“ADDRESSING THE CHALLENGES OF SUSTAINABILITY IN THE MINING INDUSTRY”

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ABSTRACT
The UN in 1987 described sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

Nalco sees sustainability as linking, or recognising, the three pillars of sustainable development, social, economic and environmental drivers, into viable solutions for our customers. Such that the impact of working with Nalco will improve our customers’ unit costs of operations in a sustainable manner.

The purpose of this paper is to demonstrate through case studies how Nalco has been using water mapping and process audit techniques coupled together with state of the art technology, to identify areas on base metals mine sites where sustainable improvements in water management result in reduced total cost of ownership.

The case studies will cover and show:

- How water mapping better identified and quantified water losses (over 50,000 m$^3$/day via evaporation) from a mine site and what could be done to reduce this and provide high quality water back to mining operations (9,000 m$^3$/day).
- How high quality water used for dust control could be reduced. 80% savings (566 m$^3$/day) in water use and the ability to switch to lower quality tails water, with minimal road preparation.
- How understanding what a client has on site via a process audit can help in developing a solution which minimises capital outlays and provides a solution to processing challenges. Using redundant site equipment and dams allowed for pre-treatment operations to be carried out without the need to spend over US$1 million for plant.
- Improved process management in RO processing can reduce maintenance costs (such as membrane replacement) and increase RO plant availability from less than 30% to over 90%.
INTRODUCTION
The United Nations in 1987 described sustainable development as: “sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

By recognising the three pillars of sustainable development:
- Social
- Economic and
- Environmental drivers

And linking them into viable solutions for our clients and customers, Nalco has been able to provide them with a return on the investment they make when working with Nalco.

The mining industry has particular issues with water and it’s management around mine sites and as part of a “social license to operate”, many mines are looking to address the use and management of the water they take onto their site, and how to extract the maximum value from it, to reduce the amount of water they require.

In areas where water is scarce, mines which can use water more efficiently and reduce their overall drawdown on resources are seen by the community in a more favourable light. Likewise were there may be an abundance of water (such as acid mine water), it may need some form of treatment to make it suitable for reuse or, alternatively, discharge.

This paper focuses on how water management solutions were arrived at for three mine sites, to show the breadth of opportunities available to the mining industry. The particular solutions were fitted with the requirements of each mine site to provide ongoing sustainable outcomes.

HOW ARE SUSTAINABILITY ISSUES BEING ADDRESSED NOW?
Many mines will respond to problems or issues on a case by case basis. There is nothing wrong in doing this, however, it does mean that potentially viable alternative solutions may not even be thought about or considered, because they do not exactly appear to address the issue being faced, or it could be that another area of the site has a need which could be satisfied by a solution, but this need is unknown to the section of the plant facing the problem. This is of particular concern on large integrated sites.

It may be that a potentially more cost effective solution (site or business wide) could be arrived at, if a broader view is taken of the site in question. Depending on the situation, it may be possible to utilise particular waste water in a different section of the plant, with only minimal remediation efforts. Or with a more complete treatment, make the final product one which would boost yield.
Hence it is having an understanding of the various processing elements or units across the whole site which can allow a company, like Nalco, to put an economic value on the material to be treated, and use this to make a decision on which way to move forward. To do this requires an in depth understanding of the water chemistry and how the unit processes work. By understanding the mechanical, operational and chemical (MOC) factors of the site and situation, this allows different process options to be tested for suitability. Financial return on investment (ROI) and sustainable return on investment (eROI) is then determined for each option. This then allows one to select the right treatment process or processes from the wide variety available now, and not just try to badge engineer a solution.

So the net benefit is derived from bringing together mechanical, operational and chemical understanding to develop solutions which deliver a measurable eROI. This holistic view is addressed by the case studies presented in this paper.

**SOME OPTIONS IN ADDRESSING SUSTAINABLE SOLUTIONS**

Mine sites can be seen as a large water circuit. Water flows around the site, and should be looked at holistically when looking at options for treatment.

In broad terms a mine water circuit can be described as shown in the diagram below (figure 1)

![Mine Water Circuit Diagram](image)

Figure 1 – Mine Water Circuit, Types of Flows around a Mine Site
Understanding processes and impacts upon these processes is critical to ensuring all the potential options are investigated. For example, water quality has an impact on the flotation process in base metals. Knowing what type of water chemistry is needed can help in the scoping and design of the plant. Therefore, activities such as water mapping and water audits can help in understanding the water circuit on a mine site.

Nalco uses processes such as water mapping and water audits, to initiate the process. By having a complete understanding of the mechanical, operational, and chemical aspects of the processes and site, it is then possible to drill down and better understand what is occurring in particular areas of the plant.

This understanding of the whole circuit provides:

- What’s used in the circuit, such reagents, modifiers and pH correction
- Quality of inputs required at various points in the circuit
- Unit processes and any limitations
- Upstream and downstream impacts, an example might be, is dust control used on feed stockpiles. Does this impact processing?

Once this is completed the process then moves onto addressing:

- What is the current situation?
- What is the desired outcome?
- What is the gap that has to be bridged?

By then being able to place an economic value on the water used in, and across, the processing circuit, the benefits from a particular solution are determined and compared to other competing solutions. Included in the sustainability assessment are considerations whether there are any by-products which could be utilised elsewhere in the plant or sold to add value to the project.

Examples of how Nalco used this methodology:

- Base metals water mapping project
- Iron ore water mapping project: 1) Dust and 2) Tailings
- Coal mine, Acid Mine Drainage (AMD) process audit – Reverse Osmosis (RO) process management and site water management
CASE STUDY 1
BASE METALS WATER MAPPING PROJECT
This project commenced because of a need to ensure the local community did not run out of water. Forward thinking management could see that should the local water supplies deplete to a level such that the town could run out of water, then the mine would have to reduce or cease operations.

Nalco was asked if it could help and a project team was put together to map water use around site. The result of this week long audit is shown in the water map (Figure 2). This map was used to find potential sources of water to help meet the fresh water make up needs to the plant.

Figure 3 then shows the water flows around the base metals concentrator.

The most obvious source of water was the tails, however, due to operational issues no change could be made to the solids concentration in the tails.

The mine quarry its old TSF (tails storage facilities) for use as underground fill in the mine. The question was asked: “Would it be possible to remove solids from the tails thickener feed, recover water and size the solids required to allow then to be used as underground fill, for less than they paid to quarry the material now?”

After reviewing potential process options a plan was developed which would allow solids recovery to occur (figure 4). It was believed that this plan could be carried out and would make “fill” available for a similar figure to current quarrying costs and recovery water from the tails which could then be recycled back into the plant and reduce the fresh make up water requirement to the site. On figure 3, the location of the proposed solids and water recovery plant in the process is also shown.
Figure 2 – Base Metals Water Map
Figure 3 Water Flows around the Base Metals Concentrator
Minimize Fresh Water Make-Up

Figure 4 Proposed Plan to recovery water and provide solids for backfill
Next steps have been to validate the process. Nalco has put a RO plant on site to test membrane performance and possible issues arising from the use of this process.

Figure 5 Reverse Osmosis Test Rig on site

As a separate possible process option, there has also been some investigation into tails stacking. The pictures below show some of the initial testing.

Figure 6 Tails Management Testing

The audit and water mapping was able to identify and quantify water flows around the whole site (which had not been done at whole of site level before) and quantify losses (over 50,000 m$^3$/day via evaporation alone) from the mine site.
To address the requirement to reduce water requirements for site, an plan was presented which allowed site to recover approximately 9000 m$^3$/day from the tails system, and also provide material which could be used as underground fill back to mining operations, up to 50,000 tonnes per month.

Subsequently, a second processing option was looked at to investigate tails stacking as a means to recover even more water from the tails and reduce the requirement for additional storage space in the TSF.

CASE STUDY 2
IRON ORE WATER AUDITING PROJECT
In a similar situation to the base metals processor, an iron ore processing site could see that it had an imperative to improve its operations from a sustainability point of view. Significant amounts of water are used around its mill and mine sites, and Nalco was asked if it could audit the water circuit and identify savings.

Again, an audit team was put together which then spent time on site understanding how water was used around the mine site. Meetings were held with senior management to understand the future desired situation and any current issues they had.

A water map was put together for the site, see Figure 7.

The water mappings showed that a significant portion of water used on site (approximately 43%) is used as road dust control, with the bulk of the remainder (31%) lost via evaporation from the tails dam. Much of the water entering site comes in as high quality town water.

With a new plant being built the water flows around the site where changing. Figure 8 shows the proposed changes in flows. The crossover point for dust suppression water between the new and old plants was now the Standpipe Buffer Tank. Again, dust control and evaporation losses accounted for the bulk of the water usage.

Site then has commenced investigations into options available for reducing the amount of water sprayed onto its roads for dust control. A number of differing reagents had been tried to reduce water consumption determined to provide sustainable solutions. Both as a spray onto the road and incorporated into the surface.

Nalco proposed the use of Haul EZ® dust control reagent, based upon a renewable resource which is mixed with water and sprayed onto the road surface. See Figure 9 for a photo of the trial situation.
Figure 7. Iron Ore Mine Site Basic Water Map
Figure 8 – Proposed Changes to Flows with a New Processing Plant
Other areas which have been investigated involve determining if tailings can be dewatered effectively and the water recovered before it enters the tails dam, as a method of reducing water loss through evaporation.

On site testing and monitoring has shown reductions in water use of over 75%, through the use of the Haul EZ® technology, and comments from site would indicate that the road surface has become harder and more durable during usage. See Figure 9 for a view of a Haul EZ® treated road.

From the analysis of the site water usage, the customer was able to understand the principle areas of water usage and loss. This understanding of the priority areas allowed focus on methods to have significant impact in reducing water usage through dust control and water loss, through tails water management. Results so far have seen a reduction in water consumption of approximately 17,000 m³/month (566 m³/day) compared to previous use for road dust control. Investigations are still ongoing relating to the tails stacking.
CASE STUDY 3
HUNTER VALLEY COAL MINE
This underground coal mine had to dewater in order to maintain production. The mine is essentially at the bottom of the seam, so water flows down through the seam from other operations. Without mine dewatering the mine would flood.

The water from underground had high levels of iron (over 500 ppm) and manganese (over 20 ppm), plus other salts, and could not be discharged from site without treatment. The water could be viewed as AMD type of effluent. There was also an imperative to treat some of the water to provide very clean water for mining equipment. The site had already installed a SWRO (seawater reverse osmosis) plant to meet its requirements for treating the discharge water and providing clean water for operations. This installation was completed without consideration of the complete water circuit and therefore was not optimally engineered. Consequently the mine was not satisfactorily meeting its water management needs.

![Figure 10, Basic Water Map of Coal Mine Site Flows](image)

The system in place involved two SWRO trains in series with the brine from each going through a third train. The brine was being sent underground for disposal. The output of the SWRO plant varied sometimes good results, sometimes mediocre, and sometimes no result. No apparent reasons could be seen for this, SWRO membranes life was poor and SWRO plant output was falling.
Site knew one of the problems - the short life span of a set of membranes within the RO trains was costing significant amounts of money in that a new set of membranes was costing approximately US$80,000. They were changing out a set of membranes, on average, every three months, which pointed to inadequate pre-treatment and insufficient RO feed water scale inhibition treatments.

Feedwater to RO plants must be to a standard, and this required that site (once mining was about to start again) develop a process to meet the RO plant feedwater requirements. This meant the iron and manganese had to be removed to levels suitable for the RO (ideally ferrous iron 4 mg/L max, ferric iron and manganese 0.05 mg/L max.))

Nalco was asked if we could investigate the water and help develop a plan to help treat the mine water, such that reliable and economic water supply of consistent quality suitable for the Coal Handling and Preparation Plant (CHPP) and underground operations.

The process involved:

1. Mapping the water circuit from mine to plant (Figure 10)
2. Analysing the mine water (Table 1)
3. Modelling tests to understand how the water reacted to pH correction
4. Predictive studies for scaling potential

The mine needs to pump approximately 2.5 ML per day to ensure the mine stays dry enough for work to take place, and to provide the necessary amount of water for processing to occur. This was to increase to 3.5 to 4 ML per day as the mine moves into lower areas of the coal seam and mine.

Table 1. Typical Analysis of Acid Mine Water

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Level (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron (II)</td>
<td>500</td>
</tr>
<tr>
<td>Manganese</td>
<td>20</td>
</tr>
<tr>
<td>Sulphates</td>
<td>10 – 14,000</td>
</tr>
<tr>
<td>Calcium</td>
<td>500</td>
</tr>
<tr>
<td>Magnesium</td>
<td>600</td>
</tr>
<tr>
<td>Sodium</td>
<td>4,000</td>
</tr>
<tr>
<td>Chlorides</td>
<td>700</td>
</tr>
<tr>
<td>Total dissolved solids</td>
<td>16 – 26,000</td>
</tr>
<tr>
<td>pH</td>
<td>&lt; 4</td>
</tr>
</tbody>
</table>
The dissolved mineral species, and small particulates in the RO feed water could impact RO, and due to the mechanics of RO there is the likelihood of scale and other types of fouling occurring in the membranes. This meant consideration would have to be given to negate or minimise these factors. Plus other issues to consider included where the brine will go, and could it have any impacts on the process?

The initial thoughts to treat the water involved the following process steps:

- pH correction of water when it comes to the surface
- Solids/liquid separation of the flocs formed
- Polishing of the pH corrected water to reduce any remaining iron or manganese
- Filtration to remove any remaining suspended solids

Figure 11. Proposed Process Flow to Treat Underground Water
The proposed solution involved aeration of the AMD water from the mine followed by pH correction with lime or caustic soda, clarification of the treated water and filtration to remove any remaining solids.

Site had some infrastructure in place which it was keen to utilise if possible. Calculated capital costs for the above process was estimated at US$3 million, plus other construction related costs. Other forms of clarification were investigated as we knew there would be significant amounts of gypsum scale formed during the pH correction phase. These involved recycle to help seed the scale. Cost became a major issue and it was decided to go with a lower cost option.

There was a medium sized lime plant, which was believed to be somewhat undersized for the calculated amount of pH correction and flows, and some other dams which could be utilised for holding time to allow for settling purposes for any flocs form. Site decided that they would try this first to save available capital for other projects.

The final process developed included aeration of the underground water once it arrived at the surface. A number of dams had aeration devices installed to facilitate this process. The major part of the pH correction utilises the existing lime plant on site, and settling of flocs was carried out after flocculant addition in a “horseshoe” dam. As the treated water was channelled out of the dam, it was polished with sodium hypochlorite to oxidise any remaining iron and manganese. Levels of iron and manganese were reduced to lower than 1ppm and lower than 10ppm respectively.

The treated water was then stored in a large process water dam, which allowed gypsum to deposit onto the bottom of the dam.

![Figure 12. Gypsum Scale Growth over rocks and branches in the process water dam](image-url)
In Figure 12 it can be seen the level of gypsum scale which formed on the bottom of the process water dam. Both Nalco and site were very concerned about the amount of scale and how it could potentially impact the process water pipe work to the SWRO, and also the final pre-treatment process (pre-filtration, green sand filters, and cartridge filters) for the SWRO. An antiscalant was used to help protect the pipework from the dam to the SWRO. This immediately helped maintain flows to the SWRO plant and reduced downtime for cleaning.

This all helped to ensure that the SWRO plant was supplied with feed water, and improved availability of the plant. The final process involved:

- Aeration of mine water once it arrived at the surface utilising existing site dams
- pH correction to facilitate removal of iron and manganese
- Solids/liquid separation of the iron and manganese hydroxides
- Final polishing via oxidation after pH correction
- Addition of an antiscalant to stop scale in pipework leading to the SWRO pre-treatment stage

Finally, to improve operation and importantly control of the SWRO units, a dosing and control system called RO TRASAR® was installed on one train as a trial. This system uses “tagged” molecules to determine actual reagent dose rates required to respond to fluctuating flows. Designed for real-time on-line monitoring of antiscalant concentration, the technology actively controls antiscalant dosing down to a level of 0.5ppm of product. This improves performance and helps reducing fouling of the membranes, thereby changing cleaning cycles and increasing availability. This system also monitors pressure drops and flows within the SWRO units and can send alarms when the unit reaches pre-set values.

The RO TRASAR®, helped get the SWRO plant back to design capacity and improved overall plant efficiency and output. All three processing RO units are working closer to design specs with Unit 3 recovering around 20% more permeate from the brine processing cycle. Additionally, the plant has just achieved 14 months trouble-free operation from one set of membranes, compared to three months prior to the changes made to mine water treatment and TRASAR® control.

CONCLUSION

Every situation on a mine site is different and it is rare that the same solution can be used on more than one site. So it is important to understand what is going on at the mine site and adapt a solution to fit the particular needs to the site. By working with a customer/client and bringing know-how, expertise of MOC factors such as water chemistry, Nalco can then bring innovation and technology to provide a solution to site needs.

Each of the case studies shows how auditing and mapping was able to identify areas where water was used, and provided a place to start identifying those areas which could be targeted to achieve the needs of the site.
Base Metals
- Water mapping better identified and quantified water losses (over 50,000 m$^3$/day via evaporation) from the mine site and then allowed some focus on what could be done to reduce this, and provide high quality water back to mining operations (9,000 m$^3$/day).
- Identify other means of process water recovery from tails

Iron Ore
- How high quality water used for dust control could be reduced with 80% savings (566 m$^3$/day) in water use and the ability to switch to lower quality tails water, with minimal road preparation.

Hunter Valley Coal
- Process auditing developed a solution which minimises capital outlays and provides a solution to processing challenges. Using redundant site equipment and dams allowed for pre-treatment operations to be carried out without the need to spend over US$3 million for a lime plant and other new water treatment plant components.
- Improved process management in SWRO processing reduced maintenance costs (such as membrane replacement from 3 monthly to over 14 months) and increased RO plant availability from less than 30% to over 90%.

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