LOOK BEFORE YOU LEACH:

DYNAMIC SIMULATION OF HEAP LEACH FLOWSHEETS

Brett Muller and Tim Newton
Simulus

Presented by
Brett Muller
brett.muller@simulus.com.au

ABSTRACT

A project-level dynamic model has been developed to simulate heap leach operations from ore handling through to final product. The model deals with the long-term effects of leach recovery rates, solution management, inventory build-up, complex reaction chemistry, and the limitations of the downstream process plant. It is applied as a decision tool for both process design and production planning functions.

The model is developed on a flexible simulation platform, allowing for ready manipulation to meet any site-specific configuration. It can accommodate single or multi-lift stacking, and multi-stage irrigation schemes. Any type of extraction rate model may be incorporated into the simulation for a comprehensive and rigorous dynamic mass balance.

INTRODUCTION

The difficulty of scaling up metallurgical test data to industrial scale heap leach practice is well known. This paper addresses the broader problem of creating a model for the entire process, considering the interactions of multiple operating heaps, solution storage, and the downstream processing plant. The Simulus models described here are dynamic, flowsheet-level models that consider the unsteady-state process mass balance over a period of several years.

The power of these models lies in their ability to rapidly and reliably show the effect of alternative configurations and leaching conditions. Developing the model forces a rigorous examination of the process design. Simulation results are often counter-intuitive, and reveal issues that were not previously apparent. In an uncertain project environment, process models are used to evaluate a wide range of operating situations, highlight the key risks, and provide a means of testing alternative solutions.

THE HEAP LEACH PROBLEM

Heap leaching is a conceptually simple process but has several characteristics that make modelling the flowsheet quite complicated. Fundamentally, it is a slow process. There is a substantial time lag between stacking ore and producing the final product. During this time the soluble inventory builds up and impacts the recovery and solution tenor. An insufficient stacking rate may not be apparent until 6 months later, when the plant is struggling with low solution grades.

Furthermore, the process is never at steady state. Any leach operation has a range of ore under leach, from freshly stacked to near-depleted material. There is usually a combination of ore types with different leaching characteristics. Seasonal variations such as rainfall or cold weather can also have a significant impact on production.

The irrigation scheme introduces a new level of complexity. Leaching may be single stage or multi-stage, with intermediate solution recycled to the heaps to build up solution grades. The new nickel laterite projects are devising more elaborate schemes than normally used in the copper industry. Multi-lift heaps further complicate the inventory estimate as high grade PLS may be held up in lower lifts.

Interactions between the heaps, solution storage and downstream plant add a further dimension. Plant flow capacity is always limited and metal recovery is dependent on solution composition, which is variable.

The combination of all these factors means that applying simplistic recovery data to process design is risky. As is normally the case with process fluctuations, the 'downs' hurt more than the 'ups' help. It is not valid to assume the variations cancel each other out and give steady production over time. Heap leaching, possibly more than any other metallurgical process, requires dynamic rather than steady state models to reliably forecast behaviour.

All of these problems are on top of the basic difficulty of scaling up metallurgical test results to industrial scale heaps. The best scale-up techniques still have a fairly wide margin of error due mainly to uneven flow patterns through a heap. A simulation model can be used to assess the impact of changes in final extraction or leach cycle time on solution grades and production rate over time.

There are several reviews of heap leach simulation techniques available in the literature. Taylor and Jansen (Ref. 1) gave an overview of existing models and presented a new approach. The Simulus model seeks to address many of the limitations noted in this approach.

ALTERNATIVE MODELS

There have been substantial advances in mathematical modelling of the chemical and physical processes involved in heap leaching. In particular, the work by David Dixon and co-workers (Ref. 2) represents the current state of the art in developing models of the process. The essence of these models is to relate metal extraction under real heap conditions to fundamental factors such as ore particle size, mineral particle size, diffusion rates, and reagent concentration.

The Simulus models take heap extraction forecasts as direct input data, and apply these to the flowsheet-level model. Several different approaches have been applied to this problem. The following discussion refers mainly to copper heap-leaching, but the same approach applies to gold or nickel processes.

SPREADSHEET MODEL

An Excel-based model was developed for two Australian copper heap leach operations. The model was primarily used for production planning, in particular to ensure that the heap stacking plan would maintain consistent cathode production in future months.

Key input data used:

- Monthly mine plan; tonnes and grade by ore type
- Recovery data; up to 16 separate extraction curves based on ore type and leach conditions
- Heap stacking & irrigation plan; physical dimensions and flow rates
- SX-EW plant capacity – flow and extraction

The monthly mass balance required an iterative calculation due to the interaction between solution inventory and recovery. A macro was used to perform the iterations on a month by month basis, with inventory carried forward each month. Figure 1 shows the model structure and interaction with metallurgical accounting functions.

The spreadsheet model was successful in forecasting PLS grade and cathode production. It was able to highlight production shortfalls well before they occurred. The forecasts were reviewed 6 months later and found to be in close agreement with actual plant performance.

Although quite effective, the spreadsheet model suffered several drawbacks. It became cumbersome and unwieldy as more heaps were added. The formulas and macros were complicated and difficult to trace. The model was inflexible with regard to alternative heap configurations and irrigation schemes and could not readily be used to investigate alternative designs. The spreadsheet method could not effectively deal with complex chemical reactions.

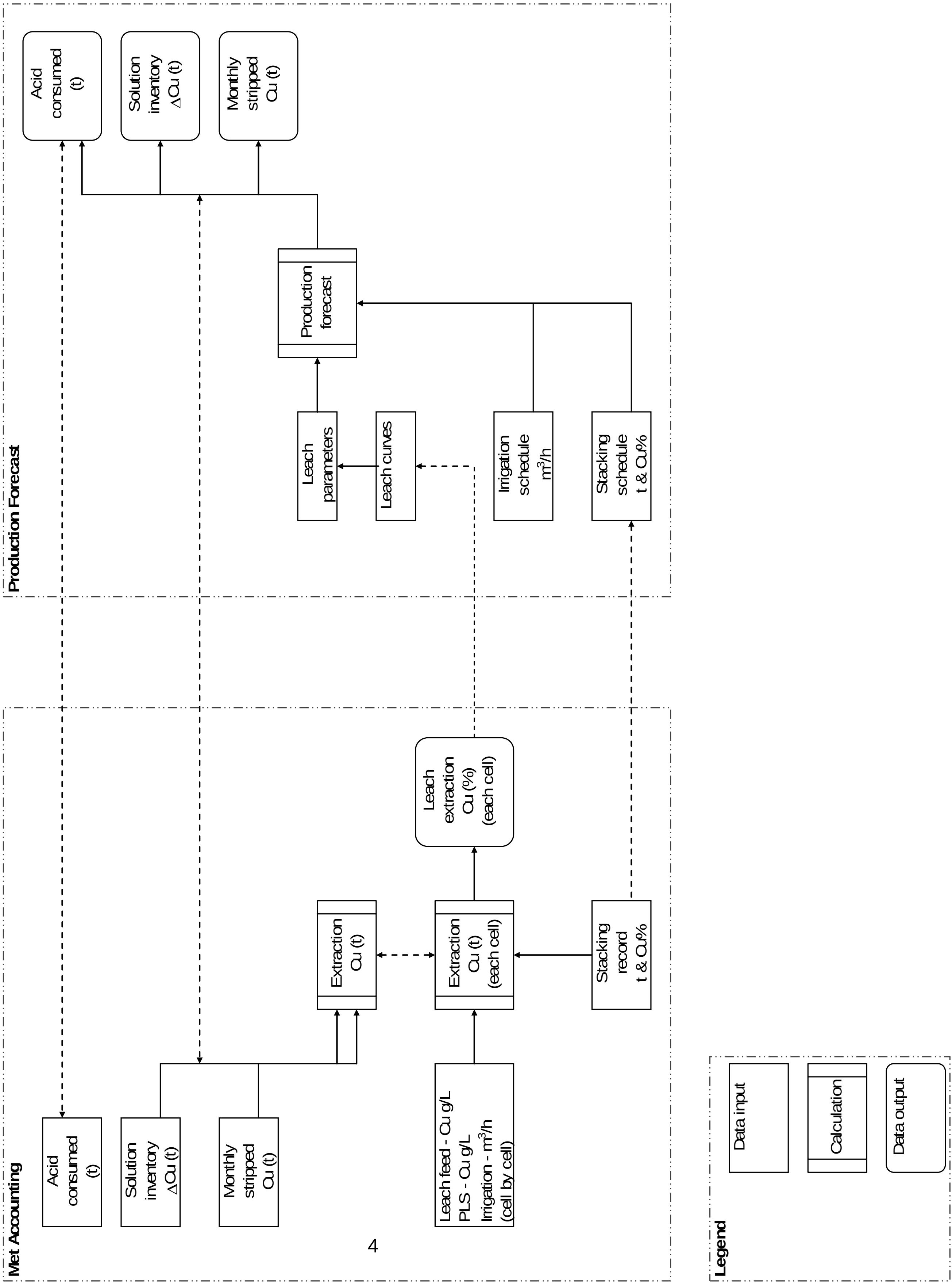

Figure 1 – Spreadsheet Model Structure

SYSCAD MODEL

SysCAD is a specialised process simulation software package, widely used in the minerals industry for flowsheet modelling. A dynamic model was initially developed for evaluation of a nickel laterite heap-leach in conjunction with an existing pressure leach operation.

The model was further developed and refined for a standalone nickel heap leach project, incorporating multi-stage irrigation and downstream processing.

The SysCAD approach successfully enabled a rigorous dynamic mass balance model, taking into account detailed reaction chemistry, stacking and irrigation sequences, solution management, inventory build-up and the downstream process plant.

Figure 2 shows the model overview flowsheet.

The drawbacks of this approach were slow simulation time, and lack of flexibility. The model structure can be modified to match any plant configuration, but significant effort is required for each site application.

IDEAS MODEL

IDEAS is a general-purpose process modelling software focussed on pulp & paper, oil sands and mining industries. It is based on the Extend simulation platform, giving the model structure a strong visual component. Rather than lines of code, the logic associated with sequencing of stacking and irrigation operations is created with model objects such as timers, switches and calculation blocks, directly connected to flow streams on the flowsheet.

IDEAS has only recently been applied to hydrometallurgical flowsheets, and is still undergoing development to meet industry-specific requirements.

Figure 3 shows the model overview flowsheet, with subsequent diagrams showing the underlying structure. The great advantage of the IDEAS model is ready duplication and rearranging of model components. It is also easily traceable and transparent, with no requirement for programming code. It is very fast to run; a 3 year simulation with 10 minute step size is complete within about 10 minutes.

Table 1 – Model Method Comparison

Model platform:	**Excel**	**SysCAD**	**IDEAS**
Method / structure	Spreadsheet	pgm code	H-Blocks
No. leach curves	16	unlimited	unlimited
Chemistry	basic	detailed	detailed
Flexibility	low	medium	high
Solve time	medium	slow	fast

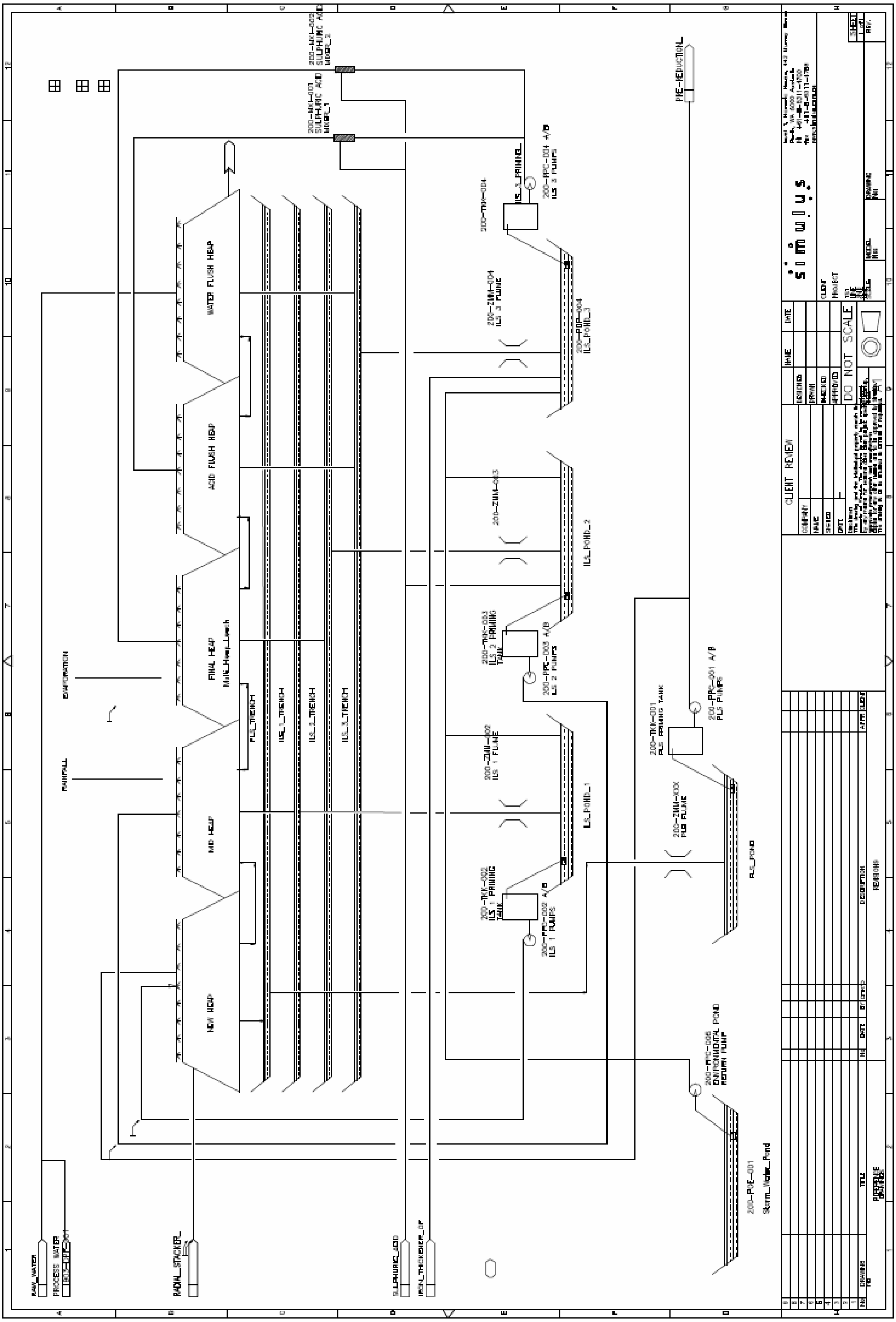

Figure 2 – SysCAD Model Overview

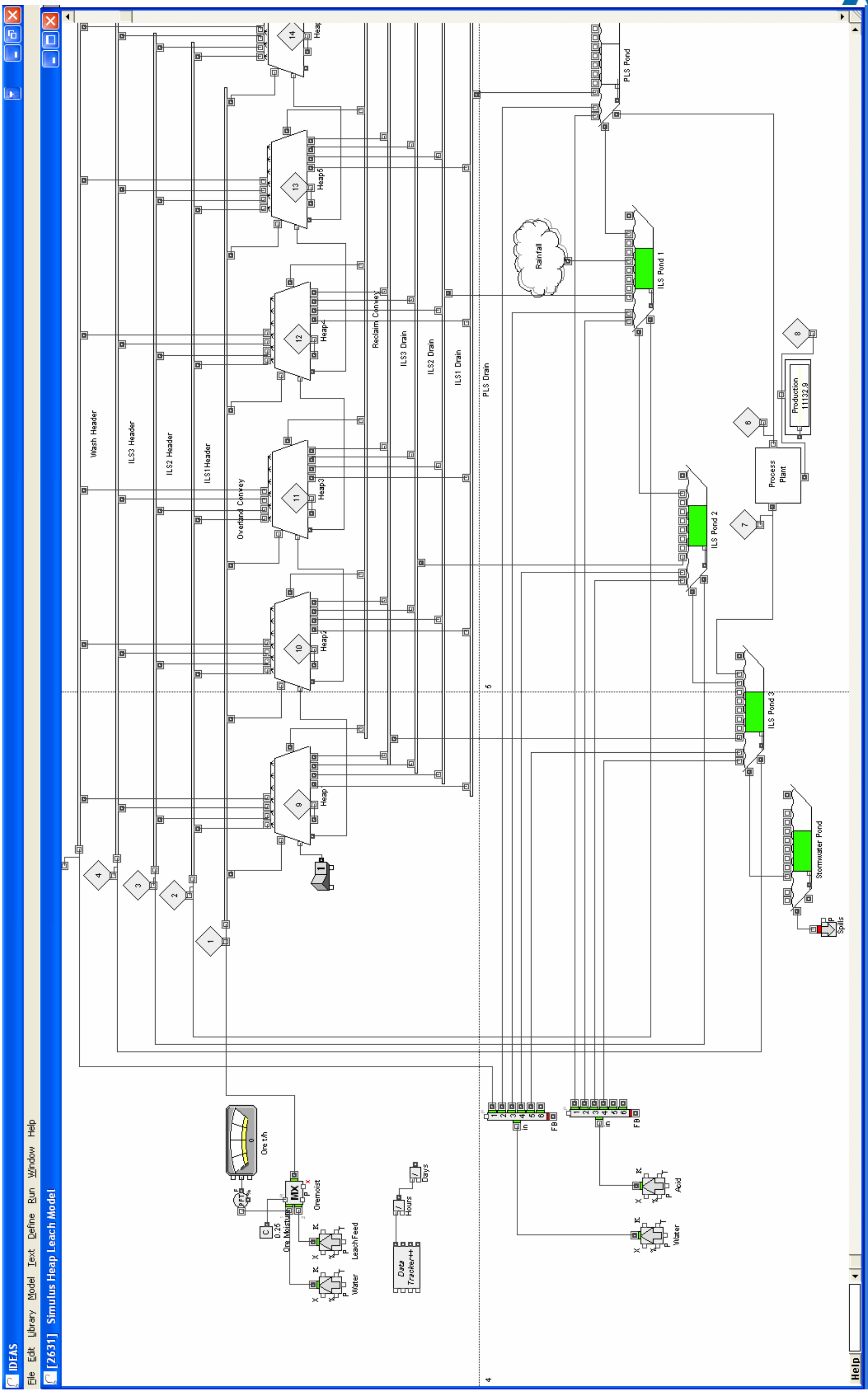

Figure 3 – <u>IDEAS Model Overview</u>

The model input data includes:

Table 2 – IDEAS Model Input Data

Area	Input Data
Ore Stacking	Ore grade & mineralogy over time Crusher / agglomerator / stacker capacity Delay times due to conveyor relocation Reclaimer capacity (for on-off pads)
Heap Leach	Heap dimensions Bulk density Irrigation capacity / specific rates / rest cycles (if applicable) Delay time due to irrigation pipe laying Multi-stage leach data – irrigation rate and time under leach independently specified for each stage Pond volumes Extraction curve as a function of time or flux, or any other relationship (by ore type if required) Other chemical reactions Heap moisture; operating and drained Rates of precipitation and evaporation
Downstream Plant	Flow capacity Metal recovery (as a function of PLS composition, e.g. SX extraction isotherms) Reliability data – duration & frequency of stoppages

The model is a collection of hierarchical blocks that perform particular functions, as listed in the table below. The sequencing and control scheme is designed to mimic realistic plant operation as closely as possible. Each block can be cut and pasted to duplicate the function in another part of the flowsheet. This modular nature makes the model easily modifiable to different sites.

Table 2 – IDEAS Model Blocks

Block	Sub-Block	Function
Heap-leach	Stacker	- Receive 'ready' signal - Feed ore at the t/h rate (global setting) - Totalise ore mass stacked - Totalise contained metal stacked - Compare total mass with heap ore capacity, stop stacking when reached - Wait for specified delay time (for stacker movement) - Transmit 'ready' signal to 'OnFlow' Control block and to 'Stacker' block in next heap
	OnFlow Control	- Receive 'ready' signal - Wait for specified delay time (irrigation pipe laying) - Calculate irrigation rate from specific L/m^2/h rate (global setting) and heap area for each leach stage - In-flow solution from each pond in sequence for the duration specified for each leach stage - Totalise volumetric flow - Record days under leach - Signal current leach stage to off-flow control
	Heap	- Volume storage, representing heap size
	Heap Reactions	- Determine extraction based on days or m^3/t cumulative flow (selectable) - Perform chemical reactions to the required extent - Track metal remaining in heap and calculate extraction - Separate reaction products into solution and solids at the specified % moisture - Transmit 'finished' signal after drain-down to final moisture

			level
	Off-flow selector	-	Direct solution to a pond depending on stage of leaching
	Reclaim	- - -	Receive ‘finished’ signal Inflow heap residue at the specified rate (global setting) Totalise mass of solids reclaimed
Pond		- - - -	Volume storage In-flow water to required level In-flow reagent to required concentration Overflow excess solution
Rainfall		-	Outflow water at the specified rate (variable function over time)
Process Plant		- -	Draw solution at the specified rate Chemical reactions for product

The extraction may be described as a function of time under leach, irrigation flux, or any combination of relevant process parameters. Any mathematical function can be readily inserted to the model to control chemical reaction extents within the heap.

Model outputs are setup to mirror the information seen in a production report. Critical numbers such as PLS grade over time are plotted for each heap, and for the combined stream. Inventory build-up is plotted against metal tonnes stacked and produced for a quick picture of the overall balance.

DESIGN DECISIONS

Dynamic interactions between the heaps and plant need to be understood to arrive at the optimum process design. As with all process design, there are a series of tradeoffs between capital cost, operating cost and recovery or production rates. Process options can normally be tested with the model, provided there is some basis to relate the variables in question.

Increasing the heap height saves on both operating and capital cost of the heap, but carries a penalty in terms of recovery. The higher solution grades mean the downstream plant can be smaller. Higher irrigation rates may shorten the leach time but also give a more dilute PLS and may exacerbate short-circuiting in the heap.

A key question is how many lifts are to be used, are the spent heaps to be removed (on/off pads), are they to be sealed after each lift, or are new lifts built directly on top. The low capital option is multi-lift on unsealed residual heaps. The penalty is the increased inventory from high grade solution being held up in lower lifts. The model is ideally suited to determine this side of the equation, and enable an assessment of the impact on cash flow.

Solution ponds should be large enough to manage plant downtime, rainfall events, and general operability. In particular they should be large enough to bring new, dry heaps on line without interrupting production. They also help smooth out the solution composition fed to the plant. Sizing is often based on experience and guesswork. The model takes into account heap moisture levels (stacked, operating and drained), equipment reliability, rainfall, evaporation, and the solution management scheme. The pond levels are tracked over time to indicate if they are ever the cause of restricted production rates.

Heap chemistry can be a complex set of dissolution and precipitation reactions. Over time, impurity elements build up in the heaps and reach saturation levels. This impacts acid consumption in the heaps, and also has effects on the downstream plant. The model can readily deal with complex mineralogy and chemistry and show the expected composition of solution in a mature operation.

Operating mines need to know that the tonnes and grade being stacked today will give sufficient production rate several months into the future. The stacked ore may be a blend of various rock types, with different extraction and acid consumption characteristics. The model can readily handle multiple ore types and leach curves, and take the guesswork out of production planning.

MODEL VALIDATION

The model is fundamentally a dynamic mass balance, performed repeatedly over a period of several years. The model output data is presented to show that the overall balance is sound in terms of total tonnes, solution tonnes, and metal tonnes.

The calculations and control logic are completely transparent and traceable, and it is easy to drill down to extract specific data for validation purposes.

Both the spreadsheet model and the SysCAD model have been validated against real plant operating data. Forecast production rates and solution grades were compared, 6 – 12 months later, with actual process outcomes. In all cases the models results compared favourably with plant data.

CONCLUSIONS

Heap leaching is a fundamentally dynamic process and requires a plant-wide dynamic model to effectively simulate process behaviour. The Simulus model combines comprehensive reaction chemistry, inventory management and downstream plant limitations to mimic real plant operation over a period of years. Any scale-up or extraction rate model can be readily integrated into the flowsheet model.

The model can be applied to design optimisation and verification, and production planning. Used in conjunction with mine plans and economic models, it can take much of the guesswork out of heap leach design and operation.

REFERENCES

1. A New Approach to Heap Leach Modeling and Scale-Up, M. Jansen and A. Taylor, ALTA 2002 Copper Proceedings

2. HeapSim – Unravelling the Mathematics of Heap Bioleaching, N. Ogbonna, J. Petersen, D. Dixon, Computational Analysis in Hydrometallurgy, 2005