Appendix CC

Cyanide utilization at the McPhillamys Gold Project

MCPHILLAMYS GOLD PROJECT

CYANIDE UTILISATION AT THE MCPHILLAMYS GOLD PROJECT

JUNE 2019

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 EXECUTIVE SUMMARY

A review of the alternative options to the use of cyanide for the recovery of gold at the McPhillamys gold project was completed. Alternative lixiviants such as chlorine and thiosulphate were assessed along with metallurgical testwork to review flotation process options, which would produce a sulphide or copper concentrate.

Table 1-1 details the results of a high-level review into the impact of different key variables on the selection of the gold recovery method for the McPhillamys Gold Project. A colour coding system has been employed to define the impact of each variable. Green indicates the best result, black moderate and red the worst result.

Table 1-1 McPhillamys Gold Recovery Method Conceptional Analysis

Variables	Cyanide Leaching	Alternative Lixiviant	Flotation
Capital Cost	Low	High	Med
Operating Cost	Low	High	Med
System Complexity	Low	High	Med
Reagent – Safety	High	Med	High
Up-Scale - large tonnes/low grade	High	Low	High

Cyanide leaching was selected as the optimal gold recovery method for the McPhillamys Project due to the following:

- It is a proven technology, especially for low grade gold deposits and is utilised to process gold bearing ores throughout the world and at several gold mines within NSW;
- Flotation testwork did not provide a saleable concentrate. The rougher concentrate produced during laboratory testwork did not;
    - Contain enough gold (>40 g/t Au) to enable the production of a sulphide concentrate.
    - Contain enough copper (>14% Cu) to enable the production of a copper concentrate.
    - Reject enough mass (<10%) to make the process economical. Cadia's final concentrate mass is 0.7% while Mt Carltons final concentrate mass is 6.8%.
- Alternative lixiviants such as thiosulphate have only been trialled on small scale applications with specific ore characteristics and as yet, have not been applied to or proven in processing large scale, low grade gold deposits where the entire ore stream is to be leached.

2.0 INTRODUCTION

Currently within the gold mining industry, cyanide (CN) is the major lixiviant utilised for the economic recovery of gold from complex ore bodies and has been utilised for over 100 years. Approximately 1.1 million tonnes of cyanide is produced annually worldwide, with 6% utilised for mining. The other 94% is utilised in industrial applications, such as the production of nylon, plastics, adhesives, fire retardants, cosmetics and as an anti-caking agent in salt. Figure 2-1 depicts the annual cyanide consumption breakdown.

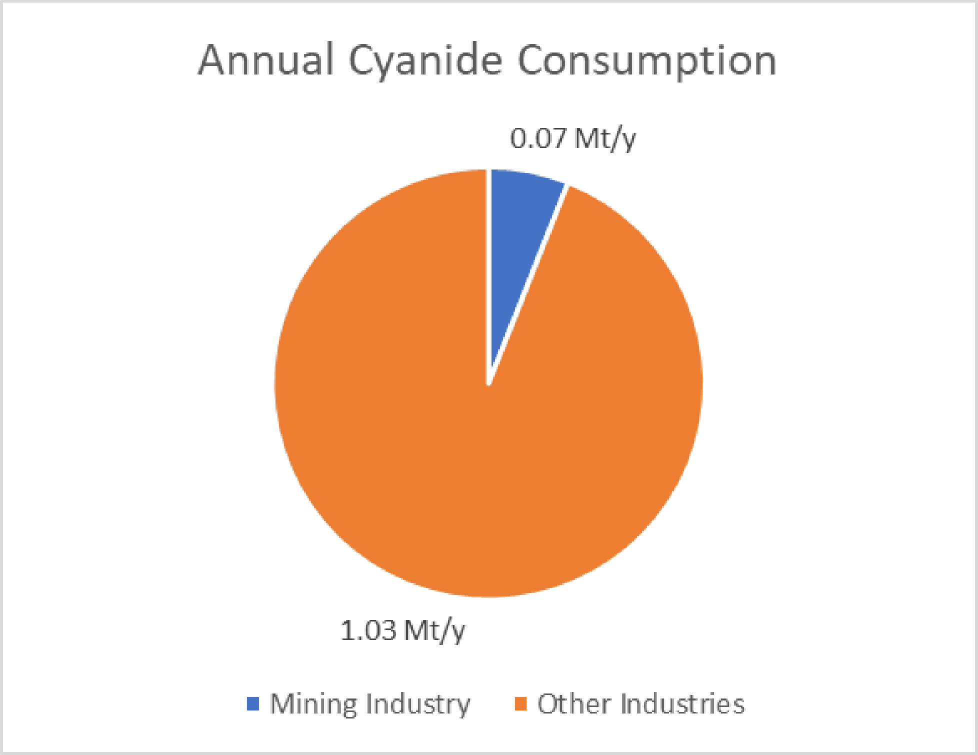

Figure 2-1 Hydrogen Cyanide Use - Globally[1]

Cyanide, under typical leaching conditions is reactive and has an affinity for gold which means that gold is preferentially leached first before the cyanide then complexes with other metals such as copper, silver, zinc and iron. The metal cyanide complexes formed during the leaching process are quite stable and low levels of cyanide (200 – 500 ppm) are required. Gold is leached using cyanide via the following reaction:

$$4Au + 8NaCN + O_2 + 2H_2O \rightarrow 4Na[Au(CN)_2] + 4NaOH$$

---

[1] Information sourced from https://www.cyanidecode.org/about-cyanide-code/faq

Cyanide can be manufactured, stored, transported, utilised and disposed of in a safe manner. It occurs naturally, with over 3,000 species of plants[2] known to synthesize cyanogenic compounds (i.e. cassava, lima beans and almonds). It is not toxic in all forms or concentrations and does not persist/accumulate in the environment.

Cyanide readily attenuates (decomposes) via the following process:

- Volatilisation, with the cyanide complexes reacting with water when the pH is below 9.0 to form HCN;
- Saponification, where HCN reacts via hydrolysis to produce ammonium formate, via the following reaction

$$HCN + 2H_2O \rightarrow NH_4COOH \; ;$$

- Thiocyanate formation, where cyanide reacts with sulphur to form thiocyanate, via the following reaction

$$S_2O_3^{2-} + CN^- \rightarrow SO_3^{2-} + SCN^- \; ;$$

- Base metal complexation, where the cyanide reacts with certain base metals to form a cyanide metal complex. The main cyanide metal complexes are formed with zinc (Zn), copper (Cu) and iron (Fe). The base metal (M) complexation reaction is as follows, with Fe forming the most stable complexes and Zn the least stable

$$M^{2+} + 4CN^- \rightarrow M(CN)_4^{2-} \; ;$$

- Biodegradation, where the carbon (C) and nitrogen (N) that form cyanide are converted via the interaction of microorganisms to carbonate (CO_3^{2-}) and ammonia (NH_3).

---

[2] Cyanide action in plants – from toxic to regulatory – Irena Siegien

3.0 ALTERNATIVE LIXIVIANTS

Current alternative lixiviants that have been utilised in small scale commercial processing of gold bearing ores are detailed below:

- mercury
- chlorine
- thiosulphate
- glycine

3.1 Mercury

Mercury is utilised to recover free gold, typically associated with alluvial deposits, though this process is typically limited to laboratories or itinerant miners, as shown in Figure 3-1

Figure 3-1 Gold Recovery Using Mercury by Illegal Gold Miners[3]

Mercury is not considered to be a commercially viable option due to safety and environmental issues associated with its use.

---

[3] Image sourced from Amazon Aid Foundation Website: https://amazonaid.org/treatment-needed-mercury-poisoning/

3.2 Chlorination

Chlorination was utilised commercially in the 1800's. The gold is dissolved in an aqueous chloride solution at pH 3. The use of chlorination commercially ceased in the late 1800's with the advent of cyanidation, but it is still utilised for the pre-treatment of carbonaceous ore at Newmont's Carlin and Jerritt Canyon mines (Nevada), though the process still utilises cyanide for final gold recovery. An atmospheric leaching process at pH 7 was developed in the 1980's to process gold ores containing cyanide soluble copper, but the high reagent consumptions stopped commercialisation. The recovery of gold from the gold/chlorine solutions is also an issue. Aluminium dust has been used but the purity of the gold is low and requires expensive refining procedures.

A chlorination vat leaching process has been developed by Dundee Substantiable Technologies called the CLEVR Process™. The CLEVR process utilises sodium hypochlorite (NaClO) with sodium hypobromite (NaBrO) as a catalyst, in acidic conditions to leach the gold from sulphide ores. The gold bearing pregnant solution is recovered from the leached slurry via a solid/liquid separation stage before the gold is recovered via deposition onto silica. The gold laden silica is recovered from the now barren solution and then direct smelted to produce a gold dore. An example of the proposed flow sheet is detailed in Figure 3-2. A small scale 15 t/d demonstration plant has been developed in Canada, but the process is not commercially available at this point. The complexity of the process is less viable for whole of ore processing, instead being more suitable for the processing of smaller scale flotation concentrates, where the gold grade has been upgraded and the overall mass of ore requiring treatment has been reduced.

Figure 3-2 CLEVR Process™ Gold Extraction Process[4]

The chlorination processing option is not suitable for the McPhillamys ore due to the following:

- Safety and environmental issues associated with using chlorine.
- The ore cannot be concentrated to produce a high grade, low mass concentrate to minimise the size of the process.
- A commercial option for a low-grade whole of ore chlorination leach has not been commercially proven at the McPhillamys throughput rate.

3.3 Thiosulphate

Thiosulphate has recently been utilised for gold recovery in Australia, in the form of a small scale vat leach pilot plant by CSIRO in Western Australia. Sodium thiosulphate readily dissolves gold but requires the use of an oxidant, such as copper or iron and an oxidant stabiliser such as ammonia to achieve an acceptable rate of gold dissolution, while minimising the rate of thiosulphate oxidation. The chemistry is highly complex and variations may result in the passivation of gold particles and lower gold recovery.

Once the gold is dissolved, ion exchange (IX) resins are utilised to recover the leached gold. IX resins are synthetic materials that consist of an inert matrix and are prepared using a solvent diluent to produce a porous structure. Typically, resins are not as mechanically strong as activated carbon

---

[4] Image sourced from Dundee Technologies web site: http://dundeetechnologies.com/clevr-process

(currently utilised with cyanide leaching) and therefore the consumption rates are quite high. In most cases a solid/liquid separation stage is required so the resins are not in contact with a slurry. Resins are also expensive, when compared to activated carbon, have a smaller particle size requiring more specialised screening and a more complex elution process to recover the gold of the resin.

CSIRO are in the process of developing a small mobile facility, the aim of which is to process small high-grade gold deposits. Currently their system has been trialled at Eco Minerals, Menzies project, where the process involved vat leaching of tailings, which had been previously processed in the early part of the last century. Key findings are:

- Thiosulfate consumption (kg/t) is typically proportional to the gold leach rate.
- The CSIRO process as shown in Figure 3-3, is based on treating small high-grade deposits where good gold liberation can been achieved at a coarse grind size. The coarse grind size is necessary as relatively high percolation rates are required for successful vat leaching;
- The process requires a solid separation stage before adsorption of leached gold onto IX resins.

Figure 3-3 CSIRO Thiosulphate Test Plant

CSIRO indicated that they have plans for an agitated leach circuit, but as yet, nothing has been constructed or commercially tested.

In addition to the CSIRO pilot plant at Menzies, Western Australia, the Barrick Goldstrike operation in Nevada USA, utilises calcium thiosulphate to leach gold after the ore has been processed via a pressure oxidation circuit. The leached gold is recovered onto resin, with the resin then subjected to a copper elution stage and then a gold elution stage. The gold pregnant solution from the elution stage is then electrowon before being smelted to produce gold dore.

The gold is leached using thiosulphate via the following reaction:

$$4Au(s) + 8S_2O_3^{2-}(aq) + O_2(g) + 2H_2O \rightarrow 4Au(S_2O_3)_2^{3-}(aq) + 4OH^-(aq)$$

The Goldstrike operation processes a high-grade gold ore (3.3 g/t Au) that was amenable to the use of thiosulphate as a gold lixiviant due to high concentrations of preg-robbing carbonaceous material and significant concentrations of arsenic (As) associated with the ore.

The thiosulphate processing option is not suitable for the processing of the McPhillamys ore due to the following:

- There is no major preg-robbing components associated with the McPhillamys ore.
- The ore cannot be concentrated to produce a high grade, low mass flotation concentrate.
- A commercial option for a low-grade whole of ore thiosulphate leach has not yet been commercially proven at throughput rates equivalent to McPhillamys, without any pre-treatments, such as pressure oxidation.

3.4 Glycine

The GlyCat™ process has been developed to process gold ores than contain high concentrations of cyanide soluble copper. The process utilises a small amount of a glycine dominant lixiviant, in conjunction with cyanide to leach the gold bearing ore. The cyanide soluble copper preferentially bonds to glycine instead of cyanide freeing the cyanide to leach the gold. The reaction of the copper with the glycine forms cupric glycinate which is an effective oxidant for gold and replaces the need for oxygen addition. Publications reference a decrease in overall cyanide consumption from 8 kg/t to 1 kg/t. Typical consumption rates for cyanide in whole of ore CIL processing circuits are less than 1 kg/t.

The Glycine process option is not amenable to the McPhillamys ore as the cyanide soluble copper levels are not high enough to justify the process.

4.0 FLOTATION

4.1 Background

An alternative processing flowsheet that does not use cyanide, but is dependent on the mineralogy of the ore, is the production of a flotation concentrate that can then be transported from site by pipeline, trucks and /or rail to a port and then sold directly to a smelter (normally overseas).

Typically, a sulphide concentrate with low copper grades requires a minimum gold grade of around 40 g/t Au, to make it a saleable concentrate. Where the gold grade of the sulphide concentrate is lower than this, then the copper grade would normally need to be greater than 14% Cu, with no deleterious elements, such as arsenic, bismuth, etc, to make it a saleable copper concentrate.

An example of this is the Cadia Valley Operations (Cadia) process plant in New South Wales, where the mineralogy of the ore has the vast majority of gold associated with copper sulphide (chalcopyrite), which is readily floatable. That is, the material that can be recovered using flotation contains most of the gold that is in the ore. Cadia produces a sulphide concentrate via a rougher/scavenger/cleaner circuit configuration, with the following design final concentrate specification:

- Au = 68 g/t
- Cu = 22%
- Mass Pull = 0.70%

Another example of a process plant that utilises flotation to produce a sulphide concentrate is the Evolution Mining Mount Carlton (Mt Carlton) operation in Queensland. Mt Carlton produces a sulphide concentrate via a rougher/scavenger/cleaner circuit configuration, with the following design final concentrate specification:

- Au = 40 g/t
- Cu = 6%
- Mass Pull = 6.8%

The mineralogy of the Cadia and Mt Carlton deposits, although significantly differently in the type of sulphides they each contain, have the common attribute that the gold is predominantly associated with sulphide minerals in the respective ores.

In Cadia's case, the gold is generally associated with chalcopyrite ($CuFeS_2$), a sulphide which can be recovered using flotation into a sulphide concentrate. In Mt Carltons case, the gold is generally associated with, pyrite (FeS_2), enargite ($Cu_3(As,Sb)S_4$) and tennantite ($(Cu,Fe,Zn)_{12}(As,Sb)_4S_{13}$), refractory sulphides that can also be recovered using flotation into a sulphide concentrate.

If in Cadia's case the ore was processed using direct cyanidation, then the levels of copper in the ore would lead to excessively high cyanide consumption and / or difficulty in preferentially adsorbing the gold species onto the activated carbon granules in the leach tanks. In Mt Carlton's case, if the ore was processed using cyanidation, then the refractory nature of the gold would mean that the cyanide would not directly dissolve the gold without other prohibitively expensive pre-treatment options.

The other benefit in producing a sulphide concentrate via flotation is that mass of material that contains the precious or saleable metals, such as gold and copper, is greatly reduced, typically to less than 10% of the original mass. Further stages of flotation are undertaken to further reduce the final concentrate mass and increase the grade of the gold/copper to saleable levels.

4.2 McPhillamys Flotation Testwork – Newmont (2010)

In 2010, Newmont undertook flotation testwork on three composite ore samples from the McPhillamys deposit.

Phase one of the flotation testwork program included a stage of gravity recoverable gold followed by a stage of flotation testing to produce a copper sulphide concentrate with gold credits. Phase two of the testwork program involved subjecting the copper flotation tails from Phase one to a bulk sulphide flotation stage with the aim of recovering any residual gold. The results from the Newmont flotation tests are detailed in Table 4-1.

Table 4-1 Newmont McPhillamys Flotation Testwork

Sample	**Head Grades**		**Testwork**	**Mass Cum %**	**Au g/t**	**Au dist %**	**Cu %**	**Cu dist %**
	Au (g/t)	**Cu (g/t)**						
D0002 (295-366)	1.93	1,010	Gravity	0.03	8,343	67.77		
			Cu Float	1.65	47.2	21.01	6.01	88.80
			Sulphide Float	20.15	1.96	10.63	0.035	6.30
			Total	**21.83**	**16.91**	**99.41**	**0.487**	**95.11**
D0004 (178-189)	6.68	2,140	Gravity	0.02	722	1.60		
			Cu Float	1.36	327	65.56	14.8	94.77
			Sulphide Float	23.36	6.77	23.40	0.028	3.09
			Total	**24.73**	**24.75**	**90.56**	**0.837**	**97.87**
D0004 (164-178)	1.76	560	Gravity	0.02	217	1.87		
			Cu Float	1.88	35.6	36.86	3.28	86.30
			Sulphide Float	17.32	4.39	41.78	0.024	5.80
			Total	**19.22**	**7.62**	**80.51**	**0.343**	**92.10**

Observations from the results from the Newmont flotation testwork program were:

- The grade of the ore samples tested was not representative of the overall grade of the McPhillamys resource, with the head grades of the composite samples higher than what would be expected to be mined. The gold resource grade for McPhillamys is 1.05 g/t Au while the copper resource grade is 50 g/t Cu (0.005% Cu).
- Mineralogical examination indicated that the primary sulphide present was pyrite. No chalcopyrite ($CuFeS_2$) was detected, which may limit the ability to upgrade a copper concentrate to produce a saleable product.
- Gravity recovery for sample D0002 (295-366) was very high, recovering 68% of the total gold. This level of gravity recovery has not been observed in other samples tested.
- To maximise the gold recovery in the sulphide concentrates from the McPhillamys samples, a mass pull of around 20% is required, which in turn provides a low gold grade. Gold recovery/grade in the combined concentrate for sample D0004 (164-178) was low, and it is not expected that this sample would produce a saleable sulphide concentrate (>40 g/t Au conc grade) at an economic gold recovery.

4.3 McPhillamys Flotation Testwork - Regis

Ore samples from throughout the McPhillamys deposit were subjected to flotation testwork. Five McPhillamys composite ore samples, as shown in Figure 4-1, each representing a two-yearly mining period were subjected to laboratory rougher flotation tests.

The rougher flotation testwork mass and assay results are detailed in

Table 4-2, while the gold grade/recovery curves are detailed in Figure 4-2 and the copper grade/recovery curves in Figure 4-3.

The results indicate that the neither the gold grade (4.07 – 6.38 g/t Au) or the copper grade (0.27 – 0.46% Cu) of the sulphide concentrate are high enough to produce a saleable concentrate (sulphide or copper) for any of the five McPhillamys composite samples.

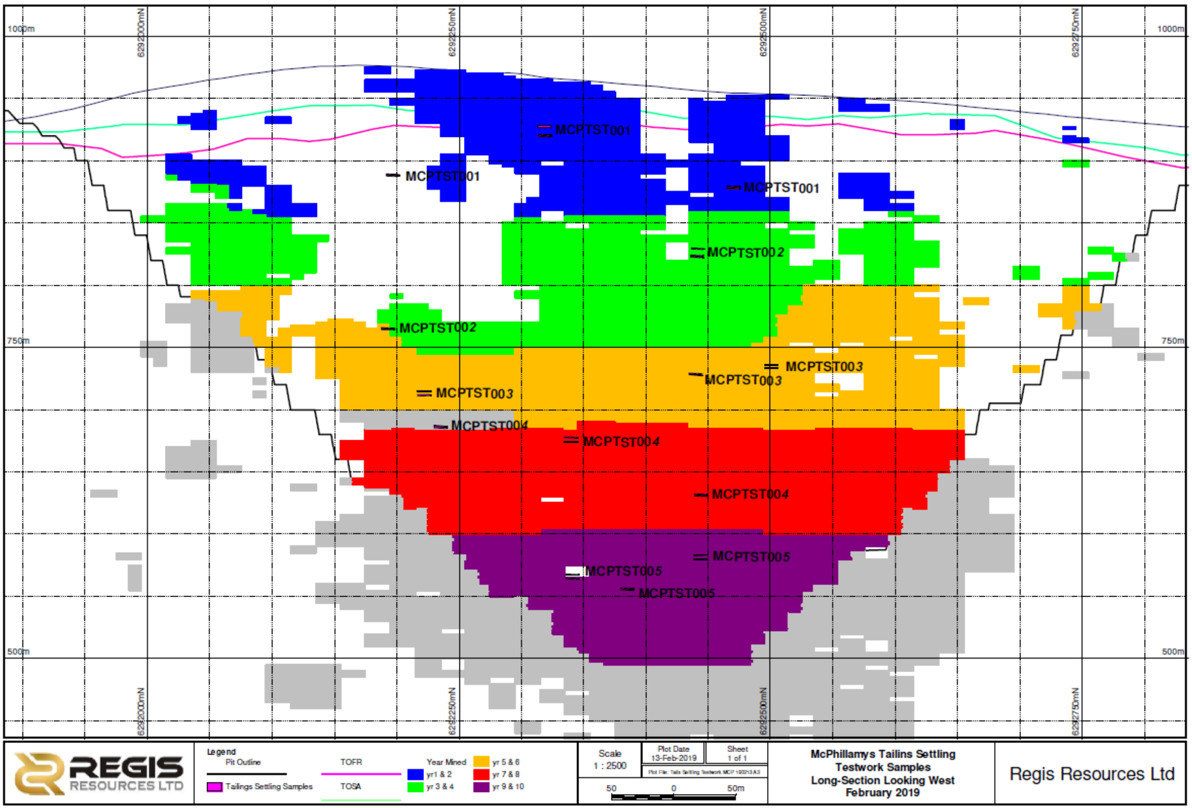

Figure 4-1 McPhillamys Gold Project Two Yearly Composite Samples

Table 4-2 McPhillamys Flotation Rougher Testwork with Cadia & Mt Carlton Results

Sample	Mining Period	Mass Cum %	Au g/t	Au dist %	Cu g/t	Cu dist %
MCPTST001	1-2	20.65	5.67	92.77	3,164	93.74
MCPTST002	3-4	17.48	4.07	96.63	3,877	94.59
MCPTST003	5-6	20.48	4.88	95.81	2,658	94.61
MCPTST004	7-8	19.77	6.38	96.03	3,872	96.17
MCPTST005	9-10	19.32	4.37	98.13	4,610	95.83
Average		**19.54**	**5.07**	**95.87**	**3,636**	**94.99**
Cadia	Rougher	3.10	17.00	72.00	45,000	93.00
Cadia	Final	0.70	68.00	69.00	220,000	90.00
Mt Carlton	Rougher	9.60	33.10	93.30	44,000	93.30
Mt Carlton	Final-	6.80	45.90	91.60	63,000	95.30

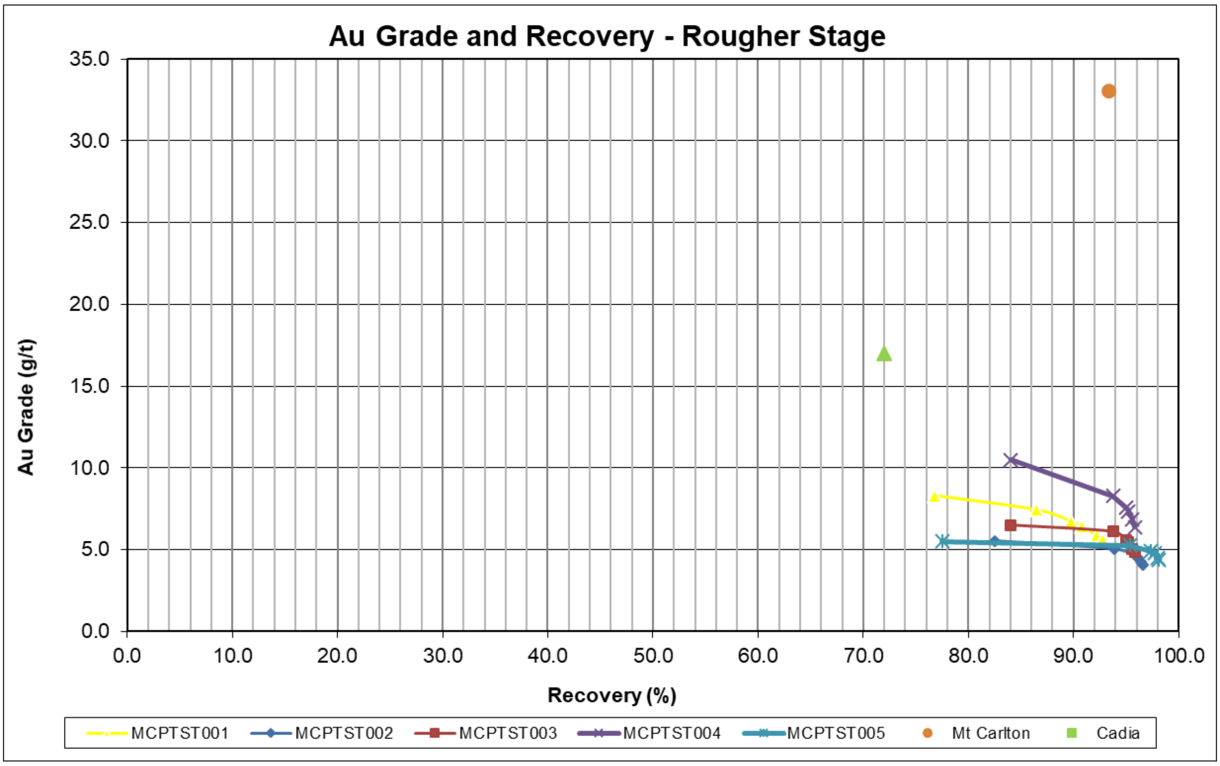

Figure 4-2 McPhillamys Gold Rougher Grade/Recovery Curve

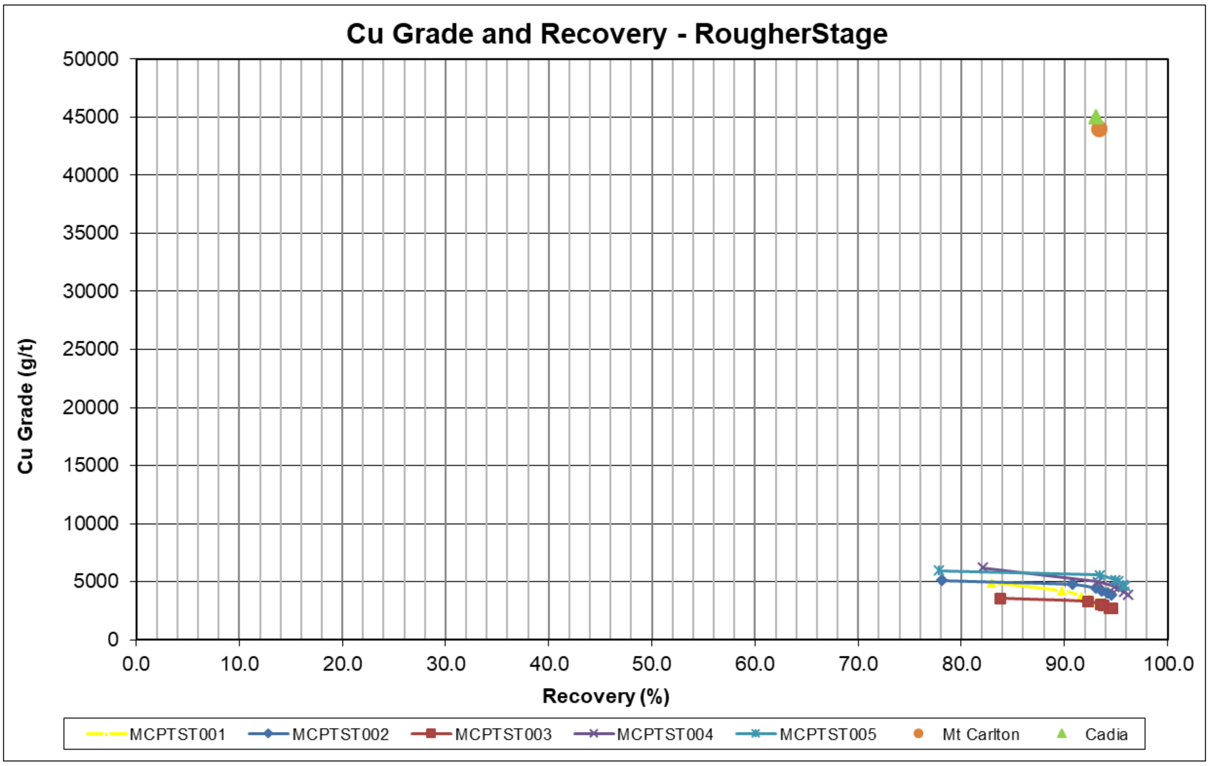

Figure 4-3 McPhillamys Copper Rougher Grade/Recovery Curve

Figure 4-4 compares the McPhillamys rougher flotation testwork mass pulls with those of Cadia and Mt Carlton.

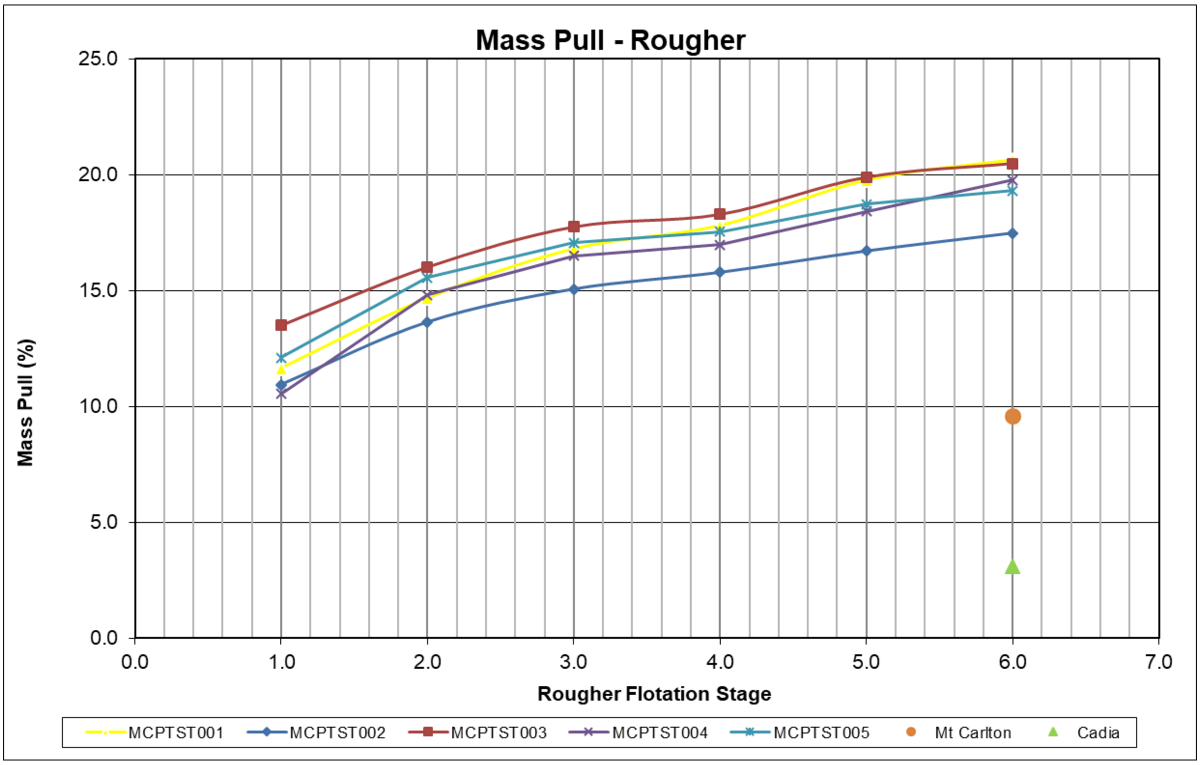

Figure 4-4 Rougher Flotation Stage Mass Pull

5.0 SUMMARY

The Table 5-1 below is a high-level review of the impact of different key variables on the selection of the desired gold recovery method for the McPhillamys Gold Project. A colour coding system has been employed to define the impact of each variable. Green indicates the best result, black moderate and red the worst result.

Table 5-1 McPhillamys Gold Recovery Method Conceptional Analysis

Variables	Cyanide Leaching	Alternative Lixiviant	Flotation
Capital Cost	Low	High	Med
Operating Cost	Low	High	Med
System Complexity	Low	High	Med
Reagent – Safety	High	Med	High
Up-Scale - large tonnes/low grade	High	Low	High

Cyanide leaching was selected as the optimal gold recovery method for the McPhillamys Project because:

- It is a proven technology, especially for low grade gold deposits and is utilised to process gold bearing ores worldwide and at several gold mines within NSW.
- Flotation testwork did not provide a saleable concentrate. The rougher concentrate produced during laboratory testwork did not:
  - Contain enough gold (>40 g/t Au) to enable the production of a sulphide concentrate.
  - Contain enough copper (>14% Cu) to enable to the production of a copper concentrate.
  - Reject enough mass (<10%) to make the process economical. Cadia's final concentrate mass is 0.7% while Mt Carltons final concentrate mass is 6.8%.
- Alternative lixiviants such as thiosulphate have not been proven in large scale, low grade gold deposits where the entire ore stream is to be leached.