THE MT GORDON CHALLENGE: IMPACTS OF HISTORIC LEGACIES, HIGHLY VARIABLE CLIMATIC CONDITIONS AND TOUGH ECONOMIC CONDITIONS ON MANAGEMENT OF ACID MINE DRAINAGE

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ABSTRACT

Aditya Birla Minerals purchased the historic Mt Gordon Copper Project, previously known as Gunpowder Copper, in November 2003. Copper has been mined from two open cut pits and two underground mines periodically since the early 1900s with various processing methodologies used including heap leach, pressure leaching and copper sulfide flotation. Environmental protection requirements have undergone significant changes since the time of commencement of mining operations. In addition, the current project experiences considerable environmental legacies arising from actions taken that would not be allowed under modern environmental protection requirements.

During the 2008/09 wet season, higher than average rainfall was experienced in the Mt Isa region. By mid April 2009, the site had received 1,310 mm of rainfall equating to a 1 in 500 year ARI, two month rainfall event. This followed a period of four years of drought conditions where the site was experiencing severe water shortages. A decision to cease mining for economic reasons had already been made in early January 2009 prior to experiencing these large rainfall events. The subsequent above average rainfall forced closure of all operations and the site was formally placed on care and maintenance in February 2009.

The Esperanza Pit and Mill Creek Dam collected about 5 gigalitres of runoff from the project area during the 2008/09 wet season, effectively containing all potentially contaminated water on site. With a pH of 2.7, acidity of 3,200 mg $CaCO_3$ L^{-1}, copper concentration of 250 mg L^{-1} and sulfate concentration of 5,500 mg L^{-1}, the challenge for Birla Mt Gordon to manage the water effectively and meet regulatory requirements began.

This paper will discuss:
- *Options identified for water treatment and water reduction given the site was on care and maintenance.*
- *Actions taken between 2009 and present to manage accumulated poor quality water.*
- *The impacts of climate on the options available for water reduction.*
- *When does stored water cease to be seen as a resource and become a liability?*
- *The use of ecological risk assessment as a tool in decision making.*

1.0 INTRODUCTION

*Aditya Birla Minerals purchased the historic Mt Go*rdon Copper Project, previously known as Gunpowder Copper, in November 2003. Copper has been mined from two open cut pits and two underground mines periodically from the project since the early 1900s with various processing methodologies used including heap leach, pressure leaching, electrowinning and copper sulfide flotation.

The rugged landscape, highly variable subtropical climate and the highly sulfidic characteristics of ore and waste rock has resulted in considerable challenges for mine water management. Since mining commenced in 1927, the site has been subjected to successive cycles of drought and high rainfall. In recent periods of water surplus, mine operators have used controlled discharge of treated mine water to the receiving environment to reduce stored water volumes.

Exceptionally high rainfall was recorded in northwest Queensland during the 2008/09 wet season. This followed a period of drought where water supplies had reduced to record lows and contributed to a decision in late 2008/early 2009 to place the operation on care and maintenance owing to lack of water for processing operations. By mid-April 2009, the site had received 1,310 mm of rainfall equating to a 1 in 500 year ARI two month rainfall event. (Uncontrolled) discharges of acidic and metalliferous flood waters were reported for numerous operational and abandoned base metal mines in the Mt Isa and Cloncurry districts. Mt Gordon was the only one of nine affected mines that did not discharge poor quality water, with the majority of stormwater being contained in the mined out Esperanza Pit.

Since this time Birla Mt Gordon (Birla) has been liaising closely with Queensland Government regulators regarding reduction of the volume of stored low quality water to a level that presents minimal environmental risk. This paper discusses the processes adopted to manage these risks during a period in which the project was predominantly non-operational and on care and maintenance with limited available on site resources.

2.0 SITE DESCRIPTION

2.1 Location and Landform

The Mt Gordon Operations are located approximately 120 km northwest of Mt Isa in North West Queensland, in the Shire of Mt Isa near the former township of Gunpowder (Fig. 1). The mining operations are located entirely on the Calton Hills pastoral lease owned by the Kalkadoon Aboriginal Council.

The project is situated in the hilly and mountainous Mt Isa highlands. Elevations range from 190 metres (RL AHD) at Gunpowder Creek to 310 metres (RL AHD) at the mine site. Slopes range from moderately inclined to steep.

2.2 History

Copper mineralisation was first discovered near Gunpowder Creek in 1923 by two Afghan brothers. From 1927, the brothers worked a small open cut on the Mammoth Number One ore body. Between 1948 and 1969, Mammoth was worked as a small underground operation. In 1969, Surveys and Mining Ltd took control and embarked on a large scale development including the Mammoth open cut, exploration decline and a copper flotation plant. In 1971, a joint venture between Consolidated Gold Fields Australia Ltd and Mitsubishi took control, establishing Gunpowder Copper Ltd which further developed the Mammoth underground mine. In 1977, due to low copper prices, the operation was placed on care and maintenance.

In 1979 the mine re-opened and production was carried out by “in situ” leaching of broken ore until 1982 when the mine was abandoned. Between 1988 and 2003, the mine was operated in turn by Rension Goldfields Consolidated Ltd, Tremelling Pty Ltd, Adelaide Brighton Cement Holding Ltd, Aberfoyle Limited and Western Metals Ltd. During this period open cut mining of the Esperanza orebody commenced and underground mining of the

Mammoth orebody continued. Ore was processed in a pressure leaching plant to produce copper cathode and tails were disposed of in a purpose built valley fill TSF. In 2003 Western Metals went into administration and Mt Gordon along with other assets was put up for sale. In November 2003, just prior to the operation being closed due to lack of interested purchasers, Aditya Birla Minerals purchased the project narrowly preventing it from becoming another mine site where the government had insufficient funds to address environmental issues. Open cut mining of Esperanza ceased in 2005, underground mining continued and ore processing changed to a conventional sulfide flotation methodology to produce copper concentrate. The operation has largely been on care and maintenance since early 2009 with only short periods of operation in 2010-2011 and 2012-2013.

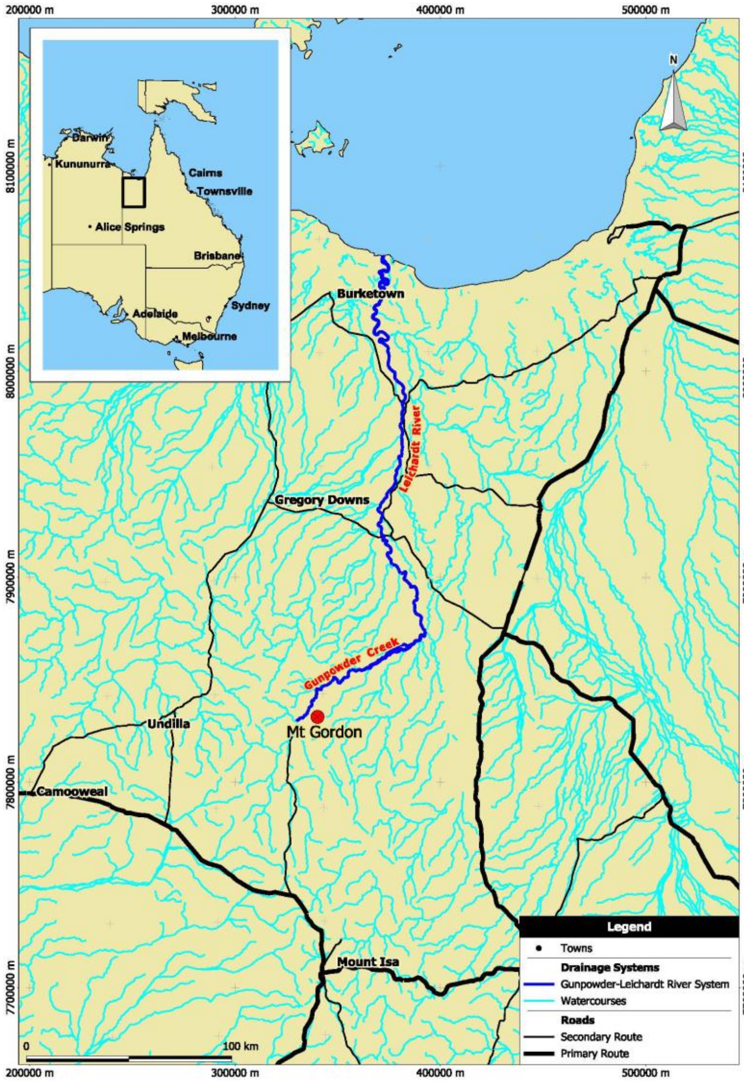

Fig. 1. **Location of Mt Gordon operations**

2.3 Climate

The Gunpowder region has a semi-arid climate with a short wet season between November and April that is influenced by the North West monsoon. The mean annual rainfall is 475 millimetres, with a distinct wet season from November to March and a dry season from May to early October. The wet season is characterised by periodic storms and heavy rainfall events. The dry season is characterised by little rainfall and a large diurnal variation in temperature. The average pan evaporation levels are expected to be similar to the 3,104 millimetres per year for the Mt Isa Aerodrome. This indicates a highly evaporative environment with a negative water balance of approximately 2,500 millimetres per annum.

2.5 Geology

The Esperanza copper-cobalt ore body is hosted by the carbonaceous shale and chert breccia of the Esperanza Formation near the convergence of the Mammoth and Mammoth extended faults. This Formation is a sequence of well bedded to locally massive, black carbonaceous to locally grey or grey-green, weakly dolomitic siltstone and pyritic shale. Carbonaceous rocks are dominant, especially in the vicinity of mineralisation. The mineralised unit of the Esperanza Formation has bands of laminated chert and bodies of chert breccia that are approximately 100 metres thick and conformably overlie the silt-shale sequence beneath. Less brecciated units of the Esperanza formation are located north of the Mammoth Extended Fault, south of the Mammoth Fault and immediately east of the highly brecciated mineralised zone. Paradise Creek Formation comprising dolomitic siltstone lies east and south of the orebody (AIMM 1998).

Mineralisation at the Mammoth deposit is hosted by the brecciated units of the Myally Subgroup. The lowermost exposed unit is a pink massive to weakly bedded quartzite which abuts the Portal Fault and is at least 60 metres thick. Overlying the quartzite is a complex sequence of interbedded laminated sandstone, arkose, siltstone and minor quartzite that is 60 metres thick nearest the surface and increases in thickness with depth. Overlying the Myally Subgroup to the surface is the conglomerate, sandstone and siltstone of the Surprise Creek Formation (AIMM 1998).

Pyritic black shale from the Esperanza deposit is the major source of acid and metalliferous drainage (AMD) at Mt Gordon. Mammoth waste rock is characterised by lower sulfide concentrations (as pyrite and associated chalcopyrite and chalcocite) and higher acid neutralising capacity (ANC).

2.6 Hydrology

The operations are located within the catchment of Gunpowder Creek. Gunpowder Creek is the main regional waterway which discharges to the Leichhardt River and subsequently to the Gulf of Carpentaria. Sub catchments potentially affected by the Mt Gordon operations include Greenstone Creek, Mill Creek, Magazine Creek and Esperanza Creek.

2.7 Hydrogeology

The main aquifer at Mt Gordon is located within fractured rock at depths 30 metres below ground level. The baseline groundwater flow regime is that of a relatively flat water table with an elevation of about 220 metres AHD at the Mammoth and Esperanza ore bodies and a gradient of about 1% towards Gunpowder Creek.

This aquifer has a very low permeability (between 10^{-7} and 10^{-9} m s^{-1}) and groundwater flow is generally along fault lines and fracturing. Faulting may give rise to hydraulic isolation and compartmentalisation where the area is virtually isolated from the regional groundwater flow system. Higher permeability brecciated fault zones act as conduits for groundwater flow. The direction of flow is dictated by lithology and structural features. Due to the low permeability of the fractured rock aquifer, groundwater flow follows a tortuous path and the speed of groundwater flow is slow, in the order of 0.3 m yr^{-1}.

2.8 Mt Gordon Receiving Environment

The ephemeral nature of watercourses within Gunpowder Creek catchment controls the amount of water in the creek systems throughout the year. Storm flow within the creeks occurs rapidly with wet season rains and is characterised by highly turbid water. Over the dry season, vast stretches of the Gunpowder Creek watercourse dry out, creating a series of pooled reaches that are subject to high impacts from visiting wildlife and cattle. Minor creeks generally dry completely.

The main receptor of poor quality water from Mt Gordon Operations is Gunpowder Creek, a major tributary of the Leichardt River (Fig. 2).

An assessment by the Australian Centre for Tropical Freshwater Research (ACTFR) in December 2002 (ACTFR 2003) identified Gunpowder Creek as a highly disturbed system as a result of both current and past land use activities, especially mining and cattle grazing. The area near Mt Gordon is also highly mineralised, which results in occasional naturally elevated concentrations of toxicants. For example, copper levels recorded at sites upstream of Mt Gordon Operations have been as high as 3 mg L^{-1}. Also, photosynthetic activity during the day by algae can increase pH values to levels exceeding 10. Gunpowder Creek supports a significant algal population, most likely as a result of nutrient enrichment of water by grazing cattle.

Recharge to the aquifer is via direct infiltration into the fractures and by infiltration through gullies and creeks where they cross these fractures. Due to the low permeability of the surrounding rock, the water table may rise by up to 10 m following recharge periods.

2.8 Mining Infrastructure

2.8.1 Mines

Two pits and two underground mines have been developed since 1927 with a third decline at Esperanza South commenced in 2007/08, but not fully developed.

Mammoth Pit and Underground was mined sporadically by a number of previous project owners. Mining of the pit ceased about 1972 with it being backfilled from 1999 to 2002 with waste from historic heap leach operations and waste rock from Esperanza Pit and Mammoth Underground. Mining in the Mammoth Underground occurred most recently between 2002 – 2009 and 2011-2013 following a period of disuse and consequent extensive period of de-watering. Mining is currently on care and maintenance, but resources in the underground are still considered economic.

Esperanza Pit was mined from 1997 to 2005. Since closure of the pit, it has been used as a water storage. This has provided contingency for capture of potentially contaminated water from the Esperanza catchment during the wet season. A water treatment plant was commissioned in 2007/08 to recover copper and cobalt from pit waters. The plant operated until January 2009 when it was partially flooded by cyclonic rainfall. The plant was not operated after this time due to technical and commercial difficulties.

2.8.2 Waste dumps

Three main waste rock dumps are present across site. A number of other likely waste rock disposal areas also exist as a result of the natural paucity of flat land and the historical use of waste to form access roads, operational platforms and other mining related infrastructure.

The North Waste Dump is formed from waste from initial development of the Esperanza Pit and received waste from 1997 to 2002. The dump has been constructed such that it only has one open face, sloping north. The southern face forms the embankment of the Esperanza TSF. The dump effectively blocks the valley between the TSF and Gunpowder Creek. The northern face of the dump has been rehabilitated and appears to be geotechnically stable and supports some vegetation, particularly on the berms. The upper surface has not been rehabilitated as it contains stockpiles of waste materials for eventual covering of the upper surface of the Esperanza TSF.

The Mammoth Waste Dump contains waste materials from historic mining of the Mammoth Pit and underground mine as well as small volumes of waste from Esperanza underground and open pit. The Mammoth Pit has been backfilled and now forms part of the Mammoth Dump. The dump fills a valley leading to Esperanza Creek, blocking a small ephemeral tributary referred to as Esperanza Creek East. Waste materials from Mammoth Underground continued to be placed on the dump until suspension of mining activities. The upper sections of the dump have been completed and the surface compacted and covered with non-mineralised waste rock. The middle and lower sections remain active.

The Esperanza Waste Dump primarily contains materials from Esperanza Pit and small volumes from the Mammoth underground and Esperanza South decline development. The dump was commenced in 1997 and contains the majority of the transitional and fresh waste rock from Esperanza Pit. The dump is located on the southern boundary of the mining tenement and blocks the valley immediately upstream of the Esperanza Pit, including Esperanza Creek. Disposal of waste to this dump ceased in 2005 when open pit mining ceased. Small volumes of waste from development of the Esperanza South decline were placed on the upper surface of the dump in 2008. Re-mining of the upper surface commenced on a trial basis in 2010 as low grade ore was identified. The trial was stopped due to processing difficulties.

Esperanza waste rock is typically highly sulfidic (up to 45%) with minor amounts of acid neutralisation capacity (ANC) provided by dolomitic strata. Pyrite and chalcopyrite are the dominant acid producing sulfide minerals and much of the waste is classified as potentially acid forming (PAF).

Mammoth waste rock is characterised by much lower sulfide contents (typically 0.2 to 2%) and variable ANC. The majority of the waste is classified as either benign or potentially acid forming – low capacity (PAF-LC).

2.8.3 Tailings storage

The operation has one historic and one operational tailings storage facility.

The Old TSF was operated up to 1985. It is located immediately north of Gunpowder Creek with the northern embankment constructed on the creek floodplain. Records indicate the facility leaked poor quality water to the environment since it was commissioned. Since closure and subsequent rehabilitation of the facility, the upper surface has been used for administration offices, laydown areas, evaporation ponds and concentrate drying bays.

The Esperanza TSF is a valley fill style facility located west of Esperanza Pit in a parallel valley. It has a footprint of about 22.6 ha with a storage volume of about 5.6 million m^3. The embankment wall was constructed in 1998 using waste materials from Esperanza Pit. The facility has been raised with natural saddles in the adjoining ridges being filled to increase containment capacity. Gunpowder Creek is located north and hydrologically down gradient of the TSF. The facility remained in use until recent suspension of operations.

Tailings produced from Esperanza ore are characterised by high sulfide contents and oxidise rapidly to form seepage with low pH and elevated concentrations of sulfate, copper, cobalt and other metals. Tailings produced from Mammoth ore, which account for most of the tailings deposited in Esperanza TSF in recent years have much lower sulfide contents, although seepage still contains elevated sulfate concentrations.

2.8.3 Water storages

Various water storages have been constructed at Mt Gordon for both process and storm water management purposes.

Raw water for the operation comes from Lake Waggaboonya (capacity 5.775 GL), which was purpose built in 1969 to supply water to the mine and associated township of Gunpowder. Smaller purpose built structures for process water storage, storm water retention and evaporation purposes are located on the Mining Lease. Many have been upgraded over time as operations have varied and environmental management expectations changed. Esperanza Pit (capacity 6.4 GL) and Mill Creek Dam (capacity 1.4 GL) are the largest of the storages with both used for retention of poor quality storm water. Two retention ponds (combined capacity of about 250 ML) and an associated diversion channel were constructed in the Upper Esperanza catchment in 2010 and 2012 to reduce clean water inflows into the Mining Lease.

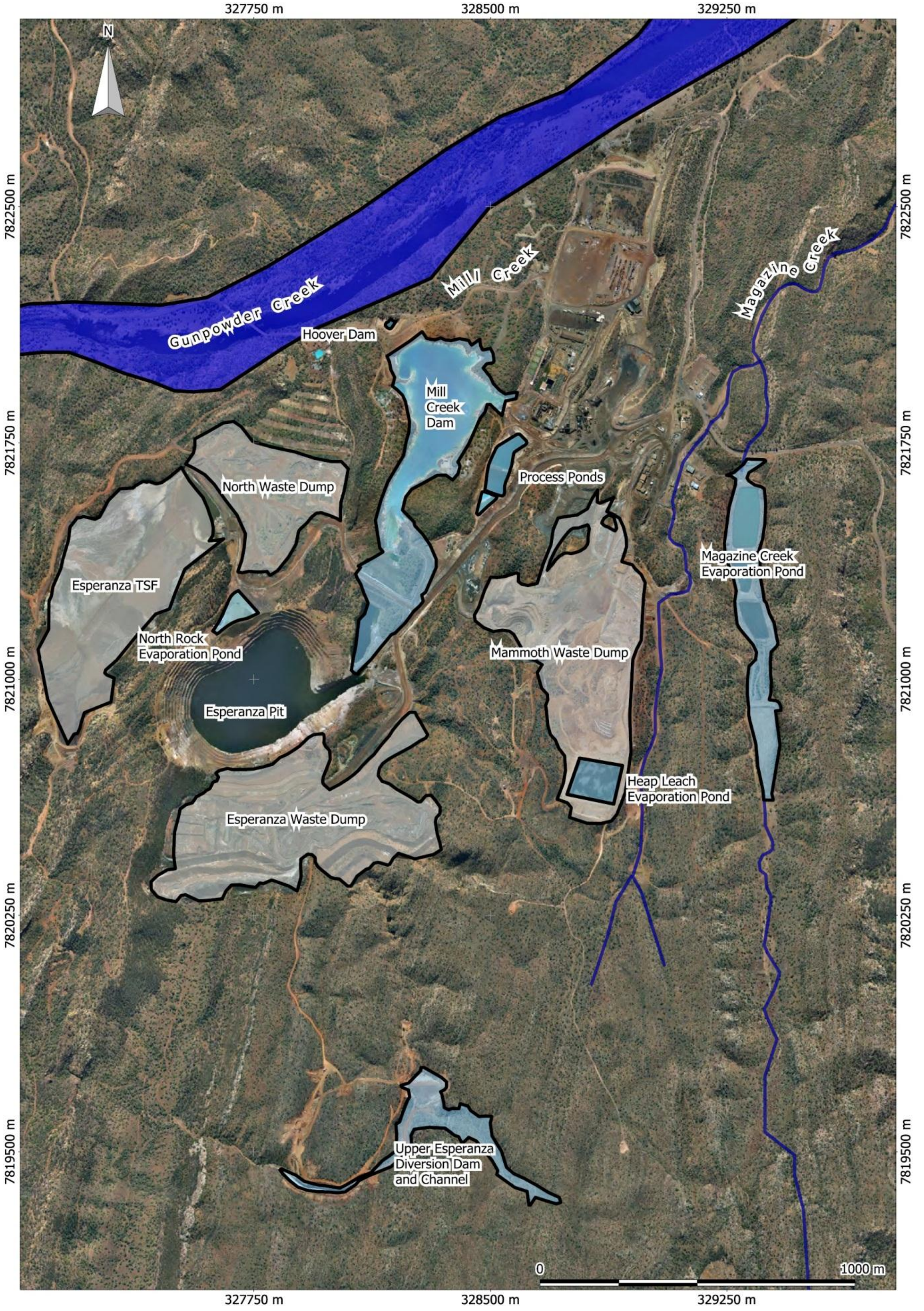

Fig. 2. **Site plan layout**

3.0 2008/09 WET SEASON EVENTS

3.1 Regional

During the 2008/09 wet season, much higher than average rainfall was experienced in the Mt Isa region with Birla Mt Gordon receiving a total of 1,310 mm. The majority of rainfall was recorded during early and late January 2009 with some significant events also occurring during late December 2008 and early February 2009 (Figure 3). Review of the rainfall record shows:

- Seven days of rainfall above 50 mm were experienced.
- Four days of rainfall above 100 mm were experienced.
- One day of rainfall above 200 mm was experienced.
- There were two major rainfall events of 521 mm over eight days and 434 mm over nine days, separated by 16 days of lighter rainfall in January 2009. This is not long enough for the catchment to dry out so the two events had a combined effect.

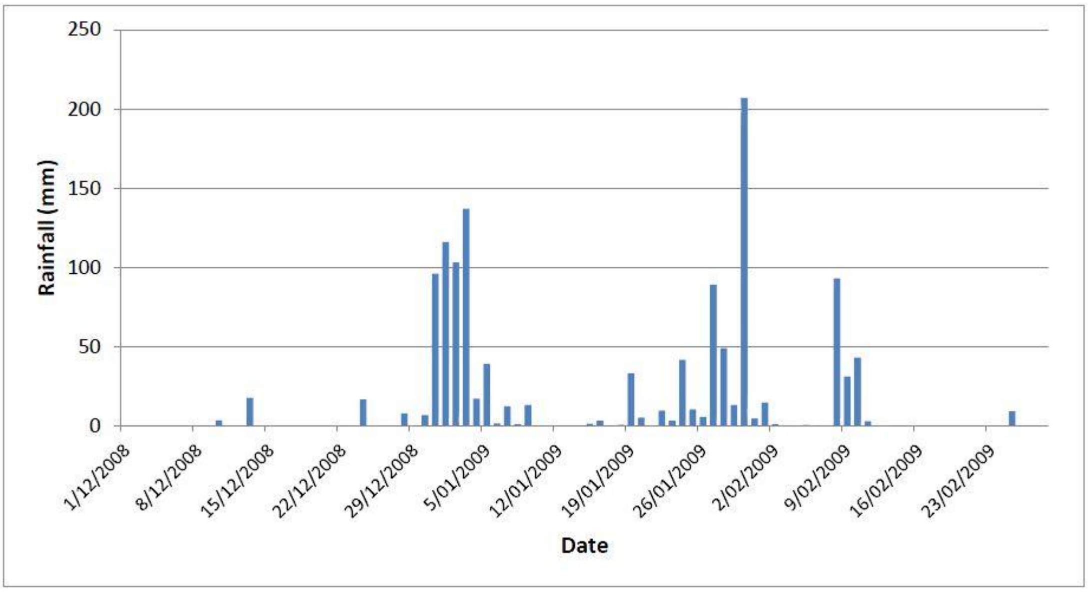

Fig. 3. 2008/09 wet season rainfall by day at Mt Gordon

Based on hydrological model information developed for the project, the rainfall is estimated to be in excess of a one in 500 year ARI two month wet season. DEHP maintain a flow gauging station on Gunpowder Creek adjacent to the mine site. Runoff recorded at this station for the wet season was 470 mm. The highest previously recorded (1971 to present) runoff for a wet season was 407 mm in 1973.

Almost all of the runoff within Birla Mt Gordon mining leases was retained on site, with minimal release of contaminants to the environment. This resulted in onsite water storages being filled to almost capacity.

3.2 Mine Site

3.2.1 Volume of poor quality water

Poor quality water captured during the 2008/09 wet season was stored in two locations – Esperanza Pit and Mill Creek Dam.

A survey on 1 October 2008 recorded the Esperanza Pit water level at RL 183.8 m (volume of 2.7 GL). By 13 February 2009, Esperanza Pit water level was at RL 221 which equates to a volume of about 5.94 GL. As of 28 August 2009, water levels in Esperanza Pit were recorded to be RL 223.01 (6.01 GL) compared to maximum pit capacity of 6.4 GL at RL228.3.

Mill Creek Dam was effectively empty prior to the 2008/09 wet season. It was estimated to contain about 700 ML of water as of May 2009, about 50% of its total capacity.

3.2.1 Water quality

Water quality data for untreated water in Esperanza Pit and Mill Creek Dam as of October 2009 is presented in Table 1. Water quality was similar in the two storages, indicating either hydraulic connection or similar sources of acidic and metalliferous drainage (AMD). Sulfidic waste rock stored in the Esperanza and Mammoth waste rock dumps and exposed sulfidic black shales in the walls of Esperanza Pit are likely sources of AMD.

Acidity in poor quality water at Mt Gordon exists in three distinct forms:

- Hydrogen ion (H^+) acidity as free sulphuric acid. This form of acidity is highly reactive and therefore rapidly neutralised by hydrated lime until sufficient calcium dissolves to initiate precipitation of gypsum.
- Metal ion acidity associated with metallic ions including aluminium, copper, manganese and iron. Initial reactivity with hydrated lime is relatively rapid, but decreases as a result of surface coating by precipitated metal hydroxides.
- ‘Latent’ or ‘stored’ acidity that can be released by oxidation of reduced metal ions such as iron (Fe^{2+}), manganese (Mn^{2+}) and cobalt (Co^{2+}).
- Equation 1 demonstrates how oxidation of reduced iron generates additional acidity. The rate of generation (and hence neutralisation) of this form of acidity is controlled by the availability of oxygen (aeration).

Equation 1: $$4Fe^{2+}\ O_2 + 10H_2O \rightarrow 4Fe(OH)_3 + 8H^+$$

4.0 WATER REDUCTION STRATEGY

A variety of environmental risk reduction options were explored by Birla in response to regulatory concerns and potential legal action if an uncontrolled discharge was to occur. It was recognised the strategy needed to include both water treatment as well as water volume reduction mechanisms. The options for pit water reduction activities were significantly constrained by the project being on care and maintenance since January 2009. Recommencement of operations in late 2009 allowed other water reduction options to be re-evaluated. Considerable pressure was applied by regulatory authorities for rapid volume reduction in stored poor quality water. Decisions made regarding the water reduction strategy were strongly influenced by the operation being on care and maintenance and regulatory actions.

Table 1. Water quality in Esperanza Pit and Mill Creek Dam as of October 2009

Parameter	Units	Esperanza Pit	Mill Creek Dam
pH		2.8	2.7
Acidity	mg $CaCO_3$/L	2,400	3,200
Alkalinity	mg $CaCO_3$/L	-	-
TDS	mg/L	8,900	8,600
Sulfate	mg/L	5,800	5,500
Calcium	mg/L		220
Cu	mg/L	250	250
Co	mg/L	16	28
Cr	mg/L		0.014
Cd	mg/L		0.0023
As	mg/L	<0.003	0.007
Pb	mg/L	0.004	<0.005
Al	mg/L		270
Fe	mg/L		130
Mn	mg/L		110
Zn	mg/L	5.9	5.2

4.1 Objectives

The primary objective of the water reduction strategy was to restore sufficient water storage capacity to reduce the risk of uncontrolled release of poor quality water to the receiving environment in following wet seasons.

Longer term objectives are to establish a sustainable water balance for the site and to minimise generation of AMD from waste storages and historic infrastructure prior to closure.

4.2 Regulatory Requirements

A regulatory framework for developing a practical and cost-effective program for water reduction was established by agreement between Birla and the Queensland Department of Environment and Heritage Protection (DEHP, formerly Department of Environment and Resource Management, DERM). The process commenced with DEHP issuing Environmental Protection Order (EPO) (STAT457) – Water Reduction and Other Actions - on 17 April 2009 in response to the volume of poor quality water on site at that time.

Birla responded by submitting a proposal for a Transitional Environmental Program (TEP) similar to earlier efforts to reduce surplus mine water in 2006 through a Voluntary Environmental Management Program (VEMP). DEHP advocated more stringent water quality targets to those achieved in the 2006 VEMP and recommended technologies including Nanofiltration, Reverse Osmosis and High Density Sludge (HDS) chemical treatment. Although these technologies were capable of producing very high quality water, the required capital expenditure and operating costs were considered excessive, especially as these options were unlikely to be required for long term water management strategies for Mt Gordon.

The end result of the process was the issue of a negotiated Court Order in September 2011, with the prime mechanism for water reduction being controlled release of treated water during the wet season according to the following criteria:

- Flows in Gunpowder Creek must exceed the 25th percentile for wet season flows.
- Treated water quality must comply with the limits listed in Table 2.
- The flow volume in Gunpowder Creek at the time of release must be at least 20 times the volume of water discharged.

Apart from water treatment methodology and appropriate treated water quality targets, the main point of discussion was the acceptable volume of untreated water that could be stored in Esperanza Pit. The maximum relative level (MRL) was set at RL 184 m at 1 November each year, which is 10 m below the RL of 194 m level of the invert of Gunpowder Creek. This was based on application of the precautionary principle and assumes good hydraulic connectivity between Esperanza Pit and Gunpowder Creek between the RL 184 and 194 elevations. Birla presented a case for increasing the MRL stating that there was no evidence of hydraulic connectivity between Esperanza Pit and Gunpowder Creek until RL of about 220 m was reached. Birla felt strongly that untreated water was a potential resource in this highly variable rainfall environment and that by limiting storage volumes to RL 184 m, regulatory agencies were potentially compromising future operations.

Table 2. Water quality discharge criteria

Parameter	Units	Limit	Limit Type
pH		7.0 to 9.0	Range
TDS	mg/L	9,000	Maximum
Sulfate	mg/L	6,000	Maximum
Cu	mg/L	2.5	Maximum
Co	mg/L	5	Maximum
Cr VI	mg/L	0.001	Maximum
Cd	mg/L	0.002	Maximum
As	mg/L	0.25	Maximum
Pb	mg/L	0.05	Maximum
TSS	mg/L	30 mg/L or 10% above background	Maximum
Dissolved oxygen	mg/L	2	Minimum
Oil and grease	mg/L	20	Maximum

4.3 Water Treatment Strategy

Of the various water treatment processes evaluated by Birla, dosing with alkali was considered to be the preferred method to meet the criteria in Table 2, taking into account timeframes for implementation and optimisation, safety to operators and the environment, and suitability of available infrastructure.

4.4.1 Lime dosing

Dosing untreated water with hydrated lime will neutralise acidity, precipitate metals and reduce soluble sulfate concentrations by precipitation as gypsum ($CaSO_4.2H_2O$). Birla had prior experience at Mt Gordon for treating poor quality water using lime dosing. Existing infrastructure included lime storage facilities, a lime slaking plant for preparing hydrated lime slurry ($Ca(OH)_2$) from quicklime (CaO) and a 60 m^3 capacity lime neutralisation tank. As the operation was on care and maintenance, this infrastructure was readily available for use.

It was understood that it is important that the relative amounts of free and metalliferous acidity are known to allow development of an effective neutralisation strategy. Analysis indicated that approximately half of the total acidity was present as hydrogen ion (H^+) acidity and half as metal acidity, dominated by aluminium, iron and manganese.

Dosing with other alkaline materials such as caustic soda, soda ash and magnesium oxide was considered, but was not implemented because of greater costs, reagent storage and handling issues. Laboratory experiments were conducted to determine the minimum time required to neutralise acidity and precipitate metals. Review of results showed that:

- The minimum dosing rate to neutralise the free acidity and remove most of the copper and cobalt was at least 2.5 grams of hydrated lime per litre (Table 3), probably closer to 3.0 grams per litre.
- At the trialled dosing rates, metal removal was effective, but only modest reductions in TDS and sulfate were realised. It would be necessary to increase the pH to 9 to 10 to achieve maximum reduction of TDS and sulfate.
- The reaction was quite rapid, with most of the neutralisation and metal precipitation occurring within one or two hours of contact time.
- Aeration did not appear to be necessary. Slightly higher pH values were achieved, but variable results were achieved in metal removal; in some cases the residual concentrations of soluble metals increased slightly.
- The effectiveness of metal removal is mainly controlled by pH:
  - Iron was reduced to insignificant levels by pH = 5.
  - Aluminium removal was maximised between pH = 6 to 7. Its solubility increased again under more alkaline conditions, although these levels were not problematic.
  - Copper removal was effectively complete by pH = 6.5.
  - Zinc removal was effectively complete by pH = 7.0.
  - Cobalt removal required a higher pH, effectively complete at pH = 7.0 to 7.5.
  - Lime dosing at these rates did not reduce manganese levels below the EIL value of 1.9 mg L^{-1} for freshwater.

In summary the results of the lime trial demonstrated that the best outcome that could be expected from lime dosing was to increase the pH to a value between 7.5 and 8.0. Water quality at this point would be suitable for natural evaporation, mechanical evaporation or irrigation to land. Based on the known acidity values of untreated water, the minimum dosing rate required to achieve this would be approximately 2,500 to 3,000 tonnes of hydrated lime per ML. At this point, sulfate levels would have been reduced by only 15% at pH 7.5, i.e. from 4,200 to 3,600 mg L^{-1}. More significant reductions were expected by increasing the target pH to values between 8.0 and 8.5. It was recognised that this treatment process would produce a significant amount of sludge consisting of gypsum and metal hydroxides.

Consideration was given to using a 60 m^3 capacity lime neutralisation tank, construction of a new HDS treatment system, *in situ* lime dosing of Mill Creek Dam and *in situ* lime dosing of Esperanza Pit. The adopted strategy was a combination of the 60 m^3 capacity lime neutralisation tank and an enhanced *in situ* lime dosing of Mill Creek Dam that utilised a natural feature known as the “Bat Cave” for lime addition and settling of water treatment sludges.

Water in Mill Creek Dam was successfully neutralised in the 2009 dry season, but re-acidified as a result of acidic inflows during the 2009/2010 wet season. It was neutralised again in the 2010 dry season and was maintained at neutrality until February 2011 at which time lime dosing was interrupted as a result of supply issues associated with adverse weather conditions elsewhere in Queensland. The dam contents were neutralised again once supplies resumed some 4 weeks later.

Table 3. Acidity and metal ion concentrations of Mt Gordon wastewater

Parameter	Concentration mg L^{-1}	Hydrated Lime Consumption mg L^{-1} (equivalent to kg ML^{-1})
Total Acidity to pH 8.3	2,400 (as $CaCO_3$)	1,780
Aluminium	110	453
Iron	110	146
Copper	93	108
Cobalt	18	23
Manganese	97	131
Zinc	5.9	6.7

In situ dosing of Esperanza Pit water was not attempted since untreated water is preferable as a resource for mining operations because of the potential for recovery of copper and other metals and problems associated with re use of treated (lime dosed) water because of scaling of pumps and pipes. By treating the 55% of the stored water needed to be removed to comply with the Environmental Authority, the remainder would be significantly more difficult to re-use in future operations. Efficient application of lime to the deep, steep sided pit was also considered problematic.

Over 3 GL of poor quality water was treated between September 2010 and December 2011. Treated water was stored in Mill Creek Dam before either being discharged to Gunpowder creek when suitable conditions were present or being used as part of other water reduction methods.

4.4 Water Volume Reduction Strategy

A considerable risk factor for the operation was the occurrence of another above average wet season. It had been recognised that runoff from upper Esperanza catchment flowing through the Esperanza Waste Dump and into Esperanza Pit was the major contributor to the volume of poor quality water being accumulated on site. In 2009/10, a 320 m diversion channel and a 200 ML dam was constructed upstream of the mining lease to divert clean runoff to Gunpowder Creek upstream of the operations. This has reduced the Esperanza Catchment area reporting to Mt Gordon operations by 68% and thus has significantly reduced the risk of future accumulations of large volumes of poor quality water on the Birla Mt Gordon site.

Options for reducing the volume of stored water were primarily based on discharge of appropriately treated water to Gunpowder Creek, passive and enhanced evaporation and beneficial re-use options such as substitution for raw water in the process plant, dust suppression and land irrigation.

An Ecological Risk Assessment (ERA) was undertaken to understand the likely impacts of releases of varying qualities and volumes of water to Gunpowder Creek. ERA is a set of formal, scientific methods used for defining and estimating the probabilities and magnitudes of adverse impacts on plants, animals and/or whole ecosystems posed by a particular stressor. The ERA process identifies the ecological receptors of concern, estimates the concentration that the ecological receptors are exposed to and, based on the magnitude of this concentration and determines whether the ecological receptors and values are at risk.

ERA is a tool advocated for use by the National Environmental Protection Council and in Chapter 3 of the ANZECC 2000 Water quality Guidelines, but in practice has been little used in Australia by the mining industry. Regulatory authorities have historically preferred to use conservative approaches applying ANZECC water quality guidelines as strict criteria. This approach was taken by DEHP with the outcomes of the ERA used by Birla to help inform decision making, but not accepted by DEHP.

4.4.1 Controlled discharge

Controlled discharge of treated water to Gunpowder Creek was considered the preferred option in terms of cost, available infrastructure and acceptable level of risk to the receiving environment.

It was recognised, however, that this option was highly dependent on flows in Gunpowder Creek, which were known to be highly variable in terms of volume and duration. Options for early wet season discharge of small volumes of treated water to Gunpowder Creek and discharge of treated water to Lake Waggaboonya were rejected by DEHP. Reasons centred on concerns regarding sulfate concentrations exceeding ANZECC livestock drinking water standards.

Controlled discharge options were thus restricted to discharge during flow events in Gunpowder Creek where treated water quality met strict quality criteria and discharge volume was tied to flow conditions.

Volumes of treated water discharged to Gunpowder Creek are shown in Table 4. Controlled discharge of 3,260 ML has occurred from 2009 to date. Drought conditions experienced in the 2012/13 wet season resulted in very little water being able to be discharged.

Table 4. Controlled Discharge Volumes 2009-2013

Wet Season	Discharge Volume (ML)
2008/09	0
2009/10	97
2010/11	1,097
2011/12	1,903
2012/13	163

4.4.2 Evaporation

A trial was established in 2009/10 to assess the effectiveness of high capacity evaporators for water reduction. Although the nominal capacity of the evaporators was 2 ML day^{-1}, results from the trial indicated much lower evaporation rates which were attributed to low evaporation efficiencies and extended downtime required for maintenance of the pumps of pipes due to scaling, especially when treated water was used.

In the negotiation process with DEHP, Birla agreed to install and operate nine high capacity evaporation units. These operated year round using predominantly untreated water from Esperanza Pit to overcome high maintenance requirements associated with use of treated water. The average dry season reduction potential was estimated to be approximately 380 ML. Total actual evaporation from the high capacity evaporators for 2011 was about 560 ML.

Other passive evaporation processes implemented were application of treated water to the Esperanza TSF during periods when the operations were on care and maintenance, use of treated water for dust suppression, construction of a low pressure land irrigation sprinkler system on the banks of Mill Creek Dam and construction of lined evaporation ponds at North Rock Dump (between Esperanza Pit and Esperanza TSF) and on a decommissioned Heap Leach Pad.

4.5 Water Re-use

Substitution of untreated and treated water in the ore processing plant were investigated and implemented when mining and ore processing operations resumed in late 2009 and then again in 2010. This improved the overall site water balance and assisted with water reduction. Use of this option was limited to when the project was operational.

A dry season land irrigation system was trialled to investigate use of treated water for pasture irrigation on Calton Hills Station. The results indicated application of treated water had not resulted in build-up of soil contaminants and warranted further investigation if ongoing needs for water reduction existed.

4.7 Current Situation

At the end of the 2013 dry season, Esperanza Pit contained about 4.3 GL of poor quality water and Mill Creek Dam contained about 600 ML of treated water suitable for discharge to the environment if water flows in Gunpowder Creek occur.

Water treatment activities have largely been suspended until water currently stored in Mill Creek Dam can be discharged. Use of high capacity evaporators is continuing and is anticipated to result in further reductions in stored water volumes in Esperanza Pit.
The wet season forecast indicates the Mt Isa region is likely to experience a below average wet season for 2013/14 and thus the opportunities for controlled discharge are likely to be very low. Discharge infrastructure is maintained ready for use in accordance with DEHP Court order requirements.

5.0 CONCLUSIONS

Within a six week period in January and February 2009, water management at the Birla Mt Gordon operation changed from one of facing extreme measures for procurement of sufficient water to maintain production to one of narrowly avoiding discharge of poor quality mine water to the environment, as was experienced at eight other mine sites in the Mt Isa region. The challenges for reducing the volume of stored poor quality water to reduce risk of overflow in following wet seasons was compounded by the mine being placed on a care and maintenance basis following these floods and a legacy of AMD issues arising from a mining history of more than 80 years.

A regulatory framework for treating and discharging excess water was established following a negotiated settlement between Birla and DEHP. Birla's position was that the process should be managed in a staged approach with the primary objective to be avoidance of the risk of overtopping in subsequent wet seasons in a cost-effective manner. It argued that some of the excess water should be considered an asset rather than a liability and offered a means of "drought proofing" the project during expected periods of below average rainfall. Ecological risk assessment was adopted to provide an improved understanding of potential impacts of uncontrolled discharge, which were found to be less severe than first anticipated. Being primarily responsible for the receiving environment, DEHP advocated stringent conditions for treated water quality and discharge volumes, and considered stored poor quality mine water as an environmental liability.

A program based on water treatment with lime dosing to neutralise acidity and reduce concentrations of sulfate and metals (soluble and particulate) to levels that have been shown to present minimal risk to key receptors in Gunpowder Creek was negotiated and successfully implemented at Mt Gordon. Water reduction has been achieved by a combination of high capacity evaporators (about 1.1GL to date), low tech passive evaporation systems and controlled discharge of treated water to Gunpowder Creek during subsequent wet seasons (3.2 GL).

Over a four year period and a cost of approximately $20 million, water volumes have been reduced to a point where there is more than sufficient capacity to store wet season runoff from a 1 in 100 year three month ARI wet season event in Esperanza Pit without using other onsite storages. Although the volume of remaining water currently exceeds limits stipulated in the current site Environmental Authority, it is regarded by Birla as a substantial asset to mine operations in a drought-prone environment. A case is currently being assessed by DEHP for what Birla considers a more appropriate MRL for water storage that considers both liability of excess water storage against the benefits of re-use of mine water.

The risk of the operation accumulating such a large volume of poor quality runoff in the future has also been substantially reduced through construction of a number of upstream diversions to prevent water from contacting oxidised waste rock and ongoing works to reduce the production of contaminated water from historic infrastructure.

6.0 REFERENCES

Australian Centre for Tropical Freshwater Research. 2003. Mt Gordon Mine Dry Season Limnological Survey. Unpublished report for Western Metals Copper.

Australian Institute of Mining and Metallurgy (AIMM). 1998. Geology of Australian and Papua New Guinean Mineral Deposits. Monograph 22 pp. 743-752.