Tailing dam management practices - A review of 3 case studies

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Abstract

Across Australia mine wastewater management has been based around evaporation. With more extreme weather conditions becoming commonplace, storm ponds and tailings dam capacity can easily reach maximum and, in some cases, spill over into the environment.

After a heavy rainfall event in early 2009, at least three north Queensland mine sites experienced issues with flooding. Two had unauthorised releases to the environment; the third was 3,381 megalitres (ML) over its reporting level. Heavy rainfall events are not uncommon in South East Asia where treating the mine wastewater for continuous discharge to the environment and reuse are becoming standard practice.

This paper describes the issues related to the unauthorised discharge: the issue of storage of tailings water compared to the a treatment approach for continuous discharge to the environment. It also discusses the methodology used to determine a treatment method to allow continuous release of treated tailings water.

Keywords: water treatment; sulfate removal, ion exchange (IX) and reverse osmosis (RO)

Introduction

Water management in the mining industry presents ongoing challenges with more extreme dry and wet season patterns. In winter, water reuse reduces the dependence of mining operations on external water sources. In many cases mine water is allowed to be released into the environment only during rainfall events to cope with the excess water.

If most of these challenges are well-understood for stormwater dams, it is less discussed for tailing dams. In recent years major rainfall events have increased pressure on tailing storage facilities and mines are more dependent on providing additional costly storage capacity. In parallel, discharge standards have become stricter and government agencies advocate maximum water reuse on site.

Water contaminated by tailings can cause serious environmental issues. Tailing water may contain high concentrations of various chemicals such as heavy metals, sulfates, chloride, that are more bioavailable/toxic because of the acidic nature of the tailing dam effluents.

On average there has been one major event involving tailing dams each year since 2009. A new approach to the design and management of tailing dam water is required to prevent damage to the environment and prevent the resulting fines and costly remediation plans. As an alternative to this situation, mining companies should go beyond legislative requirement and explore the treatment, reuse and even continuous discharge possibilities of tailing water and their associated solid by-products as a way to increase their water balance flexibility.

Methods

Through the development of three contrasting studies, this paper investigates various water treatment strategies and how the integration of water treatment into mines' design could lead to a more sustainable industry. The first study looks at the root causes, remediation approach and general consequences of unauthorised discharges based on the incidents at a copper mine site in northern Queensland. The second study examines storage issues and how understanding surface runoff and treatment options can assist when negotiating with Department of Environment and Resources (DERM). The third study explores an innovative approach to tailing dam challenges through integrated water treatment design for continuous release to the environment.

Results and Discussion

Case Study 1 - Unauthorised Discharges

Between early January and February 2009, 1191 mm of rain was recorded on the Lady Annie mine area. Rainfall records indicated these levels of rain had only occurred previously in 1893 and 1974. The mine was in receivership and unproductive at the time.

The stormwater pond system was designed in such a way that if it reached capacity the ponds would inundate the leachate pond system prior to discharging to the environment via the stormwater spillways to Saga Creek. The total stormwater pond capacity was 770 megalitres and the ponds contained minimal amounts of water before the rainfall event.

Within a three-day period the mine site received more than 340 mm of rain resulting in the uncontrolled releases. Water seeping under two leach pad liners caused ponding on the surface. Stormwater combined with leachate meant the stormwater ponds were highly contaminated. One of the two stormwater pond's liner and sidewall became damaged due to a sink hole, which caused an estimated 447 megalitres to discharge to Saga Creek. The discharge triggered immediate actions to mitigate the impacted watercourses about 54 km downstream. Table 1 shows the sampling results from the creeks directly after the discharge. The highest levels were found in the first 11 km from the point of discharge.

***Table 1**: Lady Annie Water Quality Results – February 2009*

Impacted Area Levels		**ANZECC 2000 Guideline Values**	
	mg/l	**Livestock Drinking Water**	**95% Trigger value (moderately disturbed ecosystem)**
Aluminium	0.5 to 90	5	*
Cobalt	0.17 to 4.6	1	-
Copper	1.9 to 56	1	0.0014
Nickel	0.08 to 1.6	1	0.011
Conductivity	170 to 2600	5970	250
Sulfate	64 to 1700	1000	-
Chromium	<0.001 to 0.03	1	0.0001
Manganese	1.2 to 30	-	1.9

* 0.055 if pH >6.5; 0.0008 if pH <6.5

Throughout the impacted 54 km of creeks the pH was recorded at about 4.5, whereas un-impacted areas were at pH 6.5 to 7.0. In May 2010 sampling showed that copper remained above the ANZECC 2000 95% trigger level for many areas. Location-specific difficulties complicated the ability to treat the contaminated water. Culturally significant areas combined with rugged terrain and limited access made traditional treatment methods unfeasible. Community unrest prompted extensive negotiations to obtain approval of treatment strategies with local land owners and stakeholders.

Treatment included:

- installing a series of culverts at the downstream extent of the contamination so that gates can be shut off in the event of a rainfall event causing remobilisation of contamination
- flushing 200 ML of freshwater to encourage mobilisation into a series of in-stream dams for treatment
- treating dams with treated bauxsol to reduce bioavailable metals and neutralise acidity.

Bauxsol treatment was selected because it had a proven track record for settling metals in a contained area. There were initial concerns that the sediment in the waterways would limit the ability to quickly return the ecosystem to its pre-discharge state. Acid testing on bauxsol sludge indicated re-absorption was minimal below pH 3.8. DERM instructed that part of the remediation process settled bauxsol sludge from the treated creek areas had to be removed.

The cost of repairing the pond subsurface conditions, liners, walls, surface drainage and the remediation of the creeks exceeded Aus$11M. CopperCo – the owners at the time – were fined $500,000 and ordered to pay $83,109 in investigation costs. Another mine nearby was fined $130,000 after a portion of the tailings dam had eroded away, causing contamination to a contained area affecting 11km of creek.

Due to the Lady Annie unauthorised discharge in 2009 cattle were restricted from using the contaminated creek area for drinking purposes. Cattle farmers had to relocate thousands of cattle to alternative locations with suitable drinking water. That restriction was eventually lifted at the end of 2011. Parsons Brinckerhoff continues to undertake annual water quality monitoring and reporting on the environmental and ecological condition of the creeks. DERM has specified this will continue until 2026.

Case Study 2 - Flooded Mine

The 2009 rainfall event affected many mines in northern Queensland especially those unproductive at the time. The flooded mine study 2, is north of Lady Annie mine. The mine pit was flooded, the evaporation ponds and dams were full and they were 3,381 megalitres above the reporting level. The mine Owners and DERM were concerned how to lower the stored volume before the following wet season.

A review of an earlier hydrological report confirmed a surface runoff diversion channel located adjacent to a natural dry creek tributary would substantially reduce the flows across the mine catchment area. Installation of mechanical evaporation units (Turbo-mister) would improve the evaporation rate of stored contaminated water.

Figure 1 *Mine tailings nearing capacity*

There was no simple ‘quick fix’ for the tailings dam and mine pit water. Their discharge licence only allowed them to release when the receiving creek was flowing, which was during the rainy season and the licence was capped to 500 ML per year.

The mine had a metals recovery process that could be adapted as a simple metals precipitation process. Table 2 shows the results from bench testing of the tailings water that proved the metals could be removed to acceptable limits. It also indicates that sulfates could only be reduced to ~1200 mg/l as SO_4. Typically the solubility of gypsum restricts sulfate residuals ~1600 mg/l

***Table 2**: Case Study 2 Bench Test Results – March 2009*

	Raw Sample mg/l	Test Sample mg/l	Test Sample mg/l	Release Limits mg/l
pH	2.8	8*	12	6.5-8.5
Cobalt	16	0.1	0.021	1
Copper	130	0.22	0.53	1
Zinc	5.9	0.008	0.009	-
Lead	0.009	0.001	0.003	-
Sulfate	5300	2800	1200	1000
TDS	8400	4600	3300	4000

* 1.8 g/l hydrated lime required to correct the pH

DERM indicated they would consider a continuous controlled discharge to reduce the stored volume if the metals were removed and sulfates were <600 mg/l. A technology review of emerging processes showed there were a few treatment processes in pilot stages, but had not progressed into full commercial systems due to difficulties responding to fluctuations in feed chemistry. Only two forms of technology had a proven reliability for the removal of sulfates:

- Membranes
- Reverse osmosis (RO) low recovery ratio (~60%) due to calcium sulfate fouling, meant concentrate recovery had to be considered to reduce the volume to the evaporation ponds.

Nanofiltration (NF) was originally developed for the oil industry. The first project (late 1980's) to prevent barium sulfate from forming was in the North Sea Brae field producing wells, where Marathon Oil Ltd successfully employed NF membranes for removing the sulfate ions from injected seawater. Although NF operates at lower pressures than RO it still has calcium sulfate fouling issues.

Ion exchange (IX) is a two-bed process using lime and sulphuric acid as the regenerants and produced pure gypsum as the waste product. Once the waste stream is dewatered it can sold to the building industry.

Any treatment process required to treat about 6.0 ML/day required a six-month lead time before delivery to site. That would put the construction period into the following wet season. The mine owner presented to DERM the available options and reached an agreement:

- Construct the division channel before the following wet season to reduce the surface water catchment area.
- Install mechanical evaporation units to improve evaporation rates.
- Remove metals and reduce sulfate levels to as low as possible using the existing precipitation process.

In return DERM would allow them to continuously discharge the treated tailings water to the nearby creek until they were below the reporting level. The mine also had an extraction licence for the nearby Lake Waggaboonyah. The maximum continuous extraction rate was 1.33 ML/day with a sulfate content of 3.0 mg/l SO_4. Blending the lake water with the treated mine water would ensure the discharge sulfates were <1000 mg/l.

Case Study 3 - Continuous Release

The flooded mine site (case study 2) is a clear example of the tailing dam design limitations and forms the basis for engineering an alternative approach that allows reuse and continuous discharge to the environment. A copper mine project located in South East Asia required a large volume of river water to be pumped for use in the mine operations. If standard dam management principles were applied, the extracted water would no longer be available to communities downstream whose water demand was already near current capacity in the dry season. The other issue was the location has an exstensive wet season.

Treating the waste stream to comply with weak local environmental protection requirements would be easy, but the mine owner is known for its environmental approach to the business. Therefore, from a social considerations standpoint it was imperative that the project did not reduce downstream water flow and quality. ANZECC 2000 guidelines were applied to bring the discharge limits back to near receiving water background levels. This requirement promoted the recycling of the tailing dam and drainage water while stringent discharge water quality fostered the need for a high level of water treatment to achieve combined treated water flows up to 172 ML/day.

An integrated phased water treatment approach was identified as the most cost effective treatment strategy. After extensive market evaluation, including due diligence audits of available treatment processes (in USA and China), the findings were added to the risk weighted NPV options analysis. Two viable outcomes formed a common approach to pre-treatment of metal precipitation, followed by RO or an IX process to remove sulfates. The cost of the NF membranes made that option unattractive.

RO, with conventional softening through the metal precipitation process typically achieved a 65%, recovery ratio and provided permeate with an ion make up that could affect the receiving ecosystem. Remineralisation to maintain the hardness, alkalinity and pH to near background levels was a requirement. The RO waste reject stream required further treatment through brine evaporation and crystallisation.

IX would regenerate on a 12-hour cycle and provided ~90% efficiency. Possible ion imbalance could affect the receiving ecosystem. CO_2 was added to maintain the alkalinity and pH to near background levels was a requirement. The IX waste stream is dewatered using plate and frame membrane press, eliminating the need for crystallisation. The press centrate is returned to the head of the treatment stream and the pure gypsum can be sold to the building material industry. The dollar per unit water volume treated for the IX process was ~$0.60 per m^3, based upon site specific factors such as flow, ion concentration, power and chemical costs. When comparing the RO/Evap/Crystal process with the IX process systems;

- IX capital cost is approximately 40% cheaper because it does not require an Evaporation and Crystallisation process.
- IX operational costs are approximately 50% cheaper
- IX process showed ~80% less CO_2 emissions due to the much lower power requirements.

This initiative not only transformed an environmental threat into opportunities but demonstrates the feasibility of large scale alternatives to current tailing water management thinking.

Figure 2 *IX treatment option for removing high sulfates and the Gypsum bi-product (BioteQ's Sulf-IX™ process plant)*

Conclusions

Failure of a tailings storage facility can have a profound social and environmental impact, but also affects corporate image and ultimately the bottom line.

In the unauthorised release study, no hydrological report was undertaken, which would have shown surface runoff issues and improvements to drain channels. Based on catchment area, it was calculated each stormwater pond should be suitable of handling 576 megalitres. If the stormwater ponds functioned in accordance with the design, it is estimated an overflow event up to 20 megalitres may still have occurred.

In the flooded mine study, the hydrological study was carried out late in the mine life, so the Owners had no prior understanding of surface runoff issues and how that would affect storage capacities. Once the surface water flows were understood, typically 45% reduction in captive flow could be achieved. Treatment of the stored contaminated water was possible using existing equipment, which allowed the mine Owner to negotiate a continuous release to lower the stored volume.

In the continuous release study it was estimated that stopping production for four weeks due to a spill, would more than pay for an efficient reliable treatment option. At the beginning of any mine project surface runoff and catchment areas should be fully understood and drainage channels used where possible to divert uncontaminated flows away from storage areas. The use of water treatment expertise rather than systematic increase in dams' storage capacity is an option that the mining industry could support to mitigate the risk of tailing facilities and ensure regulatory compliance. Treatment of mine water should be considered at the mine development stage, when the cost of treatment is a small percentage of the overall mine development cost.

During the wet season, the dams can store water, while the water treatment process treats all year round to discharge criteria. Treated tailing water offers a new and untapped source of water that reduces mines' dependence on external raw water. Efficient water treatment technologies can provide more flexibility to the mine water balance system. It can facilitate environmental and social backing of government agencies and affected communities.

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