Bendigo Recovering Groundwater Levels

DEPARTMENT OF ENVIRONMENT, LAND, WATER AND PLANNING

Pre-feasibility assessment of interim and longer-term options to manage mine void water

VW07617.005 | 1

Final

6 January 2015

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Project no:	VW07617
Document title:	Pre-feasibility assessment of interim and longer-term options to manage mine void water
Document no:	VW07617.005
Revision:	1
Date:	6 January 2015
Client name:	Department of Environment, Land, Water and Planning
Client no:	494255
Project manager:	Nicola Logan
Author:	Nicola Logan
File name:	C:\Users\NLogan\Documents\0_Projects\VW07617_Bendigo water management\Deliverables\4_Combined reports\Final\VW07617_Bendigo_Mine_Water_Management_combined_report - Final.docx

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Document history and status

Revision	Date	Description	By	Review	Approved
0	20/11/2014	Draft for client review	N. Logan	C.Clifton	C.Clifton
1	06/01/2015	Final for release	N. Logan	C.Clifton	C.Clifton

Contents

Executive Summary

Context

There is a long history of gold mining in the Bendigo region, with mining activities occurring over two main periods. Gold mining began as part of the 1850s' Victorian gold rush and continued uninterrupted until 1954, with the closure of the Central Deborah Mine. Mining restarted in the mid-1980s and continued until 2011. Much of this mining activity has been underground, with the mine workings dewatered to allow safe access to gold reefs.

Historic mining activities have created an extensive network of interconnected mine voids below Bendigo. In the absence of mining activities and the associated dewatering, these voids are filled by groundwater draining through rock fractures and historical workings. Once water levels reach the surface, water from the mining voids naturally discharges to the environment.

Mining and dewatering activities in the Bendigo goldfields from the 1980s led to water levels in the mine workings dropping and mine water ceasing to discharge to the environment. Since active mining and dewatering ceased in 2011, water levels within the historical mine voids have recovered and are rising towards their previous levels. Without intervention, uncontrolled discharge of mine water to the environmental appears to be imminent.

Water levels in parts of the historic workings are currently managed by the Bendigo Trust. This is required to maintain access to lower levels of the Central Deborah Tourist Mine. Approximately 1.5 ML/d of mine water is pumped from the Central Deborah Shaft and discharged into the adjacent, but disconnected, Londonderry Shaft (part of the Garden Gully Reef workings). It is expected that by about March 2015, water levels within the Garden Gully Reef will reach a level resulting in uncontrolled discharge of mine water to the environment. Discharge is expected to occur at several locations around Bendigo, including along Bendigo Creek, at Sydney Flat and at Myers Flat.

The anticipated discharge will comprise naturally-occurring groundwater, whose quality is not materially affected by its passage through the historic mine workings. However, the natural composition of mine water and its odour are likely to be of concern to the community and environmental management agencies.

In summary, the recovering water levels are cause for concern on several fronts, including that if they were left uncontrolled:

- Mine water will inundate sections of the Central Deborah tourist mine, diminish its value as a tourist attraction and the value it provides to the Bendigo Trust and wider Bendigo economy;
- Mine water levels will rise back to historic or pre-recent mining levels, with the potential to discharge to local waterways. Salt and other constituents within the discharging mine water may diminish water quality and soil and river health values and the odour of discharging mine water may detract from the amenity of these locations;
- Elevated water tables may activate urban salinity issues in Bendigo and damage roads, footpaths, buildings or other infrastructure in affected areas.

To avoid these impacts, mine water must be removed from the historic mine workings and, preferably, used for some productive outcome. Assuming that dewatering for mining operations has permanently ceased, approximately 2 ML/d of mine water must be removed from the historic workings for the foreseeable future.

The suitability of mine water for treatment and use

There are three, main conceptual end "uses" for the water contained in historical mine workings below Bendigo, namely:

- Discharge to holding ponds for evaporation;

- Discharge to the environment via a local waterway, either as an environmental flows or for downstream extraction for irrigation;
- Direct discharge to land as irrigation water.

Constituents of concern in the mine water include arsenic and hydrogen sulfide. Compared with waters typically flowing in surface waterways in the Bendigo area, the mine water is also brackish, has elevated concentrations of iron, manganese and some heavy metals (e.g. nickel, chromium, zinc and lead have all have been detected at trace concentrations). All of these constituents require treatment in order to reduce their concentrations to levels that would allow the water to be discharge to the environment or used for other purposes.

Various treatment technologies were assessed for their capacity to produce a final water quality that would be suitable to the three end "uses" listed above. While each constituent of concern could be treated individually by various treatment technologies, the combination of constituents present in the mine water narrows the range of applicable treatments.

A review of mine water quality data and water treatment options indicates that Reverse Osmosis (RO) with a pre-treatment process is the most effective water quality treatment option. RO is a well understood and proven technology, with a high reliability of operation.

There are also two alternative treatment technologies which may produce water of suitable quality for discharge to the environment; constructed wetlands and permeable reactive barriers. These options look promising but are not as well established in Australia and there is some uncertainty as to their performance in this situation, particularly with regards to the long-term management of accumulated salts. As these options could significantly reduce the ongoing costs associated with water treatment, they should be investigated further.

Short term mine water management options

Water levels within the Garden Gully Reef are expected to recover to a level which will lead to uncontrolled discharge of mine water to the environment by about March 2015. If this is to be avoided, management options are required which can be implemented almost immediately. Such options may only be interim measures and do not necessarily need to be part of any long-term, sustainable mine water management "solution".

An assessment has been made of a range of short term options to dispose of waters from the Central Deborah Mine and Garden Gully Line Reef, with or without treatment. Due to the timeframe available for implementation, these options primarily rely on existing infrastructure, although options have been considered that require some new infrastructure (but which can be developed within 12 months).

The short term options are expected to operate while longer-term responses are developed. Long term options are expected to be implementable within 2-4 years and remain in place indefinitely.

Consultation undertaken as part of the review of mine water management options highlighted two important points, namely that:

- There is currently an excess of water supply over demand in the Bendigo region and hence no available productive use for mine water, whatever its quality;
- The key infrastructure available to manage mine water in the short term are Unity Mining's Woodvale Ponds facility and New Moon Water Treatment Plant. Other facilities in the region either lack the capacity to manage the volume required, are not configured to treat the expected water quality, or are still in the concept stage of planning.

The analysis of short term mine water management options identified only two feasible alternatives (to uncontrolled discharge to the environment) that could be implemented in a timely manner and were consistent with the reported water quality and current lack of demand for additional water in Bendigo. These options involved either disposal of untreated water to an evaporation or holding facility, or RO treatment of the water for a beneficial use, with disposal of the concentrate or brine from the RO plant to the evaporation or holding facility.

While it is the only existing evaporation or holding facility in the region with the capacity to accept the volume and quality of either untreated mine water or brine from RO treatment, the Woodvale Ponds facility is currently planned for rehabilitation as part of Unity Mining's mine closure plan. Changes to the rehabilitation planning would be required to allow the short term water management options to proceed.

Several variants of the two short-term water management options are available (Table E-1). Of the five options considered, Option 1a (untreated discharge to Woodvale at a constant daily rate) has the lowest capital and ongoing operating cost. However, Option 2a (untreated discharge to Woodvale over summer and treated discharge to environment in winter) is considered to provide the highest level of flexibility and responsiveness to operational requirements.

Regulatory requirements vary between options, depending on which agency is responsible for regulatory approvals. Operation of the Woodvale facility by Unity Mining currently occurs under a Work Plan Approval issued by the Department of State Development, Business and Innovation (DSDBI), now the Department of Economic Development, Jobs, Transport and Resources. However, if another (non-mining) entity were responsible, they may require a discharge licence from EPA. Both regulatory pathways are considered in Table E-1.

Since the New Moon pumps, pipeline from New Moon to Woodvale and the Woodvale facility are essential to all feasible short term alternatives to allowing uncontrolled discharge of mine water it is recommended that this infrastructure is inspected soon to determine its current fitness-for-use. Detailed water balance modelling should also be undertaken to determine how much of the Woodvale facility is required for short term use options. Consultation with local residents about reinstatement of the facility as part of the short-term management Bendigo's mine water should also be undertaken at an early stage.

Table E-1 : Summary of proposed short term options for Bendigo Mine Water Management

Criterion	Option 1a (Untreated discharge to Woodvale at a constant daily rate)	Option 1b (Untreated discharge to Woodvale over summer at higher pumping rate)	Option 2a (Untreated discharge to Woodvale over summer & treated discharge to environment in winter)	Option 2b (Treated discharge to the environment)	Option 3 (Treated discharge to Coliban Water Recycled Water System)
New works capital cost (+/- 25%)	Nil – utilize existing infrastructure	$4.0 M (New pipeline New Moon to Woodvale to increase capacity to 4 ML/d)	$0.67 M (worst case) for RO plant at New Moon	$0.67 M (worst case) for RO plant at New Moon	$4.0 M new pipeline from New Moon to Epsom + $0.67 M (worst case) for RO plant at New Moon
Unity Mining handover costs (+/- 50%)	$1.7 M	$1.7 M	$2.0 M	$2.0 M	$2.0 M
Annual operating costs (+/-20%)	$0.2 M (pumping at Central Deborah) $0.1 M (pumping to Woodvale) $0.1 M (operation, maintenance and monitoring)	$0.2 M (pumping at Central Deborah) $0.1 M (pumping to Woodvale) $0.1 M (operation, maintenance and monitoring)	$0.2 M (pumping at Central Deborah) $0.5 M (RO and pumping costs) $0.1 M (operation, maintenance and monitoring)	$0.2 M (pumping at Central Deborah) $0.8 M (RO and pumping costs) $0.2 M (operation, maintenance and monitoring)	$0.2 M (pumping at Central Deborah) $0.8 M (RO and pumping costs) $0.2 M (operation, maintenance and monitoring)
NPC 4 years 6% p.a. discount rate	$3.0 M	$7.0 M	$5.2 M	$6.6 M	$10.6 M
Potential Revenue	None	None	Sale of 200 ML p.a.? (unlikely)	Sale of 500ML p.a.? (unlikely)	Sale of 500ML p.a.? (unlikely)
Process performance	High/reliable	High/reliable	High/reliable	High/reliable	High/reliable
Regulatory requirements: Unity Mining OR	Woodvale: Work Plan Approval (DEDJTR)	Woodvale: Work Plan Approval (DEDJTR)	Lake Neangar: discharge licence (EPA) Woodvale: Work Plan Approval (DEDJTR)	Lake Neangar: discharge licence (EPA) Woodvale: Work Plan Approval (DEDJTR)	Trade Waste Agreement (CW) EPA Amalgamated licence amendment (CW/EPA) EPA Works approval Woodvale: Work Plan Approval (DEDJTR)
Regulatory requirements: Other entity	Woodvale: discharge licence (EPA)	Woodvale: discharge licence (EPA)	Lake Neangar: discharge licence (EPA) Woodvale: discharge licence (EPA)	Lake Neangar: discharge licence (EPA) Woodvale: discharge licence (EPA)	Trade Waste Agreement (CW) EPA Amalgamated licence amendment (CW/EPA) EPA Works approval Woodvale: discharge licence (EPA)
Opportunities	Pumping to Woodvale could occur at the maximum pipeline capacity (2.3 ML/d) over 10 months of the year. This could slightly reduce operational costs.	Dewatering could occur at a higher rate (e.g. 4.0 ML/d) over the summer months, when evaporation potential is higher. This could reduce operating costs.	Discharge of treated water to the environment may provide an environmental flow benefit. This option provides a high level of flexibility under different evaporation & rainfall conditions	Woodvale Ponds would only be required for brine disposal, with as little as half the current area required. Alternatively, treatment and discharge over the winter months corresponds with higher natural flow periods.	Woodvale Ponds would only be required for brine disposal and the required area could be reduced significantly.
Limitations	The Woodvale facility should be continuously wet, so that it does not dry out and generate dust.	Current capacity of pipeline between New Moon and Woodvale is 2.3 ML/d. A second pipeline would be required for this option. The Woodvale facility should be continuously wet, so that it does not dry out and generate dust.	There is no current or immediately foreseeable demand for the treated water generated The Woodvale facility should be continuously wet, so that it does not dry out and generate dust.	No current demand for additional irrigation water The Woodvale facility should be continuously wet, so that it does not dry out and generate dust.	Coliban Water can only accept a limited volume of treated water, excess untreated water may need to be discharged to Woodvale, alternatively excess treated water could be discharged to the environment (Lake Neangar). Likely additional disposal costs The Woodvale facility should be continuously wet, so that it does not dry out and generate dust.

Criterion	Option 1a (Untreated discharge to Woodvale at a constant daily rate)	Option 1b (Untreated discharge to Woodvale over summer at higher pumping rate)	Option 2a (Untreated discharge to Woodvale over summer & treated discharge to environment in winter)	Option 2b (Treated discharge to the environment)	Option 3 (Treated discharge to Coliban Water Recycled Water System)
Community benefits	Central Deborah Tourist Mine remains open No uncontrolled discharge to the environment.	Central Deborah Tourist Mine remains open No uncontrolled discharge to the environment.	Central Deborah Tourist Mine remains open No uncontrolled discharge to the environment.	Central Deborah Tourist Mine remains open No uncontrolled discharge to the environment. Discharge of treated water to the environment could be seen as environmental flows Potential to reduce or reconfigure the Woodvale Ponds area.	Central Deborah Tourist Mine remains open No uncontrolled discharge to the environment. Discharge of treated water to the environment could be seen as environmental flows Potential to reduce or reconfigure the Woodvale Ponds area.
Community dis-benefits	The Woodvale Ponds were expected by the local community to close and be rehabilitated by 2017. All short-term options are likely to extend the operating period and any impacts on local residents by several years.	The Woodvale Ponds were expected by the local community to close and be rehabilitated by 2017. All short-term options are likely to extend the operating period and any impacts on local residents by several years.	The Woodvale Ponds were expected by the local community to close and be rehabilitated by 2017. All short-term options are likely to extend the operating period and any impacts on local residents by several years.	The Woodvale Ponds were expected by the local community to close and be rehabilitated by 2017. All short-term options are likely to extend the operating period and any impacts on local residents by several years.	The Woodvale Ponds were expected by the local community to close and be rehabilitated by 2017. All short-term options are likely to extend the operating period and any impacts on local residents by several years.
Implementation time	1-2 months, pending sign off on regulatory and management arrangements	12 months for design & construct new pipeline, sign off on regulatory and management arrangements	Pumping to Woodvale – 1-2 months, pending sign off on regulatory and management arrangements Use of RO plant – 6 months, depending on functionality of plant and need for new filters.	12 months for design & construct new pipeline, sign off on regulatory and management arrangements	12 months for design & construct new pipeline, sign off on regulatory and management arrangements

Long term water management options

A workshop was held with representatives from DELWP, Coliban Water and Unity Mining to discuss a range of short and long term water management options, as well as the available existing infrastructure, current demand and demand projections, and alternative management practices. Through these discussions it was concluded that there is no current demand for additional water in the Bendigo region, particularly expensive, treated mine water. Coliban Water is already producing treated recycled water, which is often surplus to current demand and excess water is regularly discharged to Bendigo Creek. Lack of water demand is a key challenge for the management of the mine water in Bendigo and frames the future management of Bendigo's mine water as an ongoing waste disposal problem.

While there is no current demand for additional water, future climatic variability should be considered. Under extended drought conditions, the demand for alternative water sources is likely to increase (as it did during the millennium drought) and mine water could become a useful backup to existing water resources, for non-potable uses. It would therefore be useful for long-term water management options to incorporate some flexibility, to enable water to be used if and when required.

Table E-2 lists the longer-term water management options which were short listed, based on technical feasibility and suitability to the Bendigo situation.

Table E-2: Long term water management options investigated

No.	Description	Options
1	Untreated discharge to an evaporation facility	a) Use the existing Woodvale facility b) Construct a new facility
2	Treated discharge to the environment	a) Treat the water at Central Deborah and discharge to Bendigo Creek b) Treat the water at New Moon and discharge to Lake Neangar
3	Treated discharge to the recycled water network	a) Treat the water at Central Deborah and discharge to the main sewer b) Treat the water at New Moon and discharge to the sewer at Eaglehawk c) Treat the water at Central Deborah and discharge to a recycled water network within Bendigo
4	Treatment of water through a constructed wetland	a) Treat the water near Central Deborah and discharge to the main sewer b) Treat the water at New Moon and discharge to the sewer at Eaglehawk c) Treat the water near Central Deborah and discharge to a recycled water network within Bendigo
5	Use of a permeable reactive barrier at a natural discharge site	Install a permeable reactive barrier at the New Moon discharge site

Five of the options listed in Table E-2 include RO water treatment, which produces a brine stream that requires disposal. It has been assumed that in the long term, the use of the Woodvale facility is not preferred, due to the legacy associated with the site, including the cost of rehabilitation and local community expectations for its closure. An alternative brine disposal facility may therefore be required. Likely alternatives include: a new, purpose-built facility, a proposed regional brine disposal facility and the upgrade and use of the Coliban Water's brine ponds (subject to agreement with Coliban Water).

A regional brine disposal facility is currently under consideration, but is still at a conceptual stage. It is not clear how it would be used nor whether it will actually be developed. For the purpose of this investigation it has therefore been assumed that brine would either be sent to a new facility or to the upgraded Coliban Water facility, at an estimated capital cost of $4.0 million. This does not include consideration of the cost of the associated pipeline and pumps, which will vary considerably depending on the final location of the site and is estimated to be between $1 million and $4 million.

Several of the options assume that Coliban Water would accept part or all of the mine water, which is also uncertain. Coliban Water will need to determine its capacity and willingness to accept the water and any associated long term legacy generated by constituents such as arsenic and salt. It may also depend upon the integration of treated mine water into Coliban Water's long term water resource planning and it becoming a resource for use. In the absence of a prolonged drought, this may not be the case for many years and possibly decades.

Capital, infrastructure handover (from Unity Mining) and operating costs have been estimated for each option. Net present cost (exclusive of land acquisition and long-term maintenance) over a 20 year period has also been calculated.

Six of the eleven options considered are recommended for further investigation (1a, 1b, 4a, 4b, 4c and 5). Three options were explicitly rejected (3a, 3b, 3c) and two options (2a, 2b) may be suitable but are very expensive and may not satisfy cost-benefit considerations.

Disposal of the untreated mine water to an evaporation pond (Options 1a and 1b) is considered the best understood and established method of treatment considered, with low ongoing costs and risks. However, these options are only likely to proceed at locations which have local community support.

The constructed wetland options (4a, 4b, 4c) appear very promising as a low cost passive treatment system. Although the long term costs for constructed wetlands are higher than the evaporation ponds, they may avoid the need for an evaporation facility and provide additional environmental benefits.

The permeable reactive barrier (5) offers the lowest long-term cost and also appears promising. However, the technology would need to be proven for use with Bendigo's mine water chemistry.

Both the constructed wetland and permeable reactive barrier options are promising, but uncertain regarding their ability to manage the anticipated salt load in the long-term. Vegetation within the constructed wetlands could take up the salt in the mine water, and then be harvested for stock feed. This needs further investigation and, ideally, a trial program. The permeable reactive barrier may trap salt within the barrier and, if so, may require periodic cleaning. However, this will vary according to the filter media selected and also requires further investigation. Neither option should be considered for full-scale implementation without being trialled.

This initial study has considered the options individually. However, they could (conceptually) be developed in combination. Further information on technical feasibility, cost, community acceptance, etc. would be required before implementation could commence.

Table E-3 presents a brief summary of the long term management options considered suitable for further investigation.

Table E-3: Summary of proposed long term options for Bendigo Mine Water Management

Option	New infrastructure required	Costs	NPC 20 years (6% p.a. discount rate)	Time to implement	Technical feasibility	Long term maintenance	Opportunities /advantages	Constraints/ disadvantages	Assumptions	Recommended for adoption or further study?
Option 1: Untreated discharge to an evaporation facility										
1a. Untreated discharge to the Woodvale facility	Nil	Capital – nil Handover – $1.7 M Annual ops. - $0.4 M	$5.8 M	1-2 months	Reliable/proven	Ponds will need to have the accumulated salts removed at 10-20 years	Facility is already in place	Inconsistent with community expectation that Woodvale would close and be rehabilitated in 2017.	Assumes that the ponds are in suitable condition for operation	Yes – facility is already in place, saving a lot of time in design & approvals. Low ongoing cost, known performance
1b. Untreated discharge to a purpose built facility	Evaporation pond Pipeline & pumps	Capital – $5.0 M Handover – nil Annual ops.- $0.4 M (+ pipeline of $1-4 M?)	$9.1 M	2 years	Reliable/proven	Ponds will need to have the accumulated salts removed every 20+ years	Opportunity to develop at a location with minimal community impact or possibly closer to Central Deborah (unlikely)	Requires ~100 ha of ponds. Finding suitable sites with low community impact within reasonable pipeline distances may be difficult	Also needs a pipeline to the facility, which could be anywhere in the region of $1-4 M, depending on distance, route, etc.	Yes – low ongoing cost, known performance & design requirements
Option 4: Creation of an aerobic wetland with outflow to the environment										
4a. Constructed wetland near the New Moon natural discharge site (outflow to local watercourse)	Constructed wetland Degassing tower Pipeline from New Moon to the wetland	Capital – $5.0 M Handover – nil Annual ops.- $0.3 M	$7.9 M	2-3 years (pilot study recommended before full implementation)	Proven in some situations & for some water qualities – may need further investigation	Wetlands will require refurbishment as plants reach maturity. Expect 20% per year replacement after the first two years	Potential environmental flow No brine stream created	Requires ~7 ha surface area. Engagement with neighbours required to ensure acceptance of treatment.	Assumes that it is possible to achieve a final water quality that is acceptable to EPA	Yes – this technology may be an effective passive treatment, with minimal ongoing costs, but requires further investigation
4b. Constructed wetland on Council land near Central Deborah (outflow to Bendigo Creek)	Constructed wetland Degassing tower Pumps & pipeline from Central Deborah to the wetland	Capital – $5.0 M Handover – nil Annual ops.- $0.3 M	$8.6 M	2-3 years (pilot study recommended before full implementation)	Proven in some situations & for some water qualities – may need further investigation	Wetlands will require refurbishment as plants reach maturity. Expect 20% per year replacement after the first two years	Potential environmental flow No brine stream created	Requires ~7 ha surface area. Engagement with neighbours required to ensure acceptance of treatment.	Assumes that it is possible to achieve a final WQ that is acceptable to EPA	Yes – as per 4a
4c. Constructed wetland at Epsom and incorporated with the Bendigo Creek discharge from Coliban Water	Constructed wetland Degassing tower Pumps & pipeline from Central Deborah to the wetland	Capital – $8.6 M Handover – nil Annual ops.- $0.4 M	$12.8 M	2-3 years (pilot study recommended before full implementation)	Proven in some situations & for some water qualities – may need further investigation	Wetlands will require refurbishment as plants reach maturity. Expect 20% per year replacement after the first two years	Potential environmental flow No brine stream created	Requires ~7 ha surface area. Engagement with neighbours required to ensure acceptance of treatment.	Assumes that it is possible to achieve a final WQ that is acceptable to EPA	Yes – as per 4a
Option 5. Use of a permeable reactive barrier at natural discharge site	PRBs installed at New Moon natural discharge site Monitoring bores	Capital – $1.8 M Handover – nil Annual ops.- $0.2 M	$3.7 M	2-3 years (pilot study recommended before full implementation)	Proven in some situations & for some water qualities – will need further investigation	The reactive barrier will need periodic cleaning out, possibly every 10-50 years	No brine stream created Allows mine water to connect with natural discharge sites Low maintenance requirements Potential for dispersed application at multiple potential mine water discharge points.	Not flexible once in place	Assumes that it is possible to achieve a final WQ that is acceptable to EPA& outflow rates are suitable	Yes – this technology may be an effective passive treatment, with minimal ongoing costs, and may be useful in other areas of Bendigo where mine water is already discharging and odour is an issue. Requires further investigation

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to provide a pre-feasibility level assessment of interim options to manage groundwater from the Central Deborah mine and Garden Gully Line Reef, with or without treatment and in the short and longer term, in accordance with the scope of services set out in the contract between Jacobs and the Client. That scope of services, as described in this report, was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Client and available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

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The costs presented in this report are preliminary and high level; they have been provided for the purposes of comparing options only and should not be used for budget setting. The costs associated with the sale or transfer of Unity Mining assets are indicative and will required further discussion with Unity Mining management. The costs associated with new pipelines are also indicative. Actual costs will depend on a range of factors such as final alignment, pipe size, pressure rating, material, construction method, route environment, approvals, etc.

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Glossary

Acronym/ phrase	Definition
AEP	Annual exceedance probability – the probability that a flood event of a given magnitude will be exceeded in any given year. Generally expressed as a percentage
CW	Coliban Water
DEDJTR	Department of Economic Development, Jobs, Transport and Resources (formerly the Department of State Development, Business and Innovation; DSDBI)
DELWP	Department of Environment, Land, Water and Planning (formerly the Department of Environment and Primary Industries; DEPI)
EPA	Environment Protection Authority
M	Million
Mine Water	For the purpose of this project 'mine water' refers to groundwater which has entered the mine voids under Bendigo. The quality of the water reflects the natural geology of the area and is not materially affected by passing through the mine workings. This is distinct from groundwater which does not enter the mine voids and does not need to be managed
ML	Megalitre, equivalent to one million litres or 1,000 cubic metres
PRB	Permeable reactive barrier
RO	Reverse osmosis
RWS	Recycled water system
SEPP	State Environment Protection Policy
TDS	Total dissolved solids
WRP	Water reclamation plant
WTP	Water treatment plant

1. Introduction

1.1 Challenges in managing Bendigo's mine water

There is a long history of gold mining in the Bendigo region, with mining activities occurring over two main periods. Gold mining began as part of the 1850s' Victorian gold rush and continued uninterrupted until 1954, with the closure of the Central Deborah Mine. Mining later restarted in the mid-1980s and continued up until 2011. Much of this mining activity has been underground, which has required lowering of the natural water, in order to safely access gold reefs (dewatering).

These historic mining activities have created an extensive network of interconnected mine voids below Bendigo. In the absence of mining activities, and dewatering, groundwater draining through rock fractures and historical workings fills these voids. Once the water table is above a certain level, water in the mine voids naturally discharges to the environment via historical workings and/or other low points in the topography.

In the 1980s mining and dewatering activities in the Bendigo goldfields led to water levels in the mine workings dropping and mine water ceasing to discharge to the environment. Since active mining and dewatering ceased in 2011, water levels within the historical mine voids have been recovering (rising) towards their previous levels. Without intervention, uncontrolled discharge of mine water to the environmental appears to be imminent.

Water levels in parts of the historic workings are currently managed by the Bendigo Trust, in order to maintain access to lower levels of the Central Deborah Tourist Mine, for tours on levels 2, 3 and 9 and for the purposes of maintaining ventilation through level 6. The Bendigo Trust is pumping approximately 1.5 ML/d of mine water from the Central Deborah Shaft and discharging it into the adjacent, but disconnected, Londonderry Shaft (part of the Garden Gully Reef workings), under an agreement with Unity Mining. However, it is expected that by February or March 2015 water levels within the Garden Gully Reef will reach a level allowing uncontrolled discharge of mine water to the environment. Discharge is expected to occur at several locations around Bendigo, including along Bendigo Creek, at Sydney Flat and at Myers Flat.

The anticipated discharge will comprise naturally-occurring mine water, whose quality is not materially affected by its passage through the historic mine workings. However, the natural composition of mine water and its odour is likely to be of concern to the community and environmental management agencies.

In summary, the recovering water levels are cause for concern on several fronts, including that if they were left uncontrolled:

- Mine water will inundate sections of the Central Deborah tourist mine, in central Bendigo, diminish its value as a tourist attraction and jeopardise the value it provides to the Bendigo Trust and wider Bendigo economy;
- Mine water levels will recover (rise) back to historic, or pre-current mining levels, with the potential to discharge to the environment, particularly local waterways. Salt and other constituents within the discharging mine water may diminish soil and river health values;

To prevent the uncontrolled discharge of mine water to the environment and maintain access to the Central Deborah Tourist Mine, mine water must be removed from the historic mine workings and, preferably, used for some productive outcome. Assuming that dewatering for mining operations has permanently ceased, approximately 2 ML/d of mine water must be removed from the historic workings in perpetuity.

1.2 Scope of this report

The Department of Environment, Land, Water and Planning (DELWP) (formerly the Department of Environment and Primary Industries; DEPI) has initiated this project to identify suitable shorter term and longer term options for the management of excess water in Bendigo's historical mining voids, which would allow the continued operation of the Central Deborah Tourist Mine and prevent uncontrolled discharge of that water to the environment. This project assumes that dewatering for mining operations has permanently ceased.

For the purpose of this project, “short term” is used to describe options which are either immediately implementable (i.e. within 1-2 months), relying on existing water management infrastructure, or can be implemented within 12 months if additional infrastructure is required. The short term options are anticipated to be required for approximately 2-4 years, while a longer term response is developed. “Long term” options are expected to be implementable within 2-4 years and will be in place indefinitely, probably for in excess of 20 years.

For ease of accessibility, this report has been divided into three parts:

- **Part A:** The history of mine water management in Bendigo – this section provides context for the development of short and longer-term mine water management options.
- **Part B**: Review of the mine water quality and the technologies available to treat the mine water.
- **Part C:** Identification and assessment of short and longer-term mine water management options.

Part A History and context of mine water management in Bendigo

This part of the report describes the history of mine water management in Bendigo. It also describes the existing mine water management infrastructure which could be incorporated into future water management options. The section also outlines the critical factors affecting the development of the short and longer-term mine water management options, including the implications of not managing the water, uses for the water and potential integrated water cycle management opportunities.

2. Historic and current management of water inflows into mining voids below Bendigo

2.1 Initial mining phase (1851 to 1954)

Mining in Bendigo can be considered to have occurred within two distinct periods; 1851 to 1954, and 1978 to 2011. The first phase of mining was initiated by the discovery of alluvial gold in Bendigo Creek, during the Victorian gold rush. Alluvial gold was the dominant form of production in the goldfield for the first ten years, with underground mining developing as the alluvial resource was depleted.

As the gold-bearing reefs are formed in a predictable manner, running from south-east to north-west (Appendix B), deep shafts were often sunk as part of the mining exploration process. Over the life of the goldfield over 5,000 shafts were sunk.

During the initial phase there were numerous operators (up to 1,300), with thousands of small mining leases. Dewatering for mining operations appears to have been conducted on an individual mine basis, although Unity Mining (2014) notes that the inflow volumes were generally low and operators used a bailing tank rather than fixed pumps. Mine water was released into local waterways without treatment.

The initial underground mining phase peaked between 1900 and 1920, with production gradually waning as exploration and development became increasingly difficult and costly. Mining ceased in 1954, with the closure of the Central Deborah Mine.

2.2 Period between mining phases (1954 to 1978)

During the period when mining and dewatering was not taking place, water levels in the mining voids rose and discharge was observed to occur into Bendigo Creek and local waterways. The mine voids generally run from the north-west to the south-east (see map Appendix B). When the mine void levels are at equilibrium mine water discharge points have generally occurred either along Bendigo Creek at the southern end of the voids or into the Myers Creek catchment at the north end of the mine voids (Appendix C).

2.3 Dewatering operations during recent mining phase (1978 to 2011)

After the closure if the Central Deborah Mine in 1954, the Bendigo goldfields were untouched until 1978, when WMC Ltd began mining exploration. Unity Mining (then Bendigo Mining) started exploration in 1985 and in 1992 purchased WMC's interests, consolidating their ownership of the entire goldfield.

Mine water management has changed during this period, in response to changing community expectations and mining requirements. Initially, WMC's mine water management involved the dewatering of operations and discharge of untreated water to a local watercourse.

Later, the Woodvale Evaporation Ponds were constructed, to contain and dispose of the discharged mine water through evaporation. Unity Mining ran a dewatering system which pumped mine water extracted from upstream shafts into the Londonderry Shaft. This water then passed through the Garden Gully Reef workings to the New Moon Shaft, where a pump station pumped the water to the Woodvale Ponds.

In 2006, plans to entirely dewater the old mine workings required a significant increase in mine water extraction. Since the volume to be produced exceeded the disposal capacity of the Woodvale Ponds, mine water management arrangements needed to be modified. Infrastructure was subsequently developed to treat this water at New Moon water treatment plant and provide it to Coliban Water, for use by agricultural customers. Any excess treated water was discharged to Lake Neangar. This arrangement only lasted for approximately one year, The New Moon water treatment plant uses reverse osmosis (RO) and pre-treatment to remove natural contaminants from the mine water. The waste streams from the treatment plant, as well as any flows bypassing it, were discharged to the Woodvale Ponds. These operations are illustrated in Figure 2-1.

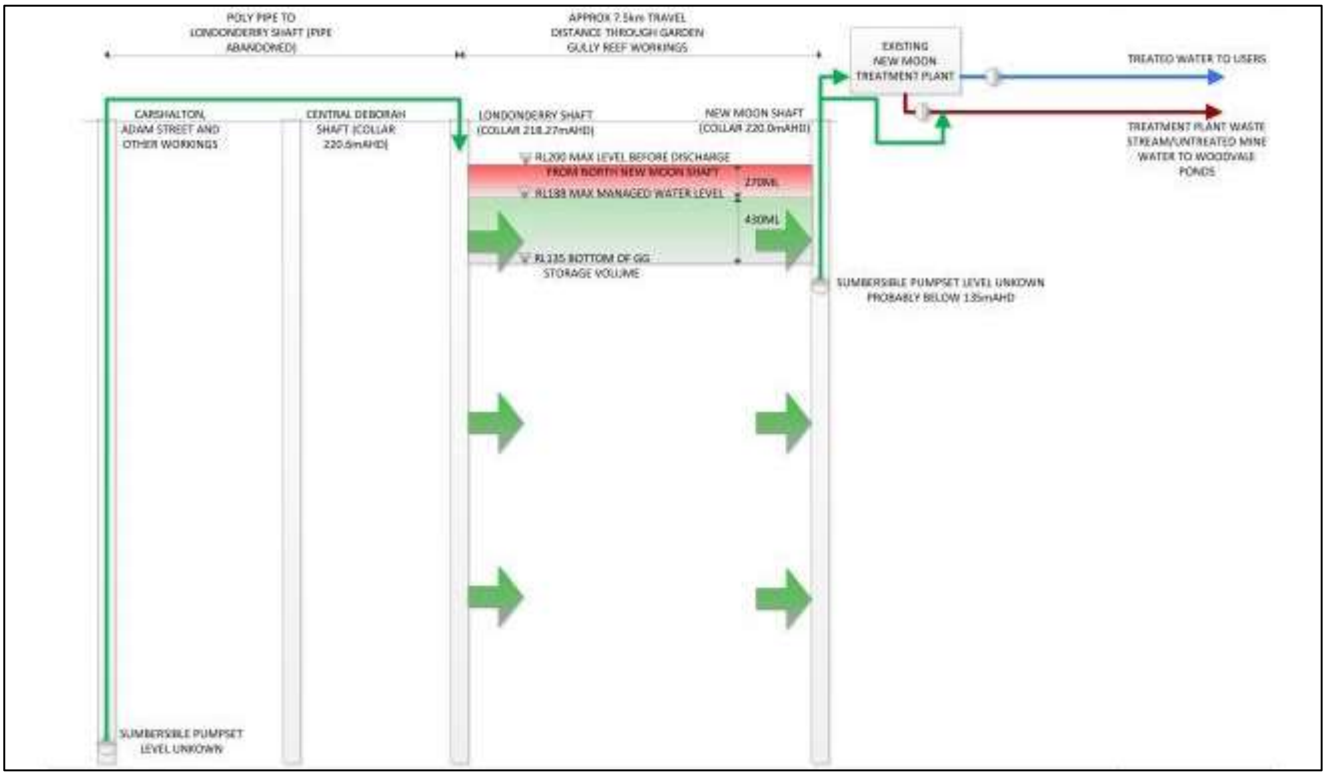

Figure 2-1 : Historic Dewatering Operations Schematic

This dewatering regime was operated to maintain access and safe conditions for Unity Mining's underground operations, but had the added advantage of preventing mine water discharge to the environment and enabling access to lower levels of the Central Deborah Tourist mine. Mining operations and dewatering by Unity Mining ceased in 2011.

2.4 Current dewatering operations (post active mining – 2012 onwards)

Since Unity Mining ceased mining and dewatering operations, water levels within the mine voids have been recovering. The Bendigo Trust has installed two pumpsets to maintain water levels in the Central Deborah Shaft below Level 10. The Bendigo Trust pumps take water from Central Deborah Shaft through a short pipeline that discharges to the Londonderry Shaft and the Garden Gully Reef workings. The historic mine voids are being operated as a storage: which is rapidly approaching capacity The nominal working volume in the Garden Gully Reef is 700ML (Styles & associates, 2012). . These operations are illustrated in Figure 2-2.

Uncontrolled discharge of mine water to the environment will occur at several locations if mine water levels continue to recover. Mine water is likely to flow from Catherine Reef United into Peg Leg Creek and from the North New Moon shaft into the Whipstick state forest via Dead Horse Gully. Discharge will also occur to the south along Bendigo Creek, at the Central Deborah, RWB United, Shamrock, Londonderry and Hustler's Royal #2 shafts. Mine water is currently observed to discharge into Bendigo Creek from Hustlers Reef at the Hustlers Royal #2 shaft near Rosalind Park, with the sulfates in the mine water creating a nuisance odour.

In addition, the Sheepshead Reef previously discharged mine water into Bendigo Creek through a shaft which was capped as part of the construction of the Bendigo Police Station car park. The Sheepshead Reef is now connected to the Deborah Reef by a drainage point constructed during mining operations. However, the shaft under the Bendigo Police Car Park is not connected to the other parts of the Sheepshead Line. Levels in this shaft have historically been independent of the reef and so it is not clear what will happen to the water in this reef if mine water levels continue to recover.

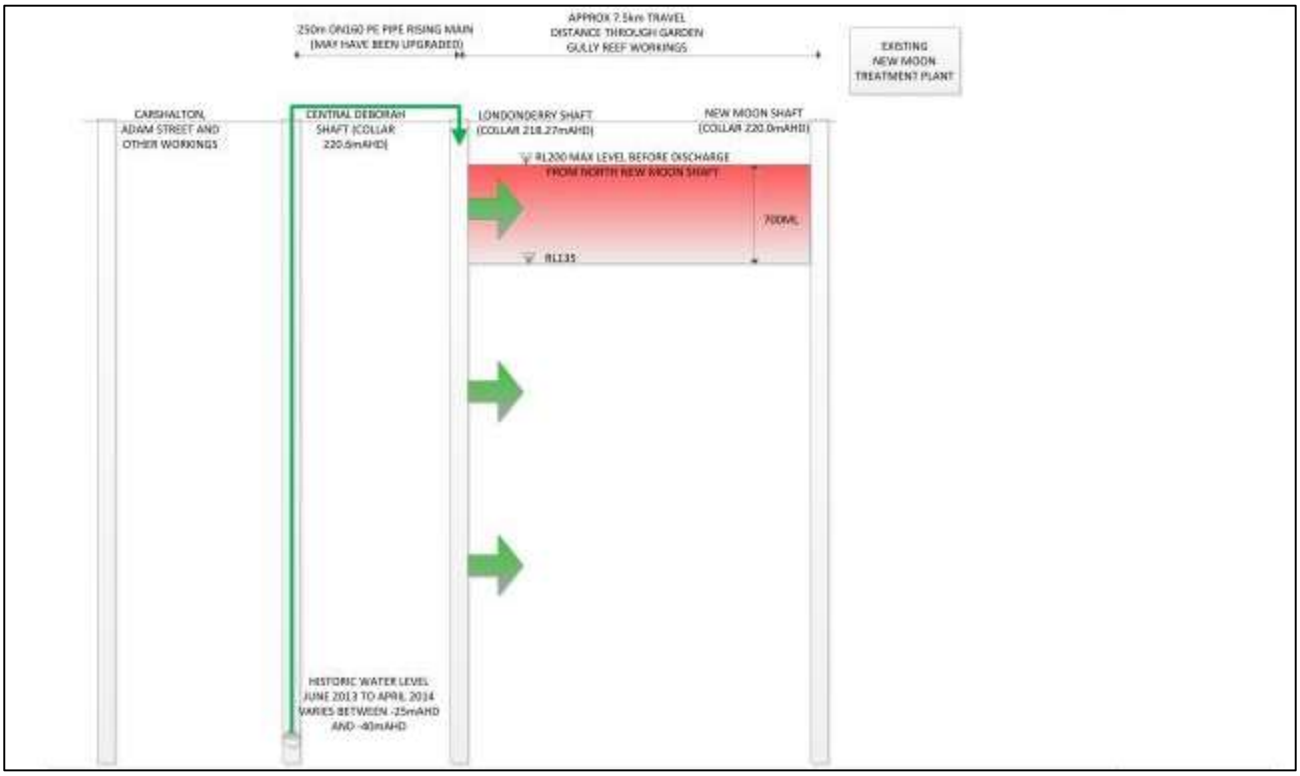

Figure 2-2 : Current Dewatering Operations Schematic

2.5 Existing dewatering infrastructure

Table 2-1 presents a summary of the current infrastructure which could be used as part of future dewatering and water treatment operations for mine void water. This is particularly relevant to any short term management options, which are likely to rely on existing infrastructure. Key infrastructure locations are depicted in Figure 2-3. A map of the mine voids is also presented in Appendix B. Detailed information on the operation of the New Moon WTP is provided in Section 5.4.

Table 2-1: Existing dewatering infrastructure

	Description	Description	Owner	Status
1	**Transfer Infrastructure**			
1.1	Central Deborah Shaft Pumpset	2 No. submersible pumps	Bendigo Trust	In use
1.2	Discharge pipeline Central Deborah Shaft to Londonderry Shaft	DN160 PE (To be confirmed)	Bendigo Trust	In use
1.3	New Moon Shaft Pumpset	Grundfos SP160-4 55kW 2900RPM submersible pump 160m3/hr or 3.8 ML/d @ 81m	Unity Mining	Not in use (but operational)

	Description	Description	Owner	Status
1.4	Transfer pipeline: New Moon to Woodvale	Capacity of 2.3 ML/d	Unity Mining	Not in use (but operational)
1.5	Transfer pipeline: New Moon to Lake Neangar	Capacity of 5 ML/d	Unity Mining	Not in use (but operational)
1.6	Transfer pipeline: Lake Neangar to Epsom WRP	2.0 ML/d	Coliban Water	In use, would need duplication to use this line again.
2	**Treatment Infrastructure**			
2.1	New Moon water treatment plant (WTP) supplied by Veolia, with RO Membranes	Max inflow of 7 ML/d to the pre-treatment facility and 5 ML/d through the remainder of the WTP. Treated water outflow 3.6ML/d	Unity Mining	In care and maintenance, condition is not clear
2.2	Woodvale Ponds – evaporation ponds (with residual sediments accumulated from previous operations)	Total surface area of 64 hectares, and storage volume of 237 ML	Unity Mining	Operational

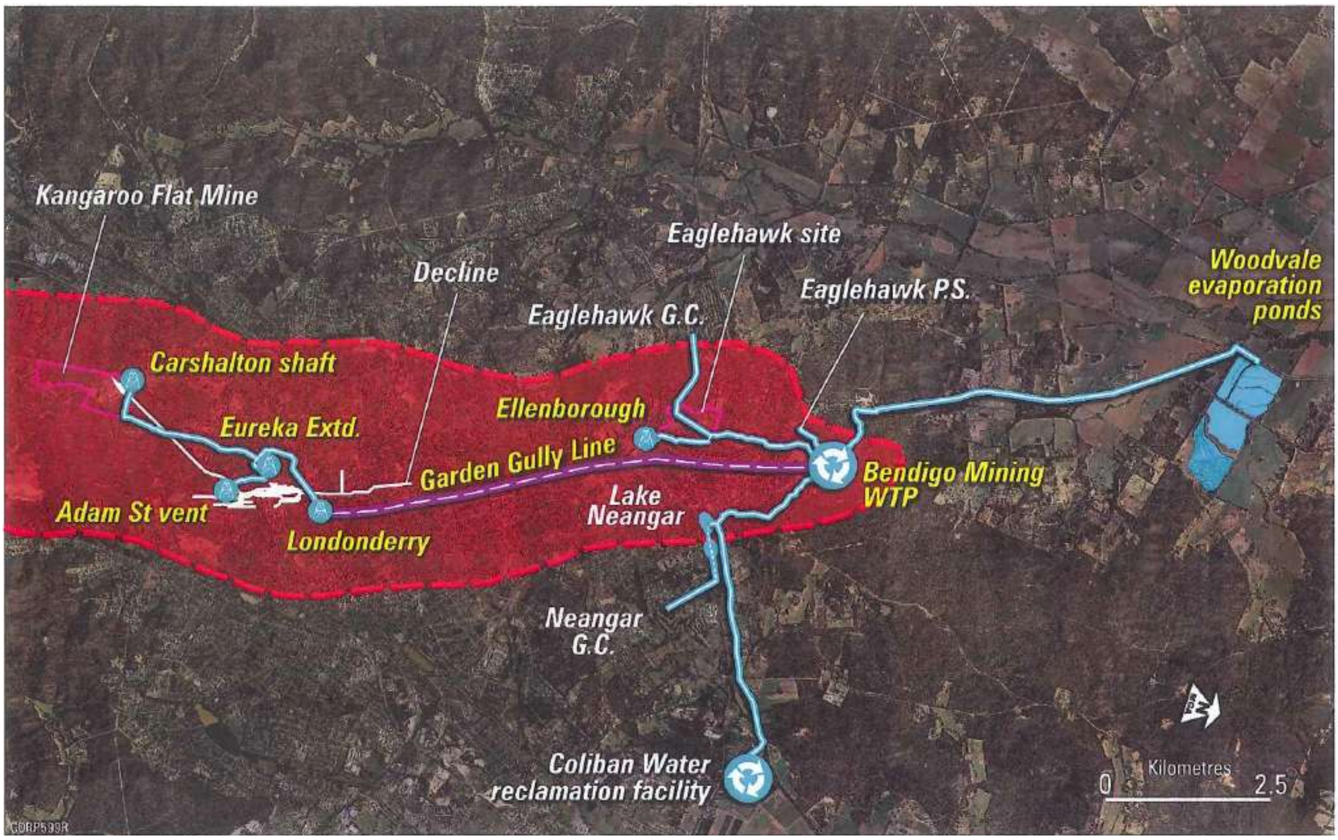

Figure 2-3 : Existing mine water management infrastructure

3. Context for the development of mine water management options

3.1 The implications of not managing mine water

As described in Section 2, water levels in the mine voids under Bendigo are recovering (or rising) due to the cessation of mine dewatering, previously required for mining exploration and operations. While the Bendigo Trust has been dewatering the Central Deborah Tourist Mine to maintain access to lower levels for guided underground tours, this has involved pumping water out of the Central Deborah Shaft and into the neighbouring Garden Gully Reef workings. However, the available storage capacity within the reef has now almost been filled.

If no action is taken to manage the rising water levels in the mine voids, the mine water will inundate sections of the Central Deborah Shaft making them inaccessible and closing all of the underground tours. In addition, the rising water levels would cause an uncontrolled discharge of mine water to the environment, affecting water quality and amenity values in Bendigo Creek and local watercourses.

The closure of the underground tours at the Central Deborah Tourist Mine would most likely reduce visitation at the attraction and potentially affect its financial viability. This would have a significant direct economic impact on the Bendigo Trust and an indirect effect on the wider Bendigo community. As the mine is a major tourist attraction, the loss of underground tours, or closure, may reduce tourism activity across Bendigo.

Once the mine water recovers to its natural level, uncontrolled discharge of mine water will occur along Bendigo Creek at the southern end of the voids and into the Myers Creek catchment at the north end of the mine voids (Appendix C). To the north, discharge will occur into Peg Leg Creek from Catherine Reef United and into the Whipstick state forest via Dead Horse Gully from the North New Moon shaft, at an expected rate of 0.4 ML/d to 0.8 ML/d. Along Bendigo Creek, discharge will occur at the Central Deborah, RWB United, Shamrock, Londonderry and Hustler's Royal #2 shafts at an expected rate of 1.1 ML/d. Mine water is currently observed to discharge into Bendigo Creek from Hustlers Reef at the Hustlers Royal #2 shaft near Rosalind Park, with the sulfates in the mine water creating a nuisance odour in the park and surrounds.

Water levels in the Garden Gully Reef are expected to reach 203.0 m AHD in February or March 2015, at which point mine water discharge will occur from the New Moon Shaft. This may have negative impacts on the environment due to the levels of salt and other constituents within the mine water.

It is also possible that the recovery of the mine water levels could cause or exacerbate existing urban salinity issues in Bendigo. Styles and Associates (2012) suggest that if the mine voids are not dewatered this will also lead to raised water tables within Bendigo, potentially contributing to urban salinity issues such as rising damp, salt damage and foundation and infrastructure damage. However, there is no indication at this time that local watertables are rising; it is only the water level in the mine voids that is rising. Land salinization and localised discharge occurs naturally now and has occurred over the mine dewatering period, indicating no/limited correlation between urban salinity and mine dewatering. However, the City of Greater Bendigo does maintain a salinity management overlay, as part of the Greater Bendigo Planning Scheme. The purpose of the overlay is to identify areas with saline groundwater discharge and manage the impacts of new developments on these areas. The Bendigo urban growth area and peri-urban surround are noted to be at a high risk of urban salinity, with some building already observed to be affected (NCCMA, 2007). While the water levels within the mine voids may not cause urban salinity this issue should be monitored.

3.2 Central Deborah mine

The Central Deborah Tourist Mine currently runs underground tours and has surface mining exhibits. The majority of visitors take one of three underground tours. These are conducted at 61 m, 85 m and 228 m underground, ventilation for the mine also occurs at mine level 6, 150 m below ground. In order to maintain access to all three tours, the mine water level must be kept below mine level 10, 246.4 m underground (RMCG, 2014). If no mine dewatering was to take place it is understood that the water level in the mine voids would come to equilibrium very close to the surface, discharging to the surface in low lying areas and along watercourses. This would mean that all three of the current underground tours would have to close.

If no dewatering occurs there may still be capacity to run underground tours at a different location. Alternatively, the underground mine experience could be recreated at the surface.

3.3 Uses for treated mine water

A workshop was held in late July 2014 with representatives from DELWP, Coliban Water and Unity Mining. As part of the workshop a range of short and long term water management options were discussed, as well as the available existing infrastructure, current demand and demand projections, and alternative management practices.

Recycled water is already produced in Bendigo by Coliban Water and the volume produced significantly exceeds current demands. Apart from the recurrence of a prolonged drought similar to the Millennium drought of the late 1990s and early to mid-2000s, or the emergence of a new industrial demand this situation is unlikely to change within the next 10-20 years. However, it is likely to be a very expensive source of water given the level of treatment required prior to its use.

A simple method for framing the end use options available for mine water management is presented in Figure 3-1. This splits the management options into either use or disposal, depending on current or expected demand for the water. Each of these uses is likely to require a level of water treatment.

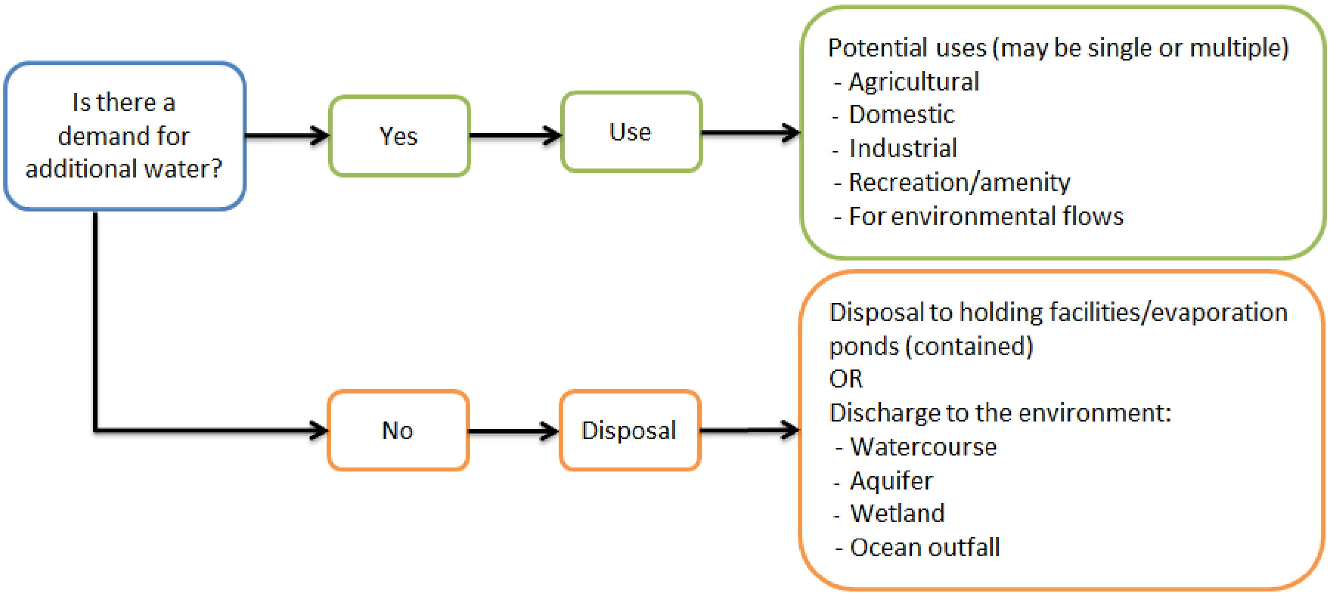

Figure 3-1: Water management options framework

3.4 Water use options

Table 5-1 presents an analysis of the generic water **use** options available to manage Bendigo mine water (from Figure 3-1). Through stakeholder discussions it was concluded that there is no current demand for additional water in the Bendigo region, particularly expensive, treated mine water. This is a key challenge for the management of the mine water in Bendigo and frames the future management of Bendigo's mine water as an ongoing waste disposal problem.

Table 3-1: Generic water use options

Option	Suitable for further investigation?	Reason
Industrial	No	No material additional demand from existing industry is expected and there no known plans for developing new water-using industries in the region. This could change in the long term (20+ years).
Agricultural	No	No current additional demand from existing irrigated agriculture and no known plans for expansion in the region. This could change in the long term (20+ years).
Domestic	No	While the population is increasing, growing demand can be met from existing potable and recycled water sources. Reuse of treated water is not considered cost effective for new developments. . This could change in the long term (20+ years).
Recreation/amenity	No	No current unmet demand. This option is already serviced by Coliban Water, who currently have a volume of recycled water greater than demand. Recreational use is likely to grow (slowly) with population growth and climate change. This could change in the long term (20+ years).
Environmental flows	No	There is no current requirement for additional environmental flows in the local area and the cost of treating water to a suitable standard and transporting it to the wider region (e.g. Campaspe or Loddon Rivers) is prohibitive.

3.5 Water disposal options

Table 3-2 presents a summary of the generic water **disposal** options available to manage the Bendigo mine water. Of these, evaporation and discharge to the environment are considered to provide the most suitable long term management options, at the present time.

Table 3-2: Generic water disposal options

Option	Suitable for further investigation?	Reason
Managed aquifer recharge (MAR)	No	Low permeability in surrounding geology means that it would not be possible to dispose of the required volume.
Fill other local mine voids	No	Current capacity is approximately 100 ML in the North New Chum workings. This is insufficient for short or long term disposal, but could potentially be of use as a one off emergency management measure.
Evaporation	Yes	Evaporation is a known technology and has been used successfully in the Bendigo region. An evaporation facility would need to be managed carefully to avoid adverse impacts on nearby residents, land and beneficial uses of surface water and groundwater resources.
Discharge to environment	Yes	There are a number of watercourses in the local area which could accept discharge of water of appropriate quality, provided this was managed in a way that provided an environmental flow or other benefit. The water would require treatment to a suitable standard prior to discharge. There are several potentially applicable treatment processes.

3.6 Regional growth

Bendigo's population is forecast to grow by approximately 1.4% per annum, increasing to 122,600 by 2021 and 139,800 by 2031 (DPCD, 2012; cited in DTPLI, 2014). Coliban Water estimates that annual urban water demand will increase by 8,000-10,000 ML by 2030, and by up to 25,000 ML by 2060 (CW, 2012).

Coliban Water has an existing recycled water network within Bendigo. The Recycled Water Factory currently has the capacity to supply approximately 2,000-3,000 ML/y of Class A water to sporting grounds, parks and schools in Bendigo (CW, 2012). The treated water supply is often far in excess of demand and Coliban Water regularly discharges excess recycled water to Bendigo Creek.

In an average year, Coliban Water has access to over 100 GL of raw water allocation. Any additional water derived from mine water disposal (up to 730 ML/y) would therefore represent an increase in supply of less than 1%. Under these conditions, the mine water does not materially improve Bendigo's water security.

The main benefit of an additional raw water resource is operational flexibility, especially during periods of peak demand (assuming suitable pre-treatment). However, this is not currently a significant consideration for Bendigo's water supply.

While several of the long term options considered in this report include mine water in the recycled water network, these scenarios are not currently considered viable, due to the lack of demand for additional recycled water. However, these scenarios could be viable under drought conditions or in the future (20+ years) if demand and willingness to pay for recycled water increases significantly.

Coliban Water has recently completed an investigation into an extension of their recycled water network to new areas of residential development. This was found not to be cost effective and is unlikely to be pursued. It therefore seems unlikely that there is potential for the mine water to form part of the Coliban Water future supply strategy for many years, at least.

3.7 Impacts of climatic variation

Water management options are considered under "current" climate conditions and do not include any consideration of the implications of climate change. Climate change is not relevant to the short-term management of mine water and is only marginally relevant to longer-term options, which are considered over a 20 year period.

However, consideration should been given to climatic variability, with the potential for extended drought and large scale flooding to affect the amount of mine water available and any demand for treated mine water. Under extended drought conditions, the demand for alternative water sources is likely to increase (as it did during the millennium drought) and mine water could become a useful backup to existing water resources, for non-potable uses. It would therefore be useful for long-term water management options to incorporate some flexibility, to enable water to be used if and when required.

Under wetter than normal conditions it could be advantageous to have additional water storage capacity available to provide flood mitigation for Bendigo. The mine water management infrastructure, or the mine voids themselves, could potentially provide some level of flood storage.

Table 3-3 presents a summary of three Bendigo flood events, their volumes and probability of occurrence. If flood storage were incorporated as part of the mine water management process, it is expected that this would require at least 500 ML of storage capacity to make a difference to the size of a flood event. The 2013 Bendigo Urban Flood Study (WaterTech, 2013) indicates that at Huntly, the March 2010 flood had a volume of approximately 2,500 ML and an annual exceedance probability (AEP) of 1 in <5. If the mine water management infrastructure included an additional flood storage of 500 ML this would be available to capture 20% of this event, but only 5% of the 1 in 50 year event. This volume would need to be available throughout the year and may not be feasible as an addition to the volume required to manage the mine water. During extreme flood events the mine water infrastructure is unlikely to be useful for flood management or mitigation, due to the large volumes of water involved in these events. The use of mine water management infrastructure for flood water storage therefore seems impractical.

Table 3-3: Bendigo Creek at Huntly flood events (WaterTech, 2013)

Flood event	Flood Volume (ML)	AEP (1 in x)
March 2010	2,500	<5
September 2010	4,500	5
February 2011	11,000	50

In addition, if the mine water infrastructure was used to temporarily store flood waters it is not clear how the resulting change in water quality would be managed. Based on the experience of mines in Queensland over recent wet years this water could possibly be discharged into Bendigo Creek under certain flow and water quality conditions; for example, when the flow is sufficient to dilute the mine water to an acceptable TDS concentration. Alternatively, the flood water could be managed as though it was originally part of the mine water, although this volume would need to be accounted for in the treatment design and may place a strain on operations.

3.8 Integrated water cycle management opportunities

Integrated water cycle management seeks to integrate all aspects of the urban water cycle (potable water supply, sewage and stormwater) to achieve social, environmental and economic benefits. The Office of Living Victoria (OLV) frames this as a "*better use of rainwater, stormwater and wastewater to deliver a more adaptable, resilient and cost effective water system*" (OLV, 2014). Often this involves the prioritising of fit-for-purpose water supply strategy, such as using non-potable water for industrial purposes. A common integrated water cycle management opportunity is to capture stormwater and treat it for non-potable reuse. This has the advantage of reducing demand for potable water for non-potable use and also reducing the strain on sewage systems, through the reduction of stormwater reporting to them.

In this instance there are several opportunities for integrated water cycle management. These include:

- Use of treated mine water for non-potable purposes, such as agriculture, aquaculture, industrial, irrigated parklands, etc.
- Diversion of stormwater to mine voids for later reuse

The non-potable water supply is currently met by Coliban Water, through their recycled water network, which has the capacity to supply approximately 2,000-3,000 ML/y of Class A water to sporting grounds, parks and schools in Bendigo (CW, 2012). As previously noted, the volume of treated water produced is often far in excess of the current demand and Coliban Water regularly discharges excess recycled water to Bendigo Creek.

The diversion of stormwater to mine voids for later reuse would need to be managed such that capacity was available in the mine voids during winter and spring, when floods typically occur. This implies that water extraction from the mine voids would need to be high during summer and autumn. If stormwater were stored in the mine voids it is likely that it would then require additional treatment, due to its mixing with mine water.

In order to be considered feasible these options would need to have sufficient demand for the water, be economically viable, and actually cheaper than the current potable supply. As Coliban Water is already producing recycled water (for non-potable use) which is in excess of current demand, these options are not considered worth pursuing at this stage. In addition, the treatment costs for mine water would make the options more expensive than potable water.

The Office of Living Victoria (OLV) announced a $1 million initiative to develop a whole of water cycle management strategy for Bendigo, in October 2014. This would provide an opportunity to consider how mine water could be incorporated in the long term management of water resources. However, the OLV was abolished in December 2014, following a change in government, and the current status of this initiative is not clear.

3.9 Short term mine water management challenges and opportunities

As the mine water is expected to reach a level at which uncontrolled discharge to the environment will occur by February or March 2015, a short term option is required which can be implemented quickly. This does not need to be the final solution, but one which can be implemented within the required timeframe, is technically suitable and can be maintained while a longer-term option is developed (expected to be 2 to 4 years).

This timeframe has been the primary driver for the development of the short term options. Key considerations have included:

- Implementation time – the timeframe is very short and limits options available to those using existing infrastructure and proven technical solutions.
- Use of existing infrastructure – given the short timeframe available the use of existing infrastructure is essential, as design and construction of new infrastructure could add in the order of 12 to 24 months to the project
- Lack of demand for additional water – frames short-term mine water management as a water disposal problem.
- Technically suitable – options need to be technically suitable to the water quality and required end use
- Economically feasible – given that there is no current demand for the mine water, cost is a significant consideration for the short term options.

The lack of clear responsibility for the mine water management and accountability for any uncontrolled discharge to the environment presents a challenge in terms of the funding, management and governance of short-term water management.

3.10 Long term mine water management challenges and opportunities

Longer-term mine water management options will be developed over the next 2-4 years and are expected to operate indefinitely, given the assumption that mining in Bendigo has ceased. Key considerations for the development of the longer-term options have included:

- Technically suitable – options need to be technically suitable to the mine water quality and required end use.
- Lack of current demand for additional water – frames this as a water disposal problem at the moment, but this could change over time and some flexibility may be required in the adopted solution.
- Implementation time – the implementation of the short term option provides time to investigate longer-term management options and potentially test their performance through pilot programs. This may be essential in identifying sustainable and cost-effective solutions for mine water management issues.
- Use of existing infrastructure – while the use of existing infrastructure may provide some cost and time savings, these should not preclude the consideration of options which do not rely on existing infrastructure.
- Economically feasible – given that there is no current demand for the mine water and hence no opportunity to offset water treatment costs by water sales, cost is a significant consideration for the longer-term options.

Again, the lack of clear responsibility for mine water management challenge presents a challenge in terms identifying, implementing and maintaining funding for a response.

3.11 Engaging the community

While specific responsibilities remain unclear, the future management of mine water is primarily a "Bendigo" issue. The Bendigo community and its environment will be affected by filling of the mining voids and uncontrolled mine water discharge and will also be the primary beneficiaries of any management scheme. Financial resources to fund the development and/or operation of whatever long-term measures are settled on will most likely be at least partly sourced locally.

To the extent that the future management of mine water involves disposal by evaporation, it is also possible that some members of the Bendigo, or wider, community will be adversely affected.

Given this context, it is essential that there is engagement with the Bendigo community to build the social licence for longer-term mine water management options.

3.12 Management of salt and brine

Treating mine water for beneficial use or release to the environment inevitably results in a brine waste stream being generated, requiring ongoing management. Historically, the Woodvale Ponds have been used for this purpose and they are proposed in this report for the short term options, due to the limited time available for implementation of any other mine water management process.

Although there are several points in favour of using the Woodvale Ponds for the longer-term options (e.g. already approved and constructed facility and pipeline) there are also a number of drawbacks. These include a community expectation that the facility will close and be rehabilitated, as well as potential mining legacy issues associated with the site. URS (2013) observed that seepage from the ponds has created a groundwater mound beneath the site, with elevated salinity levels. Arsenic appears to be held in the sediments beneath the ponds and is not mobilised. Although the risk to the environment and beneficial uses has been assessed as low, groundwater in this area will require ongoing monitoring (URS, 2013).

An alternative to the Woodvale Ponds is therefore likely to be preferred as part of the longer-term mine water management. Potential alternatives include:

- A new, purpose built facility (in the order of 30 ha, depending on storage requirements and final design)
- Use of a regional brine disposal facility
- Upgrade and use of the Coliban Water brine ponds

While a regional brine disposal facility is currently under discussion, this is still at a conceptual level and it is not clear how likely it is to actually be implemented. In addition, the cost of transporting brine to a facility distant from Bendigo is likely to be extremely high. For the purpose of this investigation it has therefore been assumed that a new facility or an upgrade of the Coliban Water facility will be required.

A number of the options outlined for the longer-term require a closed storage facility, one with no outflows and which will store and evaporate the entire volume of the untreated discharge. For the purpose of this report, such a facility is referred to as an *evaporation facility*. Other options require a facility which will store and evaporate the waste stream of a water treatment process, generally consisting of clarifier and filter waste and RO reject brine. For the purpose of this report, such a facility is referred to as a *brine facility*.

In both cases the facilities will accumulate salts, including arsenic and other metals and will need to be cleaned out on a periodic basis. The accumulated salts and sediments will need to be removed and disposed in a landfill facility. Depending on the final concentration of arsenic and other constituents, this may be classified as Category B prescribed waste, requiring disposal at an appropriately licenced landfill facility (e.g. the Lyndhurst Landfill facility, approximately 180 km from Bendigo). The frequency of cleaning will vary, depending on the design of the facility and the salt load entering it. It is expected that the initial design of the facility will incorporate sufficient salt storage such that cleaning is only required every 20 years or more.

An alternative method of managing the residual salts is to allow their accumulation over the long term (e.g. 50 years), until the facility or one of the individual ponds is essentially full. The full pond/s would then be decommissioned and capped so that the concentrated brine salts cannot leak out; much like a landfill is managed. This would remove the need to periodically empty out the ponds and dispose of the waste, but does mean that replacement ponds will ultimately be required. If this method of salt management is selected, it is recommended that a new site be selected with sufficient land that expansion can take place as and when required. Land use planning should be used to support on-going operation of the facility.

The recent water quality samples collected by URS (2014) found that the salt concentration in mine water ranged between about 4,000 mg/L and 5,000 mg/L, with a median value of 4,160 mg/L. This equates to a salt load of 4-5 t/ML of mine water. At the expected discharge volume of 730 ML/y this will result in a salt load of 2,900 to 3,700 tonnes per year (median 3,000 tonnes per year). If the total volume of untreated water was being sent to a facility of an equivalent size to the Woodvale Ponds this would equate to a *precipitated* accumulation of 6-7 mm/y. However, allowing the ponds to dry out may generate dust and the ponds should always contain some water or have alternate dust management protocols in place. (For example, previously a solution was sprayed on Pond 6 to seal the top sediments of the pond to prevent dust.) The salt will therefore sit in some volume of water and the annual accumulation of salts will need to be considered in the facility design and operations.

The accumulated salt load in any *brine facility* will vary according to the final water quality of the treated discharge.

3.13 Summary of context for the development of mine water management options

If the current management strategy (pumping from Central Deborah to the Garden Gully line) continues it is expected that uncontrolled discharge will occur by February or March 2015. If this occurs the Bendigo Trust will have to cease their pumping into the Garden Gully line. This will cause water levels in Central Deborah to rise, making sections of the tourist mine inaccessible and leading to the closure of all of the underground tours. In addition, the rising water levels would create uncontrolled discharges to the environment, affecting Bendigo Creek and local watercourses, as is already occurring on Bendigo Creek at Hustler's Royal No. 2 shaft.

Through discussions with industry it was concluded that there is no current demand for additional non-potable water in the Bendigo region, beyond what Coliban Water is already producing. This is a key challenge for the management of the mine water in Bendigo and frames the future management of Bendigo's mine water as an ongoing waste disposal problem.

In the short term, a mine water management option needs to be adopted which is technically feasible and can be implemented very quickly. This option will therefore rely on existing infrastructure, as new infrastructure cannot be approved and constructed in time to avoid uncontrolled discharge of mine water to the environment.

In the longer-term, alternative options may be developed which do not rely on existing infrastructure, although the use of existing infrastructure may provide cost savings. The longer-term option adopted should provide a technically sound, cost effective solution which is acceptable to the community.

Part B Water quality and treatment technologies

The following section provides an overview of the water quality data available to characterise the mine water and identifies the constituents of concern. A review is also provided of the water treatment options available which can treat the mine water to a quality suitable to a range of end uses.

4. Mine water quality

4.1 Historic mine water data

Table 4-1 provides a representative summary of the historic water quality profile in the Central Deborah Shaft and at New Moon, two key areas of interest for future mine dewatering to control local mine water levels. The sources for this summary are:

- Water Quality Data DELWP, 24/4/2014 to 28/4/2014
- Water Quality Data Unity Mining (Supplied by DELWP), 11/5/2010 to 10/11/2011
- Collated data summarised in Table 5 of *Bendigo Goldfield Mine Dewatering Preliminary Assessment*; Australian Groundwater Consultants Pty Ltd (AGC): December 1983

Table 4-1: Summary table of historic water quality data for Central Deborah Shaft and New Moon Shaft

Parameter	Unit	Background monitoring - Median Values (DELWP, n=4) (or detection level)	Central Deborah and New Moon Shaft	
			Range of Median Values from data sets (or detection level)	Data Set
Arsenic	mg/L	-	2.2	AGC
Arsenic (Filtered/Dissolved)	mg/L	0.004	2.53-3.3	DELWP, UM. NB Total and filtered values similar, indicating arsenic is fully dissolved, not particulate
Barium (Filtered/Dissolved)	mg/L	0.006	0.07	DELWP
Cadmium	mg/L	-	Detection - 0.02	AGC
Calcium	mg/L	112	110-120	DELWP, AGC
Chromium	mg/L	-	Detection - 0.06	AGC
Copper	mg/L	-	0.01	AGC
Cyanide	mg/L	-	Detection - 3.8	AGC
Fluoride	mg/L	0.95	0.6	DELWP
Hydrogen Sulfide	mg/L	-	2.4	AGC
Iron	mg/L	-	0.34	AGC
Iron (Filtered/Dissolved)	mg/L	Detection – 0.05	2.56 (0.025)	DELWP – (UM filtered value significantly lower suggests oxidation and sedimentation has occurred in sample)
Lead	mg/L	-	Detection - 0.04 and 0.003	AGC
Magnesium	mg/L	402	222-330	DELWP, MCL, AGC
Manganese	mg/L	-	0.71	AGC
Mercury	mg/L	Detection – 0.0001	Detection - 0.0001	DELWP, AGC Limit of detection typically <0.0001
Nickel	mg/L	-	0.017	AGC
Silica	mg/L	-	29	AGC
Sodium	mg/L	1515	918-1100	DELWP, AGC
Sulfate	mg/L	709	339-550	DELWP, UM
Sulfide	mg/L	-	25	AGC
Zinc	mg/L	-	0.05	AGC
Zinc (Filtered/Dissolved)	mg/L	0.013	Detection - 0.012	DELWP, UM
COD	mg/L	22	20-75	DELWP, AGC
Dissolved Oxygen	mg/L	-	0.6	AGC
EC	µS/cm	10750	6270-6890	DELWP, UM, AGC
pH	pH	-	6.9-7.0	UM, AGC, DELWP
Hardness	mg/L as CaCO3	-	1234	AGC

Parameter	Unit	Background monitoring - Median Values (DELWP, n=4) (or detection level)	Central Deborah and New Moon Shaft	
			Range of Median Values from data sets (or detection level)	Data Set
Total Alkalinity	mg/L as CaCO3	724	492	DELWP
TDS	mg/L	6990	4145-4310	DELWP, UM, AGC
Total Suspended Solids	mg/L	34	11-20	DELWP, AGC

- DELWP = DELWP Sampling and Testing Regime Data, 24/04/2014-28/04/2014
- UM = Historic BML Data from New Moon Shaft 28/01/2010-30/11/2011, provided by DELWP
- AGC = Australian Groundwater Consultants Report, Dec 1983, Table 5. Collated historic data from Central Deborah and New Moon, July 1980 – October 1983

Water quality data was also made available for a range of other shafts in the mine system, which UM previously dewatered from (Carshalton Shaft and Adam St Shaft), and which DELWP has been monitoring recently (Eureka, Golden Square, Jackass Flats, Kennington). This additional data has been included in Appendix A.

4.2 Key constituents

The Central Deborah and New Moon water quality data indicate that the local mine water typically has moderately high Total Dissolved Solids levels (in the brackish range), in line with the local groundwater. The mine water also has relatively high levels of alkalinity, hardness, iron and manganese, compared to local surface water. The variability in iron data, particularly the variation between DELWP and UM data for filtered/dissolved iron, suggests the iron is dissolved in the mine water, but oxidises and precipitates readily.

Arsenic levels in the mine voids are elevated and much higher than in the surrounding groundwater. Given the similarity in filtered and total values, arsenic in the mine voids appears to be dissolved rather than particulate. The analyses do not identify the form of the dissolved Arsenic; however, historically reducing groundwater conditions tend to favour the Arsenite As (III) form, over Arsenate As (V). The elevated level of sulfate is typical of groundwater where there is leaching from rock. In the reducing groundwater conditions, the high levels of sulfide and hydrogen sulfide are also to be expected.

According to the data provided in the AGC Report, December 1983, there have been historic detections of various heavy metals in the mine water in Central Deborah. The detections of cadmium and cyanide are more likely to be the result of contamination, rather than natural occurrence. The detections of nickel, chromium, zinc and lead may be a combination of trace levels naturally occurring, and historic contamination.

4.3 Target water quality criteria

The following section provides an overview of the target water quality criteria, given the following assumed general end uses of the water:

- Discharge to holding ponds for evaporation
- Discharge to environment (local waterway), as environmental flows or for irrigation extraction
- Discharge to land as irrigation water

4.3.1 Discharge to evaporation ponds

Salts and other constituents in mine water discharged to an evaporation pond remain within the pond and have no further interaction with the environment or water users. EPA requirements specify that evaporation ponds are impermeable.

On this basis, no treatment of mine water is required prior to it being discharged into an evaporation pond. Over time, it is expected that hydrogen sulfide would be released to the atmosphere from the pond surface as it evaporates. All other constituents of concern would be retained in the solid waste residue in the ponds. The hydrogen sulfide odour could cause a nuisance and a more controlled method of stripping and venting may be required.

4.3.2 Discharge to the environment

Discharge to the environment is likely to be required to be licenced by EPA and in accordance with the water quality criteria set out in the *State Environment Protection Policy* (SEPP) – Waters of Victoria. Water quality specifications will vary according to the type and location of the discharge (e.g. discharge to a lake or a watercourse).

An EPA discharge licence was previously held by Bendigo/Unity Mining for discharge of treated mine water to the environment. The details of this licence were obtained from the *Works Approval Application, New Moon Water Treatment Plant Upgrade*, Bendigo Mining: January 2006. The licence allowed the discharge of RO treated water to Lakes Neangar and Tom Thumb, with irrigation extraction from Lake Tom Thumb by Eaglehawk golf club.

Although this EPA licence may have lapsed, it is likely to be indicative of the water quality limits that would need to be met by any future discharge to the environment, particularly direct to a waterway. Water quality parameters for this licence are presented in Table 4-2.

Table 4-2: EPA Licence ES52878 water quality conditions

Characteristic	Unit	Bendigo/Unity Mining Licence conditions (ES52878)
pH	pH units	6.5-8.5
TDS	mg/L	1000
DO	µg/L	600
Turbidity	NTU	25
TSS	mg/L	25
Arsenic	µg/L	50
Iron	µg/L	300
Manganese	µg/L	100
Mercury	µg/L	0.05
Sulfide	µg/L	1
Zinc	µg/L	8

4.3.3 Discharge to Coliban Water for irrigation use

Coliban Water has previously agreed to accept treated mine water into its recycled water system, supplying local irrigation schemes. It is expected that if Coliban Water was to accept treated mine water again, for supply to irrigators, the water quality limits would be similar to its historic targets as outlined in Table 4-3 below.

The targets presented in Table 4-3 are quite stringent and in the majority of cases are much more stringent than the recycled water guidelines and ANZECC fresh water quality guidelines. The basis for the adoption of these values by Coliban Water is not clear.

Table 4-3: Historic Coliban Water water quality requirements for acceptance of treated mine water compared with guidelines

Characteristic	Unit	Coliban Water Indicative Acceptable Range (until 31 July 2007)	Current Guideline levels		
			Recycled water guidelines (EPA, 2003)	Guidelines for wastewater irrigation (EPA, 1991)	Fresh water quality guidelines (ANZECC, 2000)
Suspended Solids	mg/L	≤ 0.1	<5 Class A	-	<40 (aquaculture species)
Iron	mg/L	≤ 0.2	-	5	ID
Manganese	mg/L	≤ 0.1	-	0.2	1.9
Total Dissolved Solids	mg/L	≤ 200	-	0-175 (most plants), 175-500 (plants with moderate salt tolerance)	-
pH	pH units	6.5-8.5	6-9 Class A,B,C,D	-	-
Arsenic	mg/L	≤ 0.02 (Subject to discussion following commissioning of the plant)	-	0.10	AS III 0.024 AS V 0.013
Zinc	mg/L	≤ 0.006	-	2.00	0.008
Mercury	mg/L	≤ 0.00005	-	ID	0.0006
Sulfide	mg/L	≤ 0.0006	-	-	-
Nitrogen	mg/L	≤ 0.5	-	-	0.7
Aluminium	mg/L	≤ 0.1	-	5.00	0.055
Silver	mg/L	≤ 0.1	-	-	0.00005
Chromium	mg/L	≤ 0.00005	-	0.10	0.001
E. Coli	100 mL	0	<10 Class A	-	-

EPA (1991), *Guidelines for wastewater irrigation*. Table 3: Recommended maximum concentrations in irrigation waters and Table 4: Salinity classes of irrigation waters.

EPA (2003) *Use of reclaimed water*. Table 1: Classes of reclaimed water and corresponding standards for biological treatment and pathogen reduction.

ANZECC (2000), *Water quality guidelines – Volume 1*. Table 3.4.1: Trigger values for toxicants (at 95% level of protection)

ID = insufficient data to derive a reliable trigger value

5. Mine water treatment process options

The following section describes the treatment processes available for the removal of individual constituents of concern as well as the treatment of the combination of constituents found in the Bendigo mine water. Key constituents of concern are arsenic, iron, manganese, sulfide, sulfate and Total Dissolved Solids (TDS).

5.1 Treatment processes for removal of individual constituents

5.1.1 Arsenic treatment options

Arsenic in groundwater

Dissolved arsenic is typically present in reducing groundwater conditions in its trivalent arsenite As(III) form. Arsenite is not easily removed from water, other than by the Reverse Osmosis process. Therefore, it is usual for groundwater with high arsenite levels, to be dosed with a chemical oxidant, such as chlorine, potassium permanganate or ozone, to oxidise the arsenite to pentavalent arsenate As (V) form. Arsenate is more readily treated by a range of process options. The treatment process for the removal of arsenic in groundwater is summarised in Figure 5-1.

Under certain circumstances, it is possible for groundwater to naturally contain predominantly arsenate As (V) rather than arsenite As (III). Arsenite forms are more mobile and more toxic to biological species than arsenate forms (Kersten, 1988) and will require different treatment processes. It is expected that suitable sampling and testing will be conducted to establish the form of arsenic in the Bendigo mine water, to allow the treatment process Contractor to select the most suitable process for arsenic removal, in conjunction with considerations of treatment for other constituents of concern.

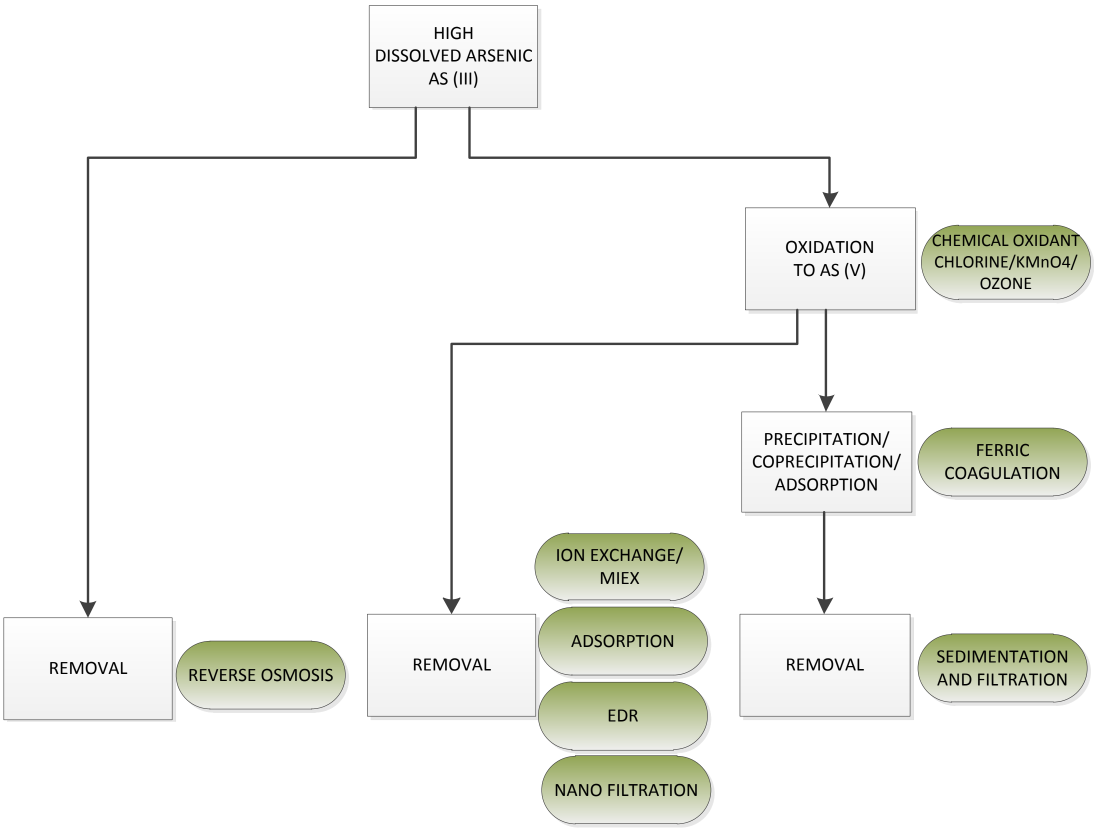

Figure 5-1: Treatment processes for removal of dissolved arsenic in groundwater

Dissolved arsenic treatment with conventional coagulation

Arsenic levels can be significantly reduced, once arsenic has been oxidised to its arsenate As (V) form. The most common and cost-effective treatment for arsenate is by conventional coagulation, flocculation sedimentation and filtration process.

Conventional coagulation and flocculation doses metal salts to destabilise and precipitate charged colloidal particles to form and aggregate floc particles with sufficient weight to settle out of the water and size to be trapped in filters. The precise mechanism by which arsenic levels are reduced in the coagulation process is not yet fully understood, but it is generally agreed to be a combination of precipitation, co-precipitation and adsorption on other particles.

Removal of arsenic is significantly enhanced when precipitating iron is present in the water. Various coagulants have been reported as effective for arsenic removal; however, the dependence on the presence of iron makes ferric salt coagulants like ferric chloride preferred.

A process comprising chemical dosing, coagulation, and flocculation, and settling in a sedimentation tank/clarifier; and filtration will collect iron and arsenic particulates as well as turbidity in waste streams as settled sludge from the sedimentation tank/clarifier and filter backwash from the filter. The filtrate will provide a clear, low arsenic concentration filtered water as the “product water”. The waste streams would typically comprise 5% of the volume of treatment process throughput with 95% recovery as “product water”.

However, the salinity of the water (TDS or EC) is not reduced by this process and is usually increased by the coagulant and pH adjustment.

The waste stream would contain 20 times the concentrations of the contaminants removed compared to their concentrations in the untreated mine water, and with arsenic and other heavy metals may have to be dewatered and disposed to a secure licensed landfill. The landfill facility will need to be licenced to accept the specific concentrations of contaminants in the waste stream, and the concentrated arsenic and TDS levels may be problematic.

The solid waste stream would be considered an industrial waste, with disposal governed by the EPA. The constituent levels in the waste steam will dictate the type of secure landfill at which the waste can be disposed, with landfill categories prescribed by the EPA. Based on expected arsenic levels, the waste may well be a Category B Prescribed Waste at least. This limits the landfill options available within Victoria to the Lyndhurst Landfill facility (also known as the Taylors Road Landfill), located 30km south east of Melbourne, and approximately 180 km from Bendigo.

Dissolved arsenic alternative treatment processes

There is a range of specialty technologies capable of targeting and removing dissolved arsenic, in arsenate As (V) form. However, it should be noted that while these technologies can be very successful in treating high concentrations of arsenate in water, they may not operate effectively in the presence of other constituents often found in groundwater, some of which are present in Bendigo mine water. For this reason, these technologies tend to be limited in their application to situations where the feed water quality is, in all other respects, of good quality, i.e. low iron, manganese, turbidity, sulfate and TDS concentrations.

The alternative technologies that can effectively remove arsenic, under suitable water quality conditions, are:

1) **Adsorption** – arsenate adsorbs to granular particles, in a granular media filter. Adsorbents include activated alumina, ferric hydroxide and titanium oxide. Each particular media type has a range of target constituents, which includes arsenic. When certain of these other constituents are present in the groundwater, they can compete for adsorption space on the media with arsenic, or can replace adsorbed arsenic, releasing arsenic back into the water stream. Adsorption media are either single use, and must be disposed of to land fill, or is regenerated periodically using chemicals producing a contaminated regenerant chemical waste stream.

2) **Ion exchange** – using a Strong Base Anion (SBA) resin – arsenate is removed from water by a process of anion exchange between anions (arsenic) in the aqueous phase with anions in the solid resin phase. High TDS and sulfate concentrations in the water compete with arsenic for resin exchange sites and reduce the effectiveness of the process to remove arsenic. **MIEX**, or Ion Exchange with Magnetic Properties, is a proprietary process very similar to traditional ion exchange, in which the ion exchange resin beads are given a magnetised component and are fed into a clarifier process, rather than used in a static filter bed. Similar issues occur as for ion exchange, with competition from other ions for exchange sites. All ion exchange resins are regenerated periodically using chemicals producing a contaminated regenerant chemical waste stream.

3) **Membranes** – Reverse Osmosis (RO) membranes are capable of rejecting arsenite As (III) without oxidation to arsenate As (V). This is the only technology reliably capable of doing so. Nanofiltration (NF) membranes are capable of rejecting dissolved Arsenate As (V).

   Membranes require significant pre-treatment to ensure all particulates which could mechanically damage or chemically or biologically foul the membranes have been removed, and add chemicals to control dissolved constituents to prevent scaling, and fouling. Pre-treatment with conventional coagulation and filtration is standard, and it is therefore likely that the majority of the dissolved arsenic will be removed in the pre-treatment rather than at the membranes.

4) **Electro Dialysis Reversal (EDR)** – Uses ion exchange resins in sheet membrane form, with an electrical current applied. The membrane system can successfully reject arsenic while operating under more difficult water quality conditions than RO and NF membranes. While EDR membranes have better tolerance to moderate suspended solids, and iron and manganese compared with RO and NF membranes, feed water requirements are still strict, and it is expected the required pre-treatment processes will reduce arsenic concentrations significantly, prior to reaching the EDR membrane.

5.1.2 Iron and manganese treatment

Iron and manganese in groundwater

Dissolved iron and manganese are common constituents in reducing groundwater conditions. Particulate iron and manganese can also be present, and will be removed in a conventional sedimentation and filtration plant. The treatment process for removing dissolved iron and manganese in groundwater is summarised in Figure 5-2.

The soluble iron and manganese in groundwater will generally precipitate when exposed to dissolved oxygen, as well as other oxidants. The susceptibility to precipitation in presence of DO means iron and manganese are usually removed upstream of storages and distribution systems, to prevent uncontrolled sedimentation, and the associated turbidity and bio-fouling risks.

Iron and manganese are also removed upstream of filtration membranes and Reverse Osmosis membranes, to prevent fouling and damage to these processes.

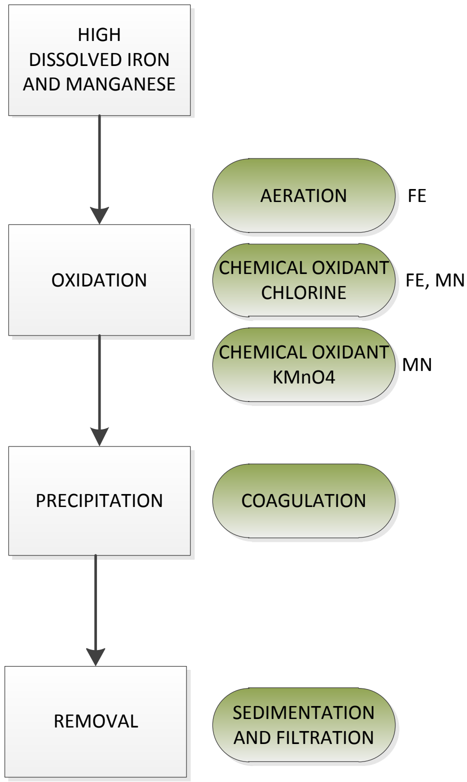

Figure 5-2: Treatment processes for dissolved iron and manganese in groundwater

Aeration to oxidise soluble iron and manganese

Aeration to introduce DO to groundwater is a very simple and effective method of oxidising iron. Iron will fully oxidise with a short detention time of around 30 minutes. However, the manganese oxidation rate with DO can be slower, requiring a detention time of some hours to fully oxidise and precipitate. It is not usually practical to supply a detention time sufficient for manganese removal by aeration alone. Therefore, if aeration is selected for iron oxidation, a two-stage process is typically required, with a chemical oxidant such as chlorine dosed before or after the aeration unit, to oxidise manganese swiftly.

A simple aeration installation followed by coagulation and flocculation in a clarifier will oxidise and precipitate iron very successfully, for removal by sedimentation. This aeration method also has capacity to strip hydrogen sulfide from groundwater. Examples of aeration facilities are presented in Figure 5-3, Figure 5-4 and Figure 5-5.

Figure 5-3: Example of spray aeration at Western Australian Groundwater Treatment Plant

Figure 5-4: Example of cascade aeration unit

Figure 5-5: Proprietary Lakeside cooling tower treating (cooling and aerating) bore water

Chemical oxidation to oxidise soluble iron and manganese

A variety of oxidants can be dosed to oxidise iron and manganese, including chlorine, and potassium permanganate. Chlorine oxidation of manganese occurs at a faster rate than aeration, but is pH dependent, and may require pH correction to minimise the detention time required for oxidation and precipitation. The advantage of using chlorine to oxidise manganese, and arsenic from As (III) to As (V), is that chlorine may already be available for post-treatment disinfection, thereby consolidating the number of chemicals held on site.

The oxidation of manganese with potassium permanganate $KMnO_4$ is almost instantaneous, removing the need for any significant detention time; however, it is more expensive than chlorine, introduces an additional chemical process to the site, and requires careful dose control following manganese concentrations in the feed water, to prevent an excess of permanganate in the water, and resulting colour issues.

Coagulation and flocculation in a clarifier will coagulate precipitated oxidised manganese for removal by sedimentation.

5.1.3 Sulfide and sulfate treatment

Sulfide and sulfate in groundwater

Sulfate is typically present in groundwater due to leaching from rock. Reducing groundwater conditions can sometimes result in high levels of hydrogen sulfide, which is a produced by the reduction of sulfate by sulfur reducing bacteria, and hydrolysis of soluble sulfides.

Hydrogen sulfide removal processes

Aeration - Where odour generation is not a concern, a simple aeration system can be used to strip gaseous hydrogen sulfide from groundwater. Granular Activated Carbon (GAC) can be used as a means of removing hydrogen sulfide gas from an air stream; however, groundwater aeration units are not typically designed for easy collection of the stripped hydrogen sulfide.

It should be noted that hydrogen sulfide in groundwater passes through reverse osmosis membranes. Therefore, it is possible to conduct aeration as a post-treatment process downstream of membranes, as well as the typical pre-treatment process. Careful consideration needs to be given to post-treatment chemical dosing, to ensure that pH and alkalinity stability are attained, even though carbon dioxide may also be stripped in the post-treatment aeration process, as well as hydrogen sulfide.

Chemical oxidation - Hydrogen sulfide can also be removed through oxidation, typically with chlorine or precipitation using ferric salts to form insoluble ferric sulphide precipitate. Significant dose rates are necessary to ensure complete oxidation to sulfate. Incomplete oxidation results in production of elemental sulfur, which can be treated for removal as a suspended solid, but can also form polysulfides which have their own taste and odour issues, and can react and form insoluble sulfides downstream. The difficulty in ensuring complete hydrogen sulfide oxidation using a chemical oxidant, favours the use of aeration, provided odour issues can be controlled.

Figure 5-6 presents a summary of the treatment processes for hydrogen sulfide.

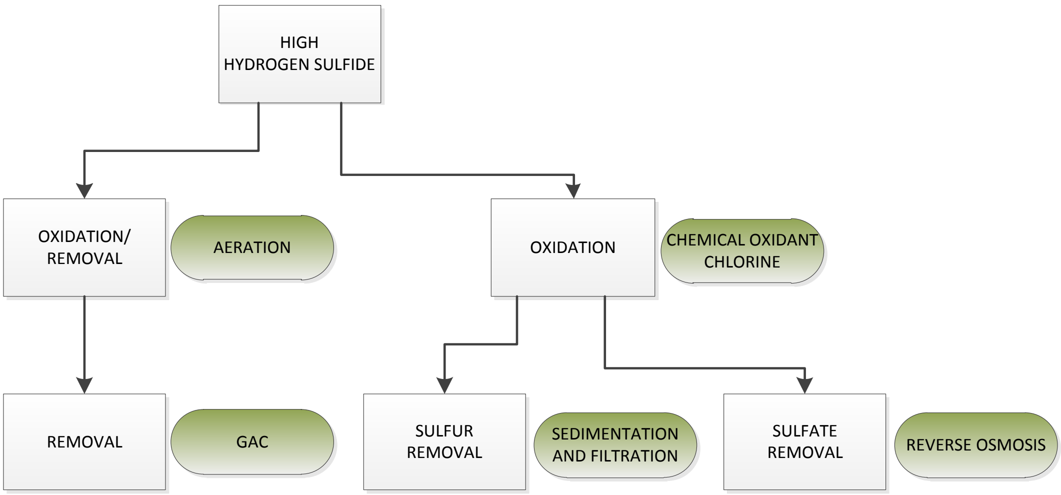

Figure 5-6: Treatment processes for hydrogen sulfide

Instream process - A Granular Activated Carbon (GAC) filter process may be effective in removing dissolved hydrogen sulfide from groundwater by adsorption. The GAC filter would need to be designed based on the levels of dissolved hydrogen sulfide in the groundwater, and the flow rate of water to be treated. The filter's effectiveness would be dependent on the contact time achieved, ie the filter bed volume, in particular the filter bed depth.

It is expected that such a GAC filter would need to be fully enclosed, operating as a pressure media filter. This is necessary to prevent the dissolved iron in the groundwater coming in contact with air, oxidising and precipitating. Precipitating iron would quickly clog the GAC filter, and prevent effective or efficient operation.

The GAC filter would only be suitable provided the particulates in the groundwater were minimal (including precipitated iron). Normally, GAC filters used in treatment plants for taste and odour removal, would be located downstream of sand media or membrane filtration, to protect the effectiveness of the GAC filters.

The GAC filter would need a backwash water system, i.e. a clean water supply to remove particulate matter that accumulates in the filter bed. There would also need to be a waste wash water disposal method. A GAC filter will not address the variety of other constituents of concern in the Bendigo mine water, nor would it operate as a passive system.

Sulfate removal processes

Most sulfate salts are highly soluble. In the presence of general high TDS, the only effective method to remove sulfate from water is Reverse Osmosis. If TDS were not a consideration, Ion Exchange could be used to remove sulfate. Figure 5-7 presents a summary of the treatment processes for sulfate.

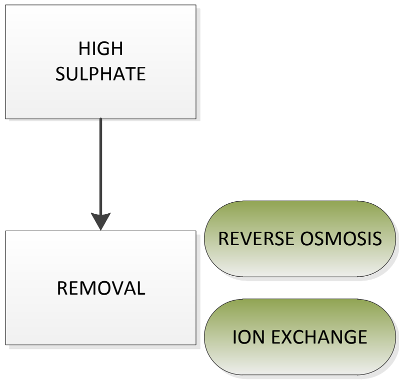

Figure 5-7: Treatment processes for sulfate

5.1.4 TDS treatment

Total dissolved solids in groundwater and removal

The Total Dissolved Solids (TDS) concentration of groundwater can vary from “freshwater”, <1000mg/L, to “brackish“, 1000-10,000mg/L, to saline or hyper-saline, 40,000 mg/L plus. The Bendigo mine water is measured in the middle of the brackish range. The TDS of the Bendigo mine water, in addition to NaCl, has a significant contribution from hardness (calcium and magnesium), alkalinity, sulfate and silicate.

Ion exchange can be used to reduce TDS; however, it is more usually applied to target particular problem constituents. Reverse osmosis after appropriate pre-treatment, is the more reliable option to remove all TDS, to meet strict water quality targets. Figure 5-8 presents a summary of the treatment processes for TDS.

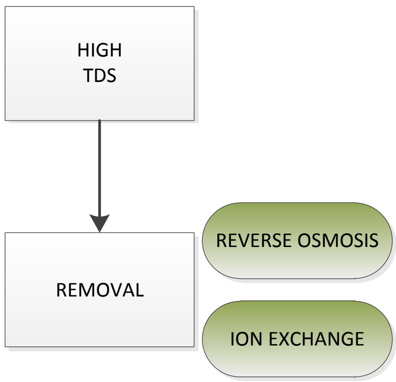

Figure 5-8: Treatment processes for TDS

5.2 Treating combination of constituents in Bendigo mine water

If the mine water is intended for discharge to the environment (local waterway), as environmental flows or for irrigation extraction, or as discharge to land as irrigation water, then based on the target water quality criteria presented in Section 5.1 a “stepped approach” is necessary to effectively remove all of the constituents of concern. It is not possible to effectively treat all the constituents of concern in a single process. Treatment will need to consist of a series of processes, each of which will address several constituents. The order of the processes is also critical to the overall effectiveness. The existing treatment plant at the New Moon site is a good example of this stepped approach.

5.2.1 Arsenic treatment in conjunction with Iron, Manganese and TDS

As presented in Section 4.1, there is a range of technologies capable or reducing the level of dissolved arsenic or iron and manganese or sulfide in water. However, with the presence of other constituents like TDS, dissolved iron and manganese, the range of practical treatment processes is reduced significantly and to the extent that any one of these processes is unlikely to reduce all constituents in the treated water to concentrations acceptable for the end use options listed above.

Iron and manganese levels need to be reduced, in order to meet likely water quality targets for discharge to environment or recycled use by irrigators. The most straightforward and cost-effective process for iron and manganese treatment is oxidation and coagulation to promote precipitation and sedimentation. Arsenic levels can be significantly reduced by this same treatment process, and the removal is enhanced in the presence of precipitating iron. Therefore, it is proposed that the majority of dissolved arsenic in the Bendigo mine water should be removed in a pre-treatment process of chemical oxidation, ferric coagulation and flocculation in a conventional clarifier

TDS levels also need to be reduced, in order to meet likely inland surface water or irrigation water quality targets. High TDS can only be reliably reduced by Reverse Osmosis membranes. The Reverse Osmosis membranes require protection from potential fouling constituents, which makes it necessary to remove the majority of dissolved iron and manganese in the groundwater ahead of the membranes. Any dissolved arsenic remaining after the oxidation and precipitation process, will be removed by the RO membranes.

It is expected that the processes described above will reliably remove arsenic as well as iron, manganese, sulphide and turbidity and salinity in the treated water to concentrations acceptable for the end use options listed above.

5.2.2 Hydrogen sulfide treatment in conjunction with Iron, Manganese and Sulfate

The need to remove iron and manganese ahead of the Reverse Osmosis membranes, described in Section 5.1 above, means the feedwater must undergo oxidation pre-treatment. Hydrogen sulfide will be simultaneously oxidised.

Chemical oxidation of hydrogen sulfide to sulfate requires a large oxidant dose rate. If it is feasible, from an odour release perspective, to strip hydrogen sulfide gas to atmosphere through an aeration process, this process will significantly reduce chemical use. A pre-treatment aeration process would have the additional advantage of oxidising dissolved iron, further reducing the chemical oxidant dose rate to the feed water.

If hydrogen sulfide cannot be released to atmosphere, then full chemical oxidation of the feed water will be required. The dose rate will need to be sufficient to oxidise all iron, manganese, arsenic and hydrogen sulfide, ensuring complete oxidation to sulfate, to avoid other odour issues associated with incomplete H_2S oxidation.

The sulfate in the water downstream of the oxidation process will be removed at the Reverse Osmosis membranes, which are already required to remove TDS.

5.3 Alternative treatment technologies

There are two alternative treatment technologies which have been reviewed for this project; constructed wetlands and permeable reactive barriers. These treatment technologies have been used with success in numerous situations worldwide and are considered worth investigating in this instance. However, at this stage additional information is required in order to confirm whether or not these options will produce the required water quality. These options should be considered further, but with some caution until additional investigations are completed.

5.3.1 Constructed wetlands

Constructed wetlands use a combination of biological and mechanical functions to reduce or eliminate water borne contaminants (ITRC, 2003). There are three general designs: aerobic wetlands, anaerobic horizontal-flow wetlands, and vertical-flow ponds (vertical-flow wetlands), and their selection is based on the biological and chemical processes required, along with water flow direction (ITRC, 2003). Initial water quality data (Table 4-1) indicates that an aerobic wetland could be suitable to treat the Bendigo mine water.

The primary contaminant removal mechanisms for metals are (ITRC, 2003):

- filtration of solids,
- sorption onto organic matter,
- oxidation and hydrolysis,
- formation of carbonates,
- formation of insoluble sulfides,
- binding to iron and manganese oxides,
- reduction to non-mobile forms by bacterial activity, and
- biological methylation and volatilization of mercury.

Removal efficiency is usually a function of residence time within the wetland; therefore, constructed wetlands may require large areas to meet the required water quality criteria. The typical removal efficiencies observed in wetlands treating metal mine drainage (Table 5-1) indicates that this is likely to achieve a suitable water quality to discharge to Bendigo Creek, although salt removal is less certain and is discussed below. The arsenic removal in constructed wetlands has been observed to vary considerably; Kadlec and Wallace (2008) quote a median reduction in 22 systems of 29% with a maximum reduction of 99%.

Table 5-1: Typical range of removal efficiencies observed in wetlands constructed to treat mine drainage (ITRC, 2003)

Parameter	Coal Mine Drainage	Metal Mine Drainage
pH	>6	>6
Acidity	75-90%	75-90%
Sulfate	10-30%	10-30%
Iron	80-90+%	80-90+%
Aluminium	90+%	90+%
Copper	Not measured	80-90+%
Zinc	Not measured	75-90+%
Cadmium	Not measured	75-90+%
Lead	Not measured	80-90+%

While it is generally thought that constructed wetlands do not remove salts, a recent paper has suggested that halophytic plants could reduce salinity levels (Shelef *et. al*., 2013), with trialled *Bassia indica* plants accumulating sodium at up to 10% of their dry weight. *B.indica* is an annual plant and grows very quickly. Each plant can accumulate up to 9 kg of dry weight in 2-4 months, indicating a high potential to affect water quality (Shelef *et. al.*, 2013). Shelef *et. al.* (2013) suggest that the harvested *B.indica plants* could be used as stock feed, although in this case the plants would require testing to ensure the fodder was suitable for animal consumption. Other halophytic plants have been successfully trialled for stock feed purposes (Malik, et al., 1986; and Yensen, 2006, in Khan et al., 2008) and may also be suitable.

Constructed wetlands have been used at several mine sites in the Northern Territory (DME, 2008). The Ranger Uranium Mine in the Northern Territory has been operating a constructed wetland since 1995. This has been found to effectively treat uranium, manganese and nitrates. The wetland consists of seven ponds with a total capacity of 50 ML, a flow path of 1 km and treats approximately 3.0 ML/d.

Within Victoria, constructed wetlands are generally used to regulate the volume and quality of stormwater runoff. For example, Ballarat has seven constructed wetlands for stormwater management, targeting sediment, nutrients, and household and industrial chemicals. A constructed wetland was recently incorporated in the design of a housing development at McIvor Forest, Bendigo, for similar purposes.

Further investigation is required to inform a suitable wetland design, in addition the final water quality criteria will need to be discussed with the EPA.

5.3.2 Permeable reactive barriers

A permeable reactive barrier (PRB) is a zone of reactive material that extends below the soil surface, intercepting and treating groundwater. The PRB is not a barrier to groundwater, but it is a barrier to the contaminants within the water, which are treated and/or removed by the reactive material (USEPA, 2008). While PRBs have been used in the USA since 2000 (Wilkin and Puls, 2003) there has been limited application of this technology with Australia.

Figure 5-9 presents a schematic of example PRB configurations, with the most common types being the continuous wall, and funnel and gate.

Treatment methods are generally through sorption or precipitation, chemical reaction, or biological mechanisms and the reactive material is selected according to the groundwater chemistry and desired final water quality. For inorganic contaminants, such as chromium and arsenic, granular iron (zero valent iron) mixed with sand or pumice is an effective filter media although compost based reactive barriers have also been used to remove metals (Wilkin and Puls, 2003).

The interaction of chemicals within the groundwater and filter media are quite complex and further investigations are required in order to properly characterise the Bendigo mine water chemistry and design a suitable filter media. In addition, the properties of the surrounding soils should also be assessed as the hydraulic conductivity of the PRB must be higher than the soil, in order to define a preferred flow path. The outflow rate through the PRB is controlled by the choice of filter media and the compaction within the barrier, in order to achieve the required treatment time. Permeability is a key consideration in the final design, as well as the size and number of PRBs required. It is therefore difficult to accurately estimate the required size of the PRB at this stage of the project. At a concept level, the reactive barrier is expected to be in the order of 25 m long, 2 m thick and 5 m wide, although the design adopted for this project would depend on a number of factors including the geochemistry, filter media, required residence time, porosity of the media and surrounding soil, general topography of the site and hydraulic gradient.

A pilot study is considered advisable, in order to test the performance of the PRB concept with Bendigo's mine water. This could possibly be implemented in an area which is already experiencing natural mine water discharge and odour, e.g. Rosalind Park.

A drawback to this option is that it is not very flexible once it's in place. If it is not found to be working well the whole barrier would need to be dug up and the design modified, or the media would need to be altered or replaced. Care should therefore be taken in the initial assessment of mine water chemistry, filter material and porosity, PRB size, placement locations and levels, etc.

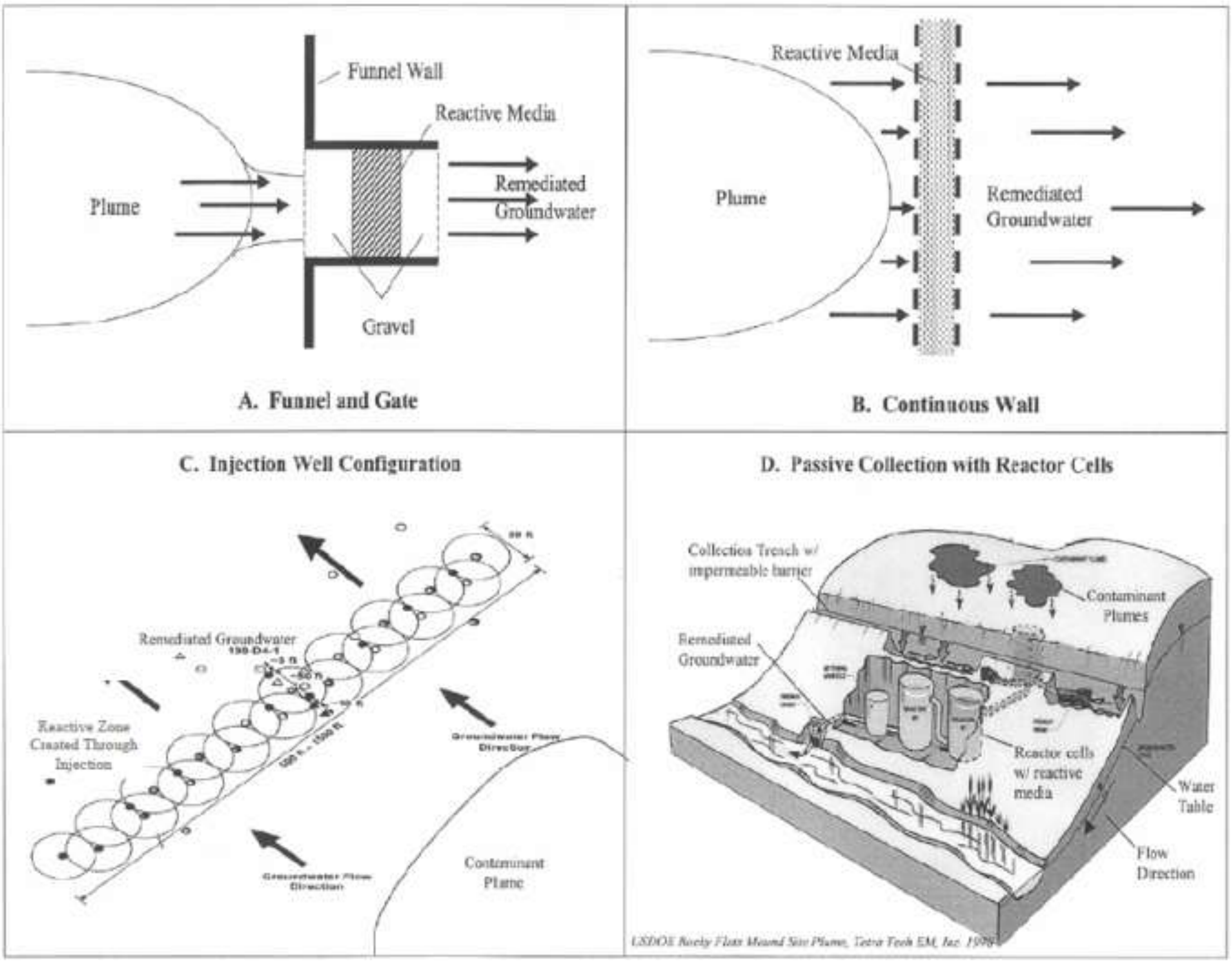

Figure 5-9 : example configurations of PRBs (ITRC, 2005)

5.4 Existing infrastructure - New Moon Water Treatment Plant

Under previous de-watering programmes, mine water has been pumped and treated at the New Moon water treatment plant, owned and operated by Unity Mining. This plant included a purpose built pre-treatment process and RO membranes, to meet the treated water quality requirements imposed on the plant output, at the time of its operation.

Figure 5-10 indicates the basic process that is used at this treatment plant, with constituents removed in a number of stages.

The pre-treatment process at New Moon protects the RO membranes from fouling constituents. Potential for fouling cannot be completely predicted from water chemistry, as it can be heavily dependent on organics in the feed water. However, it would be reasonable for DELWP to be guided on the overall Bendigo mine water quality profile by the performance of the existing New Moon Water Treatment Plant.

The land area occupied by the New Moon Water Treatment Plant is approximately 2500 m^2, and includes the reverse osmosis plant, oxidation tank, Actiflo unit, chemical storage tanks, water tanks and degasser tower, along with general storage and operational requirements, e.g. switchroom, pumps and pipes. The New Moon Water Treatment Plant was designed to treat 7 ML/d through its pre-treatment facility (oxidation tank, Actiflo unit, pressure filters) and 5 ML/d through the remainder of the WTP (reverse osmosis plant and degasser tower). Although this design volume is larger than the current volume under consideration (2 ML/d) it would not be unreasonable to expect a similar, or slightly smaller site footprint, given the same constituents of concern, and using a combination of treatment technologies. However, the final footprint will ultimately depend on the combination of technologies selected.

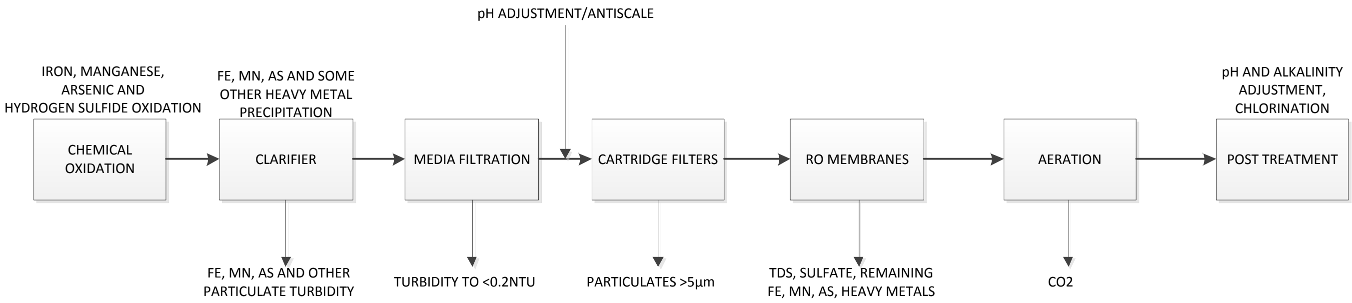

Figure 5-10: Schematic of New Moon Water Treatment Plant process, including waste streams

5.5 Summary of mine water treatment process options

Constituents of concern in the mine water include arsenic and hydrogen sulfide. Compared with waters typically flowing in surface waterways in the Bendigo area, the mine water is also brackish, has elevated concentrations of iron, manganese and some heavy metals (e.g. nickel, chromium, zinc, lead; which all have been detected at trace concentrations). All of these constituents require treatment in order to reduce their concentrations to levels that are suitable for discharge to the environment, or for other beneficial uses.

Various treatment technologies were assessed for their capacity to produce a final water quality that would be suitable to the three end “uses” described previously. While each constituent of concern could be treated individually by various treatment technologies, the combination of constituents present in the mine water narrows the range of applicable treatments. For example, most sulfate salts are highly soluble. However, in the presence of high TDS (total dissolved solids), sulfate can only effectively be remove by Reverse Osmosis. If TDS were not a consideration, Ion Exchange could be used.

A review of mine water quality data and water treatment options indicates that Reverse Osmosis (RO) with a pre-treatment process is the most effective option, from a water quality treatment perspective. RO is a well understood and proven technology, with a high reliability of operation.

There are also two alternative treatment technologies which may produce water of suitable quality for discharge to the environment; constructed wetlands and permeable reactive barriers. These options look promising but are not as well established and there is some uncertainty as to their performance in this situation. As these options could significantly reduce the ongoing costs associated with RO water treatment, they should be investigated further.

The assessment of water treatment options was based on water quality criteria outlined in the *Recycled Water Guidelines* (EPA, 2003), the *Guidelines for Wastewater Irrigation* (EPA, 1991), *Fresh water quality guidelines* (ANZECC, 2000) and determined for previous operations. However, there may be an opportunity to work with environmental regulators (including Environment Protection Authority; EPA) to establish regionally-appropriate discharge criteria through the analysis of background water quality data and consideration of the impacts of uncontrolled water discharge.

Part C Short and longer-term mine water management options

This part describes the short and longer-term options considered for Bendigo mine water management. These options are considered against a range of factors, including: technical feasibility, cost, implementation time, regulatory requirements, opportunities, limitations, etc.

Recommendations are made for short and longer-term options, and an implementation pathway is suggested.

6. Mine water management options for immediate or short-term implementation

6.1 Introduction

Water levels within the Garden Gully Reef are expected to recover to a level which will lead to uncontrolled discharge of mine water to the environment by February or March 2015. If this is to be avoided, management options are required which can be implemented almost immediately. Such options may only be interim measures and do not necessarily need to be part of the long-term, sustainable mine water management "solution".

An assessment has been made of a range of short term options to dispose of waters from the Central Deborah Mine and Garden Gully Line Reef, with or without treatment. Due to the timeframe available for implementation, these options primarily rely on existing infrastructure, although options have been considered that required supplementary infrastructure which can be developed within 12 months.

The short term options are expected to operate while longer-term responses are developed. Long term options are expected to be implementable within 2-4 years and remain in place indefinitely.

Consultation undertaken as part of the review of short and long-term water management options highlighted two important points for future management of mine water, namely that:

- There is currently an excess of water supply over demand in the Bendigo region and hence no available productive use for mine water, whatever its quality;
- The key infrastructure available to manage mine water in the short term are Unity Mining's Woodvale Ponds facility and New Moon Water Treatment Plant. Other facilities in the region either lack the capacity to manage the volume required, are not configured to treat the expected water quality, or are still in the concept stage of planning.

The analysis of short term mine water management options identified only two feasible alternatives that could be implemented in a timely manner and were consistent with the reported water quality and current lack of demand for additional water in Bendigo. These options involved either disposal of untreated water to an evaporation or holding facility, or RO treatment of the water for a beneficial use, with disposal of the concentrate or brine from the RO plant to the evaporation or holding facility.

The options outlined in the following section are:

1a Transfer untreated mine water to the Woodvale Ponds for the whole year (at a constant daily rate)

1b Untreated discharge to Woodvale over summer, at higher pumping rate

2a Untreated discharge to Woodvale over summer and treated discharge to the environment in winter

2b Treated discharge to the environment for the whole year (at a constant daily rate)

3 Treated discharge to Coliban Water for use in their Water Reclamation Scheme

It has also been suggested that additional capacity for water storage exists within mine voids in the region. However, as far as we have been able to establish there is currently only approximately 100 ML of storage available in the North New Chum workings. This volume is insufficient to act as a suitable short term mine water management option, but may be useful as an emergency reserve.

6.2 Brine disposal and management

A waste stream is produced as a by-product of the RO treatment. This contains high levels of arsenic, iron, manganese, sulfates and TDS, and also needs to be disposed of to an evaporation or holding facility. The Woodvale Ponds therefore become a central part of the short term water management options.

Consideration has been given to alternative brine disposal methods which could be implemented in the short term. The only possibility found was to tanker the brine waste from the mine water treatment site to a licensed contaminated waste land fill (e.g. the Lyndhurst Landfill facility, approximately 180 km from Bendigo) or ocean outfall (e.g. Black Rock Ocean Outfall). However, it is considered impractical to truck 0.6 ML/d waste off site, given that capacity of an average waste water tanker capacity is 11 to 15kL. This would require more than 40 truckloads per day, every day. Even if the brine waste (470 kL/d) was separated from the heavy metal waste (130 kl/d), 13 tanker loads every day would be required. This would be extremely expensive and the increased traffic would be likely to cause annoyance to the local community and congestion on local roads.

It was concluded that the Woodvale Ponds are the only feasible brine disposal site in the short term.

6.3 Estimating capital and operating costs

Costs discussed in this section are provided for the purposes of comparing options only, and should not be used for budget setting. The estimates for new works capital costs and annual operating costs are considered to have a reasonable level of confidence, in the order of ± 20%. The handover costs for the existing Unity Mining infrastructure are less certain, and are currently considered to be in the order of ± 50%.

6.4 Option 1a – Transfer untreated mine water to the Woodvale Ponds (at a constant daily rate)

Option 1a would transfer untreated mine water from the New Moon Shaft pump station to the Woodvale Ponds for evaporation. No water treatment would be used, with all contaminants accumulating as residual sediments in the Woodvale Ponds, as is currently the case.

Table 6-1: Option 1a: untreated discharge to the Woodvale Ponds

Criterion	Description
Technical feasibility	• Unity Mining has advised that the existing pumping and pipeline systems are in working order and were designed for a higher production rate than is proposed. While these assets are available, it is technically feasible to dewater from the New Moon Shaft at a rate of 1.5 to 2.0 ML/d and transfer this volume to Woodvale. • A preliminary water balance using monthly average evaporation data indicates that the Woodvale Ponds have sufficient surface area to evaporate the required 730 ML over the year. This should be confirmed through detailed water balance modelling, considering the historical range of local climatic conditions. • No investigations have been undertaken of the likely constituents, feasibility, permit requirements or cost estimates for the removal, dewatering and disposal of accumulated sediments from the Woodvale Ponds and the rehabilitation of this site.
Capital cost	• No new capital expenditure is required if existing infrastructure is intact and in good working condition, and power supplies remain connected at both pump stations. • Unity Mining (email 15/8/14) has advised that it would consider transferring the pumping assets and handing over the Woodvale Ponds to others to manage and operate, providing its current bond is released. This is understood to be held pending rehabilitation of the Woodvale Ponds. A preliminary estimate provided by Unity Mining was approximately $1.75 million. (Unity Mining would need to remove the water treatment plant and rehabilitate the rest of the New Moon site).

Criterion	Description
Operating cost	• Power costs to pump 1.5 ML/d out of the Central Deborah Shaft $150,000 per annum, including maintenance. • Power costs to pump 1.5 to 2.0 ML/d using the Unity Mining New Moon Shaft dewatering pump and the New Moon transfer pump station to transfer all this flow to the Woodvale Ponds was estimated by Unity Mining to be approximately $10,000 per month (7 days per week) or $120,000 per annum. • Operator attendance at New Moon Shaft dewatering pump, New Moon WTP, transfer pump station and the Woodvale site, estimated at 0.5 FTE, say $70,000 p.a. including overheads. • Ongoing pump station maintenance and operating costs at Woodvale of monitoring bores, vegetation and weed control and slashing for fire control, say $20,000 per annum. • This represents an approximate total annual cost of $360,000 per annum.
Assumptions	• Arrangements can be made to operate the existing Unity Mining pumping stations and Woodvale Ponds infrastructure necessary for the technical feasibility of this option for the foreseeable future. • Pumps and piping arrangements at New Moon WTP will allow 2.0 ML/d untreated water to bypass the treatment plant and be transferred to Woodvale, without operating the treatment plant. • Power supply and on-site distribution systems at New Moon are suitable to run pumps, when the rest of the site is decommissioned (WTP and other mining infrastructure). • A suitably qualified operator can be engaged to operate and maintain the mine shaft pump, (may require a mine ticket), and the skills to manage and operate the New Moon pumping facilities and Woodvale ponds. • Local community will accept an extension to the period before the Woodvale Ponds are closed down permanently and rehabilitated. This is likely to require community consultation and the risks associated with the facility would be transferred to the new owner/operator.
Opportunities	• Assuming that the total annual volume to dewater is 730 ML, pumping to Woodvale could occur at the maximum pipeline capacity (2.3 ML/d) over 10 months of the year. This could lead to slightly reduced operational costs as staff will not be required for daily site inspections during the months when dewatering is not occurring.
Implementation requirements	• Implementation of this option would take approximately one to two months, pending sign off of regulatory and management arrangements.

6.5 Option 1b – Transfer untreated mine water to the Woodvale Ponds over summer, at a higher pumping rate

Option 1b would transfer untreated mine water from the New Moon Shaft pump station to the Woodvale Ponds for evaporation. No water treatment would be used, with all contaminants accumulating as residual sediments in the Woodvale Ponds, as is currently the case.

Discharge to the Woodvale Ponds would occur over summer only, when evaporation is highest, and at a rate of 4.0 ML/d. As the pipeline between New Moon and Woodvale has a capacity of 2.3 ML/d, an additional pipeline would be required for this option.

Table 6-2: Option 1b: untreated discharge to the Woodvale Ponds over summer

Criterion	Description
Technical feasibility	• Unity Mining has advised that the existing pumping systems are in working order and were designed for a higher production rate than is proposed. While these assets are available, it is technically feasible to dewater from the New Moon Shaft at a rate of 4.0 ML/d. • Unity Mining has advised that the existing pipeline between New Moon and Woodvale is in working order and has a capacity of 2.3 ML/d, an additional pipeline would therefore be required to implement this option. • A preliminary water balance using monthly average evaporation data indicates that the Woodvale Ponds have sufficient surface area to evaporate the required 730 ML over the year (although this should be confirmed through detailed water balance modelling under a range of climatic conditions). • No investigations have been undertaken of the likely constituents, feasibility, permit requirements or cost estimates for the removal, dewatering and disposal of accumulated sediments from the Woodvale Ponds and the rehabilitation of this site.
Capital cost	• An additional pipeline would be required between New Moon and Woodvale, in the order of 8 km. A high level estimate of the cost for this pipeline is $4.0 million, which is dependent on variables such as route, pressure rating, material, construction method, access, required permits, etc. • No capital expenditure is required for new works, if existing infrastructure is intact and in good working condition, and power supplies are connected at both pump stations (as advised). • Unity Mining (email 15/8/14) has advised that it would consider transferring the pumping assets and handing over the Woodvale Ponds to others to manage and operate, providing its current bond is released. This is understood to be held pending rehabilitation of the Woodvale Ponds. A preliminary estimate provided by Unity Mining was approximately $1.75 million. (Unity Mining would need to remove the water treatment plant and rehabilitate the rest of the New Moon site).
Operating cost	• Power costs to pump 1.5 ML/d out of the Central Deborah Shaft $150,000 per annum, including maintenance. • Power costs to pump 1.5 to 2.0 ML/d using the Unity Mining New Moon Shaft dewatering pump and the New Moon transfer pump station to transfer all this flow to the Woodvale Ponds was estimated by Unity Mining to cost approximately $10,000 per month (7 days per week) or $120,000 per annum. • Operator attendance at New Moon Shaft dewatering pump, New Moon WTP transfer pump station and the Woodvale site, estimated at 0.5 FTE, say $70,000 p.a. including overheads. • Ongoing pump station maintenance and operating costs at Woodvale of monitoring bores, vegetation and weed control and slashing for fire control, say $20,000 per annum. • This represents an approximate total annual cost of $360,000 per annum.
Assumptions	• Arrangements can be made to operate the existing Unity Mining pumping stations and Woodvale Ponds infrastructure necessary for the technical feasibility of this option for the foreseeable future, with the construction of an additional pipeline between New Moon and Woodvale. • Power supply and on-site distribution systems at New Moon are suitable to run pumps, when the rest of the site is decommissioned (WTP and other mining infrastructure). • A suitably qualified operator can be engaged to operate and maintain the mine shaft pump, (may require a mine ticket), and the skills to manage and operate the New Moon pumping facilities and Woodvale Ponds. • Local community will accept an extension to the period for the Woodvale Ponds to be closed down and rehabilitated. This is likely to require community consultation and the risks associated with the facility would be transferred to the new owner/operator.
Opportunities	• Dewatering could occur at a higher rate (e.g. 4.0 ML/d) over the summer months, when evaporation potential is higher. This could lead to reduced operational costs as staff will not be required for daily site inspections during the months when dewatering is not occurring.
Implementation requirements	• Implementation of this option would take approximately 12 months, for the design and construction of the required pipeline, assuming sign off of regulatory and management arrangements.

6.6 Option 2a – Untreated discharge to Woodvale over summer & discharge to environment in winter (combination of Options 1b and 2b)

Option 2a consists of a combination of Options 1b (discharge to Woodvale – summer months) and 2b (discharge to the environment – winter months).

During summer, when evaporation rates are highest, untreated mine water would be transferred from the New Moon Shaft pump station to the Woodvale Ponds, at a rate of 2.0 ML/d. No water treatment would be used, with all contaminants accumulating as residual sediments in the Woodvale Ponds, as is currently the case.

During winter, the wet season, mine water would be treated at the New Moon RO plant at a rate of 2.0 ML/d to a quality suitable for discharge to the environment, as environmental flows or for irrigation extraction. The treatment plant would produce 1.4 ML/d (510 ML p.a.) of treated water for discharge, along with 0.6 ML/d (220 ML p.a.) clarifier and filter waste and RO reject brine flows for transfer to Woodvale Ponds for evaporation, with contaminants accumulating as residual sediments in the Woodvale Ponds.

Treated water from the New Moon WTP has been previously released to the environment, under a discharge licence issued by the EPA. The New Moon Plant is therefore capable of treating the mine water to a suitable standard for release.

The water would be released to Lake Neangar, via the Unity Mining pipeline (New Moon to Lake Neangar). Lake Neangar has a capacity of approximately 710 ML, from which it spills into Lake Tom Thumb (capacity of approximately 540 ML), which then spills into Eaglehawk Creek, a tributary of Bendigo Creek. Given the volumes of water under consideration it is likely that both Lake Neangar and Lake Tom Thumb would be filled within the first year of operations and would spill for the majority of the time that discharge is occurring.

Table 6-3: Option 2a: untreated discharge to Woodvale over summer & discharge to environment in winter (combination of Options 1b and 2b)

Criterion	Description
Technical feasibility	• The existing pumping and pipeline systems are advised by Unity Mining to be in working order, and were designed for a higher production rate than is proposed. While these assets are available, it is technically feasible to dewater from the New Moon Shaft at a rate of 1.5 to 2.0 ML/d and either transfer this volume to Woodvale, or treat the mine water to produce recycled water, discharge the recycled water to Lake Neangar and transfer the resulting 0.6 ML/d waste flow to Woodvale. • It is understood from Unity Mining and Veolia that the water treatment plant performed reliably to achieve the required EPA Licence performance for production of treated water at the design recovery rates indicated in the Veolia process flow diagram summarised in Appendix A. • A preliminary water balance using monthly average evaporation data indicates that the Woodvale Ponds have sufficient surface area to evaporate the required 474 ML over the year (although this should be confirmed through detailed water balance modelling under a range of climatic conditions). • No investigations have been undertaken of the likely constituents, feasibility, permit requirements or cost estimates for the removal, dewatering and disposal of accumulated sediments from the Woodvale Ponds and the rehabilitation of this site.
Capital cost	• No capital expenditure is required for new works, if existing infrastructure is intact and in good working condition, and power supplies are connected at both pump stations (as advised). • Unity Mining (email 15/8/14) has advised that it would consider transferring the pumping and water treatment plant assets, and handing over the Woodvale Ponds to others to manage and operate providing its current bond is released. This is understood to be held pending and rehabilitation of the Woodvale Ponds site. Rehabilitation of the unused portion of the New Moon site would also be required. Unity Mining values this at approximately $2.0 million (preliminary estimate). • The water treatment plant has not been inspected and no estimates of renewal periods have been provided for renewal of the major periodic replacement items identified by Veolia (email 25/8/14) as RO membranes and replacement “resins” (which may be the media filter greensands etc.). Veolia provided “ball park” estimates of $40,000 to recommission the water treatment plant and worst case immediate replacement cost for new RO membranes and “resins” of $630,000. Recommissioning is expected to take less than one month to complete. • If these costs were all realised (worst case scenario), the capital cost of Option 2a would be $2.7 million.

Criterion	Description
Operating cost	• Power costs to pump 1.5 ML/d out of the Central Deborah Shaft $150,000 per annum, including maintenance. • Summer operations (pumping): Power costs to pump 1.5 to 2.0 ML/d using the Unity Mining New Moon Shaft dewatering pump and the New Moon transfer pump station to transfer all this flow to the Woodvale Ponds was estimated by Unity Mining to cost approximately $10,000 per month (7 days per week) or $60,000 for six months. • Winter operations (pumping): If it is assumed that two-thirds of the power costs to pump 1.5 to 2.0 ML/d are attributed to the Unity Mining New Moon Shaft dewatering pump, and the New Moon transfer pump station transfers 0.6 ML/d of brine to Woodvale; using the estimates by Unity Mining the annual cost would be approximately $7,500 per month (7 days per week) or $45,000 for six months • Winter operations (RO treatment): Operating cost of water treatment plant (Unity Mining) of $1,000/ML or $365,000 for six months. • Operator attendance at the New Moon Shaft dewatering pump, New Moon WTP, the transfer pump station and the Woodvale site, estimated at 0.75 FTE, say $100,000 p.a. including overheads. • Ongoing pump station maintenance, treatment plant maintenance and operating costs at Woodvale of monitoring bores, vegetation and weed control and slashing for fire control, say $20,000 per annum. • This represents an approximate total annual cost of $740,000 per annum.
Assumptions	• Arrangements can be made to operate the existing Unity Mining pumping stations and Woodvale Ponds infrastructure necessary for the technical feasibility of this option for the foreseeable future. • Pumps and piping arrangements at New Moon WTP will allow 2.0 ML/d untreated water to bypass the treatment plant and be transferred to Woodvale, without operating the treatment plant (summer operations). • The existing New Moon Water Treatment Plant can be refurbished to full operation and performance to meet water quality targets for the indicative costs provided. • An EPA license for discharge to the environment can be obtained. • Power supply and on-site distribution system at New Moon is suitable to run pumps, when the rest of the site is decommissioned (i.e. any mining infrastructure not associated with the WTP or Woodvale facility). • A suitably qualified operator can be engaged to operate and maintain the mine shaft pump, (may require a mine ticket), and the skills to manage and operate the New Moon pumping facilities, Treatment Plant and Woodvale Ponds. • Local community will accept an extension to the period for the Woodvale Ponds to be closed down and rehabilitated. • Local community will accept an extension to the period before the Woodvale Ponds are closed down permanently and rehabilitated. This is likely to require community consultation and the risks associated with the facility would be transferred to the new owner/operator.
Opportunities	• The winter discharge to the environment represents a potential benefit as the creation of environmental flows. • This option provides a high level of flexibility and responsiveness to operational requirements in that both disposal options can be used, depending on environmental conditions and dewatering requirements. For example, if only the Woodvale Ponds were being used and Bendigo experienced a particularly wet winter the ponds may not have capacity to accept the mine water discharge. The addition of the RO plant provides a buffer or backup in case the Woodvale Ponds are not available, or if the required rate of dewatering increases. • There may also be an opportunity to reduce the size of the Woodvale Ponds to a smaller footprint, in line with the smaller volume than the facility was originally designed for. However, this would be costly and would reduce some of the flexibility which is an advantage of this option.
Implementation requirements	• Implementation of the discharge to the Woodvale Ponds would take approximately one to two months, pending sign off of regulatory and management arrangements. • Implementation of the use of the New Moon RO plant may take up to six months, depending on the current functionality of the plant and the need for replacement of degraded parts.

6.7 Option 2b –Treat mine water at New Moon WTP and discharge treated water to the environment, with the transfer of brine to Woodvale

Option 2b would treat 2.0 ML/d at the existing New Moon WTP to a quality suitable for discharge to the environment, as environmental flows or for irrigation extraction. The treatment plant would produce 1.4 ML/d (510 ML p.a.) of treated water for discharge, along with 0.6 ML/d (220 ML p.a.) clarifier and filter waste and RO reject brine flows for transfer to Woodvale Ponds for evaporation, with contaminants accumulating as residual sediments in the Woodvale Ponds.

Treated water from the New Moon WTP has been previously released to the environment, under a discharge licence issued by the EPA. The New Moon Plant is therefore capable of treating the mine water to a suitable standard for release.

The water would be released to Lake Neangar, via the Unity Mining pipeline (New Moon to Lake Neangar). Lake Neangar has a capacity of approximately 710 ML, past which it spills into Lake Tom Thumb (capacity of approximately 540 ML), which then spills into Eaglehawk Creek, a tributary of Bendigo Creek. Given the volumes of water under consideration it is likely that both Lake Neangar and Lake Tom Thumb would be filled within the first year of operations and would spill for the majority of the time that discharge is occurring.

Historically the Eaglehawk Golf Course has drawn its water for irrigation from Lake Tom Thumb and was licenced to extract 50 ML/a (Scott Ridges, G-MW, personal communication, August 28, 2014). However, the golf course has now closed and is unlikely to continue to use this extraction licence.

The treated water could also be discharged to other locations; however, Lake Neangar is considered a suitable site for the following reasons:

- the lakes and creek are highly modified ecosystems and discharge of treated mine water is unlikely to cause additional negative impacts (and may even lead to improved water quality conditions)
- discharge approval for this site has previously been granted by the EPA
- a pipeline from the New Moon WTP to Lake Neangar already exists.

Table 6-4: Option 2b: treated discharge to the environment

Criterion	Description
Technical feasibility	• Unity Mining has advised that the existing pumping and pipeline systems are in working order, and were designed for a higher production rate than is proposed. While these assets are available it is technically feasible to dewater from the New Moon Shaft at the rate of 1.5 to 2.0 ML/d, treat the mine water to produce recycled water and transfer the 0.6 ML/d waste flow to Woodvale. • It is understood from Unity Mining and Veolia that the water treatment plant performed reliably to achieve the required EPA Licence performance for production of treated water at the design recovery rates indicated in the Veolia process flow diagram summarised in Appendix A. • Preliminary water balance using monthly average evaporation data indicates the Woodvale Ponds have more than sufficient surface area to evaporate the required 0.6 ML/d of brine waste over the year. • No investigations have been undertaken of the likely constituents, feasibility, permit requirements or cost estimates for the removal, dewatering and disposal of accumulated sediments from the Woodvale Ponds and the rehabilitation of this site.

Criterion	Description
Capital cost	• Unity Mining (email 15/8/14) has advised that it would consider transferring the pumping and water treatment plant assets, and handing over the Woodvale Ponds to others to manage and operate providing its current bond is released. This is understood to be held pending and rehabilitation of the Woodvale Ponds site. Rehabilitation of the unused portion of the New Moon site would also be required. Unity Mining values this at approximately $2.0 million (preliminary estimate). • Although the water treatment plant has not been inspected Veolia, as the original designer of the facility, have provided "ball park" estimates of the time to recommission the plant and a worst case scenario for replacement of parts (RO membranes and replacement "resins", which may be the media filter greensands etc.). Recommissioning is expected to take less than one month to complete and will cost approximately $40,000. Replacement of RO membranes and resins will cost approximately $630,000. • If these costs were all realised (worst case scenario), the capital cost of Option 2b would be $2.7 million
Operating cost	• Power costs to pump 1.5 ML/d out of the Central Deborah Shaft $150,000 per annum, including maintenance. • If it is assumed that two-thirds of the power costs to pump 1.5 to 2.0 ML/d are attributed to the Unity Mining New Moon Shaft dewatering pump, and the New Moon transfer pump station transfers 0.6 ML/d of brine to Woodvale; using the estimates by Unity Mining the annual cost would be approximately $7,500 per month (7 days per week) or $90,000 per annum. • Operator attendance at the New Moon Shaft dewatering pump, New Moon WTP, the transfer pump station and the Woodvale site, estimated at 1.0 FTE, say $130,000 p.a. including overheads. • Ongoing pump station maintenance, treatment plant maintenance and operating costs at Woodvale of monitoring bores, vegetation and weed control and slashing for fire control, say $20,000 per annum. • Operating cost of water treatment plant (Unity Mining) of $1,000/ML or $730,000 p.a. • This represents an approximate total annual cost of $1,120,000 per annum.
Assumptions	• Arrangements can be made to operate the existing Unity Mining pumping stations and Woodvale Ponds infrastructure necessary for the technical feasibility of this option for the foreseeable future. • The existing New Moon Water Treatment Plant can be refurbished to full operation and performance to meet water quality targets for the indicative costs provided. • An EPA license for discharge to environment by irrigation can be obtained. • Power supply and on-site distribution system at New Moon is suitable to run pumps, when the rest of the site is decommissioned (i.e. any mining infrastructure not associated with the WTP or Woodvale facility). • A suitably qualified operator can be engaged to operate and maintain the mine shaft pump, (may require a mine ticket), and the skills to manage and operate the New Moon pumping facilities, Treatment Plant and Woodvale ponds. • Local community will accept an extension to the period for the Woodvale Ponds to be closed down and rehabilitated. • Brine disposal to Woodvale ponds?
Opportunities	• Dewatering and discharge could occur at a higher rate (e.g. 4.0 ML/d) over the winter months (nominally May to September), when flows are naturally higher. Overflows to Eaglehawk Creek would then retain an element of seasonality, with high flows in the winter months and low to zero flows in the summer months. This could also lead to lower operational costs, through a reduced staffing requirement. Or; • There may also be an opportunity to reduce the size of the Woodvale Ponds to a smaller footprint, in line with the smaller brine stream than the facility was originally designed for. However, this may not be feasible if dewatering and discharge only occurs during the winter months, as evaporation rates are much lower during these months and the Woodvale Ponds may not have the capacity to store the full volume of the generated brine stream until summer.
Implementation requirements	• Implementation of this option would take approximately 12 months. This is driven by the timeline for the design and construction of the required pipeline, assuming sign off of regulatory and management arrangements, including the discharge of the treated water.

6.8 Option 3 - Treat mine water at New Moon WTP and discharge treated water to Coliban Water, with the transfer of brine to Woodvale

Initial discussion with Coliban Water included consideration of discharge to the Bendigo main trunk sewer. However, Coliban Water has advised that the available capacity in the sewer system is less than the required 1.5-2 ML/d. Discharge to the sewer system could therefore only act as part of the required solution.

Instead, Option 3 considers the discharge of treated water to the Coliban Water recycled water scheme, at the Epsom WRP. The existing pipeline between New Moon and the Epsom WRP is currently being utilised by Coliban Water to supply irrigation customers and third pipe urban customers. A duplicate pipeline would therefore be required.

- Treat 2.0 ML/d at the existing New Moon WTP to a quality suitable for discharge to the Coliban Water recycled water scheme via the Lake Neangar to Epsom WRP pipeline, for reuse or discharge to Bendigo Creek.
- Produce 1.4 ML/d (510 ML p.a.) of treated water for reuse by irrigation as part of Coliban Water recycled water product or increased licence discharge to Bendigo Creek.
- Produce 0.6 ML/d (220 ML p.a.) clarifier and filter waste and RO reject brine flows for transfer to Woodvale Ponds for evaporation, with contaminants accumulating as residual sediments in Woodvale Ponds.

Table 6-5: Option 3: treated discharge to Coliban Water

Criterion	Description
Technical feasibility	• Unity Mining has advised that the existing pumping and pipeline systems are in working order, and were designed for a higher production rate than is proposed. Whilst these assets are available it is technically feasible to dewater at the New Moon Shaft at the rate of 1.5 to 2.0 ML/d, treat the mine water to produce recycled water, and transfer the 0.6 ML/d waste flow to Woodvale. • It is understood from Unity Mining and Veolia that the water treatment plant performed reliably to achieve the required EPA Licence performance for production of treated water at the design recovery rates indicated in the Veolia process flow diagram summarised in Appendix A. • Preliminary water balance using monthly average evaporation data indicates this Woodvale Ponds have sufficient surface area to evaporate 0.6 ML/d of brine waste averaged over the year. There may also be an opportunity to reduce the size of the Woodvale Ponds to a smaller footprint, in line with the smaller brine stream than the facility was originally designed for. • No investigations have been undertaken of the likely constituents, feasibility, permit requirements or cost estimates for the removal, dewatering and disposal of accumulated sediments from the Woodvale Ponds and the rehabilitation of this site. • Coliban Water has not indicated the terms and conditions under which it would accept 510 ML p.a. of recycled water from the water treatment plant. • Coliban Water has indicated that it will not accept the untreated mine water or the brine as a Trade Waste at the volumes required to resolve the problem, as the Epsom WRP is not capable of treating and disposing of the increased volume and contaminants.

Criterion	Description
Capital cost	• An additional pipeline would be required between New Moon and Epsom WRP. A high level estimate of the cost for this pipeline is $4.0 million, which is dependent on variables such as route, pressure rating, material, construction method, access, required permits, etc. • Unity Mining (email 15/8/14) has advised that it would consider transferring the pumping and water treatment plant assets, and handing over the Woodvale Ponds to others to manage and operate providing its current bond is released. This is understood to be held pending and rehabilitation of the Woodvale Ponds site. Rehabilitation of the unused portion of the New Moon site would also be required. Unity Mining values this at approximately $2.0 million (preliminary estimate). • While the water treatment plant has not been inspected, Veolia has provided “ball park “ estimates of $40,000 to recommission the water treatment plant and (worst case) immediate replacement cost for new RO membranes and “resins” of $630,000. Recommissioning is expected to take less than one month to complete. • If these costs were all realised (worst case scenario), the capital cost of Option 3 would be $6.7 million.
Operating cost	• Power costs to pump 1.5 ML/d out of the Central Deborah Shaft $150,000 per annum, including maintenance. • If it is assumed that two-thirds of the power costs to pump 1.5 to 2.0 ML/d are attributed to the Unity Mining New Moon Shaft dewatering pump, and the New Moon transfer pump station transfers 0.6 ML/d of brine to Woodvale using the estimates by Unity Mining the annual cost would be approximately $7,500 per month (7 days per week) or $90,000 per annum. • Operator attendance at New Moon Shaft dewatering pump, New Moon WTP, the transfer pump station and the Woodvale site, estimated at 1.0 FTE, say $130,000 p.a. including overheads. • Ongoing pump station maintenance, treatment plant maintenance and operating costs at Woodvale of monitoring bores, vegetation and weed control and slashing for fire control, say $20,000 per annum. • Operating cost of water treatment plant (Unity Mining) of $1,000/ML or $730,000 p.a. • This represents an approximate total annual cost of $1,120,000 per annum. • If the recycled water is accepted by Coliban Water additional disposal charges may be applicable.
Assumptions	• Coliban Water can accept treated water at the rate produced at New Moon Water Treatment Plant. However, it is understood that in an average year the Coliban Water recycled water scheme is already over-supplied. Therefore, to accept an additional flow from the New Moon WTP, Coliban Water may need to obtain an additional environmental discharge licence from EPA, to increase the volume discharged from Epsom WRP to the local waterway. • Arrangements can be made to operate the existing Unity Mining pumping stations and Woodvale Ponds infrastructure necessary for the technical feasibility of this option for the foreseeable future. • The existing New Moon WTP can be refurbished to full operation and performance to meet water quality targets for the indicative costs provided. • Power supply and on-site distribution system at New Moon is suitable to run pumps, when the rest of the site is decommissioned (i.e. any mining infrastructure not associated with the WTP or Woodvale facility). • A suitably qualified operator can be engaged to operate and maintain the mine shaft pump, (may require a mine ticket), and the skills to manage and operate the New Moon pumping facilities, treatment plant and Woodvale Ponds. • Local community will accept an extension to the period for the Woodvale Ponds to be closed down and rehabilitated.
Opportunities	• There may be an opportunity to reduce the size of the Woodvale Ponds to a smaller footprint, in line with the smaller brine stream than the facility was originally designed for.
Implementation requirements	• Implementation of this option would take approximately 12 months. This is driven by the timeline for the design and construction of the required pipeline, assuming sign off of regulatory and management arrangements.

6.9 Summary and evaluation of options for immediate or short-term implementation

The following section provides a summary of the five short term options proposed for managing mine water levels. A key factor in the selection of these options has been the current lack of demand for additional water in the Bendigo region. The basis for these options is that they will provide for either the treatment of the pumped mine waters and/or disposal of those waters and brine. According to the SEPP WoV the quality of the mine water is not suitable for discharge to the environment, and must be treated. All of the treatment options investigated therefore result in the production of a brine waste stream which must be disposed of to a holding facility or evaporation pond.

Due to the timeframe available for implementation, these options primarily rely on existing infrastructure, although options have been considered that required supplementary infrastructure which can be developed within 12 months.

It was also suggested that additional capacity for water storage exists within mine voids in the region. However, as far as we have been able to establish there is currently only approximately 100 ML of storage available in the North New Chum workings. This is insufficient volume to act as a suitable short term mine water management option, but may be useful as an emergency option, if required. In order to implement this option new pumps and a pipeline would be required to transfer the water from the Central Deborah Shaft to the New Chum Line. This would also require permission from Unity Mining and a discharge authority from G-MW.

The short term options as evaluated in the previous sections of this report are based on information provided by DELWP, Unity Mining, Coliban Water and Veolia, and are summarised for comparison in Table 7-14.

Several variants of the two short-term water management alternatives (disposal of untreated water to an evaporation or holding facility, or RO treatment of the water for a beneficial use) are available. An analysis of these options, based on information provided by DELWP, Unity Mining and water industry operators, is summarised in Table 7-14. Of the five options considered, Option 1a (untreated discharge to Woodvale at a constant daily rate) has the lowest capital and ongoing operating cost. However, Option 2a (untreated discharge to Woodvale over summer and treated discharge to environment in winter) is considered to provide the highest level of flexibility and responsiveness to operational requirements and climatic conditions.

As the short term options are expected to be in place for at least two years, and up to a maximum of four years, the total estimated cost of each option over this period is also presented in Table 7-14. These costs are presented as a Net Present Cost (NPC)[1], where costs have been discounted at a rate of 6% per annum. Note that costs are provided for the purposes of comparing options only, and should not be used for budget setting. The estimates for annual operating costs are considered to have a reasonable level of confidence, in the order of ± 20%, with new works capital costs in the order of ± 25%. The handover costs for the existing Unity Mining infrastructure are less certain, and are currently considered to be in the order of ± 50%.

Regulatory requirements vary between options, depending on the organisation responsible for the water management process. Operation of the Woodvale facility by Unity Mining currently occurs under a Work Plan Approval issued by DSDBI (now DEDJTR). However, if another (non-mining) entity were responsible, they would most likely to require a discharge licence from EPA. Both regulatory pathways are considered in Table 7-14.

Since the New Moon pumps, pipeline from New Moon to Woodvale and the Woodvale facility are essential to all feasible short term alternatives to allowing uncontrolled discharge of mine water it is recommended that this infrastructure is inspected soon to determine its current fitness-for-use. Detailed water balance modelling should also be undertaken to determine how much of the Woodvale facility is required for short term use options. Consultation with local residents about reinstatement of the facility as part of the short-term management Bendigo's mine water should also be undertaken at an early stage.

[1] NPC is the difference between the present value of cash inflows and the present value of cash outflows, over the period of interest.

Table 6-6: Summary of proposed short term options for Bendigo Mine Water Management

Criterion	Option 1a (Untreated discharge to Woodvale at a constant daily rate)	Option 1b (Untreated discharge to Woodvale over summer at higher pumping rate)	Option 2a (Untreated discharge to Woodvale over summer & treated discharge to environment in winter)	Option 2b (Treated discharge to the environment)	Option 3 (Treated discharge to Coliban Water Recycled Water System)
New works capital cost (+/- 25%)	Nil – utilize existing infrastructure	$4.0 M (New pipeline New Moon to Woodvale to increase capacity to 4 ML/d)	$0.67 M (worst case) for RO plant at New Moon	$0.67 M (worst case) for RO plant at New Moon	$4.0 M new pipeline from New Moon to Epsom + $0.67 M (worst case) for RO plant at New Moon
Unity Mining handover costs (+/- 50%)	$1.7 M	$1.7 M	$2.0 M	$2.0 M	$2.0 M
Annual operating costs (+/-20%)	$0.2 M (pumping at Central Deborah) $0.1 M (pumping to Woodvale) $0.1 M (operation, maintenance and monitoring)	$0.2 M (pumping at Central Deborah) $0.1 M (pumping to Woodvale) $0.1 M (operation, maintenance and monitoring)	$0.2 M (pumping at Central Deborah) $0.5 M (RO and pumping costs) $0.1 M (operation, maintenance and monitoring)	$0.2 M (pumping at Central Deborah) $0.8 M (RO and pumping costs) $0.2 M (operation, maintenance and monitoring)	$0.2 M (pumping at Central Deborah) $0.8 M (RO and pumping costs) $0.2 M (operation, maintenance and monitoring)
NPC 4 years 6% p.a. discount rate	$3.0 M	$7.0 M	$5.2 M	$6.6 M	$10.6 M
Potential Revenue	None	None	Sale of 200 ML p.a.? (unlikely)	Sale of 500ML p.a.? (unlikely)	Sale of 500ML p.a.? (unlikely)
Process performance	High/reliable	High/reliable	High/reliable	High/reliable	High/reliable
Regulatory requirements: Unity Mining OR	Woodvale: Work Plan Approval (DEDJTR)	Woodvale: Work Plan Approval (DEDJTR)	Lake Neangar: discharge licence (EPA) Woodvale: Work Plan Approval (DEDJTR)	Lake Neangar: discharge licence (EPA) Woodvale: Work Plan Approval (DEDJTR)	Trade Waste Agreement (CW) EPA Amalgamated licence amendment (CW/EPA) EPA Works approval Woodvale: Work Plan Approval (DEDJTR)
Regulatory requirements: Other entity	Woodvale: discharge licence (EPA)	Woodvale: discharge licence (EPA)	Lake Neangar: discharge licence (EPA) Woodvale: discharge licence (EPA)	Lake Neangar: discharge licence (EPA) Woodvale: discharge licence (EPA)	Trade Waste Agreement (CW) EPA Amalgamated licence amendment (CW/EPA) EPA Works approval Woodvale: discharge licence (EPA)
Opportunities	Pumping to Woodvale could occur at the maximum pipeline capacity (2.3 ML/d) over 10 months of the year. This could slightly reduce operational costs.	Dewatering could occur at a higher rate (e.g. 4.0 ML/d) over the summer months, when evaporation potential is higher. This could reduce operating costs.	Discharge of treated water to the environment may provide an environmental flow benefit. This option provides a high level of flexibility under different evaporation & rainfall conditions	Woodvale Ponds would only be required for brine disposal, with as little as half the current area required. Alternatively, treatment and discharge over the winter months corresponds with higher natural flow periods.	Woodvale Ponds would only be required for brine disposal and the required area could be reduced significantly.
Limitations	The Woodvale facility should be continuously wet, so that it does not dry out and generate dust.	Current capacity of pipeline between New Moon and Woodvale is 2.3 ML/d. A second pipeline would be required for this option. The Woodvale facility should be continuously wet, so that it does not dry out and generate dust.	There is no current or immediately foreseeable demand for the treated water generated The Woodvale facility should be continuously wet, so that it does not dry out and generate dust.	No current demand for additional irrigation water The Woodvale facility should be continuously wet, so that it does not dry out and generate dust.	Coliban Water can only accept a limited volume of treated water, excess untreated water may need to be discharged to Woodvale, alternatively excess treated water could be discharged to the environment (Lake Neangar). Likely additional disposal costs The Woodvale facility should be continuously wet, so that it does not dry out and generate dust.

Criterion	Option 1a (Untreated discharge to Woodvale at a constant daily rate)	Option 1b (Untreated discharge to Woodvale over summer at higher pumping rate)	Option 2a (Untreated discharge to Woodvale over summer & treated discharge to environment in winter)	Option 2b (Treated discharge to the environment)	Option 3 (Treated discharge to Coliban Water Recycled Water System)
Community benefits	Central Deborah Tourist Mine remains open No uncontrolled discharge to the environment.	Central Deborah Tourist Mine remains open No uncontrolled discharge to the environment.	Central Deborah Tourist Mine remains open No uncontrolled discharge to the environment.	Central Deborah Tourist Mine remains open No uncontrolled discharge to the environment. Discharge of treated water to the environment could be seen as environmental flows Potential to reduce or reconfigure the Woodvale Ponds area.	Central Deborah Tourist Mine remains open No uncontrolled discharge to the environment. Discharge of treated water to the environment could be seen as environmental flows Potential to reduce or reconfigure the Woodvale Ponds area.
Community dis-benefits	The Woodvale Ponds were expected by the local community to close and be rehabilitated by 2017. All short-term options are likely to extend the operating period and any impacts on local residents by several years.	The Woodvale Ponds were expected by the local community to close and be rehabilitated by 2017. All short-term options are likely to extend the operating period and any impacts on local residents by several years.	The Woodvale Ponds were expected by the local community to close and be rehabilitated by 2017. All short-term options are likely to extend the operating period and any impacts on local residents by several years.	The Woodvale Ponds were expected by the local community to close and be rehabilitated by 2017. All short-term options are likely to extend the operating period and any impacts on local residents by several years.	The Woodvale Ponds were expected by the local community to close and be rehabilitated by 2017. All short-term options are likely to extend the operating period and any impacts on local residents by several years.
Implementation time	1-2 months, pending sign off on regulatory and management arrangements	12 months for design & construct new pipeline, sign off on regulatory and management arrangements	Pumping to Woodvale – 1-2 months, pending sign off on regulatory and management arrangements Use of RO plant – 6 months, depending on functionality of plant and need for new filters.	12 months for design & construct new pipeline, sign off on regulatory and management arrangements	12 months for design & construct new pipeline, sign off on regulatory and management arrangements

7. Longer-term options to address Bendigo's mine water management challenges

7.1 Longer-term options for assessment

From the generic possibilities outlined in Table 3-2 and Section 3 a number of long term water management options have been identified, as listed in Table 7-1. The following section provides a high level discussion and scoping assessment of these options, with a summary and evaluation provided in Section 7.7.

Regulatory requirements are not dealt with in this assessment, although they may be partly addressed at times where they will impose a significant impost on the project timeline and/or technical requirements (e.g. treatment to a prescribed waste standard).

Table 7-1: Long term water management options to be investigated

No.	Description	Options
1	Untreated discharge to an evaporation facility	a) Use the existing Woodvale facility b) Construct a new facility
2	Treated discharge to the environment	a) Treat the water at Central Deborah and discharge to Bendigo Creek b) Treat the water at New Moon and discharge to Lake Neangar
3	Treated discharge to the recycled water network	a) Treat the water at Central Deborah and discharge to the main sewer b) Treat the water at New Moon and discharge to the sewer at Eaglehawk c) Treat the water at Central Deborah and discharge to a recycled water network within Bendigo
4	Treatment of water through a constructed wetland	a) Treat the water near Central Deborah and discharge to the main sewer b) Treat the water at New Moon and discharge to the sewer at Eaglehawk c) Treat the water near Central Deborah and discharge to a recycled water network within Bendigo
5	Use of a permeable reactive barrier at a natural discharge site	Install a permeable reactive barrier at the New Moon discharge site

A number of the options listed in Table 7-1 include reverse osmosis water treatment, producing a brine waste stream which requires disposal. There are limited options available for brine disposal and for the purpose of this investigation it has been assumed that brine would either be sent to a new facility or to the upgraded Coliban Water facility, at an estimated capital cost of $4.0 million.

7.1.1 Cost estimates

Capital and annual operating costs have been estimated for each option, with handover costs included where Unity Mining legacy infrastructure is to be used. Each option includes the cost of continued pumping from the Central Deborah Shaft into the Londonderry Shaft. This is estimated at $150,000, including maintenance.

As the long term options are expected to be in place indefinitely the net present value of costs (NPC) for each option has been calculated over a 20 year period (with a 6% discount rate).

Costs are provided for the purposes of an initial comparison of options only, and should not be used for budget setting. The estimates for annual operating costs are considered to have a reasonable level of confidence, in the order of ± 20%. The handover costs for the existing Unity Mining infrastructure and the new works capital costs are less certain (primarily due to unknown design factors), and are currently considered to be in the order of ± 50%.

The cost estimates do not include land acquisition costs, as these can vary widely depending on final location. The costs of long term maintenance are also not included as these are difficult to estimate at this stage and will be strongly influenced by unknown design factors. For example, the need to clean out an evaporation pond will depend on the storage capacity and design life of the facility, i.e. is it designed to operate for 10 years or 30 years prior to needing cleaning. An evaporation facility may also be designed to be managed similar to a landfill, in that it is decommissioned and capped once it is full. This avoids the need for regular cleaning out but does mean that replacement ponds are ultimately required.It is recommended that cost estimates, including land acquisition and long term maintenance costs, are assessed in more detail in the next phase of the project, once the long term options have been refined and site details are known.

7.2 Option 1: untreated discharge to an evaporation facility

This option uses a closed storage facility to store and evaporate the entire volume of the untreated mine water discharge. There is no discharge or outflow from the facility and this option does not include degassing. Salts will accumulate within the facility and will require periodic removal.

Option 1a: untreated discharge to the Woodvale facility

Option 1a would transfer untreated mine water from the New Moon Shaft pump station to the Woodvale Ponds for evaporation. No water treatment would be used, with all contaminants accumulating as residual sediments in the Woodvale Ponds, as is currently the case.

This option requires the acquisition of the Woodvale Ponds facility, New Moon Shaft pump station and pipeline from New Moon to Woodvale from Unity Mining.

Due to the proven technical feasibility and low capital and ongoing costs associated with this option, it is considered suitable for long term mine water management and should be considered further for long term management. However, this assumes that the Woodvale facility currently has the capacity and evaporative potential to accept the required 2 ML/d. This requires further investigation via a water balance study.

Table 7-2: Option 1a: untreated discharge to the Woodvale facility

Criterion	Description
Technical feasibility	• Evaporation is a known technology and has been used successfully in the Bendigo region in the past • There are no risks involved in adopting this option, as long as suitable operational and maintenance standards are adopted.
New infrastructure required	• nil
Capital cost	• No capital expenditure is required for new works, if existing infrastructure is intact and in good working condition, and power supplies are connected at both pump stations (as advised). • Assumed handover cost of $1.7 million
Operating cost	• Pumping to Woodvale - $10,000 per month (7 days per week) or $120,000 per annum. • Operator attendance at New Moon Shaft dewatering pump, transfer pump station and the Woodvale site, estimated at 0.5 FTE, say $70,000 p.a. including overheads. • Ongoing pump station maintenance and operating costs at Woodvale of monitoring bores, vegetation and weed control and slashing for fire control, say $20,000 per annum. • This represents an approximate total annual cost of $210,000 per annum.
Long term maintenance	• The ponds will need to be cleaned out occasionally, due to salt build up in the ponds (approximate rate of production is 2900-3700 tonnes of salt per year) this is expected to be required every 10-20 years. Alternatively, the ponds could be decommissioned and capped once full, requiring a new evaporation facility.

Criterion	Description
Assumptions	• Arrangements can be made to operate the existing Unity Mining pumping stations and Woodvale Ponds infrastructure necessary for the technical feasibility of this option for the foreseeable future. • Pumps and piping arrangements at New Moon water treatment plant will allow 2.0 ML/d untreated water to bypass the treatment plant and be transferred to Woodvale, without operating the treatment plant. • Power supply and on-site distribution systems at New Moon is suitable to run pumps, when the rest of the site is decommissioned (WTP and other mining infrastructure). • A suitably qualified operator can be engaged to operate and maintain the mine shaft pump, (may require a mine ticket), and the skills to manage and operate the New Moon pumping facilities and Woodvale Ponds. • Local community will accept an extension to the period before the Woodvale Ponds are closed down permanently and rehabilitated. This is likely to require community consultation and the risks associated with the facility would be transferred to the new owner/operator.
Opportunities	• Assuming that the total annual volume to dewater is 730 ML, pumping to Woodvale could occur at the maximum pipeline capacity (2.3 ML/d) over 10 months of the year. This could lead to slightly reduced operational costs as staff will not be required for daily site inspections during the months when dewatering is not occurring.
Implementation	• Implementation of this option would take approximately one to two months, pending sign off of regulatory and management arrangements, but not including any extended community or neighbour consultation process.
Further work/knowledge gaps:	• The evaporative potential of the existing pond configuration and the condition of the ponds and associated liners are unclear and needs to be established. • The condition of the pumps at New Moon and pipeline from New Moon to Woodvale should also be assessed.

Option 1b: untreated discharge to a purpose built evaporation facility

Option 1b would transfer untreated mine water to a purpose built facility in the Bendigo region. No water treatment would be used, with all contaminants accumulating as residual sediments within the facility. The water could be supplied from the Central Deborah Shaft or the New Moon Shaft, depending on the location of the facility. Pumps and a pipeline to the facility would also be required, the cost of which will vary considerably with distance, route, etc.

This option is also considered to be suitable for long term mine water management and should be considered further. However, there is likely to be community opposition to this option and it may be difficult to get approval for construction of the facility.

Table 7-3: Option 1b: untreated discharge to a purpose built evaporation facility

Criterion	Description
Technical feasibility	• Evaporation is a known technology and has been used successfully in the Bendigo region in the past • There are no risks involved in adopting this option, as long as suitable design, operational and maintenance standards are adopted.
New infrastructure required	• Evaporation facility (in the order of 100 ha, depending on pond depth) • Pumps at the New Moon or Central Deborah Shaft • Pipeline from the New Moon or Central Deborah Shaft to the facility
Capital cost	• Evaporation facility - $5 million • Pumps and pipeline – in the order of $1-4 million (depending on distance, route, etc.)
Operating cost	• As per Option 1a - approximate total annual cost of $210,000 per annum

Criterion	Description
Long term maintenance	• The ponds may need to be cleaned out every 20 years or so, due to salt build up in the ponds (approximate rate of production = 2900-3700 tonnes of salt per year).
Assumptions	• Local community will accept the construction of a new evaporation facility • It is expected that the facility design will provide sufficient salt storage such that cleaning is only required every 20 years or more
Opportunities	• The Woodvale Ponds have a legacy of community opposition to their operation and there is an expectation that they will close in 2017. A new facility could avoid these issues. • The facility could be optimised to suit the volume of discharge • A new facility would not carry any of the legacy issues associated with Woodvale
Implementation	• Implementation of this option would take approximately 2 years, pending sign off of regulatory and management arrangements.
Further work/knowledge gaps:	• Need to identify a suitable site • Water balance modelling is required to define the required size of the evaporation facility

7.3 Option 2: treated discharge to the environment

This option consists of using a water treatment plant (WTP), consisting of a pre-treatment facility and a reverse osmosis (RO) plant to treat the mine water. The treated permeate would be discharged to the environment, with the waste stream produced by the RO process sent to a brine facility for containment. Salts and chemicals will accumulate within the facility and will require periodic removal.

For the purpose of this investigation it has been assumed that brine would either be sent to a new facility or to the upgraded Coliban Water facility, at an estimated capital cost of $4.0 million.

Option 2a: treatment near Central Deborah and discharge to Bendigo Creek

Option 2a would treat 2.0 ML/d at an RO WTP near Central Deborah, to a quality suitable for discharge to the environment via Bendigo Creek. The treatment plant would produce approximately 1.4 ML/d (510 ML p.a.) of treated water for discharge, along with 0.6 ML/d (220 ML p.a.) clarifier and filter waste and RO reject brine flows for transfer to a brine facility.

Table 7-4: Option 2a: treatment near Central Deborah and discharge to Bendigo Creek

Criterion	Description
Technical feasibility	• Reverse osmosis (RO) treatment is a proven technology and has been used successfully in the Bendigo region in the past
New infrastructure required	• Water treatment plant (WTP) – pre-treatment and RO plant • Pipeline to Bendigo Creek • New brine facility or upgrade to the existing Coliban Water brine facility • Pumps and pipeline to the brine facility
Capital cost	• WTP plant - $5 million • Pipeline to Bendigo Creek – depends on distance assume $1 million • New brine facility or Coliban Water upgrade - $4 million • Pumps and pipeline to brine facility – in the order of $1-4 million

Criterion	Description
Operating cost	• Pumping to brine facility - $7,500 per month (7 days per week) or $90,000 per annum • Operator attendance at dewatering pumps, WTP, transfer pump station and the brine facility, estimated at 1.0 FTE - 130,000 p.a. (including overheads). • Ongoing maintenance (including pump station maintenance, treatment plant maintenance, operating costs for monitoring bores, vegetation and weed control, and slashing for fire control) - $20,000 per annum. • Operating cost of WTP - $1,000/ML or $730,000 p.a. • This represents an approximate total annual cost of $970,000 per annum.
Long term maintenance	• RO membranes and filters will need replacement every 10 years (approximately) • The ponds will need to be cleaned out every 20 years or so, due to salt build up in the ponds (approximate rate of production = 1500-2000 tonnes of salt per year, depending on permeate salt concentration).
Assumptions	• A site can be found near Central Deborah which is suitable for the WTP (including pre-treatment which may cause an odour) • Local community will accept the construction of a new brine facility, or an upgrade to the Coliban Water facility • It is expected that the brine facility design will provide sufficient salt storage such that cleaning is only required every 20 years or more
Opportunities	• Discharge to the environment of treated water could provide environmental flow benefits under some circumstances
Implementation	• Implementation of this option would take approximately 2 years, pending sign off of regulatory and management arrangements.
Further work/knowledge gaps:	• Water quality discharge criteria need to be established with regulatory authorities • A decision is required regarding the brine disposal option to pursue

Option 2b: treatment at New Moon WTP and discharge to Lake Neangar

Option 2b would treat 2.0 ML/d at the New Moon WTP, to a quality suitable for discharge to the environment, potentially via Lake Neangar. The treatment plant would produce approximately 1.4 ML/d (510 ML p.a.) of treated water for discharge, along with 0.6 ML/d (220 ML p.a.) clarifier and filter waste and RO reject brine flows for transfer to a brine facility.

While it would only take 3-6 months to recommission the New Moon WTP it is likely to take 2 years to either construct a new brine storage facility or upgrade the existing Coliban Water facility.

Table 7-5: Option 2b: treatment at New Moon WTP and discharge to Lake Neangar

Criterion	Description
Technical feasibility	• Reverse osmosis (RO) treatment is a proven technology and has been used successfully in the Bendigo region in the past
New infrastructure required	• New brine facility or upgrade to the existing Coliban Water brine facility • Pumps and pipeline to the brine facility
Capital cost	• Handover cost (New Moon WTP) - $1,000,000 • WTP recommissioning - $670,000 (worst case) • New brine facility or Coliban Water upgrade - $4 million • Pumps and pipeline to brine facility – in the order of $1-4 million

Criterion	Description
Operating cost	• Pumping to brine facility - $7,500 per month (7 days per week) or $90,000 per annum • Operator attendance at dewatering pumps, WTP, transfer pump station and the brine facility, estimated at 1.0 FTE - 130,000 p.a. (including overheads). • Ongoing maintenance (including pump station maintenance, treatment plant maintenance, operating costs for monitoring bores, vegetation and weed control, and slashing for fire control) - $20,000 per annum. • Operating cost of WTP - $1,000/ML or $730,000 p.a. • This represents an approximate total annual cost of $970,000 per annum.
Long term maintenance	• RO membranes and filters will need replacement every 10 years (approximately) • The ponds will need to be cleaned out every 20 years or so, due to salt build up in the ponds (approximate rate of production = 1500-2000 tonnes of salt per year, depending on permeate salt concentration).
Assumptions	• Local community will accept the construction of a new brine facility, or an upgrade to the Coliban Water facility • It is expected that the brine facility design will provide sufficient salt storage such that cleaning is only required every 20 years or more
Opportunities	• Discharge to the environment of treated water could be seen as environmental flows
Implementation	• Implementation of this option would take approximately 3-6 months for the water treatment facility, but is likely to take approximately 2 years for the brine facility upgrade or construction
Further work/knowledge gaps:	• Water quality discharge criteria need to be established with regulatory authorities • A decision is required regarding the brine disposal option to pursue

7.4 Option 3: treated discharge to the recycled water network

Coliban Water has an existing recycled water network within Bendigo. The Recycled Water Factory currently has the capacity to supply approximately 2000-3000 ML/y of Class A water to sporting grounds, parks and schools in Bendigo (CW, 2012). The volume of treated water produced is often far in excess of demand and Coliban Water regularly discharges excess recycled water to Bendigo Creek.

While these scenarios are included in the review of long term management options for Bendigo mine water they are not currently considered viable, due to the lack of demand for additional recycled water. However, these scenarios could be viable under drought conditions or in the future (20+ years) if the demand for recycled water grows.

These scenarios also indicate that in the long term the sewers would require upgrading in order to accept the required volume of discharge. Coliban Water undertook an upgrade to the sewer main which extends past Central Deborah in 2011. The sewer was installed under the heritage blue stones in the bed of Bendigo Creek, which now has very limited space for any further pipes. It's likely that any new pipeline would need to be installed in the road reserves, at significant additional cost. The length of the pipeline was 6.1 km, installed at an average cost of $1.7 million per km (CW, 2012).

There should also be consideration of the possible fee which Coliban Water may apply for accepting the water if it is classed as a trade waste, although this is not yet decided. An indicative price of $1,080,000 per year was supplied by Coliban Water, for accepting 1.4 ML/d of treated water. Trade Waste pricing has been independently endorsed by the pricing regulator and is set to recover the cost of the service provided (CW, 2012). Final trade waste costs, if applicable, would need to be considered following the final scoping of the project.

Option 3a: treatment near Central Deborah and discharge to the main sewer

Option 3a would treat 2.0 ML/d at an RO WTP near Central Deborah, to a quality suitable for discharge to the main sewer trunk. The treatment plant would produce 1.4 ML/d (510 ML p.a.) of treated water for discharge, along with 0.6 ML/d (220 ML p.a.) clarifier and filter waste and RO reject brine flows for transfer to a brine facility.

RO treatment is required as this water will end up at the Epsom STP, which is not configured to adequately treat the expected quality of the mine water, particularly the salt concentration[2]. The water would then go through the Epsom STP, which incurs further cost and means that overall this is not a cost effective solution.

In addition, the existing sewer network only has capacity to accept 0.6 ML/d and would need upgrading for this option to be effective. This would be extremely expensive and would take a number of years to execute.

Table 7-6: Option 3a: treatment near Central Deborah and discharge to the main sewer

Criterion	Description
Technical feasibility	• Reverse osmosis (RO) treatment is a proven technology and has been used successfully in the Bendigo region in the past
New infrastructure required	• Water treatment plant (WTP) – pre-treatment and RO plant • Connection to the sewer system • New brine facility or upgrade to the existing Coliban Water brine facility • Pumps and pipeline to the brine facility
Capital cost	• WTP plant - $5 million • Brine facility/upgrade - $4 million • Pumps and pipeline to brine facility – in the order of $1-4 million • Possible upgrade to the sewer network $?
Operating cost	• Pumping to brine facility - $7,500 per month (7 days per week) or $90,000 per annum • Operator attendance at dewatering pumps, WTP, transfer pump station and the brine facility, estimated at 1.0 FTE - 130,000 p.a. (including overheads). • Ongoing maintenance (including pump station maintenance, treatment plant maintenance, operating costs for monitoring bores, vegetation and weed control, and slashing for fire control) - $20,000 per annum. • Operating cost of WTP - $1,000/ML or $730,000 p.a. • This represents an approximate total annual cost of $970,000 per annum.
Long term maintenance	• RO membranes and filters will need replacement every 10 years (approximately) • The ponds will need to be cleaned out every 20 years or so, due to salt build up in the ponds (approximate rate of production = 1500-2000 tonnes of salt per year, depending on permeate salt concentration).
Assumptions	• Local community will accept the construction of a new brine facility, or an upgrade to the Coliban Water facility • This option would be acceptable to Coliban Water • It is expected that the brine facility design will provide sufficient salt storage such that cleaning is only required every 20 years or more
Opportunities	• The additional water could be used in the future to meet the growing Bendigo water demand (but may be superfluous to requirements until 2030 or 2040)
Implementation	• Implementation of this option would take approximately 2-3 years

[2] It is understood that the TDS of wastewater received at Epsom generally ranges between 500-900 mg/L, with an outflow target of 350 mg/L (Thomas, 2009). The mine water TDS concentration is generally between 4000 and 5000 mg/L, 4 to 10 times the usual water quality received at Epsom.

Criterion	Description
Further work/knowledge gaps:	• This option needs to be acceptable to Coliban Water, in terms of accepting long term management of the discharge • Final trade waste costs, if applicable, will need to be discussed with Coliban Water • Water quality discharge criteria need to be established with Coliban Water • A decision is required regarding the brine disposal option to pursue

Option 3b: treatment at New Moon WTP and discharge to the sewer at Eaglehawk

Option 3b would treat 2.0 ML/d at the New Moon WTP, to a quality suitable for discharge to the sewer at Eaglehawk. The treatment plant would produce 1.4 ML/d (510 ML p.a.) of treated water for discharge, along with 0.6 ML/d (220 ML p.a.) clarifier and filter waste and RO reject brine flows for transfer to a brine facility.

RO treatment is required as this water will end up at the Epsom STP, which is not configured to adequately treat the expected quality of the mine water, particularly the salt load. The water would then go through the Epsom STP, which incurs further cost and means that overall this is not a cost effective solution.

While this option is currently feasible, the Eaglehawk sewer will only have capacity to accept the required 1.4 ML/d up until 2018 and would need upgrading after this date. This would be extremely expensive and would take a number of years to execute.

Table 7-7: Option 3b: treatment at New Moon WTP and discharge to the sewer at Eaglehawk

Criterion	Description
Technical feasibility	• Reverse osmosis (RO) treatment is a proven technology and has been used successfully in the Bendigo region in the past
New infrastructure required	• New brine facility or upgrade to the existing Coliban Water brine facility • Connection to the sewer system • Pumps and pipeline to the brine facility
Capital cost	• Handover cost (New Moon WTP) - $1,000,000 • WTP recommissioning - $670,000 (worst case) • Brine facility/upgrade - $4 million • Pumps and pipeline to brine facility – in the order of $1-4 million • Possible upgrade to the sewer network
Operating cost	• Pumping to brine facility - $7,500 per month (7 days per week) or $90,000 per annum • Operator attendance at dewatering pumps, WTP, transfer pump station and the brine facility, estimated at 1.0 FTE - 130,000 p.a. (including overheads). • Ongoing maintenance (including pump station maintenance, treatment plant maintenance, operating costs for monitoring bores, vegetation and weed control, and slashing for fire control) - $20,000 per annum. • Operating cost of WTP - $1,000/ML or $730,000 p.a. • This represents an approximate total annual cost of $970,000 per annum.
Long term maintenance	• RO membranes and filters will need replacement every 10 years (approximately) • The ponds will need to be cleaned out every 20 years or so, due to salt build up in the ponds (approximate rate of production = 1500-2000 tonnes of salt per year, depending on permeate salt concentration).

Criterion	Description
Assumptions	• Local community will accept the construction of a new brine facility, or an upgrade to the Coliban Water facility • This option would be acceptable to Coliban Water • It is expected that the brine facility design will provide sufficient salt storage such that cleaning is only required every 20 years or more
Opportunities	• The additional water could be used in the future to meet the growing Bendigo water demand (may be superfluous to requirements until 2020? 2030?)
Implementation	• Implementation of this option would take approximately 2-3 years
Further work/knowledge gaps:	• This option needs to be acceptable to Coliban Water, in terms of accepting long term management of the discharge • Final trade waste costs, if applicable, will need to be discussed with Coliban Water • Water quality discharge criteria need to be established with Coliban Water • A decision is required regarding the brine disposal option to pursue

Option 3c: treatment near Central Deborah and discharge to a recycled water network within Bendigo

Option 3c would treat 2.0 ML/d near Central Deborah, to a quality suitable for discharge to the existing recycled water network. The treatment plant would produce 1.4 ML/d (510 ML p.a.) of treated water for discharge, along with 0.6 ML/d (220 ML p.a.) clarifier and filter waste and RO reject brine flows for transfer to a brine facility. Treated water in excess of requirements would be discharged to Bendigo Creek.

The initial capital cost of this option would be higher than Options 3a and 3b as an additional water balancing storage would be required, to store the treated water. However, annual operating costs for Coliban Water would be lower overall than Options 3a and 3b because the water would not have to go through a secondary treatment at the Epsom STP.

However, this option would mean that Coliban Water would be discharging additional water to Bendigo Creek, above their current discharge and there is therefore no real advantage.

Table 7-8: Option 3c: treatment near Central Deborah and discharge to the recycled water network within Bendigo

Criterion	Description
Technical feasibility	• Reverse osmosis (RO) treatment is a proven technology and has been used successfully in the Bendigo region in the past
New infrastructure required	• Balancing storage and connection to the existing recycled water network • Water treatment plant (WTP) – pre-treatment and RO plant • Outflow to Bendigo Creek • New brine facility or upgrade to the existing Coliban Water brine facility • Pumps and pipeline to the brine facility
Capital cost	• WTP plant - $5 million • Balancing storage - $2 million • Brine facility/upgrade - $4 million • Pumps and pipeline to brine facility and outflow to Bendigo Creek– in the order of $1-4 million • Possible upgrade to the recycled water network

Criterion	Description
Operating cost	• Pumping to brine facility - $7,500 per month (7 days per week) or $90,000 per annum • Operator attendance at dewatering pumps, WTP, transfer pump station and the brine facility, estimated at 1.0 FTE - 130,000 p.a. (including overheads). • Ongoing maintenance (including pump station maintenance, treatment plant maintenance, operating costs for monitoring bores, vegetation and weed control, and slashing for fire control) - $20,000 per annum. • Operating cost of WTP - $1,000/ML or $730,000 p.a. • This represents an approximate total annual cost of $970,000 per annum.
Long term maintenance	• RO membranes and filters will need replacement every 10 years (approximately) • The ponds will need to be cleaned out every 20 years or so, due to salt build up in the ponds (approximate rate of production = 1500-2000 tonnes of salt per year, depending on permeate salt concentration).
Assumptions	• Local community will accept the construction of a new brine facility, or an upgrade to the Coliban Water facility • It is expected that the brine facility design will provide sufficient salt storage such that cleaning is only required every 20 years or more
Opportunities	• The additional water could be used in the future to meet the growing Bendigo water demand, but may be superfluous to requirements for 20+ years.
Implementation	• Implementation of this option would take approximately 2-3 years
Further work/knowledge gaps:	• Licence conditions and costs associated with the discharge to Bendigo Creek • This option needs to be acceptable to Coliban Water, in terms of accepting long term management of the discharge • Water quality discharge criteria need to be established with Coliban Water • A decision is required regarding the brine disposal option to pursue

7.5 Option 4: creation of a constructed wetland with outflow to the environment

Constructed wetlands use a combination of biological and mechanical functions to reduce or eliminate water borne contaminants (ITRC, 2003). Removal efficiency is usually a function of residence time within the wetland; therefore, constructed wetlands may require large areas to meet the required water quality criteria.

For ideal operation of a constructed wetland, the water needs to spread out evenly across the system, maximising contact time with the vegetation (DME, 2008). DME (2008) state that an optimum residence time is between 5 and 14 days and the flow path should be through numerous cells and/or sinuous channels. The minimum water depth should be between 0.3-0.4 m and the maximum depth should be between 1-1.5 m (DME, 2008).

Assuming a residence time of 14 days and water depth of 0.5 m, disposal of 2.0 ML/d would require a constructed wetland with a water surface area of 6 ha and a total area in the order of 7 ha. This estimate is at the high end of the area which might be expected and will vary according to the final design. Additional volume may also be required to contain extreme rainfall events.

Capital costs for wetland construction are expected to range from $500,000 to $750,000 per hectare of wetland, with the two key variables being the extent of earthworks and the type and extent of vegetation required (DW, 2005). This indicates a capital cost of $3.0-4.5 million, and is assumed to be $4.5 million for the sake of cost comparison between options.

Due to the constituents of concern in the mine water, a wetland is likely to require a high level of containment to prevent spills and leakage, as per the evaporation pond design. This would include a clay liner and HDPE liner, and sufficient freeboard to contain waves (generated by the wind) and high rainfall events. In addition, the wetland may require flood protection, either being constructed off the floodplain or above a given flood level, or with surrounding levees. This may mean that gravity feeding water from the surface to the constructed wetland will be impractical, and additional pumps may be required.

A constructed wetland will require ongoing maintenance, including regular inspection of pumps, banks and inlet and outlet structures, weed removal and removal of accumulated sediment (maybe once every 10-20 years). Annual or semi-annual vegetation harvesting will also be required, in order to maintain the wetland nutrient and removal capacity and is likely to require 10-20% removal per year. The Centre for Watershed Protection (1998), Webber (2001) and United States Environmental Protection Agency (2001), reported annual maintenance costs of approximately 2% of construction costs (DW, 2005).

Option 4a: constructed wetland near the New Moon natural discharge site (outflow to local watercourse)

Option 4a would treat 2.0 ML/d at a constructed wetland near the New Moon natural discharge site, with treated outflow to a local watercourse. Ideally, this option would not require pumping, with mine water gravity fed to the constructed wetland and outflows naturally flowing to the watercourse. This will depend on the final location of the site chosen and local topography. The pipeline costs will vary according to distance, route, etc.

Table 7-9: Option 4a: constructed wetland at the New Moon natural discharge site (outflow to a local watercourse)

Criterion	Description
Technical feasibility	• Successfully used in a number of similar circumstances but requires some additional investigation to determine appropriate design
New infrastructure required	• Constructed wetland • Pipeline to and from the wetland
Capital cost	• Constructed wetland - $4.5 million. • Pipeline - $500,000
Operating cost	• Site maintenance and vegetation harvesting - $100,000
Long term maintenance	• May require sediment removal every 10-20 years, as the sediments are likely to contain arsenic and metals these will need to be taken to a suitable disposal site.
Assumptions	• Suitable land is available in the New Moon area (at least 7 ha)
Opportunities	• Likely to be more acceptable to the local community than new evaporation or brine facilities • Possible use of harvested plants as stock feed (testing required) • Final outflow may represent a benefit to the local environment • No brine stream generated
Implementation	• Implementation of this option would take approximately 2-3 years
Further work/knowledge gaps:	• Site selection • Detailed assessment of mine water quality for wetland design • Water quality discharge criteria need to be established with EPA

Option 4b: constructed wetland near Central Deborah (outflow to Bendigo Creek)

Option 4b would treat 2.0 ML/d at a constructed wetland near Central Deborah, with treated outflow to Bendigo Creek. This option would require pumping from Central Deborah to the wetland, with the remainder of the system relying on gravity. The pipeline and pumping costs will vary according to distance to the site, route, etc.

This option assumes that there is 6-7 ha of available land relatively close to the Central Deborah Tourist Mine, and ideally connected to Bendigo Creek. It seems unlikely that there will be a suitable site of this size available within the Bendigo urban area, unless it is possible to convert one of the large ex mining sites.

Table 7-10: Option 4b: constructed wetland near Central Deborah (outflow to Bendigo Creek)

Criterion	Description
Technical feasibility	• Successfully used in a number of similar circumstances but requires some additional investigation to determine appropriate design
New infrastructure required	• Constructed wetland • Pumps at Central Deborah • Pipeline to and from the wetland
Capital cost	• Constructed wetland - $4.5 million. • Pumps - $50,000 • Pipeline - $500,000
Operating cost	• Pumping cost from Central Deborah to the wetland - $60,000 • Site maintenance and vegetation harvesting - $100,000
Long term maintenance	• May require sediment removal every 10-20 years, as the sediments are likely to contain arsenic and metals these will need to be taken to a suitable disposal site.
Assumptions	• Suitable land is available near the Central Deborah Tourist Mine (at least 7 ha)
Opportunities	• Likely to be more acceptable to the local community than new evaporation or brine facilities • Possible use of harvested plants as stock feed (testing required) • Final outflow may represent a benefit to the local environment • No brine stream generated
Implementation	• Implementation of this option would take approximately 2-3 years
Further work/knowledge gaps:	• Site selection • Detailed assessment of mine water quality for wetland design • Water quality discharge criteria need to be established with EPA

Option 4c: constructed wetland at Epsom and incorporated with the Bendigo Creek discharge from Coliban Water

Option 4c would treat 2.0 ML/d at a constructed wetland at Epsom, with treated outflow from the wetland mixed with the current Coliban Water outflow to Bendigo Creek. This option would require pumping from Central Deborah to the wetland, with the remainder of the system relying on gravity. The advantage of this option is that the discharge from Epsom STP is Class A water and would dilute any constituents remaining in the outflow from the wetland, providing an additional level of confidence that the discharge would not adversely affect the environment.

This option assumes that there is at least 7 ha of available land relatively close to the Epsom STP. The pipeline cost will vary according to distance, route, etc. but are expected to be in the order of $4.0 million.

Table 7-11: Option 4b: constructed wetland near Central Deborah (outflow to Bendigo Creek)

Criterion	Description
Technical feasibility	• Successfully used in a number of similar circumstances but requires some additional investigation to determine appropriate design
New infrastructure required	• Constructed wetland • Pumps at Central Deborah • Pipeline to and from the wetland • Mixing zone within Bendigo Creek

Criterion	Description
Capital cost	• Constructed wetland - \$4.5 million. • Pumps - \$50,000 • Pipeline - \$4.0 million
Operating cost	• Pumping cost from Central Deborah to the wetland - \$120,000 • Site maintenance and vegetation harvesting - \$100,000
Long term maintenance	• May require sediment removal every 10-20 years, as the sediments are likely to contain arsenic and metals these will need to be taken to a suitable disposal site.
Assumptions	• Suitable land is available near the Epsom STP (at least 7 ha)
Opportunities	• Likely to be more acceptable to the local community than new evaporation or brine facilities • Possible use of harvested plants as stock feed (testing required) • Final outflow may represent a benefit to the local environment • No brine stream generated
Implementation	• Implementation of this option would take approximately 2-3 years
Further work/knowledge gaps:	• Site selection, including consideration of flood risk and management, as this section of Bendigo Creek is quite flood prone • Detailed assessment of mine water quality for wetland design • Water quality discharge criteria need to be established with EPA

7.6 Option 5: use of a permeable reactive barrier at a natural discharge site

A permeable reactive barrier (PRB) is a zone of reactive material that extends below the soil surface, intercepting and treating groundwater. The PRB is not a barrier to groundwater, but it is a barrier to the contaminant which is treated and/or removed by the reactive material (USEPA, 2008).

Treatment methods are generally through sorption or precipitation, chemical reaction, or biological mechanisms and the reactive material is selected according to the groundwater chemistry and desired final water quality. For inorganic contaminants, such as chromium and arsenic, granular iron (zero valent iron) mixed with sand or pumice is an effective filter media although compost based reactive barriers have also been used to remove metals (Wilkin and Puls, 2003).

The interaction of chemicals within the groundwater and filter media are quite complex and further investigations are required in order to properly characterise the Bendigo mine water chemistry and design a suitable filter media. In addition, the properties of the surrounding soils should also be assessed as the hydraulic conductivity of the PRB must be higher than the soil, in order to define a preferred flow path. The reactive barrier is expected to be in the order of 25 m long, 2 m thick and 5 m long, although the design adopted for this project would depend on a number of factors including the geochemistry, filter media, required residence time, porosity of the media and surrounding soil, general topography of the site and hydraulic gradient.

The outflow rate through the PRB is controlled by the choice of filter media and the compaction within the barrier, in order to achieve the required treatment time. Permeability is a key consideration in the final design, as well as the size and number of PRBs required. It is therefore difficult to accurately estimate the required size of the PRB at this stage of the project.

Wilkin and Puls (2003) estimated porosity loss rates of 1% to 4% per year in their studies, and concluded that it's reasonable to expect PRB lifespans to exceed 10 years. Numerical modelling conducted by Li and Benson (2005) indicates that a zero valent iron PRBs should convey flow efficiently for 30-50 years without requiring cleaning or replacement. PRBs may function adequately for a number of decades, but this is still a relatively new technology and little long term field data (10 years +) is available (Wilkin and Puls, 2003).

A pilot study is considered advisable, in order to test the performance of the PRB concept with Bendigo's mine water. This could possibly be implemented in an area which is already experiencing natural mine water discharge and odour, e.g. Rosalind Park.

A drawback to this option is that it is not very flexible once it is in place. If it is not found to be working well the whole barrier would need to be dug up and the design modified, or the media would need to be altered or replaced. Care should therefore be taken in the initial assessment of mine water chemistry, filter material and porosity, PRB size, placement locations and levels, etc.

Table 7-12: Option 5: use of a permeable reactive barrier at natural discharge sites

Criterion	Description
Technical feasibility	• Initial review of water quality data indicates that this is a feasible option; however, further investigation is required.
New infrastructure required	• PRB installed at New Moon
Capital cost	• PRB - $1.8 million • Installation of monitoring bores (x2) - $12,000
Operating cost	• Water quality monitoring will vary over time, for the first year samples should be taken every month, then quarterly in each subsequent year - $30,000 for the first year, $10,000 for each subsequent year
Long term maintenance	• The PRB may need to be cleaned out and replaced every 10-50 years
Assumptions	• Long term monitoring of the PRB performance will be required, this would need at least one bore upstream and downstream of each PRB
Opportunities	• Very low maintenance costs • Could be suitable to place in other areas of Bendigo to address mine water seepage and odour
Implementation	• Implementation of this option would take approximately 2-3 years if a pilot study is adopted, or 12 months if no pilot study is required
Further work/knowledge gaps:	• Assessment of suitable PRB sites. • Analysis of soils at the natural discharge site at New Moon. This will inform the required conductivity of the media. • Detailed assessment of mine water quality, in order to inform the selection of the PRB media. • Lifespan of PRB media when used with the Bendigo mine water.

It is currently difficult to estimate the capital and ongoing cost of this option, due to limited information on the mine water chemistry and soil characteristics in the discharge areas. Capital costs for PRB project vary significantly, according to site characteristics, plume dimensions and installation methods (USEPA, 2002).

The US EPA publication *Economic Analysis of the Implementation of Permeable Reactive Barriers for Remediation of Contaminated Ground Water* (2002) provides a breakdown of costs for 21 PRB projects, which are aggregated in Table 7-14. Some assumptions of cost can be made from this data and it is reasonable to expect that the capital cost of a PRB for this project could be in the order of $1.2-1.8 million. For the purpose of cost comparison the capital cost of this option is assumed to be $1.8 million. The operation and maintenance costs presented in Table 7-14 are quite high for the requirements of this project and have not been used.

Table 7-13: PRB cost estimates

Component	Reported costs for 22 PRB projects (USEPA, 2002)		Median cost in $USD (2014)	Median cost in $AUD (2014)
	Range	Median		
Site characterisation	$25,000-$400,000	$150,000	$198,000	$226,000
Design costs	$30,000-$340,000	$150,000	$198,000	$226,000

Component	Reported costs for 22 PRB projects (USEPA, 2002)		Median cost in $USD (2014)	Median cost in $AUD (2014)
	Range	Median		
Construction costs	$24,000-$4,570,000	$520,000	$688,000	$785,000
Operation & maintenance	$3,000-$148,000	$61,000	$81,000	$92,000
Total (capital only)			$1,084,000	$1,237,000

7.7 Other opportunities

7.7.1 Untreated discharge to Bendigo Creek under suitable flow conditions

It is worth considering if there is any potential to release untreated mine water into Bendigo Creek, under suitable streamflow conditions (for example, when the flow is sufficient to dilute the discharge by 1:10, the salinity of the receiving water is suitably low, and the addition of the discharge won't cause overbank flow). This type of dilution approach has been adopted by the Queensland Department of Environment and Heritage Protection (DEHP) for the management of excess saline mine water in the Fitzroy Basin.

Discharge could be made when the flow was above 20 ML/d (achieving a 1:10 dilution) but below bankfull flow, so that the discharge would not contribute to flooding. If a dilution factor of 1:10 is required, the flow at Bendigo Creek at Huntley (gauging station 407255) indicates that streamflow at this site is generally above 20 ML/d for 42% of the time, or 153 days per year. If the maximum discharge of 10% of the flow volume was made when flows were between 20 ML/d and 2800 ML/d[3] the long term average discharge over the 37 year streamflow record would be 48930 ML, or 1320 ML/y. This would be more than sufficient opportunity to dispose of the current mine water volumes. (These calculations are based on a review of long term streamflow data, June 1977 to August 2014, with 0.5% missing data).

This option would require ongoing pumping from the Central Deborah Shaft into the Londonderry Shaft to maintain access to the Central Deborah Tourist Mine. Additional pumps would be required at the Londonderry Shaft for the event based discharge, along with a pipeline to Bendigo Creek and outlet works at the creek.

It is not clear if this approach would be acceptable to the EPA or other regulatory agencies, but it should be considered further.

7.7.2 Salts returned to the mine voids

An alternative approach could also be taken with the salt accumulation in the evaporation ponds, where water is returned to the mine voids after a number of days of evaporation and concentration of salts. For example, water could be pumped to the ponds for the majority of the month and then pumped back to the mine voids over 2-3 days. Once returned to the mine void the water from the ponds would settle to the bottom of the mine void, as it would be denser than the *in situ* waters. This process would increase the concentration of the constituents within the mine water but would not introduce any new chemicals. This approach would avoid the problem of the long term management and disposal of the accumulated salts within the evaporation ponds.

This management of saline water is similar to the concentration and seepage approach outlined for Murray-Darling Basin (MDB) salt interception schemes (MDBA, 2011). This allows collected saline water to concentrate through evaporation, with the resulting water seeping back into the regional aquifer, which is already saline.

It is not clear if this approach would be acceptable to the EPA or other regulatory agencies, but may be considered further.

[3] This is the assumed bankfull flow level at Huntley which has been inferred from information in the Bendigo Urban Flood Study (Water Tech, 2013). This assumption should be reviewed if dilution discharges are investigated further.

This approach would not be suitable for the management of a brine facility, due to the chemicals which are used in the water treatment processes, and sent to the brine facility in the RO waste stream.

7.8 Summary and evaluation of longer-term options

Table 7-14 presents a brief summary of the long term management options presented in this section.

For completeness a base case of “Do nothing” is included. Under this scenario Bendigo Trust would stop pumping water out of the Central Deborah Tourist Mine and mine water would gradually rise to flood the mine and discharge to the environment in a number of locations in and around Bendigo. The Central Deborah Tourist Mine would close, causing a loss of revenue to the Bendigo Trust as well as to the wider community from associated tourism. Odour would also be experienced, due to the presence of hydrogen sulphide in the mine water. This option is therefore considered unlikely to be acceptable to the community.

Consequently, a benefit of each of the options described in Table 7-14 is that the Central Deborah Tourist Mine can continue to operate and negative impacts to the community and environment are avoided.

Five of the options outlined in this section include RO water treatment, which produces a brine stream that requires disposal. It has been assumed that in the long term the use of the Woodvale facility is not preferred, due to the legacy associated with the site, including the cost of rehabilitation and local community expectation of its closure. An alternative brine disposal facility may therefore be required. Likely alternatives include: a new, purpose-built facility, a proposed regional brine disposal facility and the upgrade and use of the Coliban Water’s brine ponds (subject to agreement with Coliban Water).

A regional brine disposal facility is currently under consideration, but is still at a conceptual stage. It is not clear how it would be used or whether it will actually be developed. For the purpose of this investigation it has therefore been assumed that brine would either be sent to a new facility or to the upgraded Coliban Water facility, at an estimated capital cost of $4.0 million. This does not include consideration of the cost of the associated pipeline and pumps, which will vary considerably depending on the final location of the site and is estimated to be between $1 million and $4 million.

Several of the options assume that Coliban Water would accept part or all of the mine water, which is also uncertain. Coliban Water will need to determine its capacity and willingness to accept the water and any associated long term legacy generated by constituents such as arsenic and salt. It may also depend upon the integration of treated mine water into Coliban Water’s long term water resource planning and it becoming a resource for use. This may not be the case for many years and possibly decades: unless a severe and prolonged drought occurs.

Capital, infrastructure handover (from Unity Mining) and operating costs have been estimated for each option. Net present cost (exclusive of land acquisition and long-term maintenance) has been estimated over 20 years period has also been calculated

Six of the eleven options considered are recommended for further investigation (1a, 1b, 4a, 4b, 4c and 5). Three options were explicitly rejected (3a, 3b, 3c) and two options (2a, 2b) may be suitable but are very expensive and may not satisfy cost-benefit considerations.

Disposal of the untreated mine water to an evaporation pond (Options 1a and 1b) is considered the best understood and established method of treatment considered, with low ongoing costs and risks. However, these options are only likely to proceed at locations which have local community support.

Constructed wetlands options (4a, 4b, 4c) appear very promising as a low cost passive treatment system. Although their long term costs are higher than the evaporation ponds, they may avoid the need for an evaporation facility and provide additional environmental benefits.

The permeable reactive barrier (5) offers the lowest long-term cost and also appears promising. However, the technology would need to be proven for use with Bendigo’s mine water and geology.

This initial study has considered the longer-term options individually. However, they could (conceptually) be developed in combination. Further information on technical feasibility, cost, community acceptance, etc. would be required before implementation could commence.

Table 7-14 : Summary of proposed long term options for Bendigo Mine Water Management

Option	New infrastructure required	Costs	NPC 20 years 6% p.a. discount rate	Time to implement	Technical feasibility	Long term maintenance	Opportunities /advantages	Constraints/ disadvantages	Assumptions	Recommended for adoption or further study?
Base Case: Do nothing										
Do nothing – Central Deborah Tourist Mine closes & mine water seeps to the environment	Nil	Loss of revenue from the tourist mine & associated tourism. Possible salinity impacts to roads & buildings.	Nil	Immediate	-	-	Avoids long term management of mine water & cost	Loss of amenity due to odour. Loss of revenue. Long term impact to infrastructure	Assumes that this is acceptable to the community	No – this is unlikely to be acceptable to the Bendigo community
Option 1: Untreated discharge to an evaporation facility										
1a. Untreated discharge to the Woodvale facility	Nil	Capital – nil Handover – $1.7 M Annual ops.- $0.4 M	$5.8 M	1-2 months	Reliable/proven	Ponds will need to have the accumulated salts removed at 10-20 years	Facility is already in place	Inconsistent with community expectation that Woodvale would close and be rehabilitated in 2017.	Assumes that the ponds are in suitable condition for operation	Yes – facility is already in place, saving a lot of time in design & approvals. Low ongoing cost, known performance
1b. Untreated discharge to a purpose built facility	Evaporation pond Pipeline & pumps	Capital – $5.0 M Handover – nil Annual ops.- $0.4 M (+ pipeline of $1-4 M?)	$9.1 M	2 years	Reliable/proven	Ponds will need to have the accumulated salts removed every 20+ years	Opportunity to develop at a location with minimal community impact or possibly closer to Central Deborah (unlikely)	Requires ~100 ha of ponds. Finding suitable sites with low community impact within reasonable pipeline distances may be difficult	Also needs a pipeline to the facility, which could be anywhere in the region of $1-4 M, depending on distance, route, etc.	Yes – low ongoing cost, known performance & design requirements
Option 2: RO treated discharge to the environment										
2a. RO treatment near Central Deborah and treated water discharge to Bendigo Creek	New WTP New brine disposal facility or upgraded Coliban Water facility Brine pipeline Pipeline to Bendigo Creek	Capital – $10 M Handover – nil Annual ops.- $1.1 M (+ brine pipeline of $1-4 M?)	$22.8 M	2 years	Reliable/proven	RO membranes require replacing every 10+ years. Brine facility will need to have the accumulated salts removed every 20+ years	Discharge to the environment of treated water could be seen as environmental flows	Costly	Assumes brine disposal at a new facility or upgraded Coliban Water facility Also needs a pipeline to the facility, which could be anywhere in the region of $1-4 M, depending on distance, route, etc.	Maybe – very expensive
2b. RO treatment at New Moon and treated water discharge to Lake Neangar	New brine disposal facility or upgraded Coliban Water facility Brine pipeline	Capital – $4.7 M Handover – $1.0 M Annual ops.- $1.1 M (+ brine pipeline of $1-4 M?)	$18.5 M	2 years	Reliable/proven	RO membranes require replacing every 10+ years. Brine facility will need to have the accumulated salts removed every 20+ years	Discharge to the environment of treated water could be seen as environmental flows	Costly	Assumes brine disposal at a new facility or upgraded Coliban Water facility Also needs a pipeline to the facility, which could be anywhere in the region of $1-4 M, depending on distance, route, etc.	Maybe – very expensive

Option	New infrastructure required	Costs	NPC 20 years 6% p.a. discount rate	Time to implement	Technical feasibility	Long term maintenance	Opportunities /advantages	Constraints/ disadvantages	Assumptions	Recommended for adoption or further study?
Option 3: RO treated discharge to the recycled water network										
3a. RO treatment at Central Deborah and discharge of treated water to the main sewer	New WTP New brine disposal facility or upgraded Coliban Water facility Brine pipeline	Capital – $9.0 M Handover – nil Annual ops.- $1.1 M (+ brine pipeline of $1-4 million?)	$21.8 million	2-3 years	Reliable/proven	RO membranes require replacing every 10+ years. Brine facility will need to have the accumulated salts removed every 20+ years	The additional water could be used in the future to meet the growing Bendigo water demand (may be superfluous to requirements for 20+ years)	Sewer only has capacity to accept 0.6 ML/d The sewer along Bendigo Creek has recently been upgraded and it may be difficult to upgrade any further	Assumes that Coliban Water will accept the treated water Assumes brine disposal at a new facility or upgraded Coliban Water facility. Also needs a pipeline which could be anywhere in the region of $1-4 M, depending on distance, route, etc.	No – the sewer has insufficient capacity to accept the full volume, this would require an upgrade to the existing sewer network, which would be extremely expensive. In addition, there is already an oversupply of recycled water within Bendigo.
3b. RO treatment at New Moon and discharge to the sewer at Eaglehawk	New brine disposal facility or upgraded Coliban Water facility Brine pipeline	Capital – $4.7 M Handover – $1.0 M Annual ops.- $1.1 M (+ brine pipeline of $1-4 million?)	$18.5 million	2-3 years	Reliable/proven	RO membranes require replacing every 10+ years. Brine facility will need to have the accumulated salts removed every 20+ years	The additional water could be used in the future to meet the growing Bendigo water demand (may be superfluous to requirements for 20+ years)	Sewer has capacity to accept treated water up until 2018	Assumes that Coliban Water will accept the treated water Assumes brine disposal at a new facility or upgraded Coliban Water facility Also needs a pipeline which could be anywhere in the region of $1-4 M, depending on distance, route, etc.	No (as per Option 3a)
3c. RO treatment at Central Deborah and discharge into the recycled water network within Bendigo	New WTP New brine disposal facility or upgraded Coliban Water facility Brine pipeline	Capital – $11.0 M Handover – nil Annual ops.- $1.1 M (+ brine pipeline of $1-4 million?)	$23.8 million	2-3 years	Reliable/proven	RO membranes require replacing every 10+ years. Brine facility will need to have the accumulated salts removed every 20+ years	The additional water could be used in the future to meet the growing Bendigo water demand (may be superfluous to requirements for 20+ years)	Initial demand may be low and discharge to the environment may be required for excess water	Assumes that treated water can be used directly within the existing recycled water network. Assumes brine disposal at a new facility or upgraded Coliban Water facility Also needs a pipeline which could be anywhere in the region of $1-4 M, depending on distance, route, etc.	No, there is already an oversupply of recycled water within Bendigo. Maybe reconsider in 10-20 years?
Option 4: Creation of an aerobic wetland with outflow to the environment										
4a. Constructed wetland near the New Moon natural discharge site (outflow to local watercourse)	Constructed wetland Degassing tower Pipeline from New Moon to the wetland	Capital – $5.0 M Handover – nil Annual ops.- $0.3 M	$7.9 M	2-3 years (pilot study recommended before full implementation)	Proven in some situations & for some water qualities – may need further investigation	Wetlands will require refurbishment as plants reach maturity. Expect 20% per year replacement after the first two years	Potential environmental flow No brine stream created	Requires ~7 ha surface area. Engagement with neighbours required to ensure acceptance of treatment.	Assumes that it is possible to achieve a final water quality that is acceptable to EPA	Yes – this technology may be an effective passive treatment, with minimal ongoing costs, but requires further investigation

Option	New infrastructure required	Costs	NPC 20 years 6% p.a. discount rate	Time to implement	Technical feasibility	Long term maintenance	Opportunities /advantages	Constraints/ disadvantages	Assumptions	Recommended for adoption or further study?
4b. Constructed wetland on Council land near Central Deborah (outflow to Bendigo Creek)	Constructed wetland Degassing tower Pumps & pipeline from Central Deborah to the wetland	Capital – $5.0 M Handover – nil Annual ops.- $0.3 M	$8.6 M	2-3 years (pilot study recommended before full implementation)	Proven in some situations & for some water qualities – may need further investigation	Wetlands will require refurbishment as plants reach maturity. Expect 20% per year replacement after the first two years	Potential environmental flow No brine stream created	Requires ~7 ha surface area. Engagement with neighbours required to ensure acceptance of treatment.	Assumes that it is possible to achieve a final WQ that is acceptable to EPA	Yes – as per 4a
4c. Constructed wetland at Epsom and incorporated with the Bendigo Creek discharge from Coliban Water	Constructed wetland Degassing tower Pumps & pipeline from Central Deborah to the wetland	Capital – $8.6 M Handover – nil Annual ops.- $0.4 M	$12.8 M	2-3 years (pilot study recommended before full implementation)	Proven in some situations & for some water qualities – may need further investigation	Wetlands will require refurbishment as plants reach maturity. Expect 20% per year replacement after the first two years	Potential environmental flow No brine stream created	Requires ~7 ha surface area. Engagement with neighbours required to ensure acceptance of treatment.	Assumes that it is possible to achieve a final WQ that is acceptable to EPA	Yes – as per 4a
Option 5. Use of a permeable reactive barrier at natural discharge site	PRBs installed at New Moon natural discharge site Monitoring bores	Capital – $1.8 M Handover – nil Annual ops. - $0.2 M	$3.7 M	2-3 years (pilot study recommended before full implementation)	Proven in some situations & for some water qualities – will need further investigation	The reactive barrier will need periodic cleaning out, possibly every 10-50 years	No brine stream created Allows mine water to connect with natural discharge sites Low maintenance requirements Potential for dispersed application at multiple potential mine water discharge points.	Not flexible once in place	Assumes that it is possible to achieve a final WQ that is acceptable to EPA& outflow rates are suitable	Yes – this technology may be an effective passive treatment, with minimal ongoing costs, and may be useful in other areas of Bendigo where mine water is already discharging and odour is an issue. Requires further investigation

8. Conclusions and recommendations

Water levels within the Garden Gully Reef are expected to recover to a level which will lead to uncontrolled discharge of mine water to the environment by February or March 2015. If this is to be avoided, management options are required which can be implemented almost immediately. Such options may only be interim measures and do not necessarily need to be part of the long-term, sustainable mine water management “solution”.

The short term options are expected to operate while longer-term responses are developed. Long term options are expected to be implementable within 2-4 years and remain in place indefinitely.

Consultation undertaken as part of the review of short and long-term water management options highlighted two important points for future management of mine water, namely that:

- There is currently an excess of water supply over demand in the Bendigo region and hence no available productive use for mine water, whatever its quality;
- The key infrastructure available to manage mine water in the short term are Unity Mining’s Woodvale Ponds facility and New Moon Water Treatment Plant. Other facilities in the region either lack the capacity to manage the volume required, are not configured to treat the expected water quality, or are still in the concept stage of planning.

8.1 Water quality and recommended treatment processes

Various treatment technologies were assessed for their capacity to produce a final water quality suitable to the three end “uses” identified. While each constituent of concern could be treated individually by various treatment technologies, the combination of constituents present in the mine water narrows the range of applicable treatments. While RO is the most effective and proven treatment option, there are also two alternative treatment technologies (constructed wetlands and permeable reactive barriers) which could be suitable for treating Bendigo’s mine water. As these options could significantly reduce the ongoing costs associated with RO water treatment, they should be investigated further.

The assessment of water treatment options was based on water quality criteria outlined in the *Recycled Water Guidelines* (EPA, 2003), the *Guidelines for Wastewater Irrigation* (EPA, 1991), *Fresh water quality guidelines* (ANZECC, 2000) and determined for previous operations. However, there may be an opportunity to work with environmental regulators to establish regionally-appropriate discharge criteria through the analysis of background water quality data and consideration of the impacts of uncontrolled water discharge.

8.2 Short-term management options

The analysis of short term mine water management options identified only two feasible alternatives that could be implemented in a timely manner and were consistent with the reported water quality and current lack of demand for additional water in Bendigo. These options involved either disposal of untreated water to an evaporation or holding facility, or RO treatment of the water for a beneficial use, with disposal of the concentrate or brine from the RO plant to the evaporation or holding facility.

While it is the only existing evaporation or holding facility in the region with the capacity to accept the volume and quality of either untreated mine water or brine from RO treatment, the Woodvale Ponds facility is currently being prepared for rehabilitation. This would need to be halted to allow any of the short-term water management options to proceed.

Several variants of the two short-term water management options are available, with two recommended for further consideration. These are the untreated discharge of mine water to Woodvale, which has the lowest capital and ongoing operating cost of the options considered, and the untreated discharge of mine water to Woodvale over summer with treated discharge to the environment over winter. The second option provides the highest level of flexibility and responsiveness to operational requirements and climatic conditions.

As the New Moon pumps, pipeline from New Moon to Woodvale and the Woodvale facility are essential to all feasible short term alternatives to allowing uncontrolled discharge of mine water it is recommended that this infrastructure is inspected soon to determine its current fitness-for-use. Detailed water balance modelling should also be undertaken to determine how much of the Woodvale facility is required for short term use options. Consultation with local residents about reinstatement of the facility as part of the short-term management Bendigo's mine water should also be undertaken at an early stage.

8.3 Longer-term management options

Of the long term options assessed in this report only those relating to the disposal of untreated water to evaporation ponds, creation of a constructed wetland with outflow to the environment, or the use of a permeable reactive barrier at a natural discharge site are considered suitable to investigate further.

The disposal of untreated mine water to evaporation ponds is considered the best understood and established method of treatment considered, with low ongoing costs and risks. However, this option is only likely to proceed at locations which have local community support. Alternatively, the constructed wetland and permeable reactive barrier options look promising as relatively low cost passive treatment systems, but have less certainty around their technical performance in this situation.

Further information is required in order to progress the selection of a suitable long term option, including:

- Woodvale Ponds – assessment of condition of pumps, pipeline and ponds. Long term water balance modelling should also be undertaken in order to confirm the required size and capacity of the facility.
- New evaporation pond – If a new facility is required it is recommended that a site selection study be undertaken to identify if there are suitable sites in the Bendigo region for a new evaporation pond. Long term water balance modelling should also be undertaken in order to confirm the required size and capacity of the facility.
- Constructed wetlands - it is recommended that a site selection study is undertaken to identify if there are suitable sites of at least 7 ha either near the New Moon natural discharge site, the Central Deborah Tourist Mine or Epsom STP for a constructed wetland. Further water quality analysis is also required to inform the wetland design, and water quality criteria will need to be discussed with the EPA.
- Permeable reactive barrier - it is recommended that a site assessment, and soil and geotechnical characterisation is undertaken at the New Moon natural discharge site. A detailed assessment of the mine water geochemistry is also required, in order to develop the design of the permeable reactive barrier.

It is generally recommended that further analysis of the mine water chemistry is undertaken. This will help inform a number of the options, particularly the wetlands and permeable reactive barrier options. Further water quality analysis should include a full metal suite in order to verify the constituents of concern, metal species (particularly arsenic), and dissolved and total metals.

It is further recommended that cost estimates, including land acquisition and long term maintenance costs, are assessed in more detail in the next phase of the project, once the long term options are narrowed down and site details are known.

8.4 Alternative approaches

There are two alternative approaches which could be considered for longer-term management. These are the discharge of untreated mine water to Bendigo Creek under suitable flow conditions (diluting the constituents of concern), or the return of concentrated salts to the mine voids (avoiding issues of external salt disposal).

Both of these options have advantages, but it is not clear how acceptable they may be to the EPA or other regulatory agencies. It is recommended that these options are discussed with regulatory agencies as part of the next stage of development of the longer-term options.

8.5 Suggested implementation pathway

In the short term, it is suggested that the Woodvale Ponds be readied to start receiving untreated mine water by February 2015. At the same time, water balance modelling should be undertaken to confirm the size and capacity of the evaporation facility required to manage 2.0 ML/d discharge. If the Woodvale Ponds do not have the capacity to manage this volume of mine water the New Moon WTP should be recommissioned so that RO treatment of mine water can take place over winter, when evaporation is low.

For the development of the longer-term options a number of studies need to be undertaken, in order to inform or rule out the various options. These studies could be implemented concurrently or in a few different stages, depending on the relative importance placed on decision making criteria, e.g. site availability, technical feasibility, community acceptance, cost. It is therefore suggested that these criteria are reviewed and prioritised prior to the additional studies being undertaken.

This initial study has considered the longer-term options individually. However, they could (conceptually) be developed as combinations, e.g. two small PRBs along Bendigo Creek and a wetland at New Moon. Further information on technical feasibility, cost, community acceptance, etc. is required before these options could be developed.

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Supplied data:

Bendigo Mining; *Shaft Quality Data.xlsx*; 11/5/2010 to 10/11/2012.

URS; *Water Quality Results Table_w guidelines.xlsm;* 24/4/2014 to 28/4/2014.

Coliban Water; *Mine Water Quality Parameters.pdf*; Supplied to Jacobs 6 August 2014 by email

Discussion with Process Equipment Suppliers:

Minetek, 8/8/2014 to 11/8/2014

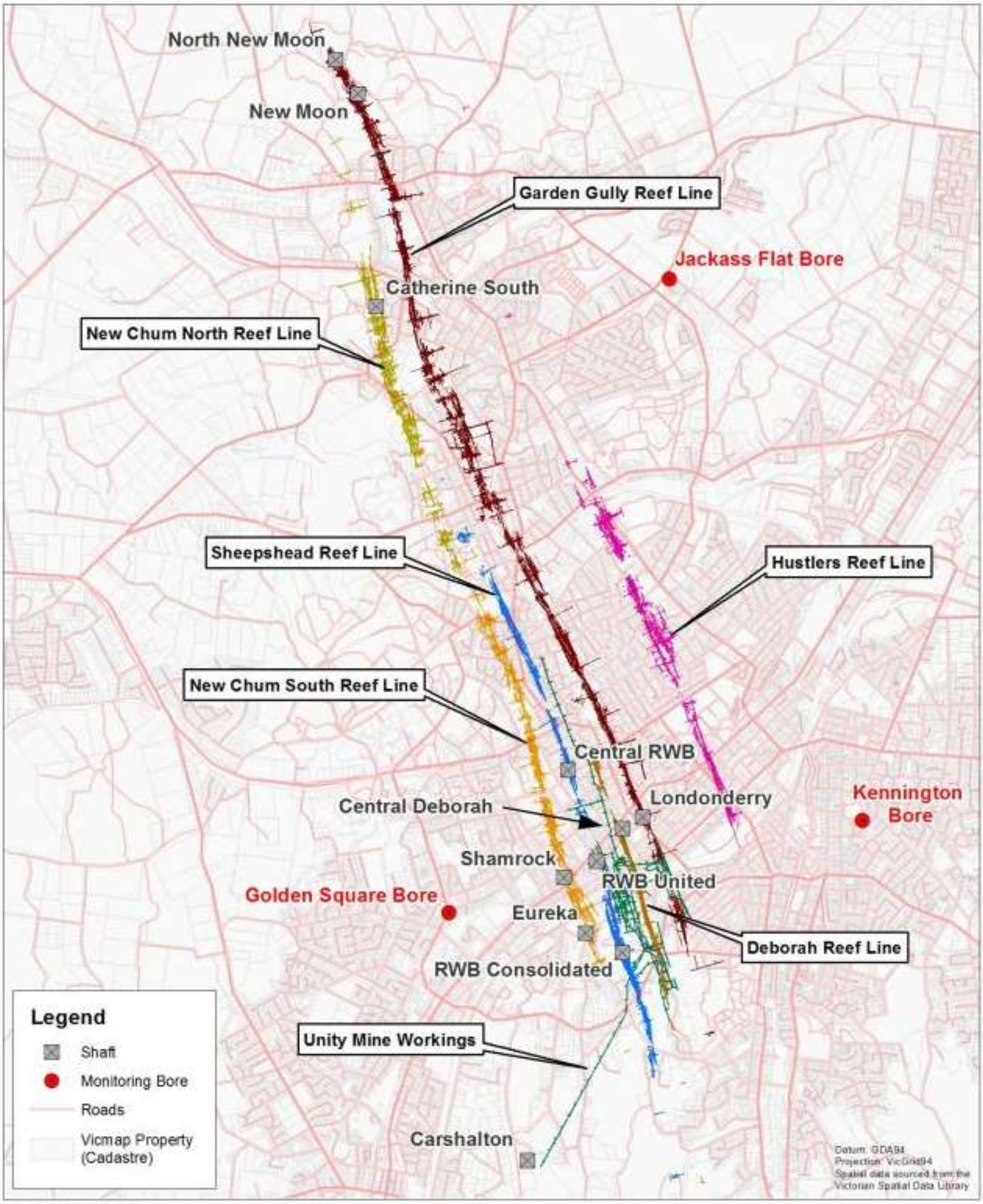
Orica Watercare, 8/8/2014 to 11/8/2014

Appendix A. Historic water quality summary table

Information Source		DEPI Data			BML Shaft WQ Data from DEPI			GHD Report from DEPI			AGC Report from DEPI			DEPI Data			BML Shaft WQ Data from DEPI			
Data Start Date		24/04/2014			28/01/2010			1/06/1986			1/07/1980			24/04/2014			28/01/2010			
Data End Date		28/04/2014			30/11/2011			1/06/1989			1/10/1983			28/04/2014			30/11/2011			
Portion of data used		Central Deborah and New Moon			New Moon			New Moon			Central Deborah and North New Moon			Eureka, Golden Square, Jackass Flats, Kennington			Carshalton Shaft and Adam St Shaft			
Parameter	**Unit**	**Median**	**Max**	**Count**	**Median**	**Max**	**Count**	**Mean**	**Max**	**Count**	**Median**	**Max**	**Count**	**Median**	**Max**	**Count**	**Median**	**Max**	**Count**	**Comment**
Arsenic	mg/L							1.8			2.2	3.2	9							
Arsenic (Filtered/Dissolved)	mg/L	2.53	2.7	11	3.3	4.09	7							0.74	1.41	9	1.26	10.2	14	
Barium (Filtered/Dissolved)	mg/L	0.07	0.118	11										0.226	0.28	9				
Cadmium	mg/L										0.005 ***[3]	0.02	7							***[3] Limit of detection affects result (variously <0.02, <0.01 and <0.0002)
Calcium	mg/L	120	122	11							110	150	7	90	169	9				
Chromium	mg/L										0.01 ***[3]	0.06	5							***[3] Limit of detection affects result (<0.002)
Copper	mg/L										0.01	0.2	5							
Cyanide	mg/L										0.015 ***[3]	3.8	5							***[3] Limit of detection affects result (<0.03)
Fluoride	mg/L	0.6	0.8	10										0.8	1	9				
Hydrogen Sulphide	mg/L										2.4	2.9	3							
Iron	mg/L							0.5			0.34	1.3	7							
Iron (Filtered/Dissolved)	mg/L	2.56	2.71	11	0.025 **[2]	0.12	7							0.23	0.46	9	0.025 **[2]	0.1	14	**[2] Limit of detection affects result (<0.05)
Lead	mg/L										0.014 ***[3]	0.25 ***[3]	8							***[3] Two detections, 0.04 and 0.003. Limit of detection affects result (variously <0.5, <0.05 and <0.002)
Magnesium	mg/L	222	238	11	235	248	7				330	350	9	210	562	9	194.5	336	14	
Manganese	mg/L							0.75			0.71	0.9	3							
Manganese (Filtered/Dissolved)	mg/L																			
Mercury	mg/L	0.00005 *[1]	0.00005 *[1]	10							0.0001 ***[3]	0.005 ***[3]	5	0.00005 *[1]	0.00005 *[1]	8				*[1] Limit of detection affects result (<0.0001), ***[3] One detection, 0.0001. Limit of detection affects result (variously <0.01 and<0.0001)
Mercury (Filtered/Dissolved)	mg/L				0.00005 **[2]	0.00005 **[2]	7										0.00005 **[2]	0.00005 **[2]	14	**[2] Limit of detection affects result (<0.0001)
Nickel	mg/L										0.017	0.018	2							
Silica	mg/L										29	40	3							
Sodium	mg/L	918	1220	11							1100	1300	8	862	2550	9				
Sulphate	mg/L	550	592	11	339	421	7				69	525	9	300	1060	9	449	802	14	
Sulphide	mg/L										25	47	5							
Zinc	mg/L										0.05	0.1	5							
Zinc (Filtered/Dissolved)	mg/L	0.0025 *[1]	0.012	11	0.0025 **[2]	0.005	7							0.021	0.096	9	0.011	0.234	14	*[1] Limit of detection affectts result (<0.005), **[2] Limit of detection affects result (<0.005)
COD	mg/L	20	84	11							74.5	85	4	44	93	9				
Dissolved Oxygen	mg/L										0.6	7.7	6							
EC	µS/cm	6400	7260	11	6890	7160	7				6270	7600	9	5900	15500	9	5415	7550	14	
pH	pH				6.9	7.1	7	8.2			6.97	7.4	10				7	8.3	14	
Hardness	mg/L as CaCO3										1234	1800	4							
Total Alkalinity	mg/L as CaCO3	492	1020	11							1500	1500	3	838	864	9				
TDS	mg/L	4145	4720	10	4190	5680	7	5800			4310	4820	9	4745	10100	8	3370	4500	14	
Total Suspended Solids	mg/L	11	24	11							20	414	7	2.5 *[1]	143	9				*[1] Limit of detection affects result (<5)

Appendix B. Mine voids and pump locations

Figure 1 - Bendigo Groundwater and Mine Water Monitoring Locations

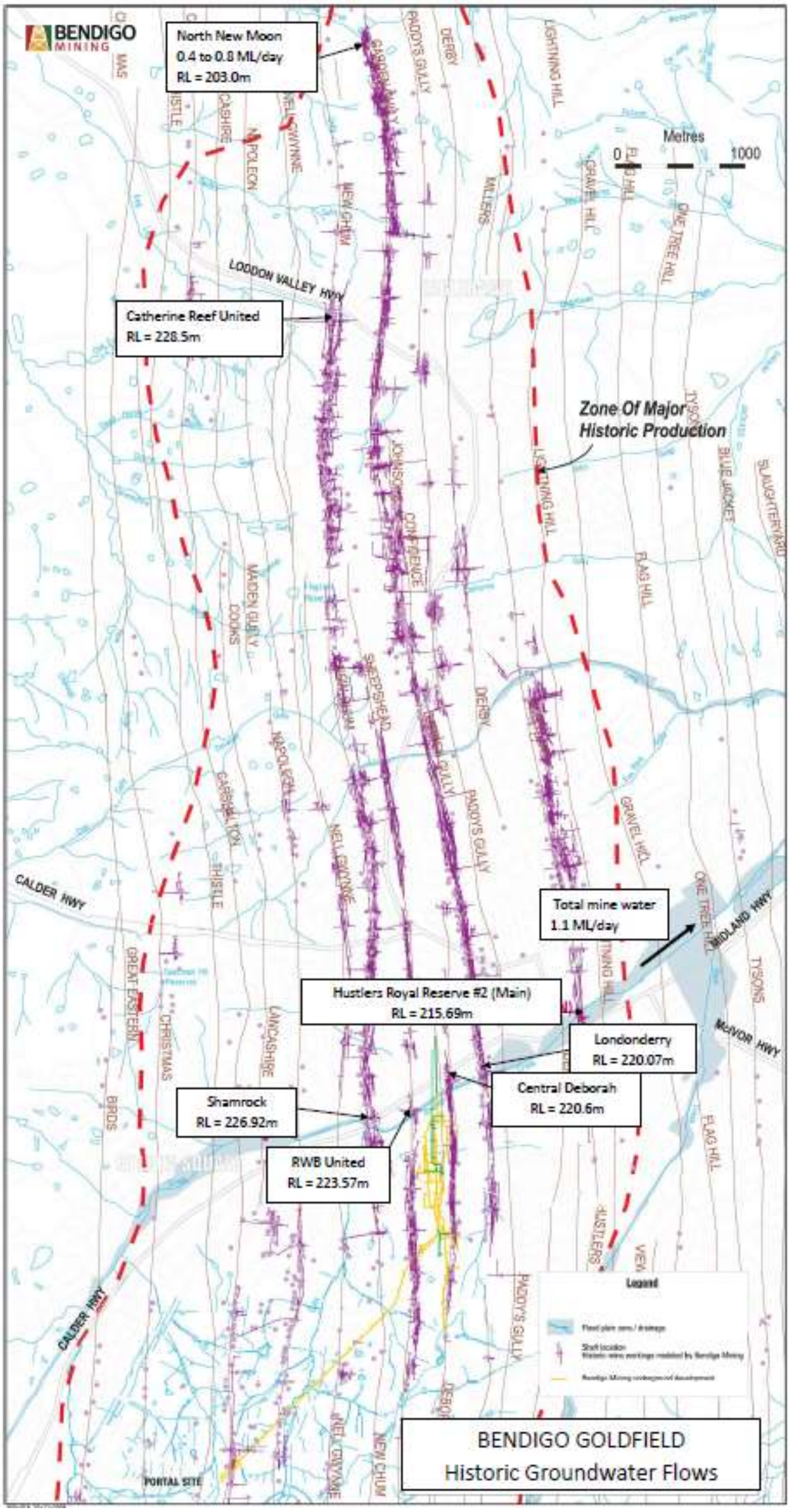


Map Produced By GLIB 13/03/2014

Department of Environment and Primary Industries

Victoria

Appendix C. Bendigo goldfield historic groundwater flows


BENDIGO MINING
North New Moon
0.4 to 0.8 ML/day
RL = 203.0m
Catherine Reef United
RL = 228.5m
Zone Of Major
Historic Production
Metres
0
1000
LODDON VALLEY HWY
CALDER HWY
MIDLAND HWY
McIVOR HWY
Total mine water
1.1 ML/day
Hustlers Royal Reserve #2 (Main)
RL = 215.69m
Londonderry
RL = 220.07m
Central Deborah
RL = 220.6m
Shamrock
RL = 226.92m
RWB United
RL = 223.57m
PORTAL SITE
Legend
BENDIGO GOLDFIELD
Historic Groundwater Flows