Addendum to the Surat UWIR 2019

Dated: 20 August 2020

This addendum is an amendment to the UWIR 2019 pursuant to a notice dated 6 August 2021 by the Chief Executive of the Department of Environment and Science (DES) under section 393(4) of the Water Act 2000.

The addendum is to give effect to the Spring Impact Management Plan (SIMP) for the Springrock, 311/Yebna 2, Lucky Last and Lonely Eddie spring sites. The SIMP was required to be submitted by the responsible tenure holder – Santos – as per section 9.7 of the Surat Underground Water Impact Report (UWIR) 2019. The SIMP must include a summary of the hydrogeological understanding of the springs, an evaluation of the options for prevention, minimisation, mitigation or offset of the predicted impacts, and a plan for implementation of the identified options.

Santos revised its initial submission following numerous discussions with the Office of Groundwater Impact Assessment (OGIA) and DES and submitted a final revision to OGIA for approval. The SIMP was approved by OGIA on 29 April 2021 as attached for implementation.

The SIMP comprises three parallel streams of work:

1. **Mitigation actions** that bring the residual risk to 'low' based on the current risk profile and predictions identified in the UWIR 2019, unless there is evidence to suggest that the risk profile is different from that identified in the UWIR 2019. Mitigation actions will be triggered by the likelihood of coal seam gas (CSG) impacts occurring at early warning indicator sites. Actions will then be implemented within one to two years of this determination.

2. **Trigger monitoring** and reporting based on OGIA's ongoing assessment of trends in groundwater pressure monitoring data. Santos will undertake monitoring and provide data to OGIA. OGIA will undertake a yearly assessment of this monitoring data to identify the likelihood of CGS impacts occurring at early warning indicator sites and notify Santos and DES of the outcome to trigger actions.

3. **Ongoing investigations** at a number of spring groups to further improve knowledge about impact pathways and springs response to those impacts. These investigations will occur in parallel with the mitigation actions and trigger monitoring.

The addendum is prepared by an external party and as such it is not guaranteed to meet the Queensland Government's accessibility standards.

Santos

Santos GLNG

Spring Impact Mitigation Plan

31 May 2021

CDM Smith

Table of Contents

Figures

Tables

Appendices

Section 1 Introduction

This Spring Impact Mitigation Plan (SIMP) is a statutory document. Chapter 3 of the *Queensland Water Act* (2000). provides the legislative framework within which an Underground Water Impact Report (UWIR) is required. The 2019 UWIR for the Surat Cumulative Management Area (CMA) (2019 UWIR) was prepared by the Queensland Government's Office of Groundwater Impact Assessment (OGIA), with a take-effect date of 16th December 2019.

The 2019 UWIR provides a strategic approach to the assessment and management of potential cumulative groundwater impacts on springs related to coal seam gas (CSG) development activities in the CMA. It details various assessments and hydrogeological conceptualisations that inform a regional-scale groundwater flow model and presents assessment of the potential for CSG industry to impact groundwater due to the abstraction of associated water from the target coal seams. This assessment informs groundwater monitoring and management strategies required under the framework mandated by the *Water Act (2000)*.

The UWIR also presents a Spring Impact Management Strategy (SIMS) for the CMA. The SIMS identifies Responsible Tenure Holder (RTH) and obligations. The SIMS in the 2019 UWIR requires Santos to prepare Spring Impact Mitigation Plans for specific spring impact mitigation sites within 6 months of the take-effect date of the 2019 UWIR.

This plan has been prepared on behalf of Santos to satisfy this requirement. It has been submitted to the Queensland Office Groundwater Impact Assessment (OGIA) for approval.

1.1 Background

The UWIR identifies that the spring mitigation plans must include:

1. A summary of the hydrogeological conceptualisation for the spring mitigation sites;
2. An evaluation of the options for prevention, minimisation, mitigation or offset of the predicted impacts, with specification of the preferred mitigation option;
3. A plan, including triggers and timeframes, for the implementation of the preferred option.

A detailed review of the hydrogeological conceptualisations for the mitigation sites of interest has been undertaken as part of a separate technical assessment (CDM Smith, 2020). The key findings of this conceptualisation review, including a summary of the current conceptualisations are provided in Section 2.

As part of the development process of this plan a number of opportunities for improvement in relation to data acquisition or technical understanding have been identified for each spring of interest. A Spring Investigation Plan has been developed and is summarised in Section 3.8.

1.2 Objective

The objective of this SIMP is to develop monitoring and management approaches that ensure no adverse impact to identified spring mitigation sites occur due to CSG activities. Effective management requires definition of triggers and mitigations, timeframes for the implementation of the preferred mitigation options and monitoring approaches for the spring that will confirm the status of the spring mitigation sites.

Figure 1-1 details the OGIA risk framework developed for springs as part of OGIAs Spring Impact Mitigation Strategy (SIMS). This framework has been used as the basis for the assessment works completed as part of the development of this plan.

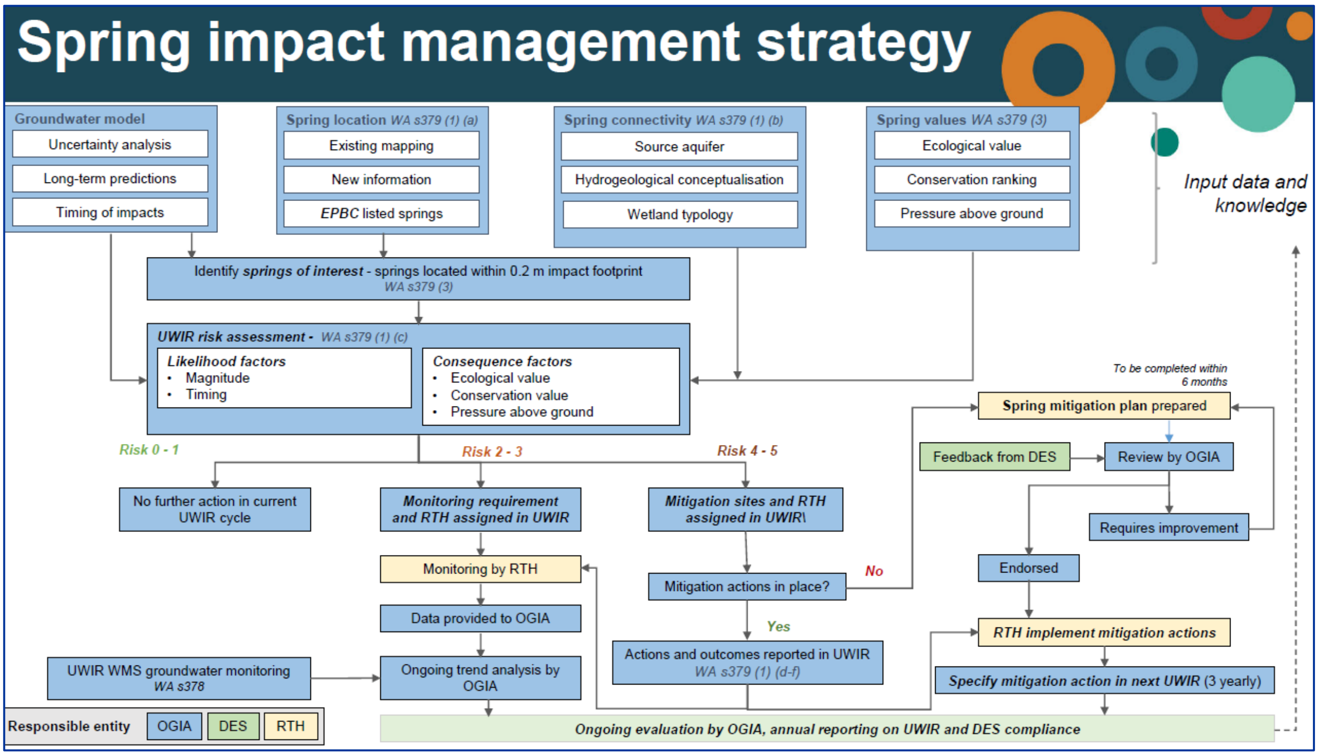

Figure 1-1 OGIA Risk Framework for Springs

1.3 Current Springs Mitigation Considerations

The UWIR identifies that there is currently reinjection occurring into the Precipice Sandstone, undertaken by APLNG at Reedy Creek. The UWIR goes on to predict that these injection activities will reduce drawdowns to less than the 0.2m threshold in proximity to some of the spring mitigation sites identified in the 2019 UWIR. It is noted that the operating parameters of the reinjection facility (including future volumes of water reinjected) may change through time, and that the RTH must consider alternative mitigation actions as needs.

This injection program forms part of the passive mitigations proposed in this plan for one of the springs complexes which Santos is the RTH, which is detailed further in Section 3.6.

1.4 Santos RTH Springs Overview

According to the UWIR Santos is the RTH for four such spring complex/watercourses, including:

- Springrock - comprising Springrock Creek, Hutton Creek (W216) and Hutton Creek (W217);
- 311/Yebna 2 – comprising 311 and Yebna 2 (591), Dawson River (W40), Hutton Creek (W81);
- Lonely Eddie – comprising Lonely Eddie (339) and;
- Lucky Last – comprising Lucky Last (230).

It is these spring groups that are addressed within this mitigation plan.

The location of the spring impact mitigation sites addressed by this plan are shown in Figure 2.

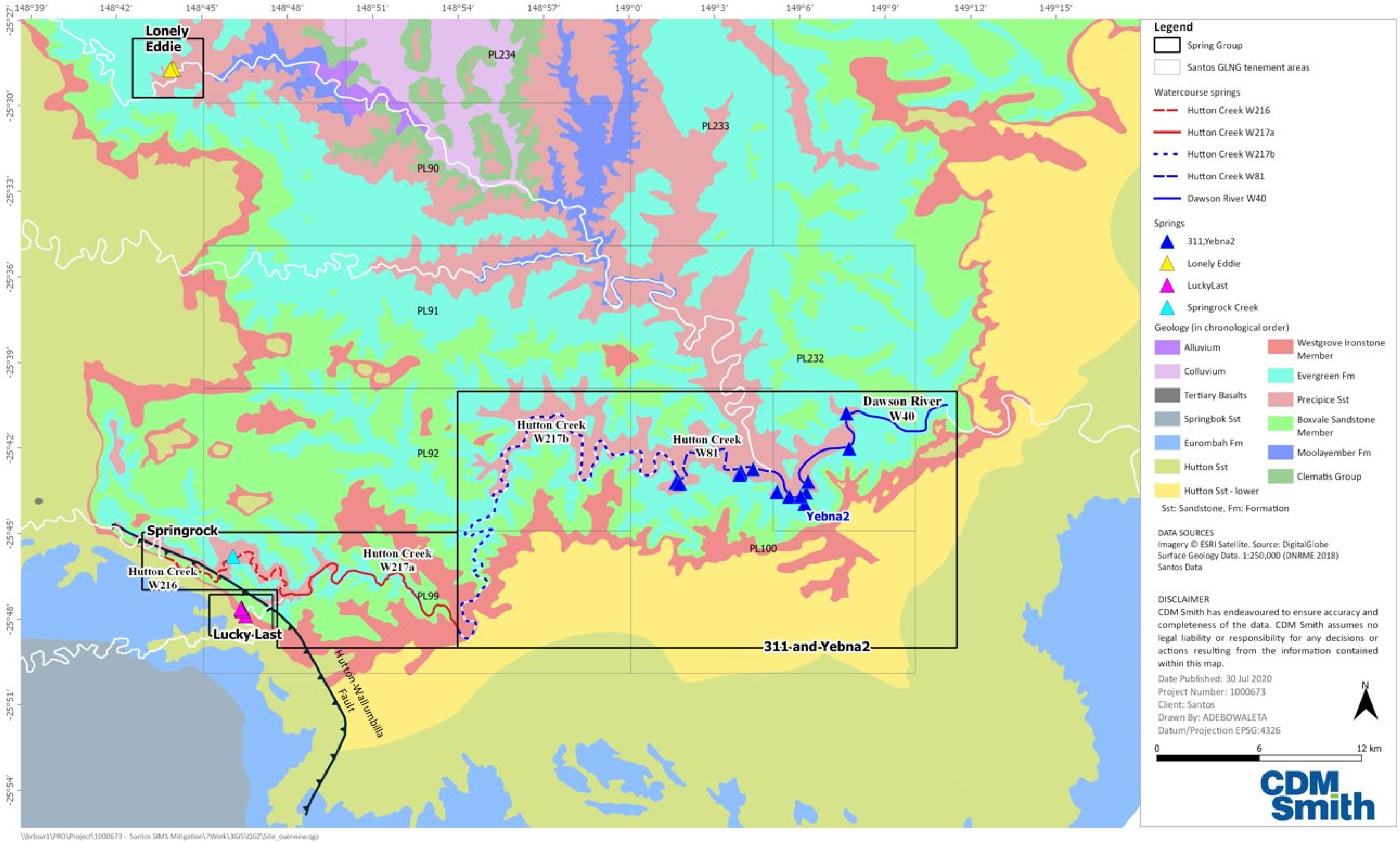

Figure 1-2 Lucky Last, Springrock, 311/Yebna 2 and Lonely Eddie Spring Locations

Section 2 Hydrogeological Conceptualisation for the Springs

The hydrogeological conceptual models developed for the 311/Yebna 2, Lucky Last and Springrock Creek groups by OGIA (2015a, 2015b and 2015c) have been reviewed using more recent field survey information and remain largely unchanged in terms of the spring typology and source aquifer. A new hydrogeological conceptual model has been developed for the Lonely Eddie spring group.

The review has developed a different ecological endpoint for the 311/Yebna 2 Spring Group and the Springrock Creek Group. These findings are important as the ecological endpoint for the spring is intrinsically linked to the Threshold Limit for the spring (detailed in Section 3.3).

The existing hydrogeological conceptual models have been enhanced with a focus on an understanding of the risk pathway between the impacted aquifer and the source aquifer of the springs. These findings are new and important in refining the UWIR 2019 risk assessment outcomes to a more site specific risk context.

The conceptual model for each spring group is summarised in Table 2-1 below (including the refined ecological endpoints). This is followed with a summary of the site-specific risk assessment outcomes (including the new risk pathway understanding) for each spring group in Section 2.1.

Table 2-1 Summary of the Hydrogeological Conceptual Model for Spring Groups

Spring Group	Geology	Source Aquifer	Spring Typology: *Groundwater Flow System*	Spring Typology: *Ecology*	Spring Typology: *Geomorphology & Regolith*	Spring Typology: *Water Regime*	Spring Typology: *Landscape Setting & Change*	Wetland Requirement	Ecological Endpoint
Lucky Last	• Lucky Last wetlands occur along a north to south orientated fault (parallel to Hutton-Wallumbilla Fault) • The Lucky Last wetlands reside on a thin sequence of alluvial sediments associated with Injune Creek, underlain by a lower Evergreen Formation surface geology.	• The source aquifer to the Lucky Last wetlands is the Boxvale Sandstone Member of the Evergreen Formation. • Groundwater flow from the Boxvale Sandstone Member is under artesian pressure, flows from the west upward along a fault where it discharges to land surface.	• There is a weak vertical connection between the Boxvale, Hutton and Precipice units, indicated by the difference in the hydraulic pressures in each • Wetlands represent discrete vertical fractures associated with faulting, providing conduits for groundwater discharge to the surface • Lucky last wetland groundwater is sourced from water flowing from the south west.	• These wetlands have little obvious internal zonation of vegetation species. • The floristic assemblages and hydrogeology indicate a relatively stable system. However, the expression of the wetted area and flora alter depending on the wetting and drying phase of the wetland.	• The Lucky Last wetland comprises twelve palustrine, circular shaped wetlands. • They vary from (1) large, mounded wetlands with deep organic rich soils that permanently discharge and contain aquatic wetland vegetation assemblages, to (2) small, sunken vents with free-flowing discharge only after significant wet periods, containing semi-aquatic wetland species indicative of dryer conditions. • Groundwater discharge from the wetlands occurs at a higher elevation than Injune Creek. Injune Creek itself receives groundwater inflows through the stream bed.	• Wetlands discharge water all the time and are permanent features of the landscape • Discharge can occur as flowing water, or via ET. During dry months discharge is diffuse • Wetlands respond to short and long term changes in rainfall (i.e. wetted area gets bigger and smaller) • Wetlands seasonally transition from diffuse to free flowing, suggesting a localised source of groundwater flow that also responds to seasonal effects	• Geometry, weathering and dissection of the landscape surrounding the wetlands are strongly influenced by structural displacement that has occurred in this area • These Wetlands are located in a broad U-shaped valley of Injune Creek • Occur in a severely degraded and deflating landscape • Cattle grazing and damage is evident, resulting in compaction and alteration of the fringing vegetation	• A permanent supply of groundwater discharge sufficient to maintain saturation of the underlying regolith; • Groundwater discharge to exceed the ET rate of vegetation cover enabling water to pool and discharge tails to develop; and • Additional seasonal input to the wetland from local groundwater systems. This creates discharge that regulates wetland salinity s and provides flow for vegetation.	• Wetland area and wetted extent • The area of aquatic to terrestrial terrestrial/invasive species at the boundary of the wetland
311/Yebna 2	• Evergreen Formation is absent underlying these wetlands (has been eroded by Hutton Crk and Dawson River) • Wetlands are located in outcropping Precipice Sandstone and Evergreen Formation along the Dawson River. • Wetlands are found along bedding planes in the outcropping Precipice Sandstone • Minor unconsolidated sediments are present • Wetlands are located on the axis of the Arcadia Anticline	• Primary source of water for wetlands is groundwater from the Precipice Sandstone.	• Local rainfall is the primary source of recharge to the aquifer and a direct source of water to the wetlands • Groundwater discharge is caused by the removal of the confining Evergreen Fmn and exposure of the Precipice Sandstone, where groundwater pressures are sufficient to drive groundwater flow to the surface • Local groundwater discharge occurs from bedding planes in the Precipice Sandstone	• Constant flow regime and fresh groundwater maintain low salinity wetlands that provide suitable habitat for aquatic vegetation and macroinvertebrates • Aquatic macro invertebrate populations are independent of changes in wetland area • Terrestrial weed species occur around smaller wetlands and larger wetlands are dominated by aquatic vegetation species	• The wetlands are located in a confined stretch of the Hutton Crk & Dawson River • The shallow wetland soils means changes in groundwater discharge lead to minor change in wetland area, because the wetlands have no effective storage capacity • These wetlands occur as groundwater flowing from sandstone bedding planes within the main channel & tributaries, as discrete point discharge zones that have accumulated sediment.	• The volume of water from the wetlands is minor compared to the volume of groundwater baseflow to watercourses • During wet phases they are inundated with surface flow and during dry phases they are maintained by groundwater • Some wetlands appear to be predominantly supported by a sole groundwater source, while others have a seasonal variability that may reflect a reduced groundwater contribution at times	• The wetlands occur in a land system characterised by shallow and freely draining soils, with no low permeability zones to confine or alter infiltration or groundwater discharge • Wetlands occur at higher elevation than the main watercourses and are mainly on the southern side of the watercourse • Stock damage is evident, with pugging and compaction influencing the soil and vegetation	• Permanent supply of groundwater discharge; • Sufficient groundwater discharge rate to maintain a free-flowing wetland, in some situations to maintain connection with in stream water; and • The wetlands are connected to ephemeral and perennial surface water sources, such that the stream water provides additional habitat for macroinvertebrates, and as such, is part of the wetland water requirements.	• Groundwater pressure is the best indicator of ecological status. • Previous conceptual model (OGIA, 2015a) reported an ecological endpoint based on streamflow, which is not supported by this assessment. • A combination of wetland chemistry, pool depth and wetland/wetted area extent has been identified as the ecological end point.

Spring Group	Geology	Source Aquifer	Spring Typology: *Groundwater Flow System*	Spring Typology: *Ecology*	Spring Typology: *Geomorphology & Regolith*	Spring Typology: *Water Regime*	Spring Typology: *Landscape Setting & Change*	Wetland Requirement	Ecological Endpoint
Springrock	• The Evergreen Fmn has been completely eroded away along Hutton Creek, revealing Precipice Sandstone at the surface • Wetlands are located on Hutton Crk in outcropping Precipice Sandstone • Creek bed has limited alluvial development, with Precipice Sandstone forming the base of the creek.	• The Springrock Creek complex occurs in the outcropping Precipice Sandstone.	• Local, topographically driven groundwater flow occurs in the outcropping Precipice Sandstone. • The Hutton Creek is moderately incised and is likely to be a point of local groundwater discharge. • Groundwater flow in Precipice is northwest to southeast • Local rainfall is the primary source of water in the region and directly recharges the aquifers and is also a possible direct source of water to the wetlands	• Seasonal surface water flow and constant fresh groundwater supply, maintains a low salinity wetland, that provides a suitable habitat for aquatic vegetation and both tolerant and sensitive aquatic macros • Macros appear dependent on change in wetland area	• Wetlands occur as pools within the exposed sandstone bedding plane and where minor stream sediment has accumulated • Groundwater discharge (and pool depths) increase downstream, as the relative difference between the elevation of the creek and the hydraulic head in the Precipice aquifer increases • Soils are freely draining rudosols, therefore rainfall infiltration is unrestricted and recharge occurs seasonally	• Wetlands in the creek discharge all year, with discharge dominated by groundwater flow. They do not have drying cycle. • They are multiple wetlands, connected particularly during high flow events • In dry periods the upper reaches of the tributary become a series of disconnected wetlands (pools), fringed by vegetation	• Wetlands located in a riverine setting of a tributary of Hutton Creek • Wetlands occur at higher elevation than the watercourse • The location of wetlands is controlled by the degree of dissection which has exposed the watertable at the surface • Little change in landscape has been observed, although some stock damage is evident at some wetlands, as indicated by pugging	• Permanent supply of groundwater discharge. • Sufficient groundwater discharge rate to maintain free flowing wetlands within the lower reaches, in some situations to maintain connection with in stream water. • The wetlands are connected to ephemeral water sources, such that the stream water provides additional habitat for macroinvertebrates, and as such, is part of the wetland water requirements.	• Previous conceptual model (OGIA, 2015c) reported an ecological endpoint based on downstream gauging of flow and field parameters. • This assessment finds that this spring cannot be characterised by changes in flow in Hutton Creek. • A more appropriate ecological endpoint for this spring is spring pool salinity.
Lonely Eddie	• The surface geology in the area comprises Precipice Sandstone. This was observed in the field and was also observed by KCB (2012). • This Dawson River dissection has cut through the Precipice Sandstone sequence entirely. This has effectively separated the Sandstone into two disconnected units either side of the creek. • The banks of the creek expose the Moolayember Formation which underlies the Precipice Sandstone.	• The springs are sourced from the Precipice Sandstone aquifer. • The average groundwater salinity of the vents was measured at 245 uS/cm EC.	• Due to the lower landscape position of the wetlands and the significant local topographic relief, it is likely that the spring discharge is associated with topographically driven groundwater flow from the north and east. • The linear jointing patterns in the sandstone appears to control the local groundwater flow. Locally derived recharge is concentrated within the joints. • Discharge at the surface appears to coincide with the break of slope and the presence of colluvium sediments. The break in slope is inferred to coincide with the base of the Precipice Sandstone sequence.	• Constant flow regime and fresh groundwater maintain low salinity wetlands that provide suitable habitat for aquatic vegetation and macroinvertebrates • Pooling of water was observed at the springs, with the presence of semi-aquatic and aquic vegetation. The presence of the wetlands was distinguishable by the slight change in vegetation assemblage. • Groundwater discharge maintains an aquatic habitat and is the source of moisture for fringing wetland vegetation.	• This spring complex is located within the riverine setting of the Dawson River, with all vents located on its northern side. • Within these wetlands, the rate of groundwater flux maintains pools of water during dry periods, creating free flowing disconnected wetlands. • The shallow wetland soils means changes in groundwater discharge lead to minor change in wetland area, because the wetlands have no effective storage capacity • These wetlands occur as groundwater flowing from sandstone bedding planes within the main channel & tributaries, occurring as discrete point discharge zones that have accumulated sediment.	• The wetlands are permanent, with a constant groundwater discharge from the exposed bedding planes at the base of the Precipice Sandstone aquifer. • Groundwater discharge wasn't observed below the point of spring discharge, suggesting that the source of groundwater is not the same as that that contributes baseflow to the Dawson River downgradient. • The wetland areas are small and unless during a severe flood event, these wetlands are unlikely to be influenced by the river.	• There were no additional discharge zones identified in the field survey, since they were first surveyed by KCB (2012), which suggests these vents are permanent features of the landscape. • The wetlands occur at the point of discharge, with groundwater flow along exposed sandstone or into colluvium. • The landscape position does not seem to be a control on discharge process, and it is more likely to be associated with joining patterns.	• Permanent supply of groundwater discharge; • Sufficient groundwater discharge rate to maintain a free-flowing wetland • The wetlands are connected to the Dawson River, such that the river water provides additional habitat for macroinvertebrates, and as such, is part of the wetland water requirements.	• OGIA (2016) note the following monitoring indicators applicable to this spring type (4a); – Groundwater pressure; – Wetland chemistry; and – Physical discharge. • The most appropriate ecological endpoint for these springs, is physical discharge from the spring vents.

2.1 Site Specific Risk Assessment for the Springs

The risks associated with the predicted drawdowns derived from the UWIR 2019 numerical groundwater model was updated within the context of the site-specific assessments and the current hydrogeological conceptualisation of each spring mitigation site.

There is a reduction to the unmitigated risk profile for all springs assessed, with the exception of Springrock Creek 561, where the profile has remained unchanged from that presented in the UWIR (2019).

It should be noted that the revised risk profiles presented for all springs identified in this SIMP requires validation (with the exception of Lonely Eddie) via the activities detailed in the Spring Investigation Plan (CDM Smith, 2020b). Outcomes of the tasks actioned as per the Spring Investigation Plan go on to will inform future risk profile assessments.

2.1.1 311/Yebna 2 Complex and Hutton Creek (W81 and W217b) and Dawson River (W40)

There is reliable data that suggests the Precipice Sandstone at these sites is unconfined due to the incision of the stream network into the aquifer. Depending on the degree of confinement change, the predicted drawdown will be lower, and possibly at the margin of the 0.2 metre drawdown threshold. In addition, any potential drawdown may also be limited considering the existing available hydraulic head of the source aquifer at this complex.

Without the implementation of the SIMP, the unmitigated risk is considered <u>Low to Moderate</u>. Specific works have been recommended to further validate the concept of aquifer confinement and the potential for groundwater head change and spring flows considering the relevant ecological endpoints identified.

2.1.2 Springrock Creek (561) And Hutton Creek (W216 and W217a)

The UWIR 2019 risk for the Springrock Creek has been accepted without change (<u>High</u>).

There is some evidence to suggest the risk to Hutton Creek W216 will <u>reduce to Moderate</u> due to the possible mitigations associated with a change in aquifer confinement. However further work is required to provide greater certainty.

The risk to Hutton Creek W217a will also reduce to <u>Moderate</u>, as the main area of predicted drawdown has intervening Evergreen Formation between the Creek and the Precipice Sandstone.

2.1.3 Lucky Last

The unmitigated risk at Lucky Last has been downgraded to Low, as a consequence of the improved understanding of the risk pathway to the spring complex. It is unlikely that the groundwater processes operating at the springs will be affected by drawdown that is sourced from the western contact zone. Any change will be insignificant compared to the existing available hydraulic head of the source aquifer. There is also ongoing uncertainty about the degree of connectivity between the Boxvale Sandstone and the Precipice Sandstone, which requires further study. As an outcome this could show that the modelled drawdown predictions should be revised to reflect such an outcome.

2.1.4 Lonely Eddie

The hydrogeological setting developed for this complex shows that the local source aquifer is not connected to the aquifer from which drawdown is predicted. This conceptualisation strongly supports the conclusion that the modelled drawdown predictions should be revised. No further management of mitigation measures are proposed because the modelled impact pathway is considered invalid. The 2019 UWIR groundwater model should be updated to reflect these findings for this location.

2.1.5 Summary

Table 2-2 summarises:

- The overall and residual risk to each spring as identified in the UWIR 2019;
- The unmitigated risk to each spring group based on the outcomes of the site specific assessments completed as part of this plan;
- The mitigated risk to each spring group, which is the mitigated scoring associated with the implementation of this SIMP.

From this it is evident that upon implementation of the SIMP, the risk of adversely impacting the springs due to CSG activities is low for all springs. It should be noted that the revised risk profiles presented for all springs identified in this SIMP requires validation (with the exception of Lonely Eddie) via the activities detailed in the Spring Investigation Plan (CDM Smith, 2020b).

The SIMP provides interim measures that protect springs until the outcomes of the Spring Investigation Plan can confirm the refined risk scores, including;

1. leading performance criteria that provide early warning of potential impacts to springs; and
2. a Mitigation Options Assessment (Section 3.6) that identifies a suite of potential mitigation measures for each Spring Group (regardless of the risk score), with most measures planned to be progressed prior to a confirmed trigger.

Table 2-2 Summary of the Refined Risk Assessment Outcomes

Group	Complex / Watercourse	UWIR 2019 Assessment		2020 Risk Reassessment	
		UWIR Overall Risk	UWIR Residual Risk	Unmitigated Risk (following site specific assessment outcomes)	Mitigated Risk (associated with the implementation of the SIMP and associated studies)
Springrock	Springrock Creek (561)	High	High	High	Low
	Hutton Creek (W216a)	High	High	Moderate	Low
	Hutton Creek (W217)	High	High	Moderate	Low
311	311 (311), Yebna 2 (591)	High	Medium	Moderate	Low
	Dawson River (W40)	High	Medium	Low	Low
	Hutton Creek (W81)	High	Medium	Moderate	Low
	Hutton Creek (W216b)	High	High	Moderate	Low
Lonely Eddie	Lonely Eddie (339)	High	High	The Lonely Eddie complex is disconnected from the depressurisation predicted within the Precipice Sandstone aquifer and is not considered further in the SIMP.	
Lucky Last	Lucky Last (230)	High	Medium	Low	Low

Section 3 Mitigation Plan

3.1 Framework

An iterative management framework summarising the components and considerations associated with the SIMP has been developed to address the objectives (Figure 3-1). The management framework allows for ongoing collection of data that will be used to both increase the knowledge regarding springs of interest and the local hydrogeological conceptual model, as well as providing the data to determine if and where adverse impacts from depressurisation are occurring and when mitigation options should be employed.

The framework is underpinned by a monitoring and investigation program which has been designed in accordance with a site-specific assessment of potentially impacted spring groups. Site specific assessments may need to be revised and updated as new knowledge becomes available. This may alter the risk profile for the springs of interest, culminating in a refinement of the monitoring program and mitigation plan.

Monitoring locations and the associated monitoring program will require periodic re-alignment with the risk assessment as this evolves. A robust monitoring program has been designed to provide data that may be used in support of routine compliance and trigger reporting, but also provide additional data to improve risk assessment.

Definitions

The SIMP Framework incorporates two specific measures of spring complex performance; Early Warning Triggers and Threshold Limits. These measures are based on SMART principles (that is, be Specific, Measurable, Relevant, Attainable and Time-bound). A description of these performance indicators is provided below:

- **Early Warning Triggers** for the implementation of mitigation actions. These are:
  - Based on leading performance indicators (e.g. water level/pressure), that provide advance warning of potential impacts to the stated outcomes for the spring complexes;
  - Include both a magnitude and timing component; and
- Site-specific **Threshold Limits** which are:
  - Lagging performance indicators that identify when the outcome has not been met;
  - Based on measured impacts to the spring complexes and include water level, water quality, wetland extent.

An **Early Warning Trigger** flag occurs when there is an excursion outside the range of an indicator, and the risk of change to the environmental value is high enough that direct action should be contemplated. Direct action would include implementing the first stages of a mitigation plan. The Early Warning Triggers have been chosen so that there is time available to understand the causes of the change and understanding of the temporal processes operating in the relevant aquifer.

A **Threshold Limit** is when there is an excursion that causes an elevated and immediate risk level to the environmental values of the Springs of Interest.

Summary

The management framework is summarised in Table 3-1 and indicates that Early Warning Triggers for each spring group are associated with specific monitoring bores that will instigate a series of specific mitigation actions, within a defined timeframe. Santos is responsible for the on-going collection and bi-annual reporting of monitoring data to OGIA and OGIA are responsible for undertaking Early Warning Trigger analysis and notifying DES and Santos of any observed exceedances, within 3 months of receiving the data.

Table 3-1 Summary of mitigation actions, triggers and responsibilities

Spring group	Springrock	311/Yebna 2	Lucky Last
Spring complex / watercourse spring	Springrock Creek (561), Hutton Creek (W216)	Hutton Creek (W217), Dawson River (W40), Hutton Creek (W81), 311 (311), Yebna 2 (591)	Lucky Last (230)
Source aquifer	Precipice Sandstone	Precipice Sandstone	Boxvale Sandstone Member
Action	Augment wetland flow (see section 3.6.2).	Offset APLNG's forecast reinjection operations and retirement of applicable groundwater extraction licence (see section 3.6.1).	Offset drawdown by retiring landholder extraction and/or stock control measures to improve wetland resilience to impact (see section 3.6.3).
Early Warning Trigger*	Confirmation of CSG impacts at site VW0903P1 or SPRGWP02. Access to additional site RN14837 is being evaluated for future trigger analysis.	Confirmation of CSG impacts at site MNHGWP02 or MW0903. The equipping of two additional sites OKSGWP05 and OKSGWP04 is being evaluated for future trigger analysis.	Confirmation of CSG impacts at site 13030882 or 123470.
Action Implemented by	Santos		
Time to implement	Within two years of confirmation of trigger at VW0903P1, and within one year at SPRGWP02.	Within two years of confirmation of trigger at MNHGWP02 and within one year at MW0903.	Within two years of confirmation of trigger at 13030882 and within one year at or 123470.
Data reporting to OGIA by	Santos (six-monthly, in accordance with WMS)		
Trigger notification by	OGIA		
Trigger confirmation by	OGIA		
Trigger confirmation and/or notification to	DES and Santos		
Trigger notification frequency	Six-monthly		

*Note, the outcomes of this determination will be presented to Santos within three months of the data submission

The remainder of this section describes the elements and linkages of the framework diagram shown in Figure 3-1.

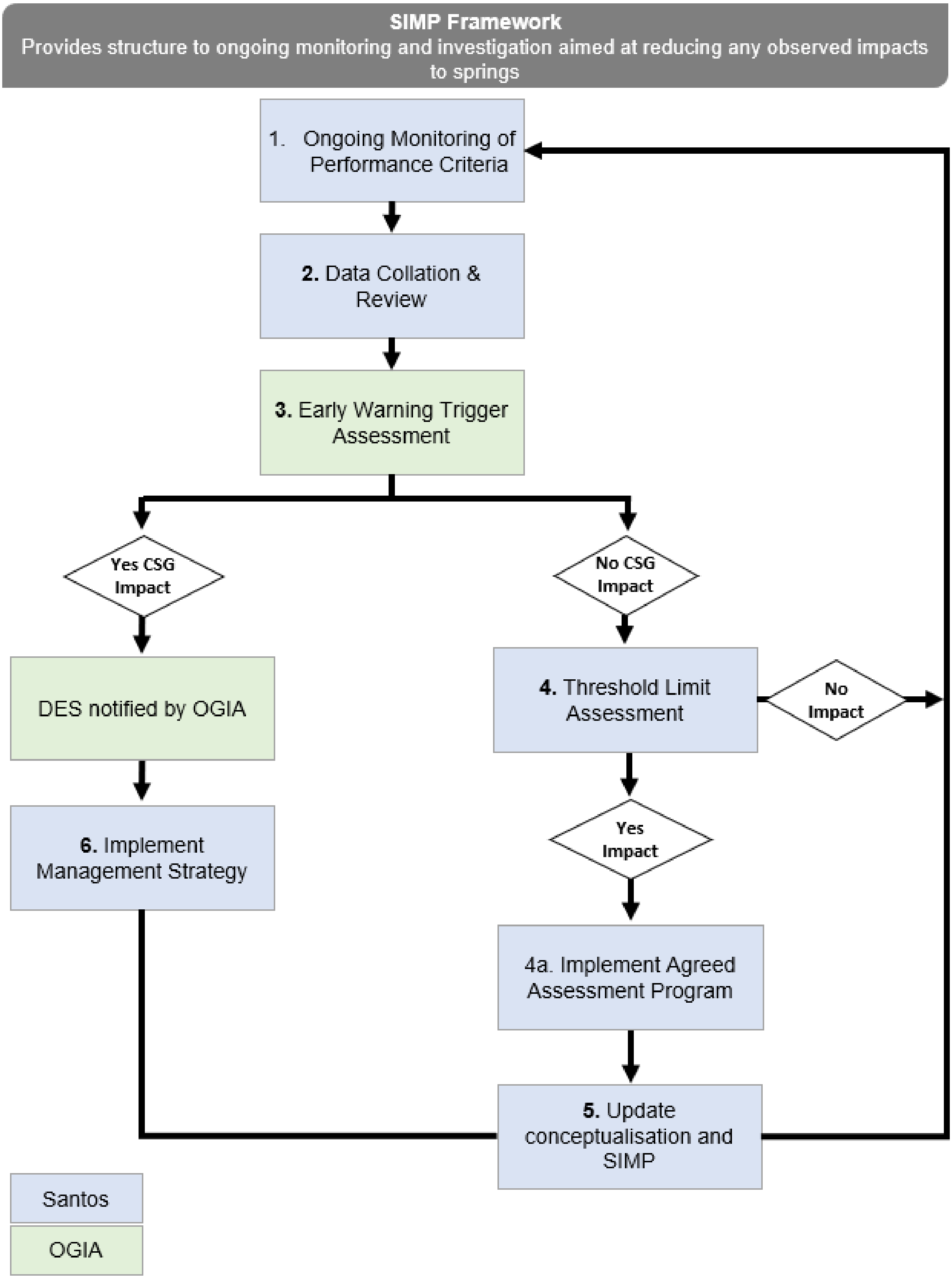

Figure 3-1 Overview of the Spring Impact Mitigation Plan Framework

(1) Ongoing Monitoring of Performance Criteria

a. Monitoring

Undertake prescribed monitoring events according to the method(s) described in the monitoring program (Section 3.4), following the appropriate procedures and protocols. The monitoring program is largely already being implemented, with minor amendments also presented in Section 3.4.

b. Spring Investigation Plan

Progress the program of works described in the Spring Investigation Plan document (CDM Smith, 2020b).

(2) Data Collation and Review

Perform bi-annual data collation and review, including:

- Assessment of quality assurance/ quality control (QA/QC). If there are significant issues identified with data or information quality, consider undertaking the monitoring event again;
- Update existing data sets associated with the monitoring program; and
- Assessment of information provided by activities undertaken as part of the Springs Investigation Program.

Provide output of collated / reviewed data to OGIA every six months.

(3) Early Warning Trigger assessment

OGIA will undertake the bi-annual Early Warning Trigger assessment for the Project area, which is based on a multiple-lines-of-evidence approach to understand the extent to which the observed trends reflect impacts from CSG depressurisation.

OGIA will notify Santos of the outcomes of the Early Warning Trigger assessment.

If no exceedance is observed, Santos will proceed to Step 4, Threshold Limit assessment.

If an exceedance is observed, OGIA will notify DES and Santos and proceed to Step 6.

DES Notification. If an Early Warning Trigger exceedance is confirmed (from Step 3), notification of regulatory agencies is required. Notification will include the relevant detail of the exceedance and specify a timeframe to undertake a management action.

(4) Threshold Limit assessment

Santos will undertake Threshold Limit assessments, which are leading indicators of spring impact.

If no Threshold Limits are exceeded, Santos will continue with Step 1 ongoing monitoring.

In the event of a Threshold Limit exceedance that is not coincident with an Early Warning Trigger exceedance, the Threshold Limit cannot be valid, as other non-CSG related activities may have driven the Threshold Limit breach. In this instance, more detailed monitoring and/or analysis may be required to better understand the cause of the observed trend, proceed to Step 4a.

a. Implement Agreed Assessment Program

An objective of Step 4a is to test the degree to which the adverse trend is explained by other influencing factors than CSG activities (because the Threshold Limit has been exceeded without an associated leading indicator of an Early Warning Indicator).

This may involve further investigations at specific springs of interest to investigate the processes driving the observed change and to verify the existing conceptual model. These investigations may involve hydrogeological studies, modelling, or spring/watercourse-based ecological studies.

A review of the spring conceptual model and risk profile, within the context of any new knowledge obtained, will be undertaken. This will lead to an update of the SIMP (Step 5).

(5) Update SIMP

Update of the SIMP will be required to acknowledge any changes in the monitoring requirements associated with any additional assessments undertaken as part of Step 4, or management strategies implemented as part of Step 6. The update of the SIMP will be done in consultation with the regulators.

(6) Implement Agreed Management Strategy

Santos is responsible for the implementation of the agreed management strategy.

The agreed management strategy could involve a range of mitigation activities that require implementation to manage possible adverse effects (see Section 3.6 Mitigation Options). Following the implementation of the management strategy(s) the SIMP will require updating (Step 5).

3.2 Early Warning Triggers

The Early Warning Trigger assessment aims to confirm CSG impacts to springs 'early' enough that there is sufficient time to implement mitigation measures before the spring impact occurs.

OGIA will undertake the bi-annual Early Warning Trigger assessment, which will compare the observed groundwater levels for monitoring bores, with the predictive outputs of the OGIA numerical groundwater model. The analysis will consider long and short term trends in groundwater levels and is based on the "multiple-lines-of-evidence" method of trend analysis described by OGIA (2019), which has a primary focus "to understand the extent to which the observed trends reflect impacts from CSG depressurisation". This approach recognises that groundwater levels may show a combined effect of non-CSG groundwater extraction from water bores, as well as induced flow from the aquifers to CSG reservoirs. The multiple-lines-of-evidence will include (but not be limited to) an analysis of; climate information, non-CSG groundwater use, CSG groundwater use and aquifer re-injection.

The trend analysis will consider patterns or clusters of trends observed for individual bores across the broader area. It may be necessary to 'weight' the bores in terms of the significance of the individual trend, based on factors such as the length of the bore timeseries. The 'pattern' identification component of the trend analysis aims to identify (for example):

- how robust an individual trend is and whether it can be seen more broadly;
- whether there are trend clusters around the contact zone that may be indicative of CSG impact;
- whether there are trend clusters identified away from the contact zone and therefore indicative of another hydraulic stress (i.e. climate or non-CSG impact).

While the Early Warning Trigger trend analysis considers the available monitoring data for all suitable monitoring bores (see the comprehensive list of monitoring bores in Table 3-4), two specific monitoring bores per Spring Group have a 'time to implement' the mitigation action defined, in the event of a confirmed CSG impact (Table 3-2).

Table 3-2 Early Warning Trigger bores with associated mitigation implementation timeframes

Mitigation Timeframe (following exceedance)	Springrock	311/Yebna 2	Lucky Last
Two Years	VW0903P1	MNHGWP02	13030882
One Year	SPRGWP02	MO0903	123470
-	RN14837*	OKSGWP05* and OKSGWP04*	

*additional sites that require access agreements and / or equipping for monitoring

3.3 Spring Monitoring - Threshold Limit

A **Threshold Limit** is a lagging indicator of an outcome not being met and is measured at the spring. A key outcome of the Site Specific Assessment for each of the spring groups (CDM Smith, 2020), was to confirm the ecological endpoint which is used to define a Threshold Limit for each spring.

Without an observed leading indicator of potential drawdown impact due to CSG activities (i.e. an Early Warning Trigger flagged (Section 3.2), a Threshold Limit cannot be valid. Continued exceedance of a Threshold Limit for a select parameter in absence of an Early Warning Trigger may require the Threshold Limit for that parameter to be revised in accordance with reporting requirements in Section 3.9.

Table 3-7 summarises the ecological endpoint for each of the spring groups and provides detail regarding the associated Threshold Limits. For these spring groups, four different endpoints have been used to characterise the springs;

- **Wetland area (aquatic vegetation) and wetted extent (extent of discharge)**

  A mapped spatial dataset of the long-term Wetland area and Wetted extent provides an indication of the natural variability of the permanent saturation in a spring, predominantly influenced by groundwater discharge. Generally, the high valued aquatic vegetation is confined to the central permanently saturated core.

- **Wetland water chemistry**

  For wetlands where regional groundwater flows provide a sustained groundwater flux to the wetland, the flux is sufficient to cause discharge away from the wetland, flushing salts. In the simplest terms, if the groundwater flux was to reduce or the form of the wetland was to be disturbed, the salinity of the water may increase, causing stress to the aquatic ecosystems. Wetland water chemistry will provide an indicator of seasonal contributions and maintenance of the aquatic habitat.

- **Physical discharge of the spring / surface water flow**

  For watercourse springs that occur within a riverine environment, surface water can play a critical role in the health of the wetlands. Surface flow events provide a seasonal flowing aquatic habitat and an additional water source that may influence the salinity and nutrients within the pools.

- **The ratio of aquatic to terrestrial/invasive species at the boundary of the wetland**

  The long-term permanent groundwater discharge has created a wetland core area dominated by aquatic species, with a very low ratio (close to zero) of aquatic to terrestrial/invasive species. If the groundwater flux to the wetland declines, the edge of the wetland would begin to dry out. Subsequently terrestrial or exotic species may begin to migrate into the wetland area. This change in vegetation pattern, caused changes in the groundwater regime will be measurable by the ratio of aquatic to terrestrial/invasive species at the periphery of the wetland. Groundwater pressure in combination with this provides a suitable ecological endpoint at this wetland type.

3.4 Monitoring Program

The purpose of the monitoring program is to:

1. Specify monitoring to allow for the bi-annual Early Warning Trigger assessment and Threshold Limit exceedances;
2. Provide supporting data that can be used to validate Early Warning Trigger trends and Threshold Limits.

The monitoring activities have been summarised for the monitoring bores (i.e. groundwater level and quality monitoring) and the springs of interest (i.e. watercourse springs and wetlands) with acknowledgement that there are already a range of existing monitoring activities already active and in place.

Santos will maintain all automated monitoring sites as far as it is practically possible. Loss of monitoring data may occur, for example due to remote monitoring equipment failure, and will be communicated with OGIA (see Section 3.4.4).

3.4.1 Groundwater Monitoring

3.4.1.1 Early Warning Trigger Monitoring Bores

Table 3-3 summarises the groundwater monitoring requirements for the **Early Warning Trigger** bores that are used to inform bi-annual trend assessments.

Figure 3-2 shows the locations of the Early Warning Trigger Bores (which also includes the regional network described in the next section).

Table 3-3 Spring Site Monitoring Bores

Group	Bore reference	Groundwater Level Monitoring Frequency**	Groundwater Quality Monitoring Frequency
Springrock	• VW0903P1VW0903P1 • SPRGWP02 • RN14837*	Daily	6 monthly
311	• MNHGWP02MNHGWP02 • MW0903 • OKSGWP05* • OKSGWP04*	Daily	
Lucky Last	• 130308822 • 123470	Daily	

* Access and equipping of these sites is being evaluated for future inclusion in the Early Warning Trigger assessment program
** Santos will maintain all automated monitoring sites as far as it is practically possible. Loss of monitoring data may occur, for example due to remote monitoring equipment failure, and will be communicated with OGIA

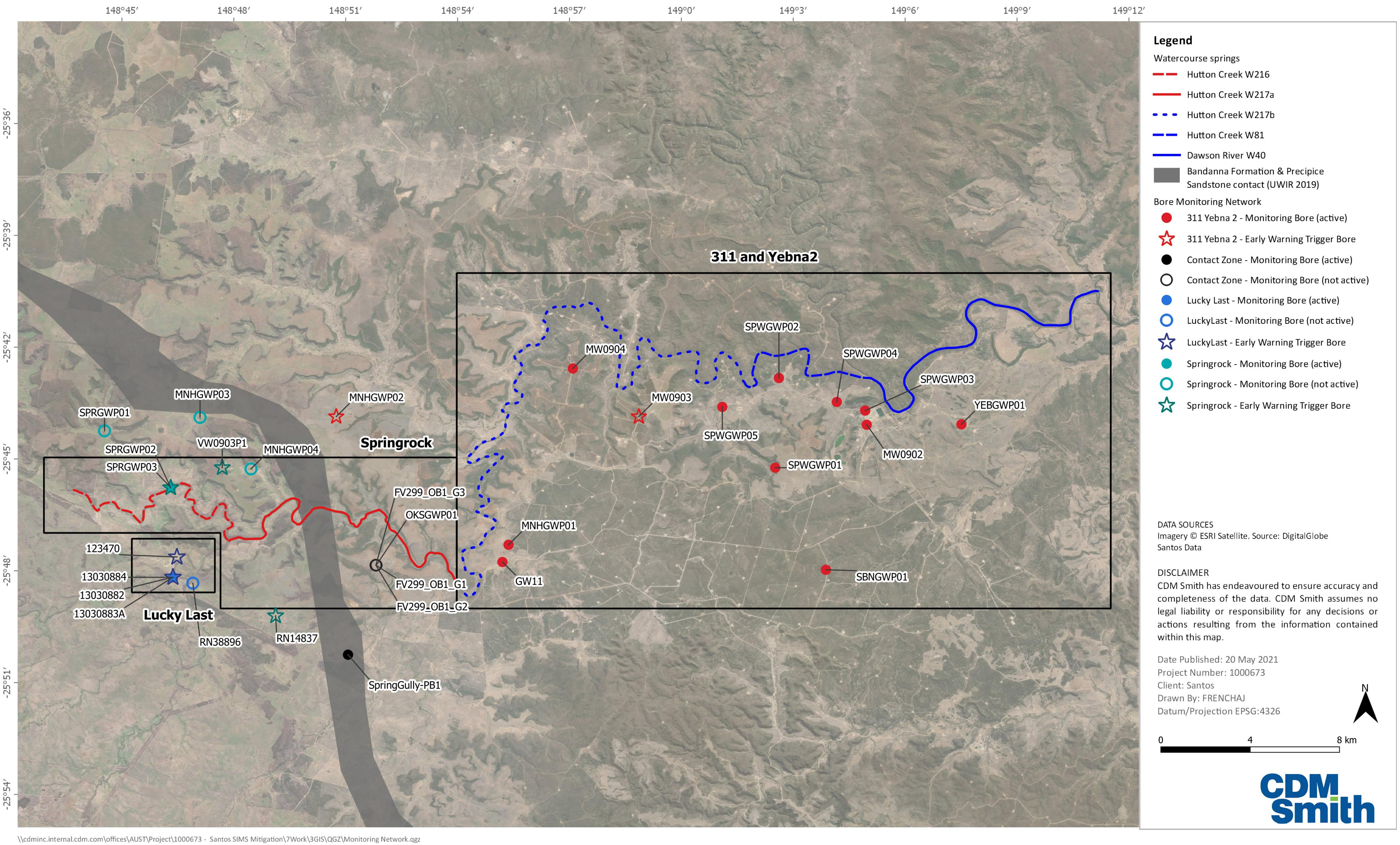

Figure 3-2 Groundwater Monitoring Network (Regional Bores and Early Warning Trigger Bores)

3.4.1.2 Regional Monitoring Bores

A set of 44 regional groundwater monitoring points has been specified for the monitoring program. The locations of the 32 existing monitoring points are shown in Figure 3-2 (i.e. the figure does not include the location of bores that are proposed to be drilled in 2021 as the exact location of these bores is not known).

Table 3-4 provides a summary of the monitoring requirements at each bore. It can be seen that most of these monitoring points should be active by end of 2021.

Table 3-4 Groundwater Monitoring Network (Early Warning Trigger Bores shaded green)

Bore ID	Aquifer Monitored	Owner & monitoring equipment	Groundwater level monitoring status	Groundwater quality monitoring required	Comment
311/Yebna 2 Bores					
MW0903	Precipice Sandstone	Santos - logger	✓	✓	No action required.
MNHGWP02	Precipice Sandstone	Santos - logger	✓	✓	No action required.
OKSGWP05	Precipice Sandstone	Santos – not equipped	2021	×	Requires logger installation
OKSGWP04	Precipice Sandstone	Santos – not equipped	2021	×	Requires logger installation
GW11	Precipice Sandstone	Santos - logger	✓	×	No action required.
MNHGWP01	Precipice Sandstone	Santos - logger	✓	×	No action required.
MW0902	Precipice Sandstone	Santos - logger	✓	✓	No action required.
MW0904	Precipice Sandstone	Santos - logger	✓	✓	No action required.
SBNGWP01	Precipice Sandstone	Santos - logger	✓	✓	No action required.
SPWGWP01	Precipice Sandstone	Santos - logger	✓	✓	No action required.
SPWGWP02	Precipice Sandstone	Santos - logger	✓	×	No action required.
SPWGWP03	Precipice Sandstone	Santos - logger	✓	×	No action required.
SPWGWP04	Precipice Sandstone	Santos - logger	✓	×	No action required.
SPWGWP05	Precipice Sandstone	Santos - logger	✓	×	No action required.
YEBGWP01	Precipice Sandstone	Santos - logger	✓	×	No action required.
YEBGWP02*	Precipice Sandstone	Santos - logger	2021	×	Requires bore construction.

Bore ID	Aquifer Monitored	Owner & monitoring equipment	Groundwater level monitoring status	Groundwater quality monitoring required	Comment
Lucky Last Bores					
123470	Precipice Sandstone	DNRME - Logger	✓	×	No action required.
13030882	Precipice Sandstone	DNRME - Logger	✓	×	No action required.
13030884	Hutton	DNRME - Logger	✓	×	No action required.
13030883A	Boxvale	DNRME - Logger	✓	×	No action required.
WMS MP_726*	Hutton Sandstone	Origin - logger	2021	×	Requires bore construction
WMS MP_725*	Boxvale Sandstone	Origin – logger	2021	×	Requires bore construction
WMS MP_727*	Precipice Sandstone	Origin – logger	2021	×	Requires bore construction
WMS MP_838*	Hutton Sandstone	Santos - logger	2021	×	Requires bore construction
WMS MP_837*	Boxvale Sandstone	Santos – logger	2021	×	Requires bore construction
WMS MP_839*	Precipice Sandstone	Santos - logger	2021	×	Requires bore construction
RN 38896*	Boxvale Sandstone	Landholder bore – not equipped	2021	×	Requires landholder agreement
Springrock Bores					
SPRGWP02	Precipice Sandstone	Santos - logger	✓	×	No action required.
VW0903P1	Precipice Sandstone	Santos - logger	✓	×	No action required.
RN14837	Precipice Sandstone	Landholder – not equipped	2021	×	Requires landholder agreement
MNHGWP03	Precipice Sandstone	Landholder – not equipped	2021	×	Requires logger installation. Until such time, collect monthly static groundwater levels (manually)
MNHGWP04	Precipice Sandstone	Landholder – not equipped	2021	×	
SPRGWP01	Precipice Sandstone	Landholder – not equipped	2021	×	
SPRGWP03	Precipice Sandstone	Santos - logger	✓	×	No action required.
Springrock N_750*	Upper Precipice Sandstone	Santos - logger	2021	×	Requires bore construction
Springrock N_750*	Lower Precipice Sandstone	Santos - logger	2021	×	Requires bore construction
Springrock N_2000*	Upper Precipice Sandstone	Santos - logger	2021	×	Requires bore construction

Bore ID	Aquifer Monitored	Owner & monitoring equipment	Groundwater level monitoring status	Groundwater quality monitoring required	Comment
Springrock N_2000*	Lower Precipice Sandstone	Santos - logger	2021	×	Requires bore construction
Contact Zone Monitoring Bores					
FV299_OB1_G1	Bandanna Formation	Santos - logger	2021	×	Requires Maintenance
FV299_OB1_G2	Bandanna Formation	Santos - logger	2021	×	Requires Maintenance
FV299_OB1_G3	Bandanna Formation	Santos - logger	2021	×	Requires Maintenance
OKSGWP01	Precipice Sandstone	Santos - logger	2021	×	Requires Maintenance
SpringGully-PB1	Precipice Sandstone	Origin - logger	✓	×	No action required.
WMS MP_874*	Precipice Sandstone	Santos - logger	2022	×	Requires bore construction

* Locations to be confirmed following the completion of land access activities. Locations of these bores are not shown in Figure 3-2

3.4.1.3 New Groundwater Monitoring Bores

Table 3-3 and Table 3-4 summarises the SIMP monitoring network. This network demonstrates that the existing monitoring infrastructure is well advanced in the context of meeting the requirements of the SIMP, subject to the construction of new monitoring infrastructure to support expanded aquifer monitoring and further investigations, as outlined in Section 3.8.

Table 3-4 indicates that new monitoring bores will be installed at all Spring Groups, including; Springrock, 311/Yebna 2 and Lucky Last.

3.4.2 Wetland Monitoring

Table 3-5 provides a summary of the wetland monitoring program. This has been designed in accordance with the site specific assessment of the spring groups and in particular the revised set of ecological endpoints.

3.4.3 Monitoring Parameters

Groundwater level monitoring is to be completed utilising:

- Groundwater level loggers – pressure transducers installed in monitoring wells recording groundwater as pressure, with this pressure data then converted into groundwater levels.
- A water level dip meter for manual water level readings may be taken to periodically confirm level logger data.

Groundwater quality sampling for groundwater monitoring bores will be conducted in accordance with the OGIA UWIR Suite A (2019), and is summarised as follows:

- Field parameters: (Electrical Conductivity (µS/cm @ 25°C), pH, Redox Potential (Eh), Temperature (°C), Free gas at wellhead (CH_4);
- Laboratory analytes:
  - Major cations and anions: Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), Sodium (Na^+), Bicarbonate (HCO_3^-), Carbonate (CO_3^-), Chloride (Cl^-), Sulphate (SO_4^{2-}), Total Alkalinity and;

- Metals (dissolved): Arsenic (As), Barium (Ba), Boron (B), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Mercury (Hg), Nickel (Ni), Selenium (Se), Strontium (Sr^{2+}), Zinc (Zn);
- Fluoride (F^-) and Total Dissolved Solids;
- Gas (dissolved): Methane (CH_4).

Groundwater quality sampling for wetlands is to be completed as per "Monitoring and Sampling Manual, Environmental Protection (Water) Policy" (DES, 2018) and is to be completed as close as possible to the primary discharge areas where water is flowing. Water chemistry suites are summarised as follows:

- Field parameters: Electrical Conductivity (µS/cm @ 25°C), pH, Redox Potential (Eh), Temperature (°C);
- Laboratory analytes:
  - Total Dissolved Solids (TDS);
  - Alkalinity - Total Alkalinity (as $CaCO_3^-$), Bicarbonate (HCO_3^-), Carbonate (CO_3^-), and Hydroxide ($CaCO_3^-$);
  - Major cations: Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), Sodium (Na^+),
  - Chloride (Cl^-), Sulphate (SO_4^{2-});
  - Metals (total and dissolved): Arsenic (As), Barium (Ba), Boron (B), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Mercury (Hg), Nickel (Ni), Selenium (Se), Strontium (Sr^{2+}), Zinc (Zn);
  - Fluoride, Bromide and Iodine;
  - Total Nitrogen as N (incl NOx and TKN);
  - Total Phosphorous (P);
  - Total Organic Carbon (TOC) and Dissolved Organic Carbon (DOC);

Table 3-5 Recommended Spring Complex Monitoring

Group	Complex / Watercourse	Confirmed Ecological Endpoint	Wetland Chemistry	Physical Discharge	Wetland and wetted Extent	The ratio of aquatic to terrestrial/invasive species at the boundary of the wetland	UWIR 2019 monitoring requirement (as per Table I-5 and Table I-6)?
Springrock	Springrock Creek (561)	▪ Spring wetland chemistry (salinity) and pool depth	▪ Install salinity logger at a rock pool location and measure salinity variability for a 12 month period. ▪ Once the baseline is established, 6 monthly quality sampling of the pool can be undertaken (assuming the salinity logger is no longer operational)	▪ Not applicable	▪ Not applicable	▪ Not applicable	▪ Yes
	Hutton Creek (W217a)	▪ Watercourse spring chemistry (salinity) and flow	▪ Annual quality sampling at all sites on this watercourse (i.e. HC12 to HC17) ▪ 6 monthly quality sampling at HC16	▪ Annual low-flow sampling at all sites on this watercourse (i.e. HC12 to HC17) ▪ 6 monthly low-flow sampling at HC16	▪ Not applicable	▪ Not applicable	▪ Yes*
	Hutton Creek (W216)	▪ Watercourse spring chemistry (salinity) and flow	▪ Annual quality sampling at all sites on this watercourse (i.e. HC1 to HC11) ▪ 6 monthly quality sampling at HC11	▪ Annual low-flow sampling at all sites on this watercourse (i.e. HC1 to HC11) ▪ 6 monthly low-flow sampling at HC11	▪ Not applicable	▪ Not applicable	▪ Not reported in UWIR
311	Dawson River (W40)	▪ Watercourse spring chemistry (salinity) and flow	▪ Annual quality sampling at all sites on this watercourse (i.e. DR1 to DR13) ▪ 6 monthly quality sampling at DR11	▪ Annual low-flow sampling at all sites on this watercourse (i.e. DR1 to DR13) ▪ 6 monthly low-flow sampling at DR11	▪ Not applicable	▪ Not applicable	▪ Yes*
	Hutton Creek (W81)	▪ Watercourse spring chemistry (salinity) and flow	▪ Annual quality sampling at all sites on this watercourse (i.e. LHC3 to LHC6) ▪ 6 monthly quality sampling at LHC6	▪ Annual low-flow sampling at all sites on this watercourse (i.e. LHC3 to LHC6) ▪ 6 monthly low-flow sampling at LHC6	▪ Not applicable	▪ Not applicable	▪ Yes*
	Hutton Creek (W217b)	▪ Watercourse spring chemistry (salinity) and flow	▪ Annual quality sampling at all sites on this watercourse (i.e. LHC1) ▪ 6 monthly quality sampling at LHC1	▪ Annual low-flow sampling at all sites on this watercourse (i.e. LHC1) ▪ 6 monthly low-flow sampling at LHC1	▪ Not applicable	▪ Not applicable	▪ Yes*

Group	Complex / Watercourse	Confirmed Ecological Endpoint	Wetland Chemistry	Physical Discharge	Wetland and wetted Extent	The ratio of aquatic to terrestrial/invasive species at the boundary of the wetland	UWIR 2019 monitoring requirement (as per Table I-5 and Table I-6)?
	311 (311), Yebna 2 (591)	▪ Spring wetland chemistry, pool depth and wetland/wetted area extent	▪ Annual water quality sampling at; ▪ Yebna2 (vent 534) ▪ Vent 693 ▪ Vent 704	▪ Install a level logger to record pool water depth at vents 693 and 704 and measure pool depth	▪ Quarterly survey of wetland area/wetted extent for the Yebna2 534 vent (EPBC listed) for one year to establish baseline ▪ Annual survey of wetland area/wetted extend post baseline	▪ Not applicable	▪ No, these are additional monitoring recommendations
Lucky Last	Lucky Last (230)	▪ Wetland area and wetted extent ▪ The ratio of aquatic to terrestrial/invasive species at the boundary of the wetland	▪ Not applicable	▪ Not applicable	▪ Annual survey of wetland area/wetted extent	▪ Bi-annual survey of the ratio of aquatic to terrestrial/invasive species at the boundary of the wetlands	▪ Yes

*The UWIR 2019 stipulates discharge and chemistry should be measured quarterly via installation of data loggers. The lack of success with data loggers in this area has led to this recommendation for manual flow and chemistry surveys on an annual basis.

3.4.4 Implementation and Data Reporting

On 1 April and 1 October of each year, Santos will submit the following to OGIA.

A spring monitoring network implementation report that includes:

- current status of the groundwater monitoring points
- planned installation of monitoring points
- emerging implementation issues
- proposed changes to the location or timing of any installations for OGIA endorsement.

A spring monitoring report that includes:

- details about the monitoring point or production well construction
- the data collected for each monitoring location including groundwater pressure, water chemistry and spring attributes
- an explanation of any gaps or changes in the monitoring record associated with maintenance issues or failure of a monitoring point.

3.5 Management Action and Response Plan

Management options are the ways in which the risk to the springs of interest can be alleviated, either by the deployment of works and measures to mitigate the aquifer depressurisation threats or by works and measures deployed to remediate or offset any impacts.

3.5.1 Action Process

The SIMP Framework (Figure 3-1) outlines the action steps that will be undertaken in the event of an Early Warning Trigger or Threshold Limit exceedance. Reporting requirements are described in Section 3.9

3.6 Mitigation Options Assessment

A mitigation phase should be undertaken at the springs/watercourses when the monitoring and management processes conclude that mitigation is required.

This section of the report:

- Identifies/confirms potential mitigation measures and response actions, tailored to site-specific conditions, impact cause, timing and magnitude;
- Provides timeframes to implement mitigation actions, with consideration for the anticipated timing of the indicated impact; and
- Outlines procedures to evaluate the effectiveness of the mitigation measures.

These mitigations are summarised in Table 3-6 below and are discussed in more detail in this section. Figure 3-3 provides the potential location of key infrastructure for the options.

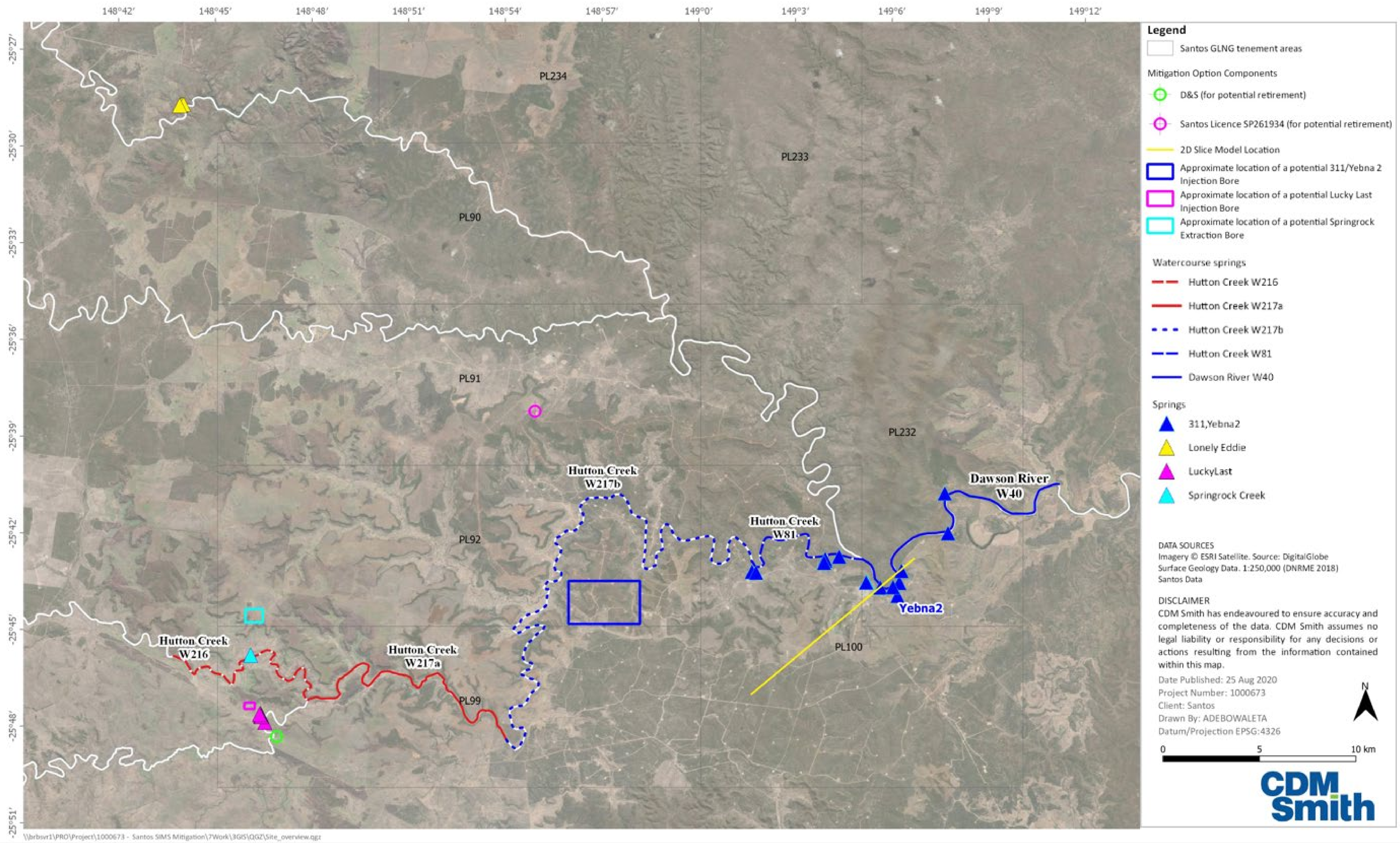

Figure 3-3 Mitigation Options; locations of proposed pumping bores, extraction bores, bores and licences for retirement and 2D model cross section location

3.6.1 Mitigation for 311/Yebna 2 Complex

The options for mitigation of drawdown impact at the 311/Yebna 2 Complex can be summarised as follows:

- Offset of drawdown due to APLNG's reinjection of treated CSG water;
- Offset of drawdown due to retirement of Santos groundwater extraction licence;
- Offset of drawdown due to Santos reinjection of treated CSG water; and
- Stock control measures to reduce impact to improve wetland resilience to impact.

APLNG's reinjection scheme is ongoing, and the beneficial effects on the reinjection scheme on regional groundwater pressures are well-documented. An agreement between Santos and APLNG would be required to formalise this mitigation option. This mitigation option may only be effective until around the year 2030, when the rate of reinjection is expected to decline below current reinjection rates.

Santos proposes to retire a groundwater extraction licence if an agreement could not be reached with APLNG, or the reinjection scheme ceases to inject enough water to offset the predicted impact, i.e. from 2030 onward. As a back-up mitigation option, Santos will consider the development of local scale reinjection of treated CSG water into the Precipice Sandstone.

Stock control measures are a mitigation option that is only applicable to the Yebna 2 spring complex where the wetland ecological community is already impacted by stock watering.

The following sections provide a summary of technical assessment of these mitigation options.

3.6.1.1 APLNG's Existing Reinjection Scheme

The existing reinjection scheme option relates to the drawdown offset effects related to current re-injection activities undertaken by APLNG operations in the vicinity of the Santos Fairview field.

Reinjection of treated water by APLNG within the Reedy Creek and Spring Gully fields has increased water levels in the Precipice Sandstone adjacent to the 311/Yebna 2 springs and the W217b, W40 and W81 water courses.

This increase is the same order as the drawdown predicted by the UWIR 2019 model in the Precipice Sandstone and is therefore considered to be mitigating those potential impacts.

It is concluded that based on current information, if APLNG continues to re-inject at the rates publicly reported, potential drawdown impacts at the 311/Yebna 2 springs and associated water courses, will continue to be mitigated, and that this is likely to extend past 2030 and potentially to 2035.

Appendix A.1 provides a technical assessment to validate the effectiveness of this option. This assessment will need on-going review (e.g. to verify the actual injection rates are similar to those that have been forecast). The Spring Investigation Plan (CDM Smith, 2020b) includes specific works to improve the understanding of this spring complex and progress towards a more detailed mitigation design.

3.6.1.2 Retire Existing Groundwater Abstraction

The retirement of existing groundwater abstraction option considers the drawdown offset effects related to the relinquishment of Water Licence (Ref 616733 held under the Water Act (2000)) for take of 89 megalitres of underground water from the Surat North 3 Management Unit (Great Artesian Basin) – the Precipice Sandstone. The point of take is under Lot 5, SP261934, which is within proximity of the 311 / Yebna complex (Figure 3-3).

An analytical model (based on Theis, 1935) was used to understand the potential drawdown offset effects related to an annual extraction rate of 89 ML/year sourced from the Precipice Sandstone aquifer, over periods of 1, 5, 10 and 50 year scenarios. The model parameterisation considered Hayes et al. (2019), OGIA (2019a), local understanding of aquifer thickness and considered the drawdown offset at various distances to nearby spring vent and watercourse springs.

The results of the assessment indicate that the retirement of the existing groundwater abstraction licence will provide some mitigation against the predicted groundwater drawdowns associated with CSG production - in summary:

- Between 2.31 m (after one year) and 6.09 m (after 50 years) at the Hutton Creek watercourse spring (W217b);
- Between 0.75 m (after one year) and 4.27 m (after 50 years) at the closest 311 spring (vent 535); and
- Between 0.30 m (after one year) and 3.50 m (after 50 years) at Yebna 2 spring vent.

The UWIR 2019 model calibrated hydraulic conductivity is low in this area (0.33 m/day) and produces a drawdown in the pumping well of over 27 m.

Appendix A.2 provides a technical assessment to validate the effectiveness of this option. This assessment is preliminary in nature and the Spring Investigation Plan (CDM Smith, 2020b) includes specific works to further validate this mitigation option.

3.6.1.3 New Santos Re-injection Scheme

A new Santos re-injection scheme option relates to the drawdown offset effects related to potential new re-injection activities using treated produced water, injected into the Precipice Sandstone aquifer in the vicinity of the potentially affected springs. This is a back-up mitigation option to those previously described for the 311/Yebna 2 complex (i.e. APLNG's existing reinjection scheme and the retirement of the existing groundwater abstraction), as the current APLG re-injection is likely to extend past 2030 and potentially to 2035.

Two forms of analysis were undertaken to test this mitigation option;

- A multi-well analytical model (based on Theis, 1935) that assumes confined aquifer conditions from the point of injection to the point of observation (i.e. the 311/Yebna 2 springs and watercourse springs); and
- A 2D slice model (using MODFLOW) that assumes confined aquifer conditions at the point of injection and unconfined aquifer conditions at the point of observation (i.e. the 311/Yebna 2 springs and watercourse springs).

A multi-well analytical model (based on Theis, 1935) was used to understand the potential re-injection configuration required to offset the UWIR (2019) predicted drawdown effects at the 311/Yebna 2 complex. The model adhered to the following considerations;

- Injection well locations should be at least 1 km from the springs and watercourse, to ensure confined aquifer conditions at the injection site;
- Injection well capacity for a Precipice Sandstone bores should not exceed 4.5 ML/year/bore (Origin, 2015); and
- Injection well target is to induce heads along the watercourse ranging from 0.9 m to 0.25 m (from west to east, according to the UWIR 2019 long-term model predicted drawdown impacts).

The multi-well analysis was parameterised based on the UWIR 2019 model, Hayes et al. (2019) and local understanding of aquifer thickness in the area. The model was able to simulate the required potentiometric surface response, via the injection of 1.0 ML/day at a distance of 2 km from the spring complex (Figure 3-3). The potentiometric response was achieved using one injection well at the western end of the target area. The injection scheme assumed one year of continual pumping at the aforementioned rate, in order to reach the pressure targets. Importantly, this is the maximum expected injection rate and the rates will be lower as the scheme moves into a phase of maintaining the pressure response, as opposed to generating it.

The 2D model (location shown in Figure 3-3) was developed to estimate the reinjection volume required to mitigate a predicted drawdown of 0.9 m to 0.25 m (across the length of the spring complex), as per the maximum drawdowns anticipated by the UWIR 2019 model from groundwater levels observed in December 2014.

The 2D slice model was calibrated against the observed conditions, which provides model confidence. The model is simple in design and demonstrates the potential of this mitigation option to offset the drawdown impact. The model findings do not provide detailed engineering design parameters for reinjection, and further aquifer testing and modelling is recommended.

The 2D slice model demonstrated that an injection scheme will increase the heads under the elevated springs and also cause a higher flux to move towards the watercourse. The 2D slice model suggests approximately 0.14 m^3/day/m of river is needed to offset drawdown in the potentiometric surface by 0.6 m.

Upscaling to a length of around 20 km (the span of the 311/Yebna 2 complex) translates to a total injection rate of 1.0 GL/year (2.8 ML/day). There are uncertainties associated with this upscaling calculation, but it provides a useful benchmark for future investigations and more complex groundwater modelling. The technical assessment to support these conclusions, including the associated assumptions and limitations, is provided in Appendix A.3. These findings are preliminary in nature, and the Spring Investigation Plan (CDM Smith, 2020b) includes specific works to improve the understanding of this spring complex, progress towards a more detailed mitigation design and inform other regulatory approval considerations (e.g. approval to inject water into an aquifer).

Appendix A.3 provides a technical assessment to validate the effectiveness of this option. This assessment is preliminary in nature and the Spring Investigation Plan (CDM Smith, 2020b) includes specific works to further validate this mitigation option.

3.6.1.4 Install New Stock Control Measures

The installation of new stock control measures is a back-up mitigation option to those previously described for the 311/Yebna 2 complex (i.e. APLNG's existing reinjection scheme and the retirement of the existing groundwater abstraction) and is a mitigation action specific to degraded spring vents (including the Yebna 2 spring and vent 536).

A review of domestic and international experience suggests that the implementation of land management practices is a valid approach to enhancing the ecological endpoints (e.g. wetland area/wetted extent and the ratio of aquatic to terrestrial/invasive species) of certain spring vents that are known to be degraded (e.g. Yebna 2). By enhancing the springs ecological endpoint, the spring becomes more resilient to other land use pressures.

Livestock exclusion (i.e. fencing) and alternative grazing schemes are widely employed land management practices to improve the environmental health of ecosystems. The demonstrated benefits of such land management practices include; reduced sediment erosion; significant vegetation regrowth and improved water quality (bacteria, turbidity, phosphorus and chloride). The land management regime requires environmental monitoring to measure the success of the land management practices according to specific criteria. The monitoring components identified, largely overlap with the monitoring specified for the ecological endpoints for these springs.

The reviewed literature has demonstrated successful approaches to land management monitoring, that include quantified scoring regimes, consistent proforma templates and measurement criteria for direct comparison of results over time and the inclusion of water quality sampling. A pilot study will be required to demonstrate the effectiveness of the implementation of land management practices and should consider the detailed guiding principles (and example monitoring proforma templates) of the Victorian Index of Wetland Condition and the UWIRs regulatory requirements for spring monitoring. The following provides an indication of some of the likely components of the monitoring program;

- **Measured wetland area and wetted area**; as per the UWIR defined methodology;
- **Disturbance area status**; with a more robust quantitative measurement approach relative to that previously recorded during the baseline surveys (consider the approach of the IWC);
- **Ratio of aquatic to terrestrial vegetation at the wetland boundary**; as per the UWIR defined methodology;
- **Herbaceous vegetation height measurements**; as a proxy for measuring the resulting effects of erosion control; and
- **Water quality changes;** measured by comparison of analytes, such as turbidity, bacteria and salinity.

Appendix A.4 provides a literature review to validate the effectiveness of this option.

3.6.2 Mitigation Considerations – Springrock Creek

The options for mitigation of drawdown impact at the Springrock Creek Spring Complex can be summarised as follows:

- New scheme that engineers the release of water to discharge into the wetland to augment wetland flows.

The design of the scheme, to release water in the upper pools to allow it to drain down to lower pools, also offsets the vulnerability of the upper pools to smaller changes in groundwater level.

The selection of mitigation options at the location of the Springrock Creek are constrained by a number of factors including:

- Absence of observed groundwater pressure effect from the APLNG's reinjection scheme in the Precipice Sandstone;
- Absence of available treated CSG water or CSG water management infrastructure, as the spring is located approximately 10km kilometres from Santos CSG fields; and
- Absence of alternative groundwater sources, other than the Precipice Sandstone, to supply water that may be used to mitigate groundwater discharge.

The following sections provide a summary of technical assessment of these mitigation options.

3.6.2.1 New Scheme to Augment Wetland Flows

The new scheme to augment wetland flows relates to improving wetland resilience to drawdown, via the release of abstracted groundwater into the upper wetland pool.

The design release rate of water needed to augment wetland flows was estimated from assessment of:

- Evaporation rates from the surface of wetland pools; and
- The observed and consistent discharge rate from the lower pools into the main Hutton Creek water course.

An analytical model (based on Theis, 1935) was used to determine whether the design release rate (8.8 ML/year) could be extracted from a bore location approximately 2km north of the spring pool (Figure 3-3), without creating an unacceptable draw-down on the closest receptor.

The results of the assessment indicate between 0.07 m and 0.23 m of estimated drawdown at the nearest receptor (Duffers Creek is located 1,400 m away and is the creek upon which the Springrock pools are located) after one year of pumping. After 50 years of pumping, the drawdown is estimated between 0.10 and 0.35 m at the creek. The range in the drawdown estimates reflect the range in the input hydraulic conductivity parameters (adopted from OGIA, 2019a). If the drawdown is confirmed to be at the higher end of the range (after local scale aquifer testing has been undertaken), the extraction bore location may need to be adjusted to reduce the potential impact to the nearby receptor.

Appendix A.7 provides a technical assessment to validate the effectiveness of this option. This assessment is preliminary in nature and the Spring Investigation Plan (CDM Smith, 2020b) includes specific works to improve the design, reduce uncertainty associated with this mitigation option and inform other regulatory approval considerations (e.g. approval to extract water from the Precipice Sandstone and to release water to the water course).

3.6.3 Mitigation Considerations – Lucky Last

The options for mitigation of drawdown impact at the Lucky Last Spring Complex can be summarised as follows, in order of preference:

- Offset of drawdown due to retirement of landholder groundwater extraction bore;
- Stock control measures to reduce impact to improve wetland resilience to impact; and
- Offset of drawdown due to Santos reinjection of treated CSG water.

The selection of mitigation options at the location of the Lucky Last springs are constrained by a number of factors including:

- Absence of observed groundwater pressure effect from the APLNG's reinjection scheme in the Precipice Sandstone;
- Absence of available treated CSG water or CSG water management infrastructure, as the spring is located approximately 10km kilometres from Santos CSG fields; and
- Absence of alternative groundwater sources, other than the Boxvale Sandstone, to supply water that may be used to mitigate groundwater discharge.

The following sections provide a summary of technical assessment of the preferred mitigation options, in order of preference.

3.6.3.1 Retire Existing Groundwater Abstraction

The retirement of an existing stock and domestic groundwater abstraction bore (Figure 3-3) option relates to the drawdown offset effects related to the relinquishment of this landholder bore. The abstraction bore is located approximately 1.4km south-east of the Lucky Last Spring Complex.

An analytical model (based on Theis, 1935) was used to understand the potential drawdown offset effects related to an annual extraction rate of 3.25 ML/year (estimated annual use based on UWIR, 2019 Table 4-1 use estimates) sourced from the Boxvale Sandstone aquifer, over periods of 1, 5, 10 and 50 year scenarios. The model utilised the Boxvale Sandstone parameters documented in the UWIR (2019) and indicates that retirement of this bore may provide 0.9 m of head at the Lucky Last springs after one year.

This analysis will be revised when the new groundwater observation bores are available (planned for 2021) and the analysis can be recalculated using the local hydraulic parameters.

The technical assessment to support this conclusion, including the associated assumptions and limitations, is provided in Appendix A.5. These findings are preliminary in nature and the Spring Investigation Plan (CDM Smith, 2020b) includes specific works to improve the understanding of this spring complex and progress towards a more detailed mitigation design.

3.6.3.2 Install New Stock Control Measures

The installation of new stock control measures is a back-up mitigation option to those previously described for the Lucky Last spring complex (i.e. the retirement of the existing groundwater abstraction).

A review of domestic and international experience suggests that the implementation of land management practices is a valid approach to enhancing the ecological endpoints (e.g. wetland area/wetted extent and the ratio of aquatic to terrestrial/invasive species) of certain spring vents that are known to be degraded. By enhancing the springs ecological endpoint, the spring becomes more resilient to other land use pressures.

Livestock exclusion (i.e. fencing) and alternative grazing schemes are widely employed land management practices to improve the environmental health of ecosystems. The demonstrated benefits of such land management practices include; reduced sediment erosion; significant vegetation regrowth and improved water quality (bacteria, turbidity, phosphorus and chloride). The land management regime requires environmental monitoring to measure the success of the land management practices according to specific criteria. The monitoring components identified, largely overlap with the monitoring specified for the ecological endpoints for these springs.

A suitable option for a pilot study program is the Lucky Last spring vent 340 (pending landholder access agreements), based on the following;

- The spring vent is significantly impacted by stock;
- The spring vent is already associated with a robust baseline dataset of wetland area / wetted extent and wetland vegetation ratios;

- The spring is a large and semi-isolated wetland that could easily be fenced-off; and
- Field surveys indicate safe physical access to the wetland.

The reviewed literature has demonstrated successful approaches to land management monitoring, that include quantified scoring regimes, consistent proforma templates and measurement criteria for direct comparison of results over time and the inclusion of water quality sampling. The pilot study should consider the detailed guiding principles (and example monitoring proforma templates) of the Victorian Index of Wetland Condition and the UWIRs regulatory requirements for spring monitoring. The following provides an indication of some of the likely components of the monitoring program;

- **Measured wetland area and wetted area**; as per the UWIR defined methodology;
- **Disturbance area status**; with a more robust quantitative measurement approach relative to that previously recorded during the baseline surveys (consider the approach of the IWC);
- **Ratio of aquatic to terrestrial vegetation at the wetland boundary**; as per the UWIR defined methodology;
- **Herbaceous vegetation height measurements**; as a proxy for measuring the resulting effects of erosion control; and
- **Water quality changes;** measured by comparison of analytes, such as turbidity, bacteria and salinity.

Appendix A.4 provides a literature review to validate the effectiveness of this option.

3.6.3.3 New Santos Re-injection Scheme

The new Santos re-injection scheme option relates to the drawdown offset effects related to new re-injection activities into the Boxvale Sandstone aquifer in the vicinity of the potentially affected Lucky Last springs. This is a back-up mitigation option, to those previously described for the Lucky Last complex (i.e. the installation of new stock control measures and the retirement of the existing groundwater abstraction).

An analytical model (Theis, 1935) was used to understand the potential re-injection configuration required to offset the UWIR (2019) predicted drawdown effects at the Lucky Last complex. The model adhered to the following considerations;

- Injection well target is to induce heads of 0.4 m, which corresponds to the maximum predicted drawdown expected to occur within 26 years (UWIR, 2019); and
- The UWIR (2019) model parameters for the Boxvale Sandstone aquifer (i.e. the hydraulic conductivity, storage coefficient and aquifer thickness) are applicable in this area.

The analysis was able to simulate the required potentiometric surface response of 0.4 m, via the injection of 0.004 ML/day (1.3 ML/year) at a distance of 1 km from the spring complex (Figure 3-3). The injection scheme assumed one year of continual pumping at the aforementioned rate, in order to reach the pressure targets. Importantly, this is the maximum expected injection rate and the rates will be lower as the scheme moves into a phase of maintaining the pressure response, as opposed to generating it.

Appendix A.6 provides a technical assessment to validate the effectiveness of this option. This assessment is. preliminary in nature and the Spring Investigation Plan (CDM Smith, 2020b) includes specific works to improve mitigation design and inform other regulatory approval considerations (e.g. approval to inject water into an aquifer).

3.6.4 Future Works to Refine the Mitigation Design

The Spring Investigation Plan (CDM Smith, 2020b) details a number of investigation approaches to improve the mitigation option designs, including;

1. Use of a local scale model to reconsider the option of offsetting the impacts via the relinquishment of groundwater entitlements, given the initial assessment suggests it provides some mitigation affect to the predicted drawdowns.
2. Use of a local scale model to assess the feasibility of aquifer injection options within the context of the local scale conditions. It is envisaged that these options would be local rather than site wide, and the model will need to have the appropriate scale to be able to consider these.
3. Installation of new monitoring bores at Lucky Last, which will help refine the understanding of the Boxvale Sandstone aquifer and its relationship between the aquifers and spring vents.

3.7 Summary

A summary of the Early Warning Triggers, Threshold Limits and the management action and response plan is provided in Table 3-8.

Table 3-6 Mitigation Options for Springs

Complex	Site	Predicted timing of 20cm drawdown impact (UWIR 2019)	Maximum impact (UWIR 2019)	Potential Mitigation Option	Potential Mitigation Option Description	Anticipated Effectiveness of the Action/s	Works Undertaken to Verify this Option	Timeframe for Implementation Green = completed Amber = to be progressed prior to confirmed trigger Red = will not be implemented until trigger exceeded	Final comment regarding the preferred mitigation option for the spring / watercourse
311 /Yebna 2	a. 311 b. Yebna2 c. W217b d. W81 e. W40	a. 2021-2023 b. 2020-2022 c. 2019 d. 2019-2022 e. 2022-2026	0.4-0.7 m (after 25 years)	APLNG's existing reinjection scheme	Offset drawdown: APLNG's reinjection scheme (forecast to inject at rates ranging from 6-20 ML/day up to 2030) is currently causing an increase in the groundwater pressure around the 311/Yebna 2 complex	• The current injection scheme is **entirely** mitigating the predicted drawdown impacts associated with CSG development	• Observation bore data analysis (including displacement pressure plots) indicate that the reinjection of treated water by APLNG has increased water levels in the Precipice Sandstone adjacent to the 311/Yebna 2 spring complex and this increase is of the same order as the drawdown predicted by the UWIR 2019 model and is mitigating those potential impacts. • Review of APLNG forecast injection rates suggest that the re-injection will continue to mitigate the potential drawdown up to 2030 and potentially to 2035.	• APLNG injection is already active • Formal agreement between APLNG and GLNG (6 months)	• Formal agreement between GLNG and APLNG. • For the 311/Yebna 2 complex, it is anticipated that the implementation of two mitigation options will manage the potential drawdown from of CSG production; - APLNG's forecast reinjection operations; and - Offset via retirement of groundwater abstraction licence. • APLNG reinjection rates may decline over time, and ongoing monitoring and verification may be required. • Back-up mitigation options include: - Santos reinjection scheme remains a potential option for future consideration. A feasibility study associated with this option is included in the future works program; and - Land management (stock fencing).
				Retire existing groundwater abstraction	Offset drawdown: Relinquish groundwater licence (SP261934 allocation 89 ML/year) to offset change within the Precipice Sandstone aquifer in the vicinity of the spring complex	• This option is anticipated to mitigate spring vents at earlier risk of drawdown (i.e. those located higher in the landscape where available head is lower relative to those located at lower elevations). • Planned works and on-going monitoring are proposed to verify the effectiveness of this option, in conjunction with APLNG's existing reinjection scheme.	• Theis (1935) drawdown analysis for confined aquifer conditions suggest that retirement of a groundwater abstraction licence of 89 ML / year will provide some mitigation against the predicted drawdowns.	• Quantify effectiveness (3 months)	
				New Santos re-injection scheme	Offset drawdown: inject treated produced water into the Precipice Sandstone to offset change within the Precipice Sandstone aquifer in the vicinity of the potentially affected springs.	• This mitigation option will only be required if the preceding options are demonstrated to no longer mitigate the predicted or observed drawdown changes • This mitigation option is expected to **entirely** mitigate the risk of predicted drawdown.	• A multi-well drawdown analysis for confined aquifer conditions based on Theis (1935) developed a re-injection scheme that entirely mitigated the predicted drawdowns. • A 2D numerical model for unconfined aquifer conditions at the site of the springs also developed a re-injection scheme that entirely mitigated the predicted drawdowns.	• Feasibility study and detailed design (e.g. how many injection wells and how much water), local-scale aquifer testing, detailed engineering design (e.g. water treatment / reticulation)) (1 year) • Landholder access and compensation agreement (1 year) • Approved Environmental Authorisation application to inject (1 year) • Construction and commissioning (1 year)	

Complex	Site	Predicted timing of 20cm drawdown impact (UWIR 2019)	Maximum impact (UWIR 2019)	Potential Mitigation Option	Potential Mitigation Option Description	Anticipated Effectiveness of the Action/s	Works Undertaken to Verify this Option	Timeframe for Implementation Green = completed Amber = to be progressed prior to confirmed trigger Red = will not be implemented until trigger exceeded	Final comment regarding the preferred mitigation option for the spring / watercourse
	Yebna 2	2020-2022		Install new stock control measures	Improve wetland resilience to drawdown: Implement land management (e.g. stock proof fencing around springs and alternate stock water source) to reduce water losses via evaporation (e.g. reduce pugged/bare soil) and improve ecosystem function.	• Landuse management can improve vegetation health and water quality (Kaufman & Kruger, 1984; Miller et al. 2019; McKergow et al. 2016; Matthews et al. 2003; Tohill & Dollerschell, 1990; Line, 2003; Ranganath et al. 2009). • The implementation of stock fencing around the Yebna2 spring is expected to improve the current spring condition and therefore increase the springs' resilience to drawdown. • Planned works and on-going monitoring are proposed to verify the effectiveness of this option.	• A review of domestic and international experience has been undertaken to understand the best practice approach to land management techniques to enhance ecological endpoints. • Preliminary concepts for a pilot trial have been developed.	• Landholder access and compensation agreement (1 year) • Design of stock control measures • Installation of stock control measures (6 months)	
Springrock Creek	Spring 258	2019	0.4-1.7 m (after 25 years)	New scheme to augment wetland flows	Improve wetland resilience to drawdown: release abstracted groundwater into the upper wetland pool or main watercourse.	• The direct release of groundwater to the spring pools to maintain the low pool / flow conditions, will **entirely** mitigate the predicted drawdown risk on the springs.	• Theis (1935) drawdown analysis for confined aquifer conditions suggest that the extraction of up to 8.8 ML/year (a highly conservative upper limit amount of water that would be required to support the Springrock pools) from the Precipice Sandstone aquifer at a location of approximately 2 km north of the spring pools, will have small impacts on surrounding receptors in the area.	• Define environmental flow required (3 months) • Engineering design (3 months) • Landholder access and compensation agreement (1 year) • EA amendment application approval to release water to the environment (1 year - concurrent with land access agreement) • Procurement and installation of bore, water storage and reticulation infrastructure (6 months)	• For the Springrock Creek complex, the preferred mitigation option is to augment wetland flows
	W216	2028-2043							
Lucky Last	Spring 230	2019	0.2-0.4 m (after 26 years)	Install new stock control measures	Apply land management options (specifically stock proof fencing) to improve the ecological health of the spring and in doing so, increase its resilience to potential drawdown.	• Landuse management can improve vegetation health and water quality (Kaufman & Kruger, 1984; Miller et al. 2019; McKergow et al. 2016; Matthews et al. 2003; Tohill & Dollerschell, 1990; Line, 2003; Ranganath et al. 2009). • The implementation of stock fencing around the Lucky Last springs is expected to improve the current spring condition and therefore increase the springs' resilience to drawdown. • Planned works and on-going monitoring are proposed to verify the effectiveness of this option.	• A review of domestic and international experience has been undertaken to understand the best practice approach to land management techniques to enhance ecological endpoints. • Preliminary concepts for a pilot trial have been developed.	• Landholder access and compensation agreement (1 year) • Design of stock control measures • Installation of stock control measures (6 months)	• For the Lucky Last complex, it is anticipated that the implementation of two mitigation options will manage the potential drawdown impacts of CSG production; – Offset via a stock and domestic bore licence relinquishment; and – Land management (stock fencing) • A back-up mitigation option associated with a Santos

Complex	Site	Predicted timing of 20cm drawdown impact (UWIR 2019)	Maximum impact (UWIR 2019)	Potential Mitigation Option	Potential Mitigation Option Description	Anticipated Effectiveness of the Action/s	Works Undertaken to Verify this Option	Timeframe for Implementation Green = completed Amber = to be progressed prior to confirmed trigger Red = will not be implemented until trigger exceeded	Final comment regarding the preferred mitigation option for the spring / watercourse
				Retire existing groundwater abstraction	Offset drawdown: Agreement with landholder to retire use of water bore (RN 38896) to offset impact in the Precipice Sandstone aquifer in the vicinity of the spring complex	• The estimated annual groundwater use of the stock and domestic bore is 3.25 ML/year (UWIR, 2019). • Planned works and on-going monitoring are proposed to verify the effectiveness of this option.	• Theis (1935) drawdown analysis for confined aquifer conditions suggest that retirement of a stock and domestic bore (estimated use 3.25 ML/y) will provide some mitigation against the predicted drawdowns.	• Landholder compensation agreement (1 year)	reinjection scheme remains a potential option for future consideration. A feasibility study associated with this option is included in the future works program.
				New Santos re-injection scheme	Offset drawdown: inject groundwater extracted from other aquifers (e.g. Precipice Sandstone) to offset drawdown in the Boxvale Sandstone aquifer in the vicinity of the springs at risk.	• This mitigation option will only be required if the preceding options are demonstrated to no longer mitigate the drawdown risk • This mitigation option is expected to **entirely** mitigate the risk of predicted drawdown.	• A drawdown analysis for confined aquifer conditions based on Theis (1935) developed a re-injection scheme that entirely mitigated the predicted drawdowns.	• Feasibility study and detailed design (e.g. how many injection wells and how much water), local-scale aquifer testing, detailed engineering design (e.g. water treatment / reticulation)) (1 year) • Landholder access and compensation agreement (1 year) • Approved Environmental Authorisation application to inject (1 year) • Construction and commissioning (1 year)	

Table 3-7 Threshold Limits (Lagging Indicators of Ecological Health)

Group	Complex / Watercourse	Ecological Endpoint	Wetland Water Chemistry	Physical Discharge / Surface water flow	Wetland area and Wetted Extent	The ratio of aquatic to terrestrial / invasive species
Springrock	Springrock Creek (561)	• Wetland Water Chemistry	• A maximum salinity value of 761mg/L TDS			
	Hutton Creek (W217a)	• Watercourse spring Water Chemistry • Watercourse spring surface water flow	• A maximum salinity value of 386mg/L TDS	• A minimum flow of 1.5 L/s.		
	Hutton Creek (W216)		• A maximum salinity value of 360mg/L TDS	• A minimum flow of 2 L/s.		
311	Dawson River (W40)	• Watercourse spring Water Chemistry • Watercourse spring surface water flow	• A maximum salinity value of 320mg/L TDS	• A minimum flow of 120 L/s.		
	Hutton Creek (W81)		• A maximum salinity value of 364mg/L TDS	• A minimum flow of 35L/s.		
	Hutton Creek (W217b)		• A maximum salinity value of 312mg/L TDS	• A minimum flow of 3 L/s.		
	311 (311), Yebna 2 (591)	• Wetland Water Chemistry • Physical Discharge (pool depth) • Wetland area and wetted extent	• A maximum salinity value of 376 mg/L TDS at the Yebna2 (vent 534) • A maximum salinity value of 291 mg/L TDS at Vent 693 • A maximum salinity value of 230 mg/L TDS at Vent 704	• Applicable but unable to determine limit based on available information (see springs investigation program)	• Applicable but unable to determine limit based on available information (see springs investigation program)	
Lucky Last	Lucky Last (230)	• Wetland area and wetted extent • The ratio of aquatic to terrestrial/invasive species at the boundary of the wetland			• Applicable but unable to determine limit based on available information (see springs investigation program)	• Applicable but unable to determine limit based on available information (see springs investigation program)

*grey boxes indicate the ecological indicator is not applicable to the spring

Table 3-8 Santos Management Action and Response Plan

Spring Group	Monitoring Location	Early Warning Trigger	Threshold Limit	Action: Ongoing Monitoring, Review and Collation	Action: Trigger Confirmation	Action: Implement Management Strategy	Action: Revise SIMP
Springrock	Springrock (561)	Groundwater trend at VW0903P1 or SPRGWP02	▪ Wetland Water Chemistry: Spring water salinity exceeds 761mg/L TDS	Santos will undertake ongoing monitoring. Biannual data collation and reviews will be undertaken, and the data packages provided to OGIA.	If the Early Warning Trigger Assessment confirms a trigger is exceeded, OGIA will notify Santos and OGIA within 3 months of receiving the data package.	▪ The preferred mitigation option for Springrock is the augmentation of wetland flows (Section 3.6.2)	Following implementation of the management strategy(s) the SIMP will require updating. This action would involve a reassessment of previously identified options to establish whether those options are still viable both within an updated risk ranking for the site, and within the context of the latest conceptual model of spring/watercourse function, and development of other options based on any new knowledge or technology available at the time of the assessment. Intervention should be based on a Best Available Technology principle.
	Hutton Creek (W217a)		▪ Watercourse spring Water Chemistry: water salinity exceeds 386mg/L TDS ▪ Watercourse spring surface water flow: flow is less than 1.5 L/s.				
	Hutton Creek (W216)		▪ Watercourse spring Water Chemistry: water salinity exceeds 360mg/L TDS ▪ Watercourse spring surface water flow: flow is less than 2.0 L/s.				
311/Yebna 2	311 (311), Yebna 2 (591)	Groundwater trend at MNHGWP02M NHGWP02 or MW0903	▪ Wetland Water Chemistry (at vent 534): Spring water salinity exceeds 376 mg/L TDS ▪ Wetland Water Chemistry (at vent 693): Spring water salinity exceeds 291 mg/L TDS ▪ Wetland Water Chemistry (at vent 704): Spring water salinity exceeds 230 mg/L TDS ▪ Physical Discharge: undefined (see future work program) ▪ Wetland area and wetted extent: undefined (see future work program)			A range of mitigation options are identified for 311/Yebna2 (Section 3.6.1). The preferred mitigation option is to offset Origin Energy's forecast reinjection operations via the retirement of one of Santos' groundwater extraction licences.	
	Dawson River (W40)		▪ Watercourse spring Water Chemistry: water salinity exceeds 320mg/L TDS ▪ Watercourse spring surface water flow: flow is less than 120 L/s				
	Hutton Creek (W81)		▪ Watercourse spring Water Chemistry: water salinity exceeds 364mg/L TDS ▪ Watercourse spring surface water flow: flow is less than 35 L/s				
	Hutton Creek (W217b)		▪ Watercourse spring Water Chemistry: water salinity exceeds 312mg/L TDS ▪ Watercourse spring surface water flow: flow is less than 3.0 L/s				

Spring Group	Monitoring Location	Early Warning Trigger	Threshold Limit	Action: Ongoing Monitoring, Review and Collation	Action: Trigger Confirmation	Action: Implement Management Strategy	Action: Revise SIMP
Lucky Last	Lucky Last (230)	Groundwater trend at 130308822 or 123470	▪ Wetland area and wetted extent: undefined (see future work program) ▪ The ratio of aquatic to terrestrial/invasive species at the boundary of the wetland: undefined (see future work program)			• A range of mitigation options are identified for Lucky Last (Section 3.6.3). • The preferred mitigation option is to retire an existing landholder extraction bore and/or stock control measures to improve wetland resilience to impacts.	

3.8 Spring Investigation Plan

In support of the iterative management framework presented in Section 3.1, there is a need to improve technical knowledge associated with the springs complexes to improve certainty of outcomes and inform future iterations of this plan.

The Spring Investigation Plan will look to define the scope and timing of planned investigations. A summary of the potential investigation options is provided for each mitigation site below as an example only.

Springrock

- Confirm Springrock Creek groundwater source via water chemistry and piezometric analysis;
- Confirm the ecological endpoint based on salinity logger data results over 12 months;
- Confirm the flow contribution to W217 via flow sampling and water chemistry analyses;
- Geological mapping, pressure head mapping and/or hydrochemical evidence to determine extent of unconfined Precipice aquifer at the spring;
- Install new bores with interference pumping tests to confirm degree of aquifer confinement;
- Local scale modelling calibrated to the pumping test data;
- Mitigation modelling experiments;
- Ongoing review of monitoring data.

Lonely Eddie

- A local geological mapping exercise to confirm the boundary of the Precipice Sandstone and Moolayember Formation in this area.

311 / Yebna 2

- Confirm ecological endpoint of spring based on wetland area/wetted extent for Yebna 2;
- Confirm ecological endpoint of based on salinity logger data over 12 months at Yebna 2, Vent 693 and Vent 704;
- Spring vent elevation survey;
- Ecological survey of 311/Yebna 2 vents to confirm endemic aquatic species and ecological resilience;
- Confirm the boundary between upper Precipice Sandstone and Evergreen Formation in bore YEBGWP01 and compared to elevations of the Yebna 2 spring to confirm groundwater discharge mechanism at this site;
- Geological mapping, pressure head mapping and/or hydrochemical evidence to determine extent of unconfined Precipice aquifer at the spring;
- Install new monitoring bore(s) to confirm aquifer confinement adjacent to the Yebna 2 spring;
- Re-assessment of Yebna 2 EPBC status (i.e. if not confined);
- Modelling of offset potential due to Santos water licence and APLNG reinjection;
- Feasibility for an offset agreement in regard to APLNG aquifer reinjection scheme;
- Ongoing review of monitoring data.

Lucky Last

- Confirm ecological limit from the wetland area and wetted extent dataset being developed by OGIA;
- Confirm ecological limit from the ratio of aquatic to terrestrial/invasive species at the boundary of the wetland, based on the dataset currently being refined by OGIA
- Undertake a simple water balance to estimate the ratio of groundwater flux versus potential evapotranspiration at the spring wetland, to confirm the sensitivity of the spring to a change in groundwater pressure;
- Install new groundwater pressure monitoring infrastructure to confirm aquifer connectivity across the fault;
- Investigation of specific land management options that reduce the current negative impact of stock and erosion on the springs;
- Ongoing review of monitoring data.

3.9 Reporting

There are three primary reporting pathways associated with the SIMP;

1. In the event of an Early Warning Trigger or Threshold Limit exceedance;

   Incidents and exceedances will be communicated to DES. They will contain information pertaining to the nature of the incident (or exceedance), and Santos proposed management response.

   When an exceedance is observed a process of data validation and trend confirmation is required. If the trend is confirmed, the risk assessment to the springs of interest may require revision based on the findings of the assessment program undertaken.

   With endorsement from regulators, the SIMP may need to be updated on the basis of investigations initiated by an exceedance. In addition to any risk assessment or conceptualisation revisions the update will acknowledge any changes recommended in the monitoring requirements associated with any assessments undertaken or refinement to management and mitigation approaches.

2. Upon gaining new knowledge from spring investigations.

   The findings from spring investigations (as outlined in Section 3.4) may lead to updates to the Site Specific Assessments for the springs of interest, which may alter their risk profile. This would potentially necessitate a refinement of the management approaches and monitoring program through an update to the SIMP.

3. Following approval of a UWIR or a UWIR annual report.

   Within four months of a UWIR or UWIR annual report, and unless directed otherwise by the UWIR, a report will be provided to DES which summarises:

   - Spring mitigation sites for which the Early Warning Trigger or Threshold Limit is predicted to be exceeded and for which Santos is deemed the RTH, and the earliest date by which the potential spring impact is predicted;
   - Progress of any proposed spring investigations for spring mitigation sites, inclusive of a timeframe for completion;
   - Progress against the implementation of mitigation plans for springs mitigation sites;
   - Any changes to the risk status to spring sites identified, with supporting evidence for any change to the risk status;

- A compliance statement including:
  a. Whether any Early Warning Triggers or Threshold Limits were exceeded;
  b. A summary of incident notifications and the outcomes of the incident reports; and
  c. A copy of any site-specific assessment or mitigation plan completed by the approval holder in the reporting period.

Section 4 Disclaimer and Limitations

This report has been prepared by CDM Smith Australia Pty Ltd (CDM Smith) for the sole benefit of Santos GLNG for the sole purpose of guiding and informing management and mitigation activities via this Spring Impact Management Plan, including the associated conceptualisations, risk assessments and technical assessments and the provision of technical advice that support these planning activities.

This report should not be used or relied upon for any other purpose without CDM Smith's prior written consent. Neither CDM Smith, nor any officer or employee of CDM Smith, accepts responsibility or liability in any way whatsoever for the use of or reliance on this report for any purpose other than that for which it has been prepared.

Except with CDM Smith's prior written consent, this report may not be:

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b. has not verified the accuracy or reliability of this information (other than as expressly stated in this report);

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If further information becomes available, or additional assumptions need to be made, CDM Smith reserves its right to amend this report.

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Appendix A Mitigation Assessment

A.1 311/Yebna 2 - APLNG's Existing Reinjection Scheme

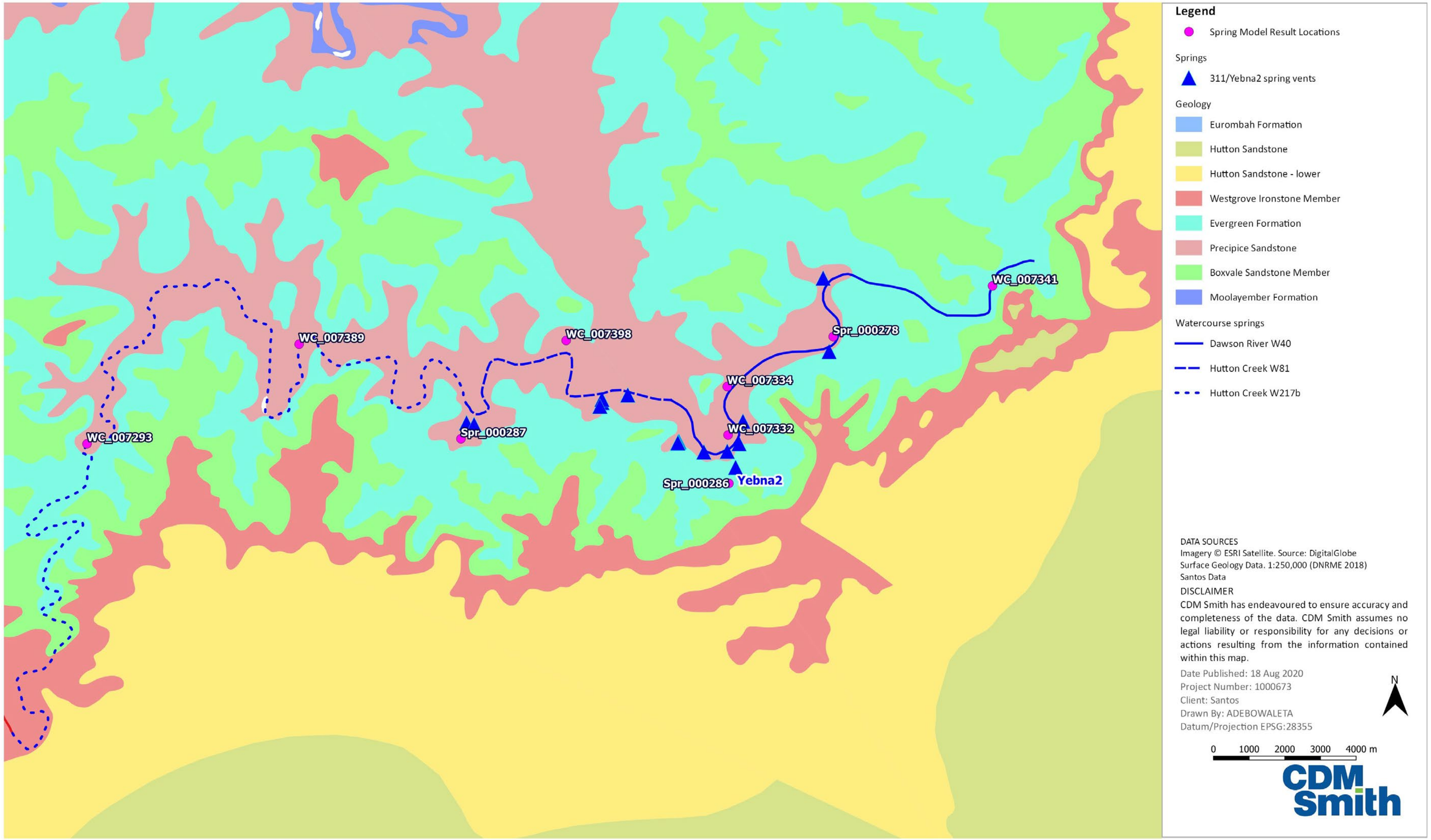
The objective of this assessment is to understand the impacts of APLNG re-injection and its potential role in maintaining water levels in the vicinity of the 311/Yebna 2 spring Complex and the water course springs (W40, W81, W217b).

Predicted Drawdown

The UWIR 2019 model predicts drawdown due to CSG operations in the Fairview field area. Figure 5-1 indicates the locations of specific sites (spring model result locations), where model outputs of predicted drawdowns were available for analysis, in the area around the 311/Yebna 2 spring complex and the watercourse springs associated with Lower Hutton Creek and the Dawson River.

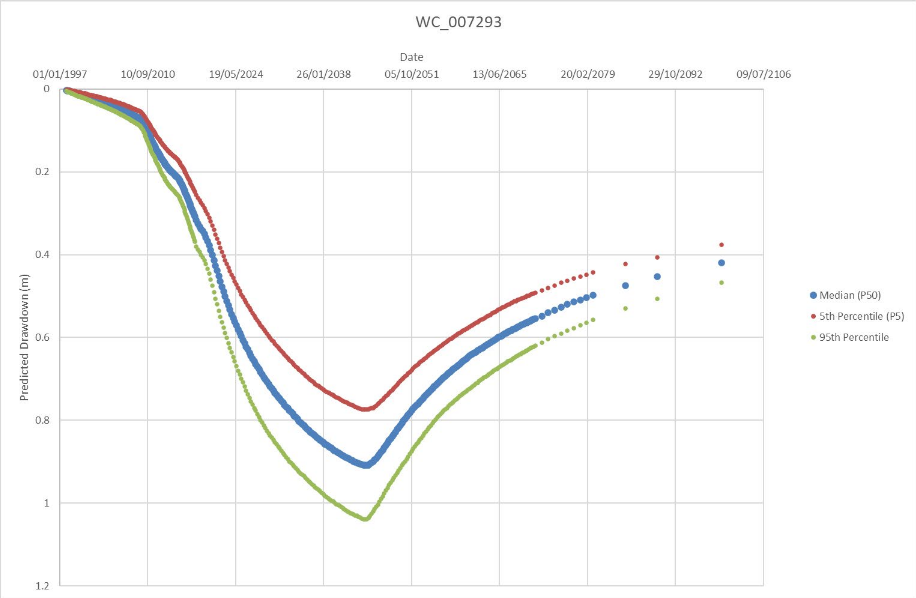
Figure 5-2 shows the predicted drawdowns (median, 5th percentile and 95th percentile) due to CSG extraction activities for the points shown on Figure 5-1. The data shows that the maximum median drawdown predictions range between about 0.25 m (WC_007398) and 0.9 m (WC_007293). Both these maximum predictions are for the water course springs associated with the lower Hutton Creek and the Dawson River. The maximum median predicted drawdowns for the 311/Yebna 2 spring complex are approximately 0.55 m.

The predictions also show that median drawdowns have potentially already exceeded the 0.2 m risk threshold adopted by OGIA at nearly all sites. These drawdowns are predicted to continue to exceed the threshold for at least the next 50 years, and in most cases for the next 75 years.



\\brbsvr1\PRO\Project\1000673 - Santos SIMS Mitigation\7Work\3GIS\QGZ\Spring_Model_Result_RAY.qgz

Figure 5-1 Location of springs and water courses and the points at which the UWIR 2019 model drawdowns are predicted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13/06/2065
20/02/2079
29/10/2092
09/07/2106
Predicted Drawdown (m)
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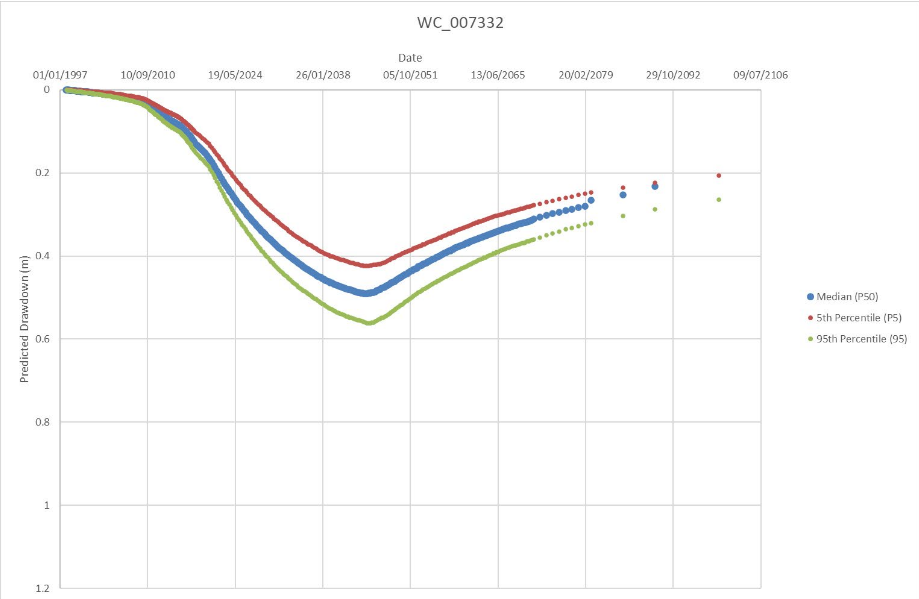
0.4
0.6
0.8
1
1.2
Median (P50)
5th Percentile (P5)
95th Percentile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29/10/2092
09/07/2106
Predicted Drawdown (m)
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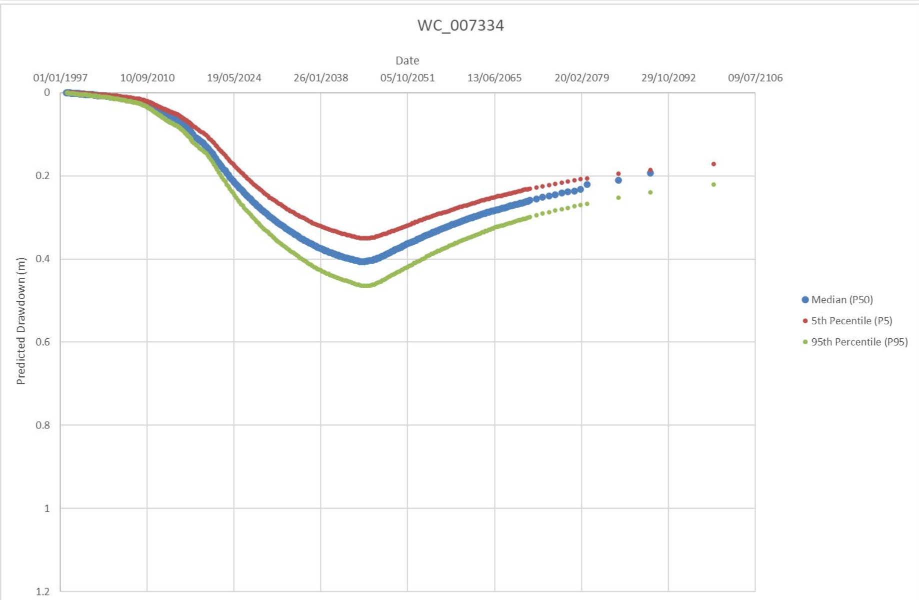
0.2
0.4
0.6
0.8
1
1.2
Median (P50)
5th Percentile (P5)
95th Percentile (95)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13/06/2065
20/02/2079
29/10/2092
09/07/2106
Predicted Drawdown (m)
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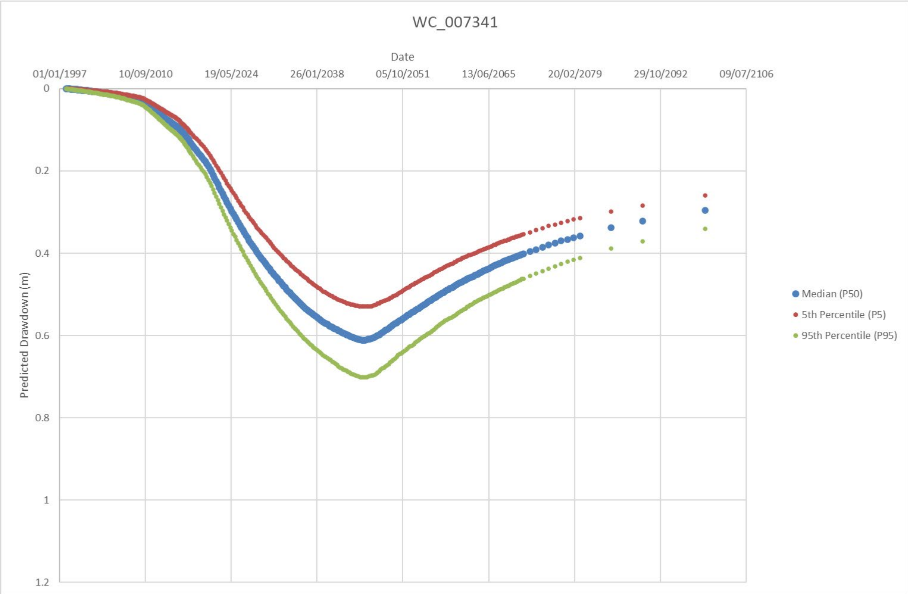
0.2
0.4
0.6
0.8
1
1.2
Median (P50)
5th Percentile (P5)
95th Percentile (P95)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0.2
0.4
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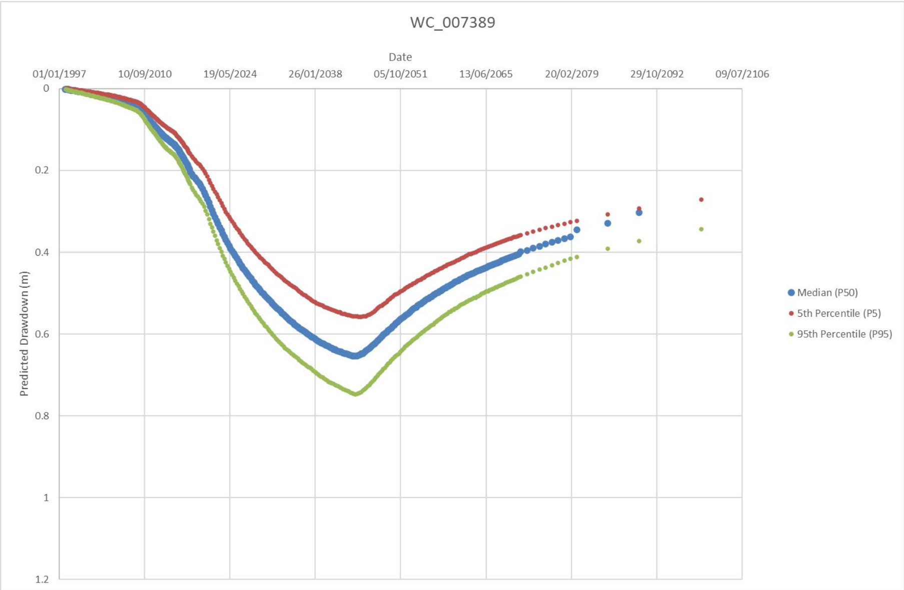
0.8
1
1.2
Predicted Drawdown (m)
Median (P50)
5th Percentile (P5)
95th Percentile (P95)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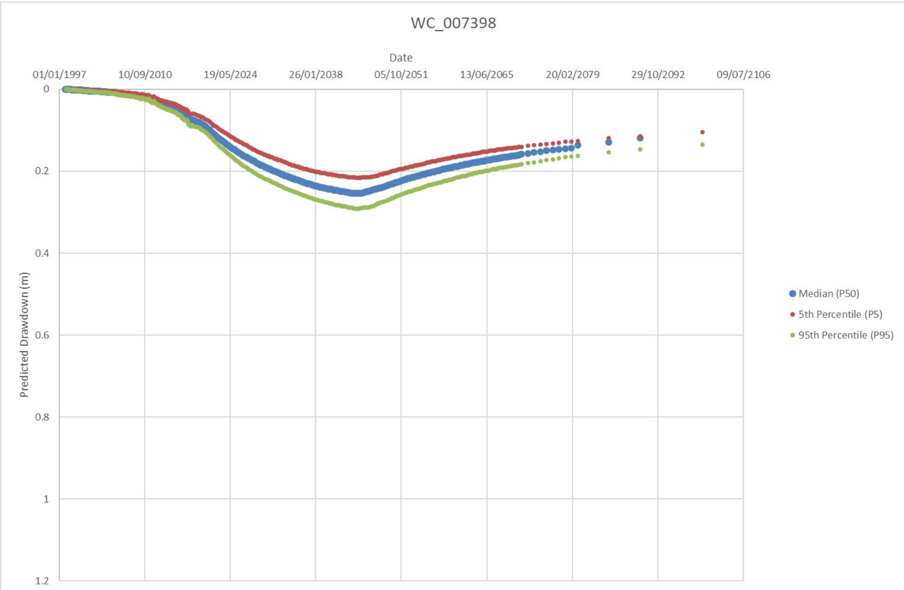
20/02/2079
29/10/2092
09/07/2106
0
0.2
0.4
0.6
0.8
1
1.2
Predicted Drawdown (m)
Median (P50)
5th Percentile (P5)
95th Percentile (P95)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05/10/2051
13/06/2065
20/02/2079
29/10/2092
09/07/2106
0
0.2
0.4
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0.8
1
1.2
Predicted Drawdown (m)
Median (P50)
5th Percentile (P5)
95th Percentile (P95)

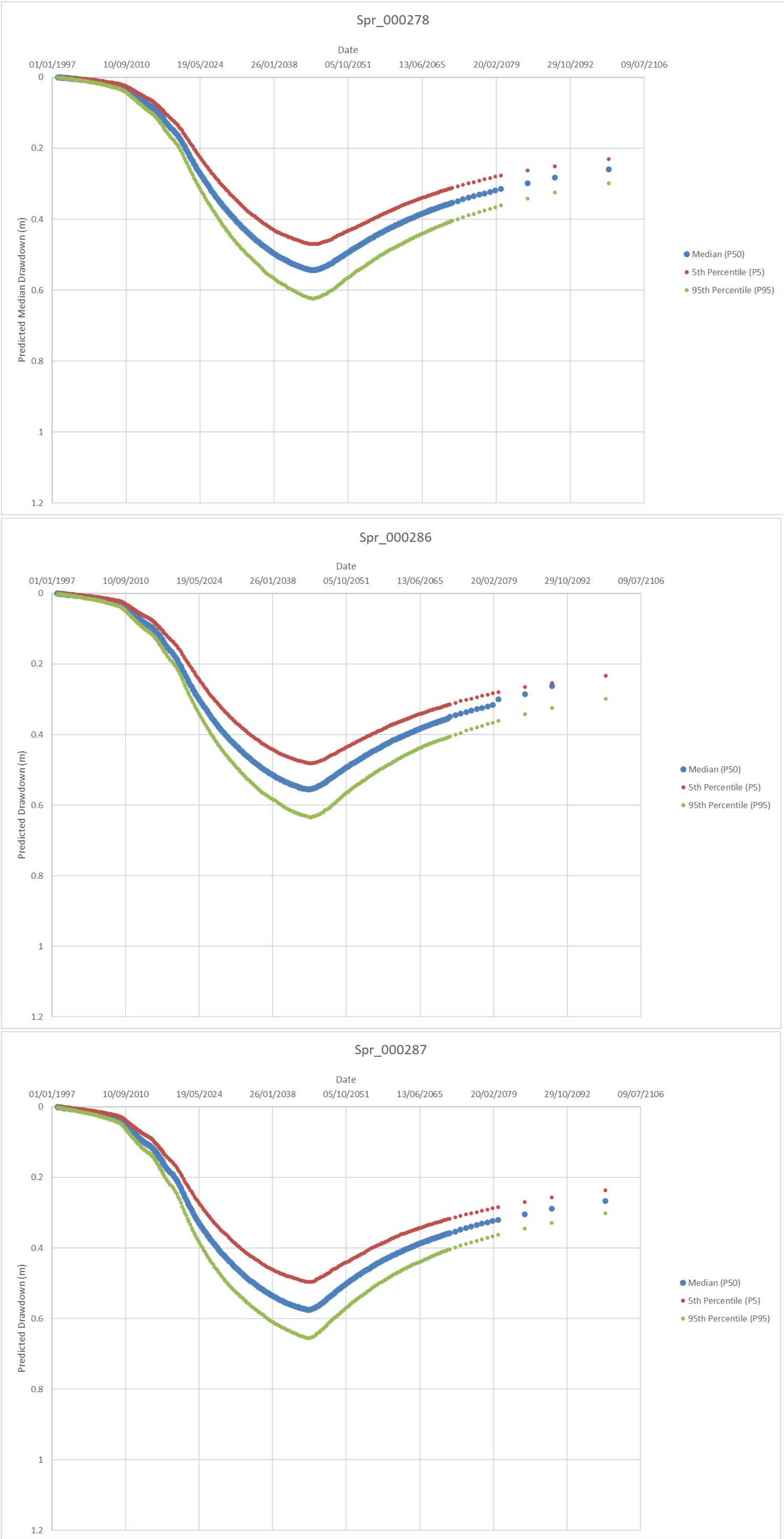


Figure 5-2 UWIR 2019 Predicted Drawdowns at Locations near the 311/Yebna 2 Complex

The Re-injection Scheme

APLNG CSG operations on their lease to the south of Fairview field, dispose of some of the suitably treated production water via re-injection to the Precipice Sandstone aquifer at two sites; the Reedy Creek and Spring Gully Injection fields. These fields are located approximately 75 km and 30 km respectively to the south of the 311/Yebna 2 spring complex. Re-injection operations commenced in January 2015 at both sites.

The re-injection operation up to June 2019 is described in Origin (2019). The primary re-injection site is the Reedy Creek field and the secondary site is the Spring Gully field. Origin (2019) reports that over 24.5 GL (of treated CSG water) has been injected to the end June 2019. Initial injection rates at Reedy Creek were over 20 ML/day, and rates stabilised to about 11 ML/day by mid-2019 (Figure 2). Re-injection at Spring Gully fell to low levels by mid-2019 (approximately 1 – 2 ML/day). No publicly available data is available for the operations of the re-injection fields since mid-2019.

The total re-injected water volume is approximately 90 % of the total produced water over the period of operation to mid-2019, with the Spring Gully field injecting 16 % of produced water in the Spring Gully Developmental Area and the Reedy Creek field injecting 83 % of produced water at the Combabula Development Area.

The highest re-injection rates across the two fields appears to have occurred over the period July 2016 to January 2017.

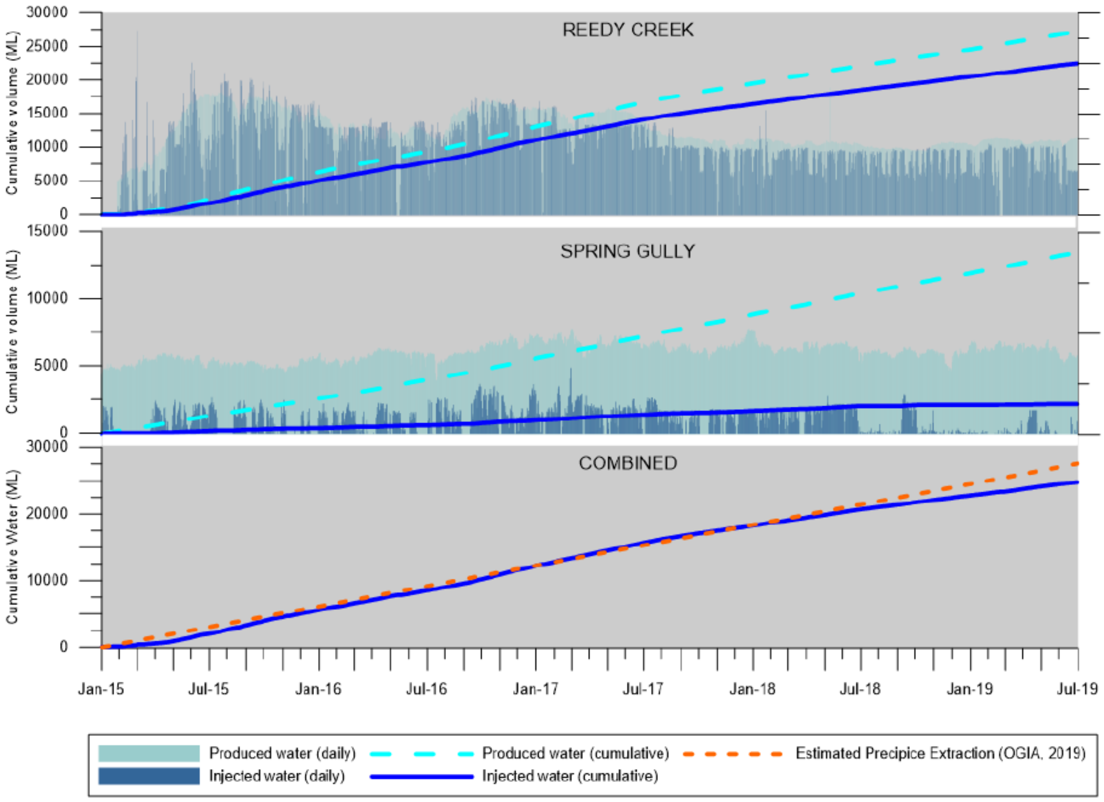


Figure 5-3 Re-injection operations undertaken by APLNG (from Figure 54, Origin 2019)

Origin (2019) reports on the pressure response in the Precipice Sandstone due to the re-injection (Figure 3). The reporting takes the form of displacement plots, showing the change in water level compared to the water level in the bore at 1 January 2015 (the commencement of re-injection). Three displacement plots are of interest (Figure 3); Spring Gully MB16-P, Spring Gully PB3 and Spring Gully MB9-P.

The plots show that water levels have risen since re-injection started, to a peak during mid 2017 and early 2018. APLNG have attributed this rise to the impacts of re-injection. The displacement has reduced since mid 2017 – early 2018, likely due to the reduced re-injection volumes since that time (Origin, 2019).

The peak displacement varies, however is generally between 1.5 and 2.0 m of additional head added to the aquifer most likely due to re-injection activities.

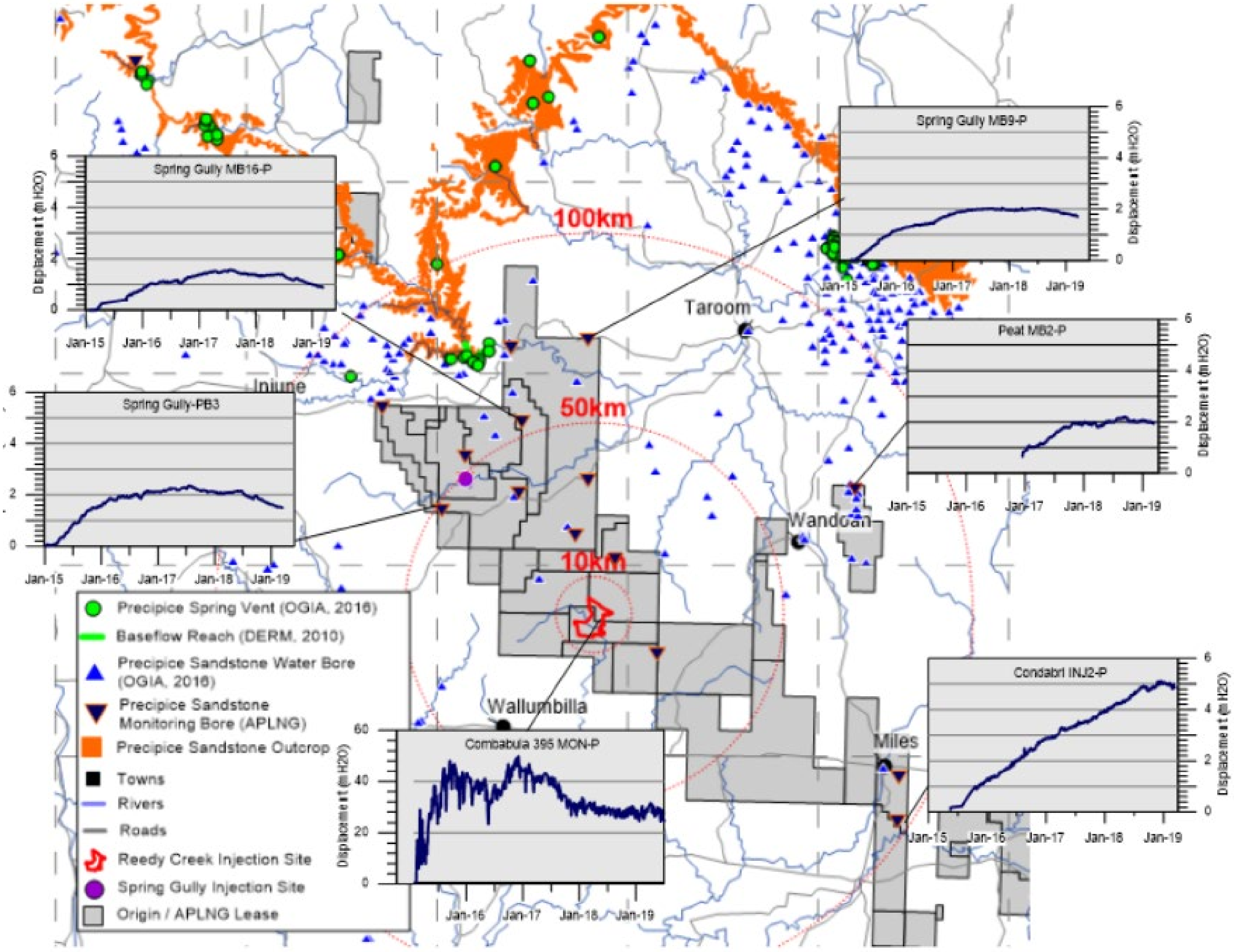


Figure 5-4 Pressure responses in the Precipice Sandstone due to APLNG re-injection (from Figure 55, Origin 2019)

The monitoring network of bores for the Precipice Sandstone was assessed for Santos's Fairview CSG field, to establish whether similar displacement patterns may exist to those reported by APLNG. Figure 5-5 shows the location of all bores assessed.

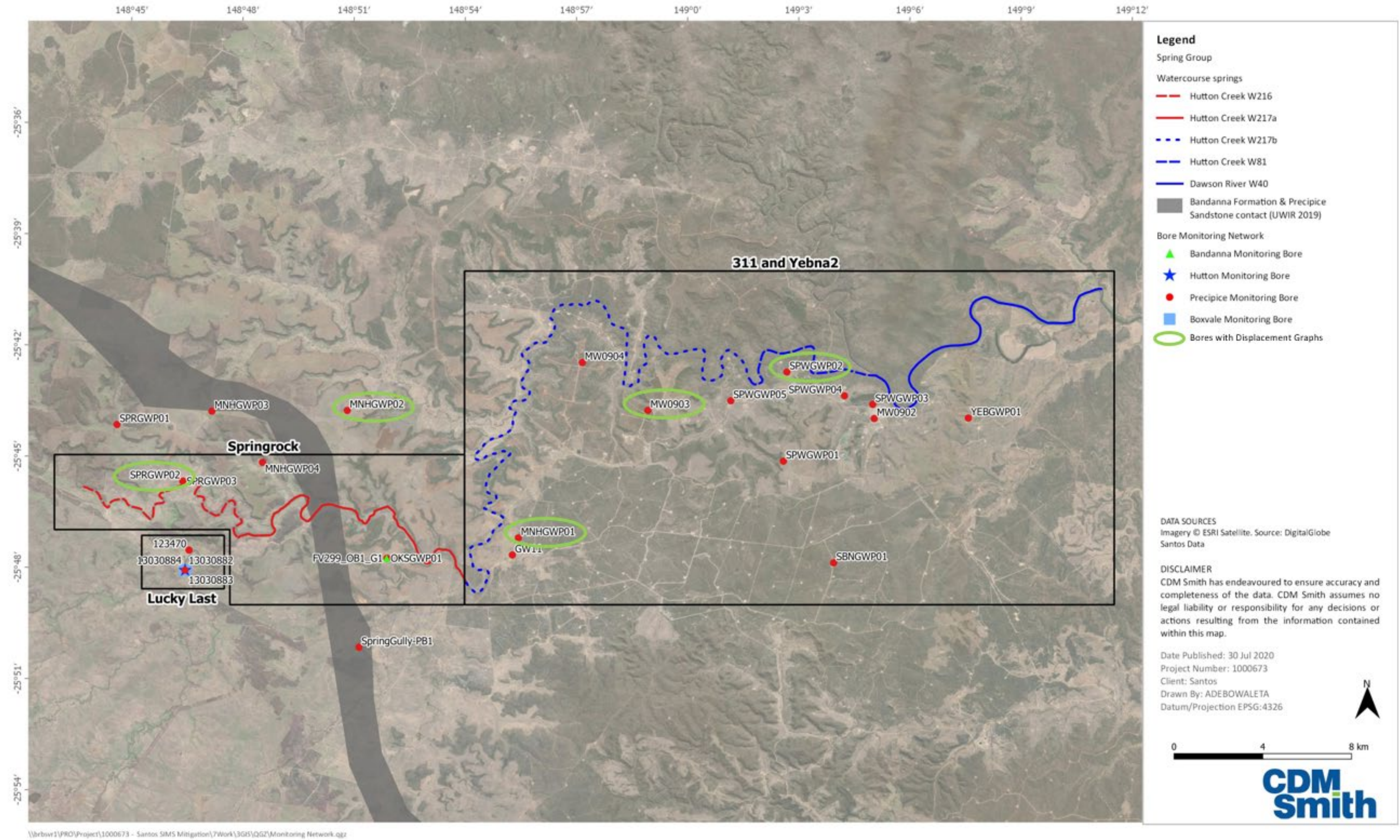


Figure 5-5 Location of Precipice Sandstone Monitoring Bores with Displacement Graphs Developed

Displacement plots for Precipice Sandstone monitoring bores adjacent to the 311/Yebna 2 springs and the W217b, W40 and W81 watercourses are shown below (Figure 5-6). These plots show a similar pattern to those published by APLNG in that there has been a rise in water level of between 1.4 to 1.7 m, peaking in early to mid-2017 and then a reduction in the displacement thereafter. Displacement in 2020 varies between about 0.7 and 1.2 m, presumably due to the lower re-injection volumes at the APLNG re-injection sites. The lower displacements compared with those reported by APLNG are probably due to the increased distance from the point of injection.

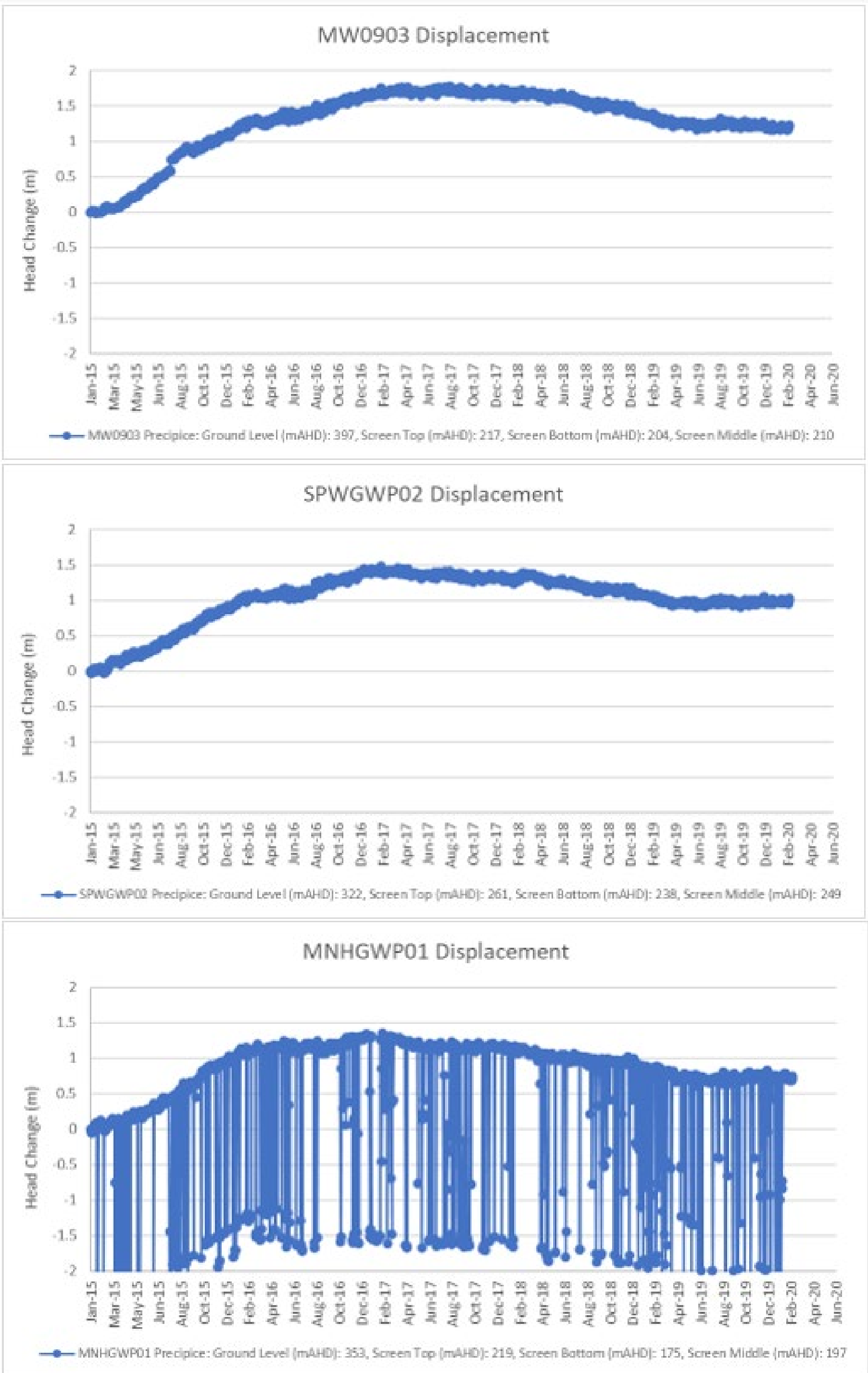


Figure 5-6 Displacement Plots – Bore located adjacent to the 311/Yebna 2 Complex

Displacement plots for the area towards Springrock Creek were also produced (Figure 5-7). These plots are interpreted to show that there has been minimal to no observable impact in this area due to the re-injection.

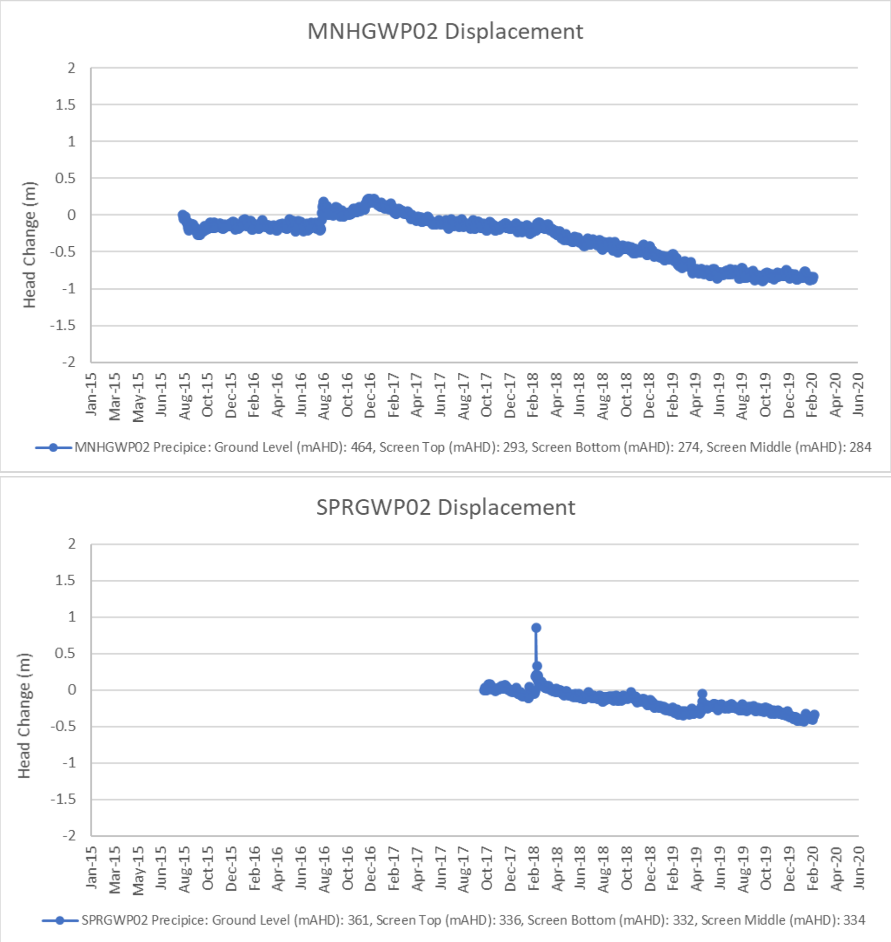


Figure 5-7 Displacement Plots – Bores Located Adjacent to Springrock Creek Complex

This data is interpreted to show that re-injection by APLNG has resulted in increased water levels underlying both the 311/Yebna 2 spring complex and the W217b, W40 and W81 watercourses. This would be acting to ameliorate any drawdown impacts currently acting at these sites as predicted by the UWIR 2019.

Future Re-injection Operations

APLNG has published their notional future water production curve as a function of the output of their total water treatment process (Figure 5-8). This planned output is notional and subject to change, and it is for total output from their treatment facilities. If it is assumed that the current averaged operations for the period 2015 to mid-2019 remain current, and that 90% of the treated water is re-injected, the plot provides some idea of future conditions (noting that re-injected volumes in mid-2019 totalled about 13 to 14 ML/day across the two re-injection fields).

Re-injected water volume is forecast to decrease from early 2020 levels around 16 to 17 ML/day to a low of about 5 ML/day by 2023. There is an increase from that point in time to a peak of about 18 ML/day in the late 2020s. This then declines consistently until it reaches low levels of less than 3 ML/day by about 2035. This level of re-injection (3 ML/day) is assumed to be the lowest level that results in observable displacement in the vicinity of the 311/Yebna 2 springs and the associated watercourses. The impact on the water levels in the Precipice Sandstone in the vicinity of the springs and water courses of re-injecting 3 ML/day has not been modelled.

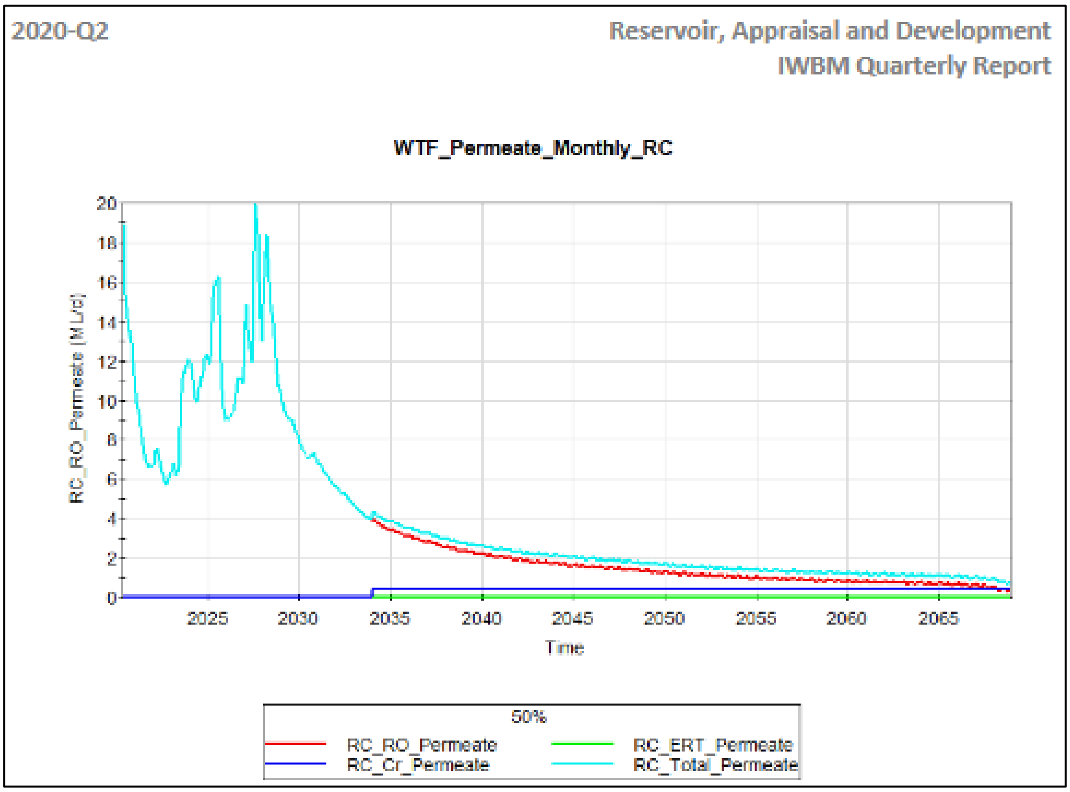


Figure 5-8 Published APLNG Future Total Water Treatment Plant Output

Conclusions

Reinjection of treated water by APLNG at its Reedy Creek and Spring Gully fields has increased water levels in the Precipice Sandstone adjacent to the 311/Yebna 2 springs and the W217b, W40 and W81 water courses. This increase is the same order as the drawdown predicted by the UWIR 2019 model and is mitigating those potential impacts. It is concluded that based on current information, that if APLNG continues to re-inject at the rates publicly reported and according to the assumptions made above, potential drawdown impacts at the 311/Yebna 2 springs and associated water courses, will continue to be mitigated, and that this is likely to extend past 2030 and potentially to 2035.

A.2 311/Yebna 2 – Retire Existing Groundwater Abstraction

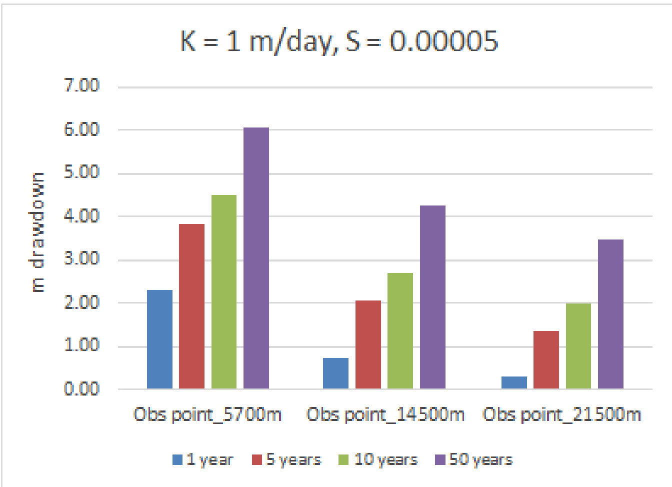
Table 5-1 Assessment Description

Item	Description
Potential Mitigation Option	Retire existing groundwater abstraction
Assessment Objective	Estimate the mitigation effect of retiring Santos Groundwater Licence SP261934
Assessment Approach	Theis Analytical Drawdown Assessment
Assessment Assumptions (associated with the Theis model)	• The aquifer is infinite, confined, homogenous and isotropic • The aquifer is horizontal and groundwater flow is horizontal • The well diameter is negligible, and the well is 100% efficient (no well loss) • The pumping and observation wells penetrate the full thickness of the aquifer • The pumping well discharges at a constant rate • Aquifer flow conditions to the pumped well are laminar, radial and horizontal
Assessment Assumptions (associated with the model inputs)	Assume full licence volume is abstracted each year at a constant rate for a range of time steps (1, 5, 10 and 50 years)
Assessment Limitations	The assessment outcomes are reliant on aquifer parameterisation that reflect local conditions. The input parameters for this assessment are largely derived from the UWIR 2019 model (OGIA, 2019a). Another source of aquifer parameters for the region is Hayes et al. (2020). The difference between the hydraulic conductivity reported by Hayes et al. (2020) and OGIA (2019a) are significant and vary by almost two orders of magnitude. Site specific investigations will need to be undertaken in this area as part of the feasibility study, to confirm the aquifer properties and these assessment outcomes.

Table 5-2 Assessment Input Details

Data Input	Value	Unit	Source
Hydraulic Conductivity	0.33	m/day	UWIR 2019 model (OGIA, 2019a)
Storage Coefficient	0.00005	None	Hayes et al. (2019)
Aquifer Thickness	60	m	Hayes et al. (2019) and local understanding of aquifer thickness in this area from observation bores.
Pumping Rate	89	ML/yr	Licence Entitlement Conditions
Observation Distance	5,700, 14,500, 21,500	m	Distance between the licence location and the watercourse spring and spring vents.
Time	1, 5, 10, 50	years	Arbitrary timeframe over which licence may be extracted
Drawdown	**Output objective**	-	-

Table 5-3 Assessment Results

Output Description	Output Range (drawdown at time)
Drawdown at 5 700 m (distance between licence location and W217b)	2.31 m (1 year of pumping) 3.84 m (5 years of pumping) 4.52 m (10 years of pumping) 6.09 m (50 years of pumping)
Drawdown at 14 500 m (distance between licence location and closest spring vent)	0.75 m (1 year of pumping) 2.07 m (5 years of pumping) 2.72 m (10 years of pumping) 4.27 m (50 years of pumping)
Drawdown at 21 500 m (distance between licence location and Yebna 2 spring vent)	0.30m (1 year of pumping) 1.38 m (5 years of pumping) 1.99 m (10 years of pumping) 3.50 m (50 years of pumping)
Graphed drawdown results	

Output Description	Output Range (drawdown at time)
Interpretation Comment	The low hydraulic conductivity used in this assessment results in a drawdown in the pumping well of over 27 m, which may not be sustainable. If pumping rate was reduced due to a more limited available drawdown, the impact would be less. There is significant uncertainty in the aquifer parameters in this area and the reporting of a value as opposed to a range doesn't reflect certainty in the values. The results of this analysis need to be validated via local investigations.

A.3 311/Yebna 2 - New Santos Reinjection Scheme

A.3.1 Analytical Solution (Theis)

Table 5-4 Assessment Description

Item	Description
Potential Mitigation Option	New Santos re-injection scheme
Assessment Objective	Estimate the location and rate of injection required to produce a 0.9 to 0.25 m increase in groundwater pressure (from west to east, as determined by UWIR 2019). This assessment calculated drawdown under the assumption of confined aquifer conditions.
Assessment Approach	Theis Analytical Drawdown Assessment
Assessment Assumptions (associated with the Theis model)	• The aquifer is infinite, confined, homogenous and isotropic • The aquifer is horizontal and groundwater flow is horizontal • The well diameter is negligible, and the well is 100% efficient (no well loss) • The pumping and observation wells penetrate the full thickness of the aquifer • The pumping well discharges at a constant rate • Aquifer flow conditions to the pumped well are laminar, radial and horizontal
Assessment Assumptions (associated with the model inputs)	It is assumed that the target impressed head at the targeted locations (see below) will be reached within one year of scheme switch on. The total injection rate will be for the first year to reach targets. This is the maximum expected injection rate, with injection rates expected to decline as the scheme moves to maintain heads once targets are reached.
Assessment Limitations	The assessment outcomes are reliant on aquifer parameterisation that reflect local conditions. The input parameters for this assessment are largely derived from the UWIR 2019 model (OGIA, 2019a). Another source of aquifer parameters for the region is Hayes et al. (2020). The difference between the hydraulic conductivity reported by Hayes et al. (2020) and OGIA (2019a) are significant and vary by an order of magnitude. Site specific investigations will need to be undertaken in this area as part of the feasibility study, to confirm the aquifer properties and these assessment outcomes.

Table 5-5 Assessment Input Details

Data Input	Value	Unit	Source
Hydraulic Conductivity	10	m/day	UWIR 2019 model (OGIA, 2019a)
Storage Coefficient	0.000175	None	Midpoint of range provided in Hayes et al. (2019): 0.0001 to 0.00025
Aquifer Thickness	60 m	m	Hayes et al. (2019) and local understanding of aquifer thickness in this area from observation bores.
Total injection Rate	**Output objective**	-	-

Data Input	Value	Unit	Source
Maximum injection rate per bore (bore capacity)	50	L/sec	Origin (2015) Table 8 – maximum proven injection bore capacity for Precipice bores (4.5 ML/day)
Drawdown	0.9 to 0.25 m (from west to east)	m	UWIR (2019) model predictions.
Observation Distance (minimum)	2000	m	Distance between mitigation target locations and injection bores. This distance is somewhat constrained by the location of the estimated confined Precipice Sandstone aquifer extent (i.e. unconfined conditions are observed at less than 1km from the Dawson River).

Table 5-6 Assessment Results

Output Description	Output Value	Comment
Pumping rate and distance of bore from Dawson River	1.0 ML/day at a distance of 2 km from the Dawson River	Injection bore located at western end of complex.

A.3.2 2D Slice Model Using MODFLOW

Table 5-7 Assessment Description

Item	Description
Potential Mitigation Option	New Santos re-injection scheme
Assessment Objective	Estimate the reinjection volume required to raise the potentiometric surface at the spring vents and the watercourse spring, from a baseline (impacted) potentiometry (a predicted reduction of 0.9 m is the maximum drawdown anticipated by UWIR 2019 model) to an unimpacted potentiometry (December 2014). This will indicate the mitigation effect of a new Santos re-injection scheme that injects treated produced water into the Precipice Sandstone to offset the change within the Precipice Sandstone aquifer in the vicinity of the potentially affected springs.
Assessment Approach	2D numerical slice model using MODFLOW
Assessment Assumptions (associated with the 2D model)	There are a number of assumptions and limitations to the MODFLOW software package, these can be reviewed in the USGS publication (https://pubs.usgs.gov/tm/06/a55/tm6a55.pdf).
Assessment Assumptions (associated with the model inputs)	• The base of the Lower Precipice Sandstone is impermeable (it is a no flow boundary); • Recharge to the Precipice Sandstone in the outcrop areas is ignored.
Assessment Limitations	The assessment outcomes are reliant on aquifer parameterisation that reflect local conditions. The input parameters for this assessment are largely derived from the UWIR 2019 model (OGIA, 2019a). Another source of aquifer parameters for the region is Hayes et al. (2020). The difference between the hydraulic conductivity reported by Hayes et al. (2020) and OGIA (2019a) are significant and vary by almost two orders of magnitude. Site specific investigations will need to be undertaken in this area as part of the feasibility study, to confirm the aquifer properties and these assessment outcomes.

Table 5-8 Model Structure Details

Variable	Model Layer 1 (Evergreen Formation)	Model Layer 2 (Upper Precipice Sandstone)	Model Layer 3 (Lower Precipice Sandstone)	Source
Layer geometry	The 1 second Shuttle Radar Topography Mission (SRTM) Digital Elevation Model for top of layer Geological model for base of layer.	Surface geology Lower Precipice used to infer top of layer (assuming Upper Precipice of approximately 20 m thickness). Geological model for bottom of layer.	Geological model for top and base of layer.	OGIA (2019b) Jacobs (2019) ELVIS - Elevation and Depth - Foundation Spatial Data
Land surface elevation	The 1 second SRTM digital elevation of the surface, adjusted to incorporate the riverbed incision, based on a 5m DEM longitudinal river chainage profile.			OGIA (2019b) Jacobs (2019)

Variable	Model Layer 1 (Evergreen Formation)	Model Layer 2 (Upper Precipice Sandstone)	Model Layer 3 (Lower Precipice Sandstone)	Source
Potentiometric surface	December 2014 (pre APLNG injection operation) Precipice Sandstone potentiometry.			Jacobs (2019)
Horizontal Hydraulic Conductivity	0.001 m/day	5 m/day (estimated at half the Lower Precipice based on yield observations)	10 m/day	UWIR 2019 (OGIA, 2019a)
Vertical Hydraulic Conductivity	0.001 m/day	0.05 m/day	0.1 m/day	Hayes et al. (2019) and OGIA (2019a)
Storage Coefficient	$2.5E^{-6}$			Hayes et al. (2019) and typical values from literature
Boundary Conditions: Constant Head Boundary	The starting conditions comprised the impacted potentiometric surface along the transect (i.e. the potentiometry impacted by scenarios of 0.6 m, 0.8 m and 1.0 m predicted drawdown).			Jacobs (2019) for initial and OGIA (2019) for maximum predicted drawdown values
Boundary Conditions: Three spring vents are represented as drain cells.	• Vent 536.1 – 280 mAHD • Vent 694 – 277 mAHD • Vent 696 – 275 mAHD			OGIA (2015a)
Boundary Conditions: The Dawson River was represented as a drain.	• Dawson River – 250.3 mAHD			Jacobs (2019) river elevation chainage dataset.
Time	Allowed initial conditions to develop to a quasi-steady state solution			

Symbol	Name	Kh (m/d)	Kv (m/d)
	Evergreen Formation	0.001	0.001
	Upper Precipice Sandstone	5	0.05
	Lower Precipice Sandstone	10	0.1

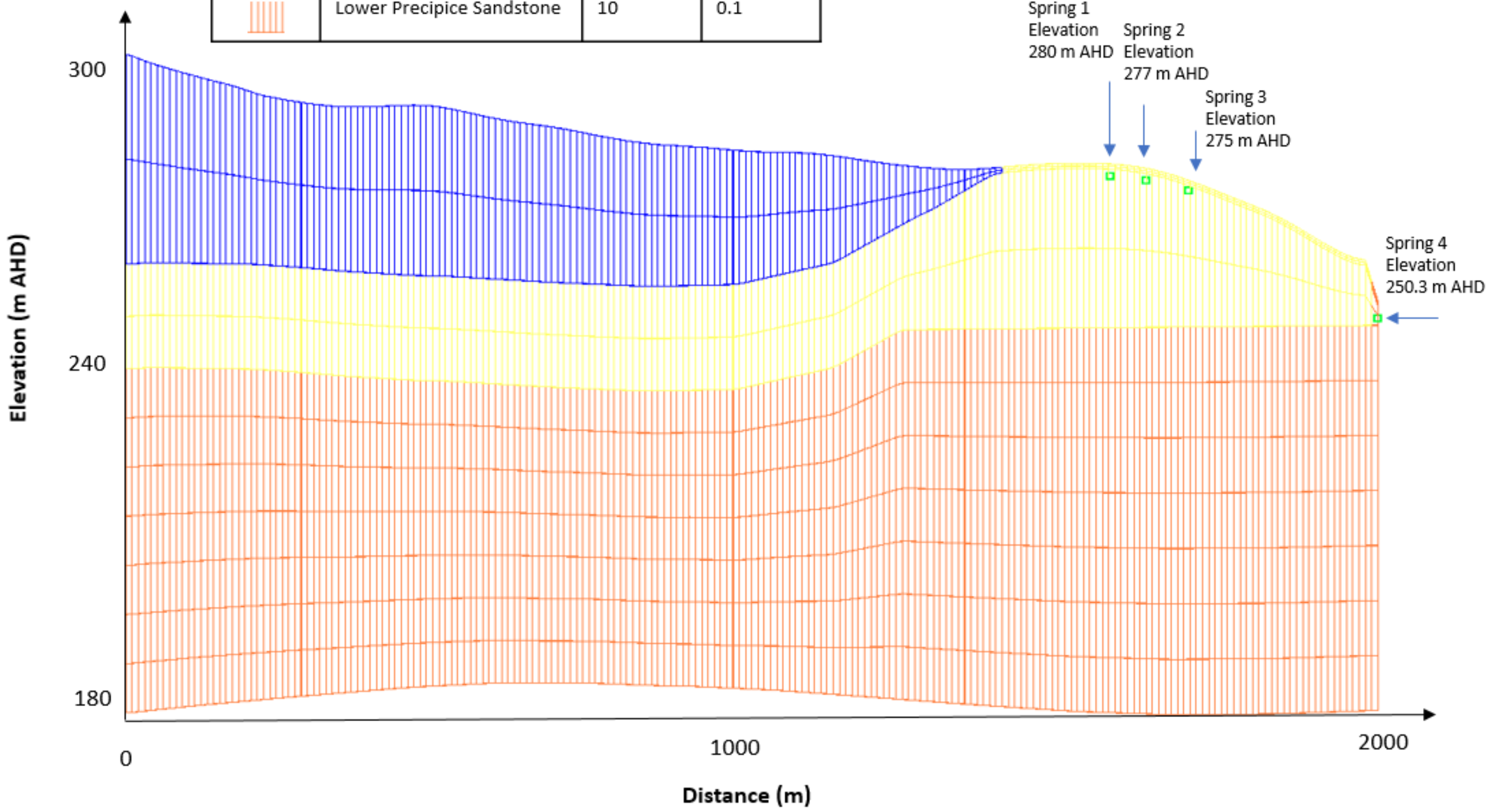
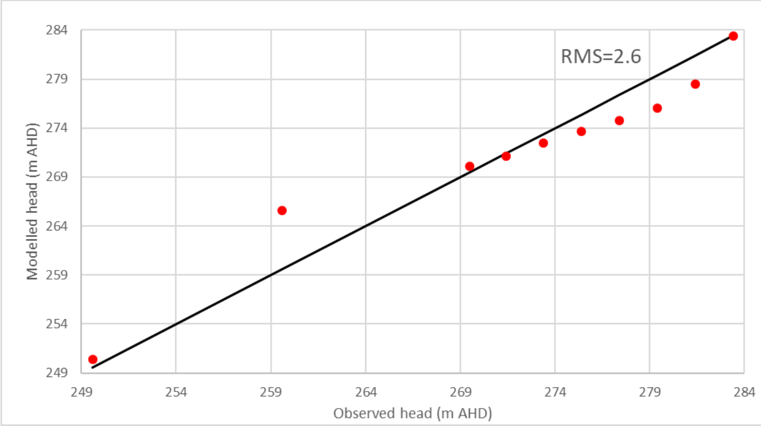


Figure 5-9 Slice Model Overview

Table 5-9 Assessment Results

<table>
<tr><th>Output</th><th>Output Description</th><th>Output Result</th></tr>
<tr><td>Model Calibration</td><td>The model was calibrated using the ten predicted drawdown groundwater levels along the section line, from the southern to northern extent.</td><td>
</td></tr>
<tr><td>Model Simulation Results</td><td>The model was run for three scenarios to assess how much water was required to increase the impacted potentiometry back to the baseline potentiometry of Jacobs (2019).</td><td><table>
<tr><th>Scenario</th><th>Predicited Potentiometric Increase Required for Mitigation</th><th>Volume of injection per 1 m of river length (m3/day)</th></tr>
<tr><td>Sc 1</td><td>0.6 m</td><td>0.14</td></tr>
<tr><td>Sc 2</td><td>0.8 m</td><td>0.19</td></tr>
<tr><td>Sc 3</td><td>1.0 m</td><td>0.23</td></tr>
</table></td></tr>
<tr><td>Model Simulation Results Extrapolated</td><td>Model results (output for a 1 m slice) are extrapolated over an estimated river length of 30 km</td><td><table>
<tr><th>Scenario</th><th>Predicited Potentiometric Increase Required for Mitigation</th><th>Volume of injection per 1 m of river length (m3/day)</th><th>Volume of injection over 20 km river length (ML/day)</th><th>Volume of injection over 20 km river length (GL/year)</th></tr>
<tr><td>Sc 1</td><td>0.6 m</td><td>0.14</td><td>2.8</td><td>1.0</td></tr>
<tr><td>Sc 2</td><td>0.8 m</td><td>0.19</td><td>3.8</td><td>1.4</td></tr>
<tr><td>Sc 3</td><td>1.0 m</td><td>0.23</td><td>4.6</td><td>1.7</td></tr>
</table></td></tr>
<tr><td>Interpretation of Results</td><td colspan="2">
The 2D slice model was able to demonstrate acceptable calibration against the observed conditions, which allows for confidence in its ability to provide a possible solution. However, the model is extremely simple in design and should be considered a demonstration of the possibility of this mitigaiton option and in no way reflects an detailed engineering design for this reinjection option.
Importantly, the 2D slice model demonstrates that an injection scheme based on the current conceputal model for the 311/Yebna 2 spring complex (i.e. aquifer conditions that transition from confined conditions at the point of injection, to uncofined at the spring vents and watercourse springs), is feasible.
The 2D slice model shows that an injection program will increase the heads under the elevated springs and also cause a higher flux to move towards the Creek/River.
The 2D slice model suggests approximately 0.14 m3/day/m of river, is needed to raise the potentiometric surface by 0.6 m.
Upscaling to a length of around 20km, the span of the 311/Yebna 2 complex translates to a total injection rate of 1.0 GL/year (2.8 ML/day).
There is uncertainty associated with this upscaling calculation, but it provides a useful benchmark for future investigations and more complex groundwater modelling.
</td></tr>
</table>

A.4 Lucky Last and Yebna 2 - Land Management Practices

A.4.1 Background

The condition of a number of Santos's Spring wetland environments are considered to be poor and in decline, due to a range of issues such as pugging from hooved animals, erosion from surface water flow, decline of vegetation due to overgrazing, spring dewatering due to physical impacts of grazing and erosion around the periphery of wetlands and changes to spring chemistry from a combination of the above.

Previous condition assessments of the springs (documented during the baseline survey exercises) demonstrate a history of spring degradation relating primarily to cattle disturbance (Table 5-10). In summary, the issues of particular concern for some of the springs on the Santos tenement include:

- Overgrazing – a reduction of vegetation around springs leads to soil exposure and erosion (Plate 1). This process can also lead to additional weed invasion as cows disperse seeds through manure, subsequently impacting the ratio of aquatic to terrestrial species at the edge of wetlands.
- Pugging – compaction of the soft soil surface of the wetland leading to the exposure of water in depressions, which increases evaporation and reduces the wetland area (Plate 2 and Plate 3).
- Erosion – soft, unvegetated soils become eroded during surface flow events, which then leads to the potential removal of soil and vegetation from the wetland (Plate 4), reducing wetland and wetted area.

Currently, there are no specific land management practices in place to protect the condition of the wetlands or maintain ecological endpoints. The implementation of specific land management practices at these wetland sites however, has potential to increase the resilience of the wetlands to additional stressors, such as changes in groundwater pressure. For example, by limiting exposure to grazing, vegetation regrowth may be encouraged and subsequently lesson the impacts of erosion (as seen in Plate 4). This may also allow the compacted soils (as a result of pugging) to recover and prevent water leakage from the wetland occurring, thereby reducing the likelihood of negatively impacting the ecological endpoint for the spring, which is its wetted area and wetland area extent.

In order to prescribe suitable land management practices to these spring environments, a review of literature has been undertaken in order to examine the practices that have been implemented to improve respective environmental resilience and value. These studies span a range of geographical locations, from the USA, New Zealand and Australia and provide an insight to the common land management practices implemented both globally and domestically. Utilising the understanding gained from these studies, a broad set of recommendations have been made regarding the types of land management practices and key aspects that should be considered as part of a pilot land management study at specific sites within Santos's tenement.

A.4.2 Objective

The objectives of the reviewed literature were primarily focussed on improving riparian habitats (streams and associated vegetation) as well as water quality within water resources which were observed to be achieved through fencing and exclusion management practices. Though many of the environmental values reviewed within the literature differ to that of Santos's springs sites, the outcomes of the land management practices employed for riparian habitats are considered applicable to these springs.

The objective of this review is to describe:

- The common land management practices used to improve environmental health;
- The key improvements observed due to the implementation of land management practices;
- The challenges encounter during the implementation phase;
- How the land management practice was monitored; and
- Recommended actions and guidance for implementation of a pilot land management program at specific sites within Santos's tenement.

Table 5-10 Santos Springs Condition Assessment

Spring Complex	Vent	Disturbance							
		Dec 2016	Jan 2016	Jun 2015	Mar 2015	Sep 2014	Jun 2014	Mar 2014	October 2013
Lucky Last (230)	287_1	10-50%	10-50%	10-50%	10-50%	NA	NA	NA	Significant cattle disturbance.
	340_1	10-50%	10-50%	<10%	>50%	NA	NA	NA	Significant cattle damage to spring.
	686_1	>50%	>50%	>50%	>50%	NA	NA	NA	Significant cattle damage to spring.
	687_1	10-50%	10-50%	>50%	>50%	NA	NA	NA	Significant stock damage to spring.
	687.1_1	10-50%	>50%	>50%	>50%	NA	NA	NA	Significant cattle damage to spring.
	687.2_1	>50%	>50%	<10%	10-50%	NA	NA	NA	Significant cattle damage to spring.
	687.3_1	>50%	>50%	10-50%	>50%	NA	NA	NA	Significant cattle disturbance to spring.
	687.4_1	>50%	>50%	10-50%	10-50%	NA	NA	NA	Significant cattle damage to spring.
	687.5_1	>50%	10-50%	<10%	<10%	NA	NA	NA	Significant stock damage to spring.
	687.6_1	>50%	10-50%	10-50%	10-50%	NA	NA	NA	Significant stock damage to spring.
	688_1	10-50%	10-50%	<10%	<10%	NA	NA	NA	Significant cattle damage.
	689_1	10-50%	10-50%	10-50%	10-50%	NA	NA	NA	Significant disturbance by cattle around spring perimeter. The spring vent at the top of the mound appears less damaged and OK for a sample.
Springrock Creek (561)	285_1	<10%	0%	0%	0%	NA	NA	Relatively undamaged	Evidence of livestock damage, although the absence of soil makes it less noticeable. Impact is worse further down the creek where access is easier.
311 (311)	536	NA	0%	0%	0%	NA	NA	NA	Poor, disturbance by cattle, some surface flow erosion around edges.
	537	NA	0%	0%	0%	NA	NA	NA	NA
	693	NA	<10%	<10%	0%	NA	NA	NA	Very good condition, slight erosion at edge of pool.
	704	NA	10-50%	>50%	0%	NA	NA	NA	Minimal disturbance to vent.
Yebna 2 (591)	534	NA	10-50%	10-50%	10-50%	NA	NA	Spring is in poor condition, heavily impacted by livestock and erosion.	Cow pugging present, erosion around the sides.

Grazing pressure – normally heavily vegetated wetland, heavy stock pressure reduces veg cover, trampling and faeces

Plate 1 Grazing Pressure

Pugging (cows hoofs change the surface of the soft wetland soil)

Left - creates holes that fill up with water and increase the evaporation form the wetland, reducing wetland area

Right – during dry periods pugged soil hardens and reduces the capacity of wetland vegetation to propagate

Plate 2 Pugging Issues

Pugging and erosion around the edges of mounded wetlands

This action creates pathways for:

1) Exposure of organic rich soils – erode and change pH
2) Water drainage away from spring, reducing wetland area

Plate 3 Erosion Issues

Poor land management around wetlands in the surrounding landscape creates erosion that after surface flow events has the potential to remove wetland soil and vegetation

Plate 4 Pugging and Erosion

A.4.3 Key Findings from the Literature

Five land management practices for improving environmental heath were observed in the reviewed literature;

1. Livestock exclusion – i.e. fencing of creeks/streams to exclude livestock
2. Alternative grazing schemes – i.e. rotational grazing, minimising overgrazing
3. Riparian buffer – i.e. strategic planting of vegetation along creek/stream edges
4. Seepage wetlands – i.e. use of wetlands to improve water quality
5. Instream structures – i.e. use of rocks, dams to control stream flow

From the studies reviewed, livestock exclusion and alternative grazing schemes were both the most commonly employed land management practices and the most relevant to the objectives of Santos's spring types (Kaufman & Krueger 1984; Line 2003; Matthews et al 2003; McKergow et al. 2016; Miller et al. 2010; Ranganath et al. 2009; Tohill et al. 1990; Zeckoski et al. 2007). Whilst these two management practises form the key focus of this review, a case summary of all identified land management practices is provided in Table 5-11 for completeness.

Impact Measurement

Measurement of the land management practices were typically made through vegetation health surveys, stream gauging and frequent water quality sampling. Vegetation health surveys were completed by both Miller et al. (2010) and Ranganath et al. (2009) who used a visual scoring methodology to assign a grading system for observing riparian vegetation health pre and post fencing. The surveys followed a procedure for undertaking this task referred to as a "Rapid Habitat Assessment (RHA)" (Ranganath et al. 2009, pp. 35), where a score of vegetation ranges from poor health (score 0) to good health (score 200). A vegetation health monitoring approach that is more closely related to a spring environment, however, is the Index of Wetland Condition Procedure prepared by the Victoria State Government (2018), which provides a basis for monitoring and evaluating wetland health within Australia. This procedure is vigorous in nature and covers a large array of criteria that require grading over the course of the monitoring period. This approach allows for simple and transparent comparison of the vegetation condition over time.

Such a procedure may be of greater use than other survey approaches, such as that undertaken by Zeckoski et al. (2007) where landowners were asked to fill in a questionnaire on the success of their recent management practice. These survey types, though useful, may be less easily comparable with future surveys, as they are irregular and not specifically tailored to measure a given environmental habitat.

Water quality sampling methods were used by almost every study reviewed and assisted in precisely determining water quality improvements following implementation of a land management practice. Consistent water quality monitoring (e.g. Turbidity and EC) at regular intervals was a standard practice observed by some of the studies (Line, 2003; Miller et al. 2010).

Observed Improvements

The reported benefits resulting from the land management practices include improvements to riparian habitats (streams and associated vegetation) and water quality associated with the ecological thresholds. McKergow et al. (2016), Miller et al. (2010) and Zeckoski et al. (2007) all concluded that implementation of fencing practices led to reduced stream erosion and bank stabilisation. Ranganath et al. (2009) further noted that livestock exclusion increased stream depth and riparian groundcover. Similar successes were reported by Queensland Government (2005), where fencing of a spring habitat (Tego Springs) previously stripped of vegetation, led to a significant regeneration of native plants, grasses and saltbushes within a 12-month period. Fencing practices were also noted to improve water quality (specifically sediment loading and bacteria content) in all instances where this was a measured objective. Improvements to water quality can be linked to several resulting factors of fencing including faecal exclusion, reduced sediment loading from lessoning of bank erosion and increased riparian growth (Kaufman & Krueger, 1984; Line 2003; Matthews et al 2003; Miller et al. 2010; Zeckoski et al. 2007).

Alternating grazing schemes were also demonstrated to provide positive outcomes for riparian habitats as well as water quality. Kaufman and Krueger (1984) found that rest-rotation grazing was the most successful land management approach for improving riparian zone vegetation when compared with other management practices. Exclusion of stock to riparian areas limits the stock interaction with streams and therefore allows recovery of creek banks and vegetation regrowth. Toill et al. (1990) subsequently noted that a minimum height of herbaceous vegetation encourages adequate vegetation cover for bank protection and sediment trapping.

Observed Challenges

Fencing and alternating grazing scheme practices, however, are not without challenges. For one, rest rotation schemes as outlined by Kaufman and Krueger (1984) and Toill et al. (1990), require constant and often daily maintenance and monitoring of livestock to reap the benefits associated with this land management practice. A similar management style is also required for fencing purposes which require some level of upkeep (i.e. fence maintenance and control of weed species). Costs associated with implementation of fencing practices were also seen as a challenge (Zeckoski et al.2007).

However, despite some of the challenges associated with fencing, Zeckoski et al. (2007) revealed in a survey of landowners whom had recently implemented fencing practices, that respondents were overwhelmingly in favour of the land management practice despite the financial implications.

Weed management is another challenge which must be considered when implementing fencing practices. Queensland Government (2005) reported the greatest threat for exotic species are from grasses such as Echinochloa polystachya, reeds such as Phragmites australis, and weeds such as Parkisonia aculeata. These species may flourish in the absence of livestock and have the ability to dominate spring wetlands by excluding other plant species and even choking springs in which they reside. This theory is supported by FOMS (2014), who suggested that a major challenge to the management of mound springs is the proliferation of Phragmites in springs which were formerly exposed to grazing but have since been protected. In this instance, a burning regime was implemented to control outbreaks of Phragmites.

Table 5-11 Case summary of land management practices

Land management practice	Environmental value observed	Impact measurement	Improvements observed	Challenges observed	Source
Alternative grazing schemes/ stock reduction	General riparian vegetation	Not specified	- Herding livestock daily limits livestock visiting stream bottoms and improve utilisation of upland areas - Rest-rotation grazing most successful for riparian zone vegetation	- Rest rotation schemes may increase trailing and trampling damage caused by streambank erosion - Objectives for herbaceous vegetation not met	Kaufman & Krueger (1984)
	General riparian vegetation	Vegetation and environmental surveys (exact methodology not specified)	- Maintenance of a minimum height of herbaceous vegetation encourages adequate vegetation cover for bank protection and sediment trapping - Selective grazing said to improve water and mineral cycles in uplands	- Constant commitment to monitor both plant growth and level of animal grazing required	Tohill et al. (1990)
	Springs, vegetation	Vegetation survey – visual survey from landowner	- Undisturbed soil around wetland following livestock exclusion - Improvements to spring water quality (turbidity)	- Pumping and channel system to remove livestock from spring required a level of effort	Queensland Government (2005)
Riparian buffer (plant buffers at creek edges)	General riparian vegetation, water resources and habitat	Not specified	- Plants along creek lines said to improve water quality, and lesson bank disturbance and increase riparian soil infiltration	- Success can be compromised by altered hydrology, excessive shading, groundwater lags or poor stream habitat selection	McKergow et al. (2016)
Instream structures	Water resources	Not specified	- Instream structures (boulders, rock dams etc) with combined rest from livestock grazing could increase water table in areas of former wet meadows	- None specified	Kaufman & Krueger (1984)
Seepage wetland	Water resources	Not specified	- Seepage wetlands shown to decrease nitrate removal and therefore ammonium	- Threatened by livestock	McKergow et al. (2016)
Livestock exclusion - fencing	Springs, vegetation	Vegetation survey (exact methodology not specified)	- Fencing led to the rejuvenation of native vegetation from a spring area previously 'denuded of vegetation' - Fencing efforts offset by cleaner spring water	- Costly - Weed control should be considered and likely involved manual removal	Queensland Government (2005)
	Springs, vegetation	Vegetation survey (exact methodology not specified)	- Fringe spring areas often most prone degradation due to grazing	- Fencing large areas expensive and often difficult due to terrain	FOMS (2014)
	General riparian vegetation	Not specified	- Fencing has shown to be an adequate multiple use system of riparian vegetation	- Grazing of a fenced riparian zone annually following August had no measurable effect on production or composition of species in riparian window	Kaufman & Krueger (1984)
	General riparian vegetation, water resources	Not specified	- Study found exclusion zones to help in streambank stabilisation and microbial mitigation	- None specified	McKergow et al. (2016)
	Riparian areas, water resources	Vegetation – visual surveys with scoring system out of 100% (using field workbook for riparian health assessment for streams and small rivers (Fitch et al. 2001) – Included six vegetation factors and five soil and hydrology factors Water – flow monitoring and sampling/analysis	- Streambank fencing improved riparian health (65 to 81%) - Vegetation cover and root mass protection were not increase by fencing, however, preferred tree and shrub establishment increased and human/livestock caused ground disturbance decreased - Turbidity and Cl concentrations decreased following fencing	- None specified	Miller et al. (2010)
	Water resources	Storm flow sampling and GPS collar tracking of livestock to draw correlations between time spent near streams and benefits	- E.coli and maximum dissolved P concentrations were lower in fenced streams compared to unfenced streams.	- Extensive monitoring of livestock and environment	Matthews et al (2003)
	Stream habitat, water resources	Weekly water grab samples	- Fencing was effective at reducing bacteria levels, turbidity and suspended sediment in the stream	- None specified	Line (2003)
	Riparian areas (streams), water resources	Survey of landowners (11 questions)	- Increased water quality (decreased turbidity and bacteria) - Reduced erosion following fencing - Increased wildlife (fish, tadpoles, frogs etc)	- Costs associated with fencing, fencing maintenance, fence replacement	Zeckoski et al. (2007)
	Riparian areas (channels)	Rapid Habitat Assessment (RHA) used to determine score of vegetation (score ranging from poor 0 to 200)	- Livestock exclusions increased stream depth and riparian groundcover. Hydraulic depth significantly deeper in exclusion reaches	- Fencing along short stream stretches does not have desired instream benefits	Ranganath et al. (2009)

A.4.4 Conclusions

Land management of wetlands is a widely accepted practice and has been demonstrated to improve the environmental health of these systems. The review of domestic and international experience suggests that the implementation of land management practices at specific spring sites within Santos's tenement is worth further consideration. The following summary highlights the key relevant learnings from the literature;

- Grazing is a significant environmental threat identified in a range of settings, including spring wetlands and riparian habitats;
- Livestock exclusion (fencing) and alternative grazing schemes appear to be the most widely employed land management practices to improve environmental health;
- Typical benefits of land management practices include reduced sediment erosion of riparian and spring areas, significant vegetation regrowth and improved water quality (bacteria, turbidity, phosphorus and chloride);
- The most common challenges associated with fencing and alternative grazing schemes were cost and maintenance (fence repairs, relocation of livestock and weed control);
- Environmental/vegetation surveys were commonly used to gauge success of land management practices, however, differed in methodology;
- Environmental/vegetation surveys should ideally capture the specific details of the environmental value under question and allow for grading in order to compare against future surveys;
- Water sampling at regular/consistent intervals is considered best practice in allowing for observations of the relative success of the land management practices implemented.

A.4.5 Recommended Pilot Program

The current condition of Santos's springs is significantly impacted by the land use practices that dominate the area. The Lucky Last and Yebna 2 springs in particular, suffer from overgrazing, pugging and erosion issues that lead to wetland area reduction and dewatering. These stressors impact the defined ecological endpoints of the wetlands that Santos are obliged to monitor and protect, including;

- Wetland area - impacted by the process of pugging, erosion and grazing;
- Wetted area and wetland discharge - impacted by pugging and erosion; and
- The ratio of aquatic to terrestrial vegetation species - impacted by erosion.

Given the current condition of the spring wetlands and the negative impact that the current land use has on the defined ecological endpoints for the springs, a combination of fencing and stock management is recommended to reduce overgrazing and pugging and to improve the water quality of the springs. Sediment control should also be considered in the management program, which may develop a minimum height threshold for herbaceous vegetation, in order to encourage adequate vegetation cover to allow for sediment trapping.

The pilot program should consider some of the more disturbed spring vents within Santos's tenement (refer to Table 5-10), however other considerations such as third party negotiations and safe physical access to the wetland, will also need to be taken into account.

One option is the Lucky Last spring vent 340 (shown in Figure 5-10) for the following reason;

- Significantly impacted by stock;
- Already associated with a robust baseline dataset of wetland area / wetted extent and wetland ratios;
- It is a large and semi isolated wetland that could be readily fenced off; and
- Field surveys indicate safe physical access to the wetland.

A critical component of the pilot program will be the development of a suitable monitoring and evaluation proforma checklist that ensures that the effect of the land management practices are measurable and comparable from one monitoring survey to the next. The monitoring proforma will allow for a rigorous determination of the effectiveness of this passive mitigation approach to improving spring resilience.

The monitoring program should be developed with consideration of the guiding principles provided by the Victorian Index of Wetland Condition[1] (IWC) and the UWIR regulatory requirements for spring monitoring. The following provides an indication of some of the likely components of the monitoring program;

- **Measured wetland area and wetted area**; as per the UWIR defined methodology;
- **Disturbance area status**; consider the approach of the IWC (see Figure 5-11 below) with a more robust quantitative measurement approach relative to that previously recorded during the baseline surveys;
- **Ratio of aquatic to terrestrial vegetation at the wetland boundary**; as per the UWIR defined methodology;
- **Herbaceous vegetation height measurements**; as a proxy for measuring the resulting effects of erosion control; and
- **Water quality changes;** measured by comparison of analytes, such as turbidity, bacteria and salinity.

[1] A link to the IWC wetland procedure can be found here https://iwc.vic.gov.au/docs/IWC%20Assessment%20Procedure%20-%20February%202018.pdf

Figure 5-10 Lucky Last (vent 340)

<table>
<tr><th colspan="5">Soils</th></tr>
<tr><td rowspan="16">IWC Assessment Procedure Step 14 – wetland soil disturbance
1. Mark with an x in column [A] the presence of activities that cause soil disturbance.
2. Show location of soil disturbance on base map 1.
3. Estimate the percentage of wetland soils in each soil disturbance severity class and enter in [B] (guidance is provided in the table at the bottom of the page).
4. For each class, multiply the % of wetland soils affected by the severity factor [C] and enter in [D].
5. Sum the results in [D] and mark result in [E] – this is the soils sub-index score.</td><td colspan="3">Activity that causes soil disturbance</td><td>[A]</td></tr>
<tr><td colspan="3">Pugging by livestock</td><td></td></tr>
<tr><td colspan="3">Disturbance or pugging by feral animals (e.g. pigs, goats, deer, rabbits, horses—please state the animal/s in box to the right).</td><td></td></tr>
<tr><td colspan="3">Carp mumbling</td><td></td></tr>
<tr><td colspan="3">Trampling by humans</td><td></td></tr>
<tr><td colspan="3">Cultivation</td><td></td></tr>
<tr><td colspan="3">Driving of vehicles in the wetland</td><td></td></tr>
<tr><td colspan="3">Other (please state)</td><td></td></tr>
<tr><td colspan="3">No activities that cause soil disturbance</td><td></td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">Soil disturbance severity</td></tr>
<tr><td>Severity of disturbance</td><td>% of wetland soils (must add to 100%) [B]</td><td>Severity factor [C]</td><td>[D]</td></tr>
<tr><td>High</td><td></td><td>0</td><td></td></tr>
<tr><td>Medium</td><td></td><td>0.1</td><td></td></tr>
<tr><td>Low</td><td></td><td>0.15</td><td></td></tr>
<tr><td>No disturbance</td><td></td><td>0.2</td><td></td></tr>
<tr><td></td><td colspan="3">Soils sub-index score</td><td>[E]</td></tr>
</table>

Figure 5-11 Example of a soil disturbance monitoring proforma (from IWC, 2018)

A.5 Lucky Last – Retire Existing Groundwater Abstraction

Table 5-12 Assessment Description

Item	Description
Potential Mitigation Option	Retire existing groundwater abstraction
Assessment Objective	Estimate the mitigation effect of retiring the nearby S&D bore.
Assessment Approach	Theis Analytical Drawdown Assessment
Assessment Assumptions (associated with the Theis model)	• The aquifer is infinite, confined, homogenous and isotropic • The aquifer is horizontal and groundwater flow is horizontal • The well diameter is negligible, and the well is 100% efficient (no well loss) • The pumping and observation wells penetrate the full thickness of the aquifer • The pumping well discharges at a constant rate • Aquifer flow conditions to the pumped well are laminar, radial and horizontal
Assessment Assumptions (associated with the model inputs)	Assume full licence volume is abstracted each year at a constant rate for a range of time steps (1, 5, 10 and 50 years).

Table 5-13 Assessment Input Details

Data Input	Value	Unit	Source	Comment
Hydraulic Conductivity	0.3	m/day	UWIR (2019)	UWIR (2019, Table H2-2) determined a calibrated horizontal hydraulic conductivity range of 9.7E-05 to 3.1E-01. The K value used here is at the upper limit of the range.
Storage Coefficient	1.0E-5	None	UWIR (2019)	UWIR (2019) shows the S for Boxvale Sandstone (model layer 21 isopach) ranges from 8.5E-6 to 1.0E-5. The S value used here is at the upper limit of the range.
Aquifer Thickness	14	m	OGIA (2019)	OGIA (2019). Table 5-8 indicates the average stratigraphic thickness of this units is 14 m and the maximum is 40 m.
Pumping Rate	3.25	ML/yr	UWIR 2019 (Table 4-1)	Estimated stock and domestic use
Observation Distance	1,400	m	Santos	Distance between the licence location and the Lucky Last spring vents.
Time	1, 5, 10, 50	years	-	Arbitrary timeframe over which licence may be extracted
Drawdown	**Output objective**	-	-	

Table 5-14 Assessment Results

Output Description	Output Range (drawdown at time)
Drawdown at 1,400 m (distance between licence location and Lucky Last Spring)	0.9 m (1 year of pumping) 1.1 m (5 years of pumping) 1.3 m (10 years of pumping) 1.5 m (50 years of pumping)
Comment regarding output	The very low transmissivity and storage values used in the assessment are potentially factors that have developed significantly large drawdown responses from this analysis. Given that the hydraulic parameters for the Boxvale Formation (OGIA, 2019a) appear low (i.e. ranging from 9.7E-05 to 3.1E-01 m/day) a rapid mass balance analysis has been undertaken to provide some confidence around the result. The mass balance considered the Boxvale Sandstone potentiometric surface at this site (approximately 14 m above ground surface) and the estimated hydraulic conductivity of 3.1E-01 m/day and indicated that a flow from this bore would be on the order of 8 ML/year. This is the same order of magnitude as the estimated S&D use for this aquifer (i.e. approximately 3.25 ML/year as per the OGIA 2019a S&D bore estimate). Conversely, if the lower value of hydraulic conductivity were considered in the mass balance (i.e. 9.7E-05 m/day) there would be negligible flow from this bore (i.e. 0.003 ML/year) and therefore insufficient water for the landholder to access. This rapid analysis confirms that the higher reported k value is a more appropriate input parameter for this analysis than the lower k value and it therefore would generate more realistic drawdown estimates.

A.6 Lucky Last – New Santos Reinjection Scheme

Table 5-15 Assessment Description

Item	Description
Potential Mitigation Option	New Santos re-injection scheme
Assessment Objective	Estimate the location and volume of injection required to produce a 0.4 m increase in groundwater pressure (i.e. the maximum predicted drawdown expected to occur at Lucky Last in 26 years (UWIR, 2019)).
Assessment Approach	Theis Analytical Drawdown Assessment
Assessment Assumptions (associated with the Theis model)	• The aquifer is infinite, confined, homogenous and isotropic • The aquifer is horizontal and groundwater flow is horizontal • The well diameter is negligible, and the well is 100% efficient (no well loss) • The pumping and observation wells penetrate the full thickness of the aquifer • The pumping well discharges at a constant rate • Aquifer flow conditions to the pumped well are laminar, radial and horizontal
Assessment Assumptions (associated with the model inputs)	• It is assumed that the target impressed head at the targeted locations (see below) will be reached within one year of scheme switch on. The total injection rate will be for the first year to reach targets. This is the maximum expected injection rate, with injection rates expected to decline as the scheme moves to maintain heads once targets are reached.

Table 5-16 Assessment Input Details

Data Input	Value	Unit	Source	Comment
Hydraulic Conductivity	0.3	m/day	UWIR (2019)	UWIR (2019, Table H2-2) determined a calibrated horizontal hydraulic conductivity range of 9.7E-05 to 3.1E-01. The K value used here is at the upper limit of the range.
Storage Coefficient	1.0E-5	None	UWIR (2019)	UWIR (2019) shows the S for Boxvale Sandstone (model layer 21 isopach) ranges from 8.5E-6 to 1.0E-5. The S value used here is at the upper limit of the range.
Aquifer Thickness	14	m	OGIA (2019)	OGIA (2019). Table 5-8 indicates the average stratigraphic thickness of this units is 14 m and the maximum is 40 m.
Observation Distance (minimum)	1,000	m	Estimated	A conservative distance that considered the potential implications of intrusive works in the vicinity of EPBC listed spring sites.
Time	1	years	Arbitrary timeframe	
Drawdown	0.4	m	UWIR 2019	Maximum predicted drawdown to impact the Lucky Last springs, within 26 years
Total injection rate	**Output objective**	-	-	-

Table 5-17 Assessment Results

Output Description	Output Value
Pumping rate to achieve 0.4 m drawdown after 1 year	0.004 ML/day at a distance of 1 km from the Lucky Last Spring

A.7 Springrock Creek – New Scheme to Augment Wetland Flows

Table 5-18 Assessment Description

Item	Description
Potential Mitigation Option	New Scheme to Augment Wetland Flows
Assessment Objective	Identify a bore location in proximity to the Springrock Creek, where groundwater extraction at a rate estimated to be required to maintain pool volume, can occur without impacting any surrounding waterways with drawdown.
Assessment Approach	Theis Analytical Drawdown Assessment
Assessment Assumptions (associated with the Theis model)	• The aquifer is infinite, confined, homogenous and isotropic • The aquifer is horizontal and groundwater flow is horizontal • The well diameter is negligible, and the well is 100% efficient (no well loss) • The pumping and observation wells penetrate the full thickness of the aquifer • The pumping well discharges at a constant rate • Aquifer flow conditions to the pumped well are laminar, radial and horizontal
Assessment Assumptions (associated with the model inputs)	Transmissivity (T) is calculated as hydraulic conductivity (k) x thickness (b) Pumping will be continuous throughout the year at the minimum rate to reach volume targets Pumping at a higher rate for shorter periods (i.e. utilising storage or pumping only during daylight hours) will results in more impact due to the flat drawdown cone and the very low S.
Assessment Limitations	The assessment outcomes are reliant on aquifer parameterisation that reflect local conditions. The input parameters for this assessment are largely derived from the UWIR 2019 model (OGIA, 2019a). Another source of aquifer parameters for the region is Hayes et al. (2020). The difference between the hydraulic conductivity reported by Hayes et al. (2020) and OGIA (2019a) are significant and vary by almost two orders of magnitude. Site specific investigations will need to be undertaken in this area as part of the feasibility study, to confirm the aquifer properties and these assessment outcomes.

Table 5-19 Assessment Input Details

Data Input	Value	Unit	Source
Hydraulic Conductivity	1 to 3.25	m/day	(OGIA, 2019a)
Storage Coefficient	0.00001 to 0.00005	None	Hayes et al. (2019)
Aquifer Thickness	60	m	Hayes et al. (2019) and local understanding of aquifer thickness in this area from observation bores.
Annual pumping requirement	8.8	ML/yr	Spring pool volume (see Table 5-20 below)
Pumping rate	0.28	L/sec	Annual requirement assuming continuous pumping.
Observation Distance	1,400	m	Distance between the bore location and Duffers Creek.
Time	1, 5, 10, 50	years	Arbitrary timeframe over which licence may be extracted.
Drawdown	**Output objective**	-	-

Table 5-20 Spring Pool Volume Calculation

Spring Pool Volume Estimation Method
Spring discharge volume: • Observed discharge at the spring is approximately 0.25L/s year (this rate has not been measured). Assume the spring discharge will need to be mitigated via flow augmentation for 12 months of the year. • This equates to approximately 7.9 ML/year **Evaporation loss volume:** • An additional volume of water will be required, to account for evaporative losses. • The pan evaporation rate recorded at the Injune Post Office is 2,000 mm/year and the spring pool area is approximately 450m^2 • The estimated volume of water needed to account for evaporative loss is approximately 0.9 ML/year. **Total annual volume of water required for spring mitigation:** • Approximately 8.8 ML/year • This is an upper estimate volume and assumes all discharge ceases to flow

Table 5-21 Assessment Results

Output Description	Output Range (drawdown at time)	Comment
Drawdown at 1,400 m (distance between proposed bore location and Duffers Creek)	0.07 to 0.23 m (1 year of pumping) 0.08 to 0.28 m (5 years of pumping) 0.09 to 0.30 m (10 years of pumping) 0.10 to 0.35 m (50 years of pumping)	Highest drawdown associated with low k (1 m/day) Storativity variation has limited effect compared to variations in T At the lower k value the pumping well would need to be more than 1.4 km away from the nearest receptor (Duffers Creek) to maintain drawdown below 0.2 m. There is uncertainty around the hydraulic parameters at this location and therefore further work is required to confirm the hydraulic situation, specifically aquifer thickness and hydraulic conductivity.

Output Description	Output Range (drawdown at time)	Comment
Drawdown output schematic