REPORT

WELLS AND GATHERING APPLICATION - RPI21/028 – SOIL EROSION, SUBSIDENCE AND RESTORATION MANAGEMENT PLAN

ARROW ENERGY

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land and water stewardship

land and water stewardship **BeneTerra Pty Ltd** **Level 16, 127 Creek Street** **Brisbane, Queensland 4000**	CLIENT **Arrow Energy**
	PROJECT Wells and Gathering Application - RPI 121/028 Provision of CPESC Services
	DOCUMENT Plan

Wells and Gathering Application - RPI 121/028 – Soil Erosion, Subsidence and Restoration Management Plan

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Authorised signatory	Print name	Title	Date
	Steve Winters	Principal Project Manager	2022.06.15

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ABBREVIATIONS

ASPAC	Australasian Soil and Plant Analysis Council
ARI	Average reoccurrence interval
BT	BeneTerra
bgs	below ground surface
CEC	cation exchange capacity
CEMP	construction environmental management plan
cm	centimetre
CSG	coal seam gas
CPESC	certified professional erosion and sediment control
CPSS	certified professional soil scientist
CROSS	cation ratio of soil structural stability (estimate of dispersibility)
DES	Department of Environment and Science
EA	Environmental Authority
$EC_{1:5}$	electrical conductivity (measured by mixing 1 part soil to 5 parts water)
EC_{se}	electrical conductivity of saturated soil extract
EGE	effective gypsum equivalent
ESA	environmental site assessment
ESC	erosion and sediment control
ESCP	erosion and sediment control plan
ESI	electrochemical stability index
ESP	exchangeable sodium percentage
EY	Exceedances per year
ha	hectare
IECA	International Erosion Control Association
ITP	inspection test plan
m	metre
ML	megalitre
mS/cm	millisiemens per centimetre
NATA	National Association of Testing Authorities
$pH_{1:5}$	negative logarithm of hydrogen ions (measured by mixing 1 part soil to 5 parts water)
RDM	residual drill mud
RoW	right of way
RPEQ	registered professional engineer Queensland
RUSLE	revised universal soil loss equation
$SAR_{1:5}$	sodium adsorption ratio of 1 soil: 5 water solution
SAR_e	sodium adsorption ratio of saturated soil extract
SCL	strategic cropping land
SMP	safety management plan
t	tonnes
µS/cm	microSiemens per centimetre
yr	year

1 INTRODUCTION

Arrow Energy Pty Ltd (AE) commissioned BeneTerra Pty Ltd (BT) to develop erosion and sediment control, subsidence and restoration plans for submission to the Department of State Development, Infrastructure, Local Government and Planning to obtain approval under the Regional Planning Interests Act 2014.

The approval relates to construction and operation of well pads and gathering pipelines over Priority Agricultural Area and Strategic Agriculture Area. Arrow Energy has an existing Environmental Authority EPPG00972513.

1.1 SITE DETAILS

The site is located 15 kilometres south-west of Dalby in Queensland, Figure 1. The total disturbance proposed is approximately 36 hectares of land, which is a combination of 13.5 kilometres of gathering right of way (RoW), four well pads and associated gas infrastructure.

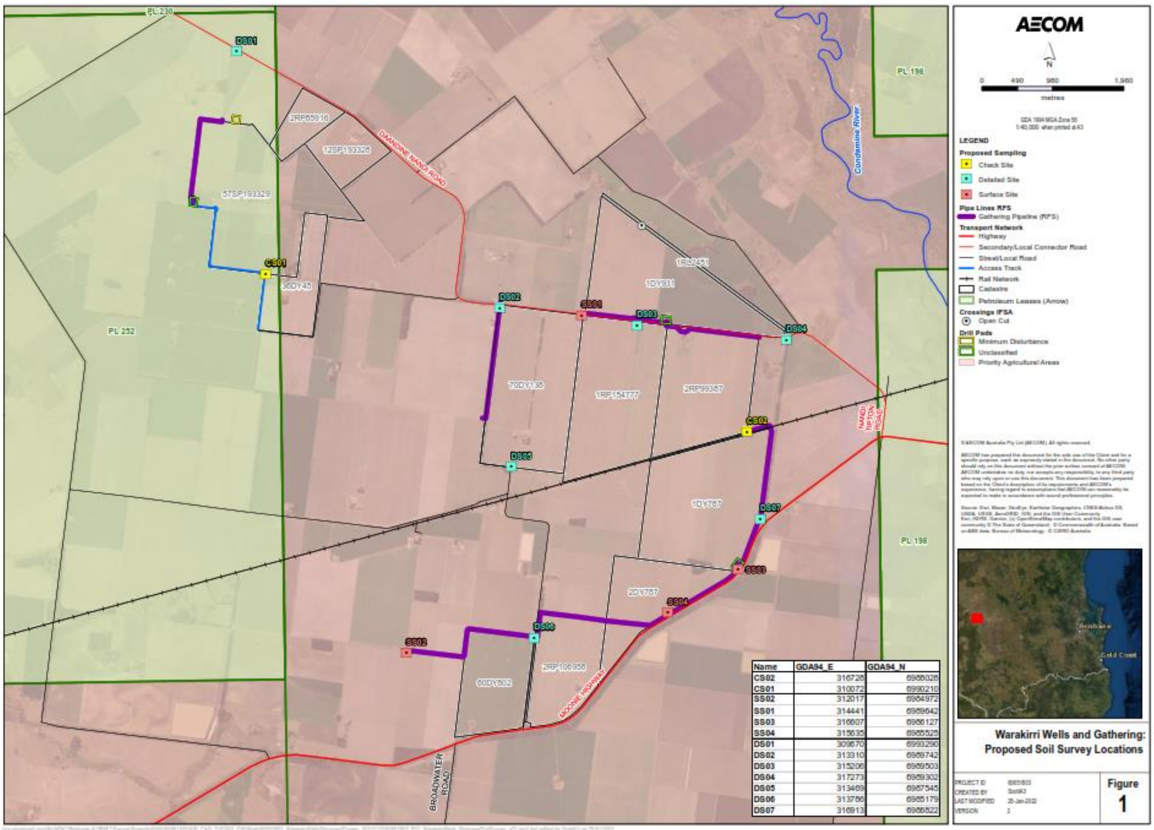

Figure 1 Overview of the project area (source: AECOM Sampling Quality & Analysis Plan, 2022).

2 SCOPE OF WORK

BeneTerra (BT) have been specifically engaged to provide a response to Issue 11 sent to Arrow Energy 5th of October 2021, with department reference OUT21/4776; RPI21/028. An extract of Issue 11 is displayed in Figure 2.

11.	**<u>Issue:</u>** The information provided in support of the application regarding remediation, restoration, erosion, sediment control and subsidence monitoring is of limited detail. Section 3.5.1 of the report states that: • the decommissioning of the pipeline will include '*Backfill, compaction and* rehabilitation *of all excavations in accordance with the Environmental Authority and the Environmental Management Plan*.' (page 34 • 'Following relinquishment of the relevant authority, the Government will assume the liability for the de-commissioned infrastructure.' Section 8.3 Reinstatement and rehabilitation of the report references the Environmental Authority as the guideline for reinstatement and rehabilitation measures. The measures in these sections as well as those referenced under the Soils Report at Appendix 8 are not considered adequately detailed to meet the relevant criteria detailed under the *Regional Planning Interests Act 2014* (RPI Act) and the RPI Regulation 2014. **<u>Actions:</u>** Provide the following detailed plans in a stand-alone format to cover all proposed works: a) Erosion and sediment control plan (ESCP), including details of how stripped/excavated soils will be managed during excavation, stockpiling and replacement/stabilisation b) Subsidence management plan (SMP) – including plans/actions to monitor/remediate subsidence in both pipeline and void areas c) Restoration Management Plan (RMP) that demonstrates that any disturbance considered temporary is in accordance with RPI Act Statutory Guideline 09/14 How to determine if an activity has a permanent impact on Strategic Cropping Land (RPI Guideline 09/14).

Figure 2 - Extract from OUT21/4776, RIDA government response

BT will provide the following plans in stand-alone format, however, they will be encompassed within this document with the specific objective to reduce duplication of information.

a. Overarching erosion and sediment control plan
b. Trench and excavation subsidence management plan
c. Land restoration management plan

The scope of works does not include:

- Soil survey of project or data quality assurance.
- Development of detailed engineered drawings issued for construction.
- Construction layout of erosion and sediment control, as construction methods and schedules have not been developed yet.
- Subsidence management of landscapes due to reservoir impact from gas extraction.

3 PROPOSED WORKS AND IMPACT

Arrow Energy propose to construct well pads, access tracks and gathering pipelines for this project. Table 1 and Table 2 display the activities associated with the asset type and the potential risk to soil resources. Similar impacts are identified in a study conducted by the *CSIRO, GISERA, 2014*.

Table 1 - Gathering pipelines

Activity	Potential risk to soil resources
Clearing	• Low risk to soil resources. Isolated area of clearing required for project where road reserves are crossed. Most of project area is located on cropping land.
Topsoil removal	• Mixing of topsoil with subsoil • Loss of nutrients mainly nitrogen • Exposure of subsoil and soil erosion • Erosion of stockpiles

Trench excavation	• Mixing of lower profile soils with upper profile soils. Approximate trench depth ranges from 1 – 1.5 m below ground surface.
Pipe installation	• Displacement of soil • Compaction (this risk also relates to multiple activities)
Backfill	• Potential for voids to be left around pipe • Backfill trench bulk density does not match surrounding terrain • Mixed lower profile soil backfilled into upper profile (inverted)
Construction operation	• Low impact, potential spills of hydrocarbon
Topsoil reinstatement	• Mixing of topsoil with subsoil • Lack of topsoil • Interrupt overland flow

Table 2 - Well pads and access tracks

Activity	Potential Impact
Clearing	• Low impact, previously clear areas
Topsoil removal	• Mixing of topsoil with subsoil • Loss of nutrients • Exposure of subsoil and soil erosion • Erosion of stockpiles
Pad preparation earthworks	• Compaction • Importation of foreign gravel for hardstand
Excavation of storage pits/trenches	• Mixing of lower profile soils with upper profile soils • Imported foreign material to site (gravel)
Storage of drill fluid and mud in trenches	• Potential alkaline and saline residue
Backfill	• Backfill in excavation bulk density does not match surrounding terrain • Mixed lower profile soil backfilled into upper profile (inverted)
Residual drill mud disposal onsite	• Potential for salinity increase greater than predevelopment levels
Topsoil reinstatement	• Mixing of topsoil with subsoil • Lack of topsoil • Interrupt overland flow
Operation of asset	• Spills of coal seam gas water • Spills of hydrocarbon

4 Erosion and Sediment Control Plan

This plan details how soil erosion is proposed to be managed, which includes details regarding stripped/excavated soils, excavations, stockpiling, and replacement/stabilisation.

4.1 Assessment Criteria

The key assessment criteria are the principles of erosion and sediment control. These key principles are explained in detail in IECA 2008 section 2.1 and summarised in Table 3.

Table 3 - Assessment criteria

Deliverable	Plan Section
Appropriately integrate the development into the site	Arrow Energy process - Infrastructure layout process. A site assessment is performed by client against, social, environmental and stakeholder constraints.
Integrate erosion and sediment control issues into site and construction planning	Section 4.6 standard drawings with controls specified
Develop effective and flexible erosion and sediment control plans based on anticipated soil, weather, and construction duration	Section 4.2 identification of site risks Section 4.3 key risk summary and controls Section 4.5 site specific plans Section 4.6 standard drawings
Minimise the extent and duration of soil disturbance	Section 4.4, timing of disturbance works
Control water movement through site	Section 4.4, drainage standard. Section 4.6, standard drawings. Section 4.5, site specific plans.
Minimise soil erosion	Section 4.4, timing of works.
Promptly stabilize disturbed areas	Section 4.4, timing of reinstatement.
Maximise sediment retention on the site	Section 4.4, sediment control standard, turbidity control and dewatering.
Maintain all ESC measures in proper working order at all times	Section 4.7 maintenance of controls
Monitor the site and adjust ESC practices to maintain the required performance standard	Section 4.7 implementation monitoring and maintenance of controls.

4.2 Risk Assessment

Receiving Environment

The project area has a maximum slope of 1%. The majority of alignment has limited visible slope, which creates a risk of ponding water during construction as any topsoil removal will create a void where water will pond. This also creates a risk post reinstatement, as minor crowning of backfilled assets can create ponding that can potentially interrupt land management operations.

The current land use for the project area is dryland cropping, which is suited to a range of crops such as, wheat, barley, legumes, cotton and sorghum. Irrigated cropping areas are adjacent to the project area.

Table 4 displays rainfall data for Loudoun Bridge weather station (station number: 41339) located at Lat: 27.21° Lon: 151.19°. The location has a distinct wet season in summer and less rainfall in winter. The site does experience rainfall variability with different weather patterns, which is shown in the large range between 10th percentile and 90th percentile.

Table 4 Rainfall data. Source: Bureau of Meteorology. www.bom.gov.au

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	82.2	76.4	62.3	25.7	35.0	36.7	29.2	25.3	24.3	53.0	70.4	98.4	618.8
Lowest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	4.6	202.0
5th %ile	3.0	3.2	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.8	9.2	19.5	425.0
10th %ile	14.8	5.1	0.0	0.0	4.0	2.8	0.0	0.0	1.1	7.7	12.5	44.8	456.4
Median	62.2	65.5	34.3	16.5	19.9	27.0	20.3	15.6	17.0	50.0	59.9	90.3	619.9
90th %ile	170.1	146.4	163.9	75.0	78.2	67.5	58.0	59.1	60.0	93.4	135.0	178.5	801.4
95th %ile	217.0	167.0	181.5	91.7	90.1	106.4	62.9	79.4	77.6	117.0	166.4	209.6	850.2
Highest	294.0	240.0	242.0	121.2	214.0	145.0	98.8	96.0	97.0	166.0	233.0	264.0	889.0

There are no mapped waterways under the Fisheries Act 1994, or Water Act 2000 within the project alignment (Figure 3*)*. The alignment does cross several shallow/wide drainage features that flow with low velocity, these features drain the cropping lands and if not reinstated to pre-disturbance level will cause disruption to cropping operations. The other notable crossings are the existing council road table drains, which have a narrow drainage width creating a risk for concentrated flow.

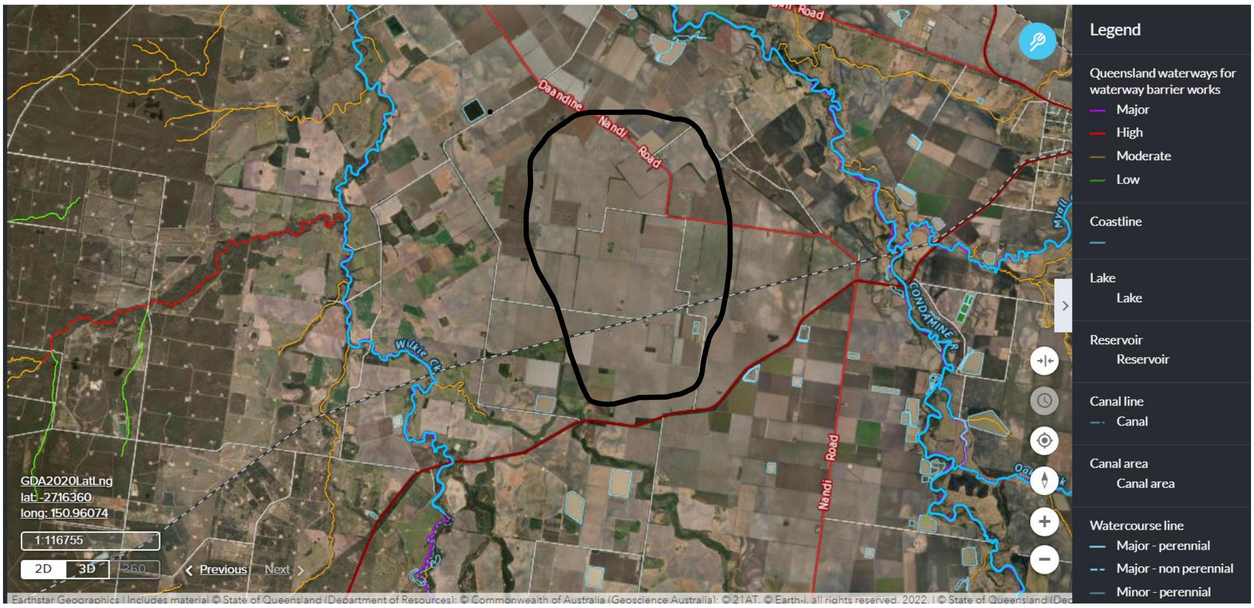

Figure 3 - Mapped water features. The black polygon outlines the project area.

Source: QLD Globe online GIS; https://qldglobe.information.qld.gov.au/

Soil Types and Risk

The soil type is melon-hole clay or black and grey vertosol, which has favourable properties in the upper profile for agricultural production, however, has detrimental properties in the lower soil profile.

The wind erosion rating is low to medium, this is due to the soil having greater than 30% of soil aggregates greater than 0.85 mm. However, once excessive trafficking occurs and soil aggregates break down, a medium dust generation risk is expected, as the soil is dominated by clay.

The general topsoil depth is 20 cm, below this exchangeable sodium and chloride increase. Below 90 – 100 cm salinity increases to moderate, elevated chloride levels may restrict root growth and exchangeable sodium increases. Topsoil is slightly to moderately dispersive, whilst the subsoil is moderately to highly dispersive. The subsoil will appear only slightly dispersive in an Emerson test, however, this is due to soluble salts masking the dispersion in lab conditions. In field conditions, leaching of soluble salts will cause dispersion as rainfall continues. The CROSS equation suggests there are limited impacts from the dispersive potentials of exchangeable magnesium and potassium. The electrochemical stability index (ESI) indicates dispersive potential, especially in the topsoil where soluble salts are low, and some sodium is evident. The material below the subsoil (100-200 cm) is saline and sodic. It is not suitable for growth media and can limit root growth for some crops.
A dispersion hazard assessment is presented in Table 5.

Table 5 - Clay dispersion hazard assessment

Landscape	CROSS*	ESP	ESI**	Ca:Mg ratio	Clay content %	Emerson
A horizon (0-20cm)	0.2 - 0.6	0.7 - 5.3	0.1-0.008	0.2 - 4	40-50	2-4
B horizon (20-90 cm)	0.9 - 1.3	4.7 - 11.2	0.05 - 0.01	0.8 - 3.4	60-70	2-4
C horizon (100-200 cm)	1.2 - 1.45	9 – 11.3	0.03 - 0.08	0.7 – 3.8	60-80	2-4

NOTE: green is low risk, orange is medium risk, red is high risk.

NOTE: ESP is not a reliable measurement where there are free carbonates or salts. Ammonium acetate extracts are merely an approximation for this measurement in this situation. So, a number of measurements are required to understand the dispersion risk. Emerson class is not a reliable test method where carbonates and soluble salts mask the dispersive properties, therefore is not a reliable test in this situation.

** Cation ratio of soil structural stability* $CROSS = (Na + 0.56K) / \sqrt{((Ca + 0.6Mg)/2)}$

***Electrochemical stability index* $ESI = Ec_{1:5}\ dS/cm / ESP$

Table 6 - Erosion hazard based on average monthly rainfall

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Risk	M	M	M	Low	Low	Low	Very Low	Very low	Very Low	M	M	H

NOTES: M = moderate risk, H = high risk,

Soil loss estimation

Soil erosion risk was determined utilising the Revised Universal Soil Loss Equation (RUSLE). This equation does not estimate soil loss from tunnel or gully erosion, which readily occur as a result of dispersive soils. The soil loss estimation for sheet and interrill erosion is displayed for different project phases in tons per hectare per year in Table 7.

Table 7 - RUSLE prediction of soil loss risk

Phase	Rainfall factor	K-factor	C-factor	Slope factor	P-factor	Soil loss (t/ha-yr)
During works topsoil removal	2030	0.06	1	0.19	1.3	31
Post works post reinstatement of topsoil	2030	0.05	0.45	0.19	0.8	7

NOTES:

- *Rainfall factor based on 2 year 6 hour storm event of 9.51 mm/h using calculation,* $R=164.74\ (1.1177)^{S}S^{0.6444}$
- *K-factor selected for subsoil based on texture of inorganic clays with high plasticity, with a 20% increase due to potential dispersion. Topsoil has not been increased by 20%.*
- *Topography factor based on a 1% slope with 80 m slope length, this is conversative as 1% is maximum project fall.*
- *Cover factor for subsoil is default of 1, whilst post construction a lower cover factor has been used based on minimum till, stubble retention farming practices and seasonal crops.*
- *The P-factor for subsoil is default for compacted surface, whilst the reinstated factor is for loose soil to 300 mm depth.*
- *Single soil loss equation used to determine project risk. It is considered representative of entire project area and catchments, as slope or soil type over project does not change.*

4.3 KEY EROSION RISK SUMMARY

The soil erosion risk rating is low based on soil loss estimation, however moderate to high, based on soil dispersion risk, which requires specific management techniques to control soil dispersion. Key risks associated with the project area are displayed in Table 8.

Table 8 - Key risks and controls

Risk	Control
Increased rainfall during wet season	Timing of works
Soils with high levels of dispersion	Topsoil stripping plus predevelopment depth 100 cm
Soil with moderate levels of salinity	Topsoil stripping plus predevelopment depth 100 cm
Clean water crossings (drainage features)	Site-specific plan for drainage features. Reinstate as per standard drawings. Site specific plans to be developed by suitably qualified person.
Flat terrain creating a dewatering risk	Rainfall preparedness plan. Consider application of gypsum or equivalent prior to rainfall to aid water quality and dewatering.

4.4 Control measures and standards

Project adopted standards based on IECA 2008 Book 1 Chapter 4 Design Standards and Techniques and Appendix P, are displayed in Table 9.

Table 9 - Design standards, techniques and methods

<table>
<tr><th>Aspect</th><th>Standard</th><th>Type of control / activity</th></tr>
<tr><td rowspan="3">Drainage design standard</td><td>4-EY</td><td>Berms within gathering RoW</td></tr>
<tr><td>2-year ARI (< 12 months)
10-year ARI (> 12 months)</td><td>Catch drain</td></tr>
<tr><td>2-year ARI (< 12 months)
10-year ARI (> 12 months)</td><td>Clean water diversion</td></tr>
<tr><td>Water quality</td><td>Refer to Arrow Energy Environmental Authority EPPG00972513, Schedule B Table 1, for specific measurements.</td><td>Dewatering plan</td></tr>
<tr><td>Sediment control</td><td>Soil loss of 31 t/ha-yr</td><td>Type 3 devices</td></tr>
<tr><td>Timing - limit of forward clearing</td><td><table><tr><td>Jan-Mar</td><td>Apr to Sep</td><td>Oct to Nov</td><td>Dec</td></tr><tr><td>6 weeks</td><td>8 weeks</td><td>6 weeks</td><td>4 weeks</td></tr></table></td><td>Clear & grade</td></tr>
<tr><td rowspan="2">Erosion control standard</td><td>On commencement of reinstatement as soon as practicable based on a risk assessment of conditions</td><td>Timing – reinstatement</td></tr>
<tr><td>5 days</td><td>Timing – limit of forward clearing in</td></tr>
</table>

(timing of works - days to stabilization post works completion, shutdown or suspension)		clean water 'drainage features'
	5 days	Timing – reinstatement of clean water 'drainage features'
Development of progressive ESCP's	All plans shall be developed by a suitably qualified person. A CPESC or CPSS is an example of a suitably qualified person. As a minimum, attendance of comprehensive (4 days) ESC training is required.	ESCP's
Wet weather preparedness	50% chance of >15 mm in wet seasons. 50% chance of >20mm in dry season.	ESCP.

4.5 SITE SPECIFIC PLANS

The following is recommended to be developed once design is completed and construction method is selected. These site-specific plans shall overlay on a GIS map, or be in simple work method statement format, or where appropriate, redline mark-up of existing standard drawings. All site-specific plans shall reference IECA 2008, Book 4 - Design Fact Sheets and Book 6 - Standard Drawings.

Table 10 - Overview of site-specific plans

Site specific Plan	Deliverable
Drainage feature crossings and road drainage crossings	• Comply with timing of works. • Delay clearing until bulk earthworks imminent. • Convey clean water through site. • Prevent mixing of clean and dirty water. • Prevent ponding of water and is reinstated to predevelopment elevation.
Rainfall preparedness plan	• Topsoil stripping and excavations will create voids requiring dewatering. Detail methods for treatment of turbid water.

4.6 STANDARD DRAWINGS FOR ASSET TYPE

Standard plans are recommended to be redline marked up once layout and design is finalised, standard plans for each asset type are found in Table 11 and Table 12. The following standard drawings are appropriate for this project, based on soil loss class, receiving environment and asset type.

Table 11 - Gathering pipelines standard drawings

Drawing number	Purpose
ORGP01-ARW-HSM-LAY-00001-001_0_3_ESC General Notes_1	General erosion and sediment control notes
ORGP01-ARW-HSM-LAY-00001-002_0_3_publication_ESC General Notes_2	General gathering RoW layout
ORGP01-ARW-HSM-LAY-00001-003_0_3_publication_ESC General Notes_3	General gathering RoW layout
ORGP01-ARW-HSM-LAY-00001-004_0_3_publication_ESC General Notes_4	Standard control details
ORG-ARW-PPL-DET-00011_1_1_publication_bank restoration drawing	Bank restoration standard drawing

Table 12 - Well Pad standard drawings

Drawing number	Purpose
ORGH01-ARW-HSM-LAY-00001-001_0_2_publication_Multi Pad_ESC_1	General erosion and sediment control notes
ORGH01-ARW-HSM-LAY-00001-002_0_1_publication_Multi pad_ESC_2	Standard well pad layout
ORGH01-ARW-HSM-LAY-00001-003_0_1_publication_Multi pad_ESC_3	Standard control details

Wet weather preparedness

The rainfall trigger has been set slightly higher than the standard 10 mm rainfall trigger. This is due to the alignment being in melon-hole, Vertosol soil type with a slope less than 1%. The high water holding capacity (10-12 mm per 100 mm of soil) of these melon-hole clay type soils reduces runoff, whilst it is noted that estimated infiltration rates will be approximately 2-5 mm per hour once cracks swell and close, it will take approximately 15-20 mm of rainfall to start to produce surface water, and greater than 25 mm for surface runoff, however, this depends on rainfall intensity.

To account for rainfall intensity, the wet season rainfall trigger is slightly reduced at 15 mm and dry season trigger is 20 mm.

4.7 Implementation, Monitoring and Maintenance

The project manager or budget holder is primarily responsible for implementation. They may delegate responsibility, however, still assume accountability for; implementation, quality assurance, monitoring and maintaining erosion and sediment control devices.

Implementation is set out in document Erosion and Sediment Control Framework Plan ORG-CNJV-ENV-PLA-00002, as summary is provided:

- Pre-construction erosion hazard risk assessment
- Determine application of ESC standard treatments and prepare ESC Line List based on erosion hazard risk assessment
- Install ESC measures in accordance with Line List
- Field inspection to review ESC treatments are installed appropriately and are effective
- ESC maintenance as required to ensure all measures are in working order

4.8 Concluding Statement

Soil erosion risk to the receiving environment is low and can be managed with implementation of suitable erosion and sediment controls. Implementation of soil amelioration as per the restoration management plan will reduce soil dispersion risk.

5 Subsidence Management Plan

This plan details how subsidence is proposed to be managed during the project, which includes actions and techniques to monitor and remediate any identified subsidence.

5.1 Assessment Criteria

The Environmental Authority regulates site stability and has the following performance criteria for subsidence of reinstated areas, an extract is displayed in Figure 4.

stable	has the meaning in Schedule 5 of the *Environmental Protection Regulation 2008* and, for a site, means the rehabilitation and restoration of the site is enduring or permanent so that the site is unlikely to collapse, erode or subside.

Figure 4 - Assessment criteria for subsidence

The plan specifically addresses the following performance criteria within:

- Section 5.3 prevention (addressed in Arrow Energy construction management processes)
- Section 5.4 monitoring and inspection frequency
- Section 5.5 subsidence identification and classification, to understand if site does not meet definition of stable.
- Section 5.6 repair method and techniques to ensure site is returned to meet the definition of stable.

5.2 Risk Assessment

The construction of well pads and gathering infrastructure involve the backfill of excavations, as described in *Section 3*. Subsidence has the potential to occur when voids are left within the backfilled soil profile, or similar compaction to adjacent area is not achieved. For subsidence to occur in this scenario, generally, the soil profile will require saturation for a slumping action to occur.

The project area is dominated by melon-hole clay Vertosol soil type, which has a high-water holding capacity with high shrink-swell potential. If backfilling of excavation occurs when soil is saturated (beyond field capacity), then excessive movement can occur during drying. This can lead to larger cracking and or settlement. It should be noted that large cracking and settlement is a natural process in this soil type, however, where infrastructure has exacerbated this, non-compliance with assessment criteria will occur. This soil type also exhibits undesired chemical parameters below surface. Once subsoil is exposed or backfilled higher in the soil profile, it is susceptible to tunnel erosion or sinkholes, particularly if a hydraulic outlet is presented (e.g. a backfilled pipeline).

The only excavation done on well pads is to establish a shallow trench for temporary storage of residual drill mud post drilling operation. The risk of this shallow trench forming notable subsidence is extremely low. This trench is approximately 300 mm depth and does not disturb the entire soil profile, unlike the gathering pipeline installation process.

Gathering pipeline installation poses a high risk for subsidence, due to the depth of excavation (1 – 1.5 m bgs), circular shape of pipe going into a rectangular shaped excavation. Arrow Energy have an existing engineering standard for installation of gathering pipelines which specifies control methods for the risk of subsidence post reinstatement. Arrow Energy backfill of pipelines is generally conducted in accordance with Australian Standard AS2566, which calls for specific particle size of soil to be placed around the pipe and different horizons within the trench, a maximum backfill layer with standard compaction and quality assurance.

5.3 Key Risk Summary

The risks and controls of subsidence are displayed in Table 13 - Risk and control summary for project subsidence

Table 13 - Risk and control summary for project subsidence

Risk	Control
Voids left during pipeline backfill	ORG-ARW-PPL-SPR-00005_3.0_1_publication_SPECs_PE Gathering Network, specifically: • Backfilling grading and bedding section. • Compaction requirements and testing section.
Dispersive soil exposed causing tunnel erosion post pipeline backfill	Refer to Section 4 (Erosion and Sediment Control Plan) and Section 6 (Restoration Plan)
Voids left during backfill of well pad trench	This is a shallow trench. The risk of developing notable subsidence is extremely low.

5.4 Subsidence Monitoring and Inspection

An inspection program needs to be risk based, rather than scheduled without purpose. To determine an inspection program a trigger event needs to be determined. To understand this, an assessment of the cause of subsidence needs to be undertaken.

Subsidence usually requires rainfall to occur for either soil settlement to occur, or, for tunnel erosion to form. Subsidence requires soil saturation, whereas tunnel erosion and sinkholes require ponding water and adverse soil chemistry for a preferential flow pathway.

To determine a critical rainfall event, the depth of soil profile where voids are likely to occur, or, where tunnel erosion will find a preferential flow path, needs to be identified. This critical depth is usually the depth of a buried asset, for example, a pipeline can have a preferential flow path along the pipe as this material can convey flow. For this project the depth is 75 cm depth, which is minimum depth of cover over pipeline.

The water holding capacity of the site soils is greater than 10 mm per 100 mm of soil. Due to the volume of water required for the soil type to reach field capacity for a profile depth of 75 cm, it is recommended that inspections occur post 75 mm of rainfall. To determine an infiltration timeframe, it is estimated that the likely hydraulic conductivity of the soil type is 2-5 mm/h. Based on an average of 3mm per hour it would take approximately 10 days for profile saturation to a depth of 75 cm. It is recommended that the timeframe of a week (7 days) is a practical timeframe.

Table 14 - Recommended monitoring frequency

Action	Event
Monitor project area	>75 mm rainfall within 7 days
Monitor project area	Observation from staff, land manager or others.

5.5 Subsidence Identification

Sink holes and tunnel erosion

These features are characterised by an opening in the soil surface for water to ingress down to the extent of excavation. They present a danger for human health, livestock and wildlife due to size and depth of the hole. An example is displayed in Figure 5.

Figure 5 - Example of tunnel erosion or sinkhole over pipeline

Subsidence

This feature is when the ground level over an asset is lower than the surrounding landscape and can lead to sink holes and tunnel erosion, or concentrated flow erosion. This feature can intercept overland flow water and re-direct it, concentrating it parallel to the install asset, which can lead to loss of soil over the asset. An example is displayed in Figure 6.

Figure 6 - Example pipeline subsidence

5.6 Repair Methodology

The repair method will be site specific, however the general process for scoping is displayed in Table 15. The general repair method options will import fill or utilise in situ material, these are displayed in Table 16 and Table 17.

Table 15 - Scoping and planning process

Requirement	Details
Site investigation	• Detail site drainage • Detail site risks, topography, vegetation constraints and soil conditions. • Land use and landholder constraints • Perform soil survey and characterization. Representative soil samples of topsoil and subsoil are required, refer to IECA 2008 Appendix C and Appendix P.
Identification of issue	• Confirm issue, subsidence, tunnel erosion or sinkhole, or combination.
Soil testing	• For soil testing parameters refer to IECA 2008 Appendix C.

Table 16 - Tunnel erosion and sinkhole repair options

Method	Benefits	Limitations	Preference
Site soil harvesting • Removal of topsoil • Reprofiling subsoil • Recompact as per adjacent landscape • Reinstate topsoil • Apply soil ameliorants as per soil tests	• No imported materials	• Excessive disturbance • Generally grading to fill sink holes or tunnel erosion only fills the upper hole, so reoccurrence is possible • Backfill may not comply with engineering specification depending on depth and pipe exposure	Least preferred
*Importation of material • Remove minor volume of topsoil • Fill tunnel erosion or sink hole • Recompact as per adjacent landscape • Reinstate topsoil • Apply soil ameliorants as per soil tests	• Material complies with pipeline engineering specification. • Potential to import a 'flowable' material which can be installed as a slurry.	• Weeds • Importation of materials cost • Landholder constraints • Importing a foreign material into cropping land	Preferred

NOTE: excavate to depth of tunnel erosion and recompact has not been considered as an option, as this involves live excavation works as a routine method, involving great risk of damage to pipelines, explosion hazard.

**Material to meet requirements within ORG-ARW-PPL-SPR-00005_3.0_1_publication_SPECs_PE Gathering Network*

Table 17 - Subsidence repair options

Method	Benefits	Limitations	Preference
Site soil harvesting • Removal of topsoil • Reprofiling subsoil and fill in subsidence • Recompact as per adjacent landscape • Reinstate topsoil • Apply ameliorants as per soil tests	• No importation of materials • Good for small, isolated areas	• Large re-disturbance of soil horizons and potential soil loss. • Limited to small depth of subsidence, for large depths of subsidence imported fill maybe required. • Backfill may not comply with engineering specification depending on depth and pipe exposure	Preferred with constraints.
*Importation of subsoil fill • Removal of topsoil • Filling subsidence with imported fill • Recompact as per adjacent landscape • Reinstate topsoil • Apply ameliorants as per soil tests	• Material complies with pipeline engineering specification.	• Weeds • Importation of materials cost • Landholder constraints • Importing a foreign material into cropping land	Most preferred

**Material to meet requirements within ORG-ARW-PPL-SPR-00005_3.0_1_publication_SPECs_PE Gathering Network*

5.7 Concluding Statement

There remains a risk of subsidence with pipeline operations post construction. Whilst there are control measures that comply to Australian Standards, subsidence is still a risk to the pipeline industry post construction.

The risk of subsidence has been mitigated to industry practice, however, if this occurs Arrow Energy have sufficient methods and techniques to deploy to significantly reduce the risk of re-occurrence.

6 Restoration Plan

This plan has been proposed in accordance with *RPI Act Statutory Guideline 09/14*.

6.1 Assessment Criteria

As per *RPI Act Statutory Guideline 09/14 How to determine if an activity has a permanent impact on Strategic Cropping Land*, information requirements for demonstrating land will be restored to pre-activity condition will be best presented through a detailed restoration plan. Assessment criteria steps and references in this document are listed in Table 18.

Table 18 - Assessment criteria steps

Assessment criteria	Plan section
1) Information on the nature of impact on the land and methods used to determine impact	An overview of the project is provided in section 3. Section 6.3 risk assessment.
2) Characterisation of the pre-activity (current) condition of the land and soils	Section 6.2 predevelopment soil and land use
3) Evaluation of the nature and risk of any predicted impacts on the land	Section 6.3 risk assessment
4) Evidence that scientifically proven and practical methods do exist for restoring the land	Section 6.4 reinstatement and restoration
5) Detail on the application of the restoration methods including timeframes	Section 6.4 reinstatement and restoration
6) A monitoring program including benchmarking and progress milestones	Section 6.6 validation and quality assurance of performance criteria
7) A fully-costed estimate of identified restoration works	Section 6.8 cost of site-specific methods
8) Restoration criteria against which successful restoration can be demonstrated	Section 6.5 performance criteria

6.2 Predevelopment Soil and Land Use

The project area is predominately flat, with a slope < 1%, and commonly <0.5%. Whilst this significantly reduces soil erosion risk from water runoff, it presents another risk of ponding water where reinstated assets are higher than predevelopment landforms.

Compaction is a risk to cropping yields. A bulk density greater than 1.5 can hinder root growth and impact crop yields. Compaction influences hydraulic conductivity, whereby restricting water movement through profile. Hydraulic conductivity based on field texture class is estimated from *Hazelton & Murphy*, 2007 Table 2.13 as being low, between 2.5 mm to 5 mm per hour. This rate is expected to drop past 90-100 cm depth, as elevated sodium restricts profile drainage. This soil type has a large water holding capacity, and as such when dry it shrinks and large cracks open up. These cracks give the impression of high hydraulic conductivity when open. There is limited ponding or runoff from 25-30 mm of rainfall, which is generally enough for cracks to swell once swollen water movement is limited. The plant available water holding capacity of the soil is estimated to be approximately 120 mm per meter of soil profile, based on clay type and using Table A1-2 from *RPI Act Statutory Guideline 08/14*, with total water holding capacity greater than 200 mm per meter of soil profile, estimated from *Hazelton & Murphy*, 2007 Table 2.7.

Due to the combination of high water holding capacity, high cation exchange capacity and low hydraulic conductivity, relying on rainfall alone to flush salinity out of the crop root zone will not yield results within the short to medium term. When seasonal rainfall is above average, deep drainage below root zone does occur in a fallow cropping system, leaching some salinity. However, once the profile goes through a drying phase as is the case with dryland cropping, minor capillary rise can occur whereby salts can rise again during soil drying. It is noted that dryland cropping has increased deep drainage compared with native woodland or pasture, catchment wide studies suggest the rates are approximately 10-15 mm per year on average, *Department of Natural Resources, Mines and Energy* (2019). Whilst *Silburn et al* (2011), found that the leachate of deep drainage was high in electrical conductivity and chloride, with rates of deep drainage averaging 10 mm per year under dryland cropping within the Darling Downs region, on grey vertosol soils. Since land clearing, a significant portion of chloride has been leached from the profile, however land clearing commenced in the 1930's and became widespread in the 1950's. This proposed development site, has seen the benefits of deep drainage over time, as chloride is lower within the profile than would be expected in a native state.

When deep drainage does occur, it can remove soluble salts from the profile at moderate rates, however occurrences are at a low rate, and will continue to be at lower rates as farming systems make use of moisture and reduce deep drainage. Thus, relying on rainfall to flush salinity from the entire profile is possible, but without specific management techniques, impacts can last many years, (this assumes 10 mm deep drainage per year and chloride is evenly leached from profile). A modelling tool, *SALF2* (2022), predicts the site has an extremely low leaching fraction, which corresponds with findings from *Silburn et al* (2011*)*, however the leaching fraction is to predict percentage of water that ends up as deep drainage at a certain depth, and not an immediate diffusion or dilution into immediate layers.

The common soil constraints with grey or black vertosol profiles within the Darling Downs in southern Queensland are generally; soil salinity, sodicity, alkaline pH in profile and acidic pH at depths below the root zone. These common properties were identified, however, most notable is low salinity within the upper profile, providing unrestricted root zone to at least 80 cm. There was no acidic pH identified, which is common in vertosol soils dominated by Brigalow vegetation. It is assumed that this acidic layer can be found below 200 cm depth.

Figure 7 through Figure 10 display the soil laboratory data from soil points, DS01, DS04 and DS07 and critical constraints compared with soil profile depth.

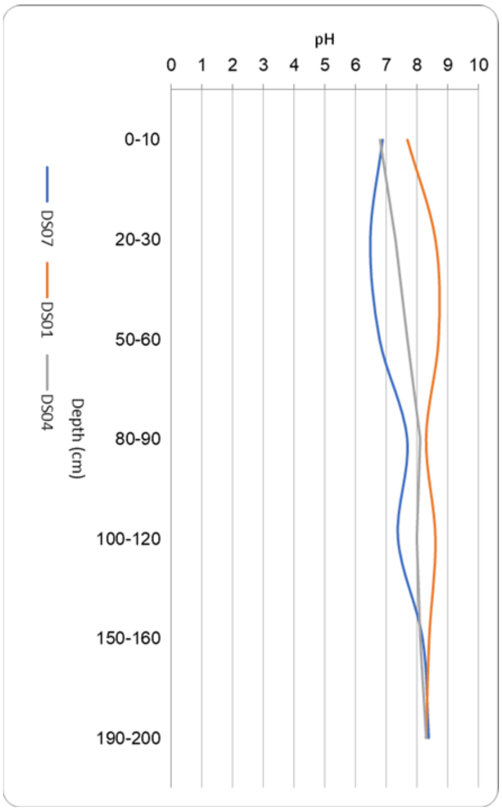

Figure 7 - pH within soil profile

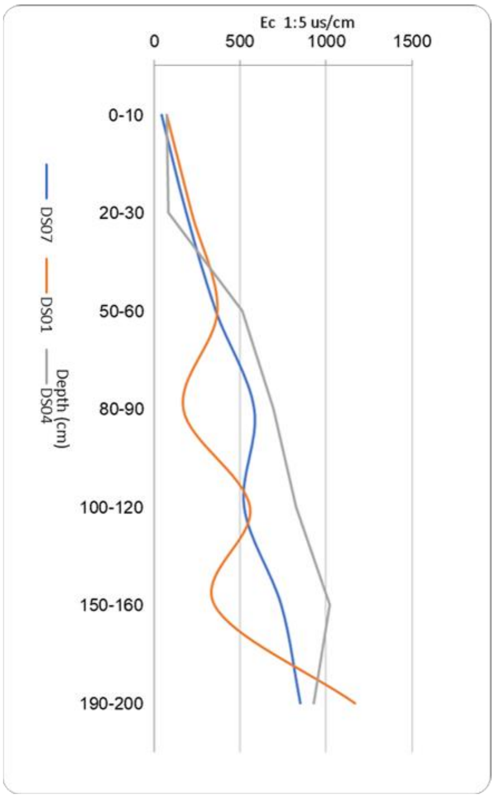

Figure 8 - $EC_{1:5}$ us/cm within soil profile

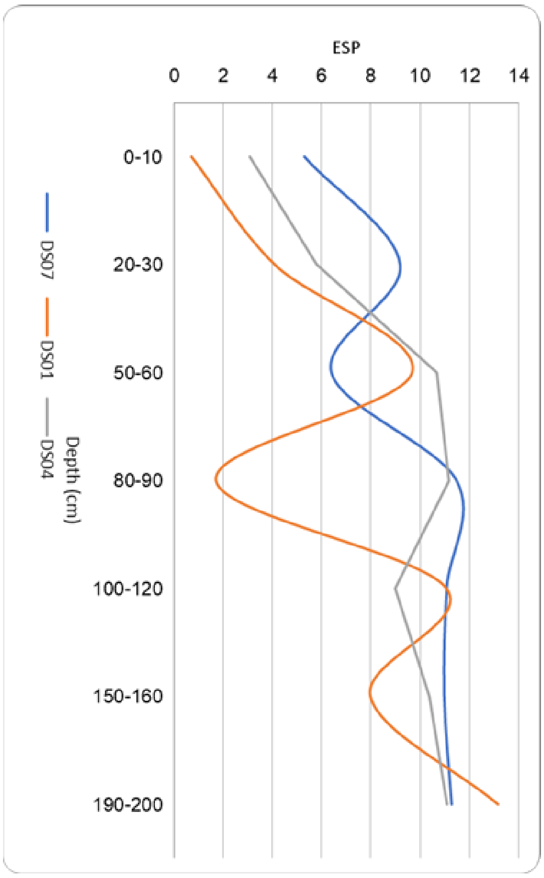

Figure 9 - ESP within soil profile

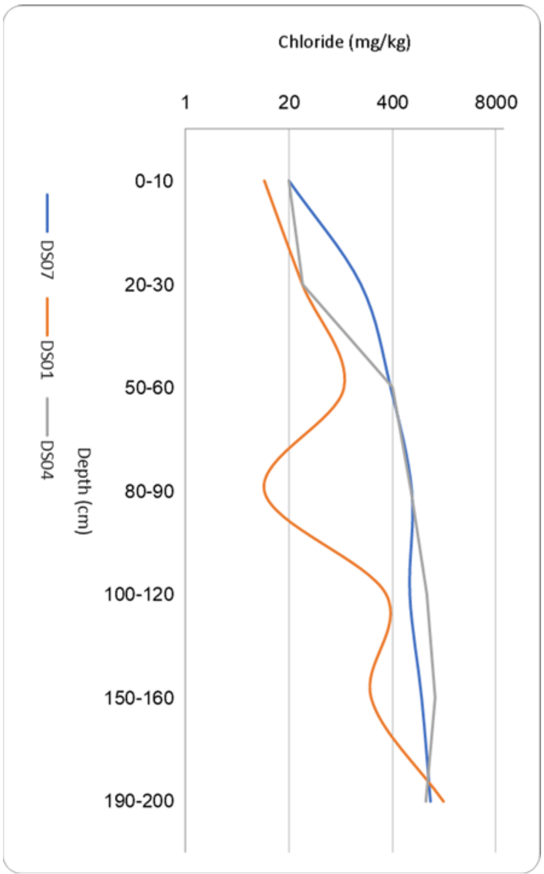

Figure 10 - Chloride within soil profile

6.3 Risk assessment

The below Table 19 identifies project specific soil attributes that are detrimental to crop growth and identifies project activities that have potential expose these risks.

Table 19 - Project specific soil risks

Risk	Activity	Potential harm
Saline soil identified at depth	Trenching or excavation	Reinstatement of layers incorrectly, resulting in salinity within root zone.
Sodic soil identified depth	Trenching or excavation	Reinstatement of layers incorrectly resulting in hyper sodicity within root zone. Restricting upper profile drainage.
Loss of SCL status	Trenching and backfilling	Inversion of soil, elevated chloride levels within soil profile above SCL thresholds.
Loss of soil moisture	Topsoil removal and excavation.	Subsoil moisture levels reduced compared to adjacent.
Compaction	Machinery movement	Compacting upper and lower layers to a bulk density > 1.5 or above background.
Loss of nutrients	Clear n grade, stockpiling.	Disturbance to topsoil resulting in potential loss of nitrogen, and diluting nutrients with deep stripping depth. Risk of losing phosphorus with soil erosion.
Loss of soil to erosion	Rainfall and wind.	Soil loss due to inadequate drainage or wind.
Importation of gravel hardstand material for well pad construction	Import foreign material	Rock and or coarse-grained material added to melon hole clay.
Disposal of residual drilling material (saline) in upper profile on well pads	Disposal of salts (potassium and sodium chloride).	Elevated levels of salinity and boron.
Decline in microbial activity	Stockpiling topsoil.	Long term stockpiles associated with well pads will have a decline in microbial activity.
Surface drainage	Reinstatement	Reinstatement levels above or below predevelopment, causing ponding or diverting flows.
Potential spills of CSG water and/ or hydrocarbon	Operating plant or construction equipment	Potential to cause compromise to soil health.

6.4 REINSTATEMENT AND RESTORATION

Proven practical methods

The soil profile is generally; moderately saline past 90-100 cm depth, elevated chloride below 100 cm, generally slightly sodic below 20-30 cm and sodic below 90 cm. A predevelopment soil depth is the defined depth of soil profile that is critical to sustain current land use which is to be reinstated to maintain the SCL status. As outlined in section 6.2, managing salinity through rainfall leaching can possibly meet the required performance criteria over many years. Returning specific horizons in order of extraction cannot be achieved by Arrow Energy within a narrow RoW width and pipeline trenching methodology. There is a risk of soil chloride impacting SCL trigger thresholds. Sodicity and pH, whilst elevated, is below SCL trigger limits to target excavation depth. An overview of the predevelopment depth is displayed in Figure 11.

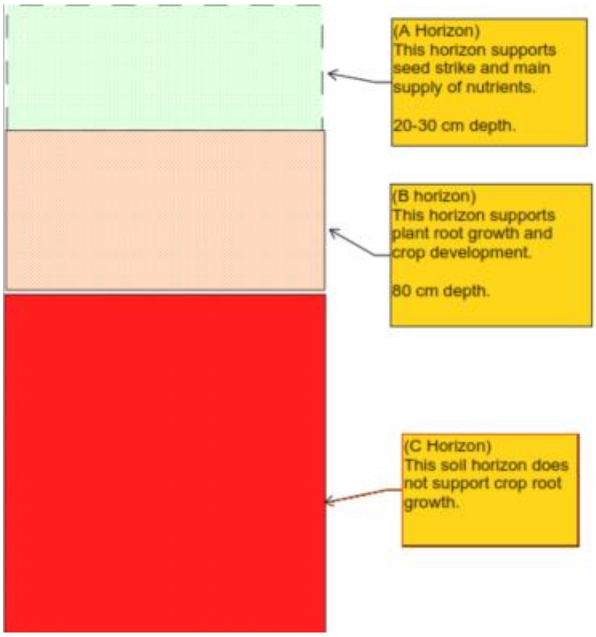

Figure 11 - Pre-development depth and soil horizon reinstatement

Due to pipe installation in trench, there will be a volume of soil displaced and spread over the RoW at 30 cm bgs. Chloride levels exceeding 800 mg/kg can occur post reinstatement within the 30 cm bgs layer, assumed to be 5 cm thick. Volume displaced by pipe diameter may increase the layer thickness. Dryland planting is between 2-20 cm depth, so a crop is likely to have sufficient growth media from the 30 cm of reinstated topsoil. *Figure 12* displays an average crop uptake through evapotranspiration, where by 40% occurs in the top quarter of profile. The top 30 cm of soil profile is expected to be sufficient to strike a seed, as this is when a plant is vulnerable to low levels of salinity and unlikely to meet species tolerance thresholds.

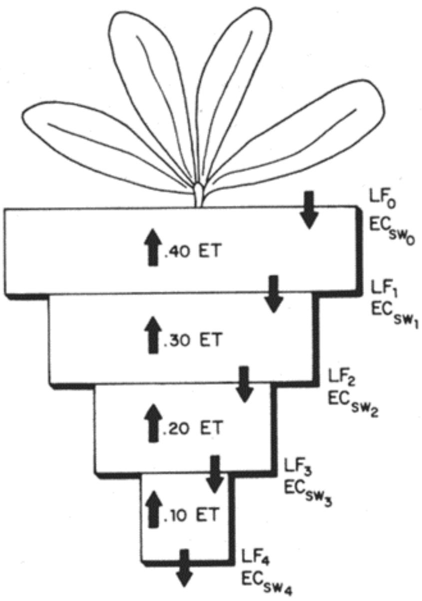

Figure 12 – Average plant water uptake from a root zone divided into quarters, illustrates effect of concentrating soil water and the proportion of uptake for evapotranspiration (ET) (Source: Ayers, R, S. Westcot, 1994)

The blending of higher chloride levels from below 100 cm compared to the upper profile represents approximately 30-40% of the excavated material, so the blended rates will be lower than the highest identified chloride level of 1400 mg/kg. An estimated chloride level based on percentage blend rates can potentially range from 400-1200 mg/kg present at a layer 30 cm bgs, based on available data. If this layer contains 1200 mg/kg of chloride and is 5 cm thick, and bulk density of 1.5, that is 75 kg of soil per m^2, or 90,000 mg/kg of chloride per m^2. During compaction relief, slight blending of the chloride into the next 15 cm layer bgs with a starting chloride of about 400 mg/kg, will end up with a chloride level around 800 mg/kg and possibly over the threshold (complete mixing is unlikely with conventional ripping). This assumes all input parameters are at worst range, so it is quite possible areas will be less than 800 mg/kg of chloride at 30 cm bgs, post backfill. Post reinstatement, it is assumed moisture drawdown is 20 mm per 100 mm of soil. A low intense rainfall event greater than 100 mm can potentially allow moisture to infiltrate to 50 cm bgs and begin to diffuse chloride into the surrounding layers. This assumes 5 mm infiltration per hour from 20 cm to 50 cm, aided with gypsum and compaction relief.

As stated above, there is potential to identify a horizon that does not meet SCL criteria within the top 100 cm post excavation backfill and not meet performance criteria listed within *Table 22,* until significant rainfall occurs. Critical salinity thresholds are below impact levels for a range of crops typically grown on the Darling Downs region. The highest $EC_{1:5}$ measured is 1.02 mS/cm, which equates to a EC_{se} of 5.9 for heavy clay, which is has a moderate salinity risk rating. This is below the 10% yield decrease for cotton of EC_{se} of 9.6. A root zone salinity calculation for a soil profile of 90 cm based on *DS07* soil sample with 30-40 cm depth artificially was increased to 1 mS/cm, to account for an artificial layer post reinstatement. The calculated root zone salinity, as per *Table 11, Salinity Management Handbook, 2011*, $EC_{1:5}$ 0.403 mS/cm or EC_{se} 2.34 mS/cm is below the critical thresholds of common crops on Darling Downs.

The reinstated area is expected to have elevated salinity and chloride levels when compared to adjacent representative areas. There is potential to reduce crop reduced yields for the medium term, until salinity diffuses into and leaches out of the profile.

Application of residual drill material (RDM) can only be assessed once volume and chemistry is known. Specific recommendations for planning and SCL protection levels are set out in *Table 21*.

It is recommended that gypsum be applied to the project area in two split application rates. One on the topsoil and one over the trench line or other excavations. The following pure gypsum application rates are recommended:

- Topsoil rate is 5 t/ha (pure gypsum)
- Trench line is 5.5 kg/m^3 rate (pure gypsum)

The topsoil application rate is based on sodium encountered at 20-30 cm depth (using below calculation) and increasing soil salinity over the ESI dispersive threshold for 18 months post reinstatement of topsoil. This has been calculated based on rainfall of 620 mm per year and gypsum solubility of 2.5 g per litre of water.

The subsoil is based on sodicity increasing with depth, which will impact on soil properties compared to predevelopment depths. The main parameter of concern that needs to be addressed is sodicity, to improve chloride diffusion and leaching. The following has been used to calculate the gypsum rates:

(ESP-5)*CEC*BD*depth = pure gypsum application rate (kg/ha) * EGE.

NOTES:

ESP = exchangeable sodium percentage

CEC = cation exchange capacity (meq/100g)

BD = soil bulk density

Depth = depth of soil profile to be ameliorated in cm (20cm depth used)

EGE = effective gypsum equivalent %

Once a gypsum source has been selected, lab analysis is required to understand the EGE (effective gypsum equivalent percentage), refer to section 6.7 for formula.

An indicative fertilizer rate is given only, as 150 kg/ha nitrogen and phosphorus fertilizer; 18% N, 20 %P; with Zn blend. This should be discussed and amended based on advice from the land manager, as the fertilizer needs to be based on the next proposed crop. There is no data supplied for ammonia levels, however the nitrate + nitrite levels vary between low to adequate. It is recommended that nitrogen levels are addressed based on the next crop post land reinstatement. Phosphorus (Colwell method) levels are moderate to adequate in most topsoil samples, however, low in one sample. Phosphorus levels can be adjusted based on next crop post land reinstatement. The exchangeable potassium levels are above the 200 mg/kg critical limits for plant growth, so are adequate. Of the micronutrients, zinc is low and should be considered based on next crop.

Compaction relief of subsoil once the trench has been reinstated is recommended to occur over the entire area impacted by heavy equipment. A bulk density < 1.5 is required to prevent restriction to root growth and aid profile leaching. A depth of at least 30 cm prior to topsoil reinstatement is required.

The pipeline methods implemented by Arrow Energy comply with APIA code of practice for onshore pipelines and IECA 2008 requirements. In-addition to this, soil amelioration specification has been developed to minimise as much as possible the risk of soil inversion.

Method and techniques

The implementation of the project overarching Erosion and Sediment Control Plan requires a specific soil management plan, which controls risks identified that have potential to compromise reinstatement achieving performance criteria.

To achieve the performance criteria and mitigate the identified soil risks, Table 20 and Table 21 summarise the key methods to prevent the degradation of the soil profile for different asset types, i.e. gathering pipelines and well pads.

Table 20 - Gathering pipelines key reinstatement techniques

Attribute	Requirement	Measurement
Topsoil depth	Remove topsoil prior to excavation	30 cm
Soil amendment *	Topsoil gypsum application	5 t/ha (EGE)
	Gypsum application over trenchline prior to trenching	5.5 kg/m^3 (EGE)
	Nitrogen and phosphorus fertilizer, with Zn blend; N: 17 | P: 18.9 | S: 2.5 | ZN: 1.88 *Fertilizer type and rate are indicative only. Seek advice from land manager for next proposed crop.*	150 kg/ha
Relieve compaction	Ripping compacted subsoil to a minimum depth of 30 cm to predevelopment bulk density	Bulk density < 1.5
Reinstate topsoil to predevelopment level	Reinstating topsoil to predevelopment level.	No ponding

Table 21 - Well pads key reinstatement techniques

Attribute	Requirement	Measurement
Topsoil depth	Remove sufficient topsoil for reinstatement. Removing topsoil depth will result in a depression that will not drain due to flat terrain. Remove to depth over excavations.	30 cm
Predevelopment depth	Remove this depth post topsoil removal and reinstate in order of extraction of excavating deeper (cellar installation and removal)	100 cm
Timing of works and stockpiling	Topsoil stockpiles are expected to be required for 25 years until gravel hardstand is removed.	25 years.

Disposal of residual drilling mud (RDM)	Disposal of RDM shall not compromise the land value. Specifically, shall not compromise the thresholds of strategic cropping land.
	A site-specific plan shall be developed by a suitably qualified person to ensure measurements are not impacted by application rates. This plan can be developed once volumes and chemistry of RDM is available, and shall consider:
	• Minimum test requirements set out in ORG-ARW-HSM-WOI-00046 – Application of RDM, plus
	  ○ Electrical conductivity of saturated paste extract (EC_{se});
	  ○ Sodium adsorption ratio of saturated extract SARe and,
		• Chloride < 300 mg/kg in the topsoil
		• Exchangeable Sodium Percentage < 6% in the topsoil, and < 15% in top 600 mm profile
		• Chloride < 800 mg/kg at 60 cm depth, & 100cm
		• pH < 9 in top 100 cm profile
		• Calcium / Magnesium ratio

	○ Boron determined from hot 0.01M $CaCl_2$ extractable test method. • Modified effective ESP based on the CROSS** equation is recommended, due to the potassium content in the drill mud. Potassium has dispersive potential, and this equation accounts for common cation dispersive potential.	>0.1 in top 100 cm of profile • CROSS < 6 in topsoil, and <15 in top 100 cm profile, both exchangeable cations & cations in soil solution. • <2 mg/kg for Boron
Soil amendment*	Rate based on native soil. Once RDM chemistry and volume is available it is expected this rate will increase.	5 t/ha (EGE) (Nominal rate)
	Nitrogen and phosphorus fertilizer, with Zn blend; N: 17 | P: 18.9 | S: 2.5 | ZN: 1.88 *Fertilizer type and rate are indicative only. Seek advice from land manager for next proposed crop.*	150 kg/ha
	Compost rate is dependent on RDM chemistry and volume that is disposed on well pad surface. Compost application rates shall be determined by a suitably qualified person once compost source is known and tested, with specific reference to salinity and chloride level and shall meet Australian Standard. Weed risk assessment shall comply with current biosecurity legislation.	5-10 t/ha (Nominal rate)
Relieve compaction	Ripping compacted subsoil to predevelopment bulk density	Bulk density < 1.5
Reinstate topsoil to predevelopment level	Reinstating topsoil to predevelopment level.	No ponding
Removal of imported material	Removal of all imported material such as gravel hardstands or roads, except for specific locations where a landholder agreement is in place.	No gravel material within profile.

*all imported soil ameliorants shall be approved by land manager. The use of some ameliorants for example, synthetic fertilizers, can have a negative impact on organic application or certification.

**CROSS equation = $(Na + 0.56K) / \sqrt{((Ca + 0.6Mg)/2)}$

Reinstatement and restoration (abandonment) timeframes

Gathering pipelines will be reinstated as per timeframes listed within Table 9 *(refer to ESCP)* and continue into the operational phase for project life-cycle. Once the operational life-cycle is complete, pipeline abandonment works will be completed.

The well pads will be reinstated post drilling and completion operations. This consists of reinstating the footprint required by drilling and completion rig operations. The well pads require surface infrastructure (hardstand, surface facilities, well head, etc) for the life of the project. Once the well operations are complete, this equipment will be removed and reinstatement will occur as per Table 21. At present, Arrow Energy is expecting to operate these assets for approximately 10 to 15 years.

6.5 Performance Criteria

The restoration performance criteria are displayed in Table 22, these are key to measure successful restoration.

Table 22 - Restoration performance criteria

Criteria	Comment
Land use altered	• Land has not been altered and can still sustain dryland intense cropping for; cotton, wheat, barley, chick peas, mung beans etc. • No yield reduction
Topsoil reinstated	• Seed strike zone reinstated not impacting on future crop strikes
Predevelopment depth reinstated	• Root zone reinstated not impacting on water holding capacity
pH within 100 cm depth	• < 9
Cl within 100 cm depth	• < 800 mg/kg
ESP within 100 cm depth	• < 15 %
Ca/Mg ratio	• >0.1
No rockiness	• No rocks > 5 mm within top 60 cm of soil profile.
Terrain reinstated	• No ponding or diverting water • No permanent drainage structures causing erosion offsite • Overland flow as per predevelopment.

6.6 Validation and Quality Assurance of Performance Criteria

The project manager is responsible for project implementation and quality assurance. Project responsibilities may be delegated through the project, however ultimate responsibility lies with the project manager / budget holder. The project manager shall be responsible for:

Site Inspections

- Visual daily inspections during construction
- Post rainfall inspection during construction
- Weekly inspections during construction
- Client inspection

Assurance and Monitoring

The following requirements are recommended to be undertaken to assure performance criteria. An assurance plan should identify:

- Construction activity being monitored
- Method of inspection or testing standard
- Frequency or timing of inspection
- Performance criteria
- Required documentation

Table 23 provides overview of data capture requirements to assure soil management techniques comply with performance criteria. This data is required for the validation report, which specifically addresses and confirms the performance criteria have been achieved.

Table 23 - Site specific soil management Assurance requirements for reinstatement

<table>
<tr><th>Activity</th><th>Confirmation</th><th>Requirement</th></tr>
<tr><td>Topsoil management</td><td>Depths removed and replaced</td><td>Photo with measuring tape, 2 per km or 1 per well pad.</td></tr>
<tr><td>Backfill operations</td><td>Backfill material in top 100 cm.</td><td>Photo and soil sample of material at 30-50 cm bgs layer, 1 per km, or 1 per well pad.
Samples analyzed for field parameters by suitably qualified person for; pH$_{1:5}$, EC$_{1:5}$, field texture, colour, verifying layers are placed and meet performance criteria, and select samples sent for exchangeable cations, SARe and chloride.
NOTE: EC$_{1:5}$ will be elevated post gypsum application. Gypsum solution saturation is 2.2 mS/cm. Gypsum portion of EC$_{1:5}$ needs to be explained if samples contain applied gypsum.</td></tr>
<tr><td>Well pad trench backfill</td><td>Removal of saline impacted material prior to trench backfill.</td><td>In situ field sampling for, pH$_{1:5}$, Ec$_{1:5}$, field texture, colour, by suitably qualified person to verify.
Disposal (burial, blending etc.) method to be developed by suitably qualified person.</td></tr>
<tr><td>RDM disposal</td><td>Disposal of RDM does not raise salinity past thresholds</td><td>Soil analysis is recommended to confirm and assure against performance criteria, depths are slightly modified from ORG-ARW-HSM-WOI-00046 – Application of Residual Drill Mid, to suit SCL.
<table>
<tr><th>Depth</th><th>Frequency</th><th>Analysis</th></tr>
<tr><td>0-15 cm
20-30 cm
50-60 cm</td><td>3 depths per well pad are sent to a lab for analysis.</td><td>Minimum requirements set out in ORG-ARW-HSM-WOI-00046 – Application of Residual Drill Mid; plus
Electrical conductivity of saturated paste extract (Ec$_{se}$); and,
Boron determined from hot 0.01M CaCl$_2$ extractable test method.</td></tr>
</table>
Soil sampling, testing and analysis shall be performed by a suitably qualified person.</td></tr>
<tr><td>Compaction relief</td><td>Ripping soil layers</td><td>Photo monitoring and visual inspection.</td></tr>
<tr><td>Removal of imported material (post well pad abandonment)</td><td>Removal of all gravel material</td><td>Photo monitoring and soil sample, 1 per well pad.
Test soil sample for field texture class and record any visual rockiness.</td></tr>
<tr><td>Soil amelioration</td><td>Rates applied and locations</td><td>Photo monitoring</td></tr>
<tr><td>Terrain reinstated</td><td>Landform reinstated to predevelopment</td><td>As build survey of surface conditions.</td></tr>
</table>

NOTE: the method to determine sufficient soil sample validation is derived from *Table 1*, within *Soil Science Australia, Guideline for Soil Survey along Linear Infrastructure, 2015*. It is considered practical for intensity of 1 site per 1 km with a mapping scale 1:25,000, for validation of reinstatement methods.

Validation Report

It is recommended a validation report is prepared by a suitably qualified person to summarise the quality assurance data captured during the project. This report will satisfy any future query regarding construction process and methods utilised to achieve the performance criteria.

The report is recommended to contain:

- Summary of key dates and milestones.
- Summary of the soil management method.
- Evidence of as per Table 23.
- Analysis of quality assurance data collated, soil samples, soil test results and photos.
- Statement addressing performance criteria.
- Summary of monitoring post reinstatement.

6.7 STANDARD

Table 24 recommends measuring and monitoring standards for the restoration management plan.

Table 24 – Standards for measuring and monitoring success of reinstatement

Aspect	Requirement
Suitably qualified person	All plans shall be developed by a suitably qualified person. A CPSS or RPEQ, CPESC (CPESC and RPEQ will need to display experience in soil chemistry and morphology) is an example of a suitably qualified person. As a minimum, SQP shall have a minimum of 5 years experience soil science. Specifically, soil chemistry, soil morphology, soil survey with particular focus in land restoration.
Soil sampling	All soil sampling shall be overseen by a suitably qualified person.
Soil testing (field testing)	All field testing shall be conducted by a suitably qualified person.
Soil testing laboratory	Laboratories engaged to perform soil testing shall be NATA and ASPAC certified.

Gypsum	• Calcium sulphate $CaSO_4\,2H_2O$.
	• Test supplied for gypsum purity
	• Weed seed free and documented evidence of compliance with *Queensland Biosecurity Act 2014*.
	• Moisture content < 15%, air dried at 40°C
	• If manufactured
	  ○ < 0.001% cadmium, and
	  ○ < 0.01% lead, and
	  ○ < 0.0005% mercury.
	
	The application rate shall be adjusted based on effective gypsum equivalent (EGE) calculation;
	
	(PF % x FF %)/100 = EGE%
	
	EGE x 1 ton = application rate for gypsum source per ton
	
	Purity factor (PF);
	Lab analysis of calcium and sulphate (CaSO42H2O) content and any neutralizing potential. The lab analysis will provide a purity percentage.

	Fineness factor (FF), is the percentage passing through a sieve, based on the following; • 0% if > 6mm • 75% if < 6mm but > 3mm • 100% if < 3mm <u>Example equation</u> PF = 90% FF = 80% (0.8 x 0.9)/100 = 72% EGE Calculated rate to displace excess sodium off exchange site is 10 ton per ha. 10 / 0.72 = 13.8 t/ha EGE actual application rate.
Compost	Composted to Australian Standard AS4454-2012, and free from all contaminants of concern (low ash content, no PFAS or other by-products that maybe accepted by compost facility). Weed seed free and documented evidence of compliance with *Queensland Biosecurity Act 2014*.
Fertilizer	N: 17 | P: 18.9 | S: 2.5 | ZN: 1.88 or approved equivalent as specified by land manager.

6.8 COST OF REINSTATEMENT METHOD

Table 25 provides an overview of cost for specified reinstatement methods and techniques. Some methods are just displayed and not costed, as these for part of general construction method. Costs associated *Arrow Energy Specification for PE Gathering Networks (Gas and Water), Version 3. 2019*, are included but not costed, as these techniques form part of general construction technique, called ‘construction works’ in table.

Table 25 - Site specific soil management methods

Activity	Price assumptions	Cost
Topsoil removal	Construction works*	NA
Soil erosion control	Construction works*	NA
Quality assurance and soil testing for backfill	Extra works. 13 x soil samples, collection and testing. 1 x technician required to collect these samples, assume 3 days work at $1500 per day (this task can be performed by personnel already onsite).	$4, 500
Compaction relief	Construction works	NA
Application of ameliorants Total disturbance estimated at 20 ha (13 km x 20 m plus well pads) *50 ton gypsum (pure gypsum) required for topsoil (5 t/ha rate; applied on 13 km of RoW at 20m wide)	Gypsum material cost $150/ton landed onsite, plus 5 days spreading at 2000 per day. Gypsum material 168 x 150 = $ 24, 600 5 x 2000 = $ 10, 000	$30, 600
	Compost material cost $50/ ton, plus, 5 days spreading at 2000 per day 50 t x 50 = $2, 500 3 x 2000 = $6, 000	$8, 500
	Fertilizer material cost $1,000/ ton Total fertilizer required 3 tons 3 x 1000 = $3,000 Plus 3 days spreading at 2000 per day	$9, 000

*13 ton gypsum (pure gypsum) required for trenchline (5.5 kg/ m2 linear trench x 26 km) Increase gypsum by 30% for EGE = 82 tons Compost rate based on 50 ton.	3 x 2000 = $6,000	
Residual drill mud (RDM) disposal on well pad	Construction works. Provisional sum included for lower application rate and removal from site. Assume loader and side tipper for 1 day per pad to relocate. Allowance for blending with specialist machinery, where blending can be achieved.	$50,000 provisional sum
RDM disposal quality assurance	Testing of well pads post application and testing. Technical 1500 per day, Lab testing 1200 per pad. Average 3000 per pad with 7 well pads.	$21,000
Topsoil reinstatement	Construction works*	NA
Removal of imported materials	Construction works*	NA
Removal of surface facilities	Construction works*	NA
Validation report	1 technician required to perform a project quality assurance report. $1500 per day for 5 days.	$7, 500
Total cost estimate of site-specific reinstatement method (Includes a $50,000 provision for RDM disposal)		$123, 600

**construction works denotes works that are already priced within project budget.*

NOTES

- *1 x technician day rate is $1,500, this allows for definition of a suitably qualified person.*
- *All machinery priced at $2,000 per day (excavator, tractor with spreader), it is noted that a tractor and spreader is highly likely to be significantly less.*
- *'Remove subsoil to predevelopment depth', to achieve this on gathering pipelines it is estimated an excavator can move ahead of trencher at a quicker rate in this soil type. This is based experience from where this technique was implemented in similar landscape.*
- *RDM disposal method is likely to be impacted, as salinity thresholds for SCL are likely to reduce disposal volumes. This cannot be accurately priced until RDM volumes and RDM chemistry is known. A provisional sum of 50,000 has been included.*
- *Gypsum cost per ton delivered to Dalby area averages 150 per ton.*
- *Compost sourced within the local government area can be delivered to site averages 50 per ton.*
- *Fertilizer price is highly volatile at present. It is assumed $1,000 per ton, however recent market conditions have impacted short term price.*

6.9 Concluding statement

Specific soil management methods and techniques exist to target and improve soil structure, therefore increasing profile drainage and maximising salinity diffusion and leaching over time. These methods are widely used in industry and routinely in cropping operations. Construction methodology presents potential to exceed SCL thresholds post reinstatement. Robust quality assurance and validation is recommended to measure and quantify the impact.

Caution is recommended to determine the application rate of RDM to the well pad during reinstatement activities. Currently, application volumes or RDM chemistry is unknown, however sufficient planning specification has been provided to meet SCL thresholds.

7 References

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