SUMMARY
The Girilambone Copper Company (GCC) commissioned its Copper leach - solvent extraction - electrowinning (SX-EW) plant in May 1993. The plant was designed by CMPS&F with the design criteria being developed utilising the available laboratory based leaching test data and inhouse technical data. The SX-EW plant was designed to treat 400 m$^3$/hr of pregnant leach solution (PLS) at an average copper grade of 4.8 g/l with a recovery of 93%. This recovery was achieved in SX by using two extraction stages in series followed by a single stripping stage.

Since commissioning the heap leaching operation has exhibited leaching characteristics which differ from those initially predicted by test work. As a consequence the average copper grade of PLS was below design and therefore to achieve design copper production targets, increased solution throughput was required. In two stages the leaching system and SX plant were upgraded. The design of the SX plant configuration was based on computer modelling using a proprietary McCabe-Thiele analysis.

INTRODUCTION
Mining at Girilambone commenced late last century. The high grade oxide ore was mined and then initially transported to smelters elsewhere. In 1881 a smelter was constructed near the mine. By 1910 some 80000 tonnes of ore at a grade of 1.95% copper had been mined. As the high grade zones were depleted the mining ceased. In the late 1980s interest in the area increased with test work indicating previously sub economic ore could be treated using the leaching and SX-EW process, allowing for the production of LME Grade A copper. A joint venture was established between Straits Resources (60%) and Nord Pacific (40%), creating the Girilambone Copper Company.

SOLVENT EXTRACTION ISOTHERM MODELLING
Isotherm modelling was performed using a computer based model, Isocalc, developed by Henkel. Isocalc generates extraction isotherms based on equilibrium extraction constants for the extraction of copper from aqueous acidic sulphate solutions with LIX reagents (equation 1). The program also allows for sulfate buffering, solution pH, reagent concentration and the stripping conditions for the loaded organic. The isotherm that is developed is then used to generate McCabe-Thiele extraction diagrams under the conditions specified. Using the extraction data a mass balance can then be developed for a specific SX circuit configuration.

\[ 2R-H_{(org)} + CuSO_4_{(aq)} \rightarrow R_2Cu + H_2SO_4 \]  

For this particular project the philosophy employed was to input the predicted PLS copper grade and use the isotherm model to determine the conditions required for the Girilambone SX circuit to achieve copper production targets. The major variables that were adjusted to achieve these conditions were the organic:aqueous flow ratio (within the limitations of the plant design, such as pumping capacity, flow capacity and settling area) and the LIX reagent concentration.

For the latter stages of the modelling it was not possible to achieve the required copper production targets within the existing plant design and configuration. New design and configurations were therefore developed and then modelled. Where more than one SX circuit design could achieve the required copper production target the modelling data along with the practical “on-site” considerations, such as capital cost and operating cost estimates, were used to determine the optimum circuit design.

Test work conducted on ore samples from Girilambone and on the basis of data collected predicted that a copper tenor of 4.8 g/l at 400m$^3$/hr could be achieved using a two stage leaching system. This was then modelled using the Isocalc program.
The GCC SX circuit was a conventional copper SX circuit with 2 extraction stages in series and one stripping stage. The PLS was predicted to contain 4.8 g/l copper and 2 g/l sulphuric acid to give an average production of 14,500 tpa copper. Modelling of this gave the following circuit mass balance using a LIX 984 concentration of 16.5% (figure 1). This indicated a predicted copper recovery of 4.46 g/l from the PLS (for a PLS of 4.8 g/l this represents a recovery of 93%).

Upon completion of commissioning the leach SX-EW facility at Girilambone in May 1993 the design volumetric throughput had been achieved. However, as the leaching was only in its early stages the anticipated high PLS grades were not achieved. At this time the circuit recoveries were typically > 90% with a LIX concentration of 14%.

During 1994 and early 1995 the leaching was reaching its potential and at a LIX concentration of 14.7% the circuit achieved close to its predicted values as shown below in figure 2.

It is common for the predicted strip isotherms to be calculated at 30 g/l Cu in spent electrolyte as this gives improved stripping efficiency and overall recovery. However, in an operating environment the spent copper concentration is a critical parameter for control of electrowinning, and 30 g/l is the minimum operating level acceptable. More commonly the spent electrolyte is controlled at 35 - 40 g/l. As a consequence the overall SX efficiency is affected. To partially overcome this the spent acid concentration is increased to 180 - 190 g/l whereas the isotherms are commonly calculated at 170 g/l. These variations can be seen when comparing figure 1 with figure 2.
STAGE 1 UPGRADE

Following the first year of operations, GCC had learnt a significant amount about their heap leaching system and the leaching characteristics of the ore. These characteristics of the ore were also changing as the predominantly oxide copper mineralogy, mined at the commencement of the project, was replaced by a mixed mineralogy of oxide and secondary sulphide. Based on the available data and further laboratory based column leach tests, it was decided that there was a need to allow for significantly higher flow rates, as the design PLS copper concentration of 4.8 could not be achieved especially during winter months. There were several scenarios investigated by CMPS&F with the target of achieving budget copper production at an annualised rate of 14,500 tpa.

The first limitation was that the volumetric flow rate capacity of the SX plant with a three mixer/settler configuration was constrained. Standard design practice indicates that the maximum settler throughput rate for effective organic/aqueous separation is 5 m³/hr of flow per m² of settler area. The GCC settlers were 12.3 m wide by 13.5 m long, giving a settling area of 166 m² giving a maximum rated capacity of 830 m³/hr of combined aqueous and organic flow.

Three major scenarios were investigated:

1. Convert the current two stages of extraction from series to parallel, as shown below.

2. Add an extra mixer settler and have two extraction stages in series followed by a third extraction mixer settler in parallel and maintain a single strip stage. This was modelled at a high organic to aqueous ratio at 18.5% LIX concentration (see figure 3). The advantage of this was that by some subtle design innovations it would be possible to allow the four mixer settlers to be configured as above but also as a two extract two strip circuit (suitable for high Cu, high acid PLS) or 2 extract, 1 strip, 1 wash circuit (for a PLS high in chloride). This would give the circuit the maximum flexibility for future operations.

3. Add a complete new SX train consisting of two extraction mixer/settlers and one strip mixer/settler.
Scenario one was modelled and this showed that it was not possible to achieve the desired recovery rates to ensure that the production could be achieved. The third option was rejected because of the high capital cost requirement. On this basis the second scenario was adopted and subsequently installed along with the increased pumping capacity required to achieved the increased PLS flow rate and resultant increased raffinate flow rate.

The new SX configuration was commissioned in January 1995. The circuit achieved design operating conditions almost immediately. Figure 4 shows operating data from the SX plant in March 1996 with a LIX concentration of 13.5%.

The impact of slower sulphide leaching rates eventually resulted in a falling PLS grade, as a consequence the organic strength became too high for the prevailing conditions. Because the organic was not being fully utilised to extract copper, the organic began to transfer significant quantities of iron into the electrolyte circuit. As a result more electrolyte had to be bled from the circuit. The electrolyte bleed then is discharged slowly into E-1 in order to allow some of the copper to be recovered. The problem is that the electrolyte also contains 180 g/l acid resulting in increased acidity in extract thereby reducing the effective extraction capacity of the organic.

The data supplied with the organic indicated that it should be possible to achieve a copper to iron selectivity of 1500:1 whereas the plant transfers were in the order of less than 500:1. A series of laboratory tests and plant monitoring indicated that by maintaining an organic copper loading of >90% the iron transfer was minimised to about 5 ppm per pass through the SX plant. Below 90% the iron transfer could reach levels of 15 - 25 ppm per pass. Further tests were done to compare the performance of other organic reagents. Under identical conditions it was found that Acorga M5640 gave 60% less iron transfer than the LIX 984 however it was not practical to make any changes to the type of organic within the circuit.

To overcome the iron transfer problem the primary organic flow was reduced, thereby reducing the O:A (organic to aqueous ratio) from 1.1:1 to 0.9:1. Although this resulted in an initial decrease in copper transfer through SX it was possible to minimise the electrolyte bleed, hence minimise copper losses. As a result the overall production rate was not affected.
STAGE 2 UPGRADE

Although the plant flow rates had increased, the new ore that was being placed for leaching (during 1995) was all secondary sulphide and copper extraction rates were lower than anticipated. A further option to allow production to be achieved was to change the SX circuit to 3 parallel extraction stages with a single strip stage. This option was investigated based on; a PLS copper grade of 1.4 g/l and a PLS flow of 1350 m$^3$/hr, with an organic flow rate of 400 m$^3$/hr. At a LIX concentration of 18% an overall copper recovery of 87.7% was predicted. Based on these data, piping configuration changes were incorporated into the SX plant and the pumping system was upgraded to allow for conversion to a three parallel extraction SX circuit configuration.

Following incorporation of these changes, the circuit was run for a short period in this mode of operation with the following results (figure 5). Although overall operational flows and copper tenors were different from those used in the modelling, the concept of the three parallel extraction stages was proven. In fact the overall recovery from the operational data was 88.8% compared to the predicted 87.7%. 
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