commercial plant size and production are likely to be sustainable in practice or may need adjustment to a reduced capacity.

The model would appear to be capable of adding significant value to heap leach/SX/EW projects in the prefeasibility, feasibility, design and operations phases by allowing a number of probing what-if questions to be asked, critically evaluating what is expected to be achieved versus what is projected to be achieved, and deciding whether the project is likely to meet current expectations or whether significant changes in mine plan, heap configuration or plant design might be desirable.

6. CONCLUSIONS

6.1 Several proprietary models are commercially available for copper heap leach modeling.

6.2 Based on references sited in the literature, some of the models have been reviewed in this paper. Other models may also be available.

6.3 Existing commercial models appear to primarily address particle size, deep multiple heaps or sulphide contributions to acid mine drainage. The constraints of an integrated SX/EW plant on copper production rate do not appear to have been addressed.

6.4 IPDS has proposed a semi-empirical, two-step kinetic model for permanent low-lift heaps, based on Excel, which allows column data to be readily scaled up using appropriate kinetic and recovery safety factors and the most likely commercial plant performance to be projected for a selected mine plan, heap height and wetting rate. The constraints of SX/EW production are taken into account

6.5 The model can be used to determine the most appropriate design criteria for a given project, audit feasibility studies or simulate and project the effects of possible improvements to a given project on existing or future heap leach operations.

6.6 The main benefits of the model are seen to be its ability to take into account the multiplicity of factors which influence heap leach design and performance and to apply suitable scale-up factors for projection of commercial heap performance from column data.

6.7 Although developed originally for fixed heap leaching, the model is adaptable to re-usable pad leaching as well as for leaching of residues from re-usable pads on secondary heaps.

6.8 Future improvements of the model potentially include spatial positioning of ore of different grade and leach characteristics, variable wetting rates, on-off cycles for sulphide leaching, early termination of primary or secondary leach cycles, selected delays between primary and secondary leach cycles and modeling of year by year outputs for a given yearly mine plan, ore composition and mineralogy. Some of these improvements have already been tested for a potential new multi–lift heap leach/SX/EW project, where the model successfully identified limitations in current copper production projections and possible solutions for enhanced copper recovery.