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Santos

PROJECT

Leewood Irrigation Project

DOCUMENT

Leewood Irrigation Management Plan

Leewood Irrigation Management Plan

AUTHOR(S)

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LIST OF ABBREVIATIONS

AMSL above mean sea level bgs below ground surface

CP centre-pivot sprinkler system

DISRD NSW Department of Industry, Skills and Regional Development

DPI NSW Department of Primary Industries

dS/m deciSiemens per metre EC electrical conductivity

EC_e electrical conductivity of a soil paste extract
 EPA NSW Environment Protection Authority
 EPL Environment Protection Licence 20350
 ESP exchangeable sodium percentage

ha hectare

kg/ha kilograms per hectare mbgl metres below ground level

mg/L milligrams per litre

ML megalitre

MLD megalitres per day

mm millimetre

mm/h millimetres per hour NSW New South Wales

ORP oxidation reduction potential
PAL Petroleum Assessment Lease
PAWC plant available water capacity
REF Review of Environmental Factors

RO reverse osmosis

SAR sodium adsorption ratio

SAR_e sodium adsorption ration of soil paste extract

SDI subsurface drip irrigation

SWD soil water deficit

t tonnes

t/ha tonnes per hectare

VRI Variable Rate Irrigation system

yr year



1 Introduction

The Leewood Produced Water Treatment and Beneficial Reuse Project was approved under Part 5 of the *Environmental Planning and Assessment Act 1979* by the NSW Department of Industry – Division of Resources and Energy (DRE) on 18 August 2015. This irrigation management plan (IMP) for the Leewood property has been prepared to satisfy condition 6 of that approval. The condition states:

An Irrigation Management Plan (IMP) must be submitted to and approved by the Secretary DISRD prior to undertaking the irrigation. This plan is to be developed in accordance with the EPA's Use of Effluent by Irrigation Guidelines (2003). The DPI and the EPA must be consulted in the development of the IMP. The IMP must set-out the following:

- a. Detailed design of the soil and groundwater monitoring program showing monitoring locations and sampling frequency.
- b. Specification for the unamended and amended quality of the irrigation water and the circumstances, under which the amendment might be varied, linked to soil and groundwater monitoring.
- c. Identification of operational triggers (such as 'trigger action response plans') to ensure that the irrigation program is being managed in a sustainable manner and to prevent unacceptable impacts to the environment. Triggers for commencement and cessation of irrigation must be clearly articulated and supported by assessment data. Triggers and associated responses must be provided for, but not limited to the following:
 - crop failure
 - excessive saturation of the soil profile (waterlogging) to ensure no surface runoff occurs from the irrigation area resulting from the irrigation
 - excessive salinity in the soil profile or groundwater ensuring that salinity levels (EC/TDS)
 remain consistent with baseline monitoring
 - Impacts to the Brigalow Woodland and Pilliga box-white cypress grassy open woodland on the northern boundary of the site – ensuring no adverse impacts occur to the vegetation in this area associated with the irrigation
- d. A program for reporting on the treatment process and irrigation operations, including further development and review of a detailed water balance.

This plan should be read in conjunction with the *Concept Design - Leewood Irrigation Project REF* (Bailey, Zupancic, & van Niekerk, 2015) provided as Appendix 3 of the Leewood Produced Water and Beneficial Reuse Project Review of Environmental Factors (REF).

Consultation was undertaken with the DPI and EPA in April 2017 during the development of this plan and outcomes of this consultation have been incorporated in the finalisation of the Plan.



The site is currently dryland, unimproved pasture, with scattered native trees, and has no history of irrigation. Santos plans to irrigate the site with treated water generated from its petroleum exploration and appraisal activities. In conjunction with the above mentioned report, this IMP will discuss the details for the beneficial reuse of the treated water dispersal, incorporating a newly established improved pasture and an irrigation system.

2 Objectives of the plan

The following are the objectives of this IMP:

- To provide context regarding the landscape where the irrigation system operates, in particular the climate, soils and topography.
- To provide details on the operational instructions for the irrigation system that comply with the NSW *Environmental guidelines- Use of effluent by irrigation* (DEC, 2004).
- To detail the monitoring program for irrigation water, soil and groundwater.
- To identify triggers from monitoring that will be used to modify the irrigation systems operation.
- To outline reporting protocols for activities relating to water treatment, irrigation system operations, maintenance and monitoring.
- To detail water quality and water amendment specifications.

3 Site description

3.1 Tenure

The Leewood site is owned and operated by Santos NSW (Eastern) Pty Ltd (Santos) and is located within Petroleum Assessment Lease (PAL) 2. The area to be irrigated is located on the eastern parcel of land and is 49 ha in size. It is adjacent to the land on which the Leewood water treatment plant is located.

3.2 Location

The irrigation site is located on the eastern half of Santos' Leewood block, approximately 24 km southwest of Narrabri on the Newell Highway. The property borders the Pilliga State Forest on the south and west boundaries. It is bounded on the southwest corner at MGA 55, 751072 E, 6622328 S and northeast corner at MGA 55, 752849 E, 6623255 S.

3.3 Climate

Australian Bureau of Meteorology records from January 1963 to April 2013, Narrabri post office [station 053030] were utilised to develop the climate statistics for this project (Bureau of Meteorology, 2014). The climatic regime is characterised by a slightly summer dominated rainfall pattern, with almost half the annual rainfall (46%) falling between November and February. Over the 50-year period mean annual rainfall at nearby Narrabri was 644 mm whereas annual mean pan evaporation was 1,966 mm. Evaporation exceeded rainfall in all months (Figure 1).



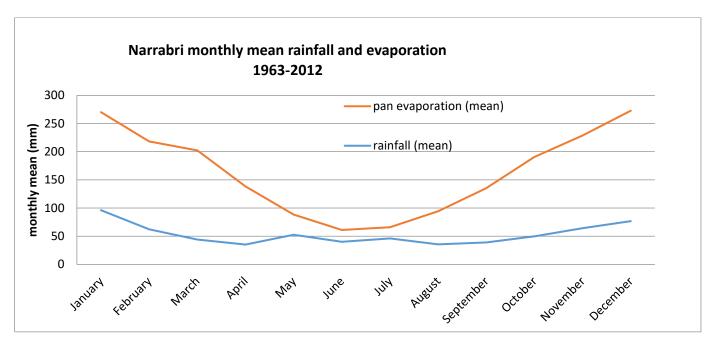


Figure 1. Mean rainfall and evaporation at Narrabri NSW (1963 - 2012)

3.4 Geologic setting

The surficial geological layer of the majority of the site is described as being Quaternary colluvium and/or residual deposits, and comprise talus, scree and sheet wash. The southwest corner of the parcel is mapped as a Cainozoic sand plain, and may include some residual alluvium. It is sand dominant, also containing gravel and clay (Geoscience Australia, 2005). Siliceous sands are dominant components of the parent material forming the soils, and consequently all the soils described at the site presented coarse sand fragments that were easily distinguishable by feel in most horizons.

3.5 Topography

The site is relatively flat, with elevations ranging from 245 m to 249 m above mean sea level (AMSL). The median slope for the irrigation area is 0.4%. The minimum slope for the area is 0.2% and maximum slope is 1.2%. The steepest slope drains a small catchment northeast toward the Newell highway and Bohena Creek. This corner also presents the best drained soils. The land rises away slightly from this corner towards the southwest, then slopes down toward a minor depression forming the drainage line that flows across the parcel from the southeast corner to the middle of the western boundary. Most of the property drains toward the northwest and overland flow enters from the southeast corner of the parcel.

3.6 Limitations of landscape

The site has been assessed for irrigation in accordance with the NSW Government's Guideline *Use of Effluent by Irrigation* (DEC, 2004)(the Effluent Guidelines). Table 1 below is an extract from Table 2.1 of the Effluent Guidelines. The slopes on this site present no limitations for sprinkler or drip irrigation whilst occasional flooding or inundation of the lower elevations present a moderate limitation. The minor drainage line is considered a severe landform limitation according to the Effluent Guidelines because of the potential for erosion and waterlogging (DEC, 2004). A mitigation strategy is proposed for selectively irrigating this area. There are no surface outcrops of rock to interfere with irrigation of this property.



Table 1. Landscape limitations for irrigation technologies- extract of Table 2.1 from the NSW Effluent Guideline (DEC, 2004)

	75	<u></u>		
Property 1	Nil or Slight	Moderate	Severe ²	Restrictive Feature
Slope (%) (for following irrigation methods)				17)
 flood/surface/ underground 	< 1	1–3	> 3	excess runoff and erosion risk
– sprinkler	< 6	6-12 ³	> 123	
- trickle/microspray	< 10	10-20 ³	> 203	
Flooding	none or rare	Occasional	frequent	limited irrigation opportunities
Landform	crests, convex slopes and plains	concave slopes and foot-slopes	drainage lines and incised channels	erosion and seasonal water- logging risk
Surface rock outcrop (%)	Nil	0–5	> 5	interferes with irrigation and/or cultivation equipment; risk of runoff

Source: Based on Hardie and Hird (1998), NSW Agriculture, Organic Waste Recycling Unit

- Notes: 1. Careful consideration should also be given to potential impacts on groundwater (see 2.6 Groundwater).
 - Sites with these properties are generally not suitable for irrigation.
 - 3. Slopes over 12% may be acceptable provided runoff and erosion risks are identified in the site selection process.

Vegetative cover

The property is primarily covered with low quality pasture grasses. Approximately 150 medium to large scattered woodland trees were identified on the eastern land parcel. Ninety of these trees were cleared from the 49 ha irrigation area in late November 2016, in accordance with the activity approval, to prepare the site for irrigation. The remaining trees outside of the 49 ha irrigation area have been retained.

Soil descriptions 3.8

The soils were initially grouped into "soil units" based on similarities in morphology, chemistry and management requirements (McDonald, Isbell, Speight, Walker, & Hopkins, 1990). Five soil units were defined for the Leewood property. Figure 2 provides the soil type distribution across the eastern land parcel including the 49 ha centre pivot irrigation area.

Red Chromosol soil unit is a friable brown loam over a friable red clay loam, well drained, and chemically and physically amenable to root growth. It covers approximately 1 ha in area.

Brown Chromosol soil unit is a friable brown loam over a hard brown clay, moderately drained, and moderately chemically and physically amenable to root growth. It covers approximately 4 ha in area.



Transitional Brown Sodosol soil unit is very similar to the Brown Sodosol unit for most of its properties (see description below). The soils of this unit were shallower than the other Sodosol units, with a sandstone parent material encountered at around 120 cm. It covers approximately 6 ha in area.

Brown Sodosol soil unit is a hardsetting brown sandy clay loam (or clay loam, sandy) over a very hard columnar brown clay, well drained in the 15 cm or so of loam at the surface, changing sharply to much lower porosity clay upon which water perches for extended periods following heavy rainfall (remaining saturated for several days to a week). Root growth often extends to 1.5 m, but is restricted by the coarse soil structure and moderate salinity of the subsoil, particularly below 1 m. It comprises approximately 58 ha in area.

Grey/Brown Sodosol soil unit is similar to Brown Sodosol unit, but with the following distinctions: often a thicker surface soil, possibly built up from erosion off the up-slope soils, usually with a distinctly bleached subsurface horizon above the coarsely structured subsoil. The subsoil is grey or grey brown, indicating poorer drainage than the other soil units. However, it appears this is due just to landscape induced inundation i.e. due to drainage line flooding, rather than to lower internal permeability of the soil. Root development and clay structure are similar to the other Sodosols, indicating that the landscape effect is more important than differences in soil morphology. These cover approximately 31 ha in area.

All five soil units shared the characteristics of being loamy and acidic in the surface grading to less acidic below the surface horizon with most becoming near neutral in the subsoil. Plant nutrients phosphorus, potassium and sulphur are marginal to deficient. Phosphorus buffering, estimated from soil type and surface texture, were moderate in the soil surface and high in the subsoil.

The majority of the soils were identified as "Magnesic Mesonatric Grey or Brown Sodosols; medium, non-gravelly, clay loamy/clayey, deep" according to the Australian Soil Classification (Isbell, 2002).

The soils in the northwest corner of the property tended to be shallower with most presenting a sandstone parent material within 1.2 m. Only about 11 ha consisted of these soils, with 6 ha of Brown Sodosols, and the remaining 5 ha being Red or Brown Chromosols- "Mottled, Mesotrophic Brown or Red Chromosol; medium or thick, non-gravelly, loamy/clay loamy, deep".

For the purposes of the irrigation design, the soils on this site were further grouped into two irrigation management classes – A and B. These were differentiated primarily due to their landscape position and susceptibility to inundation.

- Class A soils: Chromosols and Brown Sodosols more upland soils
- Class B soils: Grey/Brown Sodosols lower lying soils



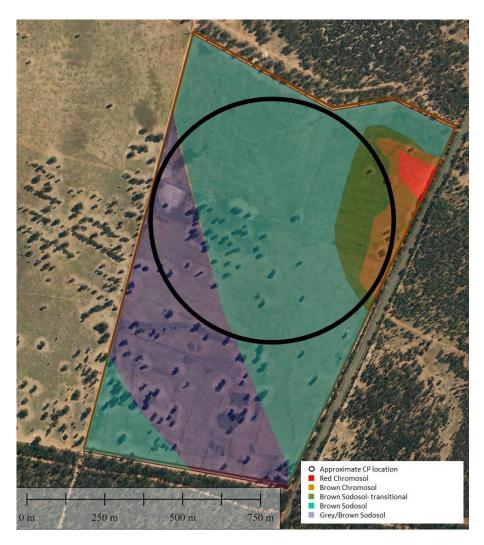


Figure 2. Soil type distribution across centre pivot irrigation area

The irrigation system design and operations would treat these as different management zones. The irrigation infrastructure, cropping and irrigation scheduling would vary according to the irrigation management class requirements as specified within the management plan.

3.9 Soil amelioration

The majority of the landscape to be irrigated is located on Sodosol soils. In accordance with the REF, the soils have been ameliorated using a combination of deep ripping and gypsum to improve soil permeability and surface condition. Additionally, agricultural lime was applied to neutralise surface acidity and to supply supplementary calcium, and fertiliser was added to improve crop vigour. Further soil amelioration and fertiliser applications will be based on the results of crop growth and soil monitoring (Appendix A).

4 Water supply for irrigation

4.1 Water volume

Produced water from wells will be collected in holding ponds at Leewood and treated by reverse osmosis (RO) technologies. The RO plant will produce 1 megalitre per day (MLD) (365 ML/yr) of permeate water (treated water) which will be available for irrigation. The irrigation system has the capacity to utilise up to 6.5 MLD, with this volume incorporating approximately 49 ha of irrigation at a maximum of 12 mm on the ground per day, with a 90% irrigation system application efficiency. Treated water availability would be limited to 6ML per day based on plant capacity and storage volumes, with treated water to be stored in the 5ML tank during periods when irrigation is not being undertaken. There is also additional system buffer capacity in the Leewood ponds in the event that irrigation is precluded.

4.2 Water quality

Expected treated water quality data, following calcium chloride dosing to amend the sodium adsorption ration (SAR), was provided in the REF and is replicated below (Table 2). The extensive suite of the expected treated water quality parameters is also provided as Appendix D of the further information provided for the REF, dated 5 June 2015. It is replicated in Appendix C of this Plan.

Table 2. Expected treated water quality¹

Parameter	Expected treated water ²
рН	6-8.5
TDS (mg/L)	<650
Salinity (dS/m)	1.0
Turbidity (NTU)	<1
SAR	<5
Calcium (mg/L)	52
Magnesium (mg/L)	0.04
Sodium (mg/L)	131
Potassium (mg/L)	7
Ammonia-N (mg/L)	6
Boron (mg/L)	0.7
Alkalinity (mg/L CaCO ₃)	262 ³
Chloride (mg/L)	120
Fluoride (mg/L)	0.3
Sulfate (mg/L)	0.0
Total N (mg/L)	<20
Total P (mg/L)	<0.05
Silica (mg/L SiO ₂)	0.9

¹ The water chemistry presented here is from the 90th percentile of that expected to come from the treatment process, that is, 90% of the water produced will be of a better quality

Chemical dosing may be required prior to irrigation to reduce the bicarbonate content. The water chemistry in Table 2 was calculated to have a Langelier saturation index of up to 1.1 (Ayers & Westcot, 1976), indicating the likelihood of calcium precipitating. Potential impacts include calcite scaling inside pipes and pumps, blockage of emitters, and elevated SAR. The adjusted SAR based on calcium lost to precipitation was 7.1 (Ayers & Westcot, 1976). Reducing the bicarbonate level of any amended waters to below 100 mg/L (83.3 mg/L of alkalinity as CaCO₃) would maintain a SAR less than 5, and would reduce the



² Treated water following calcium chloride dosing, prior to sulphuric acid dosing.

³ The alkalinity expressed as CaCO3 is approximately equivalent to bicarbonate of 314 mg/L.

risk of scaling. Based on the expected treated water quality this would require the addition of 175 mg/L of 100% sulphuric acid. The addition of the acid produces sodium sulphate, water and carbon dioxide, and results in a slightly lower total dissolved solids (TDS) of approximately 607 mg/L.

The bicarbonate levels of the water in the storage tank would be periodically sampled and measured by inhouse titration. The titration curves would be used to calibrate the threshold pH required to reduce bicarbonate to below 100 mg/L, which would occur prior to the treated water entering the irrigation system. The dosing rate would be regulated using an in-line pH electrode and EC meter.

4.3 Suitability for irrigation

The treated water would be classified as "medium strength effluent" according to Table 3.1 of the NSW Effluent Guidelines, only because it was just ranked as medium in the TDS concentration criterion of 600-1000 mg/L (DEC, 2004). It would be classified as 'low strength' with respect to other parameters. The treated water is unlikely to contain heavy metals or organic compounds as these are either not present or present in very low concentrations, and are relatively coarse materials that would be rejected by membranes in the treatment process. As a result of the treatment, the water properties would be of a high quality, more analogous to that used by conventional agricultural irrigators than that of effluent (ANZECC and ARMCANZ, 2000). The treated water meets all of the relevant ANZECC irrigation guideline values for short term irrigation (up to 20 years).

5 Irrigation design

The approved concept irrigation design combined centre pivot fitted with variable rate irrigation (VRI) technology and subsurface drip irrigation (SDI) systems to irrigate up to 97.8 ha. Due to operational requirements, Santos now plans to install the centre pivot irrigation system only. This would enable the irrigation of approximately 41 ha of Class A soils and 8 ha of Class B soils. The centre pivot system allows irrigation to occur across the entire irrigation area or on specific sections (units) at a time depending on crop requirements, localised soil conditions and water availability. The rate of irrigation can also be varied across the irrigation area based on requirements and conditions.

6 Operations and maintenance guidelines

The irrigation system infrastructure consists of a storage tank, pump, generator, filter, pipelines, valves, and a centre pivot distribution network. Table 9 and Table 10 in Appendix B outlines the monitoring and reporting requirements for these system components.

7 Irrigation scheduling and review of water balance

The irrigation schedule will be driven by crop water demand and availability of treated water. The HowLeaky model (McClymont, Freebairn, Rattray, & Robinson, 2011) parameters used in the concept design report were set so that irrigation was triggered once a 50 mm soil water deficit (SWD) occurred, and that 12 mm would be applied in an irrigation event. This forms the basis for the commencement and cessation of irrigation, subject to water availability. Irrigation of the Class B soils between the months of



October and May would be prioritised. This would allow the Class A soils to increase their soil water deficit, improving their ability to receive water when the Class B soils may be too wet to irrigate. Irrigation may be reduced on the Class B soils between June and September when evapotranspiration (ET) is low and the soils are most susceptible to overland flow from high rainfall.

An onsite weather station will record rainfall, temperature, solar radiation and wind speed. The collected data will be used to calculate evapotranspiration (ET) for that location.

Soil moisture monitoring devices will be set out as shown in Figure 4 and reviewed regularly against the weather station data. Irrigation rates will be adjusted by soil and crop type to optimise crop health and water use. The soil moisture monitoring devices will be placed at least 150 cm below ground surface (bgs) to estimate root uptake of moisture and deep drainage.

The irrigation schedule will utilise soil water sensor data along with irrigation, ET and rainfall data to develop a water balance record.

After a year of irrigation related data has been collected, the concepts and parameters used to predict and model the water balance and water utilisation potential of the system will be reviewed and evaluated using the measured water balance data. This may be repeated on an as needs basis as new water balance data is collected.

8 Agronomy

A healthy, actively growing crop is required to utilise the treated water. Monitoring and reporting requirements for the crop are found in Table 10 of Appendix B.

The crop should be inspected for weeds, pests and diseases, health and vigour by a suitably experienced person. This should include making recommendations for harvest timing. This should optimise forage quality and minimise soil compaction and weed distribution. The suitably experienced person would also make recommendations for the crop rotation sequences suitable to the goals of the project. Two transects of the surface 10 cm of topsoil should be sampled annually and the soil analysed for nutrients, SAR_e, pH_{1:5} and EC_{1:5}. One transect will be across the Class A soil area, and the other will be across the Class B soil area. For each transect, 20 to 30 cores will be collected then mixed together (composited) into a single sample for analysis. This data will provide the basis for ongoing fertiliser and amendment applications.

9 Environmental monitoring

It is expected that given the high soil water deficit schedule being applied under normal irrigation system operation that runoff and deep drainage will be predominantly driven by rainfall, and will not be highly altered from conditions under a dryland pasture regime. The water balance modelling suggests there will be small amounts of deep drainage beyond the root zone under irrigation as with the current pasture condition. Soil, vadose and groundwater monitoring will be undertaken as set out below.



9.1 Groundwater monitoring

Three groundwater monitoring bores were in place on the Leewood property prior to this irrigation project, which, in accordance with the conditions of the EPL, monitor standing water levels and groundwater quality. Quarterly monitoring and on-site analysis of Redox potential, pH, standing water level, dissolved oxygen and electrical conductivity is undertaken, whilst a broad suite of water quality parameters are tested for on a six monthly basis. In order to monitor for any changes during the irrigation activities, three additional monitoring bores were installed on the property. These three new bores are indicatively located as set out in Figure 3 and were screened in the first groundwater encountered.

The most easterly bore was installed approximately 120 m west of where it was indicated to be located in the REF. However, it remains within the landscape that slopes down toward Bohena Creek, and is still closely associated with the more freely drained soil units.

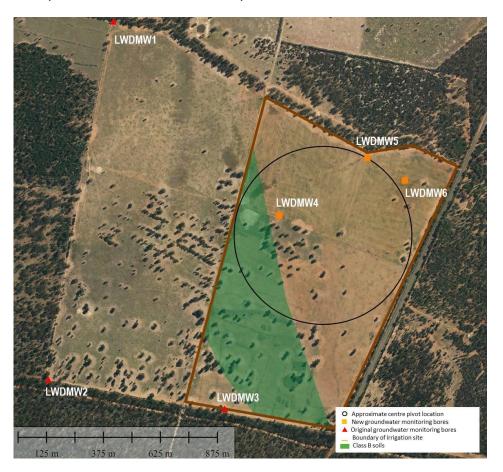


Figure 3. Locations of groundwater monitoring bores

Total depth and screened interval of groundwater monitoring bores installed in irrigation area.

Groundwater Monitoring Bore ID	Total Depth (mbgl)	Screened interval (mbgl)
LWDMW4	35	28-35
LWDMW5	35	29-35
LWDMW6	34	26-34



Monitoring will be undertaken consistent with the existing groundwater monitoring at the site, as described above. Table 7 provides details on groundwater monitoring in the event of changes to groundwater salinity outside of the expected range.

9.2 Soil and vadose monitoring

Four soil moisture and EC sensors would provide continuous monitoring and would be installed across the irrigation area, with approximate locations provided in Figure 4. The locations where the sensors are located are representative of the soil types and landform, and are spaced to assess a range of points along the pivot span. Given the reduced scope of the irrigation activity at this time relative to that assessed in the REF, the four soil monitoring locations provide adequate coverage for the centre pivot irrigation activity, and reflect the original number of bores proposed for the centre pivot area.

The soil moisture probes provide regular measurements of soil moisture, salinity, and temperature. The sensors utilize capacitance based technology to provide near continuous measurements within the soil profile. By creating a high frequency electrical field around the sensor, extending through the access tube into the surrounding soil, the sensors detect the changes in dielectric constant, or permittivity, of the soil over time. The power to each of the sensors and its data collector is supplied by a small solar panel system integrated on a pole with its data collector. The data collected is sent to a base server which can be accessed by the operator.

The sensors would measure moisture content and salinity of the rootzone and into the vadose, from the soil surface to at least 150 cm below the surface. The derived data would be used to estimate the volume and rate of water moving through the soil and vadose. Based upon monitoring bore log data describing the vadose beneath the rootzone, potential impacts to groundwater could then be estimated by hydrogeological modelling.



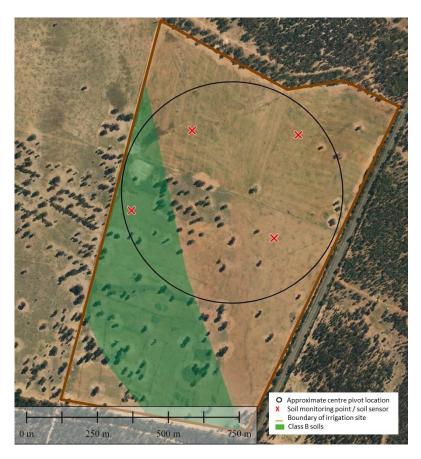


Figure 4. Indicative locations of the soil monitoring points.

A soil sampling program will be undertaken that utilises four benchmark testing zones representing various soil types and positions on the landscape. A zone would be located within a 25 m radius of each of the soil sensors. These zones would then be cored to a depth of 3 m. Three cores would be advanced per zone annually and composited by depth. That is, within 25 m of each probe, three cores will be dug to extract samples from 0-25 cm, 25-50 cm, 50-75 cm, 75-100 cm, 100-200 cm and 200-300 cm. The three samples from each core that are from the same depth will be mixed together prior to being send for analysis. The core holes should be plugged with bentonite chips to prevent water from running into the holes and skewing future results. The six composited samples would be analysed for pH, EC_e, SAR_e, and ESP on an annual basis, or as otherwise required in accordance with EPL monitoring requirements.

Visual inspections of the landscape would be made regularly to identify any areas of waterlogging or ponding, as well as to assess crop health and irrigation evenness.

9.3 Native vegetation monitoring

The Brigalow woodland and Pilliga Box –White Cypress grassy open woodland native vegetation communities located on the northern boundary of the site would be monitored to ensure no adverse impacts occur as a result of irrigation activities (Tables 10 and 16). A baseline condition survey would be undertaken prior to commencement of irrigation, and visual monitoring of vegetation undertaken on a quarterly basis in accordance with Table 8 of Appendix A.

As a part of the irrigation design to protect the native vegetation, a ten metre buffer would be left between the irrigated land and the native vegetation. Potential for sprinkler mist to affect the native vegetation



would be minimised by using low pressure drop nozzles operating at approximately 100 cm above the ground. VRI would allow for the shutdown of various spans or individual nozzles in susceptible areas. Regular visual inspections along the boundary of the sprinkler system would be undertaken. An automated control system would be linked to an anemometer indicating wind speed and direction to allow programmed shut down of the system if necessary.

10 Operations, maintenance and monitoring schedules

A set of inspection and maintenance schedules have been developed for the operation of the irrigation system. Table 9 and Table 10 summarise the inspections and maintenance required under this IMP. Irrigation plant and equipment will be operated and maintained in a proper and efficient manner.

11 Triggers for alternative actions

Monitoring of the crop, soil, landscape, native vegetation and groundwater have been related to measurement thresholds that will trigger a change in monitoring intensity and/or operational actions. The trigger action response plans (TARP) located in Appendix A outline the threshold triggers for measurements of crop health (Table 3), waterlogging (Table 4), soil salinity/sodicity (Table 5 Table 6), groundwater (Table 7) and native vegetation health (Table 8).

12 Annual report on irrigation operations

On an annual basis from the commencement of irrigation operations an Annual Irrigation Summary Report will be prepared. The report will contain summary information on:

- Weather conditions at the site, including rainfall and evapotranspiration
- Volume of water irrigated
- Irrigation system operations and maintenance
- Treated water dosing
- Soil amelioration activities
- Groundwater monitoring
- Soil moisture and soil sample monitoring
- Native vegetation monitoring
- Crop health, yield, and associated agronomic activities
- Review and refinement of a water balance for the activity

The inspection and monitoring activities tabled in Appendices A and B will provide the data upon which the above reports will be based.



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Appendix A – Trigger Action Response Plans

Table 3. Crop decline in health

TRIGGER LEVEL	TRIGGER	ACTION	CAUSE	RESPONSE	NOTES
		Crop decli	ne in health		
Normal operations	>70% green cover.	Regular field inspection.	n/a	No response necessary.	Pasture health should be assessed by a suitably experienced person. Some
Trigger level 1	40-70% green cover.	Inspect crop for cause of decline. Investigate potential causes. Adjust irrigation schedule commensurate with reduced ET.	Disease	Seek agronomic advice. This may require alteration of cultural practices, varietal selection, crop rotation or chemical treatment.	seasonal variations in pasture performance and cover do not necessarily reflect a problem with the irrigation system. Green cover may be assessed using a quadrant or defined area assessment approach, or other method consistent with that used in operations of a
			Drought	Assess whether recovery will occur once irrigation commences.	
			Waterlogging	See TARP below	similar size and nature.
			Salinity	See TARP below	
			Species suitability	Monitor for further decline. Plan rotation to more suitable variety or species.	



Trigger level 2	<40% green cover.	Inspect crop for cause of	Disease	Seek agronomic advice and	
		decline. Investigate potential		respond as above.	
		causes. Adjust irrigation			
		schedule commensurate with	Drought	Irrigate if water is available.	
		reduced ET.	Waterlogging	See TARP below	
			Salinity	See TARP below	
			Species suitability	Renovate with more suitable	
				crop.	



Table 4. Waterlogging- surface ponding and runoff

TRIGGER LEVEL	TRIGGER	ACTION	CAUSE	RESPONSE	NOTES			
		Waterlogging- surface	ce ponding and runoff					
Normal operations Trigger level 1	Surface ponding and runoff are similar to conditions outside of the irrigation site. Surface ponding and runoff as a result of irrigation activities are noticeably higher than outside of the irrigation site.	Assess infiltration rates and instantaneous application rates of emitters/sprinklers. Check soil moisture status of soils to 60 cm.	Normal landscape response to rainfall. Application rate exceeds infiltration rate.	Alter the instantaneous application rate of the emitters/sprinklers. Use minimum till ripper on sprinkler irrigated land to	The irrigation schedule is set so that under normal conditions no irrigation occurs until a 50 mm SWD is achieved. This means that the soil is unlikely to become waterlogged unless rainfall also occurs, or instantaneous application rates are too high.			
			Water applied exceeds water holding capacity of soil.	improve infiltration. Cease irrigating all units above SWD trigger.	Some irrigation above a 50mm SWD may be required for rare events, such as applying a leaching fraction.			
			Off site and on-site flows into drainage line.	Cease irrigating Class B soils.				
Trigger level 2	Persistent surface ponding and runoff, lasting more than one week, are several times higher than outside of the irrigation site.	Cease irrigating until SWD is reached across the entire irrigation unit.	Soil surface waterlogged from a combination of rainfall and irrigation.	Review irrigation schedule. Use soil water monitoring data to identify potential perched water layers within the soil profile.				



Table 5. Excessive salinity in soil

TRIGGER LEVEL	TRIGGER	ACTION	CAUSE	RESPONSE	NOTES			
Excessive salinity in soil								
Normal operations Trigger level 1	Weighted average rootzone (to 60 cm below surface) ECe remains similar to target salinity threshold of 2-4 mS/cm. Weighted average rootzone (to 60 cm) ECe is 4-8 mS/cm.	Carry out additional hand auger sampling to depths of 60 cm in areas where crop appears affected. 60 cm represents the rootzone area with the highest concentration of roots. Sample each horizon encountered and test for ECe	n/a Insufficient leaching of salts. Non-representative field sampling. Laboratory error.	No response necessary. Observe crop health. Resample and /or retest soil. If a period of high rainfall/low ET occurs, consider applying a leaching fraction irrigation event.	The five soil water monitoring sensors will provide an indication of trends in soil salinity. Additional and more regular soil monitoring using a hand auger will assist in locating more localised salinity trends, as well as assisting in estimating soil water status.			
Trigger level 2	Weighted average rootzone (to 100 cm) EC _e greater than 8 mS/cm.	and pH Carry out additional hand auger sampling to depths of 100 cm in areas where crop appears affected. 100 cm represents the major rootzone of the crop. Sample each horizon encountered and test for ECe and pH	Insufficient leaching of salts. Non-representative field sampling. Laboratory error.	Resample and /or retest soil. Cease irrigation until a period of low ET, then apply a leaching fraction calculated to remove excess salt. Resample soil following leach.				



Table 6. Excessive sodicity in soil

TRIGGER LEVEL	TRIGGER	ACTION	CAUSE	RESPONSE	NOTES			
		Evcessive s	odicity in soil					
	Excessive sodicity in soil							
Normal operations	SAR in the surface 40 cm remains at amended levels of below 8.	Soil monitoring program.	n/a	No response necessary	Sodicity of the soil will be assessed using SAR _e , which is approximately analogous in its numeric thresholds and			
Trigger level 1	SAR in surface 40 cm between 8 and 15.	Carry out additional hand auger sampling to depths of 100 cm in areas where crop appears affected.	Insufficient / ineffective calcium amendment. Non-representative field sampling. Laboratory error.	Resample and /or retest soil. Apply gypsum to the soil at a rate calculated to reduce soil SAR to <6. Irrigation may continue in order to assist gypsum incorporation into soil profile.	interpretation to ESP. Between the range of 0 and 40, SAR _e is approximately numerically equivalent to ESP, and it has the advantage over ESP in not being confounded by soluble and sparingly soluble salts in the soil,			
Trigger level 2	SAR in surface 40 cm >15.	Carry out additional hand auger sampling to depths of 100 cm in areas where crop appears affected.	Insufficient / ineffective calcium amendment. Non-representative field sampling. Laboratory error.	Resample and /or retest soil. Apply gypsum to the soil at a rate calculated to reduce soil SAR to <6. Irrigation may continue in order to assist gypsum incorporation into soil profile. Apply additional gypsum to soil to further offset sodium in irrigation water.	including gypsum and calcite. Amending soil SAR with gypsum will also moderate pH to less than 8.5. If soil pH in calcium chloride is less than 5, apply equivalent agricultural lime for half of gypsum requirement calculated.			



Table 7. Excessive salinity in groundwater

TRIGGER LEVEL	TRIGGER	ACTION	CAUSE	RESPONSE	NOTES				
	Excessive salinity in groundwater								
Normal operations	Groundwater salinity (TDS/EC)	Normal monitoring	n/a	No response necessary.	It is possible to cease or				
Normal operations	remains consistent with range	Normal monitoring	11/ 0	No response necessary.	reduce water production by				
	of natural variation.				varying output or shutting				
					down the reverse osmosis				
Trigger level 1	Groundwater salinity (TDS/EC)	Analyse and evaluate local	Sampling or analysis error or	Continue monitoring. If	plant, with the treatment				
	level outside expected range	regional groundwater data.	anomaly.	adverse trend (min. three	plant remaining shut down				
	based on regional			monitoring events) develops,	until there is capacity available				
	groundwater salinity levels			trigger level 2.	for irrigation to recommence.				
	- single monitoring event.	Undertake additional review	Regional variation in		Does and attended to the high containing				
	Single monitoring event.	(over next two monitoring	groundwater salinity caused		Pre-existing salts held within				
		events) to determine whether	by natural / seasonal		the vadose may be a source of high salt loads available to				
		possible adverse trend	fluctuation.		ground water. The increased				
		developing.			deep drainage from the				
					irrigation system may hasten				
			Increased localised recharge		the rate of vadose salts				
			from an unknown high		entering groundwater.				
			permeability zone within the						
			irrigation area.						
Trigger level 2	Groundwater salinity (TDS/EC)	Analyse and evaluate local and	Regional variation in	Assess irrigation management					
	levels trending adversely in	regional data.	groundwater salinity caused	strategy and identify					
	comparison to regional		by natural / seasonal	contributing factor/s to					
	groundwater levels.		fluctuation.	adverse localised trend in					
				groundwater salinity.					



T	T		
Undertake additional			
monitoring to confirm adverse		Implement any change to	
trend is localised in nature.			
		irrigation management	
		strategy to reduce effects of	
Investigate course of the		adverse trend.	
Investigate source of the			
elevated salinity and any			
potential effects.		Undertake a risk assessment	
		to determine physical extent	
		of adverse salinity trend in	
		groundwater and determine	
		whether increased salinity will	
		have a negative effect on	
		surrounding beneficial	
		groundwater uses.	
		Undertake notification in	
		accordance with regulatory	
		requirements.	
		Continue monitoring.	
1			

Table 8. Health of Brigalow woodland and Pilliga Box – White Cypress grassy open woodland native vegetation communities on northern boundary

TRIGGER LEVEL	TRIGGER	ACTION	CAUSE	RESPONSE	NOTES
	Heal	th of native vegetation con	nmunities on northern bou	ndary	
Normal operations	Vegetation health stable	Quarterly monitoring, including potential for sprinkler mist from the irrigation system to impact vegetation.	n/a	No response necessary	The centre pivot system will be designed to use low pressure nozzles, and to operate at approximately 100cm above the ground. VRI
Trigger level 1	By comparison with baseline conditions, reduced growth of vegetation or visible signs of stress, such as: • wilting • yellowing leaves • crown thinning • defoliation • epicormic growth • dead patches on leaves (particularly at margins and tips) • increase in presence of salt tolerant species • salt crystal accumulation on vegetation or soils	Assess cause of stress/damage. Assess sprinkler mist from pivot. Inspect foliage for salt scalding. Hand auger soil to determine moisture content, pH and ECe in the A and B21 horizons.	Natural/seasonal event such as drought, above average rainfall, insect pressure, etc. Excessive sprinkler mist affecting foliage. Subsurface and above ground runoff introducing excess soil water and salts.	Continue monitoring and visual assessment of vegetation. Adjust sprinkler nozzle parameters as required. Alter irrigation schedule in the irrigation units adjacent to the vegetation. Build a low diversion bund to redirect any run-on.	will allow spans that are close to sensitive areas to be shut down if required. Irrigation activities will be able to be changed or shut down in response to changes in weather conditions if necessary. In a triggered event an ecologist would undertake an assessment and provide recommendations for a response appropriate to the magnitude of the event, such as propagation, revegetation, seed collection etc.



Trigger level 2	By comparison with baseline	Assess cause of vegetation	Natural/seasonal event such	Continue monitoring and
	conditions, death of dominant	death. Assess sprinkler mist	as drought, above average	visual assessment of
	trees and/or understory	from pivot.	rainfall, insect pressure, etc.	vegetation.
		Inspect foliage for salt scalding		
		Hand auger soil to determine	Excessive sprinkler mist	Adjust sprinkler nozzle
		moisture content, pH and ECe	affecting foliage	parameters as required
		in the A and B21 horizons.		Consider using drop tubes to
				bring irrigation closer to the
				ground.
			Subsurface and above ground	Cease irrigation in the
			runoff introducing excess soil	adjacent area until soil dries
			water and salts.	back to background levels.
				Once this has occurred, alter
				irrigation schedule in the
				irrigation units adjacent to the
				vegetation prior to
				recommencement of irrigation
				in the adjacent area



Appendix B —Inspection and maintenance of irrigation operations that will provide data for the annual report

Table 9. Irrigation plant and equipment– Data collection, inspection & maintenance

Irrigation plant and equipment- Data collection, inspection & maintenance

Item	Description
Irrigation plant and equipment- general	All Irrigation plant and equipment will be operated and maintained in a proper and efficient manner.
Flow rates	Review recorded daily total flow to CP. Water flow meters should be checked for accuracy against the design flow rate.
Pipe work leaks	All pipe work must be inspected for any signs of leakage.
Filtration units	The mesh (CP) filter must be periodically cleaned. This filter will backflush automatically and backflush interval and backflush time should be checked to be effective. Time between backwashes can be seasonally adjusted as biological growth is more aggressive in warm, sunny periods and will often necessitate greater backwash frequency.
Chemical usage	Record volume of each chemical amendment injected.
Sensor feedback	Review electronic record of in-line sensors used to control inputs (EC, pH, ORP). Note in record average values and abnormal flux.
Sensor calibration	Clean and calibrate in-line sensors. This varies depending upon amount of fouling encountered and can vary seasonally with biological blooms.
Treatment distribution	Test water for treatment chemicals at post injection sampling port, e.g. pH, Cl ₂ .
Water quality	Periodically collect water sample post treatment from sampling port when irrigation system operating normally. Sample analysis to be
analysis	included would be pH, EC, calcium, magnesium, sodium, carbonates, chloride and sulphate.



System flush	This includes flushing of mainlines, secondary filters, submains, laterals, CP and flushing manifolds. Flushing events may be required periodically due to build-up of sediments in lines coming from suspended solids in water, suction of soil particles, chemical precipitation (scaling) and biological activity.
Variable rate	Ensure digital watering maps match up with the soil variation and crop grown. Ensure CP travel speed and nozzle cycle time change as
irrigation (VRI)	per the watering map when observing pivot operation in field. Check GPS functionality. Check results with an emission uniformity catch can test.
Application rate	In systems without VRI, determine the volume applied per irrigation event by using the water meter reading and hours run. Check the application rate (mm) against the scheduled amount as per the speed application chart.



Table 10. Agronomic & Environmental – Data collection and inspection

Agronomic & Environmental – Data collection and inspection

Item	Description
Crop stage	Inspect paddocks for growth stage of each species. Predict harvest dates.
Irrigation schedule	Electronically collect soil moisture and salinity data throughout the profile from five in-field sensors placed within and beneath the active rootzone. Schedule irrigations after SWD trigger is reached. Review against available observations and data such as from past irrigation, weather station data, calculated ET and weather forecasts.
Infiltration and moisture assessment	Monitor infiltration and moisture in soil, consistent with typical irrigation practices. Perform hand auger soil cores near moisture probes to allow correlation to be determined between probes and actual measured soil moisture. This will assist in calibrating the probes for future use to reduce management. Also core more generally before and after an irrigation event (in front and behind the CP) to assess the irrigation schedule.
Pests	Scout for insects, weeds and plant diseases.
Soil surface	Inspect soil surface for signs of cracking, surface sealing, ponding or runoff. Use findings to assist in scheduling irrigation.
Soil sampling	Five locations cored to a depth of 3m with three repetitions at each location. Composited six layers analysed for nutrients (surface), pH, EC _e , SAR _e , ESP.
Groundwater	Sample groundwater monitoring bores and analyse for standing water level, on-site analysis of Redox potential, pH, dissolved oxygen and electrical conductivity.
Groundwater chemistry	Laboratory analysis for a broad water quality suite of chemical analyses
Erosion, ponding & runoff	Observe and note patterns of erosion, ponding and runoff during weekly agronomic inspections. Adjust irrigation schedules if necessary.



Native vegetation Visual inspections of condition of native vegetation communities on the northern boundary.



Appendix C – Expected treated water quality (excerpt from Leewood Produced Water Treatment and Beneficial Reuse Project REF).

Parameter	Units	Produced Water (90th percentile Design Basis)	Expected Treated Water Post RO Plant (90 percentile	ANZECC Irrigation Guideline Values (Short Term Values < 20 years)	Australian Drinking Water Guidelines 2011
Total Dissolved Solids (TDS)	mg/L	23,800	< 650	Crop Specific – Lucerne (1273 – 3015)	Health: not necessary Aesthetic as follows: <600 Good quality 600-900 Fair quality 900-1200 Poor quality >1200 unacceptable
pH		8.57	6-8.5	6 – 9	6.5-8.5
SAR		>100	< 5 (post amendment)	Crop Specific Lucerne (46 -102)	Not referenced
Bicarbonate (as calcium carbonate equivalent)	mg/L as CaC03	12,400	260	Not referenced	Not referenced
Carbonate	mg/L as CaC03	730	2	Not referenced	Not referenced
Total Alkalinity	mg/L as CaC03	12,600	262	Not referenced	Not referenced
Chloride (CI)	mg/L	2,100	< 100	Crop Specific – Lucerne (350 – 700)	Health: n/a (note 1) Aesthetics: 250
Sodium (Na)	mg/L	6,500	131	Crop Specific – Lucerne (230 – 460)	Health: Not necessary Aesthetic: 180
Sulphate (SO4)	mg/L	18	0.0	Not referenced	500
Calcium (Ca)	mg/L	15	< 50	Not referenced	Health: Not necessary Aesthetic as follows: < 60 soft 60-200 Good quality >200 increase scaling
Magnesium (Mg)	mg/L	9.2	0.04	Not referenced	Not referenced
Potassium (K)	mg/L	81	< 5	Not referenced	Not referenced
Strontium (Sr)	mg/L	4.6	< 0.02	Not referenced	Not referenced
Barium (Ba)	mg/L	15	< 0.1	Not referenced	2
Fluoride (F)	mg/L	6.4	< 0.3	2	1.5
Silica (SiO2)	mg/L	24	< 0.9	Not referenced	0.9
Boron (B)	mg/L	1.3	0.7	Crop dependent – Lucerne (4 – 6)	4
Iron (Fe, dissolved)	mg/L	0.52	0	10	< 1
Cyanide	mg/L	0.004	<0.001	Not referenced	0.08
Manganese	mg/L	0.18	~ 0.02	10	.5
Aluminium	mg/L	6.1	~ 0.02	20	Health: n/a (note 1) Aesthetics: 2
Ammonia	mg/L	16	6-10	Crop Specific as N (25 - 125)	Health: n/a (note 1) Aesthetic: 0.5
Nitrate as N	mg/L	0.10	< 0.1	Crop Specific (25 – 125)	50
Copper Sulphate	mg/L	0.14	< 0.01	5	2
Nickel Sulphate	mg/L	0.013	< 0.01	2	0.02
Arsenic	mg/L	0.036	< 0.01	2.0	0.01
Cadmium	mg/L	0.036	< 0.002	0.05	0.002
Mercury	mg/L	0.0015	< 0.001	0.002	0.001
Selenium	mg/L	0.054	< 0.01	0.05	0.01
Zinc	mg/L	0.15	<0.01	5	Health: n/a (note 1) Aesthetic: 3
Chromium	mg/L	0.04	<0.01	(see hexavalent chromium below)	0.05



Hexavalent Chromium	mg/L	<0.05	<0.01	1	Not referenced
Molybdenum	mg/L	0.0069	<0.005	0.05	0.05
Antim o ny	mg/L	0.0011	<0.001	Not referenced	0.003
Tin	mg/L	0.0027	<0.001	Not referenced	Not necessary
Uranium	mg/L	0.0007	<0.001	0.1	0.017
Lead	mg/L	0.013	<0.001	5	0.017
Beryllium	mg/L	0.001	<0.001	0.5	0.06
Cobalt	mg/L	0.0035	<0.001	0.1	Not referenced
lodide	mg/L	0.2	<0.05	Not Referenced	0.5
Lithium	mg/L	2.9	<0.1	2.5	Not referenced
Thallium	mg/L	0.0005	<0.0005	Not Referenced	Not referenced
Vanadium	mg/L	0.016	<0.01	0.5	Not referenced
Phosphorus	mg/L	0.63	<0.05	Crop Specific (0.8 to 12)	Not referenced

