Appendix G2

Concept irrigation design

Santos
We have the energy.

REPORT

IRRIGATION GENERAL CONCEPT DESIGN

NARRABRI GAS PROJECT

FOR SANTOS

10 NOVEMBER 2015

land and water stewardship

PRODUCED BY

BENETERRA PTY LTD

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Authorised signatory	Print name	Office	Date
	Glenn Bailey	Land Resources Leader	2015-10-26

EXECUTIVE SUMMARY

The Proponent is proposing to develop natural gas in the Gunnedah Basin in New South Wales (NSW), southwest of Narrabri. The primary objective of the Narrabri Gas Project (the project) is to commercialise natural gas to be made available to the NSW gas market to support the energy security needs of NSW.

The Narrabri Gas Project is located within the Namoi catchment and is concentrated around the Pilliga State Forest. The Project area is predominantly woodland vegetation associated with the Pilliga East and Bibblewindi State Forests. The surrounding area comprises dryland and irrigated agriculture and plantations with cotton being the major agricultural industry in the Narrabri Shire (Narrabri Shire Council, 2014). The catchment also supports broadacre cropping, sheep and cattle grazing.

Total water extracted from the coal seam targets is estimated to be approximately 37.5 GL over the 25-year assessment period. The estimated water volumes would peak during the early years of the project (around the first two to four years) at approximately 10 megalitres per day and then gradually decline over the life of the project. The long-term average would be around four megalitres per day, which is equivalent to 1.5 gigalitres per year, over the 25-year assessment period.

The environmental impact assessment for the irrigation activity has assumed the use of up to 12 ML of treated water per day. This ensures the peak production volumes are catered for and provides additional operational flexibility, given the estimated peak water production rate of approximately 10ML per day between years 2-4.

Based on the expected analyte concentrations of the treated water, the water would be classified as 'low to medium strength effluent' in accordance with Office of Environment and Heritage (NSW), previously the Department of Environment and Conservation (NSW), *Environmental Guidelines: Use of Effluent by Irrigation.*

To assess the viability of utilising treated water for irrigation in the vicinity of the Narrabri Gas Project area, an irrigable land survey was undertaken across an area within a 20 km radius of the proposed water treatment facilities and subsequently a concept irrigation design was developed.

Soils of the survey area comprise deep, uniformly-textured, cracking clays, dominated by Vertosol soils, and non-clayey surfaced soils, dominated by Sodosol soils. The survey identified 9,000 ha within a 20 km radius of the proposed water treatment facilities that were classified as suitable for irrigated crop development.

A number of crops were identified as possible candidates for irrigation in the region including cotton, wheat, grain sorghum, forage sorghum, oats and lucerne. Computer modelling using the HowLeaky modelling software was employed first to evaluate the different crop water demands, secondly to predict the storage capacity requirements and thirdly the surplus water volumes at the peak treated water rate of 12 ML/d.

Based on the outcomes of the scenario modelling, lucerne (as a perennial crop) was recommended for the Narrabri Gas Project irrigation strategy. Several annual crop rotations were also investigated as comparative options. The annual cropping options were all inferior to the perennial lucerne regarding water use capacity.

The HowLeaky modelling for the simulated irrigation strategy indicated that 200 ML treated water storage provided an acceptable capacity for perennial lucerne. Subsequent modelling using a nominal irrigation area of 500 ha indicated that an annual irrigation application rate of up to 750 mm (7.5 ML/ha-yr) would be possible with a 40% probability of a surplus arising each year during the initial peak production years. In order to reduce the probability and magnitude of a surplus during the initial peak water production years, additional suitably-irrigable land is available that could be brought under irrigated lucerne cropping, if required.

The maximum daily quantity of treated water which could be utilised by the irrigation of a nominal 500 ha site is calculated as 60 ML, although typically the stored volume in the off-site treated water pond would generally be low, precluding meeting of the full potential demand and only filling during wet periods when irrigation ceases. The occurrence of surplus treated water will be infrequent, with treated water able either to be used for irrigation or stored for 95% of days. Surplus treated water would be discharged to surface water systems in accordance with approval to be obtained by Santos. Should discharge to surface waters not be possible, produced water supply would be managed by Santos using upstream storage capacity.

Amendment of the treated water would be undertaken at the Leewood water management facility (WMF) to reduce the sodium adsorption ratio and make the treated water suitable for irrigation purposes.

Estimated salt loadings from the application of amended water to the land are predicted to be consistent with typical local irrigation salt loadings.

Groundwater depth beneath much of the irrigable land in the vicinity of the WMF is in the region of 20 m below ground surface. For the proposed perennial lucerne crop scenario, it would take approximately 500 years for applied treated water to reach the groundwater table and for the alternative wheat-cotton double crop rotation, approximately 50 years.

Monitoring of water quality to ensure consistency with the identified water quality parameters would need to be undertaken regularly. Monitoring of irrigation practices for the purposes of maintaining soil structure and soil quality and managing environmental impacts would also need to be a key consideration as part of the development of an Irrigation Management Plan for the irrigation site. In addition to monitoring environmental impacts, monitoring of the performance of the irrigation system should be undertaken to ensure that the system performs effectively and achieves the uniform distribution of treated irrigation water with minimal downtime. Monitoring requirements would be consistent with existing irrigation practices and would be developed as part of an Irrigation Management Plan that would respond to particular site conditions, and relevant environmental approval or regulatory requirements.

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ABBREVIATIONS

AHD	Australian Height Datum
BT	BeneTerra
cm	centimetre
CEC	cation exchange capacity
CP	centre pivot
CSG	coal seam gas
DM	dry matter
EC-	electrical conductivity
EC_e	electrical conductivity (saturated extract)
ESP	exchangeable sodium percentage
ET	evapotranspiration
ET_c	crop evapotranspiration
FAO	United Nations Food and Agriculture Organisation
ha	hectare
HDPE	high density polyethylene
IWUI	irrigation water use index
LSI	Langelier Saturation Index
L/hr	litres per hour
m	metre
NGP	Narrabri Gas Project
MIA	Murrumbidgee Irrigation Area
ML	megalitre
ML/d	megalitres per day
ML/yr	megalitre per year
ML/ha-yr	megalitres per hectare per year
mS/cm	millisiemens per centimetre
OM	organic matter
ORP	oxidation reduction probes
PAWC	plant available water capacity
pH	negative logarithm of hydronium ion
pH_w	soil pH measured from a 1:5 soil to water extract
REF	Review of Environmental Factors
RO	reverse osmosis
SAR	sodium adsorption ratio
SAR_{se}	sodium adsorption ratio from a saturated paste soil extract
SDI	sub-surface drip irrigation
SHC	saturated hydraulic conductivity
SOP	standard operating procedure
SWC	soil water content
t	tonnes
VFD	variable frequency drive
VRI	variable rate irrigation
WMF	water management facility
yr	year

1 INTRODUCTION

The Proponent is proposing to develop natural gas in the Gunnedah Basin in New South Wales (NSW), southwest of Narrabri. The primary objective of the Narrabri Gas Project (the project) is to commercialise natural gas to be made available to the NSW gas market to support the energy security needs of NSW.

The proposed gas field development will comprise production and appraisal wells, gas and water gathering systems and supporting infrastructure southwest of Narrabri, NSW. The natural gas produced would be treated at a central gas processing facility constructed by Santos.

Water extracted from coal seams during gas development will undergo water treatment and be utilised for beneficial use purposes. Beneficial use options in consideration by Santos include drilling and construction usage, dust suppression, stock watering, irrigation and managed release to surface water.

Total water extracted from the coal seam targets is estimated to be approximately 37.5 GL over the 25-year assessment period. The estimated water volumes would peak during the early years of the project (around the first two to four years) at approximately 10 megalitres per day and then gradually decline over the life of the project. The long-term average would be around four megalitres per day, which is equivalent to 1.5 gigalitres per year, over the 25-year assessment period.

The environmental impact assessment for the irrigation activity has assumed the use of up to 12 ML of treated water per day. This ensures the peak production volumes are catered for and provides additional operational flexibility, given the estimated peak water production rate of approximately 10ML per day between years 2-4.

To assess the viability of utilising treated water for irrigation in the vicinity of the Narrabri Gas Project area, an irrigable land survey was undertaken for the area within a 20 km radius of the proposed water treatment facilities. Literature review, site investigation and water use modelling were undertaken to inform the irrigable land survey comprising investigation of soil condition, water storage availability and crop suitability.

Based on the outcomes of the irrigable land survey, a concept irrigation design was developed. As a component of the concept irrigation design, crop water consumption, water storage requirements and potential soil limitations were identified. A conceptual layout and design of irrigation infrastructure was undertaken and an operations, maintenance and monitoring program developed.

This report details the outcomes of the irrigable land survey and general concept irrigation design for the Narrabri Gas Project.

1.1 SCOPE OF WORK

The scope of work comprised the identification of suitable irrigation land within a 20 km radius of the proposed water treatment facilities and the development of a concept irrigation design for utilisation of treated coal seam gas water produced during gas development. The irrigation strategy will be developed within a 20 km radius of the proposed water treatment facilities with preference given to land parcels located closer to the Leewood facility in order to reduce the distance required to pipe treated water.

The general concept irrigation design was developed based on a peak treated water application of 12 ML/d.

The irrigable land survey and general concept irrigation design were developed in accordance with the Office of Environment and Heritage (NSW), previously the Department of Environment and Conservation (NSW), *Environmental Guidelines: Use of Effluent by Irrigation* (DEC Guidelines).

The guidelines outline management practices for the design and operation of effluent irrigation strategies with the aim of reducing risks to the environment, public health and agricultural productivity.

1.2 METHODOLOGY

The irrigable land survey and concept irrigation design comprised the following major tasks:

Irrigable land survey

1. Review of available literature, maps and geographical information to identify cropping history and soil boundaries within the study area
2. Literature review, site visit and discussion with local agronomists, agri-businesses and farmers to investigate crop suitability for the study area
3. Preliminary modelling to assess land area requirements for various crop types and to estimate water storage requirements

General concept irrigation design

4. Review of effluent water quantity and quality characteristics
5. Salt balance and assessment of potential soil limitations in accordance with the DEC Guidelines
6. Identification of cropping options based on soil assessment
7. Development of conceptual layout and design of irrigation infrastructure
8. Detailed modelling to assess crop water consumption and water storage requirements
9. Development of operation, management and monitoring plan

Table 1 details the literature, data and modelling tools utilised to undertake the above listed tasks.

Table 1 Data and modelling tools

Task	Data and modelling tools	Source
Irrigable land survey		
Task 1	Cadastral, road and township data	Federal and NSW Government sources
	Soil profile point information	Collected by GHD and BeneTerra on behalf of Santos
	Geology and gamma radiometric data	Geoscience Australia
	Aerial photography, vegetation, soil, landscape and land use data	Office of Environment and Heritage, NSW
	Land management units (LMU)	Namoi Catchment Management Authority
	Water production profile	Santos
Task 2	Australian Cotton Production Manual 2012	Australian Cotton Research Institute, 2012
	Irrigated Wheat - Best Practice Guidelines In Cotton Farming Systems	Cotton CRC, 2012
	Pastures in cropping rotations – North West NSW	Collett and McGufficke, 2005
	Leewood Produced Water and Brine Management Ponds - Agricultural Impact Statement	RPS, 2012
	FAO Irrigation and Drainage Paper No. 56 Crop Evapotranspiration - guidelines for computing crop water requirements	Allen et al., 1998
Task 3	CropWaterUse calculator	DEEDI, 2009
	HowLeaky modelling software	McClymont et al., 2008
	Narrabri Post Office (station 053030) rainfall and evapotranspiration data	Bureau of Meteorology

Task	Data and modelling tools	Source
Concept irrigation design		
Task 4	Leewood Concept Irrigation Design	Santos
	Soil sampling data	GHD and BeneTerra
	Treated water quality estimates	Santos
	Water production profile	Santos
Task 5	HowLeaky modelling software	McClymont et al, 2008
	Narrabri Post Office (station 053030) rainfall and evapotranspiration data	Bureau of Meteorology

1.3 ASSUMPTIONS AND LIMITATIONS

The following assumptions were adopted in this study:

- The Narrabri Gas Project has a minimum duration of 25 years, with no individual parcel of land irrigated continuously for more than 20 years in total
- Irrigation water quality will meet the suitability guidelines for 'low to medium strength effluent' as per the DEC Guidelines (DEC NSW, 2004) and trigger values listed in ANZECC guidelines (ANZECC, 2000)
- Centre pivot irrigators will be employed for irrigation
- Centre pivot irrigators will deliver water at 90% efficiency
- No consideration was made for private land access or future regulatory limitations on land availability
- Previously cropped Vertosol soils are most desirable but it is likely that some Sodosols will be mixed with those soils as they are commonly found in association
- Although previously cropped land is best, it may be necessary to carry out some further land preparation such as tree clearing (subject to regulatory approval) or levelling to accommodate the centre pivots
- There are no identified legal, cultural heritage or ecological issues to prevent development and operations
- Santos will design and operate storage facilities to manage treated water volumes or systemic failure
- Santos will apply for surface discharge authority

2 EXISTING ENVIRONMENT

The Narrabri Gas Project is located within the Namoi catchment and is concentrated around the Pilliga State Forest. The Namoi catchment borders the Gwydir and Castlereagh catchments and is bounded by the Great Dividing Range in the east, the Liverpool Ranges and Warrumbungle Ranges in the south, and the Nandewar Ranges and Mount Kaputar to the north. Stretching from Bendemeer in the east to Walgett on the western boundary, the Namoi catchment is approximately 42,000 square kilometres and over 350 kilometres long. Elevations range from over 1,500 metres to the south and east to 100 metres on the alluvial floodplain of the lower catchment west of Narrabri (NSW Office of Water, 2011).

2.1 LAND USE

The Project area is predominantly woodland vegetation associated with the Pilliga East and Bibblewindi State Forests. The surrounding area comprises dryland and irrigated agriculture and plantations with cotton being the major agricultural industry in the Narrabri Shire (Narrabri Shire Council, 2014). The catchment also supports broadacre cropping and sheep and cattle grazing.

The area of investigation comprised a 20 km radius around the Leewood facility, southwest of Narrabri. The area of the survey encompasses 1,257 square kilometres of land comprising over 800 square kilometres of forested land and approximately 450 square kilometres (45,000 ha), or 36%, of cleared land.

2.2 CLIMATE

The Australian Bureau of Meteorology records from 1 January 1963 to 17 April 2013, Narrabri post office [station 053030] were utilised to investigate the climatic conditions of the project area and develop the design basis for the study (BOM, 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 Narrabri was 644 mm whereas annual mean pan evaporation was 1,966 mm, with evaporation exceeding rainfall in all months (see Figure 1).

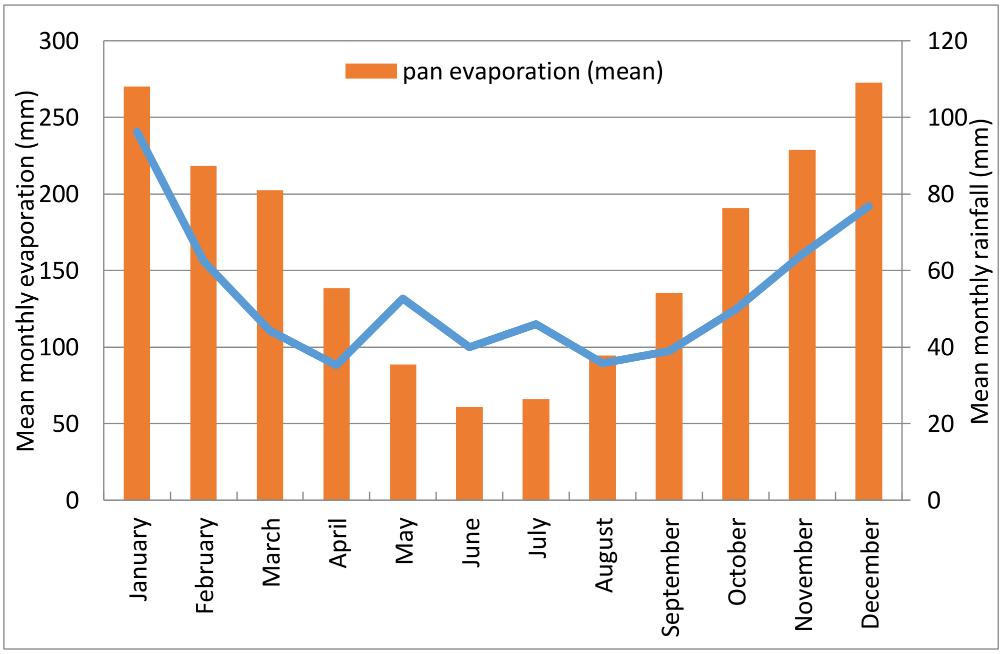


Figure 1 Mean rainfall and evaporation at Narrabri, NSW - 1963 – 2013, (BOM, 2014)

The climate of the region is cool to temperate, with hot summers and cool winters. The average daily maximum temperature ranges from 35.3°C in January to 17.0°C in July. Frosts can occur between May and October, and are common between June and August. Temperatures over 40°C have been recorded between October and March.

The growing season for lucerne and pasture grasses is predominantly September to April, with growth during the winter months being approximately a third to a quarter of the summer growth rate. Cotton is generally planted in September/October and harvested in April or May, whereas wheat is grown from May to October.

2.3 GEOLOGY

The Project is located within both the Permo-Triassic Gunnedah Basin (containing the target seams for CSG development) and the north eastern fringes of the Coonamble Embayment of the unconformably overlying Surat Basin.

The surficial geology of the survey area is comprised of five main types of deposits. Figure 2 provides the formation names, map symbols, and a description of the materials found in the formation. The distribution of the geological formations is illustrated in Figure 2. The geology is one of the key determinants of soil type distribution. Within the survey area, young colluvium deposits and sand plain materials dominate. The colluvium materials are generally associated with heavy textured cracking soils (Vertosols), and the sand plain materials are dominated by sodic texture contrast soils (Sodosols). The geology map polygons have been created by Geoscience Australia, and closely match the gamma radiometric database (Geoscience Australia, 2009). This illustrates the strong relationship the gamma radiometric database (Geoscience Australia, 2010) has to geology and soils, and its usefulness in the determination of soil distribution.

2.4 SOIL PROPERTIES

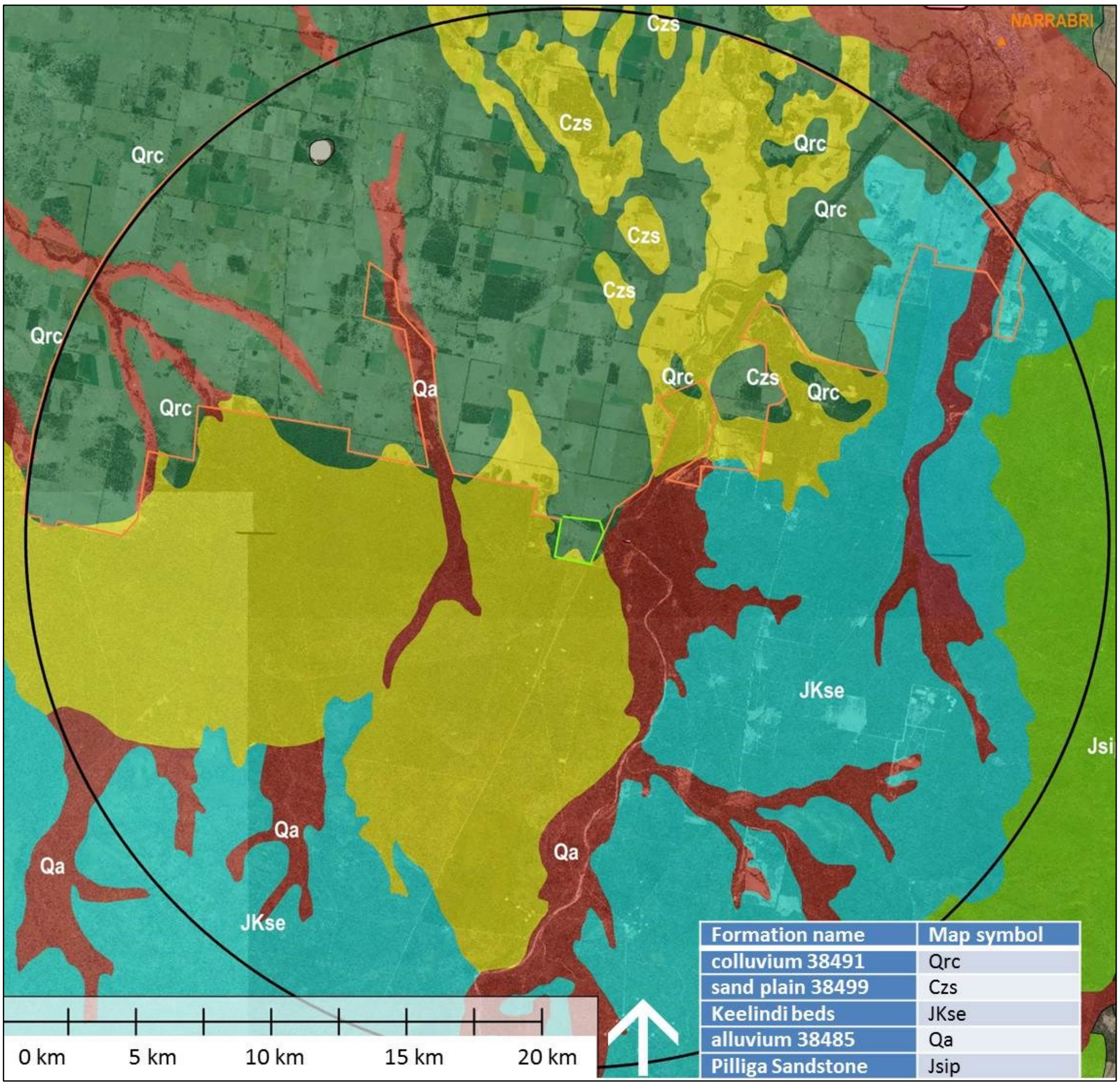
Preliminary investigation of soil properties within the 20 km radius of the proposed water treatment facilities was undertaken through investigation of the following datasets:

- Aerial photography, vegetation, soil, landscape and land use data (Office of Environment and Heritage, NSW)
- Land management units (LMU) (Namoi Catchment Management Authority)
- Geology and gamma radiometric data (Geoscience Australia)
- Surveyed soil points (Office of Environment and Heritage, 2014; GHD, 2014; BeneTerra, 2013/2014)

The datasets were interrogated and correlated in order to identify soil order distributions for the study area. Based on the outcomes of the preliminary investigation, soils of the survey area were grouped into two map units based on surface texture: a clayey surfaced map unit and a non-clayey surfaced map unit.

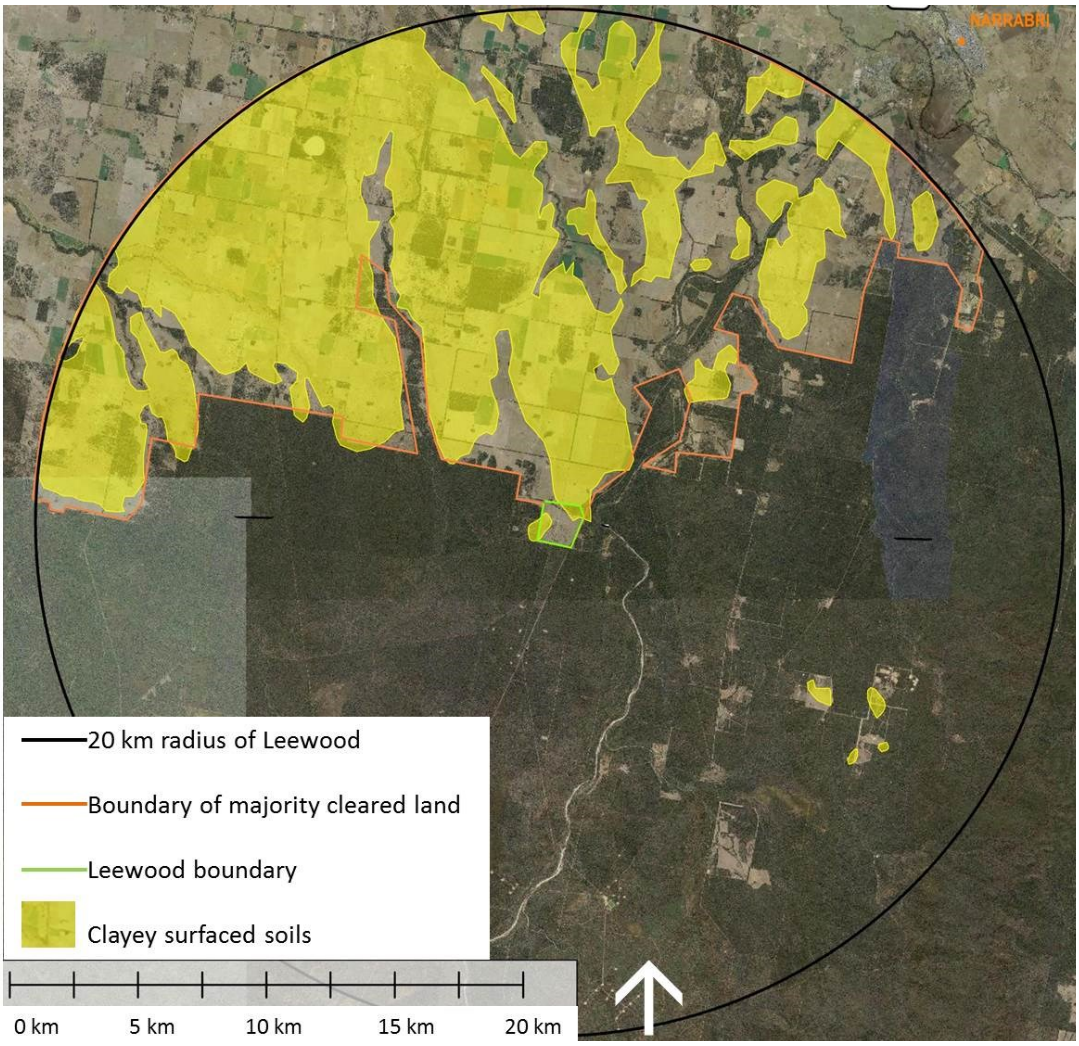
The clayey surfaced map unit occupies 280 square kilometres, 28,000 ha, or 60%, of the cleared area, as illustrated in Figure 3. The area is mainly comprised of Vertosols: deep, uniformly-textured, cracking clays. Around 75% of the cropped land is found on these soils. This is generally capability Class 3 land, with moderate inherent fertility. The remnant native vegetation found on these sites is mainly brigalow - belah woodland.

The remainder of the area has been grouped into the non-clayey surfaced soils, dominated by Sodosol soils. Sodosol soils are poorly structured, texture contrast soils with tendencies toward hardsetting and impeded subsoil drainage. The other soil orders found within this association tend to be more freely draining than the Sodosols, but generally have low inherent fertility. This map unit is mainly used for grazing, forest reserve and native vegetation remnants.



Formation name	Map symbol	Minimum age	Maximum age	Description of lithology
Colluvium 38491	Qrc	Quaternary 2.6 Ma – today	Quaternary 2.6 Ma – today	Colluvium and/or residual deposits, talus, scree, sheet wash; boulder, gravel, sand; may include minor alluvial or sand plain deposits
Sand plain 38499	Czs	Cainozoic 66 Ma - today	Cainozoic 66 Ma - today	Sand plain, may include some residual alluvium; sand dominant, gravel, clay
Alluvium 38485	Qa	Quaternary 2.6 Ma - today	Quaternary 2.6 Ma – today	Channel and flood plain alluvium; gravel, sand, silt, clay
Keelindi beds	JKse	Valanginian 140-136 Ma	Tithonian 152-145 Ma	Off-white, fine to coarse grained, poorly to well sorted, quartzose sandstone, pebbly sandstone and conglomerate interbedded with minor shale, siltstone and coal. Cross-bedded, kaolinitic and iron stained.
Pilliga Sandstone	Jsip	Kimmeridgian 157-152 Ma	Callovian 165-161 Ma	Medium to very coarse grained, well sorted, angular to subangular quartzose sandstone and conglomerate. Minor interbeds of mudstone, siltstone and fine grained sandstone and coal. Common carbonaceous fragments and iron staining.

Figure 2 Geologic formations within study area



Soil order	Number of reference profiles within cleared area*	Proportion of soils within cleared area (%)	Map unit (surface characteristic)	Estimated portion of map unit (%)	Area cleared (ha)
Vertosol	27	47	Clayey	90	25,000
Sodosol	18	31	Clayey	10	3,000
			Non-clayey	58	10,000
Dermosol	4	7	Non-clayey	13	2,000
Chromosol	3	5	Non-clayey	10	1,800
Kurosol	2	3	Non-clayey	6	1,100
Kandosol	2	3	Non-clayey	6	1,100
Rudosol	1	2	Non-clayey	3	550
Tenosol	1	2	Non-clayey	3	550

* BeneTerra soil data points not included in this count

Figure 3 Coverage of clayed surfaced soils on cleared land

2.5 TOPOGRAPHY AND DRAINAGE

The Project area is located predominantly in the Lower Namoi sub-catchment on gentle north-northwest facing valley slopes. The flat open floodplain of the Namoi River is situated to the north and west of the Project, with steep to undulating, mostly vegetated, land to the east and south. The Warrumbungle Ranges occur to the south and the Mount Kaputar National Park occurs to the north-east. Elevations within the project area range from approximately 400 m AHD in the south-east down to approximately 250 m AHD in the north-west.

2.6 GROUNDWATER

Unconfined shallow groundwater in the Project area occurs in alluvial/colluvial sediments that form a localised surface cover over the sub-cropping Permian-Triassic-Jurassic stratigraphy, with a thickness that can extend to several tens of metres (Aquaterra, 2009). Quaternary alluvium is locally subdivided into Gunnedah and Narrabri Formations within the valley of the floodplain of the Namoi River. Both the Gunnedah and Narrabri Formations are of sedimentary origin and were deposited as erosion products from streams draining the western slopes of the Great Dividing Range. The Gunnedah Formation tends to consist of cleaner and coarser grained material than the Narrabri Formation and is a major near-surface groundwater resource in the Namoi catchment.

Interpreted groundwater contours for the Upper and Lower Namoi alluvial groundwater sources generally indicate flow in the Namoi alluvial groundwater sources approximately northwest to west (URS, 2007) following the topography of the Namoi River valley. Shallow alluvial/colluvial groundwater flow in the Project area is likely to reflect the local topography and flow towards the Upper and Lower Namoi Alluvium groundwater sources. Surface water systems are likely disconnected from, or losing to, the shallow alluvial/colluvial groundwater systems.

No evidence of dryland salinity is present within the study area.

2.7 SURFACE WATER

The study area is located predominantly within the Lower Namoi sub-catchment. The Lower Namoi sub-catchment commences at Narrabri, with this location considered to be the start of the true riverine zone of the Namoi catchment due to the increased frequency of lagoons, the low gradient of the channel and the development of several anabranches and effluent channels (NSW Office of Water, 2011).

Surface water systems within the study area typically flow north to the Namoi River. The headwaters of the tributaries are generally located in forested conservation areas (Pilliga Forest) while the unforested areas of the sub-catchments are utilised predominately for sheep and cattle grazing and dryland cropping.

Bohena Creek is the main surface water system within the study area, with Jacks Creek to the east and Bundock Creek to the west. The upper reaches of Mollee Creek traverse the Leewood Water Treatment Plant area.

Majority of surface water systems within the study area are ephemeral, though Bohena Creek is classified as an intermittent stream. Localised flooding may occur in areas of low relief and through overtopping of creek banks.

3 IRRIGATION WATER QUANTITY AND QUALITY

Water extracted from coal seams during gas development will be treated by reverse osmosis, thermal brine concentration and chemical amendment and utilised for beneficial use purposes. Beneficial use options in consideration by Santos include drilling and construction usage, dust suppression, irrigation and discharge to surface water.

At peak production, it is anticipated that 12 ML/d (4,380 ML/yr) of treated water will be available for irrigation. Figure 4 shows the anticipated treated water production profile for the 25-year assessment period.

In order to optimise irrigation infrastructure requirements, an objective of the concept design was to assess the maximum amount of irrigation application achievable on a nominal 500 ha irrigation area at peak water production. Due to the rapid decline in water production, the infrastructure requirements were optimised in order to ensure an adequate and continuous supply of irrigation water to crop land without requiring excess infrastructure that would be redundant in subsequent years. The nomination of an irrigation area of 500 ha was made for the purposes of modelling the feasibility of the scheme. Given the extensive availability of suitable irrigable land (approximately 9000 ha within 20 km of Leewood WMF) (Section 4), scaling upward of the scheme to reduce further the potential for, and magnitude of, surplus treated water occurrences could be conducted if required.

3.1 TREATED WATER QUANTITY

The rate of treated water available for irrigation is estimated to peak at 12 ML/d at year two to four of gas production. Four metrics describing treated water availability were identified as a guide to future planning and detailed design, as follows:

- Peak in year 2 - 4 12 ML/d
- Average years 0 to 5 7.7 ML/d
- Average years 5 to 20 3.7 ML/d
- Average years 20-25 0.6 ML/d

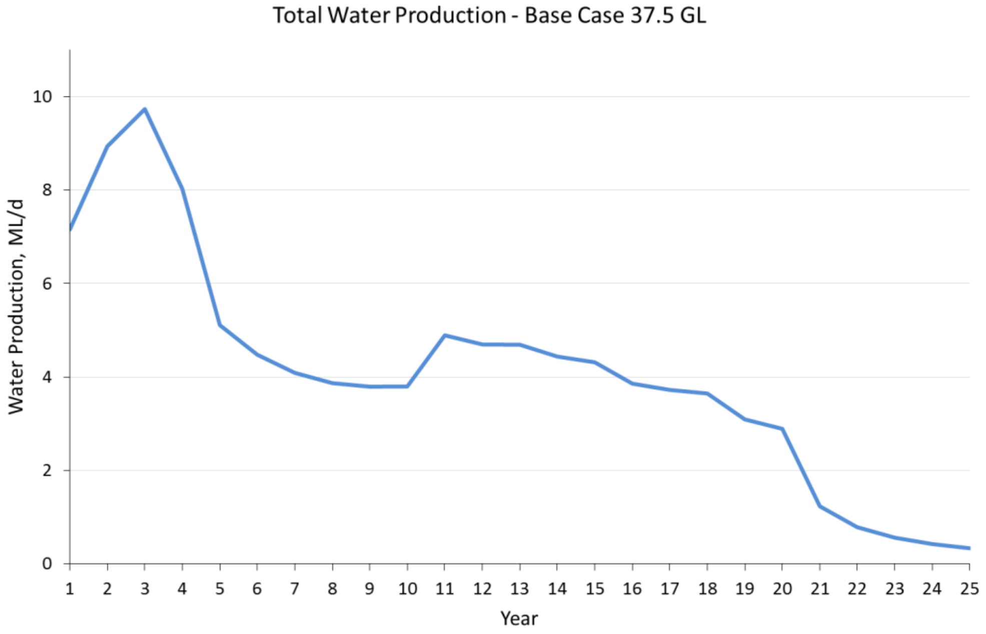


Figure 4 Predicted 25-year water production curve

3.2 TREATED WATER QUALITY

The analyte concentrations provided in Table 2 reflect the target water quality following reverse osmosis treatment, addition of thermal brine concentration distillate and amendment with calcium (gypsum) to reduce the sodium adsorption ratio (SAR) to a suitable level for application to crop land. As the effectiveness of reverse osmosis membranes diminishes with increasing influent temperature and age, the expected water quality conditions at both 25°C and 30°C have been provided.

Table 2 Expected amended treated water quality

Analyte	Amended treated water (25°C)	Amended treated water (30°C)
pH	7.1	7.7
EC (µS/cm)	566	985
TDS (mg/L)	368	640
NH_4-N (mg/L)	0.005	0.01
Na (mg/L)	77	140
Mg (mg/L)	≤0.01	0.01
K (mg/L)	0.8	1.0
Ca (mg/L)	40	65
Sr (mg/L)	≤0.01	0.01
Ba (mg/L)	≤0.001	0.027
B (mg/L)	0.12	0.68
CO_3 (mg/L $CaCO_3$)	≤0.01	≤0.01
HCO_3 (mg/L $CaCO_3$)	139	193
Total nitrogen (mg/L N)	0.005	0.010
Total phosphorus	<0.01	0.2
F (mg/L)	0.08	0.16
SiO_2 (µg/L)	0.15	0.532
SO_4 (mg/L)	96	156
Cl (mg/L)	15	83
SAR	3.4	4.8

3.3 IRRIGATION SUITABILITY

Based on the expected analyte concentrations of the treated water, the water would be classified as 'low to medium strength effluent' in accordance with Table 3.1 of the DEC Guidelines (DEC, 2004). The 30°C treated water total dissolved solid (TDS) concentration was ranked as 'medium strength', while the remaining analytes were ranked as 'low strength'.

Table 3 Comparison of treated water quality with NSW DEC Effluent Guidelines

<table>
<tr><th rowspan="2">Analyte</th><th colspan="6">Concentration for effluent strength classification</th><th colspan="2">Treated water</th><th rowspan="2">Effluent strength classification</th></tr>
<tr><th colspan="2">Low</th><th colspan="2">Medium</th><th colspan="2">High</th><th>Mean</th><th>Max</th></tr>
<tr><td>Total nitrogen</td><td colspan="2"><50</td><td colspan="2">50-100</td><td colspan="2">>100</td><td>0.005</td><td>0.010</td><td>Low</td></tr>
<tr><td>Total phosphorus</td><td colspan="2"><10</td><td colspan="2">10-20</td><td colspan="2">>20</td><td><0.01</td><td>0.2</td><td>Low</td></tr>
<tr><td>BOD</td><td colspan="2"><40</td><td colspan="2">40-1500</td><td colspan="2">>1500</td><td><40</td><td><40</td><td>Low</td></tr>
<tr><td>TDS</td><td colspan="2"><600</td><td colspan="2">600-1000</td><td colspan="2">>1000</td><td>368</td><td>640</td><td>Low-Medium</td></tr>
<tr><td>Other pollutants*1</td><td colspan="4"><5 times</td><td colspan="2">>5x</td><td><5x</td><td><5x</td><td>Low</td></tr>
<tr><td>Grease & oil</td><td colspan="4"><1500</td><td colspan="2">>1500</td><td><500 *2</td><td><500 *2</td><td>Low</td></tr>
<tr><td>EC (mS/cm) *3</td><td><0.65</td><td>0.65-1.3</td><td>1.3-2.9</td><td>2.9-5.2</td><td>5.2-8.1</td><td>>8.1</td><td>0.57</td><td>0.99</td><td>Low salinity</td></tr>
</table>

(Concentrations expressed in mg/l unless otherwise stated)(*1: ANZECC criteria for Cd, Cr & Zn)(*2: sum of C_5-C_{36} petroleum hydrocarbons)(*3: DEC guidelines table 3.4)

A thermal treatment plant is being considered for further treatment of the brine, yielding high purity distillate and after mixing with permeate, delivering low strength effluent, subject to final plant design and capacity.

The elevated electrolyte concentration and reduced sodium adsorption ratio (SAR) of the amended water would encourage aggregate stability of soil particles thus maintaining soil permeability and structural longevity. Table 2 shows that expected SAR values of 3.4 and 4.8 are predicted for the treated water at 25°C and 30°C respectively, having been balanced against the salinity of the water to reduce soil particle dispersion risk.

The predicted electrical conductivity (EC) of the treated water is 570 and 985 µS/cm at 25°C and 30°C respectively. Based on the predicted EC concentrations, the irrigation water salinity is rated as low in accordance with the DEC Guidelines (Table 3), and therefore would be suitable for moderately sensitive crops in terms of salt tolerance.

In respect of the concentrations of total nitrogen (0.005 and 0.010 mg/L), total phosphorus (<0.01 mg/L) and BOD_5, the treated water is ranked as low strength in accordance with the DEC Guidelines (Table 3).

The predicted concentrations of fluoride (0.08 and 0.16 mg/L) and boron (0.12 and 0.68 mg/L), would be safe for the proposed crops in accordance with the short-term trigger values (20 yr life cycle) of the ANZECC/ARMCANZ 2000 guidelines.

In addition, the treatment process will remove heavy metals and organic compounds from the treated water.

4 SITE SELECTION

4.1 PRE-EXISTING CROPPING ACTIVITY

Datasets obtained from the Office of Environment and Heritage (OEH) were used as an indication of pre-existing cropping activity (Office of Environment and Heritage, 2009b; Office of Environment and Heritage, 2009a). The data indicated that approximately 9,000 ha of land were used for cropping between the years of 1998 and 2009.

Assessment of aerial photography indicated that around 9,500 ha, or 20% of the cleared land area, were more recently cropped. There is no evidence of centre pivot irrigation occurring within 20 km of the proposed water treatment facility, nor indication that other forms of irrigation are taking place as evidenced by the lack of suitable water storage facilities within the study area. The remainder of the cleared land, around 35,000 ha, is predominantly pastured grazing land. The distribution of suitable soils on cleared land indicates that more cropping, with the inclusion of irrigation, could take place than is currently occurring.

The most commonly grown crops in the Narrabri region are cotton and wheat. The lack of irrigation infrastructure in the study area indicates dryland cropping. Irrigation would offer the opportunity to improve yields of cotton and wheat and several other crops such as lucerne, sorghum, sunflower and oats (Dowling, 2014; RPS, 2012). These crops could be grown successfully under irrigation on the Vertosol soils of the area. Four crops were investigated to estimate the land area needed to utilise the peak water supply:

- a perennial crop - lucerne,
- two summer crops - cotton and grain sorghum, and
- one winter crop – wheat.

4.2 LANDSCAPE AND SOIL SELECTION CRITERIA

Only cleared land was considered as potentially irrigable. The criteria for selection of suitable land was based upon the following qualities:

1. Significant aggregation of cleared land (see Figure 3)
2. Slopes less than 12%, preferably less than 3%
3. No rock at surface
4. Water holding capacity greater than 100 mm
5. Landscape not subject to inundation
6. Cropping history ranked more favourably
7. Permeability greater than 5 to 10 mm/hr in the top metre of the soil profile
8. Enables cropping flexibility
9. Ranked on need for preparation (non-dispersive soil profile, levelling, ripping, etc.)
10. Ranked on crop water use potential
11. Ranked on productivity
12. Subject to proximity to sensitive receptors and other environmental considerations
13. Ranked on distance from Leewood property.

Most of the cleared land available meets the first four points on the criteria list (1 to 4). The Vertosol soils found in the clayey surface soils unit are generally more able to meet the criteria of points 5 to 11 (Figure 3). However, soil sodicity, and to a lesser extent salinity, are common attributes of both the Sodosol and Vertosol soils within the survey area. Water provided will be suitable for irrigation purposes. The individual land owner might deem it appropriate to undertake other day-to-day farming practices to ensure that permeability of the rootzone is maintained. Previously levelled and cropped land would also be ranked more favourably.

The first cut of most desirable parcels for irrigated cropping should be selected based on the following criteria, with the other selection criteria requiring on-site assessment. The land parcels should:

- Be aggregated within the main cleared land area
- Lie within the clayey surfaced soil map unit (i.e. Vertosol soils)
- Have a previous cropping history

The land area areas that meet these criteria are approximately (Figure 5):

- 9,000 ha within 20 km radius (based on the recent aerial photography)
- 4,500 ha within 15 km radius
- 1,700 ha within 10 km radius
- 600 ha within 5 km radius

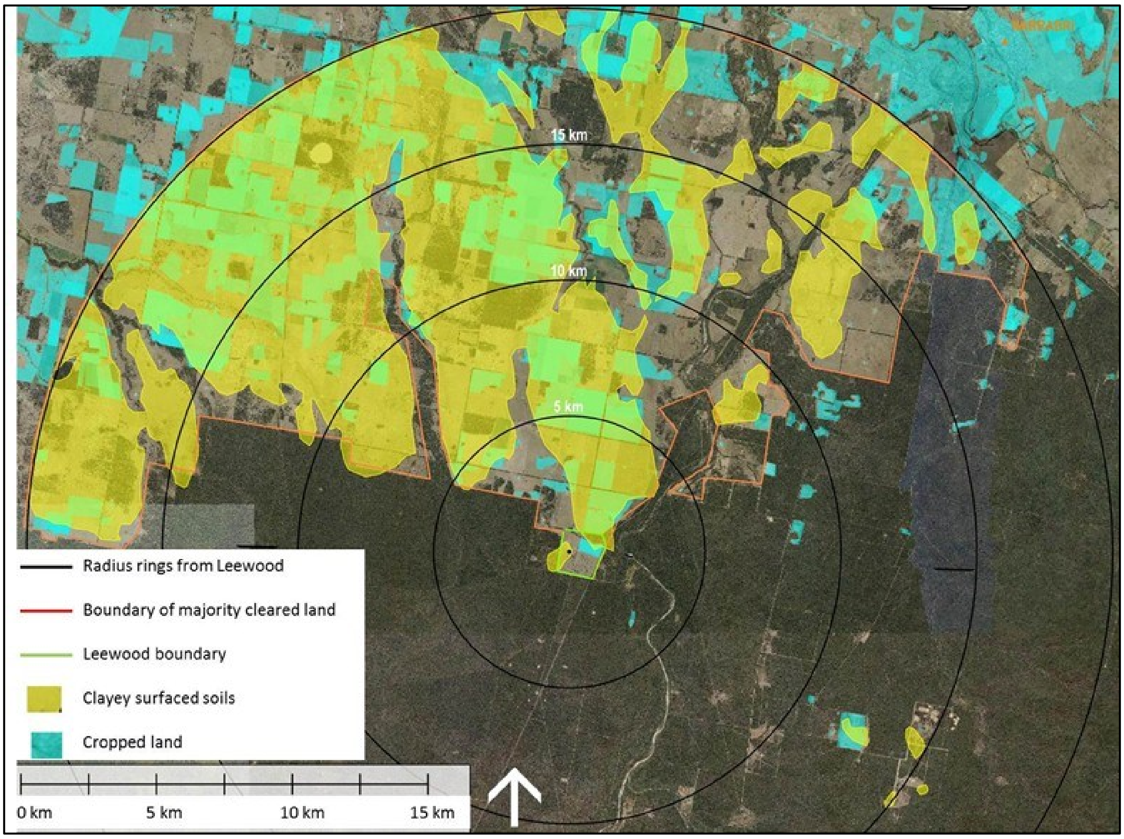


Figure 5 Radius rings encompassing suitable land

4.3 DETAILED SOIL INVESTIGATION OF AN EXAMPLE IRRIGATION AREA

BeneTerra sampled soils in an example irrigation area during December 2013. Forty soil cores to 140 cm depth were extracted from the example irrigation area.

A Certified Professional Soil Scientist characterised the soil cores in accordance with guidance contained in the Australian Soil and Land Survey Field Handbook (McDonald, et al., 1990). The characterisation process consisted of:

- Identification and measurement of soil horizon depths
- Observation of soil structure (macropores, cracks, aggregates)
- Observation of plant rooting patterns
- Soil texture estimation (clay percentage)
- Colour determination
- Consistency observation
- Field pH and presence of carbonate
- Sampling for laboratory analysis.

4.4 GENERAL FINDINGS OF SOIL INVESTIGATION

The soils of the potentially irrigable example irrigation area were generally quite uniform. The soils were identified as either '*Subnatric Black or Brown Sodosols; medium, non-gravelly, clay loamy/clayey, deep*' or '*Epipedal Black, Grey or Brown Vertosols; non-gravelly, fine/medium fine, deep*' according to the Australian Soil Classification. (Isbell, 2002)

The outlier was a free draining ‘Red Kandosol; thick, non-gravelly, loamy/loamy, deep’. Based on topography and other indicators, this soil represented only a small proportion of the example irrigation area.

For the purposes of estimating the feasibility of irrigation, the soils were grouped into units which could be interpreted as different irrigation management zones. Details and descriptions of the soil qualities of the example irrigation area can be found in the Appendix.

4.5 SOIL UNITS DESCRIPTION

Soil units are a method of grouping soils based on similarities in morphology, chemistry and management requirements. Five soil units were defined as outlined below, representative cores illustrated in Figure 6 and mapped in Figure 7:

- Slight gilgai Vertosol unit
- Medium gilgai Vertosol unit
- Strongly gilgai Vertosol unit
- Sodosol unit
- Red Kandosol unit

Slight gilgai Vertosol unit. Dark grey and brown clay soils. They varied somewhat in the abundance of carbonate in the subsoil, and the presence or absence of a strongly acidic lower rootzone (100-150 cm). They tended to have a friable surface that cracked on drying. The cracking nature of the soils indicates that they will initially exhibit rapid infiltration when first irrigated from a dry condition, but due to swelling of the clays closing the cracks, the infiltration rate of these soils will subsequently decline to a low to moderate rate (10 – 15 mm/hr). The coarsely lenticular subsoil presents imperfect internal drainage.

Medium gilgai Vertosol unit. Similar soils to the above Vertosol unit, though the microrelief is moderate.

Strongly gilgai Vertosol unit. Similar soils to the other Vertosol units, though the microrelief is greatest. These areas have pronounced humps and hollows, with the low points showing signs of water ponding. Paddocks dominated by this soil unit tended to contain more scattered trees than the slight gilgai Vertosol unit.

Sodosol unit. These soils were structureless and hardsetting brown clay loams in the surface 15 cm. The permeability of the soil surface was significantly greater than the subsoil (approximately 30 mm/h at the surface and 5 mm/h in the subsoil). The surface was prone to waterlogging and compaction. The subsoils were similar to the Vertosol units described above.

Red Kandosol unit. A red, friable, structureless, sandy loam soil. This soil had moderately low inherent fertility, was rapidly drained, and supported vigorous root growth. The soils of this unit would be suitable for irrigation, although their rapid drainage may lead to plant nutrient deficiencies and greater deep drainage than likely to occur from the Vertosols or Sodosols. These soils had a lower water holding capacity than the Vertosol units, with similar water holding to the Sodosol unit soils.

The Red Kandosol unit has strikingly different properties to the other soils of the property. The key differences being free draining porosity, uniformly loamy texture, acidic pH, and shallower rootzone. The other three soil units share the characteristics of being clayey and slightly to moderately sodic below around 15 cm, and become progressively more sodic with depth. Salinity and chloride are generally quite low in the surface 50 cm of all soils. Nutrient fertility (Appendix) is marginal to strongly deficient for phosphorus and sulphur. Nitrogen and potassium levels appear to be adequate for dryland pastures. Trace elements are difficult to interpret from a soil test, however, copper and manganese levels appear to be reasonably high, and zinc appears to be marginal for most paddocks. Phosphorus buffering, estimated from soil type and surface texture, is moderate to high in the soil surface and high in the subsoil.

Figure 6 Soil profile cores from each representative unit: (L to R) slight gilgai Vertosol; medium gilgai Vertosol; strongly gilgai Vertosol, Sodosol, Red Kandosol

The subsoils were generally whole coloured, and mottling, where it occurred, was generally slight. This indicates that, while the Vertosol and Sodosol units were all coarsely structured and exhibited imperfect drainage, they stored water relatively evenly, and are unlikely to remain saturated for more than a few weeks following periods of extended wet weather. All soils exhibited root growth to around 100 cm, with most having a few roots still present at 140 cm.

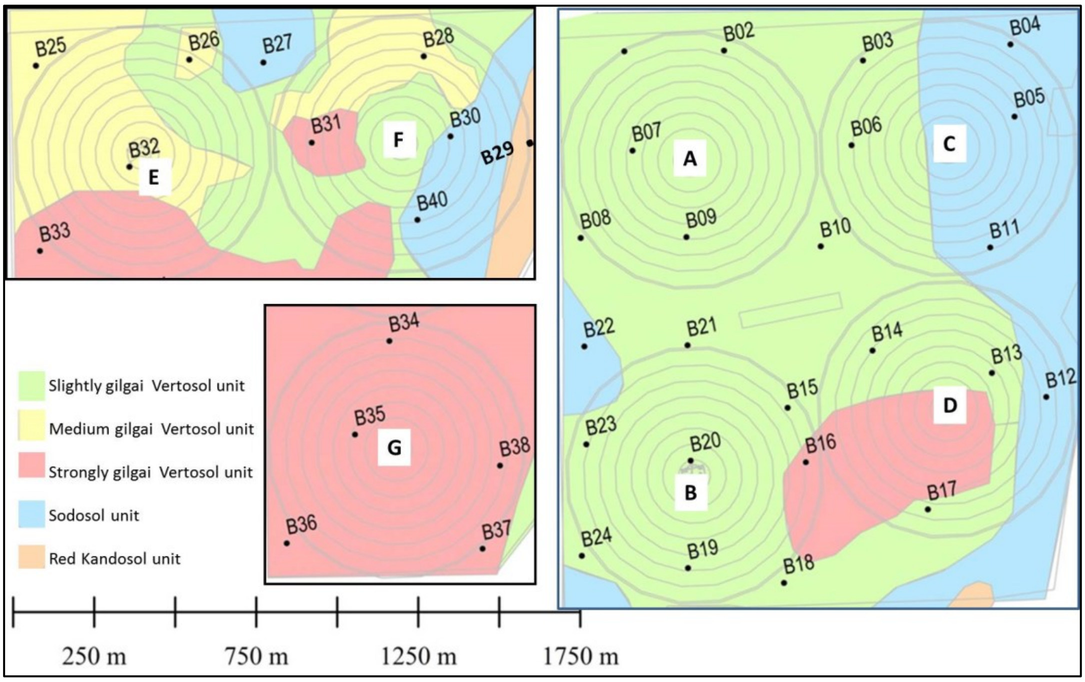


Figure 7 A representation of soil sampling and grouping of soil unit classes on the example irrigation area

5 SITE CONSIDERATION

5.1 LIMITATIONS OF LANDFORM

The study area selected to provide an example of the prospective irrigation site is assumed to sit upon a level plain. The slopes are generally slight with low ridges draining away toward minor depressions and drainage lines as represented in Figure 8.

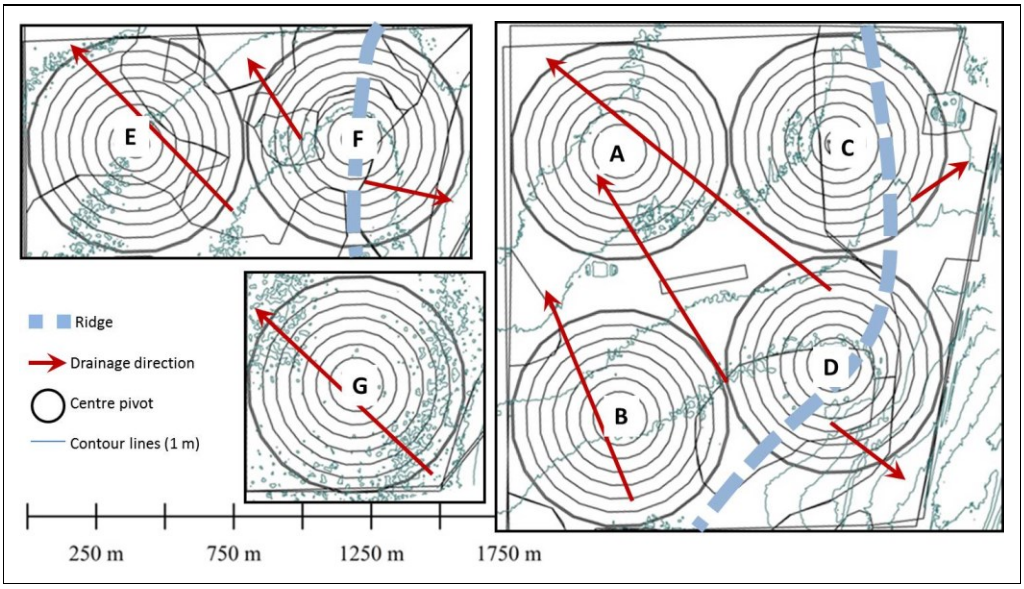


Figure 8 A representation of drainage patterns for three example land parcels showing 1 m contour lines

The slopes within the example irrigation area are assumed to present no limitations for sprinkler or drip irrigation in accordance with the DEC Guidelines. Occasional flooding or inundation of the lower elevations presents only a ‘moderate’ limitation. Potential erosion and waterlogging should not occur given the slight slopes.

5.2 SOIL LIMITATIONS

Table 4 provides a range of soil qualities of Vertosol and Sodosol units and the expected effect of amendment with reference to Table 2.2 of the DEC Guidelines.

5.2.1 SODIUM ADSORPTION RATIO AND EXCHANGEABLE SODIUM PERCENTAGE

Figure 9 shows the SAR_e and electrical conductivity of 10 selected soil profiles. The Sodosol and Vertosol soil units had an average surface (50 cm) SAR_e of 4.2, ranging) up to 10. In some cases these may rank as a severe limitation' according to the guideline. However the guideline does not give regard to the relationship of slope and sodicity. The negative effect of sodicity increases with slope due to the tendency for water to run off. The potentially irrigable soils that we identified had little slope – generally less than 1%. Prior to setting up an irrigation system, the effects of sodicity, where measured, would need to be mitigated and that limitation decreased (Table 4).
The SAR_e of the deeper soil, 50 to 90 cm, averaged 13 on the soils analysed but is not as critical a limitation as the surface SAR_e due to the higher electrolyte effect of the deeper layers which prevents the soil from dispersing.

5.2.2 ELECTRICAL CONDUCTIVITY

The baseline soil saturation paste extracts for electrical conductivity (EC_e) indicated the salt content to be relatively low in most soils. EC_e in the top 70 cm was an average of 0.8 mS/cm, with a maximum value of 2.8 mS/cm, ranking the top 0.5 m as having 'nil or slight' limitations on average, with a few sites rated as 'moderate'. The 0.7 – 1.4 m depth average EC_e was measured as 3.4 mS/cm, with a maximum of 6.4 mS/cm, ranking the 0.5 – 1.4 m as having 'nil or slight' limitations on average, with a few sites rated as 'moderate'. Salinity posed a slight limitation for these soils in the 0.7 - 1.0 m deep zone (Figure 9). It should be noted that healthy roots were observed beyond 0.1 m in all soil cores.

The amended irrigation water will contribute sodium and calcium ions in a ratio that should prevent soil dispersion. However, there is potential for EC_e to rise to an inhibitory level unless sufficient leaching occurs and this will be managed by targeting the leaching fraction seasonally, toward periods when evapotranspiration (ET) is low. This is best monitored through annual soil sampling (DEC, 2004).

Table 4 Range of soil qualities of Vertosol and Sodosol units and expected mitigation by amendment

Property	Minimum	Maximum	Mean	Table 2.2 DEC Guideline Limitation rating
SAR (0-40 cm)	0.9	10.8	4.2	Slight-moderate
SAR (0-40 cm)- if amended	n/a	5	4	nil
SAR (40-100 cm)	11.6	16.8	13.1	moderate
EC_e (0-70 cm) dS/m	0.3	2.8	0.8	nil
EC_e (70-100 cm) dS/m	0.8	6.4	3	slight
Depth to C horizon	>1.5 m		NA	nil
SHC top 1 m (mm/hr)	5	20	NA	moderate
SHC top 1 m (mm/hr)- amended	10	30	12	Slight -moderate
PAWC (mm/m)	150	250	200	nil
pH(water) surface	5.9	8.2	7.1	nil
CEC (0-40)	9.5	24.8	21	nil
Dispersion	3	1	2	moderate
Dispersion- amended	4	4	4	nil
P buffer	high	high	high	nil

5.2.3 WATER TABLE DEPTH AND BEDROCK RESTRICTIONS

All investigations to date indicate that the water table or bedrock would not be a limitation to irrigation in the study area. Supporting data includes soil surveys from the NSW Office of Environment and Heritage, GHD and BeneTerra. Groundwater bore data was available from three bores on the Leewood property.

5.2.4 SATURATED HYDRAULIC CONDUCTIVITY

The saturated hydraulic conductivity (SHC) of the Vertosol and Sodosol soils of the example irrigation area are estimated to range from 20 -30 mm/hr in the surface and 5 - 10 mm/hr in the subsoil (McDonald, et al., 1990). Water infiltration can be managed through careful irrigation scheduling that fills the surface horizon and allows enough time for that soil water to drain into the subsoil. Amendment requirements to manage soil structure prior to setting up an irrigation system will be calculated based on soil dispersivity tests, with rates derived from the soil cation status (CEC and SAR), and inherent and predicted salinity fluxes.

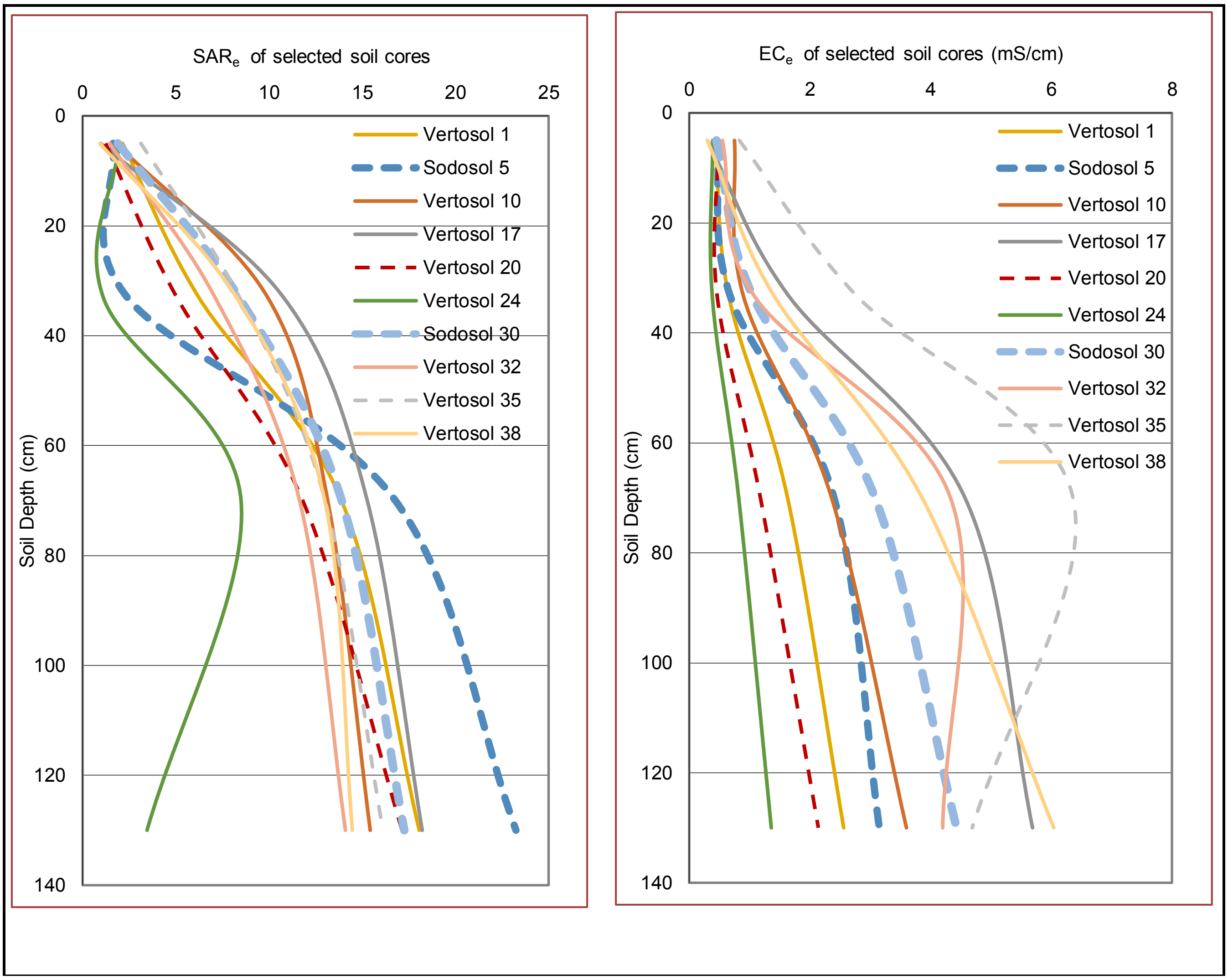


Figure 9 Sodium adsorption ratio (SAR$_e$) and electrical conductivity (EC$_e$) of selected ten profiles

5.2.5 PLANT AVAILABLE WATER HOLDING CAPACITY

These soils of the example irrigation area have ample plant available water holding capacity (PAWC) i.e. approximately 150 - 180 mm for Sodosols, and approximately 200 - 250 mm for Vertosols. The water holding capacity had a marked influence on the water use and water storage requirements simulated in the modelling process and hence for the daily time-step modelling of the water use on these soils a median value of 200 mm was used (Office of Environment and Heritage, 2014) .

5.2.6 PH OF SURFACE SOIL

The average soil pH in water (pH_w) was determined as 7.1 in the surface soil, with a range of 5.9 to 8.2 across the example irrigation area. This pH is within the ideal range for most plants. Note that pH_{CaCl2} typically is lower than pH_w, and is generally the preferred analytical method for acidic soils, but not for alkaline soils.

5.2.7 Cation exchange capacity

The cation exchange capacity (CEC) characteristic is related to a soil's ability to retain nutrients. The average CEC for the top 0.4 m of the soil profile was measured as 21 meq/100g, indicating that the soils have good capacity to store and release nutrients, and that they are comprised of a high proportion of shrink/swell clay minerals. This rates as a 'nil' limitation as per Table 2.2 of the DEC Guidelines.

5.2.8 Dispersion

Some of the soils have dispersive qualities, however soil amendment prior to setting up the irrigation system will mitigate this potential issue. Other standard agricultural practices used in the region will likely be required (i.e. application of gypsum through Deep tillage).

5.2.9 Phosphorus sorption

The soils of these parcels all have moderate to high clay contents, ranging from 20% to 55% clay, based on field texture (McDonald, et al., 1990). Soils with clay contents of this order are able to prevent phosphate leaching partly due to the sesquioxides associated with the clays. Additionally, the water to be applied to the land is low in phosphate and will not require a high sorbing soil to retain the phosphate. Hence phosphorus and phosphate mobility does not represent a potential issue.

5.2.10 Soil physical limitations

The key limitations of the site relate to permeability of the majority of the soils. Four of the soil units, with the exception of the Red Kandosol unit, portray coarse subsoil structure. Due to slower infiltration into the subsoil, saturation of the surface soil following heavy rainfall is likely to extend for several days after rain/overland flow stops. These drainage/waterlogging related issues will demand careful water scheduling options, as well as consideration of the trafficability of the sites.

5.3 SOIL MANAGEMENT

Ongoing gypsum additions will assist in addressing the existing surface and subsoil sodicity.

The strongly gilgai Vertosol unit will need to be levelled if it is to accommodate irrigation. Levelling requirements are not as precise as for flood irrigation. Following levelling, a light rip or similar cultivation may be required to loosen the exposed subsoil.

Traffic on the site needs to be restricted when soils are wet in order to ensure that the soil dries prior to harvest activities. The crop will be harvested for hay or silage thus eliminating livestock traffic.

Soil fertility will require ongoing monitoring to assess requirements. Initial fertiliser applications include phosphorus to address soil deficiencies followed by annual applications of phosphorus as necessary to maintain soil levels and replace removals from the crop. Trace elements will be monitored using plant symptoms and foliage analysis. Sulphur will be abundant due to gypsum application.

6 DESIGN CONSIDERATIONS

6.1 CROPPING OPTIONS ASSESSMENT

6.1.1 SUMMARY

The cropping options were selected in order to utilise the majority of the irrigation water during the early years of gas development when peak water production occurs. Due to the short-lived production peak, it will be necessary to choose a cropping scheme that maximises water use in the early years of the project but is sustainable when the supply significantly declines.

A number of crops have been identified as possible candidates for irrigation in the region including cotton, wheat, grain sorghum, forage sorghum, oats and lucerne. These crops vary in potential economic return to growers with decision-making often skewed by this consideration.

The wheat-cotton double crop was seen as the most viable option in terms of potential water use of annual cropping systems. Under this scenario, there would be two depressions in irrigation potential due to harvest of cotton and sowing of wheat around April and harvest of wheat and sowing of cotton around October in the simulation (see Figure 10). A wheat-cotton double crop rotation may be a useful addition as a minor component of the cropping strategy.

As coal seam gas water is produced at a relatively steady daily rate, regardless of the season, it is important to optimise crop water consumption patterns with storage capacity. The closer that crop water use matches water production, the less storage is required. Hence, it is recommended that effluent irrigation cropping decisions are primarily based on optimal, year-round utilisation of water. The best choices are crops or crop combinations with a long growing season where water consumption occurs throughout most of the year.

Based on the outcomes of the scenario modelling, lucerne was recommended for the Narrabri Gas Project irrigation strategy. Lucerne is a common choice for effluent irrigation systems because it is perennial and uses water almost year-round.

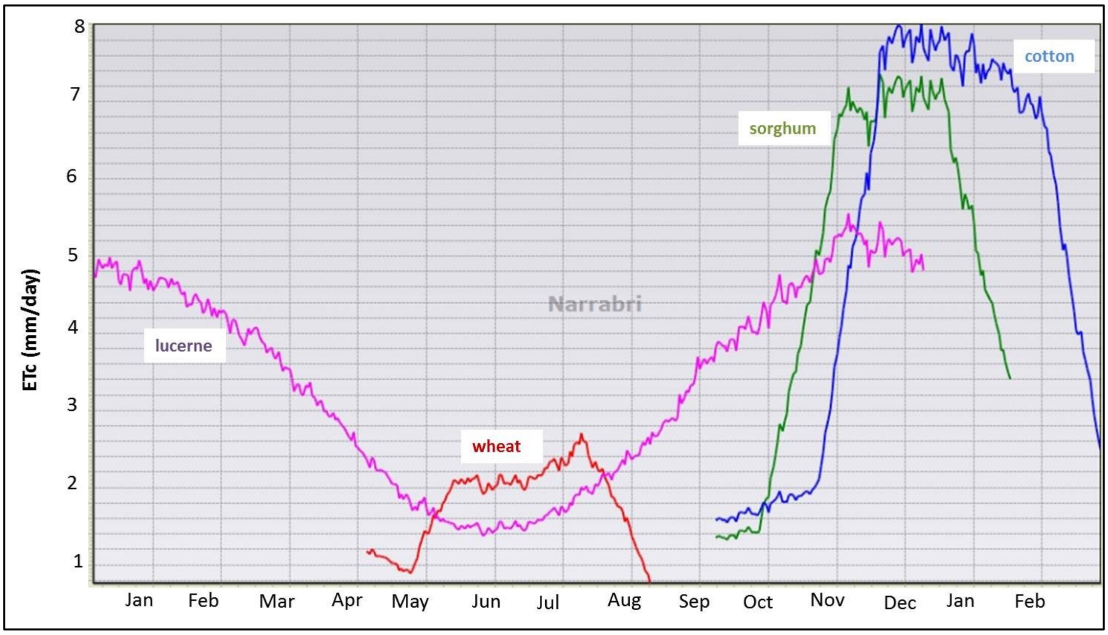


Figure 10 Annual crop water use patterns

6.1.2 Cotton

The irrigation water requirement for cotton has been reported in publications such as WaterPAK (CRDC, 2008). The Healthy Headwaters Report (van Niekerk, 2013) indicates between 4.8 and 8 ML/ha of water is required to maximise the yield of cotton in nearby Goondiwindi, Queensland. The CropWaterUse calculator (DEEDI, 2009) estimated an irrigation requirement for cotton of 6.8 ML/ha based upon a 90% irrigation system efficiency with a 30 mm soil water deficit (SWD) trigger for irrigation.

6.1.3 Wheat

Wheat typically requires between 110 and 130 days between sowing and harvest, depending upon climate, variety, and soil conditions. Growing cotton as a rotational crop with wheat is common practice in the northern New South Wales growing region. However, it must be noted that seedbed preparation and sowing method have a significant effect on seedling emergence and yield potential, particularly when watering-up. The main challenge when following cotton (or another summer crop) is having time to prepare a seedbed, and plant. After a crop of cotton, root cutting and pupae destruction is necessary prior to planting wheat.

In addition, there are challenges in ensuring timely harvest of wheat in the spring. When wheat is produced for grain there is a dry down period as the grain matures when irrigation is not required. Rainfall or cool weather during the maturation period will delay harvest and planting of the next crop. For the purposes of utilising water in the early stages of the water production cycle it is recommended that wheat is harvested as a hay or silage crop before the grain matures.

The CropWaterUse calculator estimated an average irrigation requirement of 1.34 ML/ha-yr for wheat at Narrabri, with 90% irrigation system efficiency and a 30 mm SWD trigger.

6.1.4 Lucerne

Lucerne is a perennial forage legume which is normally productive for four to eight years, but can live more than 20 years, depending on variety and climate. Longevity of a lucerne stand is dependent upon a variety of factors such as weed control, traffic patterns and disease suppression.

Lucerne exhibits autotoxicity, wherein it exudes a chemical compound that prevents new lucerne seedlings from growing in proximity to mature plants. Therefore, once lucerne fields have reached the end of their useful life they must be rotated to another species. This usually takes at least one growing season while the toxic compound degrades in the soil. It is expected that this rotation and re-establishment process would occur in stages (not all parcels at once) and later in the water production cycle when there is less pressure to maximise water use.

Table 5 presents the pros and cons of cotton, wheat and lucerne as cropping options.

Table 5 Pros and cons of cropping options

Crop	Pros	Cons
Cotton	• Production suited to the Grey Vertosol soils and climate of the Narrabri district • High water use across the summer	• No water use in the winter non-crop period hence it must be partnered with a crop with relatively high water use in winter • Dry down period prior to harvest can last up to four weeks
Wheat	• Production suited to the Vertosol soils and climate of the Narrabri district • Multiple well established marketing outlets and product types (livestock feed wheat, durum wheat) • Water use pattern complements summer cropping options, uses water in winter months	• Low water demand, needs to be partnered with summer crop options • Harvest can be extended with cool, wet weather

Crop	Pros	Cons
	• Multiple harvest opportunity on the back of adverse climate events i.e. harvest for grain, hay or silage • Soil structural effects known to enhance productivity of cotton when grown in rotation	
Lucerne	• Production is suited to heavier soils as lucerne has a high crop water demand • Perennial cover will protect Sodosols from erosion and deep tap roots can penetrate B horizon • Higher crop water demand requires less irrigation area to be developed in comparison to other crops • Water demand across the year more continuous and relatively predictable compared to annual cropping options • Will still produce economic yields with limited irrigation • Positive effect on soil nitrogen content • Positive effect on soil structure	• Frequent harvest required – at least four times annually • Poor flexibility to respond to market opportunities in other crops or downturn in lucerne prices • Re-establishment of the stand on various parcels (every 5-7 years) would reduce water use for at least one year as it is necessary to rotate to another crop for at least one growing season

6.2 IRRIGATION MODELLING

6.2.1 ESTIMATION OF WATER STORAGE AND LAND REQUIREMENTS

The HowLeaky model was employed to predict the storage capacity requirements and surplus treated water volumes at the assumed peak treated water rate of 12 ML/d or 4380 ML/yr. The HowLeaky modelling program (McClymont et al., 2008) is based on the PERFECT (Littleboy, et al., 1992) water balance model which was developed to assess the impacts of different land uses, soil conditions, management practices and climate-types on water balance and water quality.

The average annual surplus treated water volumes estimated by HowLeaky provide a relative guide for comparing modelled scenarios (Table 6).

The modelled scenarios incorporated soil water holding capacity, evapotranspiration, storage evaporation losses, irrigation application efficiencies and more. The HowLeaky model utilised a daily time-step to assess frequency and volume of surplus water for each scenario.

The perennial cropping option, lucerne, required the least amount of storage and land base due to its longer growing season and potential water use. With a storage capacity of 200 ML and nominally 500 ha of irrigated land area, there is a probability of a treated water surplus occurring in 40 % of the initial peak-water-production years when irrigating lucerne crops (Table 6). In contrast, if the irrigated area was increased to 1000 ha, and pond storage increased to 400 ML, surplus water volume may be reduced to an annual average of 46 ML with only 8% of years likely to experience surplus treated water (Table 6).

All single crop options (besides lucerne) required considerably larger land areas and/or storage capacities and would therefore be poor choices for the period of peak water production. These crops may be better suited as the production profile declines.

Double-cropping comprises the growing of two different crops on the same parcel in a single year. However, there are crop transition periods during which there is little or no water demand. Transition periods occur when the previous crop ceases to transpire in late growth stages and continues not to transpire until the following crop produces enough green leaf area to warrant irrigation. Unirrigable areas due to these factors can range from 20 - 30% of the annual cropping area.

Table 6 provides outcomes of the HowLeaky estimation of storage volume requirements for various cropping scenarios at peak irrigation water production.

Table 6 Estimation of storage volume requirements for various cropping scenarios

Crop	Growing season	Growing season length (days)	Crop water use per growing season (ML/ha-yr)	Storage volume modelled (ML)*	Annual land use required for peak supply (ha)**	Average annual surplus (ML)***	Years at which surplus occurs (%)
Lucerne	Year-round	365	7.5	200	500	200	40
Lucerne	Year-round	365	3.9	400	1000	50	8
Cotton	Summer	170	4.1	400	500	2000	99
Sorghum	Summer	130	4.3	400	500	1900	99
Wheat	Winter	125	2.0	400	500	3100	100
Wheat-cotton	W & S	295	4.6	400	500	1700	99
Wheat-sorghum	W & S	255	5.0	400	500	1526	99

**Volume of storage and irrigation areas for the double cropping scenarios have been estimated in comparison to the lucerne modelling results*
***The model incorporates storage evaporation losses and irrigation application efficiencies*
**** Total surplus volume averaged across the 50-year simulation*
Storage volume requirement estimates based on sustained treated water supply rate of 12.0 ML/d. Actual surplus and % of years within which surpluses are likely to occur will reduce significantly as water production rate declines following initial peak.

The double cropping options have disadvantages due to the non-uniformity of their peak water use potential and delayed water use during periods between harvests.

6.2.2 Modelling Water Balance and Storage

The HowLeaky modelling program was used to simulate the proposed cropping options detailed above.

The following key parameters were adopted for the simulation:

- 12 ML/d peak treated water rate
- 200 ML water storage pond
- 30 mm soil water deficit irrigation trigger

Given that the survey of irrigable land identified 9000 ha within 20 km radius of Leewood WMF, irrigable land does not represent a significant limitation to the modelling scenarios. However, in order to remain pragmatic and to demonstrate the efficacy of an irrigation scheme in close proximity to the site, a nominal area of 500 ha was selected for the HowLeaky modelling platform, based on the survey results indicating that at least 600 ha of available irrigable land lies within 5 km of the Leewood WMF.

The program employs a daily time-step simulation over a chosen look-back period as the basis of design for treated water irrigation systems. The model is used to optimise as many related factors as possible with the output predicting daily and seasonal irrigation schedules, maximum annual irrigation rates, appropriate crop choices, deep drainage rates, land area requirements and water storage requirements.

The model was run for a 50 year period using historic local climate data and a maximum irrigation rate of 60 ML/d (12 mm/d over 500 Ha). This exercise produced probabilities of the availability of water for irrigation, and the occurrence of surpluses that exceeded the nominal storage and irrigated land capacities. As can be seen in Figure 4 in Section 3.1, the peak treated water rate of 12 ML/d occurs for a period of approximately two to four years close to commencement of the project. After this initial period, the lower treated water availability substantially reduces the risk of treated water supply exceeding the irrigation demand and nominal storage, and resulting in a surplus of treated water. Hence, the occurrence of surplus treated water may be scaled in parallel with the scaling of the irrigation system to meet the supply of treated water. The offsite treated water storage will remain a fixed size while the input of treated water and consumption of irrigation water will both reduce such that the net consequence will be significantly less risk of surplus events occurring after year two of water production. In practice, the down-scaling of the irrigation network would lag behind the treated water production curve, such that demand would always exceed supply.

For the purposes of this modelling exercise it was assumed that 500 ha would be employed with a 90% application efficiency Seven CPs have been illustrated in Figure 11 in accordance with the example irrigation area. Should CPs be selected for the final scheme, adequate land area to permit siting of the requisite number of CPs would be employed. A climatic data set for a 50-year look-back period spanning 1963 to 2013 was simulated. The data were collected at the Narrabri post office [station 053030] and formed the basis for rainfall and evapotranspiration (ET) input. The mean annual rainfall calculated from the data was 644 mm and ET was 1,520 mm.

Two soil type options were selected for modelling purposes based upon the soil investigation. The Vertosol and Sodosol soils were selected, with a median plant available water holding capacity of the root zone predicted to be 200 mm, as discussed in Section 5.2.5. The maximum irrigation event was limited to 12 mm/day. The design must allow for adequate resting periods between irrigation to avoid rainfall runoff. For most plant systems, a soil water deficit (SWD) of at least 30 mm should be allowed to accrue before further irrigation takes place (DEC, 2004). To minimise rainfall runoff, the resting period between irrigation events was set such that irrigation would not occur unless a 30 mm SWD existed.

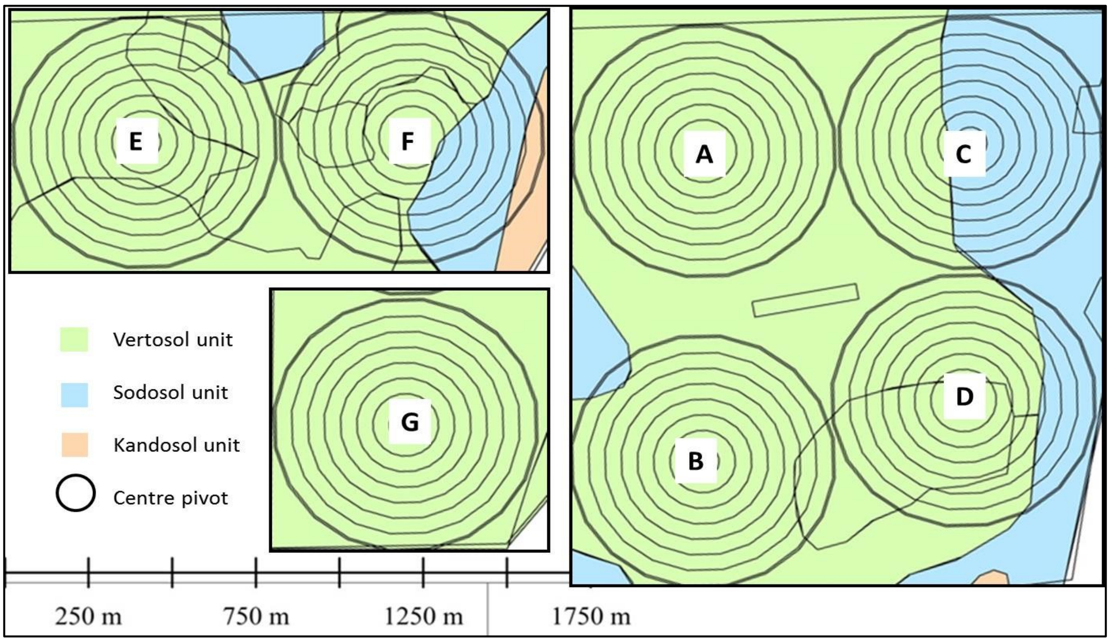


Figure 11 A representative arrangement of centre pivots across soil types on the example irrigation area

6.2.3 MODEL OUTCOMES

The outcomes of the HowLeaky modelling for the simulated irrigation strategy detailed in Section 6.2.2 above are summarised as follows:

- Annual irrigation application rate at peak production: 7.5 ML/ha-yr
- Pond storage volume: 200 ML and daily irrigation event volume of 60 ML, unless unavailable due to prior storage depletion
- Probability of a surplus of treated water occurring in a given year of peak production: ≤40%
- Average annual surplus volume during peak supply period: 200 ML

- The stored volume in the off-site treated water pond would generally be low, only filling during wet periods when irrigation diminishes
- The occurrence of surplus treated water will be infrequent, with treated water able either to be used for irrigation or stored for 95% of days (that is, around 18 days per year of surplus)
- Surplus treated water will be discharged to surface water systems in accordance with approval to be obtained by Santos.

7 CONCEPT LAYOUT AND DESIGN

7.1 IRRIGATION TECHNOLOGY

Centre pivots (CPs) require less labour than many irrigation technologies, can be operated remotely and operate on variable slopes. They typically irrigate a circular pattern so may not utilise all the available landscape. However, some flexibility is available through the use of corner attachments, variable rate irrigation technology and operation in a windscreen wiper motion, not considered in this concept design. Most CPs require a 3-phase electrical source. Larger CPs can be prone to causing runoff on the outer spans due to higher instantaneous rates of application and hence it is important to match nozzle types with soil intake rates in order to optimise infiltration. CPs are well suited to applying light frequent irrigation applications such as the 12 mm application rate as was modelled in HowLeaky. CPs were therefore chosen for this concept design.

7.2 IRRIGATION DESIGN

The irrigation system will be capable of delivering a peak water demand of 12 mm/day across 500 ha of irrigated land. The maximum effective daily irrigation rate would be 60 ML. The entire system - pump station, irrigation infrastructure and soil moisture sensors would be monitored and capable of being controlled remotely via telemetry or internet connections.

The CP systems would be supplied by a series of common mainlines and pumps. The configuration and characteristics of mainlines would be identified during the detailed design phase. Typically, there is a logistical advantage to clustering these systems on contiguous land parcels.

Design requirements include:

- Ensure the system operates efficiently
- Ensure the right type of pump, pipes and sprinklers are installed to achieve required flow rates and pressure levels
- Ensure access for repairs and maintenance
- Minimise hydraulic (friction) losses
- Minimise energy costs
- Ensure easy system operation
- Ensure that structural requirements are met
- Ensure that associated water delivery and drainage infrastructure (such as pipes, channels, gates, bore, valves, drains and culverts) are both correctly sized and located.

7.2.1 IRRIGATION SCHEDULING

Soil moisture monitoring equipment is essential in order to achieve the irrigation scheduling required for the success of the system. This should consider the soil water holding capacity, irrigation application rate and soil infiltration rate.

The soil moisture monitoring system should include either matrix potential sensors or capacitance probes connected to a field station which stores and sends data to a hub. The hub should collect and transfer data using a mobile telephone or telemetry network to a software application on the internet, accessible via computer, tablet or smart phone.

The irrigation manager is then responsible for ensuring that the soil moisture information is used to schedule the correct irrigation rates by adjusting the shift lengths as the weather and crop demand varies throughout the year.

7.2.2 Pump station requirements

It is envisioned that a redundant pump system would serve the irrigation system. All pumps would be controlled by variable frequency drives (VFD) and soft starts. This accommodates the multiple mainlines and varying flow rates required for sensitive control of water application. Small jockey pumps could maintain pressure in the lines when the systems were not running to minimise the effects of water hammer on pipelines and protect irrigation infrastructure.

Filtration must be provided to prevent nozzle clogging, with the utilisation of a coarser hydraulic screen-type filter recommended.

The pump station(s) will require an isolated switchgear room which should be located away from potential flood plains or raised above the flood water level on stilts or a platform.

7.2.3 Automation

In order to minimize the operating cost and enhance the flexibility of the systems the irrigation system should be capable of remote control. The control panels of the CPs can be linked to software on a desktop or laptop computer. The main control panel from the pump station can also be linked via computer software, as can the soil moisture monitoring equipment and filtration system.

The automation system will avoid potential overwatering. The irrigation events can be controlled to apply the required application when the operator is not on site. However, regular inspections at start-up and shut-down are recommended multiple times each week.

Rain sensors can be added to the system to shut down the pump units when it is raining.

7.3 LAND PREPARATION

The soils in this area are prone to becoming untrafficable following extended rainfall periods, i.e. periods where continuous rainfall events exceed 30 mm. The land preparation operations will be restricted during these periods to minimise traffic movements required to monitor and maintain the system in working order.

7.3.1 Land clearing

Although cleared paddocks would be targeted for development, there are areas where remnant trees and brush would interfere with the operation of centre pivots and these will therefore need clearing.

7.3.2 Gypsum

The majority of the soils in the region are inherently sodic in the subsoil. In order to maintain and improve infiltration rates, most of the soils are likely to require standard day-to-day farming techniques applied to displace sodium. For example, it is a common practice in farming, to apply gypsum into sodic layers through deep tillage, to achieve this outcome. The most appropriate technique will be best determined by the property owner themselves, based on their experience of the land and target crops to be irrigated.

7.3.3 Levelling

The strongly gilgai soil unit on the example irrigation area comprises high and low points, crests and hollows, of up to one meter depth / height over short distances. These undulations create uneven infiltration and drainage, and ponding in the hollows. Should such soils be present on the selected area, levelling would be required, and would be undertaken using a scraper to cut soil from the high points and to use the removed soil to fill the low points.

7.3.4 Ripping and cultivation

The soil may require ripping following levelling, particularly the high points that have had surface layers cut from them. Offset discs may need to be run across the site to produce a tilth suitable for sowing. Once the site has been ripped and cultivated, irrigation infrastructure will need to be installed in quick succession so as to minimise the risk of interference from wet weather.

7.4 IRRIGATION SYSTEMS INSTALLATION

7.4.1 Pump station and main lines

It is best to install the pump station and mainlines feeding the system prior to installation of the in-field irrigation infrastructure. This allows for testing of the system as it is built or shortly thereafter.

The mainlines and necessary wiring/telemetry should be laid and capped at the edge of the paddocks until the CPs are ready for connection.

7.4.2 Centre pivot sprinkler system

The centre pivots should be erected once the paddocks have been disced. The various components would arrive on a B-double semi-truck and offloaded with a telehandler and then laid out across the paddock. The spans would be assembled and erected with the same telehandler supported by two utility vehicles carrying tools and personnel. Care should be taken when driving equipment on the soft ground.

7.5 CROP ESTABLISHMENT

It is recommended that crops are sowed into a firm seedbed, with light pre-watering of the area under the CPs recommended.

7.5.1 Seed selection

A variety of lucerne suited to local conditions should be selected. Some desirable qualities of the selected lucerne seed variety include:

- Winter active to encourage year-round water consumption
- Broad disease resistance
- Inoculated with Rhizobium
- Fungicide treated seed
- Tolerant of sodic soils
- Potentially high forage production and water use
- Drought resistance

8 POTENTIAL IMPACTS OF IRRIGATION ACTIVITIES

8.1 SALT INPUTS FROM TREATED WATER AND SOIL IMPACTS

Most irrigation waters carry a salt load that presents a risk of accumulation in the rootzone particularly in arid regions or where high water tables exist. Annual rainfall of 644 mm will offset some of the effects of salt deposition by irrigation water. Given average rainfall, the weighted average EC of all water applied to the crop would be 0.57 and 0.99 mS/cm for the 25 and 30˚C water qualities respectively with a target irrigation rate of 7.5 ML/ha-yr. The average weighted rootzone salinity (EC_e), of the soils sampled was 2.55 mS/cm. The threshold EC_e for lucerne is given as 2.0 mS/cm, with a yield reduction of 25% to be expected from reaching a salinity threshold of approximately 6.0 mS/cm (DERM, 2011).

For lucerne, at an irrigation application rate of 750 mm/yr, or 7.5 ML/ha-yr, the total annual input of sodium, chloride and bicarbonate salts from irrigation is expected to be between 1734 and 3124 kg/ha-yr depending on temperature due to treated water quality (Table 7). Calcium sulphate (gypsum) addition of (2040 to 3315 kg/ha/yr) will offset added sodium and have a positive effect on soil quality. The sodium chloride salt loading from the irrigation water would then decline markedly in the years following the treated water supply peak. Note that natural salt inputs of sodium chloride from 644 mm rainfall are estimated to be approximately 32 kg/ha/yr (Biggs, 2004).

The lucerne modelling predicted deep drainage of 4 mm/yr on the Vertosols and 11 mm/yr on the Sodosols, whereas the minimum calculated deep drainage rate or leaching requirement should be 30 mm to maintain a rootzone salinity EC_e of 4.0. The shortfall in deep drainage can best be overcome by management of irrigation schedules. During periods of low ET, an excess amount of water could be applied as irrigation and rainfall, resulting in dilution and achieving adequate leaching of rootzone salts.

Table 7 Annual salt loading from 7.5 ML/ha of irrigation water on lucerne

Salt added	Treated water (25°C) (kg/ha-yr)	Treated water (30°C) (kg/ha-yr)
Sodium	578	1050
Chloride	113	623
Bicarbonate	1043	1448
Total sodium salts*	1734	3124

8.2 DEEP DRAINAGE AND GROUNDWATER IMPACTS

The HowLeaky model estimated that annual deep drainage would be 4 mm/yr and 11 mm/yr for lucerne grown on the Vertosol and Sodosol soil respectively. The annual wheat-cotton rotation indicated deep drainage of 44.9 mm/yr on the Vertosol soils and 46.5 mm/yr on the Sodosol soils.

By comparison, a study of seven irrigated Vertosol soils on cotton farms in localities representative of the area indicated average annual deep drainage of 48 mm (McGarry, et al., 2006).

Assuming a steady state of salinity within the rootzone based on suitable irrigation scheduling, the leachate concentration below the rootzone can be calculated based on salt loads introduced with the irrigation water. From Table 7 it can be seen that the annual salt introductions from 7.5 ML/ha of treated water will be between approximately 1734 kg/ha and 3124 kg/ha.

Although groundwater data for the example irrigation area were not available, there were indications of groundwater at a depth of approximately 20 m below the surface on the Leewood property. Assuming a substrate porosity of 20%, with half this porosity (10%) already filled with water at a drained upper limit (field capacity), deep drainage of 4 mm/yr under lucerne and 45 mm/yr under wheat-cotton would take approximately 500 and 50 years respectively for applied irrigation water to reach the water table at 20 m deep.

8.3 SURFACE WATER IMPACTS

In order to improve irrigation efficiency and prevent waterlogging or impacts from runoff, adequate engineering design of surface drainage will be carried out prior to the commencement of irrigation.

To ensure good surface drainage is achieved, construction of a layout with adequate gentle slopes and drainage systems to prevent ponding of runoff water from the irrigated area would be incorporated in the detailed design. This will be important in areas where the CP spans cross zones of strongly gilgai Vertosols and Sodosols. Here the automation of the CP system, including application rates, may have to be varied to reduce runoff.

Details or runoff monitoring are outlined in Section 10.3.

9 OPERATION AND MANAGEMENT

9.1 OPERATIONS AND MAINTENANCE GUIDELINES

Mechanical irrigation infrastructure must be well maintained in order to ensure the viability of the water dispersal system.

Detailed standard operating procedures should be developed or adapted to cover all aspects of operations and maintenance. Specific preventive maintenance programs for all equipment components should be developed or adapted. Operations personnel should be trained in the routine operations and maintenance of these systems and the appropriate experts should be utilised for other key aspects.

9.2 IRRIGATION SYSTEMS

Most functions of the irrigation system can be monitored electronically through a variety of market-available SCADA systems. Remote control and data tracking options are recommended.

Creation and maintenance of an accurate set of as-built drawings for the entire system is imperative to enable identification of isolation valves and workarounds when problems occur.

9.2.1 WATER AMENDMENT

The treated water would be amended to reduce SAR by introducing calcium salts directly into the treatment stream within the Leewood WMF, prior to conveyance to the offsite treated water storage pond. Some pH neutralisation with acid may be desirable dependent on the alkalinity of the treated water. However, the likely concentrations of sulphuric acid required to reduce the pH would be offset by disappearance of bicarbonate ions.

9.2.2 PUMP AND FILTER STATION

Variable speed pumps (with built in redundancy) would supply mainlines for the CP system. The pumps should be regularly inspected and maintained according to the manufacturer's recommendations. Tracking of amperage on each pump would provide a record of pump wear (as well as CP nozzle and pressure regulator wear) and indicate when replacement or repair may be needed.

Each pump would have an associated Y-strainer filter on the intake side which should be periodically cleaned and maintained according to the amount of suspended solids in the incoming water.

The water directed to the CP would pass through several rotating automated screen filters before going through the multiple field mainlines.

Filter units typically require constant monitoring. The development of differential pressure indicates the need for backwashing of the filters and decreasing time between backwashes typically indicates the requirement for filter cleaning.

9.2.3 Pipelines, valves and flow sensors

The mainline supplying water to the irrigation storage and each of the mainlines leaving the pump station would be outfitted with a flow meter that measures both flow rate and total volume. These sensors should be cleaned and maintained regularly. The frequency of maintenance would depend upon the nature of the incoming water and the meter design.

The flow meters on mainlines would be used in the pump station logic to ramp up line filling and detect leaks or line breaks. Excessive flows would trigger the pumps to shut down. Smaller increases in flow rate would indicate smaller, less obvious leakage.

Mains and sub-mains should be inspected regularly by the operators for leaks. The system would have a series of isolation valves that should be checked on a regular basis to ensure they function as intended. Pressure reduction and control valves located at the centre of each CP would require regular monitoring and calibration.

It is anticipated that electrical supply and control wires would follow the mains, unless a telemetry control unit is installed. Utility corridors should be inspected for burrowing animals or other occurrences that could intersect and damage the wires.

9.2.4 Centre pivot system

Centre pivots require regular inspection and maintenance. On a more frequent basis (daily or weekly) this would include visual inspections of sprinkler nozzle plugging, track erosion or runoff. Gearboxes and wheel drive motors will require at least annual maintenance. Cables should also be inspected for damage from wildlife. The steel structure should be inspected for corrosion at least annually.

The travel and output of the CP should be tracked remotely and daily inspections of progress should be undertaken. Catch can (rain gauge) tests should be performed to test the CP application uniformity to ensure adequate control for sensitive areas.

9.2.5 Recordkeeping

Records should be kept for:

- Water volume applied through each system
- Amendments used and concentration as evidenced by sensors and field tests
- Repairs to the system
- Weather
- Equipment maintenance records
- Changes in irrigation programs
- Water analyses.

9.3 CROP MANAGEMENT

9.3.1 Early crop care

It may be necessary to apply herbicides both before and after sowing if weed infestations are significant. The young seedlings should be inspected frequently by a qualified agronomist for pest and disease incidence. In the event that predation or disease occurs, the paddocks should be treated with an appropriate control (i.e. fungicide or insecticide).

It is anticipated that the lucerne stand will be viable for five to seven years before crop rotation is required. Typically, there is one growing season between lucerne crops where another crop is grown. The timing will be dependent on successful selection of varieties, soil preparation and how well the crop is managed in general. It is best to rotate and re-establish portions of the paddocks in phases to ensure there is always a crop to use the available water supply.

Double-cropping will require care specific to the species grown and should be overseen by a qualified agronomist.

9.3.2 Irrigation Scheduling

The irrigation schedule would be driven by soil water deficit and the availability of treated water. The HowLeaky model parameters were set so that irrigation would only occur once a 30 mm soil water deficit (SWD) occurred and that only 12 mm would be applied in an irrigation event. It may be necessary to concentrate the irrigation on a smaller selection of the area so as to maintain an area of crop in a healthy condition. Crop management is another variable that will influence the irrigation scheduling.

An onsite weather station would record rainfall, temperature, solar radiation and wind speed. The collected data would facilitate calculation of evapotranspiration (ET) in real time for the selected location.

Soil moisture monitoring devices should be placed one for every 25 ha and the data collected and reviewed weekly against the weather station data. The soil moisture data collection should be supplemented by spot checks with a hand auger. Irrigation rates should be adjusted by soil and crop type as often as necessary to optimise crop health and water use.

Some of the soil moisture monitoring devices would also be placed at least 200 cm deep to estimate root uptake of deep moisture and deep drainage.

9.3.3 Agronomy

Optimisation of agronomic care is typically required to ensure that a healthy, actively growing crop is always available to utilise irrigation water. Regular field inspections by a qualified agronomist are recommended.

The crop should be inspected for weeds, diseases and insects at key intervals and appropriate treatments recommended. Irrigation distribution should be spot checked at the same time. Leaf and forage analyses should be performed occasionally to assess plant nutrition.

The agronomist should make recommendations for harvest timing which would optimise forage quality, and minimise impacts on water utilisation and soil quality. The agronomist would also make recommendations for the crop rotation sequences suitable to the goals of the project.

The surface 15 cm of topsoil should be sampled annually and the soil analysed for nutrients, boron and salinity. These data would provide the basis for ongoing fertiliser and soil amendment applications. Subsequent deeper soil analysis to at least 100 cm should be undertaken to assess the success of the soil amelioration program and accumulation of salts in the rootzone.

9.3.4 Harvest

It is anticipated that the forage crop would be harvested typically up to five times annually. Harvest operations should be undertaken carefully to minimise soil compaction, and soils should be dried out prior to operations. Once the crop is swathed and baled, traffic patterns relating to bale removal should minimise travel upon the irrigated areas of the paddock. Bales should be stored in a location that encourages careful traffic management.

Double-crop harvesting would also be proceeded by a dry down period to reduce the risk of soil compaction.

9.3.5 FERTILISER

Soil tests have indicated that typically the limiting nutrients in these soils are nitrogen (N) and phosphorus (P), and that potassium (K) is adequate. Most of the nitrogen that the lucerne crop would require over time would come from the legume itself. Phosphorus is rapidly immobilised in soil with surface applied phosphorus held in the surface soil potentially leading to availability restrictions when the surface soil is dry. The opportunity is available prior to crop establishment to work a number of year's supply of phosphorus into the profile during the process of cultivating. Consequently, 100 kg/ha phosphorus would be applied as mono-ammonium phosphate prior to ripping. Annual applications of phosphorus fertiliser to crops as per crop removal calculations and soil test results would be recommended.

10 ENVIRONMENTAL MONITORING

Given the soil water deficit schedule being applied, it is anticipated that runoff and deep drainage would be predominantly driven by rainfall, and would not be highly altered from conditions under a dryland pasture regime. The HowLeaky lucerne model suggests that there would be small amounts of deep drainage beyond the root zone under irrigation, similar to those under the current pasture condition. Water and salts should be tracked as they pass through and beyond the root zone. Fluxes in groundwater static level and quality should also be tracked.

Consistent with typical irrigation practices, a monitoring program would be designed as part of an Irrigation Management Plan to predict and prevent harmful impacts of treated water on the receiving environment by facilitating the early detection of adverse trends.

Apart from monitoring the effects on the environment, monitoring the performance of the irrigation system is required to ensure that the system performs effectively, and to achieve the uniform distribution of treated irrigation water with minimal downtime. This aspect of monitoring will ensure that maintenance is carried out in a timely manner and that maintenance requirements are not extreme.

10.1 SOIL CONDITION MONITORING

The following section outlines strategies consistent with typical irrigation practices that would be considered as part of an Irrigation Management Plan to achieve successful soil condition monitoring.

10.1.1 SOIL CHEMISTRY

Baseline values for soil pH, electrical conductivity (EC), chloride, sulphate, cations (calcium, magnesium and sodium), exchangeable sodium percentage and soil fertility (nitrogen, phosphorus, potassium, sulphur and micronutrients) should be established within key soil horizons. Samples from representative sites selected as 'typical' would be collected from similar depths in the future and used for comparison to the baseline data. Chemical analysis would be conducted for the necessary parameters.

Comparison of soil chemical analysis results with baseline data will enable monitoring of the influence of treated water on soil chemical properties. In particular, attention must be given to monitoring the effect of irrigation water on:

- Soil salinity (EC_e, chloride and sodium levels) to ensure no build-up of salts in the soil profile occurs;
- Soil ESP and SAR as indicators of soil structural stability; and
- Changes in soil pH due to its influence on plant nutrient availability and soil chemistry toxicities.

10.1.2 CONTINUOUS SOIL MOISTURE MONITORING

Soil moisture monitoring stations located on each 25 ha of centre pivot irrigated paddock. These would ideally be equipped to measure soil moisture, detect water draining past the rootzone, and assess salinity flux throughout, and at the bottom of, the rootzone to a depth of 200 cm. These stations may be fitted with telemetry devices to allow for remote data collection. The soil moisture data would be used in decision making for irrigation scheduling.

10.1.3 ELECTROMAGNETIC INDUCTION MONITORING

Electromagnetic induction (EMI) soil surveying to track moisture and salt accumulation. EMI soil surveying can recognise areas of differing moisture conditions and/or salt loadings, allowing areas requiring supplementary attention to receive early investigation or rehabilitation. A baseline EMI survey of the selected site(s) should be conducted prior to irrigation and then compared against that in subsequent years after commencement of irrigation.

10.2 GROUNDWATER MONITORING

Where required, groundwater monitoring bore placement depending upon the depth to groundwater and the lithology of the vadose zone in the area of irrigation. Irrigation systems are typically monitored with at least three monitoring wells, with one upgradient and two downgradient.

The installation of pressure transducers with data recording capabilities would assist in the detection of deep drainage from the irrigated area. The data, coordinated with soil moisture monitoring devices, can be used to track the potential impacts of rain and localised irrigation recharge on groundwater at the site.

10.3 RUNOFF MONITORING

Although the slopes are slight and crop cover would be maintained, it is expected that some water would typically run off irrigated paddocks. Runoff would most likely be driven by rainfall events and is predicted to carry small amounts of sediment and nutrients. Losses of sediment and nutrients from the irrigated project area should be monitored by placing stormwater sampling devices upstream of the paddocks where run-on might occur and downstream where runoff might occur. The contribution from the irrigated paddocks would be calculated as a portion of the micro-catchment feeding the sampling device.

10.4 SOIL AND VADOSE MONITORING

A soil sampling protocol that utilises benchmark testing zones under each representing various soil types and positions on the landscape may be required. The zones should be no more than 2,000 m^2 in size and core sampled annually to a depth of 3 m. Three cores would be advanced per zone annually and composited by depth segments of approximately 0.5 m each except for the top 1.0 m which would be segmented in four 0.25 m parts. The core holes should be plugged with bentonite chips to prevent water from running into the holes and skewing future results. The composited samples would be analysed for pH, EC_e, chloride, sulphate, boron, SAR and other constituents that may be of concern.

As outlined above, a comprehensive monitoring network typical of normal irrigation practices would be developed for the specific site once chosen, and would be incorporated within an Irrigation Management Plan.

11 LEGAL FRAMEWORK

The irrigation concept design has been developed in accordance with the Office of Environment and Heritage (NSW), previously the Department of Environment and Conservation (NSW), *Environmental Guidelines: Use of Effluent by Irrigation*.

Infrastructure requirements for the irrigation scheme, including storage structures and irrigation pipes, will be assessed and approved under the *Environmental Planning and Assessment Act 1979 (EP&A Act)*, likely as a component of approval of the Environmental Impact Assessment.

An environment protection licence under the *Protection of the Environment Operations Act 1997* (POEO Act) is not generally required for effluent irrigation schemes, though the licence for development of the Narrabri Gas Project may include conditions relating the irrigation scheme.

12 SUMMARY

Based on the outcomes of the scenario modelling, lucerne was recommended as the crop most suitable to accommodate the peak production phase of the Narrabri Gas Project irrigation strategy. The alternative annual cropping options that were investigated proved to be inferior to perennial lucerne in utilising water consistently. The HowLeaky modelling for the simulated irrigation strategy indicated the following irrigation and storage volume requirements for a nominal irrigation area of 500 ha and an assumed peak treated water rate of 12 ML/d:

- Annual irrigation application rate at peak production: 7.5 ML/ha-yr
- Pond storage volume: 200 ML and daily irrigation event volume of 60 ML, unless unavailable due to storage depletion
- Probability of a surplus of treated water occurring in a given year during peak production: ≤40% (declining rapidly with falling treated water availability)
- Average volume of a surplus event should one occur during peak supply: 200 ML
- The stored volume in the off-site treated water pond would generally be low, only filling during wet periods when irrigation diminishes
- The occurrence of surplus treated water will be infrequent, with treated water able either to be used for irrigation or stored for 95% of days
- Surplus treated water will be discharged to surface water systems in accordance with approval to be obtained by Santos.
- Salt loading during peak flow will be comparable with conventional irrigation practices. This will decline as available water supply is diminished.

Amendment of the treated water will be undertaken at the Leewood WMF to reduce the sodium adsorption ratio of the treated water and make the water more suitable for irrigation. Dispersive soils may also need to be amended to a non-dispersive state prior to irrigation set up. The appropriate farming technique will need to be determined by the individual land owner taking into account their soil characteristics and targeted irrigation crops. The most common form will likely be the application of gypsum through deep tillage. Groundwater depth in the vicinity of the irrigation area is approximately 20 m below the surface. For the proposed lucerne and the alternative wheat-cotton double crop rotation, it would take approximately 500 and 50 years respectively for applied irrigation water to reach the groundwater table.

Whilst the amended irrigation water will contribute sodium and calcium ions in a ratio that should prevent soil dispersion, the potential for EC_e to rise as a consequence will be managed by targeting the leaching fraction of irrigation applications seasonally, toward periods when evapotranspiration (ET) is low. This is best monitored through annual soil sampling.

A management, maintenance and monitoring program has been developed for the proposed irrigation strategy. The monitoring program is designed to enable the prediction and prevention of harmful impacts of treated water on the receiving environment by facilitating the early detection of non-compliant results.

In addition to monitoring environmental impacts, monitoring of the performance of the irrigation system will be undertaken to ensure that the system performs effectively and achieves the uniform distribution of treated irrigation water with minimal downtime.

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APPENDIX

Soil Profile Descriptions and Chemistry

Profile name	Layer	Santos label	Depth (cm)		Horizon	Munsell	Colour	Mottles	Texture	Est	Structure			Moisture content	Strength	Carbonate nodules	Carbonate fiz	Roots	pH	Comments
			Top	Bot.		Colour				clay %	Grade	Type	Size (mm)					Rank		
B01	1	7300_SOIL_0.15_1312030856	0	15	A1	10YR2/2	very dark brown	-	light medium clay	40%	medium	subangular blocky	10	moist	firm	nil	nil	3	7	cracking and soft surface. Wheat stubble
	2	7300_SOIL_0.5_1312030856	15	50	B21	10YR3/2	very dark grey brown	-	medium heavy clay	50%	-	coarse	-	slightly moist	hard	common	nil	2	8.5	
	3	7300_SOIL_0.9_1312030856	50	90	B22	10YR3/3	dark brown	slight orange & grey	medium heavy clay	50%	-	coarse	-	slightly moist	hard	nil	nil	2	9	
	4	7300_SOIL_1.4_1312030856	90	140	B23	10YR4/3	brown	slight orange & brown	medium heavy clay	50%	-	coarse	-	slightly moist/moist	very hard	few	nil	1/2	5	
B02	1	7301_SOIL_0.15_1312030920	0	15	A1	10YR2/2	very dark brown	-	light medium clay	40%	medium	subangular blocky	10	moist	firm	nil	nil	3	7	cracking and soft surface. Wheat stubble
	2	7301_SOIL_0.5_1312030920	15	50	B21	10YR3/2	very dark grey brown	-	medium heavy clay	50%	-	coarse	-	slightly moist	hard	common	nil	2	8.5	
	3	7301_SOIL_0.9_1312030920	50	90	B22	10YR3/3	dark brown	slight orange & grey	medium heavy clay	50%	-	coarse	-	slightly moist	hard	nil	nil	2	9	
	4	7301_SOIL_1.4_1312030920	90	140	B23	10YR4/3	brown	slight orange & brown	medium heavy clay	50%	-	coarse	-	slightly moist/moist	very hard	few	nil	1/2	5	
B03	1	7302_SOIL_0.15_1312030936	0	15	A1	10YR3/2	very dark grey brown	-	medium clay	45%	weak	subangular blocky	10	slightly moist	firm	nil	nil	3	7	cracking and soft surface. Wheat stubble
	2	7302_SOIL_0.5_1312030936	15	50	B21	10YR3/1	very dark grey	-	medium heavy clay	50%	-	coarse	-	dry/slightly moist	hard/very hard	nil	nil	2	8.5	
	3	7302_SOIL_0.9_1312030936	50	90	B22	10YR3/2	very dark grey brown	-	medium heavy clay	50%	-	coarse	-	slightly moist	hard/very hard	nil	nil	2	9	
	4	7302_SOIL_1.4_1312030936	90	140	B23	10YR4/3	brown	-	medium clay	45%	-	coarse	-	slightly moist	hard	nil	nil	1	5	
B04	1	7303_SOIL_0.15_1312030950	0	15	A1	10YR2/2	very dark brown	-	clay loam, sandy	30%	-	massive	-	slightly moist	firm	nil	nil	2	5.5	hard setting surface. legume stubble
	2	7303_SOIL_0.45_1312030950	15	45	B21	10YR3/4	dark yellow brown	-	medium clay	45%	-	coarse	-	dry/slightly moist	firm/hard	nil	nil	2	8	
	3	7303_SOIL_0.85_1312030950	45	85	B22	10YR4/3	brown	slight orange	medium clay	45%	-	coarse	-	slightly moist/moist	firm/hard	common	medium	2	8.5	
	4	7303_SOIL_1.4_1312030950	85	140	B23	2.5Y5/2	grey brown	small red-brown	medium clay	45%	-	coarse	-	slightly moist/moist	firm/hard	common	medium	0	9	
B05	1	7304_SOIL_0.15_1312031016	0	15	A1	10YR2/2	very dark brown	-	sandy clay loam	25%	-	massive	-	slightly moist/moist	firm	nil	nil	2	5.75	hard setting surface. legume stubble
	2	7304_SOIL_0.45_1312031016	15	45	B21	10YR2/2	very dark brown	-	medium clay	45%	-	coarse	-	slightly moist/moist	firm/hard	nil	nil	2	7.5	
	3	7304_SOIL_0.9_1312031016	45	90	B22	10YR3/2	very dark grey brown	slight brown	medium clay	45%	-	coarse	-	slightly moist/moist	firm/hard	few	nil	1	9	
	4	7304_SOIL_1.4_1312031016	90	140	B23	2.5Y5/2	grey brown	brown	medium heavy clay	50%	-	coarse	-	slightly moist/moist	hard	common	nil	0	9	
B06	1	7305_SOIL_0.15_1312031027	0	15	A1	10YR3/1	very dark grey	-	light medium clay	40%	strong	subangular blocky	10	slightly moist/moist	firm	nil	nil	3	7.5	cracking and soft surface. Wheat stubble
	2	7305_SOIL_0.5_1312031027	15	50	B21	10YR3/1	very dark grey	-	heavy clay	55%	strong	lenticular	-	slightly moist	hard	nil	nil	2	8.5	
	3	7305_SOIL_1.0_1312031027	50	100	B22	10YR3/2	very dark grey brown	-	medium heavy clay	50%	strong	lenticular	-	moist	hard	nil	nil	2	6	
	4	7305_SOIL_1.4_1312031027	100	140	B23	10YR3/2	very dark grey brown	-	heavy clay	55%	strong	lenticular	-	slightly moist/moist	hard	nil	nil	2/1	5	
B07	1	7306_SOIL_0.15_1312031046	0	15	A1	10YR2/2	very dark brown	-	light medium clay	40%	medium	subangular blocky	10	moist	firm	nil	nil	3	-	cracking and soft surface. Wheat stubble
	2	7306_SOIL_0.5_1312031046	15	50	B21	10YR3/2	very dark grey brown	-	medium heavy clay	50%	-	coarse	-	slightly moist	hard	common	nil	2	-	
	3	7306_SOIL_1.0_1312031046	50	100	B22	10YR3/3	dark brown	slight orange & grey	medium heavy clay	50%	-	coarse	-	slightly moist	hard	nil	nil	2	-	
	4	7306_SOIL_1.4_1312031046	100	140	B23	10YR4/3	brown	slight orange & brown	medium heavy clay	50%	-	coarse	-	slightly moist/moist	very hard	few	nil	1/2	-	

Profile name	Layer	Santos label	Depth (cm)		Horizon	Munsell Colour	Colour	Mottles	Texture	Est clay %	Structure			Moisture content	Strength	Carbonate nodules	Carbonate fiz	Roots	pH	Comments
			Top	Bot.							Grade	Type	Size (mm)					Rank		
B08	1	7307_SOIL_0.15_1312031110	0	15	A1	10YR3/1	very dark grey	-	light medium clay	40%	strong	subangular blocky	10	slightly moist	soft/firm	nil	nil	3	7.5	cracking and soft surface. Wheat stubble
	2	7307_SOIL_0.5_1312031110	15	50	B21	7.5YR3/4	dark brown	distinct dark grey	medium clay	45%	-	coarse	-	slightly moist	very hard	few	medium	2	8	
	3	7307_SOIL_0.85_1312031110	50	85	B22	5YR3/4	dark red brown	small black & grey	medium clay	45%	-	coarse	-	dry/slightly moist	very hard	common	slight/ medium	2	9	
	4	7307_SOIL_1.2_1312031110	85	120	B23	7.5YR3/4	dark brown	-	medium clay	45%	-	coarse	-	moist	firm/hard	few	nil	2	-	
B09	1	7308_SOIL_0.15_1312031140	0	15	A1	10YR3/1	very dark grey	-	light medium clay	40%	medium	subangular blocky	10	slightly moist/moist	soft	nil	nil	3	7.5	cracking and soft surface. Wheat stubble
	2	7308_SOIL_0.5_1312031140	15	50	B21	10YR3/2	very dark grey brown	-	medium heavy clay	50%	-	coarse	-	slightly moist	very hard	common	medium	2	7.5	
	3	7308_SOIL_0.9_1312031140	50	90	B22	10YR4/1	dark grey	-	medium heavy clay	50%	-	coarse	-	slightly moist	very hard	common	nil	2	8.5	
	4	7308_SOIL_1.4_1312031140	90	140	B23	-	-	-	medium heavy clay	50%	-	coarse	-	moist	very hard	nil	nil	1	4.5	
B10	1	7309_SOIL_0.15_1312031210	0	15	A1	10YR3/2	very dark grey brown	-	light medium clay	40%	medium	subangular blocky	10	slightly moist/moist	firm/hard	nil	nil	3	7.5	cracking and soft surface. Wheat stubble
	2	7309_SOIL_0.45_1312031210	15	45	B21	10YR3/1	very dark grey	-	medium heavy clay	50%	-	coarse	-	slightly moist/moist	very hard	nil	nil	2	8.5	
	3	7309_SOIL_0.85_1312031210	45	85	B22	10YR3/3	dark brown	-	medium heavy clay	50%	-	coarse	-	slightly moist/moist	hard	nil	nil	2	7.5	
	4	7309_SOIL_1.4_1312031210	85	140	B23	10YR4/3	brown	-	medium clay	45%	-	coarse	-	slightly moist/moist	hard	nil	nil	1	4.75	
B11	1	7310_SOIL_0.10_1312031248	0	10	A1	7.5YR4/4	dark brown	-	sandy clay loam	25%	-	massive	-	dry	firm	nil	nil	3	5.75	hard setting surface. legume stubble
	2	7310_SOIL_0.4_1312031248	10	40	B21	10YR3/4	dark yellow brown	slight grey	medium clay	45%	-	coarse	-	slightly moist	very hard	nil	nil	2	8	
	3	7310_SOIL_0.8_1312031248	40	80	B22	10YR3/6	dark yellow brown	slight brown	medium clay	45%	-	coarse	-	slightly moist/moist	hard	nil	nil	1	8.5	
	4	7310_SOIL_1.4_1312031248	80	140	B23	2.5Y5/4	light olive brown	slight orange	light medium clay	40%	-	coarse	-	slightly moist/moist	hard	nil	nil	0	8.5	
B12	1	7311_SOIL_0.1_1312031310	0	10	A1	7.5YR4/6	strong brown	-	sandy clay loam	25%	-	massive	-	slightly moist	soft	nil	nil	2	6	hard setting surface. legume stubble
	2	7311_SOIL_0.5_1312031310	10	50	B21	7.5YR4/6	strong brown	-	medium clay	45%	-	coarse	-	slightly moist	hard/very hard	nil	nil	2	6.5	
	3	7311_SOIL_0.95_1312031310	50	95	B22	7.5YR3/4	dark brown	slight grey	medium clay	45%	-	coarse	-	moist	hard	nil	nil	0	5.5	
	4	7311_SOIL_1.4_1312031310	95	140	B23	10YR5/2	grey brown	distinct red & brown	medium clay	45%	-	coarse	-	slightly moist/moist	very hard	nil	nil	0	5	
B13	1	7312_SOIL_0.15_1312031330	0	15	A1	10YR3/2	very dark grey brown	-	light medium clay	40%	strong	subangular blocky	10	slightly moist/moist	firm/ hard	nil	nil	3	7	cracking surface. Fallow cultivated pasture
	2	7312_SOIL_0.5_1312031330	15	50	B21	10YR3/3	dark brown	-	medium clay	45%	-	coarse	-	slightly moist/moist	hard	nil	nil	2	7.5	
	3	7312_SOIL_0.9_1312031330	50	90	B22	10YR3/3	dark brown	-	medium clay	45%	-	coarse	-	slightly moist/moist	hard	nil	nil	2	7	
	4	7312_SOIL_1.4_1312031330	90	140	B23	7.5YR4/4	dark brown	slight orange	medium clay	45%	-	coarse	-	dry/ slightly moist	very hard	nil	nil	0	5.5	
B14	1	7313_SOIL_0.15_1312031353	0	15	A1	10YR3/4	dark yellow brown	-	medium clay	45%	strong	subangular blocky	10	slightly moist	firm/ hard	nil	nil	3	6.5	cracking surface. Fallow cultivated pasture
	2	7313_SOIL_0.5_1312031353	15	50	B21	10YR3/3	dark brown	-	medium heavy clay	50%	-	coarse	-	slightly moist	very hard	nil	nil	2	8	
	3	7313_SOIL_0.9_1312031353	50	90	B22	10YR3/3	dark brown	-	medium heavy clay	50%	-	coarse	-	slightly moist	very hard	few	nil	2/1	8	
	4	7313_SOIL_1.4_1312031353	90	140	B23	10YR3/4	dark yellow brown	-	medium clay	45%	-	coarse	-	dry/slightly moist	very hard	nil	nil	1	6.5	

Profile name	Layer	Santos label	Depth (cm) Top	Depth (cm) Bot.	Horizon	Munsell Colour	Colour	Mottles	Texture	Est clay %	Structure Grade	Structure Type	Structure Size (mm)	Moisture content	Strength	Carbonate nodules	Carbonate fiz	Roots Rank	pH	Comments
B15	1	7314_SOIL_0.15_1312031415	0	15	A1	10YR2/2	very dark brown	-	light medium clay	40%	strong	subangular blocky	10	slightly moist/moist	firm	nil	slight	3	7.5	cracking and soft surface. Fallow cultivated pasture
	2	7314_SOIL_0.5_1312031415	15	50	B21	10YR4/2	dark grey	darker grey	heavy clay	55%	-	coarse	-	moist	firm/ hard	few	nil	2	8.5	
	3	7314_SOIL_0.9_1312031415	50	90	B22	10YR5/2	grey brown	-	heavy clay	55%	strong	lenticular	-	moist	firm/ hard	few	nil	2/1	7.5	
	4	7314_SOIL_1.4_1312031415	90	140	B23	10YR5/2	grey brown	-	heavy clay	55%	-	coarse	-	moist	firm/ hard	nil	nil	2/1	4.5	
B16	1	7315_SOIL_0.15_1312031435	0	15	A1	7.5YR3/4	dark brown	-	medium clay	45%	medium	subangular blocky	10	slightly moist	soft/firm	nil	nil	3	7.5	cracking and soft surface. Wheat stubble
	2	7315_SOIL_0.5_1312031435	15	50	B21	7.5YR3/4	dark brown	-	medium clay	45%	-	coarse	-	moist	firm/ hard	common	medium	2	8	
	3	7315_SOIL_0.9_1312031435	50	90	B22	7.5YR3/4	dark brown	-	medium clay	45%	-	coarse	-	slightly moist/moist	hard	nil	nil	2	9	
	4	7315_SOIL_1.4_1312031435	90	140	B23	7.5YR4/6	strong brown	-	medium clay	45%	-	coarse	-	slightly moist/moist	hard/very hard	nil	nil	1	8.5	
B17	1	7316_SOIL_0.15_1312031504	0	15	A1	10YR3/3	dark brown	-	medium clay	45%	strong	subangular blocky	10	slightly moist/moist	firm	nil	nil	3	7	cracking and hard surface. Pasture
	2	7316_SOIL_0.5_1312031504	15	50	B21	10YR3/2	very dark grey brown	-	medium clay	45%	-	coarse	-	dry/slightly moist	hard/very hard	nil	nil	2	8.5	
	3	7316_SOIL_0.9_1312031504	50	90	B22	10YR3/2	very dark grey brown	-	medium clay	45%	-	coarse	-	dry	hard	nil	nil	2	7.5	
	4	7316_SOIL_1.4_1312031504	90	140	B23	10YR3/3	dark brown	-	medium heavy clay	50%	strong	lenticular	-	dry/slightly moist	very hard	nil	nil	2/1	4.75	
B18	1	7317_SOIL_0.15_1312031520	0	15	A1	10YR3/1	very dark grey	-	medium clay	45%	strong	subangular blocky	10	slightly moist/moist	firm	nil	nil	3	7.5	cracking and soft surface. Wheat stubble
	2	7317_SOIL_0.5_1312031520	15	50	B21	10YR3/1	very dark grey	-	medium heavy clay	50%	-	coarse	-	slightly moist/moist	firm/ hard	nil	nil	2	8	
	3	7317_SOIL_0.95_1312031520	50	95	B22	10YR3/1	very dark grey	-	medium heavy clay	50%	-	coarse	-	moist	firm/ hard	nil	nil	2	8.5	
	4	7317_SOIL_1.4_1312031520	95	140	B23	10YR4/3	brown	light grey	medium clay	45%	-	coarse	-	slightly moist	very hard	nil	nil	1	8.5	
B19	1	7318_SOIL_0.15_1312031545	0	15	A1	10YR3/2	very dark grey brown	-	light medium clay	40%	strong	subangular blocky	10	moist	soft/ firm	nil	nil	3	7	cracking and soft surface. Wheat stubble
	2	7318_SOIL_0.5_1312031545	15	50	B21	10YR3/2	very dark grey brown	-	medium heavy clay	50%	-	coarse	-	dry	very hard	few	slight	2	8.5	
	3	7318_SOIL_0.9_1312031545	50	90	B22	10YR3/2	very dark grey brown	-	medium clay	45%	-	coarse	-	slightly moist	hard	few	slight	2	8	
	4	7318_SOIL_1.4_1312031545	90	140	B23	10YR3/3	dark brown	-	medium clay	45%	-	coarse	-	slightly moist/moist	hard	nil	nil	2	8	
B20	1	7319_SOIL_0.15_1312031600	0	15	A1	10YR3/2	very dark grey brown	-	medium clay	45%	strong	subangular blocky	10	slightly moist/moist	firm	nil	nil	3	7.5	cracking surface. Wheat stubble
	2	7319_SOIL_0.4_1312031600	15	40	B21	10YR4/2	dark grey brown	-	medium heavy clay	50%	strong	lenticular	-	dry	very hard	common	nil	2	8	
	3	7319_SOIL_0.8_1312031600	40	80	B22	10YR3/3	dark brown	-	medium heavy clay	50%	-	coarse	-	slightly moist	hard	few	nil	2	8	
	4	7319_SOIL_1.3_1312031600	80	130	B23	10YR3/3	dark brown	-	medium clay	45%	-	coarse	-	slightly moist	hard	nil	slight	1	9	
B21	1	7320_SOIL_0.15_1312031615	0	15	A1	10YR3/2	very dark grey brown	-	medium clay	45%	strong	subangular blocky	10	slightly moist/moist	firm	nil	nil	3	7.5	cracking and soft surface. Wheat stubble
	2	7320_SOIL_0.55_1312031615	15	55	B21	10YR4/2	dark grey brown	-	medium heavy clay	50%	-	coarse	-	dry/slightly moist	very hard	few	slight	2	8.5	
	3	7320_SOIL_0.95_1312031615	55	95	B22	10YR4/2	dark grey brown	-	medium heavy clay	50%	-	coarse	-	slightly moist/moist	hard/very hard	nil	nil	2	9	
	4	7320_SOIL_1.4_1312031615	95	140	B23	10YR4/3	brown	-	medium clay	45%	-	coarse	-	slightly moist/moist	hard/very hard	nil	nil	1	4.75	

Profile name	Layer	Santos label	Depth (cm) Top	Depth (cm) Bot.	Horizon	Munsell Colour	Colour	Mottles	Texture	Est clay %	Structure Grade	Structure Type	Structure Size (mm)	Moisture content	Strength	Carbonate nodules	Carbonate fiz	Roots Rank	pH	Comments
B15	1	7314_SOIL_0.15_1312031415	0	15	A1	10YR2/2	very dark brown	-	light medium clay	40%	strong	subangular blocky	10	slightly moist/moist	firm	nil	slight	3	7.5	cracking and soft surface. Fallow cultivated pasture
	2	7314_SOIL_0.5_1312031415	15	50	B21	10YR4/2	dark grey	darker grey	heavy clay	55%	-	coarse	-	moist	firm/ hard	few	nil	2	8.5	
	3	7314_SOIL_0.9_1312031415	50	90	B22	10YR5/2	grey brown	-	heavy clay	55%	strong	lenticular	-	moist	firm/ hard	few	nil	2/1	7.5	
	4	7314_SOIL_1.4_1312031415	90	140	B23	10YR5/2	grey brown	-	heavy clay	55%	-	coarse	-	moist	firm/ hard	nil	nil	2/1	4.5	
B16	1	7315_SOIL_0.15_1312031435	0	15	A1	7.5YR3/4	dark brown	-	medium clay	45%	medium	subangular blocky	10	slightly moist	soft/firm	nil	nil	3	7.5	cracking and soft surface. Wheat stubble
	2	7315_SOIL_0.5_1312031435	15	50	B21	7.5YR3/4	dark brown	-	medium clay	45%	-	coarse	-	moist	firm/ hard	common	medium	2	8	
	3	7315_SOIL_0.9_1312031435	50	90	B22	7.5YR3/4	dark brown	-	medium clay	45%	-	coarse	-	slightly moist/moist	hard	nil	nil	2	9	
B22	1	7321_SOIL_0.15_1312040840	0	15	A1	7.5YR3/2	dark brown	-	sandy clay loam	25%	weak	subangular blocky	10	slightly moist/moist	firm	nil	nil	3	6	hardsetting surface. Wheat stubble
	2	7321_SOIL_0.5_1312040840	15	50	B21	7.5YR4/4	brown	-	light clay	35%	-	coarse	-	slightly moist	hard	nil	nil	2	7	
	3	7321_SOIL_0.9_1312040840	50	90	B22	10YR4/4	dark yellow brown	slight brown	light medium clay	40%	-	coarse	-	dry	hard	nil	nil	2/1	8	
	4	7321_SOIL_1.4_1312040840	90	140	B23	10YR5/2	grey brown	distinct brown	light medium clay	40%	-	coarse	-	slightly moist	hard	nil	nil	0	8.5	
B23	1	7322_SOIL_0.15_1312040905	0	15	A1	7.5YR3/2	dark brown	-	light medium clay	40%	medium	subangular blocky	10	slightly moist	firm	nil	nil	3	6.5	cracking surface. Wheat stubble
	2	7322_SOIL_0.5_1312040905	15	50	B21	5YR3/4	dark red brown	-	medium clay	45%	-	coarse	-	dry	hard	nil	nil	2	8.5	
	3	7322_SOIL_1.0_1312040905	50	100	B22	5YR3/4	dark red brown	-	medium clay	45%	-	coarse	-	dry	hard	common	nil	2	9	
	4	7322_SOIL_1.4_1312040905	100	140	B23	10YR4/2	dark grey brown	distinct brown	light medium clay	40%	-	coarse	-	slightly moist/moist	hard	nil	nil	0	8.5	
B24	1	7323_SOIL_0.15_1312040920	0	15	A1	10YR3/2	very dark grey brown	-	medium clay	45%	strong	subangular blocky	10	moist	firm	nil	nil	3	6.5	cracking surface. Wheat stubble
	2	7323_SOIL_0.5_1312040920	15	50	B21	10YR3/2	very dark grey brown	-	medium clay	45%	-	coarse	-	dry/ slightly moist	hard/ very hard	nil	nil	2	8	
	3	7323_SOIL_1.0_1312040920	50	100	B22	10YR3/2	very dark grey brown	distinct grey	medium clay	45%	-	coarse	-	slightly moist	hard	few	nil	2	9	
	4	7323_SOIL_1.5_1312040920	100	150	B23	10YR3/3	dark brown	slight grey & brown	medium clay	45%	-	coarse	-	slightly moist/moist	hard	nil	nil	0	8.5	
B25	1	7324_SOIL_0.15_1312040938	0	15	A1	10YR3/2	very dark grey brown	-	medium clay	45%	strong	subangular blocky	10	slightly moist/moist	firm	nil	nil	3	6.5	cracking and soft surface. Wheat stubble
	2	7324_SOIL_0.5_1312040938	15	50	B21	10YR3/2	very dark grey brown	-	medium clay	45%	-	coarse	-	dry	very hard	nil	nil	2	7	
	3	7324_SOIL_0.9_1312040938	50	90	B22	10YR3/2	very dark grey brown	-	medium clay	45%	-	coarse	-	moist	firm/ hard	nil	nil	2	8	
	4	7324_SOIL_1.4_1312040938	90	140	B23	10YR3/3	dark brown	-	light medium clay	40%	-	coarse	-	slightly moist	hard	nil	nil	0	7	
B26	1	7325_SOIL_0.15_1312040955	0	15	A1	10YR2/2	very dark brown	-	medium clay	45%	strong	subangular blocky	10	slightly moist/moist	firm	nil	nil	3	6.5	cracking and soft surface. Wheat stubble
	2	7325_SOIL_0.5_1312040955	15	50	B21	7.5YR3/4	dark brown	distinct grey	medium clay	45%	-	coarse	-	moist	firm	common	nil	2	8	
	3	7325_SOIL_0.9_1312040955	50	90	B22	10YR4/3	brown	distinct brown & grey	medium clay	45%	-	coarse	-	slightly moist	hard/ very hard	common	slight	2	9	
	4	7325_SOIL_1.4_1312040955	90	140	B23	10YR4/3	brown	slight grey & brown	medium heavy clay	50%	-	coarse	-	slightly moist/moist	hard	few	nil	1/0	8	

Profile name	Layer	Santos label	Depth (cm)		Horizon	Munsell Colour	Colour	Mottles	Texture	Est clay %	Structure			Moisture content	Strength	Carbonate nodules	Carbonate fiz	Roots	pH	Comments
			Top	Bot.							Grade	Type	Size (mm)					Rank		
B27	1	7326_SOIL_0.1_1312041030	0	10	A1	10YR4/4	dark yellow brown	-	sandy clay loam	25%	-	massive	-	slightly moist	firm	nil	nil	3	6	hardsetting surface. Wheat stubble
	2	7326_SOIL_0.5_1312041030	10	50	B21	10YR3/4	dark yellow brown	-	medium clay	45%	-	coarse	-	dry	hard/ very hard	nil	nil	2	7.25	
	3	7326_SOIL_0.9_1312041030	50	90	B22	10YR3/3	dark brown	slight brown	medium clay	45%	-	coarse	-	slightly moist	hard	few	nil	2	8.5	
	4	7326_SOIL_1.4_1312041030	90	140	B23	10YR3/3	dark brown	slight brown	medium clay	45%	-	coarse	-	slightly moist	hard	nil	nil	1	7.5	
B28	1	7327_SOIL_0.15_1312041045	0	15	A1	10YR3/2	very dark grey brown	-	light medium clay	40%	strong	subangular blocky	10	moist	firm	nil	nil	3	-	cracking and soft surface. Wheat stubble
	2	7327_SOIL_0.5_1312041045	15	50	B21	10YR3/2	very dark grey brown	-	medium heavy clay	50%	-	coarse	-	dry	very hard	nil	nil	2	-	
	3	7327_SOIL_0.9_1312041045	50	90	B22	10YR3/2	very dark grey brown	-	medium clay	45%	-	coarse	-	slightly moist	hard	nil	nil	2	-	
	4	7327_SOIL_1.4_1312041045	90	140	B23	10YR3/3	dark brown	-	medium clay	45%	-	coarse	-	slightly moist/moist	hard	nil	nil	1	-	
B29	1	7328_SOIL_0.2_1312041145	0	20	A1	5YR3/4	dark red brown	-	sandy loam	15%	-	massive	-	dry	soft/ firm	nil	nil	3	5.5	hardsetting surface. Wattle regrowth
	2	7328_SOIL_0.5_1312041145	20	50	A21	2.5YR4/6	red	-	sandy loam	15%	-	massive	-	dry	soft/ firm	nil	nil	3	5.75	
	3	7328_SOIL_0.9_1312041145	50	90	A22	2.5YR4/6	red	-	sandy loam	15%	-	massive	-	dry	soft/ firm	nil	nil	2	5.5	
	4	7328_SOIL_1.3_1312041145	90	130	B2	2.5YR4/8	red	-	light sandy clay loam	20%	-	massive	-	dry	firm/ hard	nil	nil	2	6	
	5	7328_SOIL_1.4_1312041145	130	140	C				sandstone											
B30	1	7329_SOIL_0.15_1312041211	0	15	A1	10YR2/2	very dark brown	-	light medium clay	40%	medium	subangular blocky	10	slightly moist/moist	soft/ firm	nil	nil	3	6	hardsetting surface. First appeared to be a loam over clay. Wheat stubble
	2	7329_SOIL_0.55_1312041211	15	55	B21	10YR3/3	dark brown	-	medium clay	45%	-	coarse	-	slightly moist/moist	firm/ hard	nil	nil	2	7.5	
	3	7329_SOIL_0.95_1312041211	55	95	B22	10YR3/2	very dark grey brown	slight brown	medium heavy clay	50%	-	coarse	-	slightly moist/moist	hard	common	nil	2/1	8	
	4	7329_SOIL_1.5_1312041211	95	150	B23	10YR3/2	very dark grey brown	slight grey	medium heavy clay	50%	-	coarse	-	slightly moist/moist	hard/ very hard	nil	nil	2/1	8	
B31	1	7330_SOIL_0.15_1312041245	0	15	A1	10YR3/2	very dark grey brown	-	medium clay	45%	medium	subangular blocky	10	moist	firm	nil	slight	3	7.5	cracking and soft surface. Wheat stubble
	2	7330_SOIL_0.5_1312041245	15	50	B21	10YR3/1	very dark grey	-	medium heavy clay	50%	-	coarse	-	dry	very hard	common	nil	2	8.5	
	3	7330_SOIL_0.95_1312041245	50	95	B22	10YR5/2	grey brown	-	medium heavy clay	50%	-	coarse	-	dry	very hard	common	medium	2	8.5	
	4	7330_SOIL_1.4_1312041245	95	140	B23	10YR4/2	dark grey brown	-	medium heavy clay	50%	-	coarse	-	slightly moist	very hard	few	nil	1	8.5	
B32	1	7331_SOIL_0.15_1312041340	0	15	A1	10YR3/2	very dark grey brown	-	medium clay	45%	medium	subangular blocky	10	slightly moist/moist	firm/hard	nil	nil	3	8	cracking and soft surface. Wheat stubble
	2	7331_SOIL_0.5_1312041340	15	50	B21	10YR3/2	very dark grey brown	-	medium heavy clay	50%	-	coarse	-	dry/ slightly moist	very hard	few	nil	2	8	
	3	7331_SOIL_1.0_1312041340	50	100	B22	10YR3/3	dark brown	-	medium heavy clay	50%	-	coarse	-	slightly moist	very hard	nil	nil	2	7.5	
	4	7331_SOIL_1.4_1312041340	100	140	B23	10YR3/3	dark brown	-	medium heavy clay	50%	-	coarse	-	slightly moist	very hard	nil	nil	1/0	6	
B33	1	7332_SOIL_0.15_1312041400	0	15	A1	10YR3/2	very dark grey brown	-	medium clay	45%	medium	subangular blocky	10	moist	firm	nil	slight	3	-	cracking and soft surface. Wheat stubble
	2	7332_SOIL_0.5_1312041400	15	50	B21	10YR3/1	very dark grey	-	medium heavy clay	50%	-	coarse	-	dry	very hard	common	nil	2	-	
	3	7332_SOIL_0.9_1312041400	50	90	B22	10YR5/2	grey brown	-	medium heavy clay	50%	-	coarse	-	dry	very hard	common	medium	2	-	
	4	7332_SOIL_1.4_1312041400	90	140	B23	10YR4/2	dark grey brown	-	medium heavy clay	50%	-	coarse	-	slightly moist	very hard	few	nil	1	-	

Profile name	Layer	Santos label	Depth (cm) Top	Depth (cm) Bot.	Horizon	Munsell Colour	Colour	Mottles	Texture	Est clay %	Structure Grade	Structure Type	Structure Size (mm)	Moisture content	Strength	Carbonate nodules	Carbonate fiz	Roots Rank	pH	Comments
B34	1	7333_SOIL_0.15_1312041410	0	15	A1	10YR3/2	very dark grey brown	-	medium clay	45%	medium	subangular blocky	10	slightly moist	hard	nil	nil	3	8	cracking and soft surface. Rough pasture
	2	7333_SOIL_0.55_1312041410	15	55	B21	10YR5/3	brown	-	medium heavy clay	50%	strong	lenticular	-	dry	very hard	nil	nil	2	8.5	
	3	7333_SOIL_0.95_1312041410	55	95	B22	10YR3/3	dark brown	-	medium heavy clay	50%	-	coarse	-	slightly moist	very hard	nil	nil	2	7	
	4	7333_SOIL_1.4_1312041410	95	140	B23	10YR3/4	dark yellow brown	-	medium clay	45%	-	coarse	-	slightly moist/moist	very hard	nil	nil	2/1	5	
B35	1	7334_SOIL_0.15_1312041435	0	15	A1	10YR3/3	dark brown	-	medium clay	45%	medium	subangular blocky	10	dry	very hard	nil	nil	3	7.5	cracking and soft surface. Fallow
	2	7334_SOIL_0.5_1312041435	15	50	B21	10YR3/2	very dark grey brown	-	medium clay	45%	-	coarse	-	moist	firm/hard	nil	nil	2	6.5	
	3	7334_SOIL_0.95_1312041435	50	95	B22	10YR3/3	dark brown	-	medium heavy clay	50%	-	coarse	-	moist	hard/ very hard	nil	nil	2	6	
	4	7334_SOIL_1.4_1312041435	95	140	B23	10YR3/3	dark brown	-	medium clay	45%	-	coarse	-	slightly moist/moist	hard/ very hard	nil	nil	2/1	6.5	
B36	1	7335_SOIL_0.15_1312041454	0	15	A1	10YR3/2	very dark grey brown	-	medium clay	45%	strong	subangular blocky	10	dry/ slightly moist	very hard	nil	nil	3	6.5	cracking and soft surface. Fallow
	2	7335_SOIL_0.5_1312041454	15	50	B21	10YR3/3	dark brown	-	medium heavy clay	50%	-	coarse	-	moist	hard	nil	nil	2	6.5	
	3	7335_SOIL_0.9_1312041454	50	90	B22	10YR3/2	very dark grey brown	distinct grey	medium heavy clay	50%	-	coarse	-	moist	very hard	nil	nil	2	6	
	4	7335_SOIL_1.4_1312041454	90	140	B23	10YR3/2	very dark grey brown	distinct grey	medium heavy clay	50%	-	coarse	-	slightly moist	very hard	nil	nil	2/1	6.5	
B37	1	7336_SOIL_0.15_1312041515	0	15	A1	10YR4/2	dark grey brown	-	medium clay	45%	strong	subangular blocky	10	dry	very hard	nil	nil	3	6.5	cracking surface. Rough pasture
	2	7336_SOIL_0.5_1312041515	15	50	B21	10YR4/2	dark grey brown	-	medium clay	45%	-	coarse	-	dry	very hard	nil	nil	2	7.5	
	3	7336_SOIL_0.9_1312041515	50	90	B22	10YR2/1	black	-	medium heavy clay	50%	strong	lenticular	-	slightly moist/moist	very hard	nil	nil	2	7.5	
	4	7336_SOIL_1.4_1312041515	90	140	B23	10YR3/2	very dark grey brown	-	medium heavy clay	50%	-	coarse	-	slightly moist	very hard	nil	nil	2/1	5.5	
B38	1	7337_SOIL_0.15_1312041540	0	15	A1	10YR3/2	very dark grey brown	-	light medium clay	40%	medium	subangular blocky	10	dry	very hard	nil	nil	3	6.5	cracking surface. Rough pasture
	2	7337_SOIL_0.5_1312041540	15	50	B21	10YR3/2	very dark grey brown	-	medium clay	45%	-	coarse	-	dry/ slightly moist	hard/ very hard	nil	nil	2	7.5	
	3	7337_SOIL_1.0_1312041540	50	100	B22	10YR3/3	dark brown	-	medium heavy clay	50%	-	coarse	-	slightly moist	hard/ very hard	nil	nil	2	7	
	4	7337_SOIL_1.4_1312041540	100	140	B23	10YR3/3	dark brown	-	medium clay	45%	-	coarse	-	slightly moist	hard/ very hard	nil	nil	1	6	
B39	1	7338_SOIL_0.15_1312041605	0	15	A1	10YR3/2	very dark grey brown	-	medium clay	45%	strong	subangular blocky	10	slightly moist	hard/ very hard	nil	nil	3	7	cracking and soft surface. Rough pasture
	2	7338_SOIL_0.5_1312041605	15	50	B21	10YR3/1	very dark grey	-	medium heavy clay	50%	-	coarse	-	dry	very hard	nil	nil	2	8	
	3	7338_SOIL_1.0_1312041605	50	100	B22	10YR3/2	very dark grey brown	-	medium heavy clay	50%	-	coarse	-	slightly moist	very hard	nil	nil	2	6	
	4	7338_SOIL_1.5_1312041605	100	150	B23	10YR3/3	dark brown	-	medium clay	45%	-	coarse	-	slightly moist	very hard	nil	nil	1	5	
B40	1	7339_SOIL_0.15_1312041635	0	15	A1	10YR3/3	dark brown	-	clay loam	30%	-	massive	-	dry	firm	nil	nil	3	6	hardsetting surface. Wheat stubble
	2	7339_SOIL_0.5_1312041635	15	50	B21	10YR3/2	very dark grey brown	-	medium clay	45%	-	coarse	-	dry	very hard	nil	nil	2	8.5	
	3	7339_SOIL_0.95_1312041635	50	95	B22	10YR3/3	dark brown	-	medium clay	45%	-	coarse	-	slightly moist	very hard	few	nil	1	9	
	4	7339_SOIL_1.4_1312041635	95	140	B23	10YR3/3	dark brown	distinct brown	medium clay	45%	-	coarse	-	slightly moist	very hard	nil	nil	0	8.5	

Tabular data of key soil chemistry parameters from ten selected soil cores

	B01-1	B05-1	B10-1	B17-1	B20-1	B24-1	B30-1	B32-1	B35-1	B38-1	depth
pH	7.6	5.9	7.8	6.9	8	6.7	6.2	8.2	7.4	6.5	15
pH	9.1	8.2	9	9.2	8.9	8.3	8.1	8.8	6.3	7.3	50
pH	9.2	9.2	7.4	8.2	9.4	9	9	6.9	5.8	7.2	90
pH	6	9.2	4.9	5.1	9	8.4	8.5	5.1	5.7	5.5	140
Cl	15.5	8.5	19.7	10.8	22.5	23.1	22.4	15.3	71.7	26.4	15
Cl	26.7	37.5	67.4	194.6	3.5	2	114.3	94.9	215.8	140.8	50
Cl	215.1	407.7	171.1	496.4	109.3	22.1	467.9	432.2	593.9	433.4	90
Cl	386.8	555.4	415.2	577.6	189	105.8	590.3	377.5	561.7	533.9	140
ECe	0.43	0.46	0.75	0.3	0.49	0.39	0.45	0.55	0.83	0.3	15
ECe	0.65	0.67	0.89	1.63	0.46	0.38	1.04	1.06	2.75	1.39	50
ECe	1.63	2.4	2.36	4.57	1.18	0.82	3.08	4.33	6.36	3.86	90
ECe	2.56	3.15	3.6	5.69	2.14	1.36	4.43	4.2	4.69	6.04	140
SUM	22.4	9.49	24.8	17.6	24.3	20	14.3	23.1	24.2	19.1	15
SUM	24.4	16.6	26.5	24	27	21.3	21.5	27	21.5	21.5	50
SUM	22.2	24.9	22.5	22.7	24.1	20.5	26.5	21.4	20.5	19.5	90
SUM	20.2	25	20.3	19.2	20.7	17.2	23.3	15.5	19	16.4	140
ESP	2.367	6.53	2.302	4.136	1.648	3.402	6.285	2.036	4.671	5.392	15
ESP	7.617	13.51	13.87	14.9	6.509	5.874	15.01	10.74	16.43	12.86	50
ESP	21.49	26.26	24.14	25.67	18.29	13.79	23.15	22.93	27.88	23.94	90
ESP	32.18	31.5	29.88	34.11	24.41	25.31	29.54	28.36	30.53	28.81	140
SAR	2.146	1.636	1.799	0.957	1.23	1.972	1.889	1.45	3.126	0.922	15
SAR	6.227	2.389	9.923	10.77	5.049	1.104	8.379	7.099	8.414	8.248	50
SAR	13.89	16.78	13.15	15.27	11.81	8.5	13.9	11.64	13.01	12.99	90
SAR	18.06	23.25	15.43	18.22	17.14	3.456	17.26	14.1	16.11	14.47	140

Name	Ammonium Nitrogen	Nitrate Nitrogen	N	Phosphorus Colwell	Potassium Colwell	Sulphur	Organic Carbon	DTPA Copper	DTPA Iron	DTPA Manganese	DTPA Zinc	Boron Hot CaCl2
	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg	%	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg
B01-1	2	13	15	5	280	3.8	0.92	0.98	15.12	17.32	0.9	0.87
B05-1	1	13	14	19	194	5.1	0.93	1.44	62.66	9.79	0.75	0.35
B10-1	3	39	42	6	268	4.5	1.07	1.19	16.9	11.47	0.47	0.73
B17-1	2	12	14	3	200	3.3	0.99	1.12	22.98	31.38	0.39	0.43
B20-1	2	13	15	4	179	4.4	1.02	0.89	12.08	8.94	0.37	0.52
B24-1	2	16	18	6	185	5.6	1	1.23	31.28	19.35	0.48	0.58
B30-1	1	15	16	5	164	4	1.09	1.22	57.93	17.1	0.27	0.41
B32-1	0	16	16	7	308	4.6	0.78	0.76	10.71	7.89	0.31	0.56
B35-1	8	25	33	7	361	8.2	1.2	1.09	18.85	16.65	0.4	0.72
B38-1	7	10	17	7	304	5.6	2.45	0.77	53.13	23.12	0.41	0.55