



Water use options McArthur River Mine

Prepared for MET Serv
December 2011





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A handwritten signature in dark ink, appearing to read 'G. T. Dale', is written over a light blue horizontal line.

Dr Glenn Dale
Managing Director and Chief Technical Officer
2 December 2011

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Revision history

Revision	Author/Reviewer	Date	Remarks ¹
0.1	George Lambert	21/11/11	Working draft
0.2	Steve Brown	23/11/11	Working draft
0.3	Neil Halpin	24/11/11	Working draft
0.4	Dan Rattray	24/11/11	Working draft
0.5	Glenn Dale	24/11/11	Working draft
1.0	Glenn Dale	28/11/11	Final Copy
2.0	Glenn Dale	2/12/11	Final Copy
1. Working draft; Draft for approval; Approved for release; Final copy;			

Distribution list

Date	Revision	Name	Title
28/11/11	1.0	Brett Harwood	Principal Consultant - Environment
2/12/11	2.0	Brett Harwood	Principal Consultant - Environment

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Glossary

ANZECC	Australian and New Zealand Environment and Conservation Council
Ca	Calcium
dS/m	Deci siemens per metre
ECe	Electrical conductivity of a saturated solution extract
ET	Evapotranspiration
ha	Hectare
K	Potassium
Kp	Pan coefficient
l	Litre
LSI	Langellier Saturation Index
mg	Milligram
Mg	Magnesium
ML	Megalitre
mm	millimetres
m molec	Millimoles charge units
Na	Sodium
SAR	Sodium adsorption ratio
$\mu\text{S/cm}$	Microsiemens per centimetre

Executive Summary

Concept level investigation has been carried out to establish the potential suitability for beneficial use of McArthur River mine inflow waters by irrigation of a range of tree and crop types. . The area investigated includes the mine tenement and surrounding pastoral land.

Investigations at this stage are based on limited available data. Notwithstanding, the study has found potential for irrigation development for a number of crop and soil type combinations. More detailed site investigation will be required, particularly for soil and landscape characteristics, in order to establish the suitability of specific on-ground sites and to inform irrigation system design.

Crop options

- Potentially viable crop options from a technical and practical perspective include:
 - mixed pasture and legume species on red and yellow earth soils and on red dermosols under pivot/lateral move irrigation;
 - mixed waterlogging tolerant pasture and legume species on black vertosols under contour bank irrigation;
 - tree crops (nominally *Khaya senegalensis*) on red and yellow earth soils and on red dermosols under drip irrigation.
- Weed potential of specific legume species included in the pasture-legume mix needs to be considered, e.g., *Leucaena* may be prone to escape and off-site weed infestation as a result of seasonal flooding.
- Agricultural crops were reviewed but not considered practical for the location and soils due to the requirement for a very intensive and a high level of management expertise, combined with distance from markets.
- Annual forage cropping is an option more aligned to the existing grazing enterprise, but also requires a relatively high level of management expertise and may be subject to a number of soil limitations.
- Pondered pastures are technically feasible on the poorly drained black vertosol soils, but suitable species are generally declared weeds and it is unlikely that this option would not receive environmental approval.

Water balance

- Potential annual plant water use demand for pastures and trees ranges from 2440 mm/yr to 2660 mm/yr.
- Daily plant water use demand for pastures and trees ranges from 5.2 to 9.8 mm/day.
- The deficit of rainfall to evaporation is very low in the wet season months of December to March and high in the dry season months of April to November.

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- In an average rainfall year, there is a rainfall deficit in all months of the year (small in wet season months).
- In a 90th percentile rainfall year, there is an excess of rainfall over evaporative demand in the months of January, February and March.
- The low to negative wet season rainfall deficit requires some level of balancing storage for any irrigation solution.
- A number of crop/storage option combinations enable full utilisation of all mine water inflows. These are summarised below based a 16.1 ML/yr mine water inflow rate, and on irrigation capacity to utilise rainfall from a succession of 90th percentile rainfall years.

Option No	Crop Option	Hectares required (ha)	Required storage volume (ML)
1	Pivot irrigated pasture	308	2614
2	Contour bank irrigated pasture plus balance of pivot irrigated pasture	590	1638
3	Forest irrigation (drip)	295	2275

- Required storage volume may be reduced to some extent by increasing the crop area, in effect utilising crops as a wet season storage. The surplus of rainfall over evaporation in wet years limits the capacity to implement this trade-off.

Water quality and treatment

- There are no plant or soil impediments to use of the palaeochannel water for irrigation provided the water is applied to suitable soils and managed appropriately to ensure a leaching fraction (sufficient to avoid rootzone accumulation) is achieved. Accordingly, there is no requirement to treat this water for irrigation purposes.
- The water does have a high hardness which may cause fouling of irrigation equipment by scaling. This can be managed by use of poly lined irrigation infrastructure and periodic acid flushing of irrigation lines.

Recommended options

A hierarchy of three possible irrigation management options is recommended:

1. Pivot irrigation of pasture grasses on red and yellow earths and red dermosol soils, with balancing storage for low water use months (nil discharge).
2. Contour bank irrigation of water logging tolerant pasture grasses on black soils with supplementary pivot irrigation of red and yellow soils to utilise excess storage volume (nil discharge).
3. Drip irrigation of forest species (*Khaya senegalensis*) on red and yellow earths and red dermosols soils, with balancing storage for low water use months (nil discharge).

The viability of all options should be reviewed subject to site inspection and detailed soil evaluation.

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Total cost per megalitre for these three options over a 15 year project period is estimated at \$12.7m, \$13.2m and \$10.8m.

Average cost per megalitre for these three options over a 15 year project period is estimated at \$144, \$150 and \$122 respectively. These are total cost estimates, and do not account for returns from grazing or timber. Costs will be substantially reduced when grazing/timber returns are considered.

Potentially suitable soil types (particularly soils described as deep earthy sands, medium to deep yellow massive earths, and medium to deep red massive or structured earths) occur on the tenement area and surrounding grazing property.

It should be noted that all options will require some degree of clearing existing native vegetation. Capacity to secure environmental approvals to allow clearing will need to be established.

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1. Introduction

1.1 EIS

McArthur River Mine is a zinc, lead and silver open-cut mine located approximately 60 kilometres south of Borroloola in the Northern Territory. McArthur River Mine is owned by Xstrata.

MET Serve is assisting McArthur River Mine in the preparation of an EIS in support of a proposed mine expansion.

1.2 Mine water use options

The mine expansion is expected to generate water at rates the order of around 16 ML per day. MET Serve has requested Tree Crop Technologies (TCT) to prepare a high level paper on water use options. Lands on the adjoining McArthur River Pastoral Lease are available for irrigation.

1.3 Terms of reference

Met Serve has requested TCT to provide:

- Conceptual groundwater reuse options utilising tree/ crop irrigation;
- Estimates of water demand (volume/ha) for various tree/ crop irrigation options;
- Estimates of cost/ ha or cost/volume of water for each option;
- Conceptual treatment options based on limited water quality data available;
- A preferred conceptual option (based on water volume).

2. Climate

The climate is typical of the dry tropics of northern Australia which has a definite wet and dry season. The wet season generally runs from November to March, the wettest period being from December to February.

The dry season is usually very dry with very little rain expected from April to October inclusive.

3. Native vegetation

It is assumed that all areas being considered for irrigation development will be suitably cleared of native vegetation so that development is not impeded. With pasture, it is possible and even beneficial to retain strategic trees or belts of trees for shade surrounding pivot irrigated areas.

For all proposed irrigation developments, clearing of existing native vegetation will be required, particularly for pivot irrigation. Capacity to secure environmental approvals to allow clearing will need to be established. It is possible that a limited degree of clearing may be a condition under the grazing lease.

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4. Soils

4.1 Cracking clay soils (Cz 28)

From the data provided, this appears to be a very flat, flood prone, wet area containing melon holes. Soils are light clays being poorly drained, remaining wet and boggy for long periods during the wet season. Depending on the size of the melon holes, it may be very difficult to irrigate even through the dry season.

4.2 Yellow and red massive earths (Cz 26 & Cz 27)

From the data provided, Cz 26 & Cz 27 are on low sloping land (> 2%), either yellow or red massive earths with hard setting surfaces and reasonably deep profiles with low salts to 100cm+. It is assumed that unlimited irrigation is available.

4.3 Red Dermosol (Cz/PM3 (7,6))

Cz/PM3(7,6) is a red dermosol to 1.4m deep, but with a hard setting surface.

From experience, it is assumed that these soils are very poor in chemical fertility (particularly P & K), have very low organic matter content and consequently very low water infiltration rates.

Given the correct mechanical preparation and the support of irrigation, it should be possible to provide a suitable seed bed in the dry season.

4.4 Suitability of red and yellow earths and dermosols

Although limited soil information is available information, a number of factors indicate the likely suitability of the red and yellow soil types for irrigation.

Firstly, the red/yellow colour of these soils indicates a high level of oxidation, in turn, indicating that these soils are freely draining. The yellow soils may be less well drained than the red soils, but should still be suitable for irrigation.

The soils classed as Earths are now classified as Kandosols under the Australian soil classification. Both Kandosols and Dermosols are non-texture contrast soils (Dermosols with a structured B horizon and Kandosols with a massive B horizon). The lack of texture contrast indicates that the B horizon texture is not strongly contrasting with the surface texture. In contrast, texture contrast soils, such as Sodosols typically have a relatively low permeability heavy clay B horizon. The structured B horizon of dermosols indicates that these have good permeability. The massive structure of the B horizon of Kandosols indicates they lack structure, but this is typically due to a sandy loam texture which is normally inherently structure-less but free draining. Again, the red colouration supports this.

Visual inspection of the imagery indicates that the red soils are located higher in the landscape. This is as expected, but also provides confidence that these soils are reasonably well drained.

Soil depth will definitely require significantly more in-depth field investigation. Many pits show shallow soils, but equally, there are pits (particularly for Cz27 soils) greater than 2m depth. Section 10.3 of the Terrain and Soils report describes moderate to deep earthy sands, medium to deep yellow massive earths, and medium to deep red massive or structured earths. These would all be worthy of more detailed investigation for irrigation.

5. Conceptual groundwater reuse options utilising crop irrigation

5.1 Annual crop species

Based on the soils information provided, the only potentially suitable soils are Cz 26, Cz 27 (Red and Yellow Massive Earths) and Cz/PM3 (7,6) (Red Dermosol). These are not good cropping soils requiring very special management to prepare them to the stage of being suitable for sowing seed. Although not stated, it is assumed these soils are very poor in natural fertility and have a low plant available water holding capacity (PAWC), meaning that anything growing on them would need regular water applications i.e. 50 to 70 mm of irrigation every 5 to 10 days (depending on plant maturity) during the dry season.

Possible grain crop options are grain sorghum, maize, soybean, peanuts, millets and even sugarcane. In southern areas of Queensland, these crops are grown during summer when the risk of frost is very low. In the McArthur River region, these crops would be grown during the winter dry season.

However, limitations would include:

- Serious soil problems (hard setting surfaces, low organic matter levels, low fertility, very poor infiltration rates, low PAWC etc.);
- Long distances to transport produce;
- Variable prices for product;
- Lack of sufficient area to make it worthwhile to invest in infrastructure;
- Extremely difficult to access specialised machinery; and
- Handling equipment and personal expertise.

Other limitations would include proliferation of insect pests and wild life such as pigs, birds (ducks, geese, parrots, finches etc.) and other grazing animals which tend to congregate onto isolated cultivated areas. This situation occurs in isolated areas on good soil in northern central Queensland. In this region, bird infestations alone make it uneconomic to grow grain sorghum, maize or sunflowers.

In addition to the above crops, cotton is also a possibility but this crop requires very intensive and a high level of management expertise. Experience in the Ord river area suggests that insect pests and weed control may be serious limitations to the growth of cotton. Accordingly, it is not considered a viable option for McArthur River.

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Due to the combination of agronomic and commercial limitations, it is considered that cropping options are not viable for the McArthur River region.

5.2 Annual forage species

Forage sorghum, millet and lablab bean are possible species to grow in the well-drained areas (Cz 26, Cz 27 -Red and Yellow Massive Earths, and Cz/PM3 (7,6) - Red Dermosols). Being annuals, they need to be sown each year into a prepared seed bed, or by zero tillage methods.

They cannot tolerate water logging for more than a few days and require high soil fertility conditions. Moisture requirements are high, requiring 50 to 70 mm of good quality water (electrical conductivity of water – < 0.65 to 1.0 dS/m) on reasonably free draining soil, every 5 to 10 days.

However, they can be grown for grazing or for hay making, the later requiring specialised harvesting machinery and dry storage facilities. Hay making requires specialised skills.

Annual forage crop species represent a possible alternative if cattle are being grazed on company or neighbouring properties, but are subject to the same soil management issues as annual crops.

5.3 Perennial forage species

All species listed here are tropical, intolerant to frosts unless specifically stated. They can all tolerate irrigation water quality to moderate salinity levels (0.65 to 1.3 dS/m conductivity) and moderate root zone soil salinity levels (ECe 0.95 to 1.9 dS/m).

It is most desirable to combine grasses with legumes so that the latter can provide at least some of the nitrogen requirements for the companion grasses. All species given below are suited to mixed grass legume situations.

5.3.1 Perennial pasture species – black cracking clay soils

5.3.1.1 Conventional pasture species

A selection of the best species suited to wet conditions, exhibiting tolerance to flooding, water logging and low to moderate salinity are listed below.

Grasses

- 1) Tully humidicola (Brachiara humidicola cv Tully). A strongly stoloniferous, very aggressive grass. It will tolerate acid, low soil fertility and high sodicity, but will perform well on fertile soil and responds well to fertiliser.
- 2) Floren Blue grass (Dichanthium aristatum cv Floren). Tufted. Likes clay soils and tolerates moderately salinity. Produces extremely well under good fertility conditions. Very palatable.
- 3) Bambatsi (Panicum coloratum (makarikariense) cv Bambatsi). Tufted. Likes clay soils. Specifically planted on clay soils of the brigalow flood plains in central Queensland. High yielding potential.

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- 4) Kazungula setaria (*Setaria sphacelata* (anceps) cv kazungula). Tufted. Very tolerant to flooding and water logging. High yielding given good soil fertility conditions.
- 5) Digit grass (*Digitaria milanijana*) Stoloniferous. Responds very well to fertility.

Legumes

- (1) Glenn & Lee Joint vetch (*Aeschynomene Americana*). Short lived perennials. Tolerant to water logging and likes moderate soil fertility conditions.
- (2) *Vigna luteola*. Very productive, short term perennial. Tolerates poorly drained conditions.

The above species are suited to establishment on black cracking clay soils subject to waterlogging, but may also be cultivated under shallow flooded conditions with a water depth to approximately 0.5 m. This makes these species potentially suited to irrigation via construction of long shallow contour banks across broad areas. This may be economical where the natural gradient is less than 1.5°, allowing for wide spacing between water retention banks.

The cultivation of waterlogging tolerant grass and legume species under a contour bank irrigation approach represents a technically feasible and relatively low cost option to provide a year round water management option on poorly drained black soil areas, subject to suitably level slope conditions (<1.5°).

5.3.1.2 Ponded pasture species

Where it is possible to keep areas permanently wet by flooding using high retention banks (1 to 1.5 m high), a situation of flooded pastures (or ponded pastures) could be established. This system was successfully developed on the coastal flood plains in central Queensland during the 1980's. Grass species used were native water couch, para grass and Aleman grass.

However, there may be environmental restrictions on this type of pasture system and it would need to be cleared with the Territory government.

Irrigation of ponded pastures presents an attractive technical option from a water management and productivity viewpoint, however, all viable species have a significant weed potential with the capacity to clog natural waterways, and for this reason are unlikely to be acceptable. A native hymenachne presents one non-weed option, but is a poor pasture species relative to the introduced ponded pasture species alternatives.

While ponded pasture species have technical attraction given their capacity to increase production from flooded areas, the weed potential of viable species effectively discounts this option.

5.3.2 Perennial pasture species - Red and yellow earths and red dermosols

5.3.2.1 Conventional pasture species

Planting the selected pasture species on the prepared soil surface and providing the required fertiliser and regular light irrigations, it is proposed that pasture establishment would be possible

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and that reasonable growth should be achieved in the first season. The emphasis is on regular light irrigations as heavy applications would result in a very high runoff rate. Sprinkler irrigation systems or even low contour banks (level and only 10 to 20 cm high) would be seen to be the best alternative in the establishment phase. The idea is to keep the surface moist until germination and establishment has been achieved.

By retaining all the plant material on the pastured sites for 12 months at least, the soil organic matter levels should gradually increase making them more receptive to heavier irrigation rates. Grazing may be commenced after that 12 month establishment phase. Fertiliser use is critical for pasture growth as growing plant material is the only way to improve the poor soil condition.

The best pasture species options are given below. They are all capable of high dry matter yields and animal performance if soil fertility requirements are met. Special characteristics are:

Grass species

- 1) Rhodes grass (*Chloris gayana* cv Callide & Fine cut) – Quick growing, high growth rates and dry matter yield potential, tolerates moderate soil and water salinity, requires moderate soil fertility and tolerates moderate but not regular waterlogging. Both creeping and erect in habit. It is highly palatable and makes very good hay.
- 2) Kazungula setaria (*Setaria sphacelata* (anceps) cv kazungula). Tufted. Very tolerant to flooding, water logging and drought. High yielding given good soil fertility conditions. It is quite palatable when young. Not suitable for horses because of high oxalate content.
- 3) Bisset creeping blue grass (*Bothriochloa insculpta* cv Bisset). Stoloniferous with low fertility requirement, but responds very well to high fertility conditions. Slow to establish but then actively competes with all other companion species. Very palatable and drought tolerant but responds well to irrigation. Makes very good hay.
- 4) Tully humidicola – described above. Tully humidicola – (*Brachiara humidicola* cv Tully). The toughest tropical grasses around. It is a strongly stoloniferous and very aggressive. It will tolerate acid, low soil fertility and high sodicity, but will perform well on fertile soil and responds very well to fertiliser applications. It is readily eaten when young and best managed by keeping it well grazed. Very aggressively competes against weeds.

Legumes

- 1) Glenn and Lee joint vetch (as above)
- 2) Leucaena – under irrigated conditions, it is a forage legume grown in rows 3 to 5 m apart with a grass grown between the rows. This legume requires high soil fertility conditions particularly phosphorus. It is usually planted in rows 3 -6 months before sowing the grass to ensure good establishment before introducing the grass (any of the species mentioned above). Planting is done with a row planter and if irrigation is available, it could be planted in March /April at McArthur River and the soil surface kept wet until emergence to guard against soil surface crusting. Irrigate as necessary to keep it growing strongly. Weed control – Spray over the row with spinnaker and keep the weeds out of between the rows before

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planting the grass. Before grazing, the grass and the Leucaena should be well established and this may take 12 months. Other special management requirements are to make sure it is kept from growing too tall for animals to graze. At times this may mean trimming it down to 1 m high. Most times it can be kept under control by heavy grazing. It will also require applications of phosphorus and perhaps sulphur every 2-3 years depending on soil requirements. Cattle grazing Leucaena need drenching with a special rumen fluid to introduce the correct rumen micro-organisms. Notwithstanding the highly productive grazing potential of Leucaena, there is a very high likelihood of escapes leading to off-site weed infestation. On this basis, Leucaena is not considered a viable crop option.

- 3) *Centrosema macrocarpum* (brasilianum) – tolerates acid conditions. Produces well under irrigation and good fertility conditions.
- 4) *Vigna luteola*. Very productive, short term perennial. Tolerates poorly drained conditions.

The cultivation of suitable grass and legume pasture species on well drained soils under pivot irrigation presents a highly feasible option to significantly enhance grazing reliability and yield. This option is substantially restricted to irrigation during the dry season.

Table 1: Summary of crop, forage and pasture species options

	Productivity under fertile conditions	Productivity under low fertility	Waterlogging tolerance	Fertility requirement	Poorly drained Black soils	Medium to well drained red soils	Soil salinity tolerance	Acid tolerance	Weed potential	Breadth of soil type adaptation	Food crop	Fodder value	Habit	Commercial suitability	Irrigation salinity
Annual crops															
Grain sorghum	✓✓✓	x	x	High	x	✓	x	x		Low	Yes		na	x	
Maize	✓✓✓	x	x	High	x	✓	x	x		Low	Yes		na	x	
Soybean	✓✓✓	x	x	High	x	✓	x	x		Low	Yes		na	x	
Peanuts	✓✓✓	x	x	High	x	✓	x	x		Low	Yes		na	x	
Millet	✓✓✓	x	x	High	x	✓	x	x		Low	Yes		na	x	
Sugarcane	✓✓✓	x	x	High	x	✓	x	✓		Low	Yes		na	x	
Annual forages															
Forage sorghum	✓✓✓	✓	x	High	x	✓✓	✓	x		✓✓		✓✓	na	✓✓✓	<1 dS
Millet	✓✓	✓	x	High	x	✓✓	x	x		✓		✓✓	na	✓✓✓	<1 dS
Lablab bean	✓✓✓	✓	x	High	x	✓✓	x	x		✓		✓✓✓	na	✓✓✓	<1 dS
Perennial grass pastures															
Tully humidicola	✓✓✓	✓✓	✓✓✓	Low	✓✓✓	✓✓		✓✓✓		Moderate		✓	Stoliniferous	✓✓✓	
Floren Blue grass	✓✓✓			Mod	✓✓✓	✓	✓✓	x		Low		✓✓✓	Tufted	✓✓✓	
Bambatsi	✓✓✓			Mod	✓✓	✓	✓	x		low		✓✓	Tufted	✓✓✓	
Kazungula setaria			✓✓✓	Low / mod	✓	✓✓✓		✓		moderate		✓✓	Tufted	✓✓✓	
Digit grass	✓✓✓			Mod		✓✓		✓		moderate		✓✓	Tufted	✓✓✓	
Rhodes grass	✓✓✓		x	Mod	✓	✓✓✓	✓✓✓	✓		Moderate		✓✓✓	Both tufted and stoliniferous	✓✓✓	
Bisset creeping blue grass	✓✓✓	✓✓✓	✓	Low to mod.		✓✓✓		✓		moderate		✓✓✓	Stoliniferous	✓✓✓	

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	Productivity under fertile conditions	Productivity under low fertility	Waterlogging tolerance	Fertility requirement	Poorly drained Black soils	Medium to well drained red soils	Soil salinity tolerance	Acid tolerance	Weed potential	Breadth of soil type adaptation	Food crop	Fodder value	Habit	Commercial suitability	Irrigation salinity
Ponded pasture perennial grass spp															
Native water couch	✓✓	✓	✓✓✓	✓			×		✓✓✓			✓✓	Stoloniferous		
Para grass	✓✓✓	✓	✓✓✓	✓✓	✓✓✓		×		✓✓✓			✓✓✓	Stoloniferous		
Aleman grass	✓✓✓	✓	✓✓✓	✓✓	✓✓✓		×		✓✓✓			✓✓✓	Tufted and stoloniferous		
Perennial legume pastures															
Glenn & Lee Joint vetch	✓✓✓	✓✓✓	✓✓✓	✓✓	✓✓	✓✓✓		✓✓		✓✓		✓✓✓	Upright	✓✓✓	
<i>Leucaena</i>	✓✓✓			✓✓✓		✓✓✓			✓✓✓			✓✓✓	Upright shrub	✓✓✓	
Centrosema macrocarpum	✓✓✓			✓✓		✓		✓✓✓		✓		✓✓	Stoloniferous	✓	
Vigna luteola			✓✓✓		✓	✓		✓		✓		✓✓	Stoloniferous	✓	

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6. Conceptual groundwater reuse options utilising tree irrigation

6.1 *Khaya senegalensis*

“African Mahogany”, a deciduous evergreen tree that can attain heights from 15 to 30 metre and a diameter up to 1 metre. It is a useful durable timber species. It’s nominal temperature range being 24.5 – 31.5 degrees and mean annual rainfall from 400 – 1700 mm. It is tolerant to a wide range of soil conditions, from neutral to very strongly acidic and from well drained, coarse sandy loam to somewhat poorly drained clay. Khaya prefers neutral, deep, sandy loam soil that is well drained. Older trees have a resistance to fire but young plantings are susceptible. Pest and disease can be an issue with incidence of shoot borers and borer attack to sapwood.

Being a high value cabinet wood, African Mahogany is reasonably well suited to production in small, isolated stands. It is likely that a quality resource would find market opportunities, either by log export to processing centres in northern Australia, or with initial on-site processing utilising portable break-down sawing equipment.

6.2 *Eucalyptus camaldulensis*

“River Red Gum”, an Australian native, occurs the length of the Murray Darling Basin extending into central north Queensland. It is a durable species growing on a range of soils from alluviums through to heavier clays with a pH range from 4.5 - 8. It tolerates periods of inundation. It’s timber is extremely durable with wide uses. It is susceptible to insect attack and form issues which may limit its application in the target region.

6.3 *Pinus caribaea*

“Caribbean Pine”, from the Caribbean Islands, has been extensively used as a plantation species in the sub-tropics. Its natural temperature range being 22 – 37 degrees and rainfall from 1000 – 3000 mm. Soils are generally loams or sandy loams and generally well drained and with a pH range from 5.0 – 5.5. It is an excellent timber species though with low durability. Pest and disease is not an issue with Australian plantings. It is susceptible to fire, especially in its younger years. While Caribbean pine is a well proven and reliable species throughout northern Australia, it is anticipated that the relative small resource that could be supported by irrigation at McArthur River would be difficult to market due its timber being a commodity wood product.

Table 2: Summary of tree species options

Species	Climate and fire				Soils and adaptation					Commercial properties			Domestication			Pests and diseases		
	Natural rainfall range (mm)	Extended drought tolerance	Frost tolerance	Fire tolerance	Salt tolerance	Sodic soil tolerance	pH range	Cracking clay soils	Breadth of soil type adaptation	Commercial timber	Mature density	Biodiesel production	Improvement program	Represented in tax trials	Represented in seed orchards	Resistance to leps and scale	Resistance to fungal disease	Resistance to browsing insects
<i>K. senegalensis</i>	400 - 1750	✓✓✓		✓✓✓	✓	✓	4.5 – 8.5	✓	✓✓✓	✓	850		✓✓✓	✓✓✓	✓✓✓			
<i>E. camaldulensis</i>	250-1250	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	4.5-8.5	?	✓✓	✓✓✓	800	x	✓✓✓	✓✓✓	✓✓✓	✓✓✓	?	?
<i>P. caribaea</i>	1000-3000	✓		✓			5-5.5		✓	✓✓✓	650		✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓

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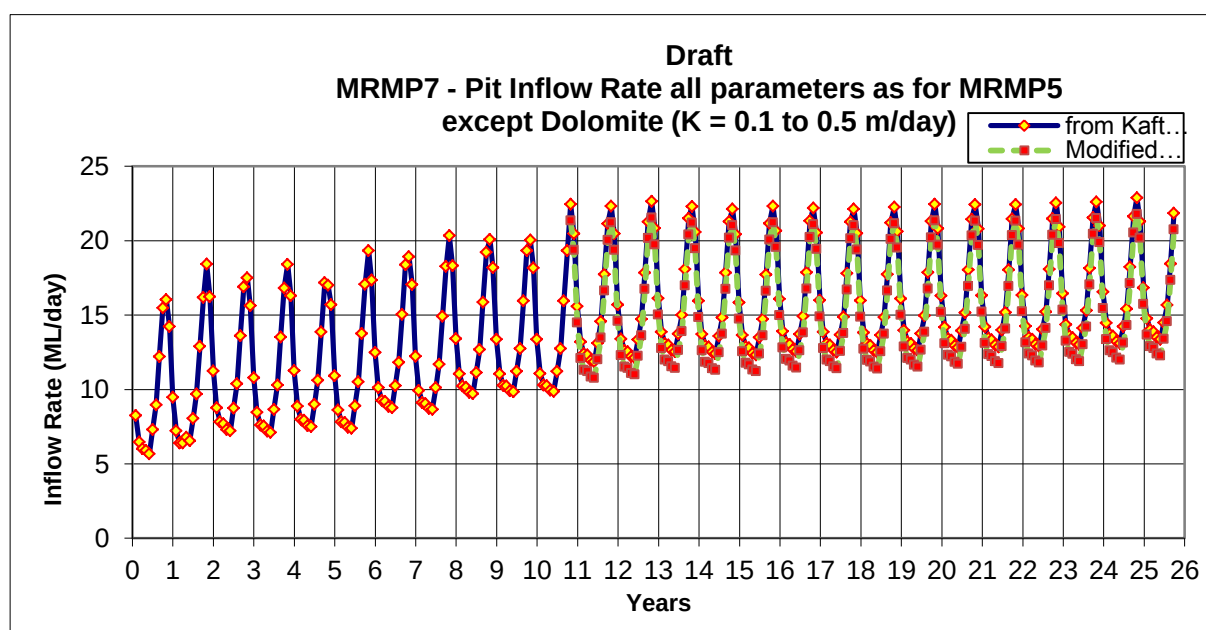
7. Estimation of water demand

Assumptions regarding monthly variation in rainfall, evaporation, plant water use demand and water yield are summarised in Table 3.

Water inflow assumptions are based on the average monthly variation in projected water yield for the period 1 January 2022 to 31 December 2036. This represents the period of stable and regular fluctuation in water inflow rates from year 11 to year 26 in Figure 1 (data provided by Dr Sharmil Markar, Director / Principal Engineer, WRM Water & Environment Pty Ltd).

Potential per hectare water use of irrigated pastures and trees was modelled for average (50th percentile) and wet (90th percentile) rainfall years. Watload is a monthly time-step model.

Figure 1: Projected pit inflow rates (WRM Water & Environment Pty Ltd)



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7.1 Climatic, crop factor and water yield assumptions

Table 3: Climatic, plant water use and water inflow assumptions

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average (50 th percentile) rainfall (mm)	208.4	186.7	143.7	33.7	7.3	1.7	2.4	0.4	4.9	21.2	49.1	122.1	784.2
90 th percentile rainfall (mm)	415	368	291.4	79.2	16.4	4	1.2	0.2	11.9	56.5	133.5	207.1	1202.4
Mean daily evaporation (mm)	7.4	6.7	6.7	6.8	6.4	5.8	5.9	7.2	8.9	9.7	9.9	8.9	7.5(av)
Mean monthly evap (mm)	229.4	187.6	207.7	204	198.4	174	182.9	223.2	267	300.7	297	275.9	2747.8
Pasture pan coefficient	0.84	0.89	0.91	0.90	0.89	0.90	0.90	0.87	0.89	0.87	0.91	0.90	0.89(av)
Tree pan coefficient	0.92	0.97	0.99	0.98	0.97	0.98	0.98	0.95	0.97	0.95	0.99	0.98	0.97(av)
ET trees (mm/day)	6.8	6.5	6.6	6.7	6.2	5.7	5.8	6.8	8.6	9.2	9.8	8.7	7.3(av)
ET trees (mm/month)	211.0	182.0	205.6	199.9	192.4	170.5	179.2	212.0	259.0	285.7	294.0	270.4	2662
ET pasture (mm/day)	6.2	6.0	6.1	6.1	5.7	5.2	5.3	6.3	7.9	8.4	9.0	8.0	6.7(av)
ET pasture (mm/month)	192.7	167.0	189.0	183.6	176.6	156.6	164.6	194.2	237.6	261.6	270.3	248.3	2442
ET past. practical (mm/month)	0	0	0	183.6	176.6	156.6	164.6	194.2	237.6	261.6	270.3	0	1645
Water inflow (ML/day)	22.4	20.7	16.1	14.0	13.2	13.1	12.8	12.6	13.8	15.0	18.0	21.4	16.1(av)
Water inflow (ML/month)	694.7	580.1	500.6	419.5	409.6	393.2	395.3	391.7	414.0	466.0	539.2	663.3	5867.2

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7.2 Irrigated pastures

Irrigated pastures are suitable for the medium to well-drained, red and yellow earths and red dermosols. Centre pivot or lateral move irrigation is suitable for these soil types subject to more detailed evaluation of specific site conditions (slope, landform, adequate area). Preliminary visual inspection of satellite imagery in combination with limited soil type maps indicates that it should be possible to locate suitable areas of red/yellow soils for installation of centre pivots.

Although pastures in this region have a high year round potential water demand, pivot irrigation in the wet season months is likely to be impractical due to access problems, and practical considerations relating to operation of pivots under excessively wet conditions. In any event, the potential irrigation loading in the wet season months is relatively low due to the majority of plant water use demand being met by rainfall. Accordingly, it has been assumed for design purposes, that irrigation water is not applied in the months of December to March inclusive.

Preliminary calculations of leaching requirement necessary to maintain the rootzone salinity at less than 2 dS/m, indicate a leaching requirement in the order of 12% based on an irrigation rate of 2300 mm/yr. Based on this leaching fraction, and assuming a sprinkler irrigation efficiency of 85%, per hectare water balance parameters for an average rainfall year are detailed in Table 10. Based on this scenario, irrigation loading rate is 2036 mm/ha/yr (20.4 ML/ha/yr).

Table 4: Per hectare water balance parameters – Pasture irrigation – average rainfall year

Month	Rainfall (mm)	Pan evaporation (mm/ha)	Pasture water use (mm/ha)	Irrigation loading (mm/ha)
Jan	208.4	229.4	193	0
Feb	186.7	187.6	167	0
Mar	143.7	207.7	189	0
Apr	33.7	204	184	206
May	7.3	198.4	177	224
Jun	1.7	174	157	204
Jul	2.4	182.9	165	214
Aug	0.4	223.2	194	255
Sep	4.9	267	238	307
Oct	21.2	300.7	262	322
Nov	49.1	297	270	303
Dec	122.1	275.9	248	0
Annual	781.6	2,748	2442	2036

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Based on these per hectare water balance characteristics, the overall design parameter of an irrigation system designed to achieve 100% utilisation of water (based on average annual rainfall), is summarised in the second column of Table 11. Under this scenario, assuming an annual groundwater production of 5685 MI/yr (average 16.1 MI/day) 100% of water can be consumed by pivot irrigation of a minimum area of 263 ha of pastures irrigated at the rate of 2036 mm/ha/yr, requiring a minimum pond storage of 2399 MI (approximately 40 ha at an average depth of 6m).

Table 5: Pasture irrigation scenarios – average and 90th percentile rainfall years

Water balance component	50th percentile rainfall year	90 th percentile rainfall year
Total groundwater produced per year	5865 MI/yr	5865 MI/yr
Minimum pasture area required	263 ha	307.7 ha
Annual effluent loading rate	2036 mm/ha/yr	1838 mm/ha/yr
Minimum pond storage required	2399 MI	2614 MI
Pond area (assuming average depth of 6m)	40.0 ha	43.6 ha
Annual net pond loss/gain	676 MI	387 MI
Total excess rainfall	542 mm	1051 mm
Number of months of excess rainfall	4	4
Irrigation method & rotation type	Sprinkler (Pivot)	Sprinkler (Pivot)
Leaching Fraction	12%	12%
Proportion of maximum Irrigation load applied	1.00	1.00

Table 12 presents per hectare water balance parameter for pasture irrigation in a 90th percentile rainfall year. Based on this scenario, irrigation loading rate is reduced to 1838 mm/ha/yr (18.4 MI/ha/yr).

Based on these per hectare water balance characteristics, the overall design parameter of an irrigation system designed to achieve 100% utilisation of water in an 90th percentile rainfall), is summarised in the third column of Table 11. Under this scenario, assuming an annual groundwater production of 5685 MI/yr (average 16.1 MI/day) 100% of water can be consumed by pivot irrigation of a minimum area of 308 ha of pasture irrigated at the rate of 1838 mm/ha/yr, requiring a minimum pond storage of 2614 MI (approximately 44 ha at an average depth of 6m).

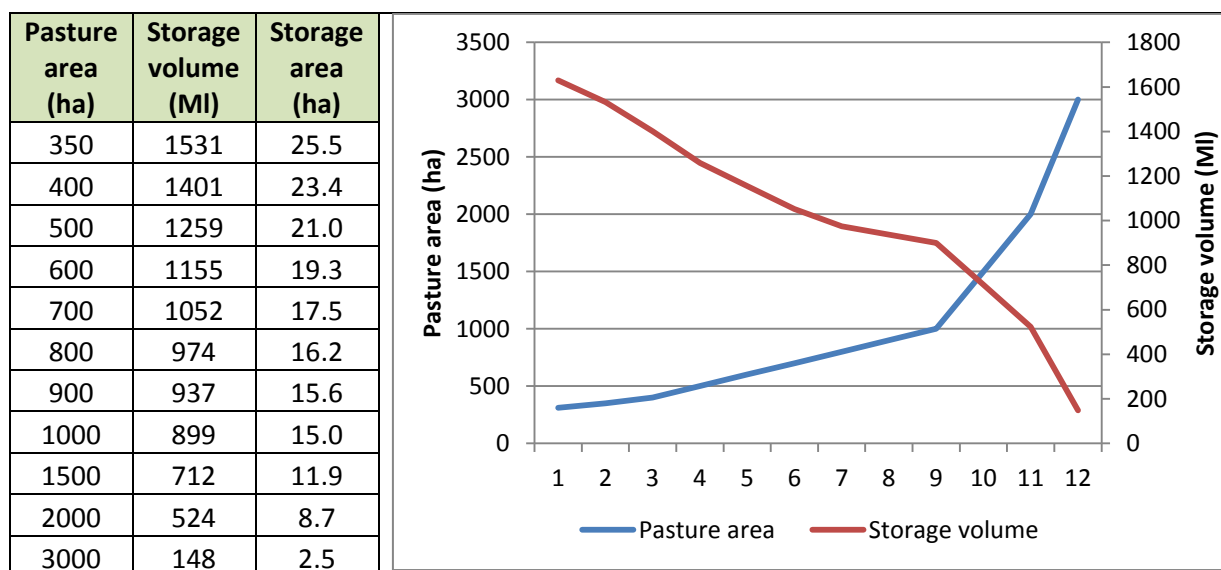
Table 6: Per hectare water balance parameters – Pasture irrigation – 90th percentile rainfall year

Month	Rainfall (mm)	Pan evaporation (mm)	Pasture water use (mm)	Irrigation loading (mm)
Jan	415	229	211	0
Feb	368	188	182	0
Mar	291.4	208	206	0
Apr	79.2	204	200	156
May	16.4	198	192	214
Jun	4	174	171	202
Jul	1.2	183	179	216
Aug	0.2	223	212	256
Sep	11.9	267	259	299
Oct	56.5	301	286	284
Nov	133.5	297	294	212
Dec	207.1	276	270	0
Annual	1584.4	2748	2662	1838

An alternative strategy to minimising pasture area by offsetting water surplus in the wet months with pond storage is to increase the pasture area, effectively utilising irrigated pastures as a balancing storage. This strategy involves deficit irrigation of the pasture area.

Where the marginal value of pasture area required to utilise 1 ML of water is less than the cost of dam storage for 1 ML, this strategy will prove more economic. The trade-off between pasture area and pond storage volume for an average rainfall year is summarised in Table 13. It can be seen that pond storage can be virtually, but not fully eliminated for an average rainfall year with a pasture area of 3000 ha (residual storage volume requirement of 148 ML). Note, however, economic pasture production requires intensive management and fertiliser application. Returns in productivity from pasture improvement are unlikely to be realised below an irrigation water supply of approximately 50% of the rainfall deficit. At this irrigation rate, pasture area is approximately 560 ha, and storage volume requirement is 1196 ML (20 ha). It is not recommended that a deficit irrigation strategy is requiring larger pasture areas be utilised.

Table 7: Trade-off between pasture area and pond storage volume



7.3 Contour bank irrigated pastures

Contour bank irrigated pastures are potentially suited to the relatively low permeability, black vertosol soils with grades of less than 1°.

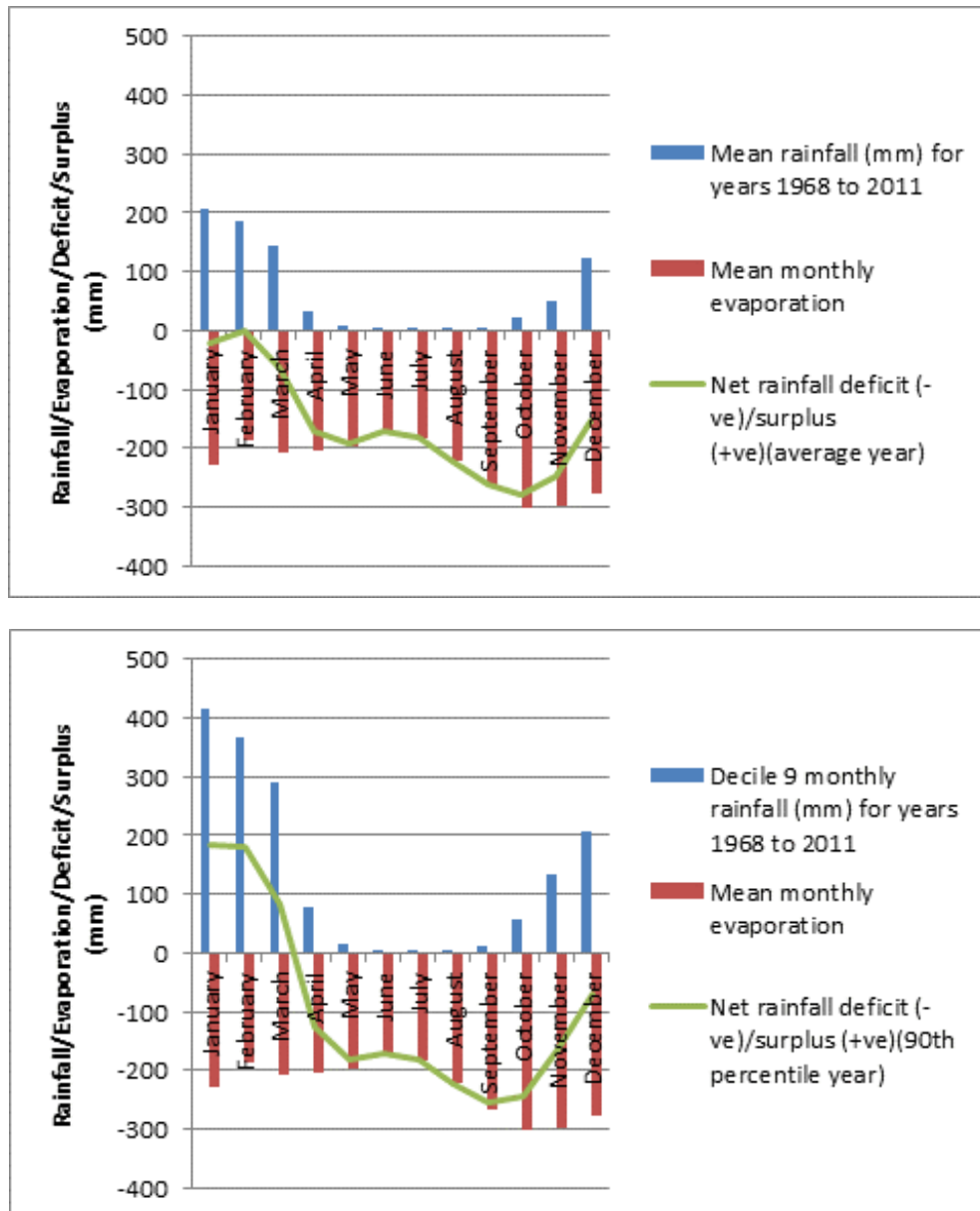
The concept of contour bank irrigated pastures is a less conventional approach to water management, but has potential in the circumstances of the present project.

A potential downside of contour bank irrigated pastures would be control of wild life particularly pigs, large water loving snakes and crocodiles. Experience from central Queensland indicates water birds may be attracted, but are not a major production consideration. Conversely, this may have positive environmental benefits.

Contour bank irrigated pastures can be expected to evaporate water at a rate equivalent to the pan evaporation rate (rate of evaporation from a ponded surface), and effective water use per hectare is therefore pan evaporation less rainfall, assuming these pastures are constructed to exclude run-on.

A comparison of rainfall and evaporation, plus monthly net deficit/surplus of rainfall over evaporative losses, is illustrated in Figure 2 for an average and 90th percentile rainfall year.

Figure 2: Rainfall/evaporation water balance for an average (top) & 90th percentile (bottom) year



Effective water use per hectare for an average rainfall year is summarised in Table 8. Under this scenario, a 350 ha area of irrigated contour bank pastures flooded to 50 cm will hold a total volume of 1750 ML. This is sufficient to absorb projected mine infows plus rainfall. The water held by the contour bank irrigated pastures increases to a peak of 1600 ML in March, then gradually declines to zero in the months of September, October and November, before filling again from December. Under this scenario, the 330 should be able to operate as a closed system. However, this system has no buffer for above average rainfall years.

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Effective water use per hectare for a 90th percentile rainfall year is summarised in Table 9. Under this scenario, a 500 ha area of irrigated contour bank pastures flooded to 50 cm will hold a total volume of 2500 ML. This is sufficient to absorb projected mine inflows plus rainfall in all months except February and March. Excess water from these months must be removed to storage (potentially for pivot irrigation of pastures). The water held by the pastures increases, reaches peak capacity of 2500 ML in March and April, then gradually declines to zero in the months of October and November, before filling again from December. Under this scenario, the 500 pasture area requires a storage volume of approximately 1638 ML (allowing for rainfall inputs), requiring a ponded area of approximately 31 ha (based on a depth of 6m). This buffer allowance requires operation in conjunction with an alternative offtake system, but provides robust capacity to manage all mine inflows in a wet year.

Table 8: Effective water use by contour bank irrigated pastures, consecutive average rainfall years

Parameter - Average year sequence	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Pasture area (ha)	350	350	350	350	350	350	350	350	350	350	350	350
Pasture flood depth (cm)	50	50	50	50	50	50	50	50	50	50	50	50
Pasture storage capacity (MI)	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750
Starting volume (MI)	0	125	746	1323	1600	1424	1164	955	718	330	0	0
Mine inflow (MI)	663	695	580	501	420	410	393	395	392	414	466	539
Net Pasture water losses (+ve)/gains (-ve)	538	74	3	224	596	669	603	632	780	917	978	868
Spare Capacity (MI)	1625	1004	427	150	326	586	795	1032	1420	1923	2262	2078
Water held (MI)	125	746	1323	1600	1424	1164	955	718	330	0	0	0

Table 9: Effective water use by contour bank irrigated pastures, consecutive year of 90th percentile rainfall

Parameter - Average year sequence	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Pasture area (ha)	500	500	500	500	500	500	500	500	500	500	500	500
Pasture flood depth (cm)	50	50	50	50	50	50	50	50	50	50	50	50
Pasture storage capacity (MI)	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
Starting volume (MI)	0	319	1942	2500	2500	2296	1795	1339	825	102	0	0
Mine inflow (MI)	663	695	580	501	420	410	393	395	392	414	466	539
Net Pasture water losses (+ve)/gains (-ve)	344	-928	-902	-419	624	910	850	909	1115	1276	1221	818
Spare Capacity (MI)	2181	558	-924 ¹	-919 ¹	204	705	1162	1675	2398	3259	3255	2778
Water held (MI)	319	1942	3424	3419	2296	1795	1339	825	102	0	0	0
Water held after removal of excess to storage(MI)	319	1942	2500	2500	2296	1795	1339	825	102	0	0	0

1. Overtopping of contour banks, diverted to storage for pivot irrigation.

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7.4 Trees

Irrigated trees are suitable for the medium to well-drained, red and yellow earths and red dermosols. Drip irrigation is the only practical method for irrigation of trees on these soils.

Preliminary calculations of leaching requirement necessary to maintain the rootzone salinity at less than 2 dS/m, indicate a leaching requirement in the order of 12% based on an irrigation rate of 2300 mm/yr. Based on this leaching fraction, and assuming a drip irrigation efficiency of 95%, per hectare water balance parameters for an average rainfall year are detailed in Table 10. Based on this scenario, irrigation loading rate is 2381 mm/ha/yr (23.8 ML/ha/yr).

Table 10: Per hectare water balance parameters – Forest irrigation – average rainfall year

Month	Rainfall (mm)	Pan evaporation (mm/ha)	Plantation water use (mm/ha)	Irrigation loading (mm/ha)
Jan	208.4	229.4	211	47
Feb	186.7	187.6	182	34
Mar	143.7	207.7	206	103
Apr	33.7	204	200	203
May	7.3	198.4	192	219
Jun	1.7	174	171	199
Jul	2.4	182.9	179	209
Aug	0.4	223.2	212	250
Sep	4.9	267	259	300
Oct	21.2	300.7	286	316
Nov	49.1	297	294	299
Dec	122.1	275.9	270	201
Annual	781.6	2,748	2,662	2,381

Based on these per hectare water balance characteristics, the overall design parameter of an irrigation system designed to achieve 100% utilisation of water (based on average annual rainfall), is summarised in the second column of Table 11. Under this scenario, assuming an annual groundwater production of 5685 ML/yr (average 16.1 ML/day) 100% of water can be consumed by drip irrigation of a minimum area of 236 ha of trees irrigated at the rate of 2381 mm/ha/yr, requiring a minimum pond storage of 1515 ML (approximately 25.9 ha at an average depth of 6m).

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Table 11: Forest irrigation scenarios – average and 90th percentile rainfall years

Water balance component	50th percentile rainfall year	90 th percentile rainfall year
Total groundwater produced per year	5865 MI/yr	5865 MI/yr
Minimum plantation area required	235.8 ha	294.7 ha
Annual effluent loading rate	2381 mm/ha/yr	1937 mm/ha/yr
Minimum pond storage required	1515 MI	2275 MI
Pond area (assuming average depth of 6m)	25.3 ha	37.9 ha
Annual net pond loss/gain	427 MI	337.0 MI
Total excess rainfall	0 mm	282.0 mm
Number of months of excess rainfall	0	3
Irrigation method & rotation type	Drip	Drip
Leaching Fraction	12%	12%
Proportion of maximum Irrigation load applied	1.00	1.00

Table 12 presents per hectare water balance parameter for forest irrigation in a 90th percentile rainfall year. Based on this scenario, irrigation loading rate is reduced to 1937 mm/ha/yr (19.4 MI/ha/yr).

Based on these per hectare water balance characteristics, the overall design parameter of an irrigation system designed to achieve 100% utilisation of water in an 90th percentile rainfall), is summarised in the third column of Table 11. Under this scenario, assuming an annual groundwater production of 5685 MI/yr (average 16.1 MI/day) 100% of water can be consumed by drip irrigation of a minimum area of 295 ha of trees irrigated at the rate of 1937 mm/ha/yr, requiring a minimum pond storage of 2275 MI (approximately 37.9 ha at an average depth of 6m).

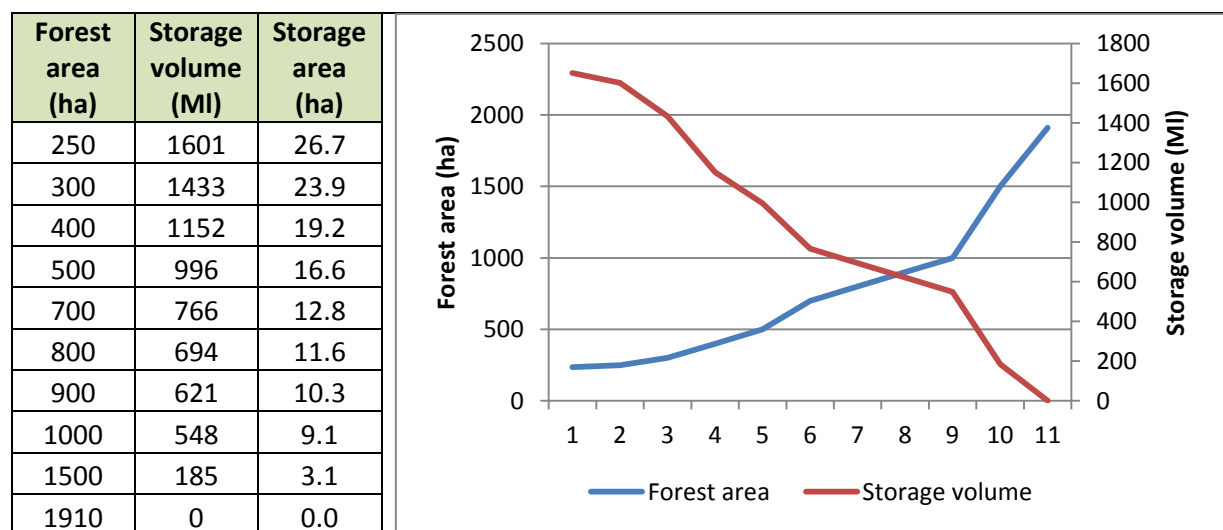
Table 12: Per hectare water balance parameters – Forest irrigation – 90th percentile rainfall year

Month	Rainfall (mm)	Pan evaporation (mm)	Plantation water use (mm)	Irrigation loading (mm)
Jan	415	229	211	0
Feb	368	188	182	0
Mar	291.4	208	206	0
Apr	79.2	204	200	159
May	16.4	198	192	209
Jun	4	174	171	197
Jul	1.2	183	179	210
Aug	0.2	223	212	250
Sep	11.9	267	259	293
Oct	56.5	301	286	282
Nov	133.5	297	294	218
Dec	207.1	276	270	119
Annual	1584.4	2748	2662	1937

An alternative strategy to minimising forest area by offsetting water surplus in the wet months with pond storage is to increase the forest area, effectively utilising the forest as a balancing storage. This strategy involves deficit irrigation of the forest plantation area.

Where the marginal value of forest area required to utilise 1 ML of water is less than the cost of dam storage for 1 ML, this strategy will prove more economic. The trade-off between forest area and pond storage volume for an average rainfall year is summarised in Table 13. It can be seen that pond storage can be eliminated for an average rainfall year with a forest area of 1910 ha. Note, however, that tree production will fall as the irrigation supply falls below approximately 50% of the rainfall deficit (i.e., below approximately 490 ha of irrigated forest, requiring a storage volume of 1011 ML).

Table 13: Trade-off between forest area and pond storage volume



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8. Water quality and conceptual water treatment options

Water quality provided by MET Serv is based on monitoring bores which intercept one or two palaeochannels containing permeable sands and gravels that pass to the east of the existing McArthur River channel. The base of the palaeochannels is up to 34m below ground surface (RL 5 m). Width is approximately 800m across the southern perimeter of the mine pit and represents a significant source of groundwater. Incomplete data, sampled over an 18 month period from June 2009 to December 2010, is available from nine bores. Full data is detailed by MET Serv in the report "Assessment of Palaeochannel Water Quality for McArthur River Mine May 2011". A summary of average data for all available analyses is presented in Table 14.

Table 14: Palaeochannel water quality analysis

Category	Analysis	Analysis value	ANZECC Long Term Trigger Value - Irrigation	ANZECC Stock Watering Guidelines
Physico-chemical	pH	7.35	6-8.5	
	Electrical Conductivity (EC)(μ S/cm)	1451		
	Salinity (PSS)	0.56		
	Total Dissolved Solids (TDS) (mg/l)	869		4000
	Turbidity (NTU)	44.3		
	Dissolved Oxygen (mg/l)	0.76		
	Hardness (mg/l)	751	< 60 ¹ >350 ²	
Cations	Calcium (mg/l)	109		1000
	Magnesium (mg/l)	110		
	Sodium (mg/l)	48.3	230 ³	
	Potassium (mg/l)	0.0087		
	Sulfate (mg/l)	130		1000
	SAR	0.70		
Anions	Chloride (mg/l)	118	350 ⁴	
	Carbonate/Bicarbonate alkalinity (mg/l)	751		
Metals	Arsenic (mg/l)	0.0042	0.1	0.5
	Cadmium (mg/l)	0.00017	0.01	0
	Copper (mg/l)	0.00065	0.2	1
	Lead (mg/l)	0.0014	2	0.1
	Zinc (mg/l)	0.056	2	20

1. Hardness < 60 with respect to corrosion
2. Hardness > 350 with respect to fouling.
3. With respect to foliar injury to moderately tolerant plants
4. With respect to increased cadmium uptake by crops (<300 mg/l for foliar injury to moderately tolerant plants)

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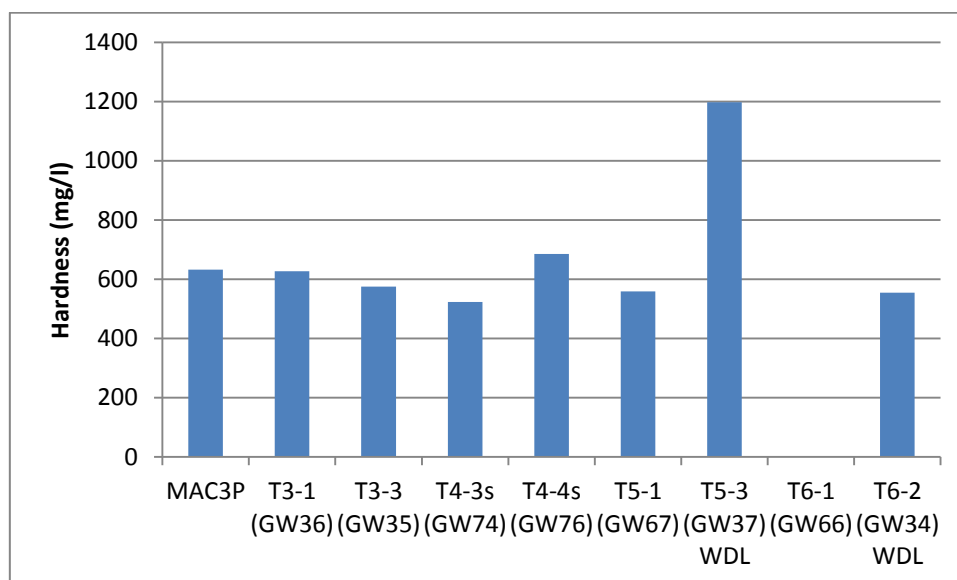
Comparison of the available palaeochannel data indicates that only hardness exceeds the recommended ANZECC water quality guidelines for irrigation use. No analytes exceed the ANZECC water quality guidelines for stock watering.

MET Serve report that two results exceeded the ANZECC Irrigation trigger value for Chloride. The reported trigger value is based on the effect of chloride with respect to increased cadmium uptake by crops. Based on a blended average as would be expected in any water collected for irrigation, chloride levels are well below the nominated trigger value and are not of practical concern. Notwithstanding, this should be reassessed on a weighted average basis in the development of any future irrigation scheme.

8.1 Hardness

The variation in average hardness between bore sites is illustrated in Figure 3.

Figure 3: Harness by bore site



Water hardness is primarily the amount of calcium and magnesium, and to a lesser extent, iron in the water, measured by adding up the concentrations of calcium, magnesium and converting this value to an equivalent concentration of calcium carbonate (CaCO₃) in milligrams per litre (mg/L) of water.

The principal concerns in relation to hardness are its effect on fouling or corrosion potential of irrigation systems rather than effects on plants or soils *per se*.

As noted by MET Serv, every groundwater bore monitored exceeded the ANZECC guidelines for hardness with respect to fouling of agricultural water systems. This occurs as a result of scale formation due to precipitation of calcium carbonate.

Conversely, every monitoring result exceeds the maximum ANZECC trigger value with respect to corrosion potential.

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In drip or pivot irrigation systems, scaling can be managed by periodic acid injection through the irrigation lines. TCT has managed irrigation systems with higher concentrations of calcium and magnesium salts than occur in the palaeochannel water with no negative effects.

8.2 Langelier Saturation Index

The Langelier Saturation Index (LSI) is a calculated value that provides a more detailed indication on whether water will precipitate, dissolve, or be in equilibrium with calcium carbonate than a simple hardness value. In addition to the simple concentration of Calcium and Magnesium the LSI also takes into account the modifying effects of pH conductivity, bicarbonate concentration and water temperature.

In order to calculate the LSI, it was assumed that all anions balancing the reported calcium and magnesium may be attributed to bicarbonate alkalinity. The scaling/corrosion potential of water indicated by its LSI value is presented in Table 15.

Table 15: LSI (Carrier) Indication of corrosion/fouling potential

LSI (Carrier)	Indication
$-2,0 < -0,5$	Serious corrosion
$-0.5 < 0$	Slightly corrosion but non-scale forming
$LSI = 0,0$	Balanced but pitting corrosion possible
$0.0 < 0.5$	Slightly scale forming and corrosive
$0.5 < 2$	Scale forming but non corrosive

The LSI value for the palaeochannel water is 0.55 assuming a water temperature of 25°C and 0.65 assuming a water temperature of 30°C. Based on these results, the palaeochannel water is supersaturated with respect to calcium carbonate ($CaCO_3$) and scale forming may occur, but the water is not corrosive.

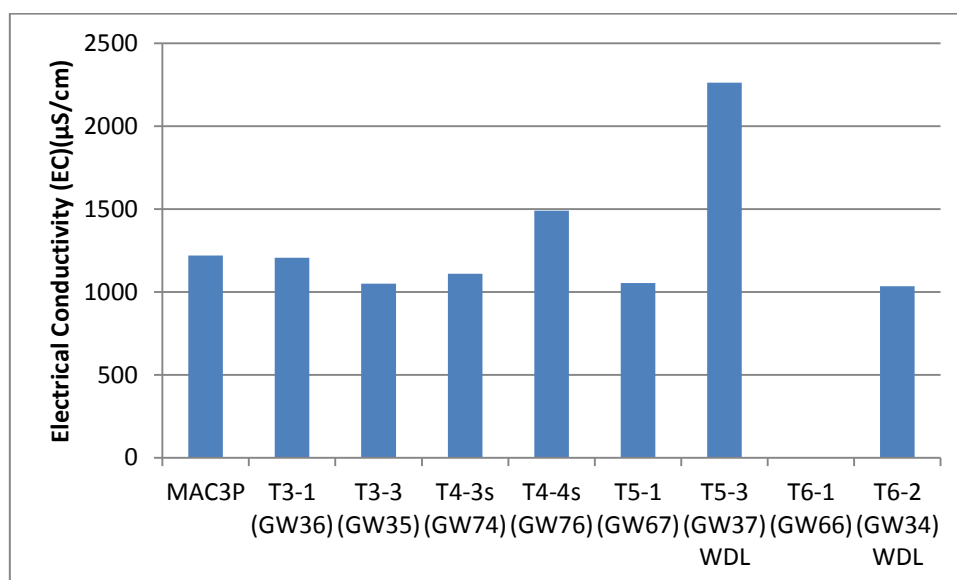
In drip or pivot irrigation systems, scaling can be managed by periodic acid injection through the irrigation lines.

8.3 Salinity

Salinity is typically measured as electrical conductivity (EC) of the water. This provides an estimate of the total dissolved salts, but not the composition of the salts. Average salinity from all analyses is 1451 $\mu S/cm$ (1.45 dS/m), but the average result from bore T5-3 is 2262 $\mu S/cm$ (2.26 dS/m). The

maximum recorded value (4050 $\mu\text{S}/\text{cm}$) was also recorded from this bore. The average for all other bores is between 1000 and 1500 $\mu\text{S}/\text{cm}$ (Figure 4).

Figure 4: Salinity (Electrical conductivity) by bore site



All potential irrigation options require some level of water storage. The salinity of water in storage will both increase as water is lost by evaporation, and decrease as the storage captures rainfall. Preliminary modelling indicates that on the assumption of a 6 to 8 m deep storage, average water salinity applied to irrigation will have an average salinity of 1.7 to 1.8 dS/m.

Salinity of irrigation water does not have a specific trigger value *per se*, but requires assessment in terms the potential for salt accumulation in the rootzone as a result of irrigation exceeding the salinity tolerance of the respective crop. This requires a more detailed knowledge of soil physical and chemical profile than is available. In addition, the potential for negative impacts from irrigation salinity, are influenced by management and landscape scale characteristics. Any irrigation development would require detailed soil profile characterisation, assessment of hydrogeology and groundwater flow paths, and design and implantation of an irrigation system specific to the soil, landscape conditions, climate and crop type.

Notwithstanding, the average irrigation water salinity provides an indication of the likely salinity impact from irrigation. Generally, most crops are tolerant to a soil solution EC of less than 2000 $\mu\text{S}/\text{cm}$ (2 dS/m). Given an average palaeochannel water salinity of 1451 $\mu\text{S}/\text{cm}$ (1.45 dS/m), and supply water salinity of 1.7 to 1.8 dS/m (after net pond evaporation), TCT does not expect that with good irrigation system design and management on suitable soils (i.e., soils with an adequate depth and permeability), that rootzone salinity is likely to become an issue.

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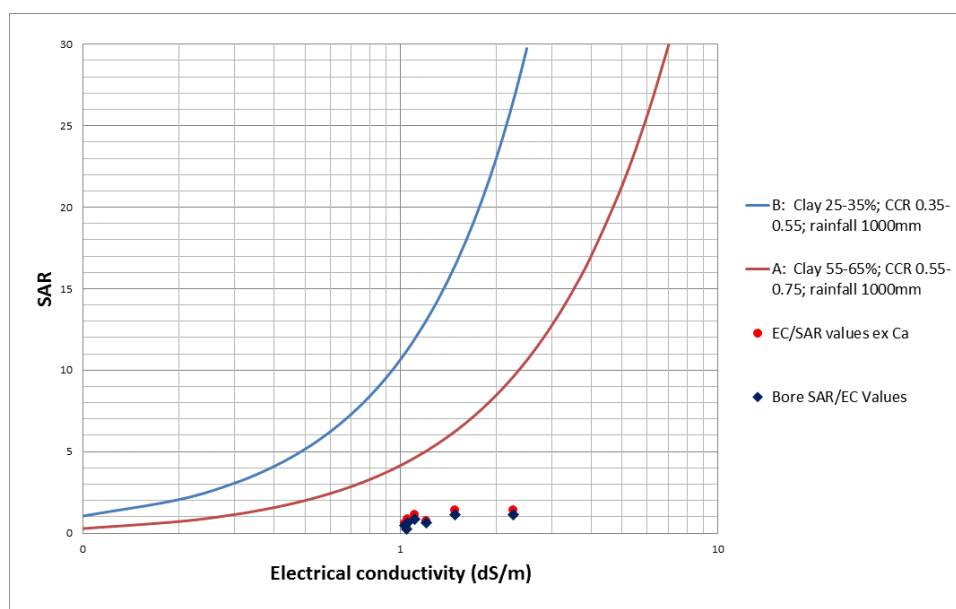
8.4 Sodicity

As with salinity the effects of sodicity in irrigation waters are situation-specific, and there is no specific trigger value *per se*. Rather, the potential effects of sodicity are the result of a complex interaction between the ionic balance of the water, its salinity, crop type, climate, rainfall, soil type and management.

Sodicity, measured as the Sodium Adsorption Ratio (SAR) is an excess of sodium in the soil relative to calcium and magnesium can lead to soil structural decline. This results from a weakening of the chemical bonds between soil particles, leading to clay particles, becoming detached on wetting and clogging soil pores. As a result, the pore structure of the soil is lost, restricting the entry of both water and oxygen. Reduced soil permeability limits leaching, so that salt accumulates in the soil. A degraded soil structure also restricts root development and, consequently, has a negative impact on plant health by increasing the risk of drought stress and likelihood of nutritional deficiencies. The dispersive nature of sodic soils makes them more susceptible to erosion, particularly when wet. On drying, sodic soils typically set hard, restricting seed germination.

The interaction of sodicity, sodicity and generic soil types is illustrated in Figure 5. Sodium Adsorption Ratio (SAR) values calculated from the average for each bore site are shown as blue diamonds. Values to the right of the two threshold curves are associated with stable soils. Values to the left of the curves are associated with soil structural decline. On this basis, all sodicity values are low, and irrigation with palaeochannel water is unlikely to lead to soil deterioration.

Figure 5: Sodium Adsorption Ratio (SAR) by bore site



Notwithstanding the low *in situ* SAR values, elevated levels of bicarbonate in irrigation waters can give rise to precipitation of calcium carbonate in soil. This will effectively increase the sodium adsorption ratio (SAR) and may lead to soil structural problems. The potential for this situation to

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arise was investigated by assuming that all calcium in the palaeochannel water is precipitated. Residual SAR values ranged between 0.3 and 1.2 (red dots in Figure 5). At these values, soil structure is expected to remain stable regardless of bicarbonate concentration. This supports the suitability of the palaeochannel water for irrigation.

8.5 Ionic composition

The negative impacts of salinity are generally considered in terms of the effect of sodium chloride. The major cation and anionic components of the palaeochannel water is summarised in Table 16.

Table 16: Molar amounts of principal cations and anions

	Cations			Anions		
Ion	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	CO ₃ ⁻⁻	SO ₄ ⁻⁻	Cl ⁻
mg/l	109.2	109.6	28.3	751.1 ¹	130.3	117.5
m molec/l	5.5	9.0	2.0	8.1	2.7	2.5
Sum cations/ anions	16.5			13.3		

1. As CaCO₃

From the available data, the stoichiometry between cations and anions is significantly unbalanced, with 16.5 m molec/l of cations (calcium, magnesium and sodium). But only 5.2 molec/l of anions (sulphate and chloride) being reported. It should be expected that the molar concentration of cations approximates that of anions.

In order to account for this discrepancy, it has been assumed that all of the reported hardness is balanced by carbonate alkalinity. Under this assumption molar concentration of anions (carbonate, sulphate and chloride) is 13.3 m molec/l. This brings the stoichiometry between cations and anions into much closer balance, and within a reasonable range of analytical accuracy.

On this basis the approximate molar ratio of salts (values adjusted to achieve ionic balance) in order of precipitation from solution is:

CaCO ₃	~4.1 m molec/l
MgCO ₃	~4.0 m molec/l
MgSO ₄	~2.7 m molec/l
NaCl	~1.6 m molec/l

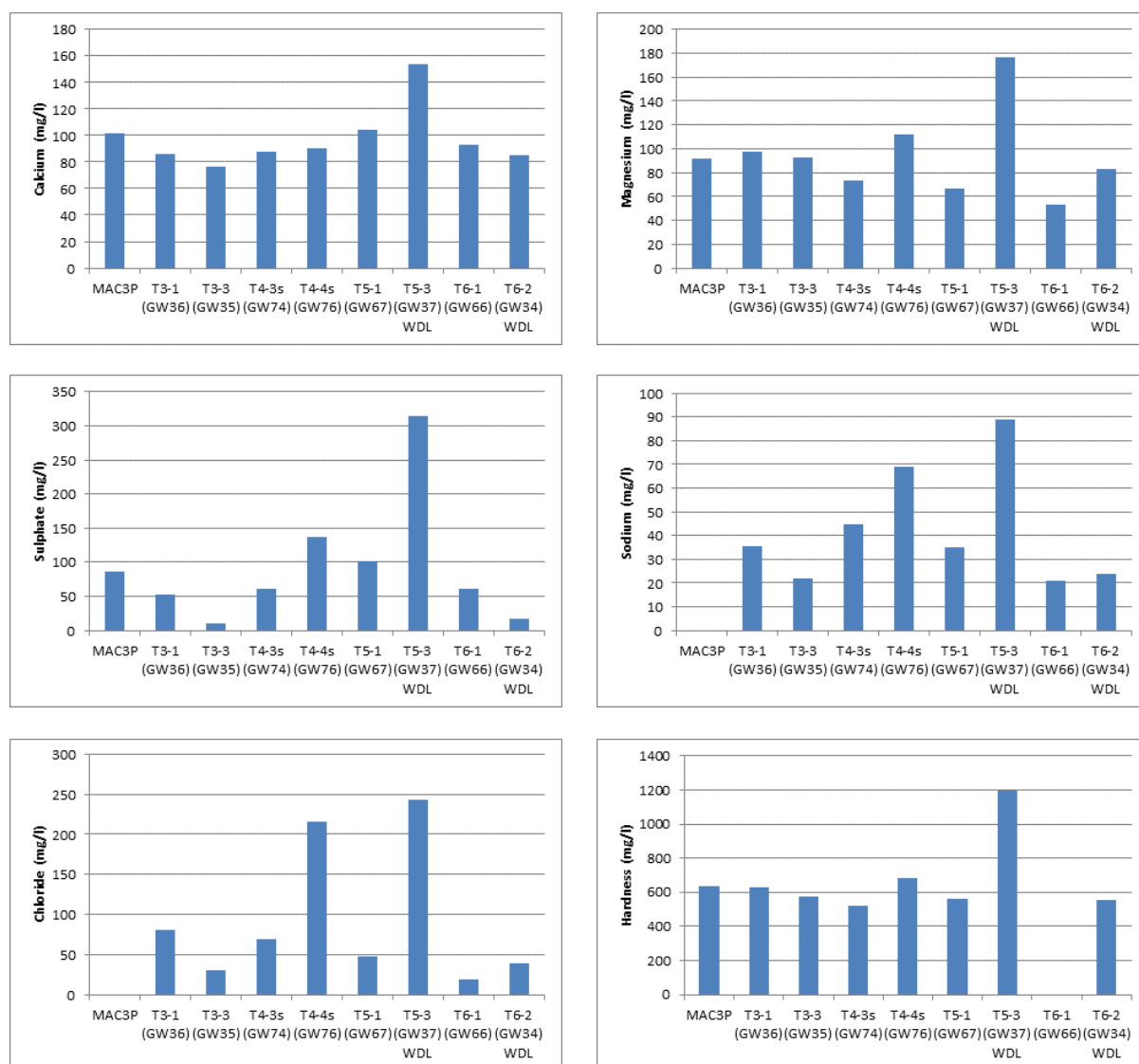
Sodium chloride represents a relatively small component of the overall dissolved salts. The dominant component is comprised of calcium and magnesium salts. In solution, calcium (and to a lesser extent magnesium) has a beneficial effect on soil properties by improving soil structure and permeability. From the analysis in this Section and Section 8.4 above, even if the majority of the

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unidentified anion is carbonate, and all calcium carbonate precipitates out in the soil, SAR values remain low, and no detrimental soil impacts are expected.

The concentration of all cations and anions (including the inferred concentration of carbonate) is illustrated in Figure 6.

Figure 6: Concentration of dominant palaeochannel water ionic components



8.6 Water quality summary and treatment requirements

Based on the above evaluation of water quality characteristics, there are no plant or soil impediments to use of the palaeochannel water for irrigation provided the water is applied to

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suitable soils and managed appropriately to ensure a leaching fraction sufficient to avoid rootzone accumulation is achieved. Accordingly, there is no requirement to treat this water.

The water does have a high hardness which may cause fouling of irrigation equipment by scaling. This can be managed by use of poly lined irrigation infrastructure, and periodic acid flushing of irrigation lines.

9. Estimates of cost/ ha or cost/volume of water for each option

9.1 Cost summary

Summarised cost estimates for the first 15 years for three most viable options are presented in Table 17. All cost estimates are based on the areas required to manage min inflows in a 90th percentile rainfall year. Note, cost per hectare estimates are irrelevant, as options that require a smaller area have a higher unit cost per hectare, even if having a lower total cost.

Total cost for all three options over a 15 year period is similar, ranging for \$10.8 to \$13.2 million. Cost per megalitre managed is also similar, ranging from \$122/ML for forest irrigation, to \$150 for contour bank plus pivot irrigation. These costs take no account of returns from grazing or trees. Net costs less returns will be substantially less.

Note, all costs are estimates subject to numerous assumptions and may vary widely. Costs are intended to indicate the order of magnitude of alternative options only.

Table 17: Cost summary for three viable irrigated water management options

Option	Total cost (15 years)	Volume managed (ML)	Cost/ML	Hectares required (ha)	Cost/ha (15 years)
Pivot irrigated pasture	\$12,704,240	88,148	\$144	308	\$41,248
Contour bank irrigated pasture plus balance of pivot irrigated pasture	\$13,253,440	88,148	\$150	590	\$22,463
Forest irrigation (Drip)	\$10,774,347	88,148	\$122	295	\$36,523

9.2 Pivot irrigated pastures (grass plus legumes)

Key assumptions as follows:

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- Pivot CAPEX - \$5000/ha
- Cost of balancing storage - \$2500/MI
- Irrigation OPEX - \$230/ha assuming electrical power (higher cost for diesel)
- Land preparation - \$100/ha (no clearing cost)
- Seed - \$100 - \$150 per ha – planting 5 to 7 kg seed per ha
- Establishment fertiliser – assuming a highly concentrated mixed N, P, and K fertiliser is required at 300 kg per ha, \$200 to \$250 /ha
- Herbicides - \$50/ha
- Electric fencing - \$50/ha
- Pasture management costs (intensive fertilizer regime - \$670/ha/yr
- Livestock management cost \$60/ha
- Irrigated area – 308 ha
- Pond storage area – 2614 MI (44 ha)

9.3 Contour bank irrigated pastures with supplementary pivot irrigation

9.3.1 Contour bank irrigation

- Landforming for contour banks - \$2000/ha
- Cost of balancing storage - \$2500/MI
- Irrigation OPEX - \$100/ha
- Land preparation - \$100/ha (no clearing cost)
- Seed - \$100 - \$150 per ha – planting 5 to 7 kg seed per ha
- Establishment fertiliser – assuming a highly concentrated mixed N, P, and K fertiliser is required at 300 kg per ha, \$200 to \$250 /ha
- Herbicides - \$50/ha
- Electric fencing - \$50/ha
- Pasture management costs (fertilizer regime - \$228/ha/yr
- Livestock management cost \$60/ha
- Irrigated area – 508 ha
- Pond storage area – 1638 MI (30 ha)

9.3.2 Pivot irrigation

- Pivot CAPEX - \$5000/ha
- Cost of balancing storage – Nil (accounted for with contour bank irrigation)
- Irrigation OPEX - \$230/ha assuming electrical power (higher cost for diesel)
- Irrigation OPEX - \$230/ha assuming electrical power (higher cost for diesel)
- Land preparation - \$100/ha (no clearing cost)
- Seed - \$100 - \$150 per ha – planting 5 to 7 kg seed per ha
- Establishment fertiliser – assuming a highly concentrated mixed N, P, and K fertiliser is required at 300 kg per ha, \$200 to \$250 /ha
- Herbicides - \$50/ha

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- Electric fencing - \$50/ha
- Pasture management costs (intensive fertilizer regime - \$670/ha/yr
- Livestock management cost \$60/ha
- Irrigated area – 90 ha

9.4 Forest irrigation species

- Drip system CAPEX - \$6600/ha
- Cost of balancing storage – \$2500/ML
- Forest establishment cost 0- \$4100/ha
- Forest management cost year 2 - \$1500/ha
- Ongoing management costs - \$123/ha
- Irrigated area – 295 ha
- Pond storage area – 2275 ML (38 ha)

Table 18: Detailed cost schedule – pivot irrigation of pastures, area and storage for 90th rainfall

Project year	Cost type	Unit cost	Units	Quantity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Year					2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
1. Pasture Irrigation (Pivots)																			
Storage volume	CAPEX	2500	\$/MI	2614	6,535,000														
Install agricultural irrigation	CAPEX	5000	\$/ha	308	1,540,000														
Irrigation management costs	OPEX	230	\$/ha/yr	308	70,840	70,840	70,840	70,840	70,840	70,840	70,840	70,840	70,840	70,840	70,840	70,840	70,840	70,840	70,840
Establish improved pastures	CAPEX	\$550	\$/ha	308	169,400														
Electric fencing	CAPEX	\$50	\$/ha	308	15,400														
Pasture management costs	OPEX	\$672	\$/ha/yr	308	206,976	206,976	206,976	206,976	206,976	206,976	206,976	206,976	206,976	206,976	206,976	206,976	206,976	206,976	206,976
Livestock management costs	OPEX	\$60	\$/ha/yr	308	18,480	18,480	18,480	18,480	18,480	18,480	18,480	18,480	18,480	18,480	18,480	18,480	18,480	18,480	18,480
Sub-total costs					8,556,096	296,296	296,296	296,296	296,296	296,296	296,296	296,296	296,296	296,296	296,296	296,296	296,296	296,296	296,296

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Table 19: Detailed cost schedule – Contour plus pivot irrigated pastures, area and storage for 90th rainfall

Project year	Cost type	Unit cost	Units	Quantity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Year					2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
2. Countour bank pastures																			
Storage volume	CAPEX	2500	\$/MI	1638	4,095,000														
Landforming	CAPEX	2000	\$/ha	500	1,000,000														
Irrigation management costs	OPEX	100	\$/ha/yr	500	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Establish pastures	CAPEX	\$550	\$/ha	500	275,000														
Electric fencing	CAPEX	50	\$/ha	500	25,000														
Pasture management costs	OPEX	\$228	\$/ha/yr	500	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000	114,000
Livestock management costs	OPEX	\$60	\$/ha/yr	500	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Sub-total costs					5,589,000	194,000	194,000	194,000	194,000	194,000	194,000	194,000	194,000	194,000	194,000	194,000	194,000	194,000	194,000
2. Pasture Irrigation (Pivots)																			
Storage volume	CAPEX	2500	\$/MI	0	0														
Install agricultural irrigation	CAPEX	5000	\$/ha	90	450,000														
Irrigation management costs	OPEX	230	\$/ha/yr	90	70,840	70,840	70,840	70,840	70,840	70,840	70,840	70,840	70,840	70,840	70,840	70,840	70,840	70,840	70,840
Establish improved pastures	CAPEX	\$550	\$/ha	90	49,500														
Electric fencing	CAPEX	\$50	\$/ha	90	4,500														
Pasture management costs	OPEX	\$672	\$/ha/yr	90	206,976	206,976	206,976	206,976	206,976	206,976	206,976	206,976	206,976	206,976	206,976	206,976	206,976	206,976	206,976
Livestock management costs	OPEX	\$60	\$/ha/yr	90	18,480	18,480	18,480	18,480	18,480	18,480	18,480	18,480	18,480	18,480	18,480	18,480	18,480	18,480	18,480
Sub-total costs					800,296	296,296	296,296	296,296	296,296	296,296	296,296	296,296	296,296	296,296	296,296	296,296	296,296	296,296	296,296
Total Contours Plus pasture					6,389,296	490,296	490,296	490,296	490,296	490,296	490,296	490,296	490,296	490,296	490,296	490,296	490,296	490,296	490,296

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Table 20: Detailed cost schedule – Forest irrigation, area and storage for 90th rainfall

Project year	Cost type	Unit cost	Units	Quantity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Year					2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
3. Forest Irrigation																			
Storage volume	CAPEX	2500	\$/MI	2275	5,687,500														
Install forest irrigation	CAPEX	\$6,600	\$/ha	295	1,947,000														
Irrigation operational costs	OPEX	\$230	\$/ha	295	67,850	67,850	67,850	67,850	67,850	67,850	67,850	67,850	67,850	67,850	67,850	67,850	67,850	67,850	67,850
Forest plantation establishment	CAPEX	\$4,100	\$/ha	295	1,209,500														
Forest management costs Yr 2	CAPEX	\$1,500	\$/ha	295		442,500													
Ongoing management costs	OPEX	\$123	\$/ha/yr	295			36,161	36,161	36,161	36,161	36,161	36,161	36,161	36,161	36,161	36,161	36,161	36,161	36,161
Sub-total costs					8,911,850	510,350	104,011	104,011	104,011	104,011	104,011	104,011	104,011	104,011	104,011	104,011	104,011	104,011	104,011

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Revision Date: 28 November 2011

DRN: QTE-007

Document Title: MET101 Metserv Report V2 Final

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10. A preferred conceptual option

TCT recommends a hierarchy of three irrigation management options:

1. Pivot irrigation of pasture grasses on red and yellow earths and red dermosol soils, with balancing storage for low water use months (nil discharge).
2. Contour bank irrigation of water logging tolerant pasture grasses on black soils with supplementary pivot irrigation of red and yellow soils to utilise excess storage volume (nil discharge).
3. Drip irrigation of forest species (*Khaya senegalensis*) on red and yellow earths and red dermosols soils, with balancing storage for low water use months (nil discharge).

Characteristics of these three options are summarised below:

Option No	Crop Option	Total cost (15 years)	Cost/ MI	Hectares required (ha)	Required storage volume (MI)
1	Pivot irrigated pasture	\$12,704,240	\$144	308	2614
2	Contour bank irrigated pasture plus balance of pivot irrigated pasture	\$13,253,440	\$150	590	1638
3	Forest irrigation (Drip)	\$10,774,347	\$122	295	2275

10.1 Option 1 – Pivot irrigated pastures

This option is recommended as the preferred option due to the following reasons:

- It involves a conventional approach to irrigation management;
- It is targeted to the red and yellow better drained soils expected to have a higher reliability of access than the black soil areas;
- It compliments and enhances the productivity of the existing grazing enterprise, offering the potential to increase herd size and reduce the impacts of seasonal variability;
- Cost per hectare is mid-range, but will be lower than forestry in the short term when returns from grazing are taken into account; and
- This option is most complimentary to the existing enterprise, and offers the lowest risk.

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Potential issues with this option include:

- Wheel tracking may be a major constraint on the operability of pivots and could result in the need for more operational supervision and land maintenance;
- Pigs may accentuate the wheel tracking problem as they tend to follow wheel lines and create wallows as the water recedes; and
- I guess if the system is never run in conditions that favour wheel rutting or bogging, the proposal might get around this component as I can see there are no alternate methods of irrigating pastures on a large scale in this region.

The potential for wheel tracking may be reduced by:

- Constructing elevated wheel tracks;
- Managing pigs;
- Not running in in conditions that favour wheel rutting or bogging (i.e., operate in drained soil conditions only);
- Use tracked pivots rather than wheeled pivots (this will add another \$500/ha); and
- Ensure pivot irrigation areas are not subject to periodic flooding.

10.2 Option 2 – Contour bank irrigated pastures

This option has merit by providing a reliable offtake for irrigation water throughout the year, however it has a number of limitations:

- It involves an unconventional approach to irrigation management;
- Access to black vertosol soil areas may be restricted for many months of the year, making cattle management difficult;
- Temporarily flooded areas may attract wild pigs and crocodiles;
- Potential cattle damage to contour banks is undefined;
- The capacity to ensure no flow-on to contour bank irrigated areas is undefined; and
- The extent of suitable land with very low gradients is undefined.

Notwithstanding, the positives of this option include:

- Robust capacity to manage water provided excess is diverted to storage;
- Potential attraction to wildlife, especially birds;
- Potentially high productivity from high water availability; and
- Combines irrigation of both black and reds soils, providing a diversity of irrigation areas.

10.3 Option 3 – Forest irrigation

Trees could provide high water use capacity, but are recommended only as a lower priority for the following reasons:

- Establishment of trees would create a stranded resource;
- Availability of skills and experienced contractors in the region is limited;

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- Pasture improvement offers greater benefits to improving the reliability and productivity of the existing grazing enterprise; and
- Drip irrigation requires extensive maintenance.

The positives of this option include:

- Potential high, water use from trees;
- There is growing interest in *Khaya* plantations in the top;
- Forest irrigation is a proven and reliable option with a high capacity to use water; and
- The marginal cost may be reduced by increasing forest area and reducing storage volume, improving the buffer in irrigation volumes and system reliability.

11. References

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Water use options McArthur River Mine Supplementary Report

Prepared for MET Serv
January 2012





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A handwritten signature in black ink, appearing to read 'G. T. Dale', is written over a light blue horizontal line.

Dr Glenn Dale
Managing Director and Chief Technical Officer
11 January 2012

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Revision history

Revision	Author/Reviewer	Date	Remarks ¹
0.1	Glenn Dale	09/1/2012	Working draft
1.0	Glenn Dale	11/1/2012	Final Copy

1. Working draft; Draft for approval; Approved for release; Final copy;

Distribution list

Date	Revision	Name	Title
11/1/2012	1.0	Brett Harwood	Principal Consultant - Environment
11/1/2012	1.0	Drew Herbert	Project Manager – MRM Phase 3 Dev. Study

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Glossary

ANZECC	Australian and New Zealand Environment and Conservation Council
Ca	Calcium
dS/m	Deci-siemens per metre
ECe	Electrical conductivity of a saturated solution extract
ET	Evapotranspiration
ha	Hectare
K	Potassium
Kp	Pan coefficient
l	Litre
LSI	Langellier Saturation Index
meq	Milliequivalents
mg	Milligram
Mg	Magnesium
ML	Megalitre
mm	millimetres
m molec	Millimoles charge units
Na	Sodium
SAR	Sodium adsorption ratio
$\mu\text{S/cm}$	Micro-siemens per centimetre

Executive Summary

Background

TCT has previously carried out a concept level investigation to establish the potential suitability for beneficial use of McArthur River mine inflow waters by irrigation of a range of tree and crop types. This investigation identified pivot irrigation of pastures as the preferred option.

WRF have subsequently revised mine water inflow estimates and water management options, resulting in a significantly altered estimate of the pattern and volume of water proposed for diversion to irrigation. This report re-evaluates the physical and cost parameters associated with these revised water production estimates.

As previously noted, investigations at this stage are based on limited available data. More detailed site investigation will be required, particularly for soil and landscape characteristics, in order to establish the suitability of specific on-ground sites and to inform irrigation system design.

Water supply

- Projected water supply varies significantly in terms of both pattern and volume within and between years for each projected scenario.
- As diversion of water to irrigation is structured as the option of last resort, it has been assumed that irrigation capacity must be designed to cope with the maximum water yields.
- On the basis of the above, the irrigation water supply for the year 2024 (90th percentile, wet year) has been used as the basis for irrigation system design.
- Design water supply to irrigation is 2,272 ML/yr. Average daily water supply is 6.2 ML/day, varying between 0 and 18 ML/day.

Water demand

- Potential annual plant water use demand for pastures is 2,396 mm/yr, but practical limitations of wet season operation and access limit this to 1,614 mm/yr.
- Daily plant water use demand for pastures and trees ranges from 5.1 to 8.8 mm/day (6.6 mm/day average).
- Potential irrigation loading after allowing for practical limitations, irrigation system efficiency, rainfall interception losses and minimum required leaching fraction is 1,796 mm/ha/yr (17.96 ML).
- Based on the maximum projected annual water supply (2,272 ML/yr), minimum required pasture irrigation area is 125 ha.
- Minimum required pond storage volume is 652 ML. Pond area assuming an average depth of 6 m is 10.9 ha.

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Water quality and treatment

- Water quality for irrigation was reviewed in the prior TCT report. In that report, it was noted that available water analyses were inadequate to account for all major ionic components in solution.
- It is highly recommended that a complete water analysis be carried out. This would include all major anions, cations, pH and conductivity but would also include the total alkalinity (presently lacking). The pH can then be used to calculate the forms of alkalinity (carbonate, bicarbonate, hydroxide, etc).

Cost estimates

Cost and returns are estimated as follows

Expense/Return	Cost/return (\$)
Delivery pump station (18 MI/day capacity) and mainline (5 km) CAPEX	\$4,934,950
Distribution system OPEX	\$22,703/yr
Storage pond (652 MI, 10.9 ha)	\$2,608,000
Irrigation system CAPEX	\$843,750
Irrigation system OPEX	\$98,500/yr
Site clearing and pasture establishment (125 ha)	\$137,500
Annual pasture and livestock management costs	\$91,500/yr
Annual livestock returns	\$145,250/yr

Further investigations

Potentially suitable soil types (particularly soils described as deep earthy sands, medium to deep yellow massive earths, and medium to deep red massive or structured earths) occur on the tenement area and surrounding grazing property. A detailed on-site feasibility study will be required to positively establish the suitability of these soils and the site for irrigation development. It is recommended that this work be carried out in staged approach as follows:

- 1 Site soil survey and impact assessment modelling
- 2 Desktop water resource review and impact analysis
- 3 Site hydrogeological assessment (if required)
- 4 Full feasibility study report and beneficial use plan preparation

1. Introduction

1.1 EIS

McArthur River Mine is a zinc, lead and silver open-cut mine located approximately 60 kilometres (km) south of Borroloola in the Northern Territory. McArthur River Mine is owned by Xstrata.

MET Serve is assisting McArthur River Mine in the preparation of an EIS in support of a proposed mine expansion.

1.2 Water quantity and mine water use options

The mine expansion is expected to generate water at rates the order of around 16 ML per day. TCT's initial report presented conceptual irrigation scenarios and associated costs based on this level of water production. Based on this report, MRM have advised that irrigated perennial pasture on well drained soils is the preferred option for off-site irrigation use.

Further consideration by MRM of overall water management options has determined that the preferred strategy is to maximise on-site management of water and river discharge, with off-site irrigation taking any residual surplus volume. In summary, diversion of water to irrigation is to be the option of last resort. This changes the irrigation water supply volume to irrigation significantly from the estimates presented in TCT's original report.

1.3 Terms of reference

MRM and Met Serve have requested TCT to provide:

- Revised water demand and irrigation area estimates for the preferred option of perennial pasture irrigation on well drained soils based on a significantly revised water yield scenario;
- Revised estimates of cost/ha or cost/volume of water for the perennial pasture option; and
- Outline of requirements and costs to progress site based project feasibility investigation.

2. Preferred irrigation reuse option

Per TCT's initial report, the preferred irrigation management option is pivot irrigation of perennial pasture species on well drained red and yellow earths and re dermosols.

It is most desirable to combine grasses with legumes so that the latter can provide at least some of the nitrogen requirements for the companion grasses. All species given below are suited to mixed grass legume situations. Potential species include:

Grass species

- 1) Rhodes grass (*Chloris gayana* cv Callide & Fine cut);
- 2) Kazungula setaria (*Setaria sphacelata* (anceps) cv kazungula);
- 3) Bisset creeping blue grass (*Bothriochloa insculpta* cv Bisset); and
- 4) Tully humidicola – (*Brachiara humidicola* cv Tully).

Legumes

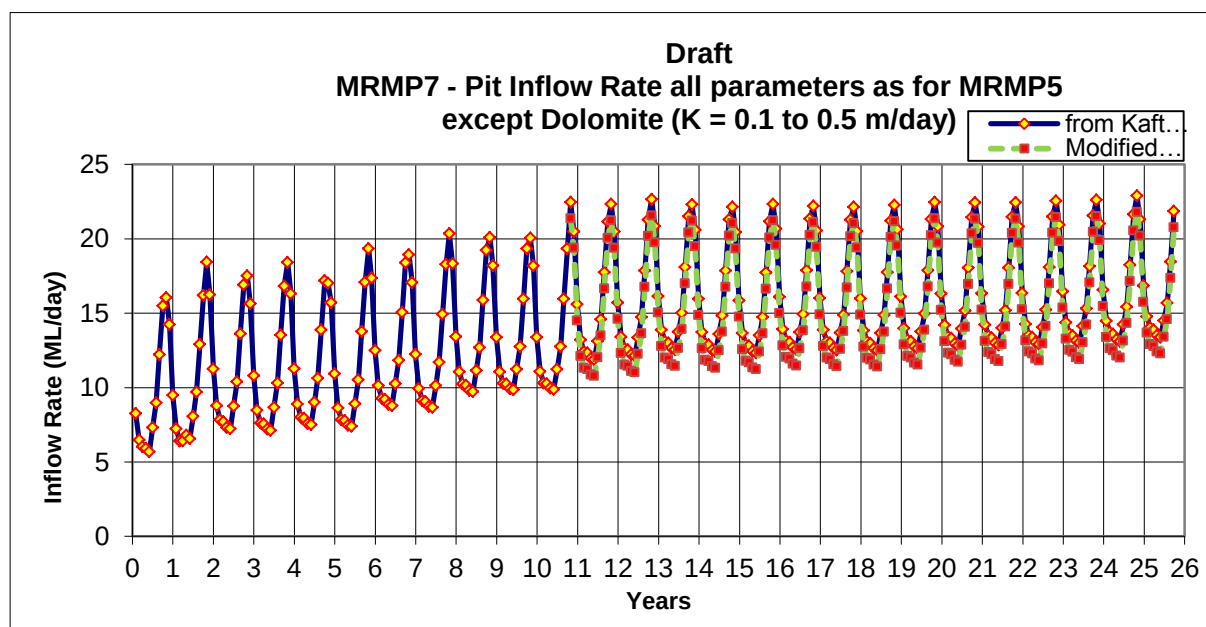
- 1) Glenn and Lee joint vetch;
- 2) *Centrosema macrocarpum* (brasilianum); and
- 3) *Vigna luteola*.

Note: This option is substantially restricted to irrigation during the dry season.

3. Irrigation water supply

The originally provided water inflow data projected a gradual build-up in water inflows, with regular seasonal fluctuations reaching a relatively constant annual average of 16.1 ML/day (annual range from 112 to 22 ML/day) from project year 11 (2022) onwards (Figure 1).

Figure 1: Projected pit inflow rates (WRM Water & Environment Pty Ltd)



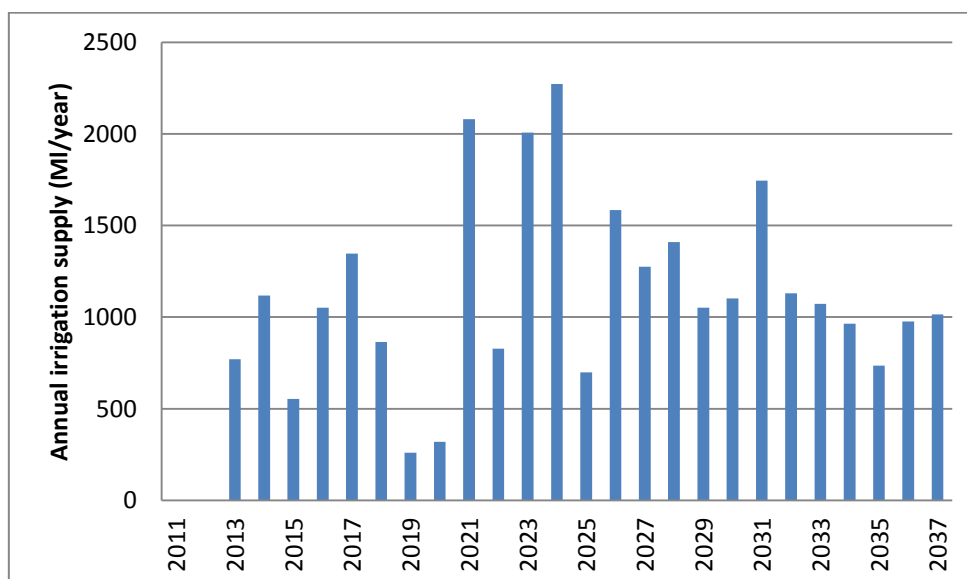
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The revised irrigation water supply volumes provided by WRM are significantly more variable. Three scenarios have been provided for the period from 2011 to 2037:

- 10th percentile (dry simulation);
- 50th percentile (median simulation); and
- 90th percentile (wet simulation).

Within each scenario, the annual pattern and volume of irrigation supply varies considerably. For the 90th percentile scenario, the variation in total annual irrigation supply varies from a minimum of 260 ML/year in 2019, to a maximum of 2,270 ML/year in 2024 (illustrated in Figure 2).

Figure 2: Total annual irrigation supply, 90th percentile scenario



The variation between years within scenarios (for the period from 2015 to 2036), and between scenarios is further illustrated in



Table 1. This variation is up to 9 fold for the 90th percentile scenario.

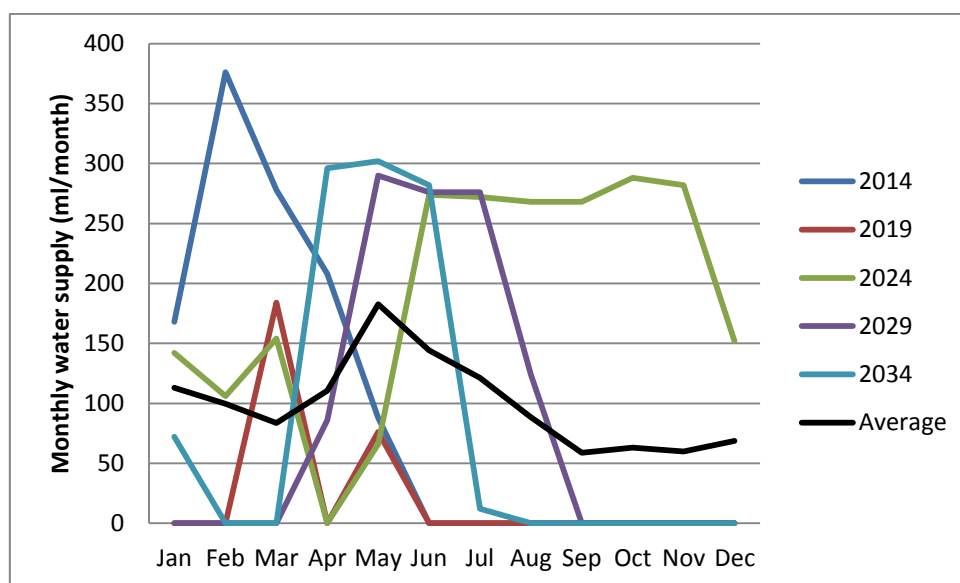
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Table 1: Variation in irrigation supply within and between scenarios (2015-2036)

Scenario	Minimum MI/yr (MI/day)	Average MI/yr (MI/day)	Maximum MI/yr (MI/day)
10 th percentile (dry year)	184 (0.5)	995 (2.7)	2,064 (5.7)
50 th percentile (Median)	384 (1.4)	1,113 (3.1)	2,100 (5.8)
90 th percentile (wet year)	260 (0.7)	1,129 (3.2)	2,272 (6.2)

Variation between the pattern of water supply within a year is also significant. The pattern of monthly water supply for a selection of years, and for the average across all years, is illustrated in Figure 3.

Figure 3: Variation in monthly irrigation water supply for select years



The wide variation in the projected irrigation water supply between years within a scenario, and between scenarios presents a challenge for design of an efficient irrigation system. As the irrigation system is intended to take excess flows, it is assumed that it effectively provides the backstop required to ensure licence conditions are met. On this basis, the irrigation system should be designed to handle the maximum volume of water delivered in a wet year. For this purpose, the irrigation supply projection for 2024 (2,272 MI/year, average of 6.2 MI/day) has been chosen for further simulation. Water supply data for this year are presented in Table 2.

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Table 2: Projected irrigation water supply, 2024, 90th percentile scenario

Month	Monthly water supply (MI/month)	Average daily water supply (MI/day)
Jan	142	4.6
Feb	106	3.8
Mar	154	5.0
Apr	0	0.0
May	66	2.1
Jun	274	9.1
Jul	272	8.8
Aug	268	8.6
Sep	268	8.9
Oct	288	9.3
Nov	282	9.4
Dec	152	4.9
Annual	2272 (Total)	6.2 (average)

4. Estimation of water demand

Assumptions regarding monthly variation in rainfall, evaporation, plant water use demand and water yield are summarised in

Table 3. These assumptions are as per the prior report.

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4.1 Climatic, crop factor and water yield assumptions

Table 3: Climatic, plant water use and water inflow assumptions

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average (50 th percentile) rainfall (mm)	208.4	186.7	143.7	33.7	7.3	1.7	2.4	0.4	4.9	21.2	49.1	122.1	784.2
90 th percentile rainfall (mm)	415	368	291.4	79.2	16.4	4	1.2	0.2	11.9	56.5	133.5	207.1	1,202.4
Mean daily evaporation (mm)	7.4	6.7	6.7	6.8	6.4	5.8	5.9	7.2	8.9	9.7	9.9	8.9	7.5(av)
Mean monthly evap (mm)	229.4	187.6	207.7	204	198.4	174	182.9	223.2	267	300.7	297	275.9	2747.8
Pasture pan coefficient	0.83	0.87	0.89	0.88	0.87	0.88	0.88	0.86	0.87	0.86	0.89	0.88	0.87(av)
ET pasture (mm/day)	6.1	5.8	6.0	6.0	5.6	5.1	5.2	6.2	7.8	8.3	8.8	7.8	6.6(av)
ET pasture (mm/month)	190	164	185	180	173	153	161	191	233	257	265	243	2,396
ET past. practical (mm/month)	0	0	0	180	173	153	161	191	233	257	265	0	1,614
Water inflow (ML/day)	4.6	3.8	5.0	0.0	2.1	9.1	8.8	8.6	8.9	9.3	9.4	4.9	6.2(av)
Water inflow (ML/month)	142	106	154	0	66	274	272	268	268	288	282	152	2,272

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4.2 Irrigated pastures

As per previous projections, key assumptions are as follows:

- Irrigated pastures are suitable for the medium to well-drained, red and yellow earths and red dermosols.
- Centre pivot or lateral move irrigation is suitable for these soil types subject to more detailed evaluation of specific site conditions (slope, landform, adequate area).
- No irrigation has been assumed in the summer (wet season) months of December to March inclusive due to access problems, and practical considerations relating to operation of pivots under excessively wet conditions.
- Pasture crop factor is 0.9 that of trees for the same region.

Irrigation loading projections are based on a 90th percentile rainfall year (

- Table 3).
- Target leaching fraction is 12% based on preliminary calculations of leaching requirement necessary to maintain the rootzone salinity at less than 2 dS/m under an irrigation rate of 2,300 mm/yr.
- Sprinkler irrigation efficiency is 85%.

Based on these assumptions, key water balance parameters are detailed in Table 4. Irrigation of between 152 and 293 mm/ha/month during the period April to November gives an annual irrigation loading of 1,796 mm/ha/yr or 17.96 ML/ha/year.

Table 4: Per hectare water balance parameters – Pasture irrigation – 90th percentile rainfall year

Month	Rainfall (mm)	Pan evaporation (mm/ha)	Pasture water use (mm/ha)	Irrigation loading (mm/ha)
Jan	415	229.4	190	0
Feb	368	187.6	164	0
Mar	291.4	207.7	185	0
Apr	79.2	204	180	152
May	16.4	198.4	173	209
Jun	4	174	153	198
Jul	1.2	182.9	161	211
Aug	0.2	223.2	191	251
Sep	11.9	267	233	293
Oct	56.5	300.7	257	278
Nov	133.5	297	265	204
Dec	207.1	275.9	243	0
Annual	1,584.4	2,748	2,396	1,796

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Based on these per hectare water balance characteristics, the overall design parameters for an irrigation system designed to achieve 100% utilisation of water in a 90th percentile rainfall year and maximum assumed mine water inflow rates, are summarised in Table 5.

Under this scenario, and based on an annual irrigation water supply of 2,272 MI/yr (average 6.2 MI/day), an irrigation area of 125 ha with dam storage of 652 MI (10.9 ha at 6m average depth), is required.

Table 5: Pasture irrigation design parameters – 90th percentile rainfall years

Water balance component	90 th percentile rainfall year
Total groundwater produced per year	2,272 MI/yr
Minimum pasture area required	125 ha
Annual effluent loading rate	1,796 mm/ha/yr
Minimum pond storage required	652 MI
Pond area (assuming average depth of 6m)	10.9 ha
Annual net pond loss/gain	97 MI
Total excess rainfall	342 mm
Number of months of excess rainfall	4 months
Irrigation method & rotation type	Sprinkler (Pivot)
Leaching Fraction	12%
Proportion of maximum Irrigation load applied	1.00

5. Water quality and conceptual water treatment options

Water quality for irrigation was reviewed in the prior TCT report. In that report, it was noted that available water analyses were inadequate to account for all major ionic components in solution.

The sum of the cations is 16.5 meq and the anions 6.0 meq. The quantity of cations and anions should be close to balanced. Presently anions totalling 10.6 meq are missing from the analysis. It was postulated that missing ions comprised carbonates (approximately 650 mg/l of bicarbonate alkalinity), but this has not been verified.

It is highly recommended that a complete water analysis be carried out. This would include all major anions, cations, pH and conductivity but would also include the total alkalinity (presently lacking). The pH can then be used to calculate the forms of alkalinity (carbonate, bicarbonate, hydroxide, etc).

Most labs offer a standard water analysis suite. The standard stock or domestic water profiles provided by SGS laboratories should prove adequate for this purpose.

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6. Estimates of cost/ ha or cost/volume of water for each option

6.1 Assumptions

Key cost assumptions for pivot irrigated pastures (grass plus legumes) are as follows:

- Main delivery pipeline - \$606,990/km
- Delivery pump station cost (with capacity to pump 18 MI/day) - \$1.9 million
- Pivot CAPEX - \$6,750/ha
- Cost of balancing storage - \$4,000/MI
- Irrigation OPEX - \$788/ha (Assuming diesel power. Less for grid power)
- Land clearing cost - \$500/ha
- Pasture establishment cost - \$550/ha including:
 - Land preparation - \$100/ha (no clearing cost)
 - Seed - \$100 - \$150 per ha – planting 5 to 7 kg seed per ha
 - Establishment fertiliser – assuming a highly concentrated mixed N, P, and K fertiliser is required at 300 kg per ha, \$200 to \$250 /ha
 - Herbicides - \$50/ha
- Electric fencing - \$50/ha
- Pasture management costs (intensive fertilizer regime) - \$672/ha/yr
- Livestock management cost \$60/ha/yr

Additional key assumptions as follows:

- Irrigated area – 125 ha
- Pond storage area – 652 MI (10.9 ha)
- Main delivery pipeline – 5 km
- Maximum daily delivery volume to storage pond – 18 MI
- Average daily irrigation volume – 6.2 MI
- Annual irrigation volume – 2,270 MI

6.2 Cost summary

Summarised cost estimates for the first 15 years are presented in Table 6. All cost estimates are based on the area required to manage maximum projected annual irrigation supply under the 90th percentile (wet year) scenario (i.e., for 2024).

Total cost for all three options over a 15 year period is similar, ranging for \$10.8 to \$13.2 million. Cost per megalitre managed is also similar, ranging from \$122/MI for forest irrigation, to \$150 for contour bank plus pivot irrigation. These costs take no account of returns from grazing or trees. Net costs less returns will be substantially less.

Table 6: Cost summary for pivot irrigated pasture

Expense/Return	Cost/return (\$)
Delivery pump station (18 ML/day capacity) and mainline (5 km) CAPEX	\$4,934,950
Distribution system OPEX	\$22,703/yr
Storage pond (652 ML, 10.9 ha)	\$2,608,000
Irrigation system CAPEX	\$843,750
Irrigation system OPEX	\$98,500/yr
Site clearing and pasture establishment (125 ha)	\$137,500
Annual pasture and livestock management costs	\$91,500/yr
Annual livestock returns	\$145,250/yr

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Table 7: Detailed cost schedule – pivot irrigation of pastures, area and storage for 90th rainfall

Project year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Delivery infrastructure															
Main delivery pump station	1,900,000														
Trunk line construction	3,034,950														
Storage pond construction	2,608,000														
Distribution system OPEX	22,703	22,703	22,703	22,703	22,703	22,703	22,703	22,703	22,703	22,703	22,703	22,703	22,703	22,703	22,703
Pasture Irrigation															
Site preparation and clean up	62,500														
Install agricultural irrigation	843,750														
Irrigation management costs	98,500	98,500	98,500	98,500	98,500	98,500	98,500	98,500	98,500	98,500	98,500	98,500	98,500	98,500	98,500
Establish improved pastures	68,750														
Fencing	6,250														
Land rental	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pasture management costs	84,000	84,000	84,000	84,000	84,000	84,000	84,000	84,000	84,000	84,000	84,000	84,000	84,000	84,000	84,000
Livestock management costs	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500
Livestock returns	145,250	145,250	145,250	145,250	145,250	145,250	145,250	145,250	145,250	145,250	145,250	145,250	145,250	145,250	145,250

Project Costs and Returns															
CAPEX	8,524,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OPEX	212,703	212,703	212,703	212,703	212,703	212,703	212,703	212,703	212,703	212,703	212,703	212,703	212,703	212,703	212,703
RETURN	145,250	145,250	145,250	145,250	145,250	145,250	145,250	145,250	145,250	145,250	145,250	145,250	145,250	145,250	145,250
Net cashflow	-8,591,653	-67,453	-67,453	-67,453	-67,453	-67,453	-67,453	-67,453	-67,453	-67,453	-67,453	-67,453	-67,453	-67,453	-67,453

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7. Further feasibility development steps and cost

TCT has undertaken a high level review of Northern Territory legislation relating to the licencing of mine by-product water for irrigated use. While this review is ongoing, it is likely that diversion of mine by-product water for beneficial use via pasture irrigation will require some form of appropriate licensing, possibly under the Water Act. It is anticipated that the key consideration in any licence will be avoidance of environmental harm. It would be further anticipated that any licence for beneficial use of by-product water will require ongoing monitoring to ensure that relevant licence conditions continue to be met.

Based on Queensland legislation, key issues that must be addressed in any application for beneficial use of by-product water include an assessment that:

- a) Application of the water to the land will not result in degradation of the quality of the soil to which it is applied, or deterioration to crop productivity (i.e., the productive capacity of the soil is preserved); and
- b) Application of the water to the land will not result in off-site environmental impact to land and water resources.

Key topics to be addressed in a comprehensive feasibility study will include the following:

General site and land resource review including:

- Geology
- Climate
- Rainfall and evaporation
- Temperature
- Landform and topography
- Vegetation
- Infrastructure
- Potential irrigation areas
- Current land use

Detailed soil and site survey incorporating:

- Desktop assessment of potential investigation areas
- Planning of soil sampling locations
- Soil electromagnetic (EM) Mapping
- In-field pit characterisation to Australian Standards
- Sample collection and lab analysis to Australian Standards
- Soil type and soil property mapping to Australian Standards
- Modelling of soil behavioural characteristics under irrigation
- Soil management requirements
- Identification and mapping of potential irrigation areas

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Update of by-product water characteristics (if applicable) including:

- Water supply volume
- By-product water analysis and review against Australian irrigation standards

Review of proposed pasture species

- Review species suitability and management requirement in light of soil mapping results and irrigation water quality review

Detailed analysis and modelling of irrigation impacts on soils and plant productivity including:

- Water balance
- Rootzone salinity and leaching
- Soil sodicity impacts
- Impact of treated water on soil structure

Analysis of impacts of irrigation on water resources including:

- Review of surface water resources
- Review of groundwater resources
- Conceptual Understanding of hydrogeology
- Sources
- Pathways
- Receptors
- Assessment and evaluation of irrigation impacts on water resources

Beneficial use plan

- Outline of proposed irrigation development plan
- Crop establishment and management practices
- Irrigation system design
- Monitoring and reporting plan
- Risk management plan
- Stakeholder engagement plan

While the above represents a comprehensive outline of topics and issues to be addressed in a complete feasibility study, it is recommended that this be approached in a staged manner to first establish the availability of land suitable for irrigation development within an economic distance of the mine site. In this regard, it is recommended that the staged priority for undertaking the components of a feasibility study should be:

- 1 Site soil survey and impact assessment modelling
- 2 Desktop water resource review and impact analysis
- 3 Site hydrogeological assessment (if required)
- 4 Full feasibility study report and beneficial use plan preparation

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