Water resource management plan

Evaluation of prevention or mitigation options for Fairview Springs

AE-C

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6 September 2013

OPTIONS FOR FAIRVIEW SPRINGS

Evaluation of Prevention or Mitigation Options (EPMOR)

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REPORT

Golder Associates

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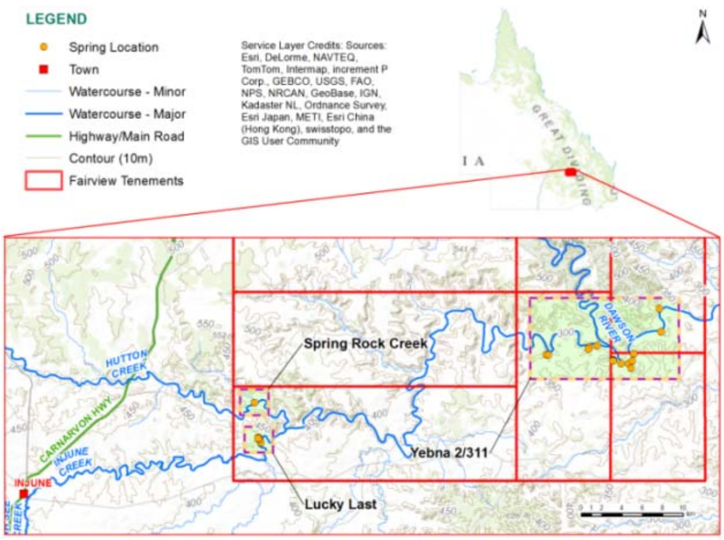
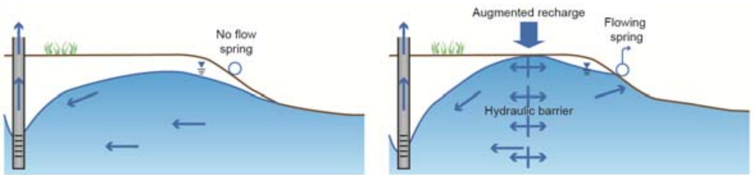
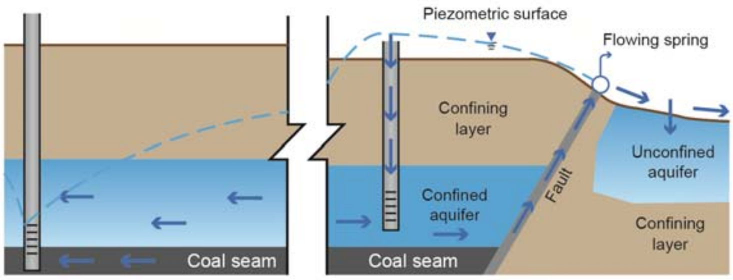
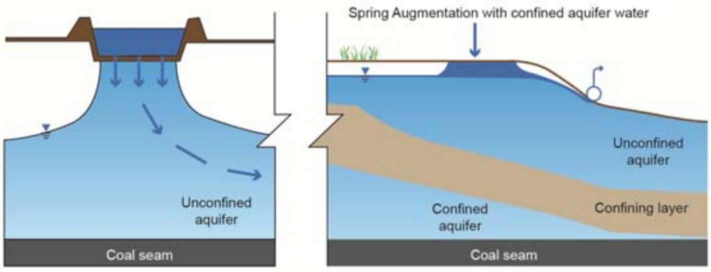
Executive Summary

This Evaluation of Prevention or Mitigation Options Report (EPMOR) has been prepared for the Santos GLNG Project (Santos) by Golder with the support of Santos for the Office of Groundwater Impact Assessment (OGIA) and the Department of Environment and Heritage Protection (DEHP). The report addresses a condition issued to Santos under the Water Act 2000 (Queensland) that options be identified to prevent or mitigate potential impacts to three spring complexes that may be caused by production of Coal Seam Gas from the Santos Fairview project area. The Water Act condition stems from the approval of the 2012 Underground Water Impact Report (UWIR) produced by the predecessor to OGIA, the Queensland Water Commission (QWC). The objective of the report is to identify the most suitable spring impact prevention or mitigation options at three spring complexes within the Santos Fairview CSG project area. The assessment and selection of spring impact prevention or mitigation options relies on:

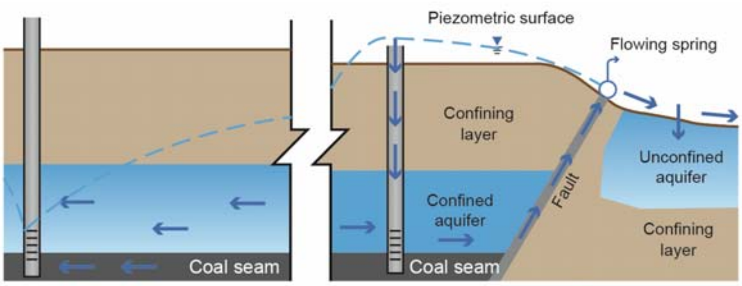
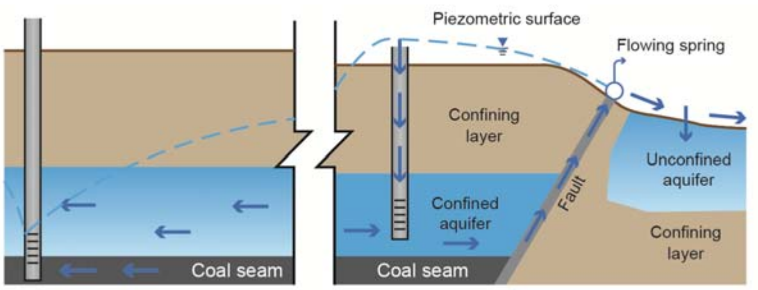
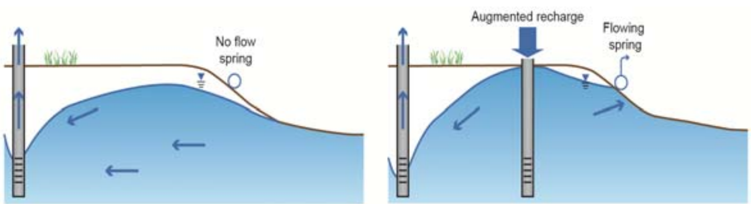


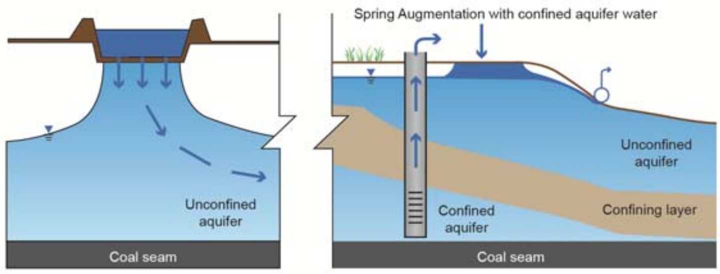
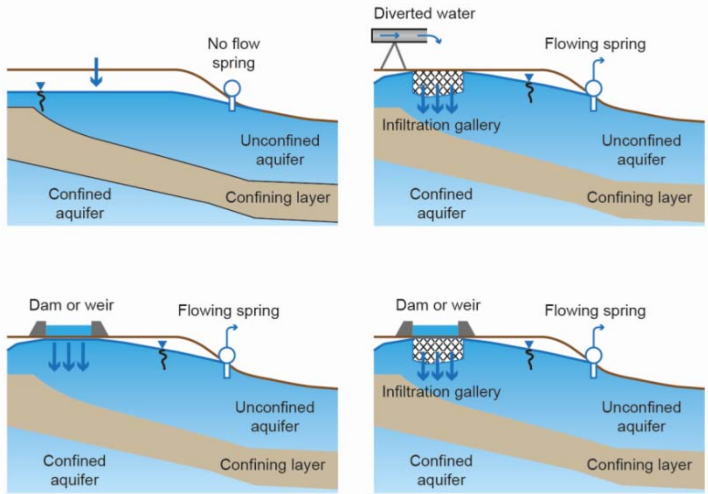
- The definition of the understanding of the hydrogeological settings for each spring complex.
- The level of impact expected at the spring complex based on the model prediction published in the Surat UWIR (QWC, 2012).
- The understanding of the vulnerability of the environmental values at the springs.
- An analysis of a wide range of options, based on a range of criteria that include effectiveness and site specific hydrogeological information.

The estimated potential for impacts at the spring complexes is based on calculations completed by QWC based on available information in 2011. Since then, understanding of key aspects related to the geology and hydrogeology of the Fairview area has evolved. With this new knowledge, the estimated potential of impact occurring is considered to be significantly lower than previously assessed. Nevertheless, this EPMOR report is developed on the basis of the model outcomes published in the Surat UWIR. The identified preferred options for preventing or mitigating potential spring impacts are set out in the tables below. The options are classified as to whether they are prevention: stopping changes in groundwater levels well before they reach the spring areas; or as mitigation: preventing adverse impacts at the springs. The scale, in terms of distance from the spring is also indicated. Typically, preventative options need to be implemented at greater distances from the springs. The hierarchy in the options below reflects Santos commitment to minimise adverse environmental impacts as defined in Santos standard EHS10. This results, where technically possible, to favour avoidance as a spring impact management solution over spring impact mitigation solutions.

<table>
<tr><th colspan="4">285 (Spring Rock Creek)</th></tr>
<tr><th>Classification</th><th>Option</th><th>Description</th><th>Scale</th></tr>
<tr><td>Mitigate</td><td>1</td><td>Recharge the aquifer by infiltration at or close to the spring.
Water source: treated associated water from CSG operations.

</td><td>Spring</td></tr>
<tr><td>Avoidance</td><td>2</td><td>Hydraulic barrier. Active control and prevention of groundwater level changes reaching the springs by recharging either the Bandanna Coals or the Precipice Sandstone.
Water source: treated CSG water.

</td><td><10 km</td></tr>
<tr><td>Avoidance</td><td>3</td><td>Increase recharge to Precipice Sandstone. This is a variation of above option where water is infiltrated from surface to recharge the Precipice, rather than by direct injection.
Water source: treated associated water from CSG operations.

</td><td>~10 km</td></tr>
</table>

230 (Lucky Last)

Classification	Option	Description	Scale
Avoidance	1	Hydraulic barrier. Active control and prevention of groundwater impact propagation reaching the springs by recharging the Bandanna coals through injection wells. Water source: CSG water.  	<10 km
Avoidance	2	Hydraulic barrier. Active control and prevention of groundwater level changes reaching the springs by recharging the Precipice Sandstone through injection wells. Water source: treated associated water from CSG operations.  	<10 km
Mitigate	3	Recharge the aquifer by injection at or close to the spring. Water source: treated associated water from CSG operations.  	~10 km

<table>
<tr><th colspan="4">591/311 (Yebna 2/311)</th></tr>
<tr><th>Classification</th><th>Option</th><th>Description</th><th>Scale</th></tr>
<tr><td>Mitigate</td><td>1</td><td>Support of ground water levels at springs by infiltration or injection of water taken from the Precipice further from the springs.
Water source: Precipice aquifer.

</td><td>Spring</td></tr>
<tr><td>Avoidance</td><td>2</td><td>Increase recharge to Precipice Sandstone. Infiltration of water from surface structures or infiltration galleries to recharge the Precipice.
Water source: treated associated water from CSG operations.

</td><td>~10 km</td></tr>
</table>

The prevention or mitigation options identified in this report are intended to be implemented only if the risk to a spring is imminent, or high as defined by Green (2013). A program of monitoring the aquifer systems has commenced to ensure that potential impacts to groundwater pressure supporting springs and impact propagation can be detected in advance of reaching the spring areas.

The monitoring of the risk of potential impact to the spring; enables a staged response approach to the potential implementation of spring mitigation. If confirmed, a spring impact risk assessment will be required. This would assess the vulnerability of the ecological values at the springs and confirm if the drawdown has the potential to result in an adverse impact on the environmental values.

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APPENDICES

1.0 INTRODUCTION

Santos Gladstone Liquefied Natural Gas (GLNG) is a project that will convert coal seam gas (CSG) to liquefied natural gas (LNG) for export to global markets. The GLNG Project involves extraction of CSG followed by conversion of CSG to liquefied natural gas (LNG) for export. It comprises the following components:

- The current and ongoing development of projects in CSG fields in the regions of Fairview, Roma, Arcadia Valley and Scotia.
- The construction and operation of a 420 km underground pipeline that will transport CSG from the CSG fields to Curtis Island, near Gladstone.
- The construction and operation of a CSG to LNG facility on Curtis Island.

The GLNG Project is a joint venture partnership between the following companies: Santos Limited; PETRONAS, the national oil and gas company of Malaysia and the world's second largest LNG producer; Total, the world's fifth largest publicly-traded international oil and gas company; and KOGAS, the world's largest buyer of LNG. Santos is developing and operating the CSG fields on behalf of the joint venture.

In May 2010, the Queensland Coordinator-General approved the GLNG project under the State Development and Public Works Organisation Act 1971. In October 2010, the Minister for Sustainability, Environment, Water, Population and Communities (SEWPaC) granted approval under the Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth) (EPBC).

This Evaluation of Prevention or Mitigation Options Report (EPMOR) has been prepared by Santos GLNG for the (Queensland) Office of Groundwater Impact Assessment (OGIA) and the Department of Environment and Heritage Protection (DEHP). The report addresses a condition issued to Santos under Section 384 of the Water Act 2000 (Queensland) that options be identified to prevent or mitigate potential impacts to 3 spring complexes that may be caused by CSG production from the Santos Fairview project area.

The Water Act condition stems from work completed by the predecessor to OGIA, the Queensland Water Commission (QWC) for the Surat Cumulative Management Area (Surat CMA). The Surat CMA includes the Surat and Southern Bowen Basin areas, as declared under the Queensland Water Act 2000, to provide management and oversight of overlapping underground water impacts from multiple petroleum tenures with CSG operations. In 2012 the Queensland Water Commission produced an Underground Water Impact Report (UWIR) for the Surat CMA and a condition of its approval by DEHP was the development of this EPMOR report (DEHP, 2012; QWC, 2012).

1.1 Project Aim

This Evaluation of Mitigation Options Report (EPMOR) is required to:

- Discuss the advantages and disadvantages of each of the options listed in Section 8.5.1 of the UWIR and any additional options the responsible tenure holder identifies, and their relative viability for protecting the specified spring complex.
- Identify the option or combination of options that are the preferred approach for mitigating impacts at the site, including the rationale for the proposed option.
- Identify a program to assess local hydrogeology at the site to provide increased certainty with regard to the spring's source aquifer and improve the understanding of the relationship between reductions in water pressure in the source aquifer and the flow of water to the spring.

The report is to be provided to the Queensland Water Commission (QWC) in September 2013, within nine months of the UWIR for the Surat CMA being approved by DEHP in December 2012. OGIA will evaluate these reports in consideration of the other initiatives by the tenure holders in relation to spring impact mitigation such as implementation of the Queensland Government's CSG Water Management Policy. From this OGIA will advance amendments to the UWIR to require implementation action as appropriate. Due to the recent changing in name from QWC to OGIA, both names are used within the report to indicate provenance of documentation referenced.

QWC identified 71 spring complexes in the Surat CMA. A risk assessment was undertaken by QWC for each of these spring complexes on the basis of the likelihood of there being reductions in the flow of water and the consequences on spring values if a reduction in flow to the spring complex was to occur. Mitigation strategies may be required to be developed at those spring complexes where an impact on groundwater levels of greater than 0.2 m is predicted in the source aquifer of the spring complex. It is acknowledged that a reduction of more than 0.2 m in the source aquifer of the spring complex may not result in an adverse impact on the springs. However, this must be proven through hydrogeological investigations if mitigation actions are not pursued.

Of the 71 spring complexes identified by QWC in the Surat CMA, it is predicted by modelling completed by QWC that the potential long term impact on groundwater levels in the source aquifer will exceed 0.2 m at five springs or spring complexes. Three of the five spring complexes have been allocated as the responsibility of Santos GLNG as they lie within the Fairview CSG field. The remaining two spring complexes are the responsibility of Asia Pacific Liquefied Natural Gas (APLNG).

A summary of the three spring complexes on Santos tenements for which mitigation measures may be required are presented in Table 1 and depicted in Figure 1.

Table 1: Summary information of spring complexes selected for mitigation.

Spring Complex	Spring Complex Number	Primary Source Aquifer as Defined by the UWIR	Number of Spring Vents in Complex
Yebna 2/311*	591/311	Evergreen Formation / Precipice Sandstone	17
Lucky Last	230	Evergreen Formation / Precipice Sandstone	12
Spring Rock Creek	561	Evergreen Formation / Precipice Sandstone	1

* Spring complex 311 (16 vents) and Spring complex Yebna 2 (1 vent only – vent number 534) are located in the same area and are often referred jointly as Yebna 2/311.

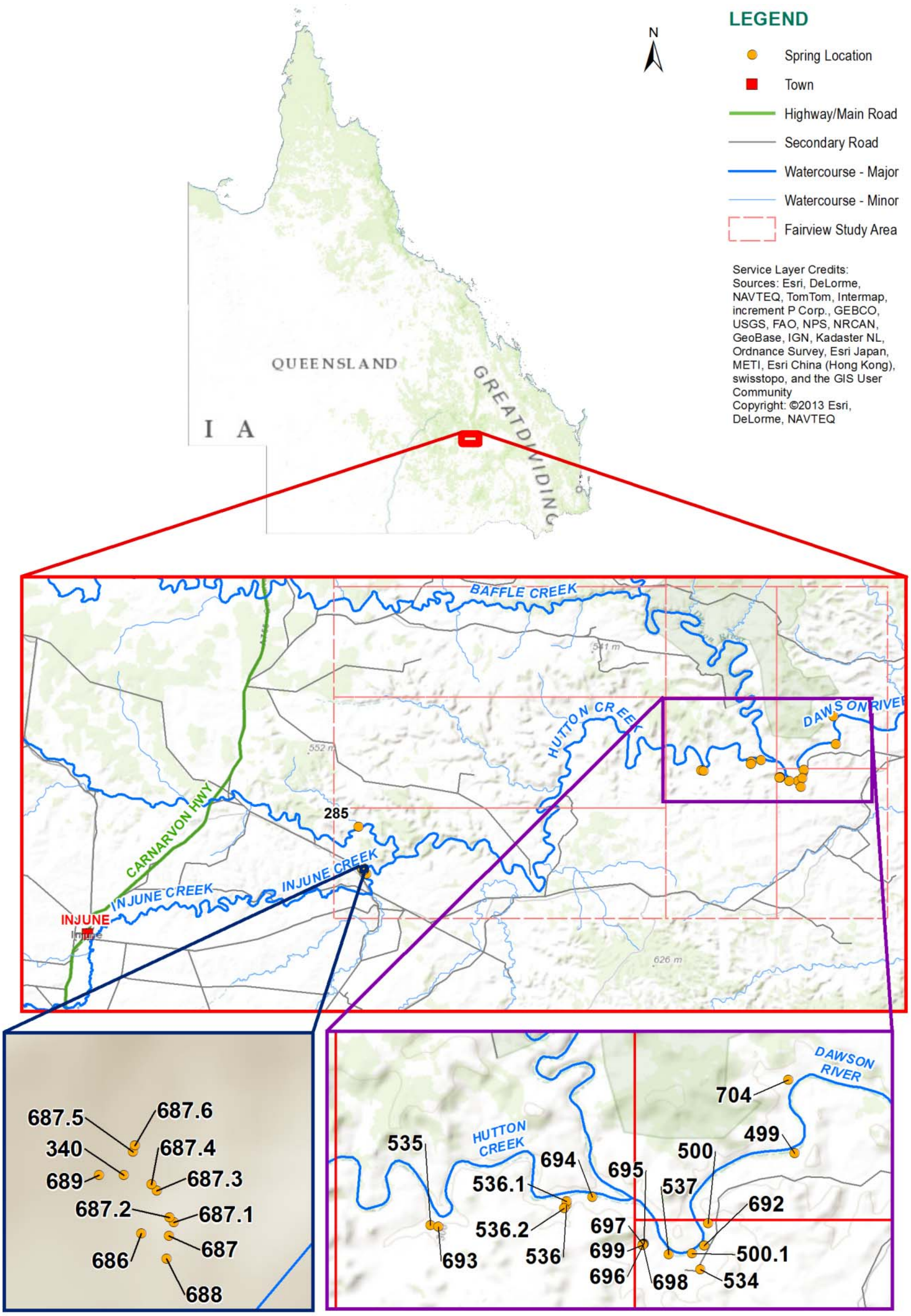


Figure 1: Spring location with major surface water features indicated.

1.2 Intended Audience

The current report has been prepared to assist Santos in developing possible spring impact prevention and mitigation options. The intended audience for this document is the Department of Environment and Heritage Protection (DEHP) and the Office of Groundwater Impact Assessment (OGIA). The purpose of the document is to present the candidate methods of mitigation should it be required, and timelines for implementation of mitigation programs.

1.3 Structure of Document

The document is divided into three major parts, which are further subdivided into relevant sections. The outline of the document is provided in Figure 2. Part I describes the regional physical and hydrogeological setting of the Great Artesian Basin (GAB) and the spring complexes to provide the context within which the Evaluation of Prevention or Mitigation Options (EPMOR) is developed. A literature review and initial screening of potential management options is also presented in Part II. The spring complexes are described in detail with their associated conceptual models and spring vulnerability assessments. Part III details the analysis options to develop three mitigation options for each spring complex with the associated possible management options.

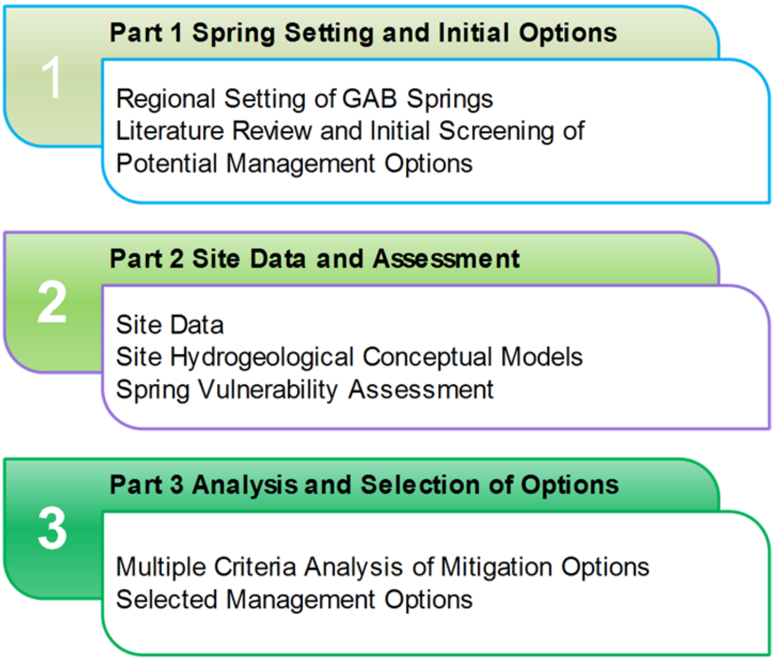


Figure 2: Document structure.

PART I
REGIONAL SETTING AND CONCEPT MITIGATION OPTIONS

2.0 REGIONAL SETTING FOR SPRING COMPLEXES

This section describes the regional occurrence of spring vents in the aquifer outcrop areas on the eastern margin of the Great Artesian Basin. The springs included in this chapter refer to both GAB and local spring systems which do not originate from GAB aquifers. Firstly the physiographical characteristics of the GAB and springs in its eastern margin is described, as this assists in developing a conceptual model of individual spring vent sites. Secondly, the classification of springs is presented, as outlined in the Allocating Water and Maintaining Springs in the Great Artesian Basin (Green et al., 2013; Love et al., 2013).

The description of the Great Artesian Basin, the Surat and Bowen Basins and the local setting of the spring complexes relies on a number of historical reports which are summarised in Table 2.

Table 2: List of reports relevant to the current study.

Topic	Reference
Springs in the Great Artesian Basin: Their origin and nature	(Habermehl, 1982)
Hydrogeology of the Surat Basin, Queensland	(Quarantotto, 1989)
Artesian Springs of the Great Artesian Basin in Queensland	(Wilson, 1995)
Hydrogeology and Environmental geology of the Great Artesian Basin, Australia	(Habermehl, 2001)
Spring wetlands of the Great Artesian Basin, Queensland, Australia	(Fensham and Fairfax, 2003)
Great Artesian Basin Water Resources Plan - Ecological Assessment of GAB springs in Queensland	(Fensham and Fairfax, 2005)
Identification of Source Aquifers to Significant Springs Dependent on Groundwater Flow from the Great Artesian Basin	(EHA, 2009)
Ecological and Botanical survey of springs in the Surat Cumulative Management Area	(Fensham et al., 2011)
Hydrogeological attributes associated with springs in the Surat Cumulative Management Area	(KCB, 2011)
Desktop Assessment of the Source Aquifer for Springs in the Surat Cumulative Management Area	(KCB, 2012)
Spring mitigation: remote sensing	(Halcrow, 2013b)
Spring mitigation option assessments and selection–EPMOR Ecology assessment	(URS, 2013)

2.1 Physiographical Classification

The Great Artesian Basin (GAB) is the largest groundwater basin in Australia (and one of the largest in the world), underlying 22% of the Australian continent, including considerable areas of Queensland, New South Wales, the Northern Territory and South Australia. These groundwater resources are of great national and societal significance (Love et al., 2013). Groundwater sourced from the GAB supports the iconic GAB discharge springs. The isolated nature of these springs has resulted in the preservation of many endemic, rare and relict species of great ecological, evolutionary and bio-geographical significance (Love et al., 2013).

With the exception of the far north and far eastern parts, the GAB largely occurs in the arid and semi-arid interior of central and eastern Australia. Due to the ephemeral nature of surface watercourses in these regions, groundwater from the GAB is often the only reliable water source. Consequently, exploitation of the GAB groundwater resource has played, and continues to play, a vital role in supporting agriculture, mining, industry, civil and cultural communities in Australia (Ah Chee, 2002; Cox and Barron, 1998; Leek, 2002).

The following report sections describe four main physical characteristics that are used in the classification of the physiographical setting of the spring vents: geology; faulting; surface water; and groundwater.

2.1.1 Geology

Geologically, the GAB is a non-marine to marine Triassic-Jurassic-Cretaceous hydrogeological super-basin that covers much of eastern and central Australia. The GAB contains four large epi-continental depressions, the Carpentaria, Bowen, Surat and Eromanga Basins. The Eromanga Basin is volumetrically the largest. The eastern margin of the GAB abuts the Great Dividing Range and it is from here that the majority of present day groundwater recharge occurs, flowing in a largely westerly and south-westerly direction toward South Australia (Love et al., 2013).

This assessment considers springs in the Surat Basin which covers part of south-east Queensland and north-east New South Wales. The specific focus of this study is the northern extent of the Surat Basin where the geological strata thin against underlying Bowen Basin sediments.

Geological classification is firstly based on rock classification: igneous; sedimentary; or metamorphic, which is followed by the depositional age of the rock and is further divided into sub-classes. The generalised geological model for the GAB in Queensland is presented in Figure 3 (DEHP, 2013), in which a succession of sedimentary formations of different periods can be observed.

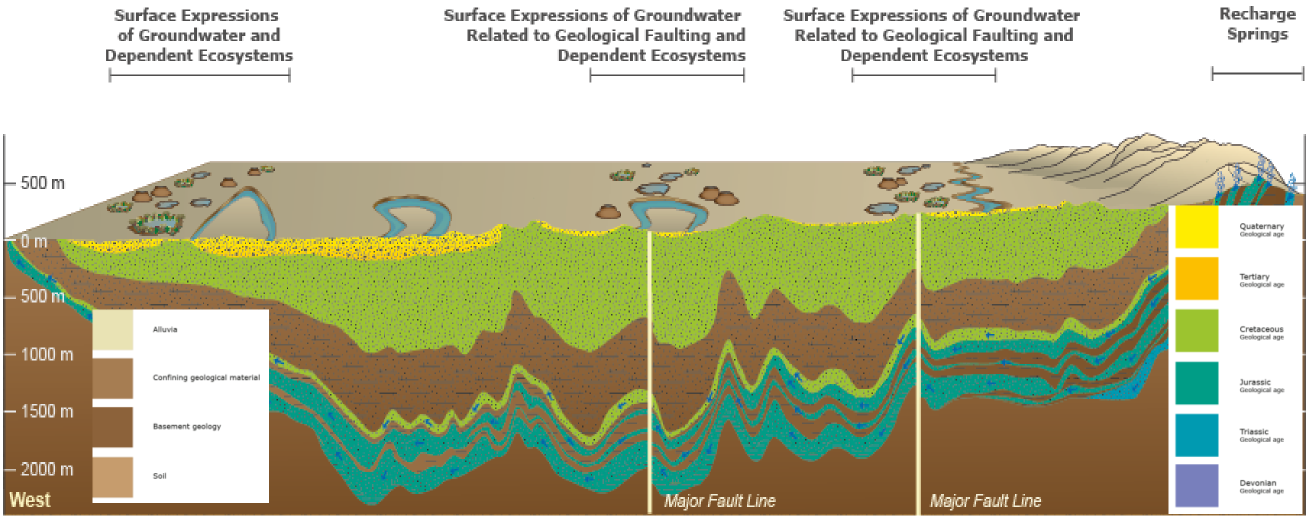


Figure 3: Generalised geology of the Great Artesian Basin in Queensland (DEHP, 2013).

The Surat Basin is connected to the Clarence-Moreton Basin to the east over the regional structural feature of the Kumbarilla Ridge. The basins comprise a Jurassic to Cretaceous aged sequence of alternating strata of water-bearing sandstones and non-water-bearing siltstones and mudstones which generally dip in a south-westerly direction. Groundwater recharge occurs mostly to the north and north-east as the permeable sandstones outcrop in these areas (Figure 3). The recharge mechanism is dominated by rainfall infiltration mechanism in the outcrop areas; however indirect recharge occurs via leakage from streams or overlying aquifers.

The main aquifers within the Surat and Clarence-Moreton basins are the Jurassic Precipice and Hutton Sandstones and the Jurassic-Cretaceous Bungil Formation, the Mooga and Gubberamunda Sandstones and their equivalents. These aquifers are generally laterally continuous and have significant water storage, permeability and porosity. The regional groundwater flow direction of the northern Surat Basin is dominantly from the outcrop areas in the north and north-east to the south and south-west.

CSG production in the northern Surat Basin is from the Walloon Coal Measures. The Walloon Coal Measures lie between the underlying Precipice and Hutton aquifers and the overlying Bungil, Mooga and Gubberamunda aquifers. Walloon CSG production lies to the south of the northern Surat Basin springs.

CSG production in the Bowen Basin is from the coal bearing Bandanna Formation. The Triassic Bowen Basin strata underlie the Surat Basin within the Taroom Trough (KCB, 2012). These two Basins are structurally separate sedimentary basins but in certain sections are stratigraphically and hydraulically interconnected (DME, 1997). The main aquifers within the Bowen Basin are the Clematis Group, Showgrounds and Aldebaran Sandstones. Minor aquifers occur in the Moolayember Formation and some of the more sandy sequences within the Permian sedimentary units with generally poor water quality.

The coal bearing Bandanna Formation is generally isolated from the overlying major groundwater-producing aquifers by thick, very low permeability mudstones. However, there are some areas where these mudstones are eroded and there is a high potential for connectivity between the coal measures of the Bowen Basin and important aquifers in both the Bowen and Surat Basins (KCB, 2012).

This study assesses methods to mitigate potential impacts on spring complexes located within the Fairview CSG field that may be caused in overlying aquifers by CSG production from the Bandanna Formation. This method of potential impact was identified by QWC.

2.1.2 Faulting

Mound springs tend to align along faults; for example, the set of aligned springs between Marree and Dalhousie Springs in South Australia is referred to in this and subsequent volumes as the 'Mound Spring Line' (Love et al., 2013). Most of these high value mound springs are located in South Australia or the Northern Territories (Gotch, 2013).

The link between active seismicity and carbonate-depositing springs is a concept that has been studied and discussed previously in the international literature. The reason for this linkage is, not only can faulting tap artesian groundwater and bring this water to the surface in the form of spring discharge (Love et al., 2013), but active deformation by faulting is thought important in relation to maintaining these openings by 're-breaking' faults and fractures (Curewitz and Karson, 1997; Hancock et al., 1999; Muir-Wood, 1993).

In particular, the occurrence of calcareous spring deposits in conjunction with active springs has been interpreted in the past as evidence for tectonic activity, as the precipitation of calcium carbonate is considered to be adept at reducing the permeability within the associated spring conduit (Hancock et al., 1999). Natural discharge from the GAB aquifer to surface has previously been interpreted to be aided by the occurrence of faulting, as this provides a means for pressurised groundwater within the GAB aquifers to migrate through the confining layers and escape to the surface (Aldam and Kuang, 1989; Krieg et al., 1985).

The link between neotectonics and spring discharge is important because it helps explain the distribution of discharging springs and provides a means by which hydraulic connectivity between the aquifer and the surface is established (Love et al., 2013). The data suggests that an important control on conductivity within the GAB is the permeability and porosity inherent in the fault and fracture networks that are, in the vicinity of springs systems, responsible for spring formation. Tectonic linkage may also be used to help explain rates of diffuse discharge associated with fracture sets that crosscut the upper confining beds of the GAB.

2.1.3 Surface Water

Surface water plays an important role in defining the characteristics of springs acting as a recharge source or a receiving environment. In either instance the geochemical processes associated with the mixing of the surface water and groundwater has an effect on the local environment. As noted by Love et al. (2013) surface water can support a diverse set of habitats. Reductions in recharge to the GAB during recent geological time have been reported (Love et al., 2013; Smith, 1989), with estimated discharges from springs decreasing as compared to the paleo-environment. Springs can also substantially influence the surface water features and environment in creeks and rivers by directly discharging into the main flow path, thus sustaining the flow of the surface water body during drier periods.

2.1.4 Groundwater

The GAB hydrogeological basin consisting of the interconnected geological basins straddling Queensland, Northern Territory, South Australia and New South Wales is a confined groundwater system fed by rainwater entering the basin predominantly along its eastern margin. Along the eastern margin the aquifer sediments outcrop as sandstones or are buried beneath freely draining material. At a regional scale groundwater pressure gradients are generally from these recharge areas towards the western and southern margins. Knowledge on groundwater recharge rates and transmission times are limited in many areas, however some waters in the GAB are known to be in excess of a million years old (Habermehl, 2001). Locally recharge and discharge patterns can vary from this regional scale picture.

Groundwater discharge in the GAB occurs by both natural and anthropogenic means (Love et al., 2013). Natural discharge mechanisms can be divided into two categories: point leakage via numerous springs; and diffuse upward leakage from the main aquifers through the overlying aquitards. Anthropic discharge occurs from either flowing artesian bores or from pumping from groundwater bores. The casing of many artesian bores has been subjected to significant corrosion and has resulted in leakage within the well casing as well as uncontrolled free flowing artesian waters at the surface. Over the last few decades there has been significant government intervention to remediate many of these artesian outlets either by installing new headworks and piping to control flow for stock use or by abandoning the well after cement grouting. It is estimated that 50% of discharge is from bores, 45% from vertical upward leakage and only 5% from springs throughout the GAB (Woods et al., 1990).

2.1.5 Spring Classification

The source of water to a spring influences the temporal variation of a spring and how the spring is affected by water use activities. Spring source water can be:

- Groundwater dominant.
- Surface water dominant.
- Dependent on groundwater and surface water.

Groundwater dominant springs are classified as either artesian or non-artesian (Figure 4). Artesian springs result from the upward movement of water to the surface from a confined aquifer. Non-artesian springs are a result of water tables intersecting ground surface. In Part II the setting of the Fairview springs is set out and the springs classified. The majority of springs at Fairview are non-artesian.

Information regarding spring classification has been obtained from The Allocating Water and Maintaining Springs in the Great Artesian Basin (AWMSGAB) project (Green et al., 2013) and UWIR (2013). This project has surveyed and mapped springs in the Great Artesian Basin (GAB) and classified them according to their spatial arrangement or common attributes (Love et al., 2013). This allows risk assessments to be conducted at a group scale. Figures 5 and 6 illustrate schematically some of the mechanism for spring formations in shallow and deeper systems.

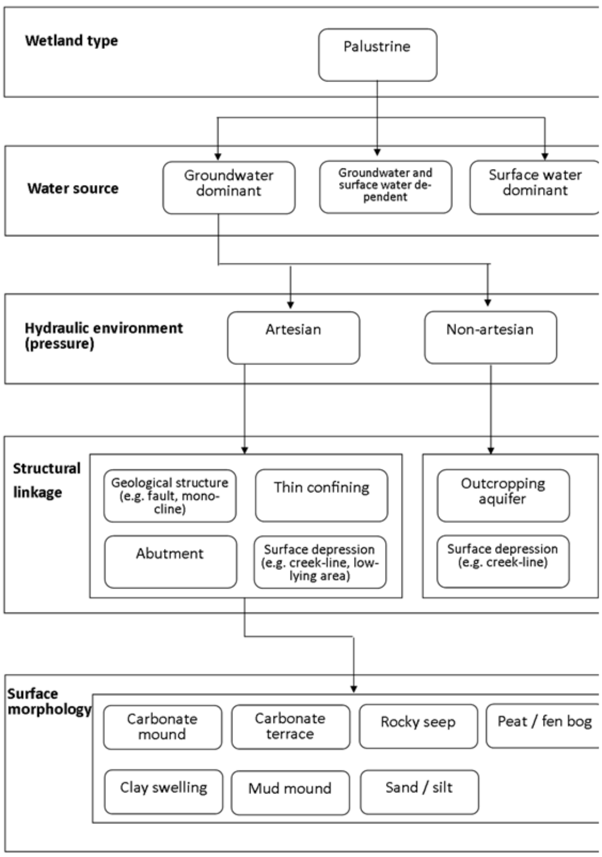


Figure 4: Flow Chart Outlining Spring Classification Procedure (Green et al., 2013).

Springs vents with similar water chemistry and related common geological features are classified into spring groups (Figure 4). Spring groups that share similar geomorphological settings are referred to as "spring complexes" and clusters of spring complexes are referred to as "supergroups" (Green et al., 2013; Habermehl, 1982).

Figures 5 and 6 illustrate the four main structural links (artesian springs) through which groundwater reaches the surface from a confined aquifer. The structural links are described as:

- Geological Structure – Water flows upwards from the aquifer through a fault line. These faults are common geological structures in the GAB.

- Abutment – Aquifers abut against an impermeable outcrop and water is forced along the edge of the outcrop onto the surface.

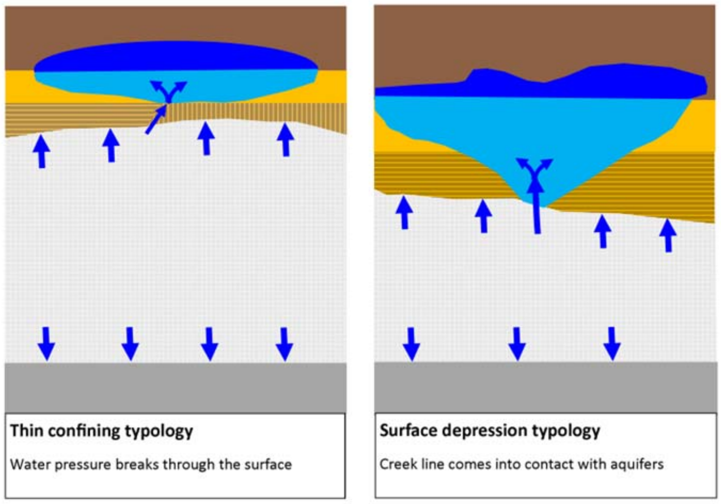


Figure 5: Conceptualisation of structural linkage features that form shallow spring systems.

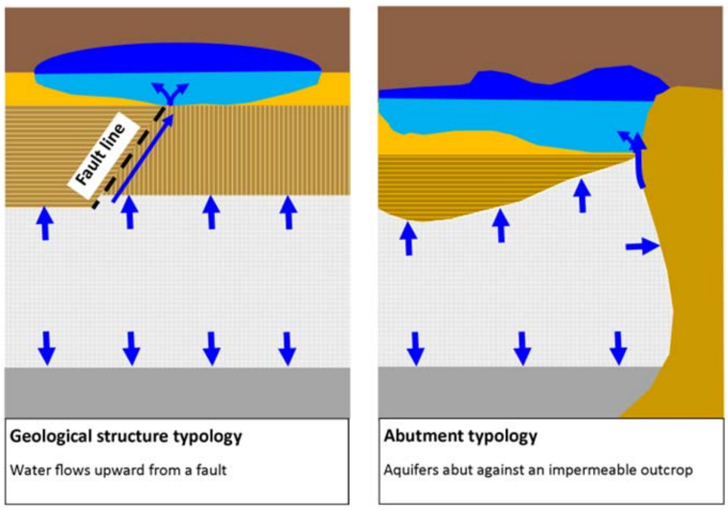


Figure 6: Conceptualisation of structural linkage features that form deeper spring systems.

- Thin confining – Water pressure breaks through a relatively thin confining layer to the surface. Most common at the margins of the GAB.

- Surface depression – The creek line comes into contact with the aquifer as a result of low lying topography. Can also be described as a water table aquifer and groundwater seeps.

In terms of surface morphology there are seven types used to describe GAB springs (Figure 4):

Carbonate Mound: A rocky travertine (mound) positioned above the surrounding terrain that will usually form a raised vent area that may or may not be accompanied by a travertine tail feature.

- Carbonate terrace: Lateral flow of groundwater deposits creating travertine terraces that can be raised above the surrounding landscapes but does not form the distinctive mound.

- Rocky seep: groundwater seeps from rocky cracks and fissures; significant deposits of travertine are not associated with this morphological type.

- Peat/fen/bog: Spring substrate is largely organic in origin and can form large mounds. Fens are alkaline while peats are acidic.

- Clay swelling: Groundwater emerging just below the surface creates a swelling mound of mud/clay with little or no water discharge. The mound is quite plastic and will deform under pressure often releasing more water.

- Mud mound: Mounds formed as groundwater emerges below the surface into unconsolidated soil. The mound is forced upwards under pressure of the discharging groundwater.

- Sand/silt: Mounds that form when wind-blown sand is deposited around wet vegetation and then is expanded as more vegetation grows on the substrate. The resulting wetland vegetation may deposit large amounts of organic matter and form a peat bog at the vent.

Non-artesian springs can either be water table springs or contact springs (UWIR, 2012). These springs have the following surface morphology:

- A spring can form where there is a change in the geology within the landscape. This type of spring is often referred to as a contact spring. Where a higher permeability formation abuts a lower permeability formation, there is a restriction to flow at the boundary. As a result, water tends to flow laterally and may find expression at the surface as a spring.
- Permeability can vary within an individual aquifer. Water restricted by a lower permeability layer can flow laterally through a higher permeability layer as a perched watertable, and may find expression at the surface as a spring. This type of spring typically occurs within outcropping aquifers and forms in a similar way to a contact spring.
- Where an aquifer outcrops high in the landscape, such as in Carnarvon Gorge, Expedition Ranges and the Great Dividing Range, a spring can form where there is a change in the slope of the ground surface.
- Where an outcropping aquifer has been eroded to create a depression in the surface of sufficient depth to reach the water table, a spring can form. This type of spring is generally associated with creeks and streams, and is referred to as a watercourse spring (also sometimes referred to as baseflow springs).

2.2 Selection of Mitigation Options and Monitoring Program Design

The potential for impact to springs from production from the Fairview CSG field has been identified by OGIA. A range of options exist that might be used to mitigate potential impacts. As illustrated in Figure 4, Figure 5 and Figure 6 a number of possible spring morphologies exists that can be supported from different structural and hydraulic environments. It should be kept in mind that mitigation need only be required if spring risk is imminent or high as defined by Green (2013). Mitigation options should be selected that are appropriate for, and address:

- The type of spring present at the site and in general it should conform to the basic structural and hydrological controlling factors present.
- The source of the reduction of flow at the spring so that the expected flow volumes are maintained.
- The expected impact period. Additional augmentation might alter the spring behaviour. Springs will be season and the ecology of the spring will be adapted to these seasonal fluctuations in water level and quality.

To assist in selecting the most appropriate mitigation options for a spring complex the following preparatory steps are required:

- Collect and collate site data relating to geology, surface water and groundwater.
- Bring together and assemble ecological and environmental values.
- Define spring description and type as outlined in Figure 4.
- Develop site conceptual model.
- Perform spring risk assessment.

Once candidate mitigation option(s) have been identified, and the steps to integrate the solution into management plan have been completed, the hydrogeological system will need to be carefully monitored. Initially, the monitoring is intended to determine if the springs are impacted by to anthropogenic activities. If impacts are detected moving toward the springs, then the monitoring information would be used to determine the expected timing of impact to provide the timeline for mitigation implementation. At this stage, candidate mitigation options can be developed, tested against the conceptual site model and further developed. Once mitigation measures are operational monitoring will assist in ensuring mitigation effectiveness and determining the duration for which mitigation is required.

As a minimum, monitoring will be required for both surface water features and groundwater bore data. Additionally the influence of climate change on the area should also be considered during the assessment of mitigation options.

Thus monitoring should assist in the following:

- Providing additional information regarding the hydrogeological settings of springs and assisting in refining local conceptual models.
- Evaluating seasonal and longer term trends at springs, and predicting the onset and magnitude of aquifer depressurisation / drawdown caused by CSG production.
- Defining the probable extents of drawdown.
- Informing on seasonal and long term changes in water quality at the springs, and with other information whether this is influenced by CSG production.

2.3 Summary

This chapter provided the background setting of the GAB which is characterised by the outcropping of aquifers along its eastern margin. The broad regional and physical settings of the springs of the northern Surat Basin are described along with the methodology of spring classification. Finally, the broad objectives and physical variables of monitoring for spring impact were outlined.

In the following chapter, potential management solutions will be presented which will become the basis of the EPMOR. These options follow the Santos hierarchical method to manage risks to the environment from water activities (Santos 2013). The Santos method has a preferred order in which options should be applied, these are:

1) Avoid impact to environmentally sensitive areas, including MNES.
2) Minimise influence of CSG activities.
3) Manage impacts on predefined trigger based adaptive management procedures.
4) Response timelines are designed so that contingency plans to protect the environment can be implemented on time, before the un-mitigated impact would occur.

3.0 LITERATURE REVIEW OF POTENTIAL MITIGATION SOLUTIONS

This section presents a review of methods that could be applied to mitigate spring impacts from CSG-induced aquifer depressurisation. Where previous experience of methods to support groundwater levels and spring flows is available in the literature this is referenced. Section 3.1 describes mitigation options that augment the flow of water recharging the aquifer systems and include surface and subsurface methods as set out in Figure 7. These methods are ranked according to ease of use and applicability (Santos 2013). More indirect techniques, such as creation of hydraulic or physical barriers are reviewed in Section 3.2. In Chapter 4 an initial screening of these potential methods is presented.

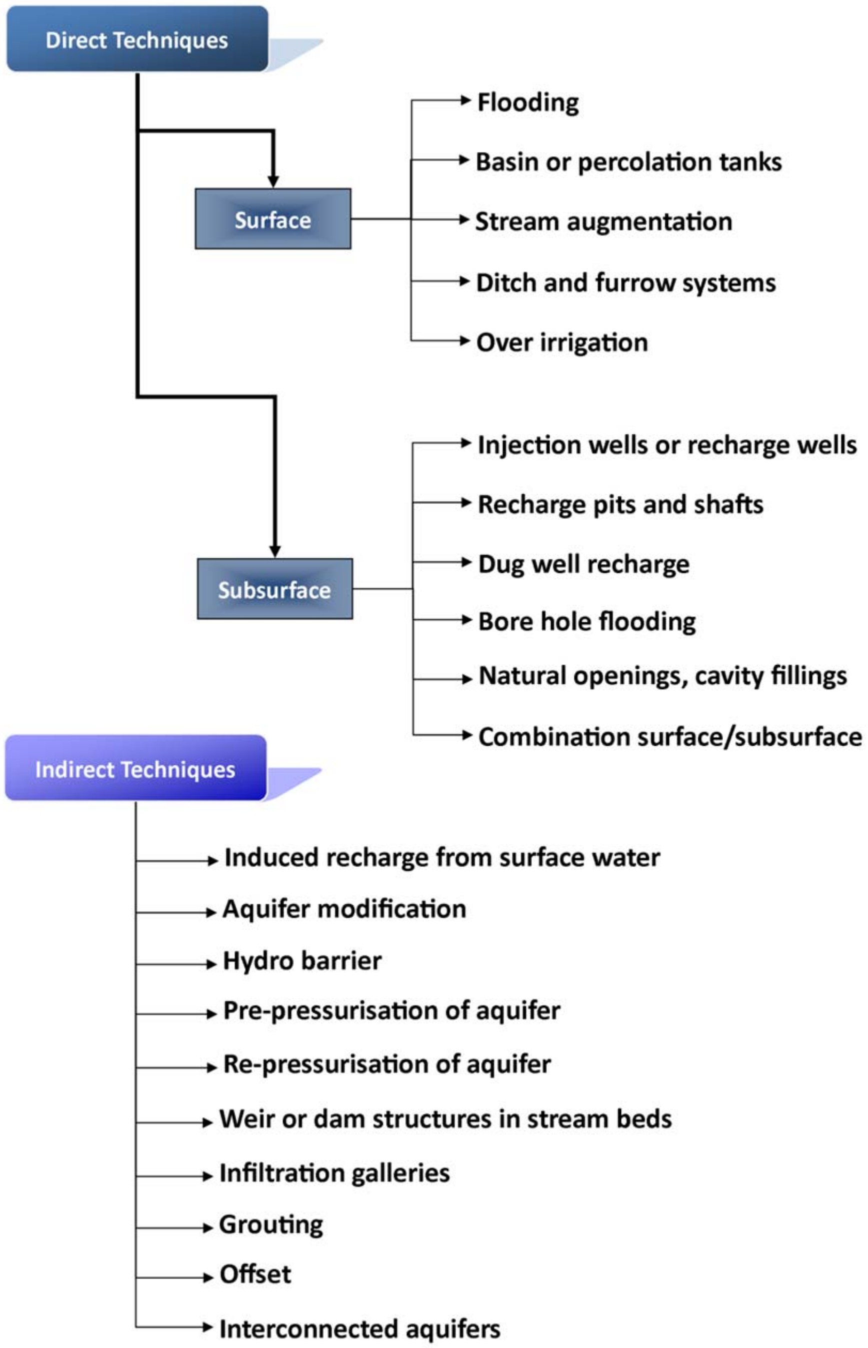


Figure 7: Summary and classification of potential mitigation options to mitigate spring impact.

In Figure 7 '**Direct Techniques'** refers to the location of implementation being at or extremely close to an impacted spring. For example, the augmentation or maintenance of flow by irrigation or discharge of water at a spring is a direct method. '**Indirect Techniques'** are those that could be implemented some distance from the impacted spring to either physically prevent depressurisation reaching a spring, or by countering the effects of depressurisation by adding additional water to the aquifer away from the spring itself. Generally indirect methods are preferred over direct methods due to operability and ease of application over the long term. Methods that are effective in preventing or mitigating the spring impact in the same timeframe as CSG operations would be considered favourable, as it would limit further disturbance of the spring complexes and the surrounding environment.

3.1 Mitigation Methods – Direct Techniques

3.1.1 Direct Recharge Methods – Surface Spreading

The direct recharge methods involve the artificial recharging of the aquifer; that is causing an increase in the amount of water that infiltrates to the aquifer vertically. The most prevalent methods of artificial recharge of groundwater include different techniques that increase the contact area and residence time of surface water with the soil. This allows the maximum quantity of water to be infiltrated into the unsaturated zone which eventually augments the groundwater storage (Bekele et al., 2011). Areas with gently sloping land without gullies or ridges are most suited for these surface water spreading techniques (Glendenning et al., 2012; O'Hare et al., 1986) (Figure 8).

3.1.1.1 Flooding

Flooding is useful where a favourable hydrogeological situation exists for recharging the unconfined aquifer by spreading surface water from streams over large areas for a sufficiently long period of time to recharge the aquifer system (Bouwer, 2002; O'Hare et al., 1986). Flooding requires a significant source of water and may be operated continuously or on a seasonal basis.

3.1.1.2 Ditches and Furrows

In areas with irregular topography, shallow, flat-bottomed and closely spaced ditches and furrows provide maximum water contact area for recharging water from the source stream (Choudhary and Chahar, 2007).

3.1.1.3 Recharge Basins

Artificial recharge basins are either excavated or enclosed by dykes (O'Hare et al., 1986). These systems are constructed parallel to intermittent stream-channels so that overflow can be used for recharging the aquifer.

3.1.1.4 Run-off Conservation Structures

In areas receiving low to moderate rainfall and not having access to water transfer systems from other areas, the maximum use of in-situ precipitation in the catchment is required (Bouwer, 2002). To facilitate the harvesting of the rainfall in the catchment the following methods are typically used:

- ***Gully plugs*** are the smallest run-off conservation structures built across small gullies and streams to store surface water during the rainy season and to promote infiltration to underlying aquifers. The barrier is typically constructed using local stones, earth and weathered rock.
- ***Contour barriers*** are a watershed management practice aimed at building up soil moisture storages that promotes infiltration once saturation (field capacity) is reached during the wet season. In this method the run-off is impounded by putting barriers on the sloping ground along contours of equal elevation. This technique is generally adopted in areas receiving low rainfall.
- ***Percolation tanks*** can be used around stream-channel sections with sufficiently high hydraulic conductivity for sub-surface percolation. Small tanks can be placed adjacent to these streams to collect high peak flow from the stream.

- ***Surface irrigation*** can be used to augment groundwater resources by over irrigating to promote percolation of excess water into the groundwater system.

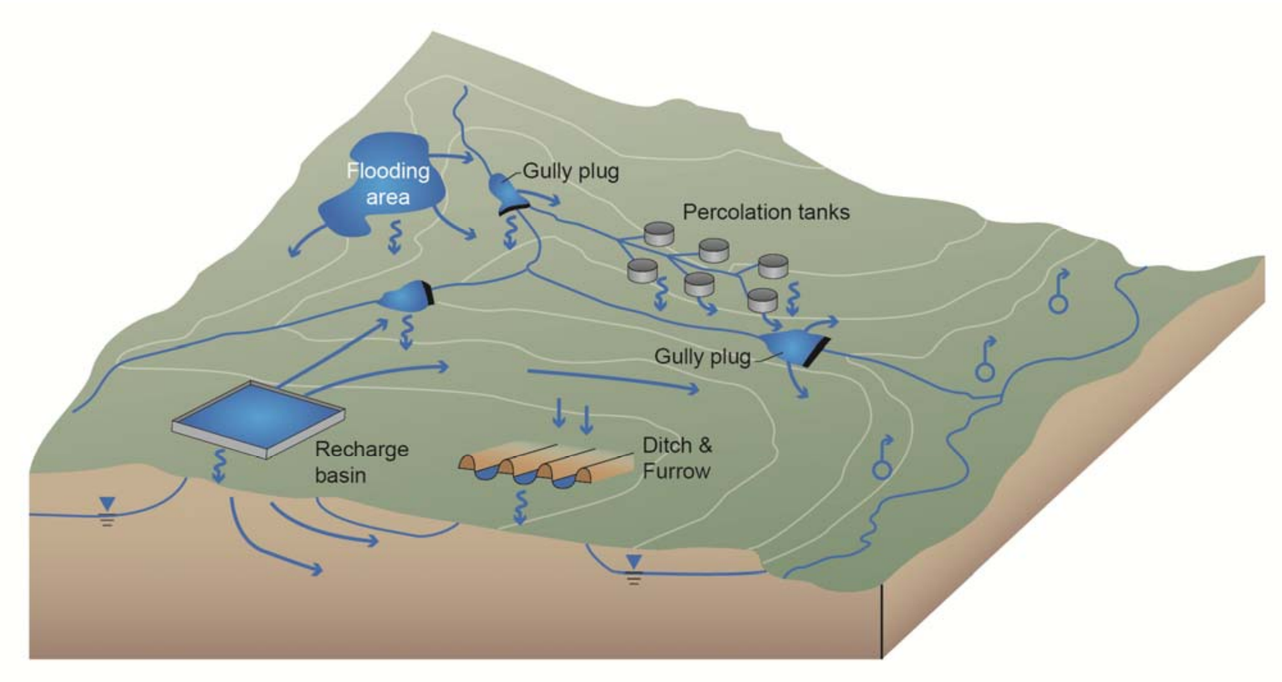


Figure 8: Summary of surface water spreading techniques used to augment recharge.

3.1.2 Direct Recharge Methods – Sub-Surface Techniques

When impervious layers overlie deeper aquifers, the infiltration from the surface cannot recharge the sub-surface aquifer under natural conditions. The techniques adopted to recharge the confined aquifers directly from surface-water sources are grouped under sub-surface recharge techniques Figure 9.

3.1.2.1 Injection wells

Injection wells are structures with the purpose of augmenting the groundwater storage of a confined aquifer by injecting treated surface water under pressure. Due to higher well losses caused by clogging, injection wells display lower efficiency as compared to a pumping well (Wanga et al., 2012). Thus these methods require some consideration of the aquifer mineralogy and expected water quality over the period of injection.

3.1.2.2 Gravity-head Recharge Wells

In addition to specially designed injection wells, ordinary bore wells can be used as recharge wells by gravity inflow (Bekele et al., 2013). The advantage of this method is that gravity supplies the driving force for injecting the water into the subsurface.

3.1.2.3 Recharge Pits and Shafts

Recharge pits and shafts are structures that directly introduce water into the saturated zone of unconfined (phreatic) aquifers. This overcomes loses and delays due to wetting up of the unsaturated zone when conducting artificial recharge of phreatic aquifer from surface water sources (Bekele et al., 2013). Recharge pits are excavated of variable dimensions that are sufficiently deep to penetrate less permeable strata. As in case of other water spreading methods, the source water used should be as silt free as possible.

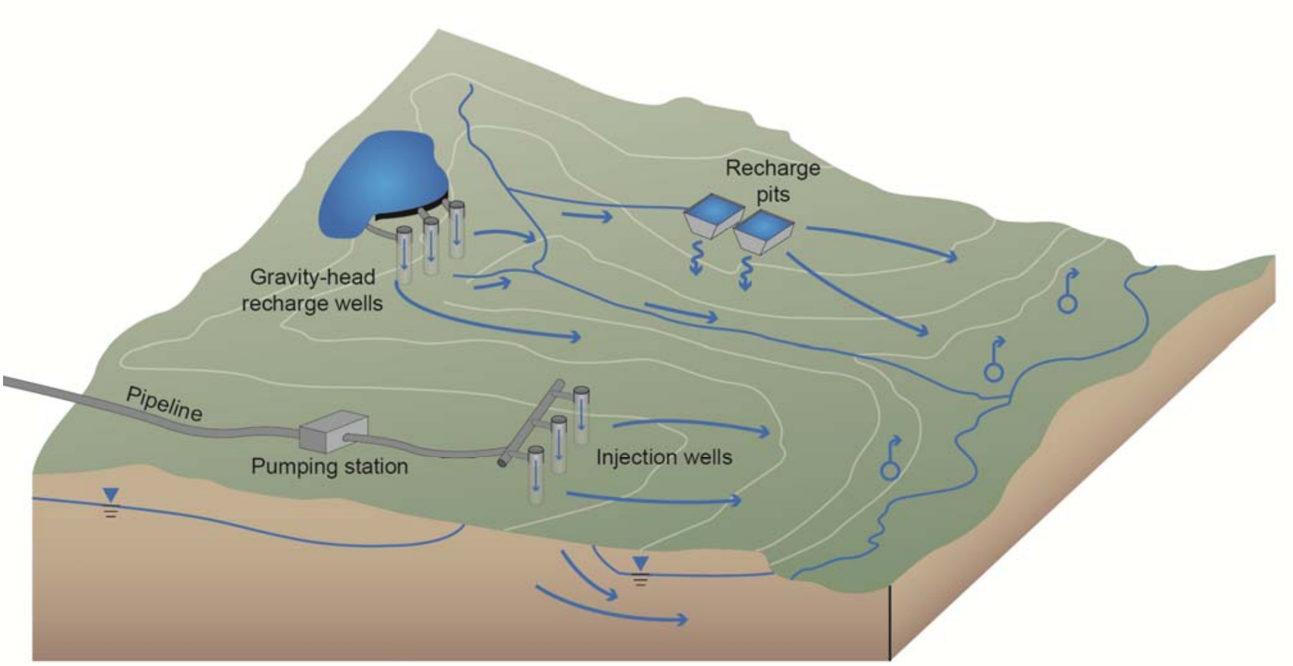


Figure 9: Summary of sub-surface techniques used to augment recharge.

3.2 Mitigation Methods – Indirect Techniques

Indirect techniques are implemented at some distance from the spring, with the aim of preventing depressurisation and reduced flow. A potential advantage of indirect methods is the natural groundwater chemistry is more easily maintained than with direct methods applied at the spring, or in close proximity.

3.2.1.1 Induced Recharge/Pump Volume Augmentation

This method of artificial recharge involves pumping water from an aquifer which is hydraulically connected to a surface water body (river, dam or infiltration system), to induce recharge to a water table reservoir (O'Hare et al., 1986; Reddy, 2008). When the cone of depression intercepts a river recharge boundary, a hydraulic connection is established with the surface water body (Figure 10) such that part of the pumping volume yield is directly obtained from this source (constant head boundary). In such methods there is actually no artificial build-up of ground water storage but only passage of surface water to the pump through the aquifer.

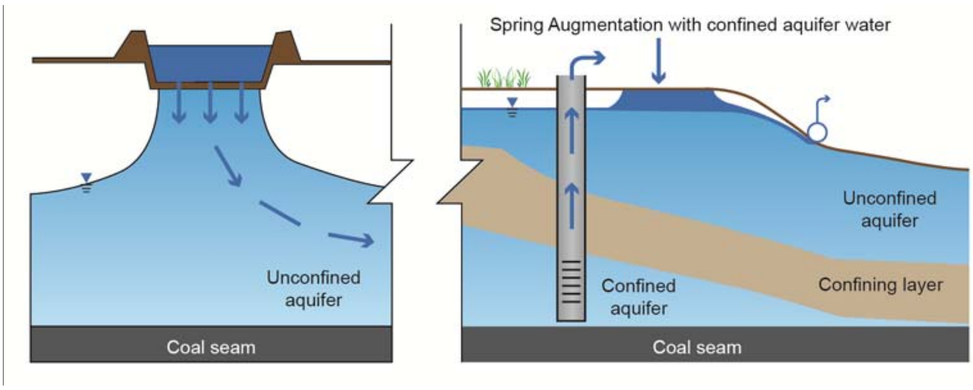


Figure 10: Induced recharge to confined aquifer for recharge.

3.2.1.2 Increasing Recharge by Aquifer Modification

Hydro-fracturing is a recent technique that is used to improve secondary porosity in hard rock strata (O'Hare et al., 1986). Hydro-fracturing is a process whereby hydraulic pressure is applied to an isolated zone of bore wells to initiate and propagate fractures and extend existing fractures (Figure 11). The water under high-pressure breaks and opens up fissures and cleans away clogging. The method to increase recharge potential requires extension of existing fractures and propagation of new vertical fractures to be initiated. These increase vertical permeability leading to better conditions for artificial recharge. Hydro-fracturing can also be applied near surface to create fractures that intercept the ground level, this results in higher recharge from rainfall due to increased infiltration rates.

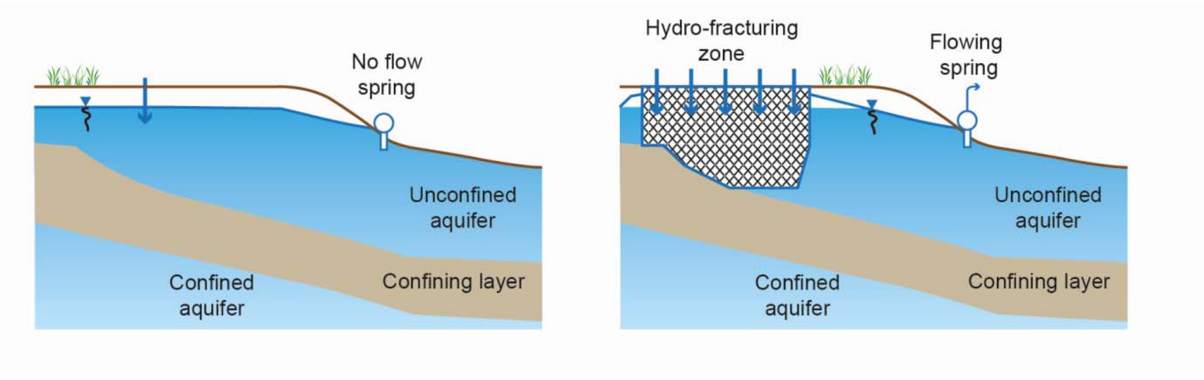


Figure 11: Increasing recharge by modifying the infiltration capacity of the subsurface by hydraulic fracturing.

3.2.1.3 Hydro Barrier

A hydro barrier acts as a groundwater divide between the spring complex and the reduction in water levels from CSG production (O'Hare et al., 1986). A hydro barrier is designed to allow ongoing supply of sufficient water to maintain water levels at the spring complex, without being impacted by the regional water table lowering due to CSG abstraction (Figure 12).

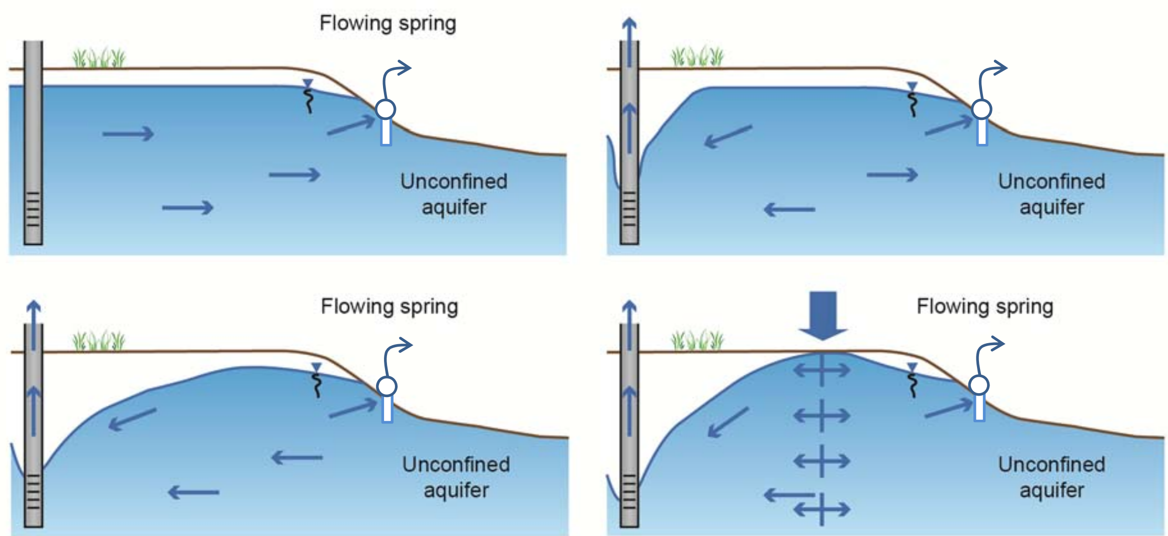


Figure 12: Mitigating spring impacts with a hydro-barrier.

3.2.1.4 Aquifer Pressurisation

Pressurisation of confined aquifers can be done to negate the impact of dewatering on springs that rely on confined aquifer systems (O'Hare et al., 1986) (Figure 13). Water is injected into the target aquifer system at a specified rate depending on the final piezometric pressure required (Figure 14). Pre-pressurisation of the aquifer can be applied as pre-emptive measure, however, a perennial spring might be converted to a continuous flowing spring as a result. The piezometric surface in the area will be elevated and secondary springs might appear. This technique also allows ample monitoring to occur before the system is impacted. Re-pressurisation of an aquifer system is done once the cone of depression reaches at a specified monitoring point. The piezometric surface obtained through application of pressurisation in the area should be equal to the initial state of the aquifer.

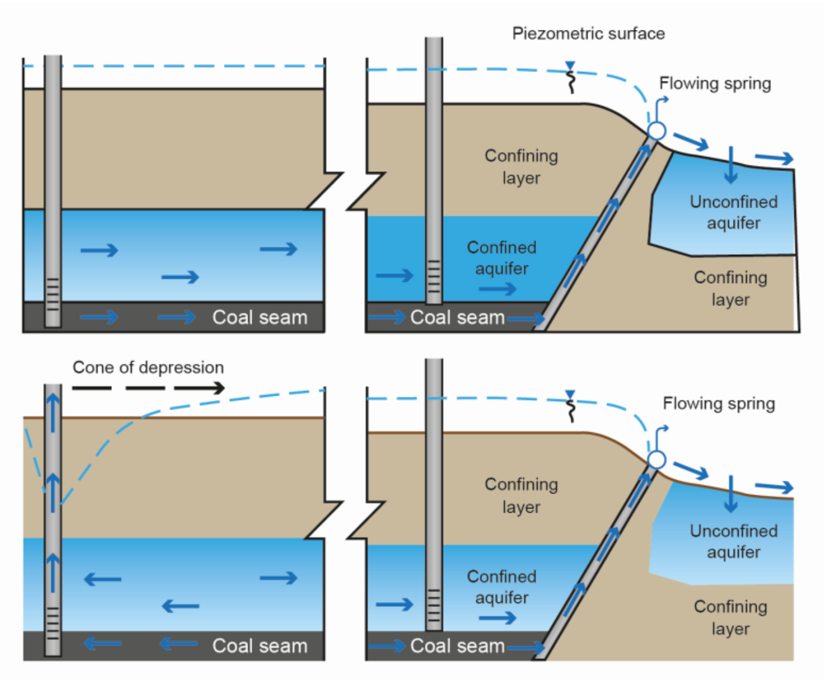


Figure 13: Confined aquifer under natural conditions (top) and cone of depression (bottom).

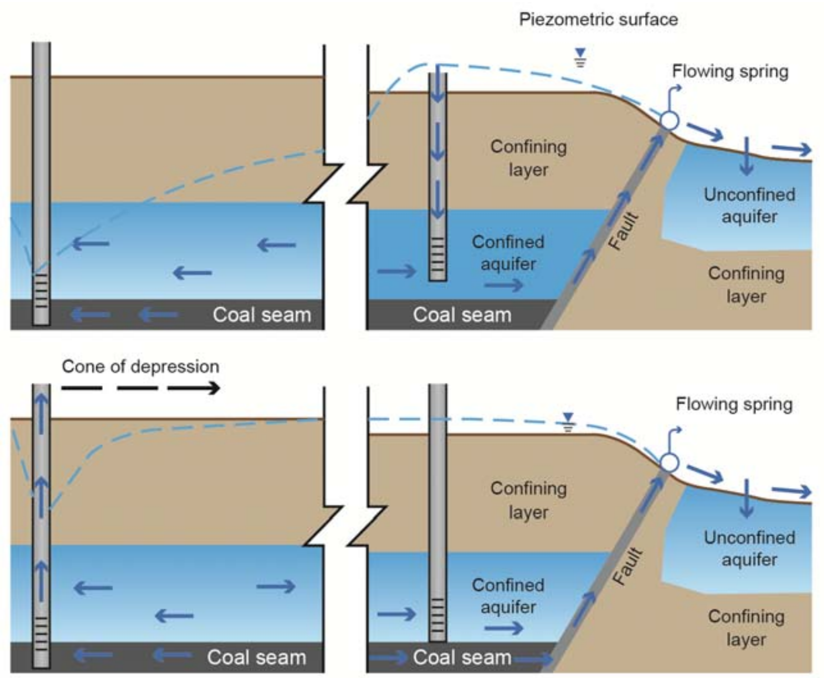


Figure 14: Aquifer pre-pressurisation (top) or re-pressurisation (bottom).

3.2.1.5 Enhanced Natural Recharge

Weir or dam structures can be constructed in tributaries to allow additional recharge (Figure 15), i.e. by reducing the outflow of surface water from the catchment (Bekele et al., 2013). In addition infiltration galleries can be used to enhance the natural recharge to specific areas. These methods allow for adequate water to be stored in the aquifer system to maintain the spring during low flow periods (Glendenning et al., 2012).

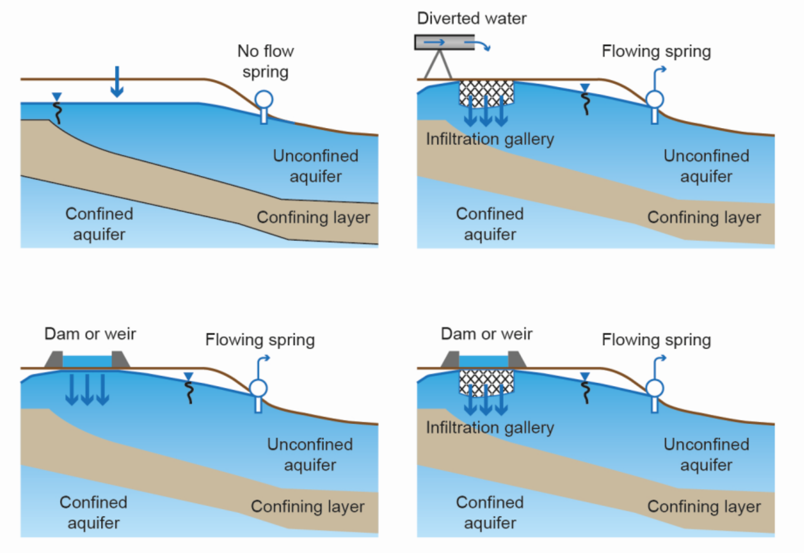


Figure 15: Enhanced natural recharge by a combination of surface and subsurface structures.

3.2.1.6 Grouting

The use of grouting screens or curtains in mining to act as an ingress reduction method is relatively common. (O'Hare et al., 1986). Grouting is typically applied in a limited aerial extent and depth (Figure 16). Grouting has a number of known short comings when it comes to aquifer systems: the grout used tends to degrade, and breaches of the barrier by groundwater may occur. Hence, grouting is not necessarily a long term solution. The method can be costly as the extent of grouting required to protect a spring might span a large distance.

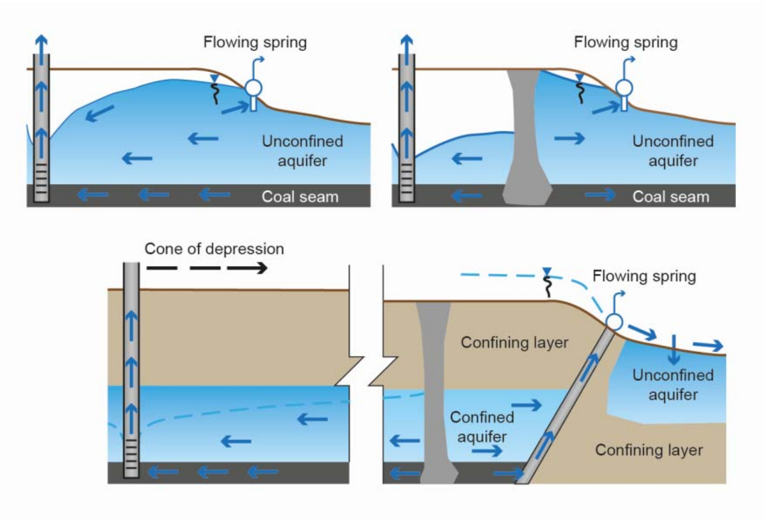


Figure 16: Effect of grouting on unconfined and confined aquifer systems.

3.2.1.7 Offset Impact Mitigation Options

Offset impact options can generally be grouped into four subgroups.

- Offset impacts by relocating existing water bores.

Relocate an existing bore so that it has less impact on the spring complex but still meets the bore owner's needs. In the context of the current region where cattle farming is predominant and low abstraction volumes are required it might not be possible to reduce impacts to the spring by means of bore relocation.

- Offset impacts through surrender of entitlements that are not needed.

In this method the bore owner is financially incentivised to not use part of the entitlement. As noted in the preceding bullet this option will not be effective in the study area as there is no significant water abstraction in the spring areas.

- Offset impacts through improved water use efficiency.

In this method the water bore owner is incentivised to improve the efficiency of their water use and to not use a portion of their water entitlement. As noted in the preceding bullet this option will not be effective as there is no significant water abstraction in the spring areas.

- Offset impacts through supply substitution.

Assist the bore owner to arrange a supply from another source to reduce the impact on the spring complex, that the original entitlement or part of the entitlement can be surrendered. This option is similar to that raised in the previous bullet and is not expected to have a significant effect on reducing the impact at the spring.

3.2.1.8 Interconnectivity between Coal Seams

This method would require wells to be drilled through and completed with screens within the Bandanna and Early Permian coal seams. The wells act to locally interconnect these aquifer systems. With CSG production first from Bandanna coals, the Early Permian coal seams would act as a source of water that would flow through the wells into the Bandanna. In effect this would supply water from a deeper to a shallower formation.

The objective of this method is to reduce the overall depressurisation in the Bandanna as it propagates from the CSG fields towards the springs, and hence to reduce the declines in groundwater pressures in the source aquifers for springs. Interconnecting coals promoting the flow between seams may not be permitted by regulators as it requires creation of direct pathways between what can be considered separate aquifer systems. The method also depends on the phasing of CSG production between Bandanna and Permian coals and may not be a long term method once Permian CSG production commences.

3.3 Summary

This section has presented a review of methods that could be applied to mitigate spring impacts from CSG-induced aquifer depressurisation, including methods to enhance recharge by surface and subsurface techniques. Additional indirect methods, such as the hydraulic barrier have been presented, with relevant examples of their previous application cited from literature with illustrations showing their implementation.

In Chapter 4.0 an initial feasibility screening of candidate mitigation methods in undertaken, to exclude those that are inherently unfeasible for the Fairview spring complexes. After a description of the local setting of the springs in Part II, the selection of the preferred options from the candidate mitigation methods is described in Chapter 8.

4.0 INITIAL FEASIBILITY SCREENING OF CANDIDATE MITIGATION METHODS

Candidate mitigation methods reported in the literature, and other options have been presented in Chapter 3.0. In this Chapter an initial screening of the options is presented.

Figure 17 presents a list of the candidate mitigation options from Chapter 3.0. The list includes an indicative ranking of ticks and crosses. Some of the candidate mitigation options are excluded at this stage on the basis of cost, technical feasibility or relevance and this is indicated by crosses.

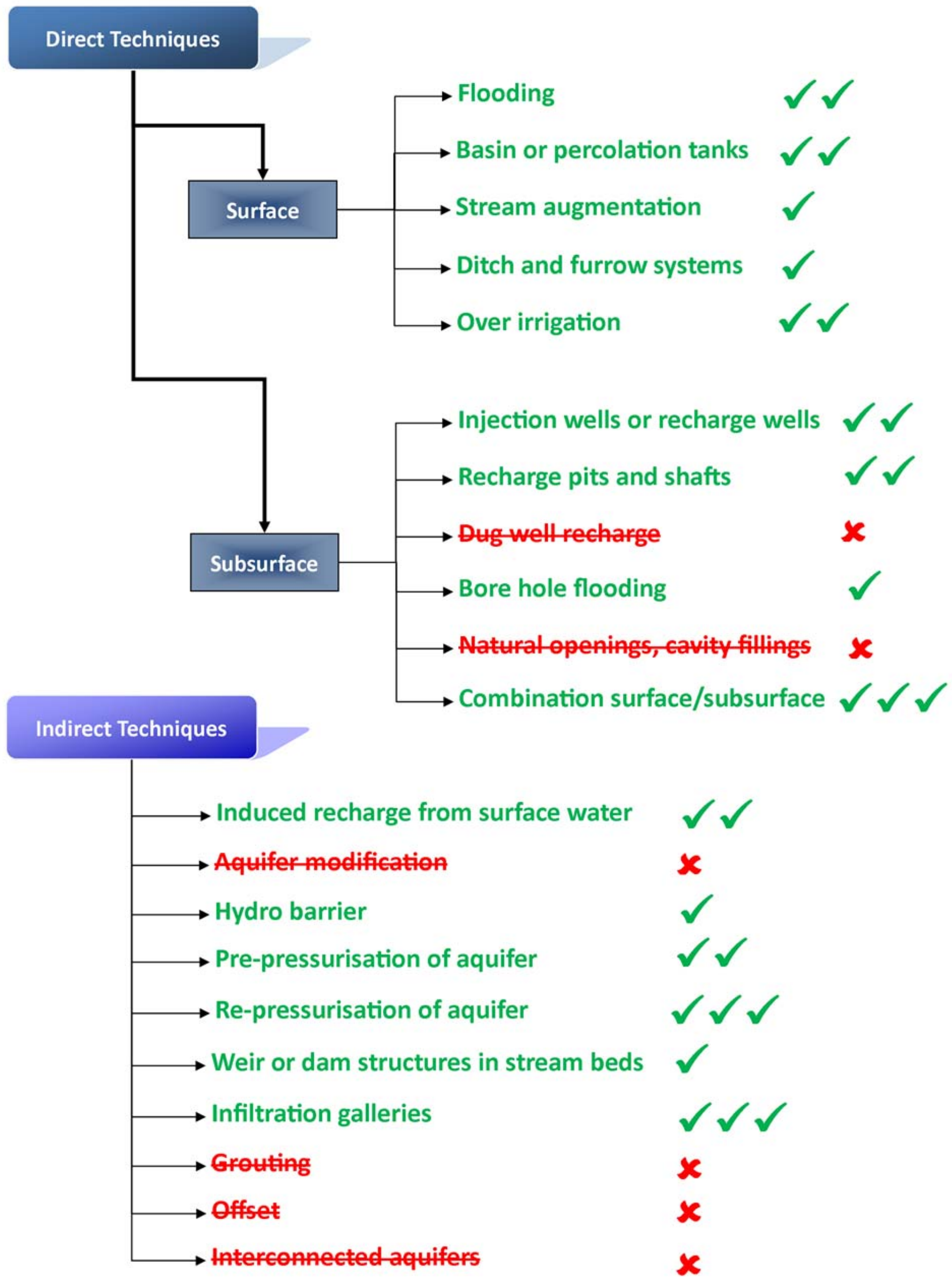


Figure 17: Selected methods of mitigation options to reduce or eliminate impact to springs.

Most of the direct surface recharge methods listed in Figure 17 are deemed to be possible solutions for spring impact mitigation. Within direct subsurface recharge techniques there are two options which would most likely not be applicable since they rely on the natural setting to be favourable, i.e. dug well recharge and natural openings.

Two indirect recharge methods were excluded from further analysis since they would require extensive modification to the aquifer system and were assessed as being unrealistic considering the extent of the spring settings (grouting and aquifer modification). The offset mitigation options will most likely not be effective as land use is dominated by cattle farming and generally abstraction volumes are low. Hence, offset methods are precluded.

The remainder of the methods are given an initial indicative ranking in Figure 17 according to their likely ease of application and long term applicability. The methods with the highest literature ranking consisted of techniques that either increased the contact time of water with the subsurface (water table aquifer) or directly influenced the aquifer system (confined aquifer).

4.1 Summary

A literature review of potential methods to prevent or mitigate spring impact has been reported in Chapter 3.0 and an initial feasibility screening of the candidate options list has been completed in this Chapter.

The options that have passed this initial screening are taken forward to identify the preferred candidate options Chapter 8.0 – Selection of candidate mitigation. These candidate options will only be applied if spring risk is imminent or high as defined by Green (2013). Furthermore the preferred order in which these options would be selected would adhere to Santos guidelines:

1) Avoid impact to environmentally sensitive areas, including MNES.
2) Minimise influence of CSG activities.
3) Manage impacts on predefined trigger based adaptive management procedures.
4) Response timelines are designed so that contingency plans to protect the environment can be implemented on time, before the un-mitigated impact would occur.

In Part II of this document the site data (Chapter 5.0) for the spring complexes is presented to enable development of individual hydrogeological conceptual models (Chapter 6.0). In Chapter 7.0 a spring risk assessment is performed to evaluate the overall environmental significance of the spring complexes, and risk factors that might trigger the mitigation options discussed in the preceding two chapters.

PART II
SITE DATA, CONCEPTUAL MODELS AND SPRING RISK ASSESSMENT

5.0 FAIRVIEW SPRINGS SITE DATA

This chapter presents site data of the Fairview Spring complexes to lay the foundation for assessing possible mitigation or prevention options.

The UWIR, prepared by QWC (now OGIA) to assess the potential impact on groundwater from cumulative CSG development in the Surat and Bowen Basins, was released in December 2012 (QWC, 2012). The UWIR identified five spring complexes which might be impacted by a reduction in the groundwater levels in the source aquifer. An EPMOR must be produced for each of these spring complexes to identify the mitigation measures that the responsible tenure holder will undertake. The spring complexes identified for further investigation, and the tenure holders responsible, are: Barton (QPLNG/Origin); Lucky Last (GLNG/Santos); Scott's Creek (APLNG/Origin); Spring Rock Creek (GLNG/Santos); and Yebna 2/311 (GLNG/Santos).

A remote sensing survey (Halcrow, 2013b) has been undertaken at each of these five spring complexes, comprising a total of 37 spring vents, to assist the development of conceptual hydrogeological models for each spring complex. The survey also provides a baseline dataset to be used in the future to determine the spring discharge variability by means of ground surveys with a differential GPS system.

The current report focuses on the three spring complexes allocated to the GLNG project and Santos: Yebna 2/311, Lucky Last and Spring Rock Creek spring complexes. Table 3 summarises the number and types of vent for the spring complexes. A map showing the vent position and location in Figure 18, and shows the spring locations along the valleys of the Dawson River, Hutton and Injune Creeks in relation to the GLNG Fairview CSG tenements.

Table 3: Data summary of spring complexes (Halcrow, 2013b).

Spring complex	**Yebna 2/311**	**Lucky Last**	**Spring Rock Creek**
Spring complex number	591/311	230	561
Number of artesian vents	1	12	0
Primary source aquifer as defined by the UWIR	Evergreen Formation Precipice Sandstone	Evergreen Formation Precipice Sandstone	Evergreen Formation Precipice Sandstone
Number of water table spring vents	17	0	1
Total number of spring vents	18	12	1
Spring vent numbers	499, 500, 500.1, 536.1, 536.2, 534-537, 692-9, 704	340, 686-689, 687.1-6	285
Aerial description	Spring vents are generally located within steeply incised valleys/gullies which lead to the Dawson River.	The spring complex is located on a flat valley bottom within the floodplain of the Injune Creek.	The spring complex is located in an incised gully leading to Hutton Creek.
Surface morphology	Yebna 2 peat mound 311 rocky seeps	Peat mounds and rocky seeps	Rocky seeps
EPBC listed	No	Yes	No

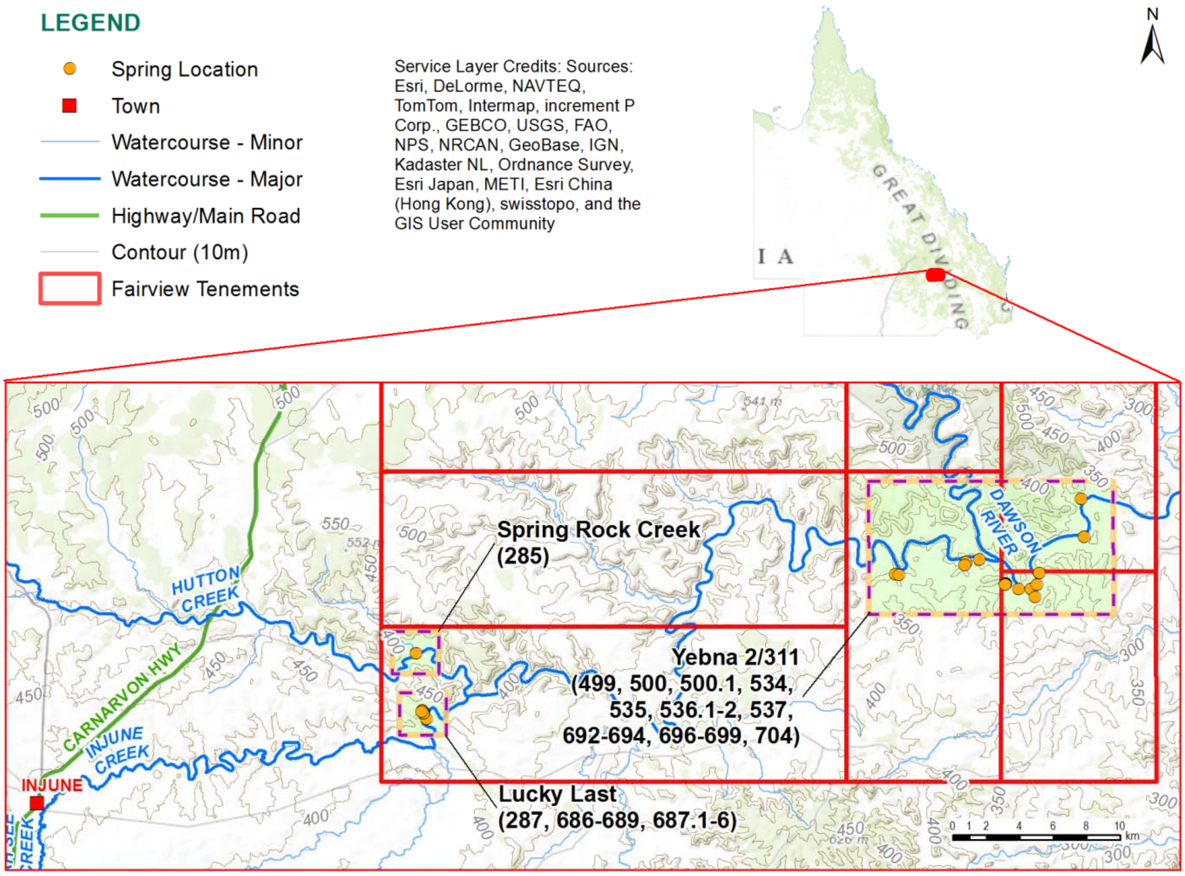


Figure 18: Location of spring vents in the Injune area showing major topographic features.

The geology and hydrogeology of the northern Surat and southern Bowen basins are described in some detail in the Surat UWIR (QWC, 2012). For brevity, this information is not repeated in this report. To assist the reader a stratigraphic column (Figure 19) for the Fairview area is repeated here to set the context of the geological sequence.

WRP Management Unit Equivalents	Basin	Group	Litho-stratigraphy	Geologic Age	Hydrogeological Characteristics
Surat North GMA 20			Alluvium (Condamine)		Aquifer
					Aquifer
Surat North 2	Surat Basin		Hutton Sandstone	Jurassic	Major Aquifer (GAB)
Surat North 2	Surat Basin	Evergreen Formation	Boxvale Sandstone (*)	Jurassic	Confining Bed
Surat North 3	Surat Basin		Precipice Sandstone	Jurassic	Aquifer (GAB)
Surat North 4	Bowen Basin		Moolayember Formation	Triassic	Confining Bed
Surat North 4	Bowen Basin	Mimosa Group	Clematis Sandstone	Triassic	Major Aquifer (GAB)
Surat North 4	Bowen Basin	Mimosa Group	Showgrounds Sandstone	Triassic	Aquifer
Surat North 4	Bowen Basin	Mimosa Group	Rewan Formation	Triassic	Confining Bed
	Bowen Basin	Blackwater Group	Bandanna Formation	Late Permian	Target Coal Measure
	Bowen Basin	Blackwater Group	Black Alley Shale	Late Permian	Confining Bed
	Bowen Basin	Back Creek Group	Peawaddy Formation	Early Permian	Confining Bed
	Bowen Basin	Back Creek Group	Catherine Sandstone	Early Permian	Water bearing
	Bowen Basin	Back Creek Group	Ingelara Formation	Early Permian	Confining Bed
	Bowen Basin	Back Creek Group	Freitag Formation	Early Permian	Water bearing
	Bowen Basin	Back Creek Group		Early Permian	
	Bowen Basin	Back Creek Group	Aldebaran Sandstone	Early Permian	Aquifer
	Bowen Basin	Back Creek Group	Cattle Creek Group	Early Permian	Water bearing
	Bowen Basin		Reids Dome Beds	Early Permian	Water bearing
THOMSON FOLD BELT			Timbury Hills Formation*	Carboniferous to Devonian	
			Fork Lagoons Bed	Late Ordovician	

(*) No information on the stratigraphic position, just the group they belong to

Figure 19: Stratigraphic Sequence in the Fairview Area.

The following sections describe the three spring complexes at the local site scale including the geology, setting, ground and surface water and springs environmental values. The site descriptions related to visits made in July 2013, a relatively dry period of lower than average flows.

5.1 Spring Rock Creek

Spring Rock Creek is located along Hutton Creek, approximately 4 km upstream of its confluence with Injune Creek, in the headwaters of the Dawson / Fitzroy river system.

5.1.1 Geology

The Spring Rock Creek spring is located within the Boxvale Sandstone as defined in Figure 20 (KCB, 2011). Boxvale Sandstone outcrops are clearly visible at the site (Figure 21). Very fine to medium grained quartz rich sandstone is observed at the site (Figure 21), which is highly weathered in some sections. Medium to very coarse beds of sandstone were also found in the vicinity.

Approximate thickness of formations present in the area was estimated from drill logs. The maximum thickness of the Evergreen Formation that overlies the Precipice Sandstone is estimated to be 130 m and the Precipice Sandstone in the order of 40-60 m. These formations are underlain by the Moolayember Formation which is 250-300 m thick in the area. Although initial mapping in the area indicates that the spring was located in the Precipice Sandstone, further investigations indicate that it is actually located in the Boxvale Sandstone group (Fensham and Fairfax, 2003; KCB, 2011; Halcrow, 2013b). Recent field investigations support those findings and are reported in Section 5.1.3.

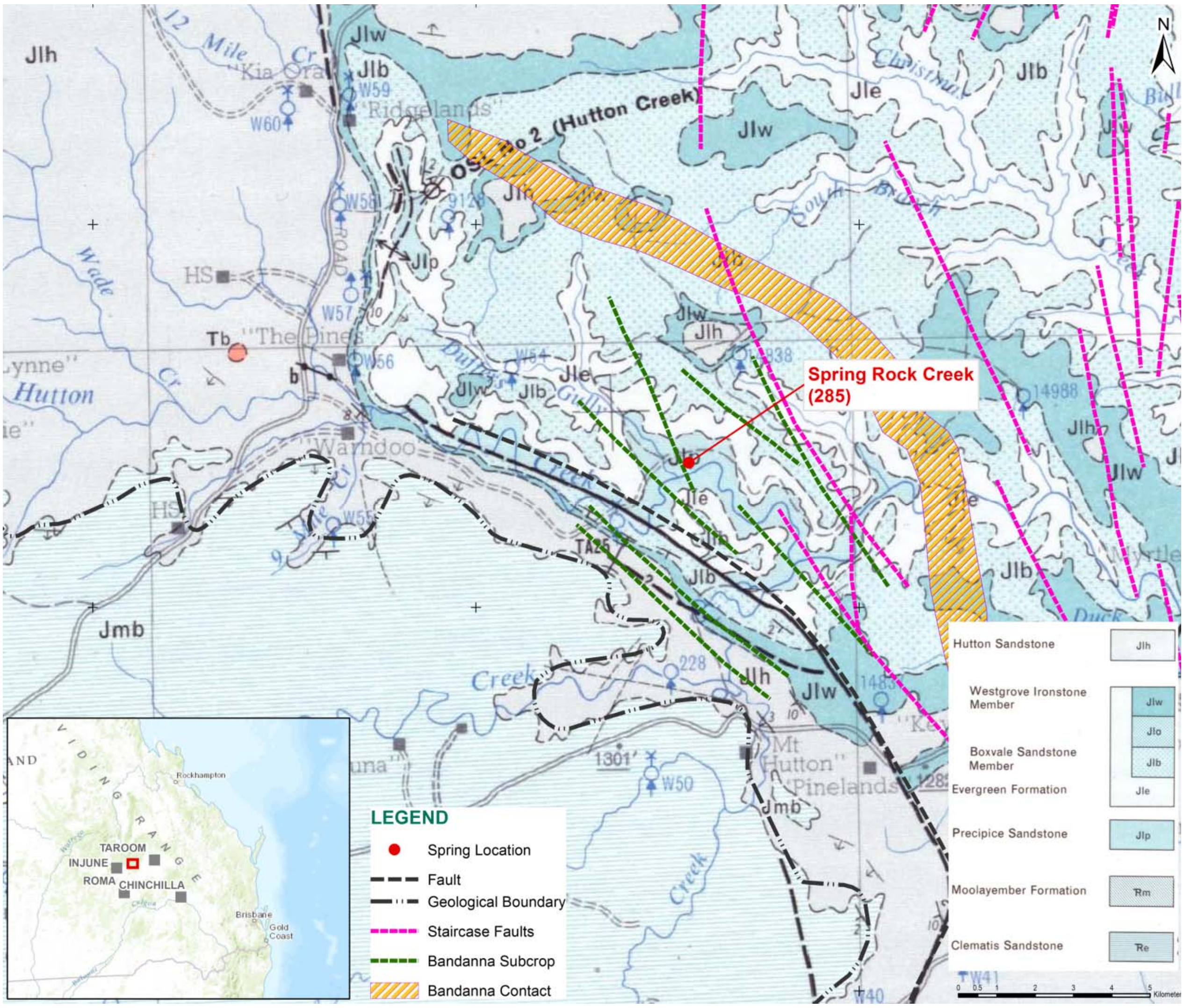


Figure 20: Local geology map at Spring Rock Creek spring complex.

Figure 21: Boxvale Sandstone outcrops at Spring Rock Creek.

5.1.2 Surface Water

The Spring Rock Creek Spring Complex is located close to Duffers Creek and this watercourse flows into Hutton Creek. The spring vent is approximately 0.2 km from Hutton Creek, identified as one of the major streams within the Dawson/Fitzroy River Basin.

Watercourses within the Dawson/Fitzroy River Basin are generally ephemeral, with the exception of the Dawson River downstream of Dawson's Bend. Summer rainfall (November – March) dominates, with little or no flow during winter when the ephemeral streams are typically dry or reduced to a series of pools (Halcrow, 2013b). The pools located in Duffers Creek are all fed by groundwater.

5.1.3 Groundwater

The main aquifer from which Spring Rock Creek draws its water is the Boxvale Sandstone which is approximately 40-60 m thick. Due to the currently limited amount of piezometric data in the area, it is not possible to construct a contour map of water levels. However, to confirm that the source aquifer is the Boxvale (Section 12.1) water quality results obtained from field and laboratory samples can be compared to published water qualities for the respective Boxvale and Precipice Sandstone aquifers (KCB, 2012; Santos, 2013). Electrical conductivity (EC) of sampled water was high (1000–1400 uS/cm) and would indicate Boxvale Sandstone as the origin for the water; if the Precipice Sandstone aquifer was present the EC would be significantly lower (Section 12.1). In addition, chloride and alkalinity values are of the same order and can be generally classified as a sodium/chloride water type. The Boxvale aquifer system is intermittently located within the Evergreen Formation, an aquitard, resulting in low flow volumes (~1 L/s) at the site. Long term average recharge rates of 1 to 10 mm/yr have been estimated for GAB recharge beds. At these rates, Spring Rock Creek would require a recharge area of 3 to 30 km^2.

The confining aquitard present in the area is dominated by the Evergreen Formation. Low permeability zones within the Boxvale Sandstone also exist, however, and could act as zones from which water can seep to creek beds due to localised water level build-up (Figure 22).

Figure 22: Groundwater seepage zone (yellow section) from local strata above Spring Rock Creek spring.

Groundwater usage in the area is limited to stock farming and the presence of cattle paths could be seen along the course of Duffers Creek. Due to the remoteness of the area it is unlikely that bores would be used to extract significant quantities of water. Further details are collated in the following associated reports (Halcrow, 2013a; Santos, 2013).

5.1.4 Ecology and Environmental Values

The Spring Rock Creek Spring Complex is not classified as an Environment Protection and Biodiversity Conservation Act (EPBC, 1999) listed community and also has no EPBC/Natural Conservation Act (NCA, 1992) listed species (Fensham et al., 2011) (Table 3).

An ecological assessment of the Spring Rock Creek spring complex was conducted by URS (Section 12.3) (URS, 2013). The values assessed included flora, fauna and water flow. The purpose of the URS study was to identify the species and environmental conditions present at the site and outline anything that is protected, endangered or at risk of decline due to a change in conditions at the site.

The report identified the following ecological and environmental features:

- Tusked frog *(Adelotus brevis*) – Vulnerable species under the Queensland NC Act – Vent 285
- Large pool of water with aquatic life and fish present.

5.1.5 Summary of General Spring Description

A site visit was completed during July 2013 to collect field samples during the dry period (Figure 23 and Figure 24). During the field visit the flow condition of the spring was assessed as very low (0.1–0.2 L/s, Figure 22) and a high EC value was measured at the spring vent (1200 μS/cm).

A summary of notable features and previous observations at the Spring Rock Creek spring complex is given in Table 4.

Figure 23: Spring Rock Creek site (9 July 2013) sampling program.

Figure 24: Panoramic image showing the creek with the location of the spring.

Table 4: Summary of Spring Rock Creek data (Fensham et al., 2011).

Spring vent	General vent description
285	■ An open depression was observed with an incised stream discharging into Hutton Creek. ■ The spring vent appeared to receive baseflow from the Boxvale Sandstone which outcrops nearby. ■ A groundwater fed stream and pools were observed. ■ Indications of permanency observed from presence of fish and comments from landholder (URS, 2013). ■ Spring vent flow approximately 1.0 L/s (KCB, 2011). ■ Spring vent estimated to be 10–50 % affected by stock damage in Queensland Herbarium. ■ No damage from pigs reported. ■ Not an EPBC listed spring. ■ Surface morphology classified as rocky seeps.

5.2 Lucky Last

Lucky Last spring complex is located along Injune Creek, some 25 km from the town of Injune and approximately 4 km upstream of the confluence with Hutton Creek.

5.2.1 Geology

Lucky Last spring complex is located within a complex geological region, with major faulting structures being observed in the area (Figure 25). Interpretation of the seismic data and drilling logs has produced an understanding of the subsurface structures, although this might be updated as more information is obtained about the site. The surface geology at the spring complex is the lower Evergreen Formation, which overlies the Precipice Sandstone. An inverse stress regime is also present in the area, i.e. overburden structures are under shear pressure while the deeper formation does not exhibit the same principal stress environment. The Evergreen Formation is described as fine grained, weathered silicified sandstone/siltstone (KCB, 2012). The Clematis Sandstone is not present and the Hutton Sandstone outcrops to the southwest of the spring vents approximately 150 m from spring vent 285 (Figure 26).

The spring vents are located on a regional fold structure called the Arcadia anticline. A number of west-northwest to east-southeast trending faults pass through the area. Potentially some dislocation and thrusting scars along these faults. The surface geology suggests that northeast of the faults, the strata has been thrust upwards, bringing the Precipice Sandstone and Evergreen Formation to the surface.

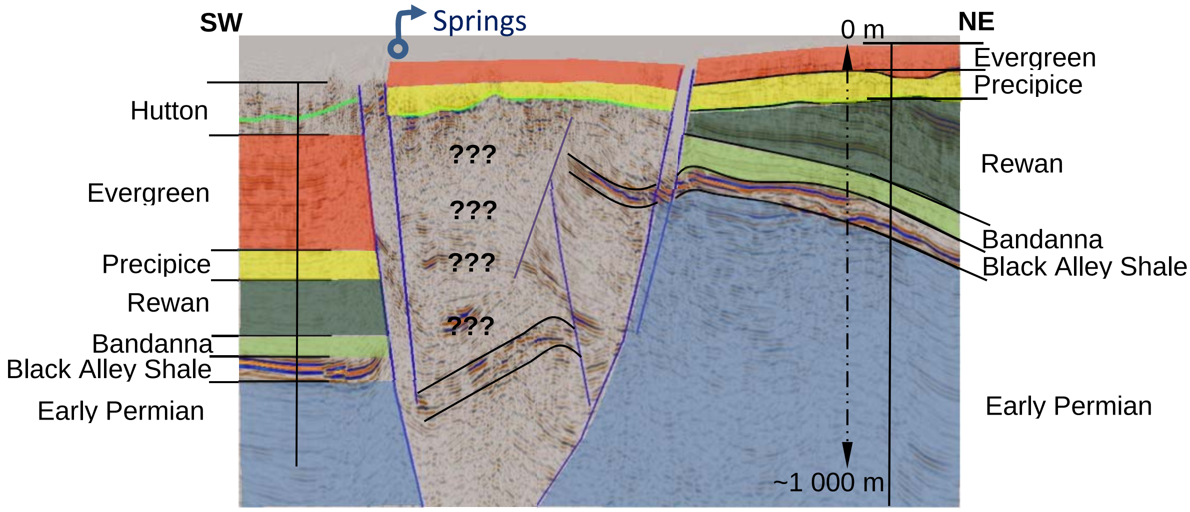


Figure 25: Seismic cross section of area that transects Luck Last spring complex.

Approximate thickness of formations present in the area was estimated from nearby bore logs and from seismic data. Due to the complexity of the site, further work is required to confirm the geological structures present in the subsurface. The maximum thickness of the Evergreen Formation that overlies the Precipice Sandstone is estimated to be 50 m and the Precipice Sandstone in the order of 40-60 m. These formations are underlain by the Moolayember Formation which is 250-300 m thick in the area (Fensham and Fairfax, 2003; Halcrow, 2013b; KCB, 2012).

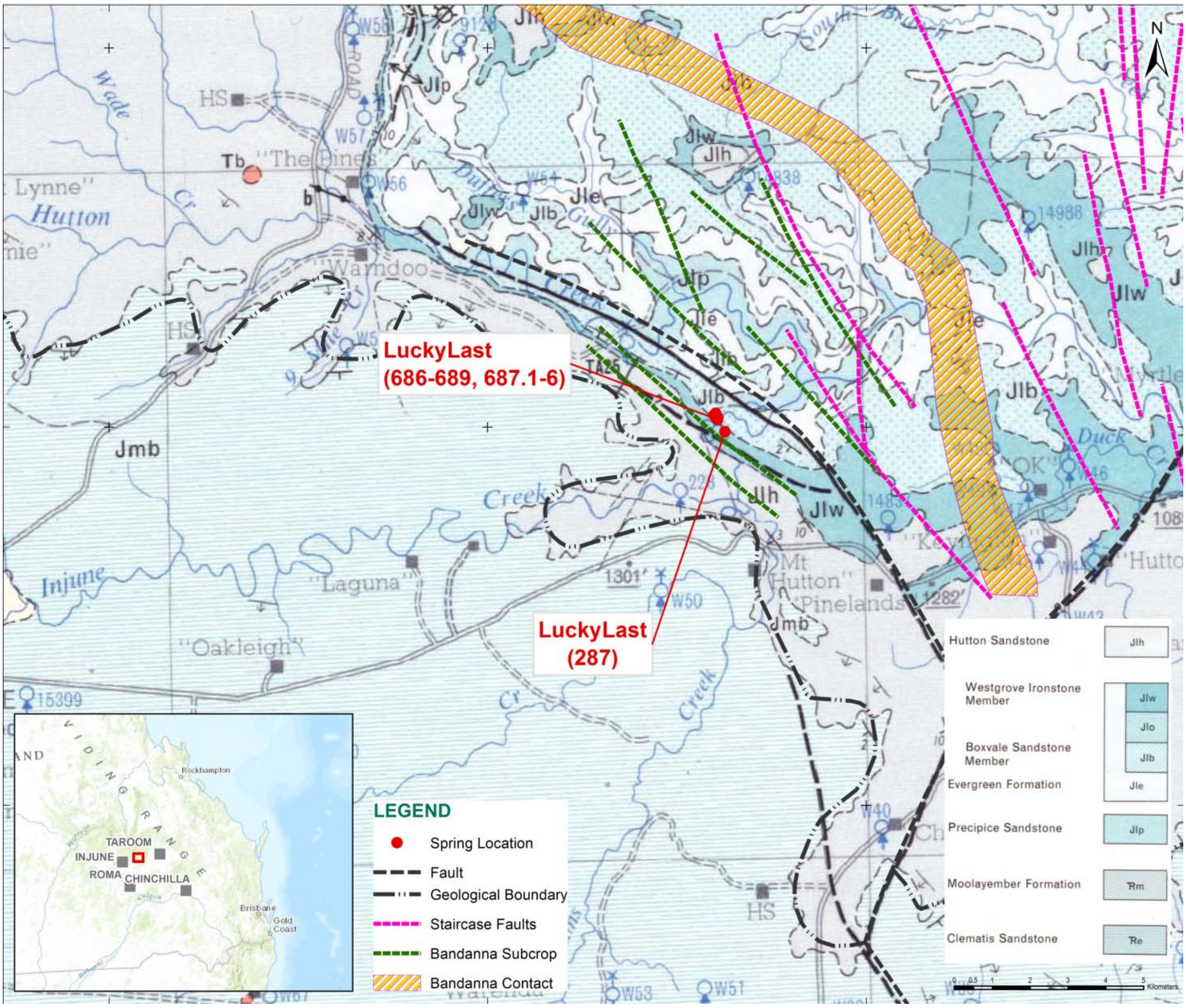


Figure 26: Local geology map at Lucky Last spring complex.

5.2.2 Surface Water

The spring vents are located close to Injune Creek with an outflow channel from the mound observed. The spring vent complex is approximately 0.1 km from Injune Creek.

The springs are located in clusters, with the main spring complex (Spring vent 688) producing enough flow to reach Injune Creek (Figure 29). The remainder of the spring vents have either minimal surface expression, i.e. damp patches (Figure 27) or a water saturated zone with a drainage section extending a short distance from the mound (Figure 28).

Surface water flow is dominated by groundwater baseflow produced from the spring complex. Anecdotal information from local farmers indicated that the pools in the creeks fill-up with water during the winter months. This observation would indicate that during the winter, when evapotranspiration is at its lowest, groundwater recharge to the creeks is the most evident.

Figure 27: Lucky Last spring complex (687.6) with minimal surface moisture expression and evidence of poaching by cattle.

Figure 28: Panoramic image of Lucky Last spring complex (689) with surface moisture expression.

Figure 29: Panoramic image of Lucky Last (688) spring complex showing the extensive mound.

5.2.3 Groundwater

The main aquifer from which Lucky Last draws its water is the Precipice Sandstone which is approximately 40-60 m thick. Due to limited piezometric data in the area it is not possible to construct a contour map of water levels. The source aquifer of the spring water is confirmed as the Precipice Sandstone (Section 12.1) based on hydrochemical analysis results from field and laboratory samples. These were compared to published water qualities for the respective Boxvale and Precipice Sandstone aquifers (KCB, 2012; Santos 2013). Electrical conductivity (EC) of sampled water was moderately low (200–400 μS/cm) which would indicate Precipice Sandstone as the origin for the water (Section 12.1). If the Boxvale Sandstone aquifer were present the EC would be significantly higher. Low flow volumes of ~0.6 L/s (Vent 688) were observed at the site, which may indicate that the piezometric pressure in the area is not particularly elevated. If groundwater recharge occurred over aquifer outcrop at estimated rates of 1 to 10 mm/yr then Vent 688 would require an area of 2 to 20 km^2 to supply the observed flow.

Recharge of water to the Precipice will be limited by the presence of the Evergreen Formation, the main aquitard present in the area. In addition, groundwater flow will also be affected by the presence of faults that can create preferential flow paths for water to reach the surface. This is most evident in Figure 30 where mapping of spring vents on two field investigation indicates that secondary spring vents can appear in the area. The occurrence of vents in the area is mostly driven by fractures and preferential pathways to surface. It is also expected that the most vents will be observable during the winter period as evapotranspiration has decreased, while in summer the converse will occur. Surface morphology of the springs can be classified as either peat mounds or rock seeps as indicated in Figure 27 to Figure 29. In the three main spring vents (689, 687 and 686) the trees can be observed growing in the vents; this would indicate that these vents were dry. Thus it is likely that these spring vents undergo a drying cycle in which the moisture content is low enough to allow germination of trees in the centre of the mound and then dieback during the wetter periods.

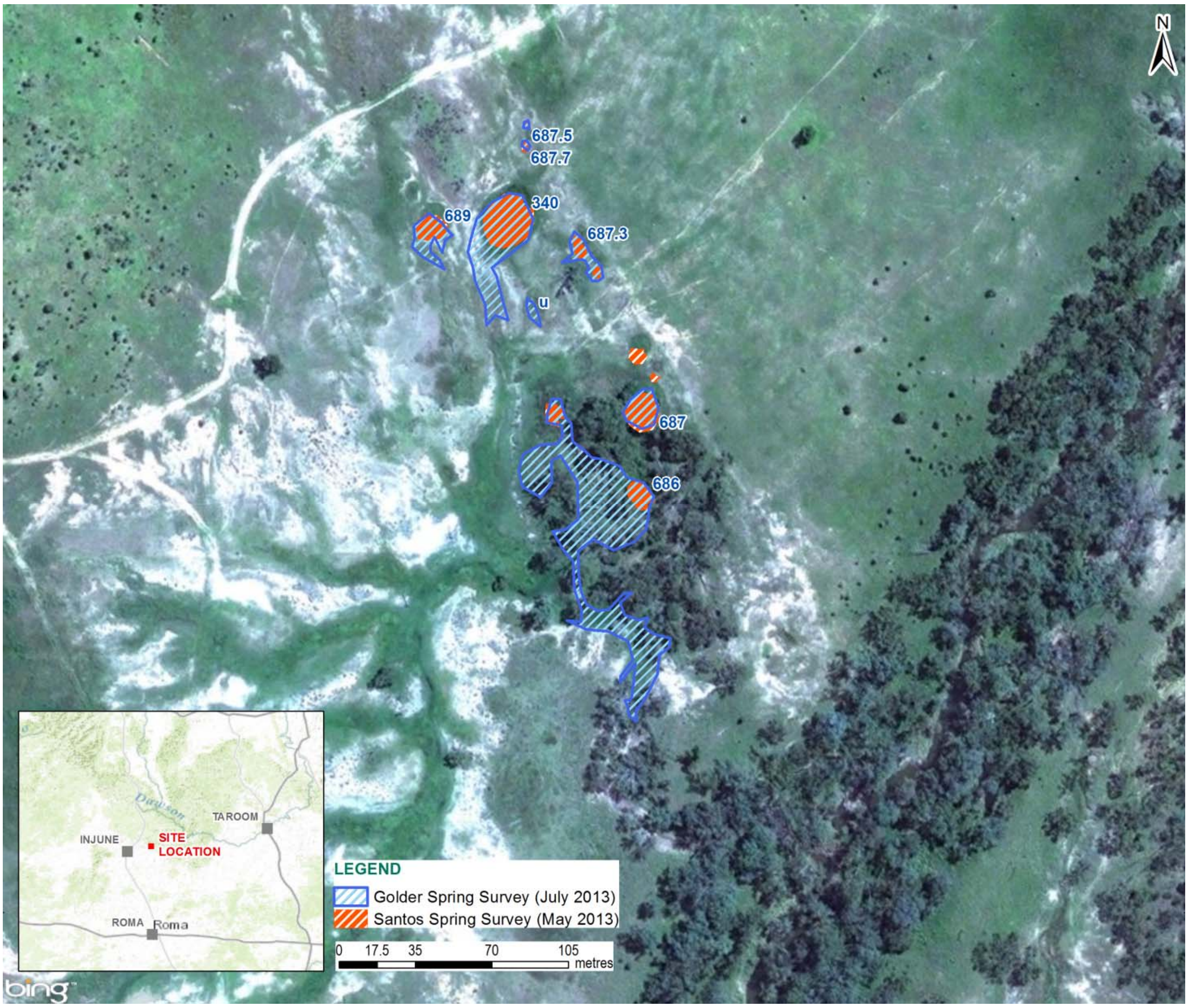


Figure 30: Lucky Last spring complex – red (May) and blue (July) surveys.

Groundwater usage in the area is limited to stock watering bores. The springs themselves have been significantly trampled by cattle (Figure 27–Figure 29) and in some instances sampling stations will need to be installed in the springs to obtain a representative sample of the groundwater emanating from the subsurface.

5.2.4 Ecology and Environmental Values

An ecological assessment of the Lucky Last spring complex was conducted by URS (Section 12.3) (URS, 2013). The values assessed included flora, fauna and water flow, the purpose of which was to identify the species and environmental conditions present at the site and outline anything that is protected, endangered or at risk of decline due to a change in conditions at the site.

The report identified the presence of the following key ecological and environmental features:

- *Eriocaulon carsonii* – conservation significant species listed as endangered under the Commonwealth EPBC Act and the Queensland NC Act – Vents 340, 787, 687.1, 687.4, 687.6 and 689
- *Eucalyptus tereticornis* – Vents 686, 687 and 688.
- Tusked Frog – Vulnerable species under the Queensland NC Act – Vent 689.

- Weeds including – Cirsium vulgare, Conyxa sumatrensis, Chloris virgate, however a full list is available in Section 12.3 (URS, 2013).
- Cattle and pigs – disturbed ground and damage at several vents as noted in Figure 27 – Figure 29.

5.2.5 Spring Description

A site visit was completed during July 2013 to collect field samples during the dry period (Figure 23 and Figure 24). During the field visit the flow condition of the spring was assessed as low (0.6 L/s Vent 688, Figure 22). Water flowed into the creek from the main spring mound (Vent 688) and an isolated spring mound across the creek (Vent 689). Stagnant pools of water were present at the other mounds at Lucky Last.

The most notable features of the Lucky Last spring complex from the July 2013 and other visits are listed in Table 5.

Table 5: Summary of Lucky Last spring complex data (Fensham et al., 2011).

Spring vent	General vent description
686-689, 687.1-6	■ Surface expression of groundwater which was either stagnant for springs surrounding the main mound. ■ Spring water from mound 688 and 689 discharging into Injune Creek. ■ The spring vents appeared to receive water from the Precipice Sandstone. ■ A groundwater fed stream and pools were observed. ■ Indications of variable groundwater flow conditions, with cycles of wetting and drying over the past 20 years (URS, 2013). ■ Ecological condition of springs is poor due to cattle impact and weeds. ■ Spring vent 688 flow approximately 0.6 L/s into Injune Creek. ■ Spring vents estimated to be 50–80 % affected by stock damage. ■ Damage from pigs reported. ■ An EPBC listed spring complex. ■ Surface morphology as peat mounds (vent 689, 340, 687 and 686) and rocky seeps (vent 687.3, 687.5 and 687.7)

5.3 Yebna 2/311

The Yebna 2/311 spring complex comprises two separate spring complexes which are assessed herein as a single complex. Spring Vent 534 is the only spring vent belonging to the Yebna 2 spring complex. All other spring vents belong to spring complex 311.

Yebna 2/311 is located downstream of Spring Rock Creek and Lucky Last complexes, along the lower reaches of Hutton Creek before the confluence with the Dawson River, and along the Dawson.

5.3.1 Geology

Geological mapping suggests that the surface geology consists mainly of the Precipice Sandstone with vent 534 being located possibly at the contact between the Evergreen Formation and Precipice Sandstone. This has been confirmed by outcrops of the Evergreen Formation and Precipice Sandstone at numerous vent locations within the spring complex (Figure 31) (Halcrow, 2013b). The Precipice Sandstone consists of fine to coarse grained sandstones and is overlain by the lower Evergreen Formation. Within the Evergreen Formation the Boxvale Sandstone member can be identified and consists of labile to sub-labile, fine to medium grained sandstones seen in outcrop at spring Vent 704 (Figure 32).

The spring vents of the Yebna 2/311 spring complex are located close to the most southerly extension of the Comet Ridge Structure and to the west the Mimosa Syncline (Finlayson, 1990). The spring vents are located around a regionally significant anticline known as the Purbrook Anticline. Spring vents associated with spring complex Yebna 2/311 lie on the eastern limb of the Purbrook Anticline with strata known to dip to the south-southeast. Only one small fault is mapped on regional 1:250,000 geological mapping (KCB, 2012) and geophysical cross-sections suggest that faults present in the area of the spring vents do not extend to the Precipice Sandstone and occur only in the coal measures at depth.

In the area of the spring vents, based on local groundwater abstraction bores, it is considered that the Boxvale Sandstone Member and the Precipice Sandstone are in hydraulic continuity and may act as one unit (Halcrow, 2013b).

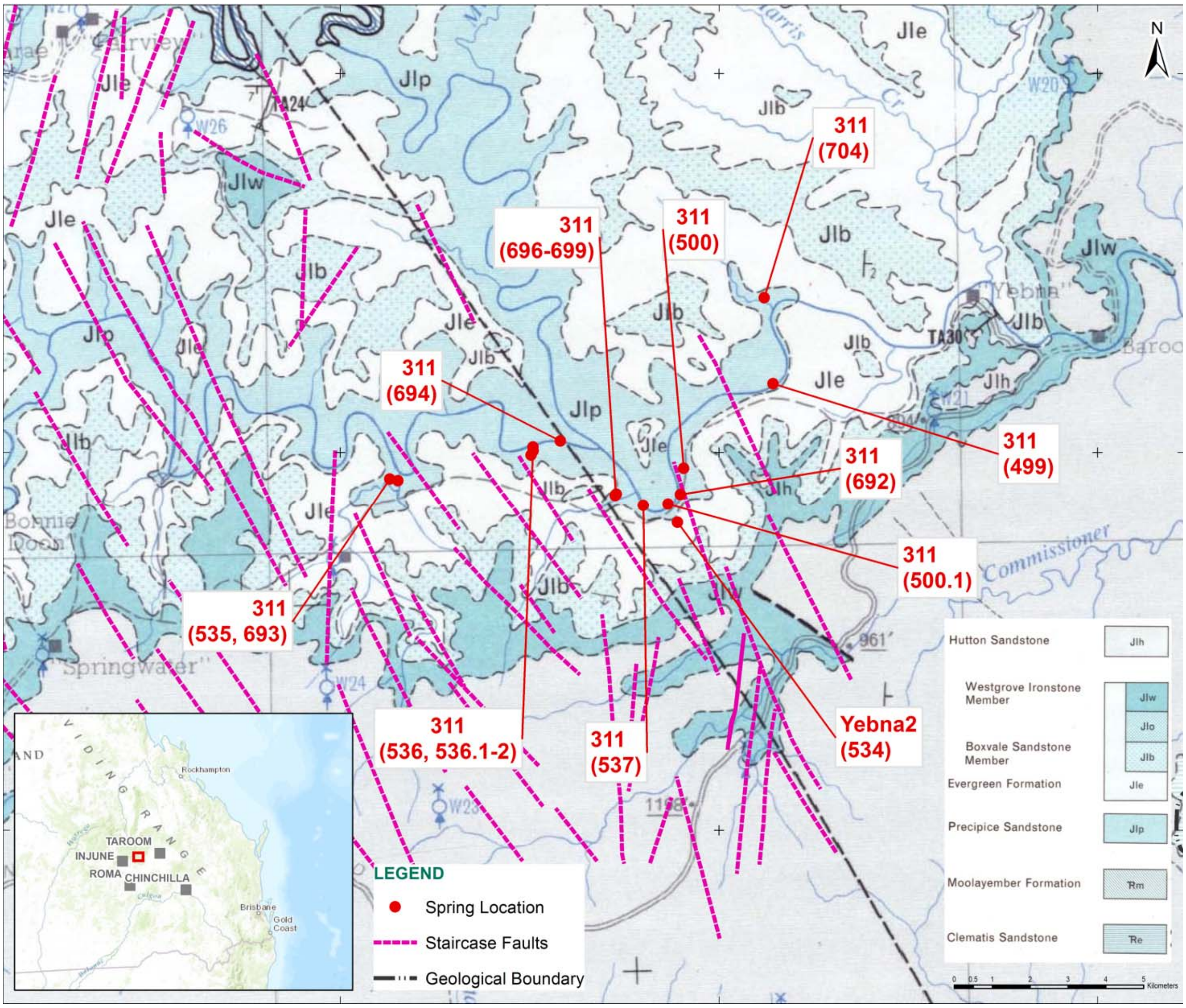


Figure 31: Local geology map at Yebna 2/311 spring complex.

Figure 32: Precipice Sandstone outcropping at 311 (Vent 704).

5.3.2 Surface Water

Spring Complex Yebna 2/311 is located within the Fitzroy River Basin. All spring vents associated with the spring complex are located on the banks of the Hutton Creek and Dawson River.

Watercourses within the Fitzroy River Basin are generally ephemeral with the Dawson River, Hutton Creek, Baffle Creek and Juandah Creek. The Dawson River is perennial in its lower reaches. Summer rainfall (November – March) dominates, with little or no flow during winter when the streams are reduced to a series of pools.

Most water table vents in spring complex 311 produces enough flow to reach the Dawson River (Figure 33). Surface water flow is dominated by groundwater baseflow produced from the spring complex in the surface water bodies.

Figure 33: Groundwater seeping from outcropping rock face.

5.3.3 Groundwater

The assessment undertaken to date (KCB, 2012) had the aim of identifying the source aquifer for the Yebna 2/311 spring complex (spring vents 500, 500B, 500A, 534, 535, 536, 536A, 537, 537A and 499). The study (KCB, 2012) indicated that the most likely source aquifers for the spring complex are the coarse grained Precipice Sandstone, and the Boxvale Sandstone Member of the Evergreen Formation. To confirm that the source aquifer is the Precipice Sandstone (Section 12.1), results obtained from field and laboratory samples can be compared to published water qualities for the respective Boxvale and Precipice Sandstone aquifers (KCB, 2012; Santos, 2013).

The Precipice Sandstone forms the basal Jurassic aquifer in the Surat Basin. This aquifer has a relatively high primary hydraulic conductivity and is known to have two units: upper and lower Precipice Sandstone aquifers. The basal unit consists of coarser particles and is less well cemented. The Precipice Sandstone in this area is assumed to be approximately 51 m thick based on local bore logs. Discharge rates from local bores abstracting from the Precipice Sandstone have been noted at 140 m^3/day from pumping tests (RN58177). The Precipice Sandstone in the vicinity of the springs is considered to be semi-confined by the fine grained shale and coal horizons in the Evergreen Formation, and is sub-artesian. The Precipice Sandstone is fully unconfined along the Dawson River. Due to the limited amount of piezometric data in the area it is not possible to construct a contour map of water levels.

Yebna 2 (spring vent 534) is the only spring vent in the area defined as artesian, and an investigation into its source aquifer was performed using water quality data. The system has the same water type as vents 500.1, 535, 536, 694 and 695. These systems are spatially located on the south side of the Dawson River and thus it could be expected that groundwater flow direction and source aquifer (water type) properties are the same. Thus Yebna 2 might be an expression of a semi-confined aquifer system which receives recharge water locally from the higher elevated zones where the Precipice Sandstone aquifer is unconfined.

Further details are collated in the following associated reports (Halcrow, 2013a; Santos, 2013) and Section 12.3).

5.3.4 Ecology and Environmental Values

An ecological assessment of the Yebna 2/311 spring complex was conducted in 2013 (Section 12.3) (URS, 2013). The values assessed included flora, fauna and water flow. The purpose of the survey was to identify the species and environmental conditions present at the site and outline anything that is protected, endangered or at risk of decline due to a change in conditions at the site.

The report identified the following significant ecological and environmental features:

- Good to moderate base flow at most vents.
- Tusked frog *(Adelotus brevis*) – Vulnerable species under the Queensland NC Act – vents 500, 535 and 536.
- Cattle – disturbed ground and damage to multiple vents.

5.3.5 Spring Description

A site visit was performed during July 2013 to collect field samples during the dry period. Water flow was observed from most of the springs visited and assessment of previous reports indicate a steady flow rate over reported time periods (Halcrow, 2013a; URS, 2013).

The key features of the Yebna 2/311 spring complex are listed in Table 6.

Table 6: Summary of Yebna 2/311 spring complex data (Fensham et al., 2011).

Spring vent	General vent description
499, 500, 500.1, 534-537, 536.1-2, 692-699, 704	■ Most spring vents are located among open depressions, however some springs discharge directly into surface water features. ■ The spring vents appeared to receive water from the Precipice Sandstone. ■ A groundwater fed stream and pools were observed. ■ Spring vents estimated to be 10–50 % affected by stock damage. ■ Damage from pigs reported. ■ EPBC listed spring vent 534 (no listed species, classified until now as a member of the Great Artesian Basin).

5.4 Summary

The localised physical environment of the spring complexes has been reported in this chapter including the geology, surface water, groundwater and ecological setting. The three spring complexes that are reported, Spring Rock Creek (561), Lucky Last (230) and Yebna 2/311 (311/591) have different features.

- Lucky Last has the most complex geological setting and highest environmental value. Lucky Last spring complex is fed from the Precipice Sandstone aquifer and can be classified as GAB artesian springs.

- Spring Rock Creek, although relatively close to Lucky Last is limited in spatial extent and exhibit a simpler geological and hydrogeological setting. Spring Rock Creek spring vent is fed by the Boxvale Sandstone and appears to be a water table discharge spring.

- The Yebna 2/311 spring complex is more widely spaced than the other springs with potentially two aquifers contributing to spring flow, although the Precipice Sandstone aquifer is the primary source of water for these spring vents.

All springs along the Dawson River and Hutton creek can be interpreted to be seepage points on bedding plains. Only Yebna 2 vent shows a more complex setting. All data collected by Santos follow standard Australian sampling procedures and QA/QC checks, with results maintained in an EQUIS database within Santos.

In the following chapter the data presented in this chapter will be used to develop a site conceptual model for each of the spring complexes which will include a geological and groundwater model. The site conceptual models conceptual models and candidate mitigation options from Chapter 4.0 will form the basis of the MCA analysis in Chapter 8.0.

6.0 SITE CONCEPTUAL MODELS

6.1 Background on Conceptual Models

A hydrogeological conceptual model provides a simplified description of a groundwater system such that further modelling activities or assessments can be performed. Thus, conceptual models act to communicate how the system functions and as the basis for mathematical model design. Conceptual models incorporate information from a variety of sources, disciplines and project stakeholders. An important aspect of conceptual models is that they clearly and as simply as possible distil relevant information into a working hypothesis. The focus of this chapter is on the development of a groundwater conceptual model for each spring complex to inform the multiple criteria analysis of potential spring mitigation options.

Guiding principles for the development of a groundwater conceptual model are summarised from Barnett et al. (2012):

1) *The level of detail within the conceptual model should be chosen, based on the modelling objectives, the availability of quality data, knowledge of the groundwater system of interest, and its complexity.*

2) *Alternative conceptual models should be considered to explore the significance of the uncertainty associated with different views of how the system operates.*

3) *The conceptual model should be developed based on observation, measurement and interpretation wherever possible. Quality-assured data should be used to improve confidence in the conceptual model.*

4) *The hydrogeological domain should be conceptualised to be large enough to cover the location of the key stresses on the groundwater system and the area influenced or impacted by those stresses. It should also be large enough to adequately capture the processes controlling groundwater behaviour in the study area.*

5) *There should be an ongoing process of refinement and feedback between conceptualisation, model design and model calibration to allow revisions and refinements to the conceptual model over time.*

The complete description of the methods used and steps to follow are presented in the Australian groundwater modelling guidelines (Barnett et al., 2012).

The most succinct method to communicate and document a conceptual groundwater model is a pictorial representation of the groundwater flow system highlighting the key geological and hydrogeological data, typically on to a simplified cross sectional figure. In the following sections preliminary conceptual models are developed for the three spring sites by:

5) Defining the geological framework which includes expected thickness, continuity, lithology and structure of aquifers or confining units.

6) Applying the established geological framework to develop the hydrogeological framework, including the groundwater boundaries, hydrostratigraphic units and flow system.

7) Defining geochemical boundaries and transport perimeters.

6.2 Spring Rock Creek

6.2.1 Geological and Groundwater Conceptual Model

A number of geological maps exist for the Spring Rock Creek area although no detailed mapping of the area has been performed. In general most maps indicate that the creek is located in the Precipice Sandstone although outcrops of lower Evergreen Formation are evident while accessing the site. In addition field parameters taken at the site of the water quality indicate elevated EC readings which are higher than that expected for the Precipice Sandstone aquifer system. As noted in the general geological description the Boxvale Sandstone outcrops consist of very fine to medium grained quartz rich sandstone. Medium to very coarse beds of sandstone were also found in the vicinity. In some sections the sandstone is highly weathered.

Approximate thickness of formations present in the area was estimated from drill logs. The maximum thickness of the Evergreen Formation that overlies the Precipice Sandstone is estimated to be 130 m and the Precipice Sandstone in the order of 40-60 m. These formations are underlain by the Moolayember Formation which is 250-300 m thick in the area.

The generalised geological model of the area consists of Evergreen Formation, Boxvale and Precipice Sandstones (Figure 35 and Figure 36). Due to weathering deep incised valleys have formed in the area, with the springs located in the low lying areas (change in vertical extent 120 m). Outcropping of Evergreen Upper and Lower sections can be observed as well as the intermittent occurrence of the Boxvale Sandstone. From drilling logs it is assumed that Precipice Sandstone will underlay the area (Figure 35 and Figure 36). The Boxvale Sandstone is known to occur intermittently within the Evergreen Formation. There is no drilling data in the immediate vicinity of the springs, hence a conceptual interpretation of the extent of the Boxvale Sandstone is presented in Figure 35 and Figure 36.

The conceptual groundwater model for Spring Rock Creek is based on the local geology model, drilling data, preceding information presented in reports (Fensham et al., 2011; Halcrow, 2013a; KCB, 2012, 2011) and Section 5.1.

Geochemical characterisation of the spring water indicates it is sourced from the Boxvale Sandstone (Halcrow, 2013a; KCB, 2012). Water produced at Spring Rock Creek eventually reports to Hutton Creek which is located approximately 200 m from the spring vent. Few drilling logs exist in the area that include water levels and water quality analysis. Due to the low permeability and layered nature of the Evergreen Formation, it is expected that the Boxvale Sandstone aquifer will be under confining conditions until it reaches the discharge point at Spring Rock Creek. Additionally due to the intermittent nature of the Boxvale Sandstone the potentiometric elevation is indicative only, and may be discontinuous in places.

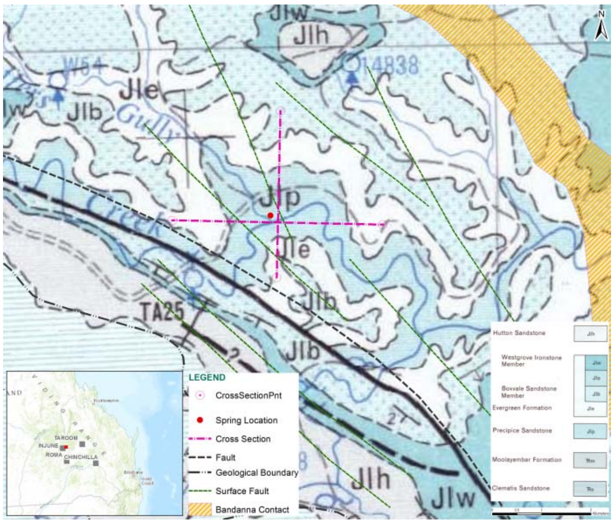


Figure 34: Location of cross section lines for Figure 35 and Figure 36.

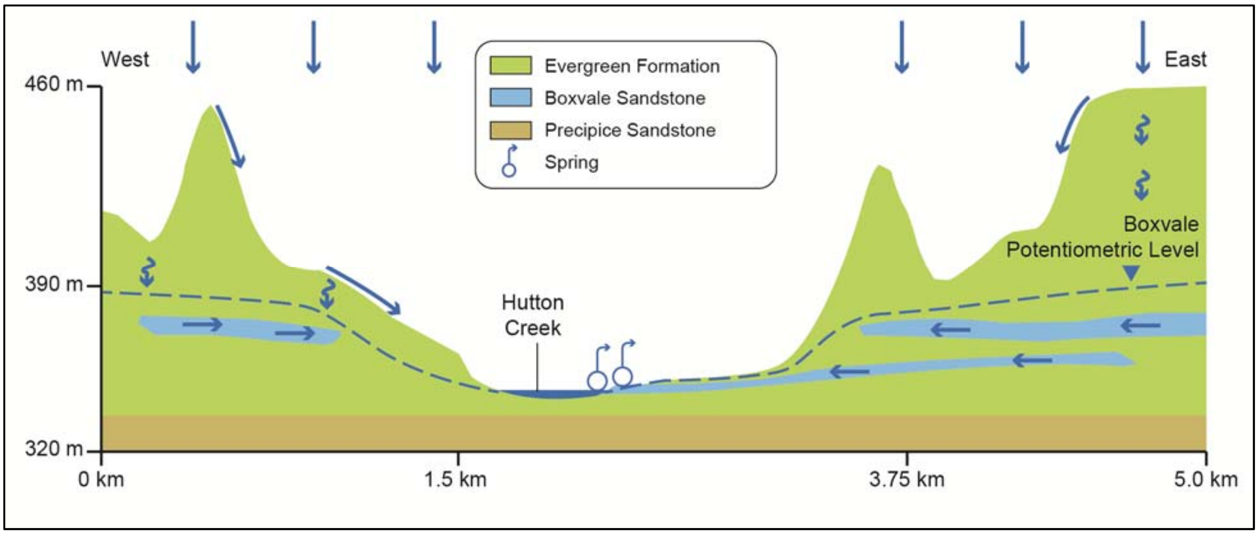


Figure 35: Spring Rock Creek east-west cross section of conceptual hydrogeological model.

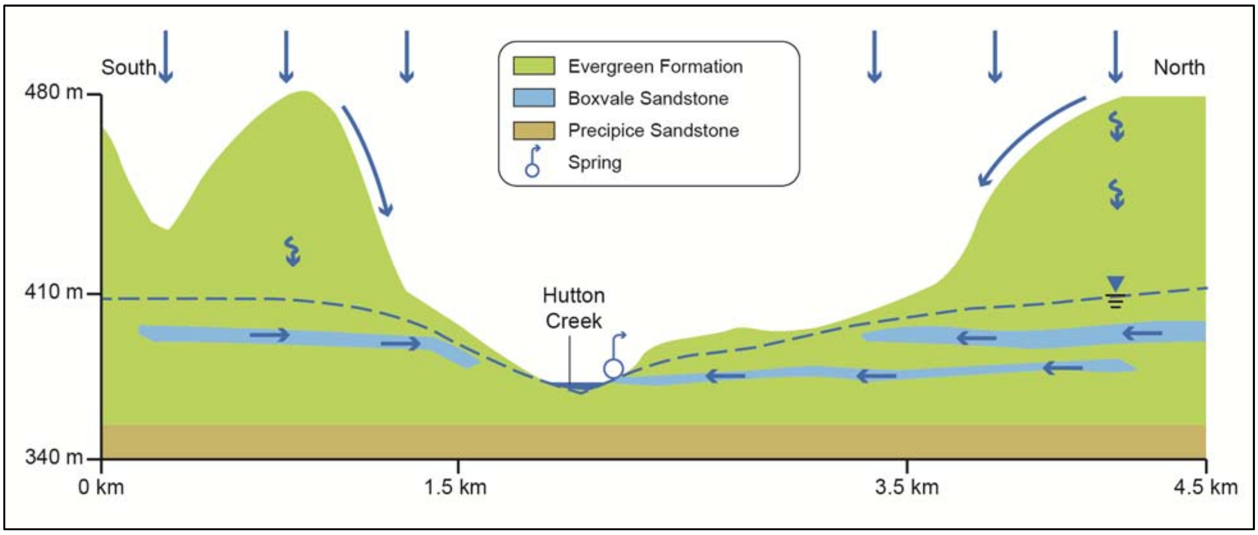


Figure 36: Spring Rock Creek north-south cross section of conceptual hydrogeological model.

6.3 Lucky Last

6.3.1 Geological and Groundwater Conceptual Model

Similarly to Spring Rock Creek, a number of geological maps exist for the Lucky Last area although no detailed mapping of the area has been performed. In general, most maps indicate that the tributary of Injune Creek flowing at the spring complex is in the Lower Evergreen Formation, the maps diverge on the presence or not of the Precipice Sandstone along Injune Creek. In addition, field parameters taken at the site of the water quality indicate elevated EC readings which are higher than that expected for the Precipice aquifer system. Lucky Last spring complex is located within a complex geological region, with major faulting structures being observed in the area (Figure 25). Interpretation of the seismic data and drilling logs has produced an understanding of the subsurface structures. An inverse stress regime is also present in the area, i.e. overburden structures are under shear pressure while deeper formation does not exhibit the same principal stress environment. The Hutton Sandstone outcrops to the southwest of the spring vents approximately 150 m from spring vent 285.

The maximum thickness of the Evergreen Formation that overlies the Precipice Sandstone is estimated to be 50 m and the Precipice Sandstone in the order of 40-60 m. It is important to note that the East-West geological section includes the unconformity Surat sediments and sharply dipping Bowen Basin sediments, including the Bandanna Coals. This means that, as indicated on the geological maps, the Bandanna Coals lie at subcrop beneath the Precipice aquifer.

The generalised geological model of the area consists of a mixture of formations as the faulting in the area has a complex structure (Figure 38 and Figure 39). The profile of the landscape surrounding the springs consists of a grass plain, with the springs located in clusters of mounds or surface vents. Out cropping of lower Evergreen Formation can be observed as well as the intermittent occurrence of the Boxvale Sandstone. From drilling logs it is assumed that Precipice Formation will underlay the area (Figure 38 and Figure 39). A major fault structure has been mapped to the south-west which is under compressional strain. The Boxvale Sandstone is known to occur intermittently within the Evergreen Formation. With an absence of drilling logs in the vicinity of the springs a conceptual interpretation to the extent of the Boxvale Sandstone is presented in Figure 38 and Figure 39. Inspection of extinct vents indicates that fracturing of the Evergreen Formation may be the most likely conduit for the surface water expression.

The conceptual groundwater model for Lucky Last is based on the conceptual model of the local geology, drilling data, preceding information presented in reports (Fensham et al., 2011; Halcrow, 2013a; KCB, 2012) and Section 5.2. Geochemical characterisation of the spring water indicates it is sourced from the Precipice Sandstone (Halcrow, 2013a; KCB, 2012). Some of the water produced at Lucky Last report to a tributary of Injune Creek which is located approximately 200 m from the major spring vent (Vent 688). Few drilling logs exist in the area that include water levels and geochemical analysis.

It is interpreted that the Precipice Sandstone aquifer is under confining conditions at Lucky Last. Although major faulting is present in the area it has been hypothesised that the presence of major faults might have reactivated secondary or minor faults. These secondary faulting systems should be open or under a reduced stress regime (red arrows in Figure 38 and Figure 39), this would in effect create a pathway for water to migrate to surface. Considering the layout of the spring vents (Figure 26 and Figure 30), the springs occur in a linear arrangement within a band of 40 m that is running north-west and south-east. The linear arrangement is slightly deviated from that observed from the major faults to the south and north of this area (Figure 30). Further assessment of Figure 30 clearly indicates a change in vegetation on the northern side of the spring, which might be due to a fault structure or lineament. Thus if secondary faulting or fracturing occurred, it might be nearly perpendicular to the major fault. Although not confirmed, a visual interpretation of possible water bearing features can be made which roughly correspond to the spring vent locations (Figure 30).

The potentiometric surface of the Precipice Sandstone aquifer system is expected to be consistent over the area due to the relatively minor changes in topography (overburden) and the expected thickness of the aquifer itself (Figure 38 and Figure 39). Additionally, due to the intermittent nature of the Boxvale Sandstone in the Evergreen Formation, the potentiometric level for the Boxvale Sandstone aquifer is only indicative of expected pressure levels and it may be discontinuous in places. Pools have been observed in Injune Creek during the dry season and these are most likely sustained by discharge from Boxvale and Precipice aquifers. It should also be highlighted that the Bandanna Formation subcrops under the Precipice Sandstone to the east of the spring complex. The Precipice Sandstone can be divided into two aquifer–type systems (USQ, 2011). The upper Precipice Sandstone aquifer is generally finer grained material and well cemented, which results in reduced hydraulic conductivity values and connectivity in the aquifer system. The lower Precipice Sandstone aquifer consists of coarser grained material and generally has a higher hydraulic conductivity compared to the upper Precipice Sandstone system.

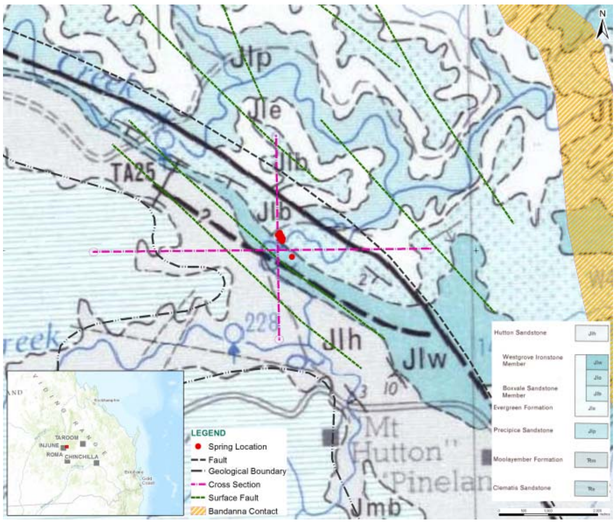


Figure 37: Location of cross section lines for Figure 38 and Figure 39.

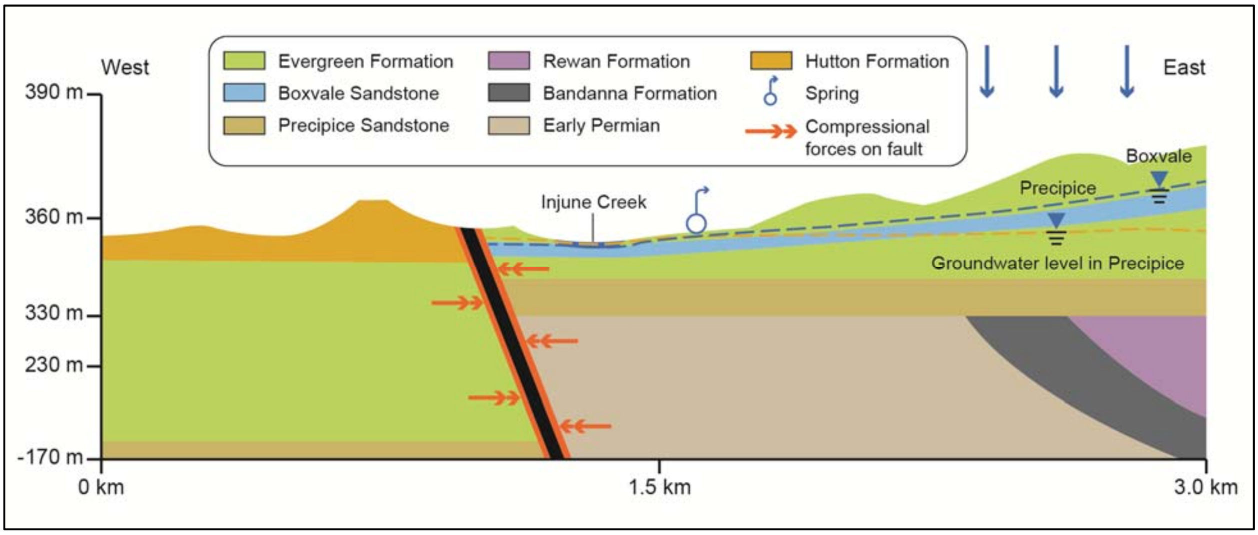


Figure 38: Lucky Last east-west cross section of conceptual hydrogeological model.

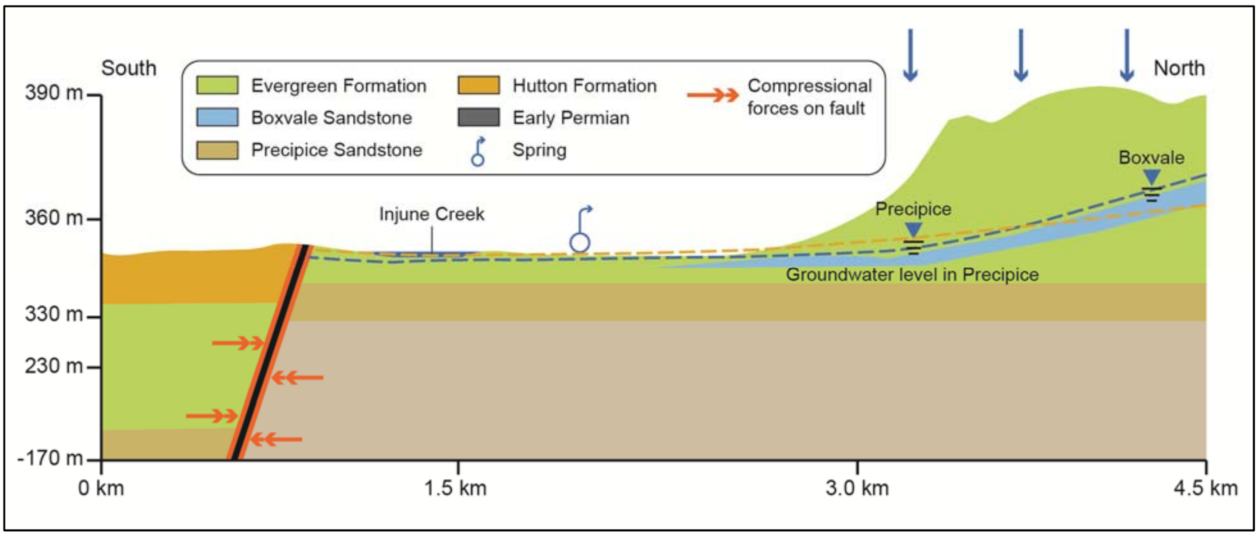


Figure 39: Lucky Last north-south cross section of conceptual hydrogeological model.

6.4 Yebna 2/311

6.4.1 Geological and Groundwater Conceptual Model

Geological mapping suggests that the surface geology consists mainly of the Precipice Sandstone with areas of Evergreen Formation (Boxvale Sandstone Member) further downstream or when moving away from Hutton Creek and the Dawson River. The spring vents of the Yebna 2/311 spring complex are located close to the most southerly extension of the Comet Ridge Structure and to the west the Mimosa Syncline (Finlayson, 1990). Only one small fault is mapped on regional 1:250,000 geological mapping (KCB, 2012) and geophysical cross-sections suggest that faults present in the area of the spring vents do not extend to the Precipice Sandstone and occur only in the coal measures at depth. The broad geological regime is therefore thought to be less complex than at Lucky Last.

The generalised geological model of the area consists of Evergreen Formation and Precipice Sandstones (Figure 41). Due to weathering deep incised valleys have formed in the area, with the springs located in the low lying areas (change in vertical extent of 80 m). Out cropping of Evergreen Formation can be observed at higher elevations, however around the spring vents it is predominantly Precipice Sandstone. Water table seeps are observed in the incised valley structures.

The conceptual groundwater model for Yebna 2/311 is based on the conceptual model of the local geology, drilling data, preceding information presented in reports (Fensham et al., 2011; Halcrow, 2013a; KCB, 2011, 2012) and Section 5.0. Geochemical characterisation of the spring water indicates it is sourced from the Precipice Sandstone (Halcrow, 2013a; KCB, 2012). Water from the spring vents flows to the Dawson River which is located approximately 200 m away.

Relatively few drilling logs exist in the area with both water levels and water quality analysis. It is postulated that the Precipice Sandstone aquifer will be under semi-confining conditions until it reaches the discharge point at 311 and is confined at Yebna 2 by the presence of the Evergreen Formation. The potentiometric surface presented in Figure 41 is illustrative of expected pressure levels, however from seepage zones present at 311 it is inferred that these points indicate approximate water level in these areas. Yebna 2 does not have a significant flow at the vent and would thus express the piezometric surface in this area.

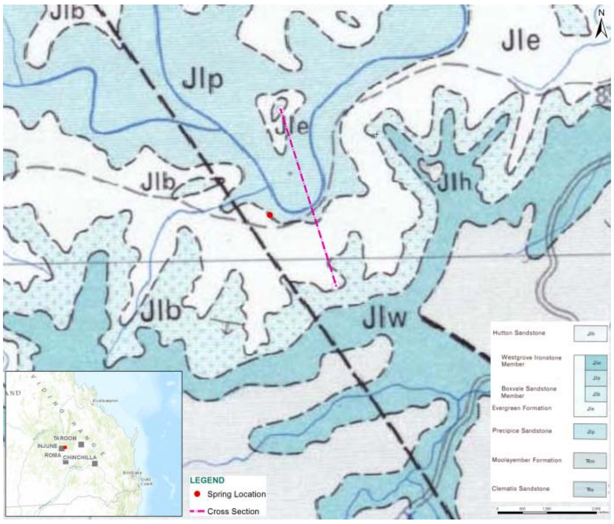


Figure 40: Location of cross section line for Figure 41.

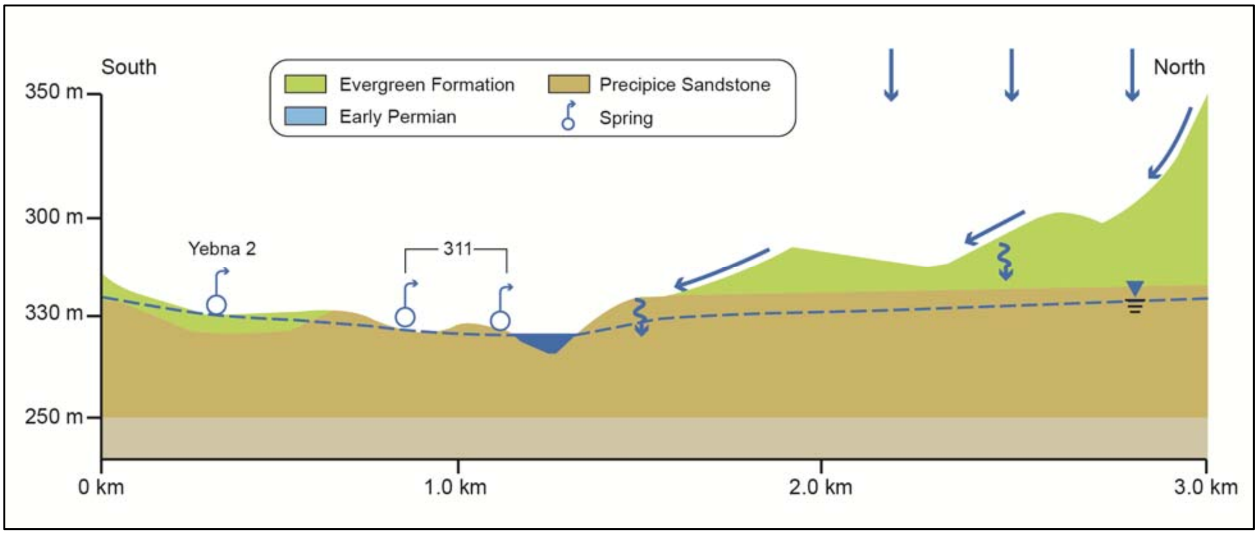


Figure 41: Yebna 2/311 north-south cross section of conceptual hydrogeological model.

6.5 Summary

An initial conceptual understanding of the spring complexes has been synthesised into pictorial representations of the geology and groundwater systems. Current knowledge on the localised piezometric surface at the spring vents are limited due to minimal monitoring data points; but preliminary interpretations regarding piezometric levels were inferred from data and hydrogeological judgement. The source aquifer for each of the spring vents is identified with some confidence from water quality data (Section 12.1) and included in the hydrogeological model.

The following bullets summarise the general interpretation at each spring complex:

- Spring Rock Creek spring is fed by the Boxvale Sandstone aquifer and the system is a water table discharge spring system.
- Lucky Last spring complex is fed by the Precipice Sandstone aquifer and is an artesian discharge spring system. Artesian pressures are not expected to be very high (probably less than 2 m head). The springs are associated with major faults in the area.
- Yebna 2/ 311 spring complex is fed primarily by the Precipice Sandstone aquifer and the system is a water table discharge spring system. The Yebna 2 vent is believed to be a contact spring rather than an artesian discharge spring due to proximity of unconfined zone close to the spring vent.

7.0 SPRING RISK ASSESSMENT

To management and mitigate potential risks to the springs it is helpful to establish the broad context in which the springs lie and the quality of the environmental values present at the springs. Establishing this context enables subsequent risk assessments to be tailored and focussed.

This section presents risk analyses that consider the nature and magnitude of risk to the spring complexes following a risk assessment method put forward by (Green et al., 2013) for springs in the GAB. In ‘Evaluating Water Use Impacts on Great Artesian Basin Springs’ (Green et al., 2013) the risk factors include drawdown and ecosystem vulnerability, including water quality, erosion and fire. Figure 42 below outlines the proposed method for undertaking a risk assessment on springs in the GAB as proposed by (Green et al., 2013). The following sections in this chapter systematically address each of these steps to complete the risk analysis.

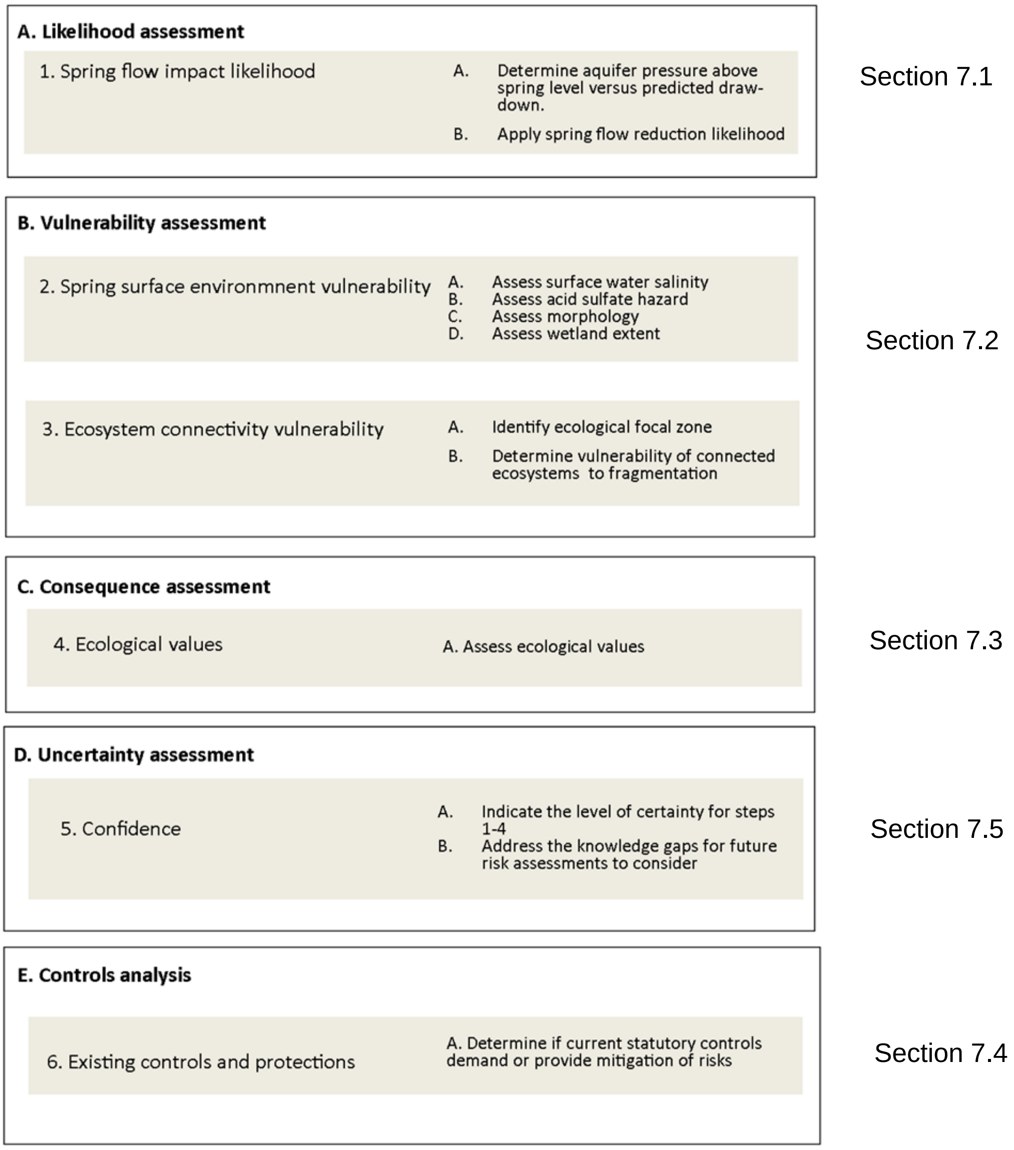


Figure 42: Method for undertaking a risk assessment on springs in the GAB (Green et al., 2013).

It should be noted that under this assessment Ecosystem connectivity vulnerability will not be assessed as the spring complexes are not isolated habitats. Thus Ecosystem connectivity vulnerability cannot be assessed.

7.1 Likelihood Assessment

The expected drawdown at a spring or spring complex is subject to the nature of the groundwater development, its proximity to the subject springs and the nature of the hydrogeological connections between the development and the springs.

Firstly, to determine the likely impact of aquifer drawdown on the flow of a spring, the predicted range of aquifer drawdown at a spring should be compared with potentiometric head elevation of the spring above spring surface level.

To predict the possible impact of CSG activities at the springs, a groundwater model was constructed which included the most up to date information available (QWC, 2012). In the current document a response was required for impacted springs as indicated in the UWIR (QWC, 2012). The Immediately Affected Area (IAA) and the Long-term Affected Area (LAA) are identified for aquifers in which water level or water pressure impacts are predicted to exceed trigger thresholds.

The following section from the UWIR (QWC, 2012) highlights the primary purpose of the model and it's intended use. From the model prediction no significant aquifer system could be identified in the IAA, however a number of impacts were noted for the LAA's and those applicable to the present study are listed in Table 7.

"The primary purpose of the model was to predict regional water pressure or water level changes in aquifers within the Surat CMA in response to extraction of CSG water. More specifically the model was used to:

- *Define the IAA of consolidated aquifers – that is the areas of the aquifers where water pressures are predicted to decline by more than 5 m within the next three years (to beginning of 2015).*
- *Define the LAA of consolidated aquifers – that is the areas of the aquifers where water pressures are predicted to decline by more than 5 m at any time in the future.*
- *Identify potentially affected springs – springs where the water pressure in aquifers underlying the spring sites is predicted to decline by more than 0.2 m at any time in the future.*
- *Predict the rate and volume of water that will move from the Condamine Alluvium into the Walloon Coal Measures as a result of CSG activities.*
- *Analyse the trends in water pressure changes due to extraction of CSG water.*
- *Estimate the quantity of CSG water that is expected to be produced.*

It should be noted that the model is designed for regional water pressure impact assessment and is not designed to be used to directly predict water pressure or water level variations at a local scale. Therefore, predicted impacts on individual bores or specific locations are of a generalised nature only."

Table 7: Inferred source aquifers of the spring complexes.

Spring complex	Spring complex number	Primary source aquifer	Estimated initial impact[1]	Maximum impact		Total risk rank
				Magnitude (m)	Timeframe (Yrs)	
230	287, 340, 686-9, 687.1-6	Precipice	5-40 years	1-1.5	40-60	5
311	499-500, 500.1, 535-537, 536.1-2, 692-699, 704	Precipice	40-50 years	0.2-0.5	50-60	4
561	285	Boxvale	5-60 years	1-1.5	30-50	4

[1] Estimated years from 2012 before impact exceeds 0.2 m.

The likelihood component of a spring flow rate reduction risk, arising from a groundwater development, is determined by the probability that the development will result in spring flow reduction of a particular amount (as a percentage of initial flow rate). To evaluate this, an estimate is required of both the expected pressure drawdown in the spring source aquifer at the location of the spring or spring complex, and the initial (prior to the expected drawdown) elevation of the aquifer pressure above spring elevation. It is also assumed that the correct geological and hydrogeological model has been used to determine the proposed impact at the springs. Note that currently piezometric head elevation of the spring complexes can only be inferred rather than measured at most spring sites.

7.2 Risk Assessment

Table 8 below provides ratings for the estimated risk of spring flow reduction as a result of various aquifer drawdown and aquifer pressure categories.

Table 8: Flow reduction risk matrix (Green et al., 2013).

Predicted drawdown	Aquifer pressure above spring surface			
	> 15 m	10-15 m	5-10 m	< 5 m
0.1-0.6 m	Low	Low	Moderate	Extreme
0.6-1.5 m	Low	Moderate	High	Extreme
> 1.5 m	Moderate	High	Extreme	Extreme

For the risk assessments, a range of plausible aquifer drawdown scenarios were used to provide flow reduction risks to take forward for use in the vulnerability assessment.

The spring flow reduction risk ratings were then combined with the results from vulnerability assessments. Vulnerability assessments take into account the effects of spring flow reduction on the quality and quantity of water, extent of wetland vegetation and condition of physical surface environment.

When interpreting risk and vulnerability a clear distinction between spring complex type is required as spring complex 230 (Lucky Last) and Yebna 2 can be defined as artesian springs. In contrast spring complex 311 and 561 (Spring Rock Creek) can be classified as water table driven seepage zones. Yebna 2 and some of the Lucky Last spring vents can be classified as very low flow or no flow vents with only spring Vent 688 and 685 producing enough water to flow into the creek system.

An assessment of the spring complexes has been performed following the procedure by Green (page 38, Table 4.4) (Green et al., 2013). Observations relating to each spring complex are listed in Table 9.

Table 9: Minimum and maximum spring flow reduction impacts.

Spring complex	Lucky Last 688	Lucky Last 287, 340, 686-7, 689, 687.1-6	Yebna 2 311	Spring Rock Creek 285
Spring complex number	230	230	591/311	561
Primary source aquifer	Precipice	Precipice	Precipice	Boxvale
Variable				
Aquifer draw down category	High	High	Low	Low
Flow vulnerability category	Very high	NA	NA	Low
Minimum aquifer drawdown (m)	0.2	NA	Low	Low
Maximum aquifer drawdown (m)	1.5	NA	Low	1.5
Minimum aquifer pressure head (m)	-1.0	-1.0	NA	NA
Maximum aquifer pressure head (m)	1.5	1.5	NA	NA
Minimum % flow reduction	1	0	NA	NA
Maximum % flow reduction	50	0	NA	NA
Flow reduction impact category	Extreme	Low	Low	Low

Risk ratings reported for aquifer drawdown have been derived considering the conceptual models reported previously for the geology and hydrogeology, particularly based on the perceived degree of connectivity between the springs and geological units to be subject to direct depressurisation during CSG production.

- Lucky Last has been rated as high risk since the source aquifer has been identified as the Precipice Sandstone. In the area of these springs there is a high probability of the Precipice Sandstone being hydraulically connected with the Bandanna formation, hence the high risk rating.
- Yebna 2/311 has been assigned a low risk as the regional description of the area includes an unconfined aquifer which would indicate that local recharge might be dominant in the area. Thus it is expected that the unconfined aquifer system would contribute the bulk of the water for the spring discharge in the area due to local recharge.
- Spring Rock Creek has been assigned a low risk as the source aquifer has been identified as the Boxvale Sandstone. Thus it is expected that there is no direct connection with the Precipice Sandstone and the spring complex sources its water from the Evergreen Formation.

As noted previously, a number of springs are no flow springs and do not support an extensive ecosystem in their surrounding areas. Additionally, the seasonality observed at the spring vents means the spring complexes may dry out during certain periods of the year which can be indicated by the presence of trees or dry land species.

7.3 Vulnerability

7.3.1 Chemical Environmental Vulnerability

7.3.1.1 Salinity

Springs frequently discharge into a pool which retains the water before it overflows and spills into a wetland environment and seeps into the surface sediments. Water leaves the surface environment by evaporation, transpiration, and surface or groundwater flow. If spring flow decreases there is an increase in the residence time of water in the surface environment. This causes the proportion water leaving the environment by evaporation to increase and the proportion leaving by surface and groundwater flow to decrease. This can result in an increase in the average salinity of the water within the spring pool.

Springs which are vulnerable to increased salinity as a result of flow reduction are those with:

- Low out flows of water from the environment.
- Water and/or wetland vegetation spread over a wide area (providing greater evaporation surface).
- Higher salinity spring discharge.

Low vulnerability springs are those with:

- High rates of flow through and out of the pool or wetland environment.
- Water and/or vegetation covering a small area compared to the rate of spring flow.
- Lower salinity spring discharge.

Table 10 below highlights the characteristics of springs with, high, medium and low vulnerability to salinity.

Table 10: Risk rating for spring surface water salinity vulnerability (QWC, 2012).

Surface water salinity vulnerability rating	Spring environment characteristics
High	Low outflow, large area/flow rate ratio, high spring discharge salinity.
Medium	Moderate outflow, small-large area/flow rate ratio, moderate spring discharge salinity.
Low	High outflow, small area/flow rate ratio, lower spring discharge salinity.

7.3.1.2 Acidification

Sulfidic soils and sediments (Acid Sulfate Soils – ASS) are associated with springs in the GAB. This can lead to environmental hazards including acidification of soil and water, dissolution and mobilisation of metals, deoxygenation and production of noxious gases.

The risks from associated ASS hazards vary depending on the concentrations of sulphide minerals and calcium carbonate present. As flow reduces soils can dry out and oxidise. This then allows the production of sulphuric acid to occur which can be mobilised due to rainfall or restoration of spring flow. As a result spring water pH is lowered and concentrations of trace metals increase.

Springs which are vulnerable to acidification as a result of spring flow reduction are those with:

- High concentrations of sulphide minerals in the surrounding soils and sediments.
- Low concentrations of calcium carbonate in the surrounding soils and sediments.
- Organic rich sediments.
- Naturally low pH sediments and spring surface water.
- Static or low flow water conditions.

Table 11 below highlights the characteristics of springs with high, medium and low vulnerability to acidification.

Table 11: Acidification vulnerability risk rating

Acidification vulnerability rating	Spring environment characteristics
High	Low pH sediments or spring surface water, presence of organic rich sediments, presence of static or low flow water conditions, high sulfur concentration in spring water, absence of calcium carbonate
Medium	Combination of some of the "high" vulnerability characteristics above and some "low" vulnerability characteristics below.
Low	Neutral-high pH sediments or surface water, absences of organic rich sediments, flowing or oxygen rich water, low sulfate concentrations in spring water, presence of calcium carbonate.

7.3.2 Physical Environmental Vulnerability

7.3.2.1 Erosion

Erosion of the physical landscape in a spring environment can create a threat to the condition of the ecosystem. Erosion environment can occur as a result of spring flow reduction, the drying of soils and sediments and livestock damage.

Sandy and silty sediments such as those in the Fairview region have a high vulnerability to erosion resulting from spring flow reduction. These sediments allow easy access to water for plant roots which establishes vegetation and stabilises the environment. Flow reduction causes a decline in the vegetation cover and root systems. This allows the sediments to dry out and exposes them to wind and rain resulting in intense erosion.

Cattle and pigs also cause erosion and damage to the environment through, over grazing, trampling and rooting of vegetation and soil and the destabilisation of wetland edges. The effects of livestock erosion can be compounded where flow reduction and vegetation removal also occur.

- Nearly all springs in the Fairview complexes have been heavily impacted by cattle through trampling, grazing, fouling and pigs through rooting and wallows (URS, 2013).
- Flow reduction in the Lucky Last Spring complex may result in the loss of wetland systems and replacement of wetland species with non-wetland species. The complex is also identified as having damage from cattle and pigs (URS, 2013).

7.3.2.2 Fire

Fire is frequently used as a means to control vegetation growth and reduce the risk of wild fires in the GAB. This can be potentially damaging to spring environments if misused.

- Where peat is present, if a spring surface has become dry from reduced flow, there is a risk that fire can spread into the underground peat layer. Fires can smoulder in the peat for long periods and can reduce the peat bog in size.
- Fire may cause the destruction of aquatic plants if water levels are not high enough.
- Fire may impact on rare and threatened plants associated with mound springs (Arthraxon hispidus and Dimeria) (Fensham and Fairfax, 2005).

The risk of fire to spring environments can be reduced by conducting controlled burns at appropriate times in the season and only when water levels are sufficient.

7.4 Consequence Assessment

The third step of the risk analysis process given in Figure 42 involves conducting a consequence assessment to determine the ecological impact that may occur if a decrease in spring flow were to arise.

The overarching principle of the consequence assessment is the maintenance of ecosystem integrity (Green et al., 2013). Some principles for maintaining GAB spring ecosystem integrity (structure and function of biota and hydrology) are as follows:

- The integrity of the ecological focal zone incorporates spring vents, tails, diffuse discharge and the wetted zone associated with spring discharge.
- Maintaining biodiversity correlates to maintaining habitat diversity.
- Spatial and temporal connectivity relates to the system's resistance (ability to withstand disturbance) and resilience (ability to recover from disturbance).
- Groundwater pressure maintains system integrity through maintaining the biotic threshold for: flow volume (wetted area and connectivity), water quality (pH / EC), soil chemistry (pH) and water temperature.
- Spring ecosystem resistance has adapted through slow change of critical environmental parameters with artesian springs being one of the most stable non-marine aquatic environments.

7.4.1 Assess Ecological Values

To evaluate the ecological values of a spring group, an application of the criteria from the HEVAE guideline (HEVAE, 2012) is recommended as summarised in the risk assessment plan for the GAB (Green et al., 2013).

- Diversity – spring group exhibits exceptional diversity of species or habitats and/or hydrological and/or geomorphological features/processes.
- Distinctiveness – spring group is a rare/ threatened or unusual aquatic ecosystem and/or it supports rare/threatened species/ communities and/or it exhibits rare or unusual geomorphological features/ processes and/or environmental conditions.
- Vital habitat – spring group provides habitat for unusually large numbers of a particular species of interest and/or it supports species of interest in critical life cycle stages or at times of stress and/or it supports specific communities and species assemblages.
- Evolutionary history – spring group exhibits features or processes and/or supports species or communities which demonstrate the evolution of Australia's landscape or biota.
- Naturalness – the spring group's aquatic ecosystem values are not adversely affected by modern human activity to a significant level.

The following describes a method to rate the ecological values for a spring group based on the five HEVAE criteria of diversity, distinctiveness, vital habitat, evolutionary history and naturalness.

- Diversity

A number of measures have been examined to determine the ecological values of habitat diversity. Grazing has a strong negative impact on floristic diversity.

The diversity of habitat is also important. Springs with greater variety of habitat support more species. Wetland diversity can be determined by calculating the ratio of functional wetland habitat to the number of vents. The functional wetland habitat is the sum of springs with saturated, free water or free water and tail classes as per the spring survey (Green et al., 2013). Ecological diversity value rating for each of the respective spring complexes have been summarised in Table 12.

Table 12: Initial ecological diversity value rating for the respective spring complexes.

Spring Complex	Lucky Last	Yebna 2/311	Spring Rock Creek
Spring Complex Number	**230**	**591/311**	**285**
Source Aquifer	**Precipice**	**Precipice**	**Boxvale**
Habitat rating			
Habitat diversity rating	Low	Low	Low
Floristic diversity rating	Low	Low	Low
Wetland diversity rating	Low	Low	Low

- Distinctiveness

Distinctiveness is a measure of how rare or unusual a spring groups is. Spring groups that rank highly here are those that contain multiple rare threatened or unusual species or contain multiple unique or unusual geomorphological features.

In general due to location and spring vent morphology most of the spring complexes can be classified as low ecological distinctiveness.

- Vital habitat

Vital habitat is a measure of just how important a GAB spring group is in supporting groundwater dependent flora and fauna as well as other non-aquatic flora and fauna in the area. Non-groundwater dependent flora and fauna include species that may be dependent of springs as a water source or other terrestrial flora and fauna that benefit from the presence of springs. The lowest ranking possible under the GAB risk assessment is medium. The Fairview springs are classified as medium, largely due to the impact that grazing has had on the spring complexes.

- Evolutionary history

Evolutionary history is the ranking of a spring group features, processes, species or communities that demonstrate the evolution of Australia’s landscape or biota. Because of their age and stability, GAB springs are recognised as important sites for the study of evolutionary history. The lowest rating for the spring complexes have been assigned since the assessment for endemic species existing within the arid-zone (< 500 mm mean annual rainfall) does not apply for this area (mean annual rainfall 590 mm).

- Naturalness

Naturalness is the measure of how affected a GAB spring group is to post-European human disturbance. This includes impacts from stock and feral animals and weeds as they have been introduced by human activity. All vents suffer from a degree of grazing and/or trampling damage, in addition weeds have also been noted at most of the vents and would classify as a high level of physical disturbance. Thus the naturalness rating for all spring complexes is low.

7.5 Summary

The final step in the Risk Assessment is the consideration of existing control measures that are in place through the operation of the water allocation plan or related statutory controls. The Controls Analysis process is outlined and described in the Part III of the document. The assessments contributing to the overall Vulnerability Assessment presented in this section are for all the spring complexes are summarised in Table 13.

Table 13: Risk assessment summary for spring complexes.

Risk Assessment Step	Spring Complex/Complex Number/Primary Source Aquifer	Rating*	Confidence*
Spring Complex	**Lucky Last / 230 / Precipice**		
Likelihood	Aquifer pressure	H	M
	Flow reduction	E	M
Vulnerability	Surface water salinity	L	H
	Acid sulfate hazard	L	H
	Wetland extent	M	H
	Ecological focal zone	NA	H
	Wetland connectivity vulnerability	M	H
Consequence	Diversity	L	H
	Distinctiveness	L	H
	Vital habitat	L	H
	Evolutionary history	L	H
	Naturalness	L	H
Cumulative Index[1]		*M*	*H*
Spring Complex	**591/311 – Yebna 2/311**		
Likelihood	Aquifer pressure	L	M
	Flow reduction	NA	M
Vulnerability	Surface water salinity	L	H
	Acid sulfate hazard	L	H
	Wetland extent	L	H
	Ecological focal zone		H
	Wetland connectivity vulnerability	L	H
Consequence	Diversity	L	H
	Distinctiveness	L	H
	Vital habitat	L	H
	Evolutionary history	L	H
	Naturalness	L	H
Cumulative Index[1]		*L*	*H*
Spring Complex	**285 – Spring Rock Creek**		
Likelihood	Aquifer pressure	L	M
	Flow reduction	L	M
Vulnerability	Surface water salinity	L	H
	Acid sulfate hazard	L	H
	Wetland extent	L	H
	Ecological focal zone		H
	Wetland connectivity vulnerability	L	H
Consequence	Diversity	L	H
	Distinctiveness	L	H
	Vital habitat	L	H
	Evolutionary history	L	H
	Naturalness	L	H
Cumulative Index[1]		*L*	*H*

* E = Extreme (4), H = High (3), M = Medium (2), L = Low (1), NA = Not applicable, 1 = Cumulative Index {0.3xLikelihood + 0.2xVulnerability + 0.5xConsequence}

PART III
MONITORING RESPONSE AND POTENTIAL MITIGATION OPTIONS

8.0 SELECTION OF CANDIDATE MITIGATION OPTIONS

8.1 Introduction

In the preceding chapters information was presented about:

- The regional setting for GAB springs.
- A review of potential management options to mitigate predicted impacts to spring vents from CSG production.
- Fairview springs site data.
- Site conceptual models, characterising the hydrogeological setting at the spring complexes.
- A spring vulnerability assessment.

The information gathered in the above bulleted list is required as inputs to a decision for preferred management options at the spring complexes. To assess and determine the most appropriate spring mitigation option(s) an objective method is needed to assess both numerical classifications and subjective judgements. Ideally the method used should also be transparent and recognised as an appropriate decision support system.

Multiple criteria analysis (MCA) is a decision-support technique that can incorporate financial and non-financial factors. It can be applied to a range of systems that demand a variety of input variables.

All MCA approaches make the options and their contribution to the different criteria explicit, and all require the exercise of judgement. Formal MCA techniques usually provide an explicit relative weighting system for the different criteria. The main role of the technique is to deal with the difficulties that human decision-makers have in handling large amounts of complex information in a consistent way without bias.

MCA techniques can be used to identify a single most preferred option, to rank options, to short-list a limited number of options for subsequent detailed appraisal, or simply to distinguish acceptable from unacceptable possibilities. Detailed information relating to key features and stages of the MCA is reported in Section 12.2. In the current EPMOR a list of preferred options was required, which could be presented to the respective government agencies. For the purpose of this EPMOR, MCA has been used to determine the preferred mitigation options, should it become necessary.

8.2 Assessment Criteria

The assessment objectives for the MCA have been developed based on the criteria of applicability, cost, social and environmental considerations as set out in Table 14.

Table 14: Objectives of prevention or mitigation options for spring complexes.

Criterion	Criteria Definitions	Project Specific Examples
Schedule/Timing	Can it be implemented in time, once/if impacts are detected?	If impact occurs in 5 years but method requires 10 years to be effective, is it a useful option?
Likelihood of successful implementation	Can the mitigation option be constructed?	Will water be available, can infrastructure such as pipelines be put in place?
Cost	Order of magnitude cost estimates.	Cost effectiveness of option?
Effectiveness	Will the mitigation option work as intended?	Even simple options may not work, e.g. augmented flow may infiltrate within a creek bed
Environmental impact	What is the level of environmental impact from the construction, operation and decommissioning? Are there permanent impacts?	Pipeline maintenance and environmental footprint.
Social acceptability	Will stakeholders agree with the proposed methods, is there social and generational equity in the method?	Does the mitigation option require use of controversial activities?

8.3 Results of Multiple Criteria Analysis

Each of the spring vent complexes was assessed via the MCA method and summary results of the analyses are presented in this section. The three highest scoring options from the mitigation methods selected to be taken forward from Section 3.3 and Figure 17; are reported for each of the spring complexes. The selected prevention or mitigation option is described as it would apply to the individual spring complex together with potential methods of implementation.

In some instances the predicted impact on the springs will occur substantially after the period of expected maximum water extraction. Hence mitigation would only need to be implemented at a later date. Monitoring programs will be required to assess the propagation of the drawdown and to determine when it reaches a set point at which to trigger the selected mitigation option.

8.3.1 Spring Rock Creek

The three highest scoring options in the MCA for prevention or mitigation at Spring Rock Creek spring complex are recharge at spring with groundwater by infiltration, hydraulic barrier or augmenting recharge to the Precipice Sandstone (Table 15).

8.3.1.1 Recharge at Spring with Groundwater by Infiltration

Due to its local hydrogeological setting, the Boxvale Sandstone aquifer system is most likely discontinuous and only intermittently connected. With little outcrop, it can be assumed that the main source of aquifer recharge in the area is vertical percolation of water from the overlying Evergreen Formation. The moderately elevated EC levels measured at the spring vent support this assumption as do the relatively low spring discharge rate. Where the Evergreen Formation is unconfined it will have higher storativity values that can contribute to vertical leakage during drier periods, maintaining spring flows.

If the springs are impacted, the preferred mitigation option identified is intended to recharge the localised aquifer system using treated water from CSG operations. From the conceptual model developed, the likelihood of the spring being impacted from CSG water abstractions is relatively low, due to the presence of the lower Evergreen Formation. This may act as an aquitard below the Boxvale Sandstone, limiting depressurisation from below. In addition no significant faulting has been observed in the immediate vicinity of the spring complex.

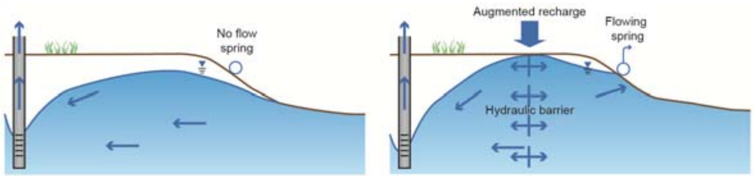
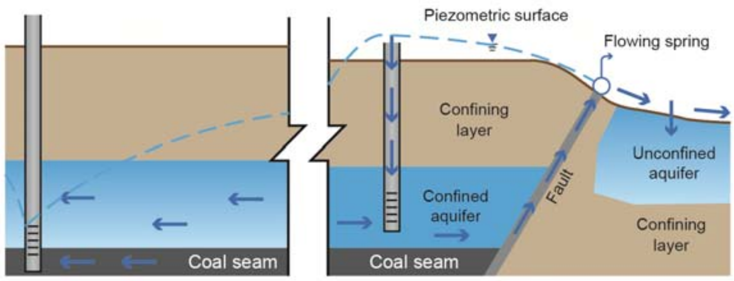
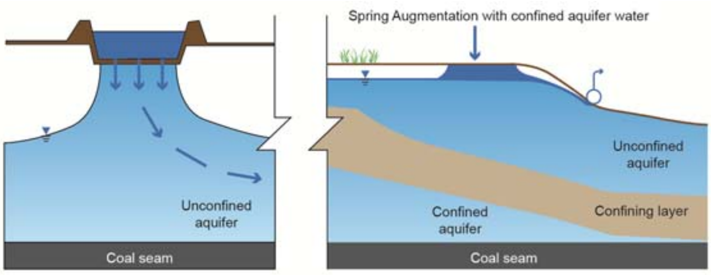
This method, achieved the highest ranking in the MCA due to its likelihood of successfully maintaining flows at the spring, and the volumes of water required for recharge being relatively low. One potential issue of the method is the maintenance of the natural hydrochemistry of the spring.

8.3.1.2 Hydraulic Barrier – Increase Pressure by Recharge to Coals

If there were to be direct connectivity between the Boxvale Sandstone aquifer at Spring Rock Creek and the Precipice Sandstone aquifer, depressurisation could propagate to the Boxvale Sandstone. In this case, a hydraulic barrier could be used between the spring and the centre of depressurisation. The barrier would be formed locally by increasing the hydraulic pressure from injection water, either into the Bandanna coals or the Precipice Sandstone. Treated CSG water may be an appropriate water source depending on hydrochemical compatibility.

The pressurisation would act as a hydraulic barrier, maintaining aquifer pressures such that the depressurisation would no longer propagate beyond the barrier in the direction of the springs. The natural level of hydrostatic pressure would maintain flows at the spring. Due to the nature of hydraulic barriers it should be implemented within a 10 km radius as it would take a certain amount of time to ensure that it works effectively.

Table 15: MCA results for Spring Rock Creek complex.

<table>
<tr><th colspan="4">285 (Spring Rock Creek)</th></tr>
<tr><th>Classification</th><th>Option</th><th>Description</th><th>Scale</th></tr>
<tr><td>Mitigate</td><td>1</td><td>Recharge the aquifer by infiltration at or close to the spring.
Water source: treated associated water from CSG operations.

</td><td>Spring</td></tr>
<tr><td>Avoidance</td><td>2</td><td>Hydraulic barrier. Active control and prevention of groundwater level changes reaching the springs by recharging either the Bandanna Coals or the Precipice Sandstone.
Water source: treated CSG water.

</td><td><10 km</td></tr>
<tr><td>Avoidance</td><td>3</td><td>Increase recharge to Precipice Sandstone. This is a variation of above option where water is infiltrated from surface to recharge the Precipice, rather than by direct injection.
Water source: treated associated water from CSG operations.

</td><td>~10 km</td></tr>
</table>

This method is likely to be effective, if operated at the correct location and the right time. The volumes of water required are larger than for Recharge at the Spring Complex and for this reason it scores lower on the MCA.

8.3.1.3 Augment Recharge to Precipice Sandstone

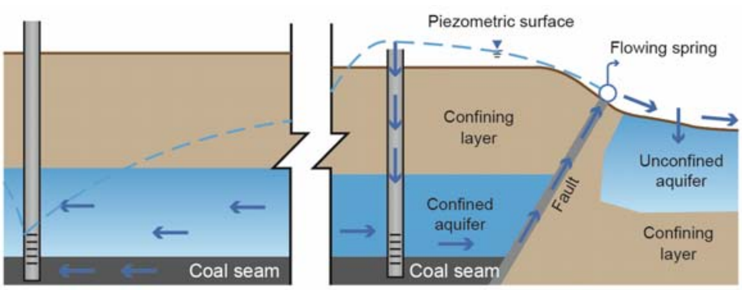
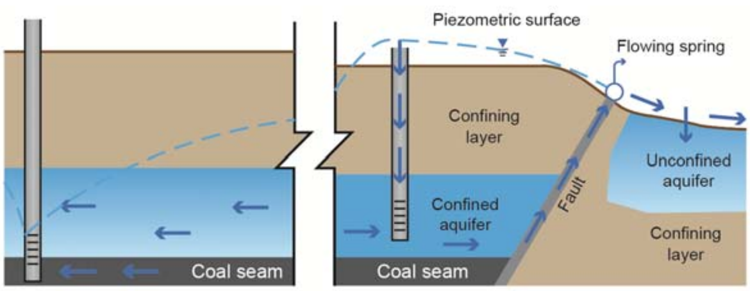
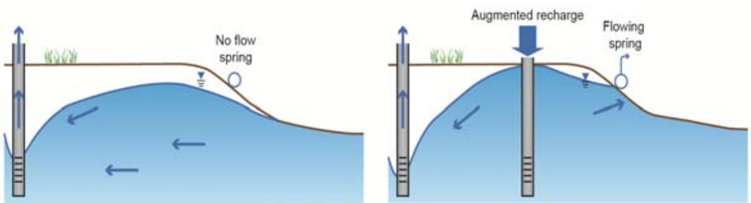
Considering that the impact of CSG activities will most likely propagate the fastest through the Precipice Sandstone aquifer system, augmenting recharge into this aquifer to maintain pressure and groundwater levels is another option. Due to the high transmissivity of the Precipice Sandstone it would require a considerable amount of treated water to augment and mitigate impacts.

In the MCA this method achieves a lower score than Recharge at the Spring Complex, or Hydraulic Barrier options. This is due to both the relatively high volumes of water required, and the duration over which recharge would be needed to mitigate the impacts.

8.3.2 Lucky Last

At Lucky Last, the three highest scoring options in the MCA for prevention or mitigation are hydraulic barrier, augment flow at spring with deeper artesian water or augmenting recharge to Precipice Sandstone (Table 16).

Table 16: MCA results for Lucky Last spring complex.

230 (Lucky Last)			
Classification	**Option**	**Description**	**Scale**
Avoidance	1	Hydraulic barrier. Active control and prevention of groundwater impact propagation reaching the springs by recharging the Bandanna coals through injection wells. Water source: CSG water. 	<10 km
Avoidance	2	Hydraulic barrier. Active control and prevention of groundwater level changes reaching the springs by recharging the Precipice Sandstone through injection wells. Water source: treated associated water from CSG operations. 	<10 km
Mitigate	3	Recharge the aquifer by injection at or close to the spring. Water source: treated associated water from CSG operations. 	~10 km

8.3.2.1 Hydraulic Barrier – Increase Pressure by Recharge to Coals

A hydraulic barrier to prevent impacts from propagating into the Precipice Sandstone would consist of locally increasing the hydraulic pressure by injection of water into the Bandanna coals. CSG water or treated CSG water might be an appropriate water source for injecting into the coals.

The pressurisation would act as a hydraulic barrier, maintaining aquifer pressures such that the depressurisation signal would no longer propagate beyond the barrier in the direction of the springs.

Preliminary investigation (using an analytical model) into the construction of a hydraulic barrier has been performed. The models assumed that the Bandanna Formation subcrops beneath the Precipice Sandstone at a specified distance from the spring complex (conceptual model figures in Figure 38 and Figure 39). The following assumptions were made regarding the spring complex:

- Conservative flow at springs, no seasonal variation was included.
- Two dimensional model would supply an indicative assessment.
- One injection well in the Bandanna formation.

The results of the analytical model indicated that four wells injecting at around 2 L/s (220 ML/annum) may be sufficient to maintain the barrier between the Precipice Sandstone and the Bandanna Formation during the production phase. Subsequently in the post production phase, while the formations are recovering it is expected that injection should be maintained for a further 2+ years. The injection is required to create a hydraulic head mound at the injection point that will be sufficient to maintain spring flow while piezometric levels recover within the Bandanna Formation. These results are only preliminary and further investigative work will be required to obtain a viable solution that will consider all local physiographical and hydrochemical characteristics.

The analytical scoping calculations indicate that the volumes, rates and durations of water injection required to create the hydraulic barrier and avoid impacts reaching Lucky Last are considered practically feasible.

8.3.2.2 Hydraulic Barrier – Increase Pressure by Recharge to Precipice Sandstone

This method is essentially the same as that above with the difference that the Precipice Sandstone would be the injection target. Treated CSG water may be an appropriate water source for injecting in the Precipice Sandstone, raw untreated CSG water is unlikely to be suitable for aquifer injection.

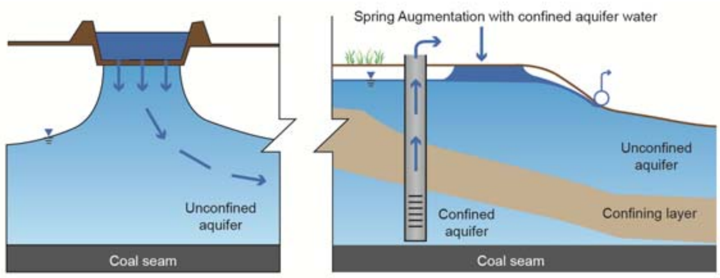
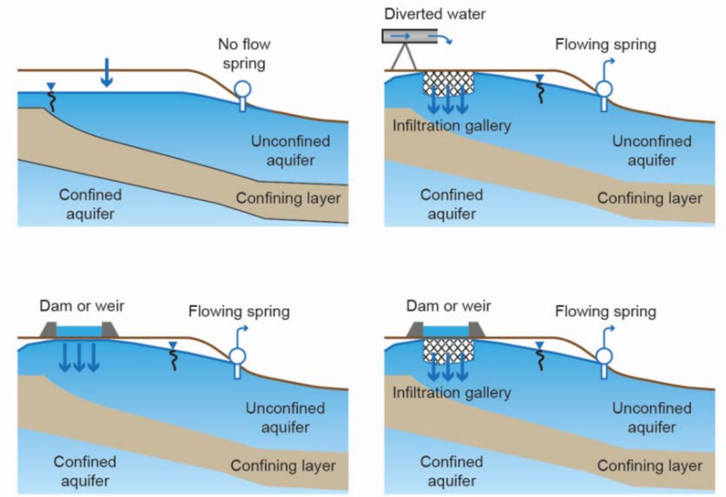
8.3.2.3 Recharge at Spring with Groundwater by Infiltration

It can be assumed that the main source of aquifer recharge for the Precipice Sandstone aquifer does not occur in the immediate vicinity as the aquitard (Evergreen Formation) will restrict recharge. Local recharge injection wells would be required that can augment the groundwater system with treated CSG water. Faulting in the area might complicate matters as it is suspected that surface faults might be under pressure and reduce the effectiveness of approach. The recharge options might therefore be required closer to the spring complex.

8.3.3 Yebna 2/311

The two highest scoring prevention or mitigation options from the MCA for the Yebna 2/311 spring complex are recharge at spring with groundwater by infiltration and increase water level in Precipice Sandstone (Table 17).

Table 17: MCA results for Yebna 2/311 spring complex.

591/311 (Yebna 2/311)			
Classification	**Option**	**Description**	**Scale**
Mitigate	1	Support of ground water levels at springs by infiltration or injection of water taken from the Precipice further from the springs. Water source: Precipice aquifer. 	Spring
Avoidance	2	Increase recharge to Precipice Sandstone. Infiltration of water from surface structures or infiltration galleries to recharge the Precipice. Water source: treated associated water from CSG operations. 	~10 km

8.3.3.1 Augment Water Level at Spring with Precipice Sandstone Water

Considering the local hydrogeological setting for the Yebna 2/311 spring complex, the Precipice Sandstone aquifer water could be used to augment the local water level near the spring vents. The spring vents in the 311 group can be classified as seepage points were the water table intersects the weathered zone, i.e. incised valley structures (Figure 33). Thus to maintain the flow at these springs an increase in water table level would be sufficient to maintain the spring flow. To do this the localised aquifer system would be recharged with Precipice Sandstone groundwater abstracted from further afield, maintaining groundwater levels and flows at the springs.

This option scores highly in the MCA as is it relatively simple to implement, has a high likelihood of success and with implementation close to the spring would require less water than other options. One issue with this method is the need to locate water sources in the Precipice Sandstone, potentially causing depletion elsewhere. Surface water or treated CSG water might be used to augment recharge to the Precipice by use of infiltration basins.

8.3.3.2 Increase Water Level to Precipice Sandstone by Infiltration

The Precipice Sandstone aquifer consists of two sections of variable transmissivity. The upper zone which has finer material, increased cementation and a lower transmissivity, and is most likely the source of spring water in the area. In general the Precipice Sandstone aquifer is under semi-confined (Yebna 2) or unconfined (311) conditions where the spring vents are located. Spring volume decrease would be mitigated by increasing the local recharge to the aquifer, which would be achieved either by infiltration galleries or surface structures using treated CSG water or surface water runoff.

8.4 Summary

The proposed options for mitigation of spring impacts reviewed and initially classified in Chapter 3.0 have been ranked using a MCA weighting scheme. The three highest scoring options for each spring complex have then been presented with some initial discussion of how they may be implemented. The MCA ranking completed has identified an initial set of options (Table 18). Further work will be required to verify assumptions made in the MCA and feasibility studies will be necessary to scope out each of the spring complex mitigation options. After feasibility a further refinement of the MCA assessment will determine if the mitigation options identified here remain the optimum solutions.

Chapter 9.0 will combine the current conceptual understanding of the spring complexes and present possible management options that could be applied to prevent or mitigate impacts to these systems.

Table 18: Summary of preferred prevention or mitigation options for the spring complexes.

Classification	Option	Description	Scale
285 (Spring Rock Creek)			
Mitigate	1	Recharge the aquifer by infiltration at or close to the spring. Water source: treated associated water from CSG operations.	Spring
Avoidance	2	Hydraulic barrier. Active control and prevention of groundwater level changes reaching the springs by recharging either the Bandanna Coals or the Precipice Sandstone. Water source: treated CSG water.	<10 km
Avoidance	3	Increase recharge to Precipice Sandstone. This is a variation of above option where water is infiltrated from surface to recharge the Precipice, rather than by direct injection. Water source: treated associated water from CSG operations.	~10 km
230 (Lucky Last)			
Avoidance	1	Hydraulic barrier. Active control and prevention of groundwater impact propagation reaching the springs by recharging the Bandanna coals through injection wells. Water source: CSG water.	<10 km
Avoidance	2	Hydraulic barrier. Active control and prevention of groundwater level changes reaching the springs by recharging the Precipice Sandstone through injection wells. Water source: treated associated water from CSG operations.	<10 km
Mitigate	3	Recharge the aquifer by injection at or close to the spring. Water source: treated associated water from CSG operations.	~10 km
591/311 (Yebna 2/311)			
Mitigate	1	Support of ground water levels at springs by infiltration or injection of water taken from the Precipice further from the springs. Water source: Precipice aquifer.	Spring
Avoidance	2	Increase recharge to Precipice Sandstone. Infiltration of water from surface structures or infiltration galleries to recharge the Precipice. Water source: treated associated water from CSG operations.	~10 km

9.0 MONITORING, TRIGGERS AND RESPONSE

9.1 Requirement for Spring Impact Mitigation

In accordance with ANZECC guidelines, the highest level of protection is for high conservation/ecological value systems is ‘no change’, where ‘no change’ is defined as changes to the baseline mean or median value of 10% or one standard deviation. Santos has therefore adopted a threshold value for water quality in surface water as exceeding surface water quality objectives (WQOs) by more than 10% from baseline conditions. However, these values can only be applied once a baseline assessment has been performed to determine the natural variation in measured parameters. Santos should revisit proposed protection limits as the springs can most likely not be classified as high conservation/ecological value systems (Table 13)

9.2 Preferred Mitigation Options

The methods for impact mitigation and avoidance described and selected in this study are not intended to be implemented immediately. There is the potential that impacts of CSG production will propagate to springs, but there is a significant degree of uncertainty. This section discusses planned monitoring of groundwater systems to assess whether depressurisation is propagating toward springs. The currently planned monitoring of the three spring Fairview complexes by Santos is also described.

The spring complexes are located in a dynamic system with seasonal and longer term variability. These spring complexes are located in areas with varying degrees of geological and hydrogeological complexity. Additionally, some springs host ecological communities that are listed as Matters of National Environmental Significance (MNES) under the Environment Protection and Biodiversity Conservation Act, 1999 (EPBC Act). Trigger levels will be set in order to determine whether a change observed in the field, such as a decline in groundwater level in a piezometer, is a natural fluctuation or attributable to CSG production.

This section describes the definition of trigger levels and also sets out the response planned by Santos, once triggers are exceeded by clear signals of depressurisation. The spring monitoring program will need to adequately account for the interdependency and natural variability of the groundwater systems as well as detect impacts related specifically to CSG operations in the area. Additionally, the potential future impacts related to CSG operations are not certain and the level of impact can currently only be predicted through groundwater models. Through further iterations of field data collation, conceptualisation and modelling the extent, magnitude and timing of predicted impacts would become more certain. In time, further analysis would be required to update monitoring, triggers and response plans to suit the newly developed understanding.

Finally, predicted impacts do not always temporally overlap with CSG production operations (Figure 43) and the sourcing of water for use to mitigate potential impacts can therefore pose a challenge. Thus, multi-component mitigation options might be necessary, with different methods being used to mitigate impacts in the short and long term.

Note that in Figure 43 Spring Rock Creek is represented as not having predicted impact. This is due there being no predicted impact in the QWC cumulative impact model on its source aquifer, the Boxvale Sandstone.

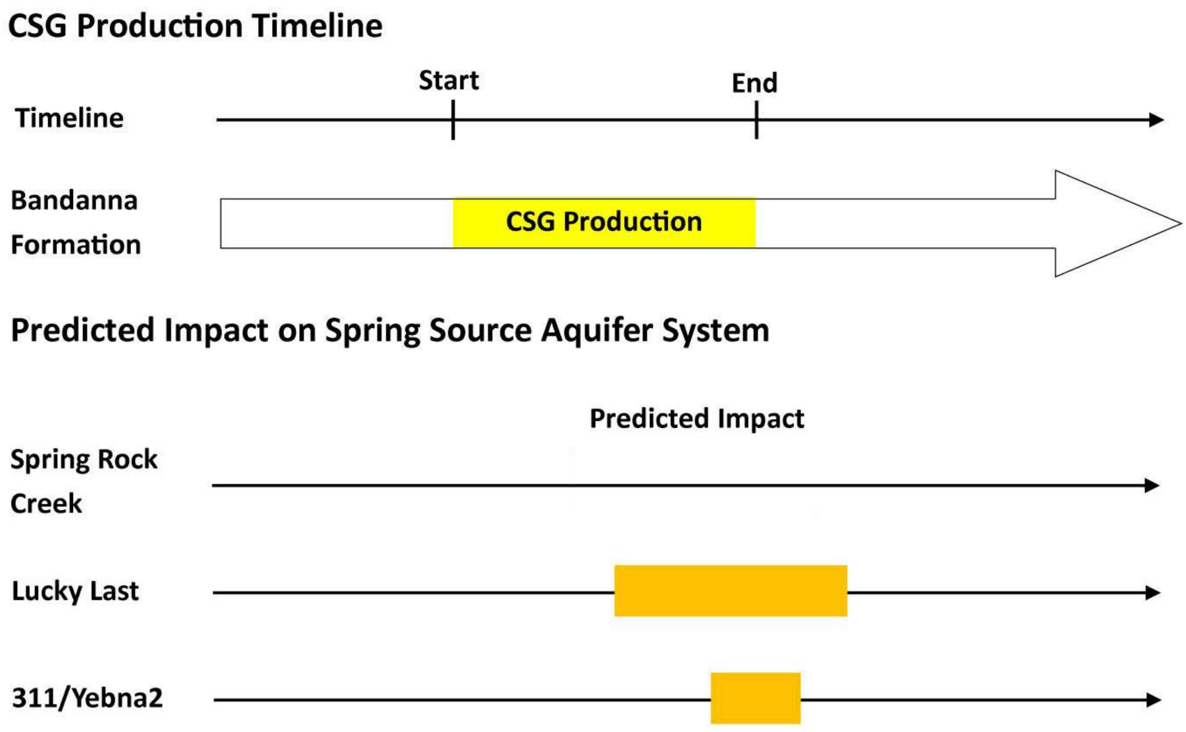


Figure 43: Schematic representation of predicted impact time line.

9.3 Spring Monitoring Objectives

To implement the preferred mitigation or avoidance options, the most appropriate monitoring strategy for current and future hydrological data collection activities would be required. The development of this strategy, the objectives of spring monitoring should be clearly defined to ensure they meet the operational and functional needs of the monitoring program. The strategy itself should establish monitoring priorities, show where a single monitoring activity may serve more than one purpose and focus on efficiencies.

The following section sets out the conditions to be achieved by monitoring; as extracted from the Joint Industry Plan (JIP) for an Early Warning System relating to the EPBC spring complexes.

In essence the monitoring of EPBC springs needs to satisfy to following conditions (JIP, 2013):

- *The establishment of sufficient baseline data prior to the commencement of main production.*
- *Long-term monitoring programs for groundwater regimes, or for the condition and function of the EPBC Springs, should be implemented prior to CSG water extraction. A staged approach is acceptable with the primary focus for installation being in areas closer to impact as predicted by the Surat Basin groundwater model.*
- *Collect data to establish how ecosystems function and/or condition are influenced by CSG water extraction.*
- *Allow understanding of non-CSG production effects that may affect aquifer water level responses and spring behaviour.*
- *It is noted that changes to aspects such as ecosystem health (e.g. ecological diversity) and physio-chemical spring attributes (e.g. spring flow and spring water quality) are secondary impacts that would reflect changes to groundwater pressure and groundwater quality.*
- *The establishment of aquifer source monitoring infrastructure to enable early detection of potential impacts to EPBC springs.*
- *The establishment of drawdown threshold values and response actions which escalate with increasing levels of risk.*

The UWIR does not require the monitoring of fauna and flora; OGIA is of the view that "the identification of ecological assemblages is a matter for further research rather than regular monitoring" (Section 8.4, CSGW). Accordingly, OGIA has identified a research project called "Ongoing knowledge about springs" (Appendix I of the Surat UWIR) (QWC, 2012). Finally, monitoring of the springs requested by the Surat UWIR has been incorporated by the Industry with the monitoring of EPBC springs. The proposed spring monitoring program addresses both the requirements of the Surat UWIR and the Projects approval conditions.

9.3.1 Timeline for Monitoring Objectives

At the current stage of monitoring, data is still being collected and the development of an effective baseline is ongoing. Considering Figure 43, sufficient time remains available to develop an effective monitoring program and collect baseline information before the currently predicted on-set of Spring Complex impacts. The source aquifers for the spring vents have been identified, and field sites to monitor these aquifer systems will be developed and equipped with suitable instrumentation to effectively monitor water level fluctuations and water quality.

9.3.2 Water Quality Objectives

Currently for each spring vent and cluster, the following will be performed (JIP, 2013):

- Tabulation of water chemistry
- Preparation of tri-linear diagram plots of major ion chemistry
- Assessment of temperature and water chemistry correlations between springs and source aquifers
- Comparison against reliable water quality for local source aquifer
- Isotopic age dating.

All attributes shall be documented for reference throughout the life of CSG activities.

In the development of mitigation options, presentation of site data and conceptual model development, an assessment of the current state of field information relating to water quality has been conducted. As noted in the development of site conceptual models, there remain areas where data needs to be improved as it will affect the assessment of the expected natural water quality. It is still uncertain as to the level of expected natural fluctuation within each of the spring complexes and this uncertainty impacts on the risk assessment and management options implemented. Current surveys reported within Section 5.2 indicate that the vents differ significantly over a hydrological cycle.

Reporting criteria as indicated in the Australian Guidelines for Water Quality Monitoring and Reporting (ANZECC/ARMCANZ, 2000) and Queensland Water Quality Guidelines (QWQG, 2009) methodology should also be adhered to as both references clearly stipulate procedures to determine statistical relevance of data collected. Since the recharge of the springs is not well understood at the current time, water quality can naturally vary as recharge fluctuates during the year and should be evaluated over multiple seasons. Once the baseline data at the spring is sufficient to assess the expected natural variation in data, an upper and lower limit can be set to evaluate possible spring impact.

9.3.3 Water Quantity Objectives

Similar to water quality objectives, an extensive set of flow measurements at the springs is required to understand the seasonality of flow at the spring complexes, and what might indicate a CSG induced risk to the spring.

Some springs are water table driven and the flow mechanism in these springs is related to water table elevation. It is expected that flow volumes in these systems would fluctuate significantly over the course of a hydrological year (wet versus dry period) as well as long term changes (droughts, wet periods and climate change). These groundwater discharge systems are technically seepage points and not spring vents.

In contrast, spring complexes that are under artesian conditions depend on the piezometric level of the source aquifer being higher than ground level. Flow volumes from these vents can also reflect short term changes, i.e. reduction of flow as deep rooted vegetation abstracts water from the confined aquifer system as well as reduced recharge to the aquifer at the source due to drought. It is expected that these changes would be less significant than that observed for the water table aquifer and long term monitoring would be able to produce the naturally occurring minimum and maximum flow volumes expected at the spring vents.

Thus, to effectively monitor the flow of water at the spring vents local piezometers would be required to monitor the confined aquifer system. In regards to the Precipice Sandstone aquifer and upper and lower piezometric level will be required as it is expected that there is a change in the aquifer sub-units. This would also assist in developing an early warning system, as the lower Precipice Sandstone aquifer has a higher hydraulic conductivity due to coarser material.

9.4 Ongoing Monitoring Program

Santos intends to use a common field team with Origin and QGC to undertake the spring baseline monitoring to ensure consistency between sites and visits. The start of the spring monitoring baseline assessment occurred in quarter three of 2013. Spring water quality sampling will be undertaken quarterly and reported on a six-monthly basis.

Installation of remote sensing equipment in bores located close to the springs will also be required to determine actual water level fluctuations prior to predicted impact.

9.5 Definition of Trigger for Impact

A trigger for impact at a spring complex can be defined as a value in a measured parameter that can be interpreted to result in an agreed response. If a trigger value is activated it should first be verified by a second independent measurement or laboratory analysis. Triggers can be associated with a certain level of drawdown change over a time period or change in water quality trend over the long term. In each of these examples there is an expected upper and/or lower limit of change before activating the trigger. Ideally, comparison of measurements at which a trigger has been set should be linked to a reference bore in the same aquifer system that is not impacted by CSG activities.

Santos proposes to use an early warning and response system (EWS) similar to that being developed for EPBC springs (JIP, 2013):

- Initially, the use of groundwater levels variations will act as a proxy of potential impact to springs. Changes to measurable attributes at the springs such as discharge volumes, wetted area and vegetation response may not necessarily reflect regional changes to pressure head in the source aquifer due to CSG activities. Reliable assessment of the potential influence of CSG water extraction on the springs must rely on regional scale groundwater level monitoring of the springs' source aquifers. To understand the effects of CSG production on water level variations, external natural and anthropogenic impacts must first be removed from the water level response.

- The focus of monitoring on the EPBC springs will be on the primary source aquifers. It will be important to understand the mechanism by which drawdown is likely to propagate from the source to the receptor (EPBC spring). The protection of all receptors requires a robust conceptual model to be developed. The vertical and areal distribution of the springs allows the development of fewer models, with the level of risk relative to the distance from the source of the potential drawdown. Therefore, focussing monitoring efforts on the gas fields in closest proximity to the springs, and the formations through which the drawdown must propagate, will be the most effective approach to managing potential risks. Monitoring will therefore focus on the currently determined spring source aquifer.

- Santos will use the regional cumulative impact model (CIM) developed for the Surat CMA UWIR (QWC, 2012). The EWS uses the 95th percentile prediction of drawdown at selected locations for 200 model runs. A 95th percentile drawdown, also referred as Upper P95, is a statistical measure that indicates 95% of the model scenarios have a smaller predicted drawdown. In other words, there is only 5% likelihood that this value would be exceeded. The P95 has been adopted to provide the assurance that sufficient time for assessment and implementation of mitigation would be available where necessary. With the recent updates to the CIM discussed above (Section 4.0), Lucky Last is the only spring complex predicted to experience greater than 0.2 m of CSG related drawdown, with the first prediction of drawdown exceeding 0.1 m occurring in 2017.

- A drawdown trigger process will be developed that responds to increasing levels of risk to MNES allowing for sufficient assessment and implementation time before predicted potential impact. The EPBC spring EWS defines three levels of exceedance which correspond with escalating response to manage the risk to the EPBC spring and mitigate the impact where required.

9.6 Response

The EWS is designed to provide sufficient warning time of impact propagation and potential impact at an EPBC spring (JIP, 2013). The following notes on the EWS should be considered:

- The CIM is considered to be highly conservative in its current state. It is assumed therefore, that the time between the predicted exceedance of the proposed mitigation or management trigger and occurrence of potential impacts at a spring is the minimum likely time. There is, in other words, considerable uncertainty regarding the model's predictions and many factors that could increase the time over which the impact could propagate to the springs.

- Zero drawdown of piezometric levels in the source aquifer is a conservative proxy for zero impact at the springs. This is because a drop of groundwater pressure at a spring may not necessarily result in any impact or any immediate impact to the spring ecosystem. The vulnerability of a spring complex to decreasing piezometric levels will need to be assessed for each system.

The flow chart diagram on Figure 44 provides a summary of the early warning system monitoring and response process applied to EPBC Springs under the EPBC Act. It should be noted that this EPMOR is setting out early the selection of spring impact options that would be triggered by an exceedance of the investigation trigger. The trigger levels developed in the JIP would apply to the spring complexes where an impact over 0.2 m is predicted. The following excerpt has been adapted from the JIP (2013) to assist in explaining the exceedance response process:

Before an exceedance is considered to have been reached, the observations will be carried out for up to three months beyond the initial exceedance measurements. The following explanatory details are presented to support Figure 9-1:

1) *When an Investigation Trigger value is exceeded (at an EWMI or TMP), the responsible Proponent will:*

   - *verify the exceedance by:*
     - *Assessing observation data with historical data for the bore, this may include the use of a statistical trend procedure to remove natural variations;;*
     - *Assessing water level data in neighbouring bores monitoring the same aquifer;*
     - *Reviewing the model predictions and assess with observed water levels;*
     - *Identifying the potential causes that may have contributed to the exceedance; and*
     - *Increasing monitoring if necessary; then,*
     - *Notify SEWPaC within 10 days of confirmation of the exceedance*
   - *Where an observed exceedance cannot be ruled out, the responsible Proponent will undertake a risk assessment and other studies resulting in nomination of a concept mitigation approach. This will include field investigations to assess site specific features, an assessment of the vulnerability of the spring to the level of predicted drawdown and a review of the hydrogeological conceptual model to understand the actual level of risk of impact to the EPBC springs. A methodology is proposed in Table 9-4 for the selection of potential impact management/mitigation solutions. One key element is the multi-criteria analysis which ensures that a range of criteria are taken into consideration in the selection process and in particular:*
     - *The timing available for implementation of the management/mitigation option;*
     - *The timing of the Proponent CSG activities; and*
     - *Other criteria such as technical success rate of the solution, environmental footprint, stakeholder and regulatory acceptability.*

2) *When a Management/Mitigation trigger is exceeded, the responsible Proponent will:*

   - *Move to carry out detailed mitigation design and develop a mitigation plan. To this end, the previously selected impact management/mitigation concept(s) will be developed in detail. This will involve:*
     - *Confirmation of the concept options;*
     - *Additional field investigations;*
     - *Hydrogeological modelling;*
     - *Detailed engineering design studies.*
   - *Develop a mitigation plan. The mitigation plan will identify the potential of time before impact, the timing of mitigation and will potentially be redefining the value used as a “zero impact proxy”.*
   - *Submit the mitigation plan to SEWPaC; then,*
   - *Implement the mitigation plan.*

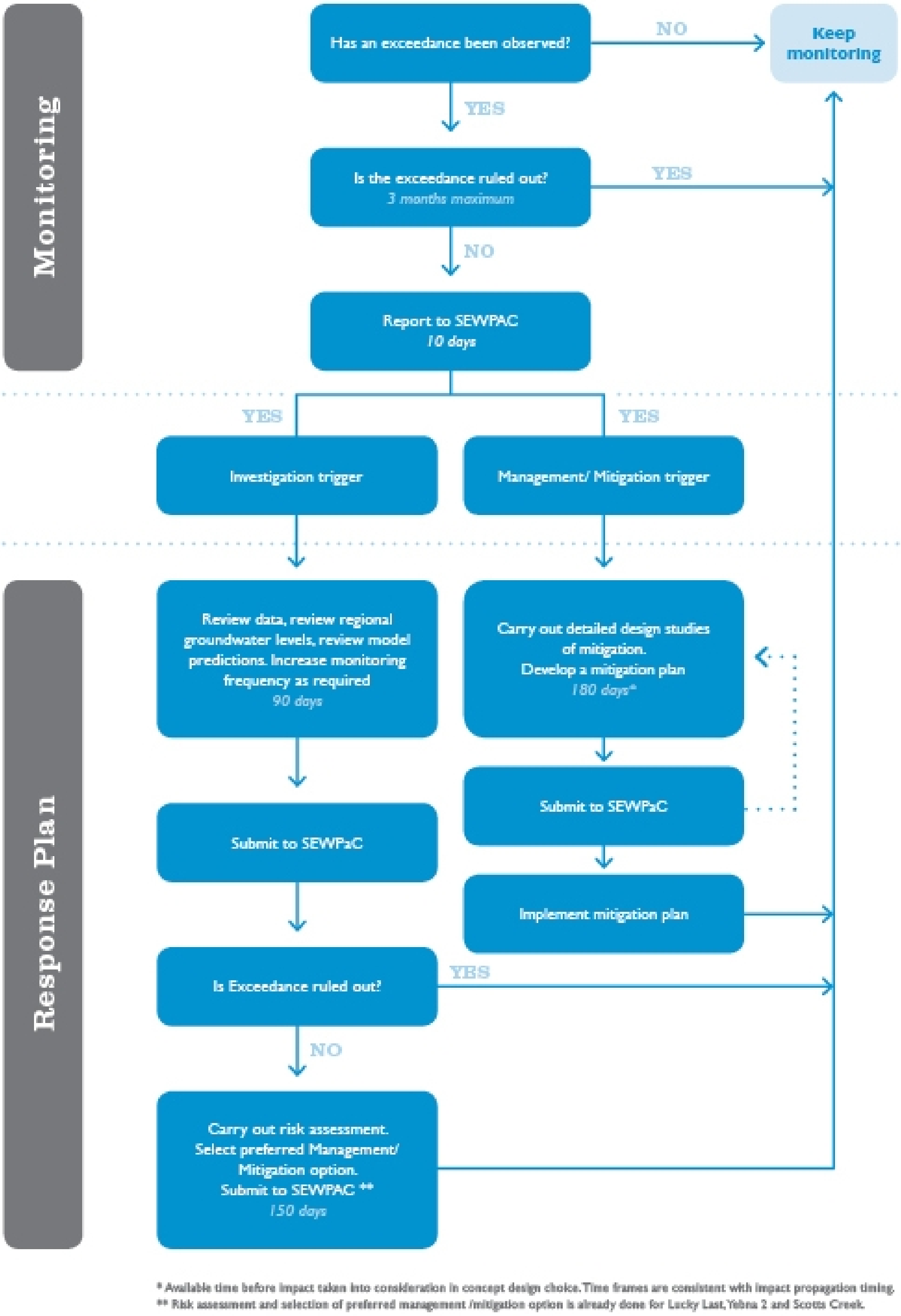


Figure 44: Early Warning System Monitoring for off-tenure EPBC Springs (JIP, 2013).

9.7 Summary

The methods for impact mitigation and avoidance described in this study are not intended to be implemented immediately (Chapter 8.0). There is the potential that impacts of CSG production will propagate to springs, but there is a significant degree of uncertainty attached to this prediction. Site data for the spring complex sites were used to determine the source aquifer (Chapter 5.0). Geological and hydrogeological conceptual models were developed based on the site data (Chapter 6.0). These conceptual models were used to inform the selection of prevention or mitigation options. However, due to uncertainties associated with the predicted impact a monitoring program is required to verify the predicted model results. This section has set out the objectives of the monitoring program for the springs, including the timeline and specific elements of monitoring for quality and quantity impacts. The current monitoring program has been outlined and the joint industry plan (JIP, 2013) for the setting of triggers, and the response to triggers have been discussed.

10.0 CONCLUSION

10.1 EPMOR Approach Taken and Outcomes

This document has set out information and assessments of the optimum candidate spring impact prevention or mitigation strategies for the three Fairview spring complexes, identified of potential risk and assigned to Santos GLNG by OGIA in the Surat UWIR:

- In Part I, Chapters 2.0 to 4.0, the regional setting of the Great Artesian Basin and its springs are set out together with a full range of spring impact potential prevention or mitigation options. Chapter 3.0 presents potential avoidance and mitigation methods that include options listed in Section 8.5.1 of the Surat UWIR (DEHP, 2012; QWC, 2012). Additional options are also identified and explained. In Chapter 4.0 an initial screening of spring impact management methods is presented that identifies viable options for spring impact mitigation. These candidate options are taken forward for more detailed assessment in Chapter 8.0, taking account of the local conditions at each spring.
- In Part II of the document, Chapter 5.0 to 7.0 describes the individual spring complex local geology and hydrogeology setting and provides a discussion on the assessment of their vulnerability. Preliminary hydrogeological conceptual models are presented in Chapter 6.0 for each of the spring complexes. The conceptual models indicate the most likely source aquifer for the springs and assist in the understanding of the relationship between potential reductions in groundwater pressure in the source aquifer and the flow of water to the spring. The assessment of risk to the springs completed in Chapter 7.0 shows that the overall risks rating of environmental impacts at spring complexes is low to moderate. This combined risk rating takes account of the likelihood of possible impact, the vulnerability of the spring complexes and the consequent environmental loss if drawdown impacts were to occur. The low to medium risk rating is in large part a result of the current low environmental value of the spring complexes.
- Part III of the document details the selection of candidate prevention and mitigation options and presents the monitoring and response plan to ensure that impacts are detected and acted on in a timely manner. The candidate mitigation options first identified in Chapter 4.0 are ranked in Chapter 8.0 using a multiple criteria analysis method. With detailed consideration given to the conceptualisation of the spring complexes presented in Chapter 6.0, the three current preferred options for each site are identified and the rationale for these options explained. In Chapter 9.0 the overall monitoring and response system is set out. This covers the objectives of the monitoring programs, through the currently planned monitoring, proposals for setting trigger levels and the proposed response if trigger values were activated.

The conclusions highlighted in the above points are summarised for each spring complex in Table 19.

Table 19: Summary table of key features and results.

Spring Complex	**Surat UWIR (QWC, 2012)**		**EPMOR Conclusions**						
Spring Complex (Number)	Expected maximum drawdown (years)*	Expected Source Aquifer	Santos Interpreted Source Aquifer	Type of spring	Geological feature associated with spring	Spring rating risk assessment	The preferred spring impact and mitigation options		
Yebna 2/311 (591/311)	1-1.5 (30-50)	Precipice Sandstone, Evergreen Formation	Precipice Sandstone	Mound (Yebna 2) Rocky seep (311)	Incised valleys crossing water table	Low	Support water level at spring with Precipice Sandstone water	Increase water level to Precipice Sandstone by infiltration	
Lucky Last (230)	1-1.5 (40-60)	Precipice Sandstone, Evergreen Formation	Precipice Sandstone	Mound and rocky seeps	Fractured rock	Medium	Hydro barrier – associated water recharge to coals	Hydro barrier – associated water recharge to Precipice	Recharge aquifer by injection close / at spring with associated water
Spring Rock Creek (561)	0.2-0.5 (50-60)	Precipice Sandstone, Evergreen Formation	Boxvale Sandstone	Rocky seep	Fractured rock	Low	Recharge aquifer by injection close / at spring with associated water	Hydro barrier – associated water recharge to Coals or Precipice	Increase recharge to Precipice from surface infiltration

* = Expected maximum drawdown from CSG production, starting from 2012.

11.0 LIMITATIONS

Your attention is drawn to the document - “Limitations”, which is included in Appendix A of this report. The statements presented in this document are intended to advise you of what your realistic expectations of this report should be, and to present you with recommendations on how to minimise the risks associated with the services provided for this project. The document is not intended to reduce the level of responsibility accepted by Golder Associates, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in so doing

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12.0 SUPPORTING INFORMATION

12.1 Spring Water Quality Description

Although a small dataset is available an analysis of the information can still be performed. In order to assist in the evaluation expanded Durov diagrams will be used. In the following section the general description of the expanded Durov diagram is given and will be followed by interpretation of data from the spring complexes.

The expanded Durov diagram has the distinct advantage over other interpretative methods (such as the Piper diagram) in that it provides a better display of hydrochemical types and some processes. The significance of nine fields on the expanded Durov diagram can be discussed with respect to Figure 45: Explanation of expanded Durov diagram with quadrant numbering. as follows:

1) HCO_3^- and Ca^{2+} dominant, frequently indicates recharging waters in limestone, sandstone, and many other aquifers.

2) HCO_3^- dominant and Mg^{2+} dominant or cation unselective, with Mg^{2+} dominant or Ca^{2+} and Mg^{2+} important, indicates waters often associated with dolomites, where Ca^{2+} and Na^+ with important partial ion exchange may be indicated.

3) HCO_3^- and Na^+ dominant, normally indicates ion-exchanged waters although the generation of CO_2 at depth can produce HCO_3^- where Na^+ is dominant under certain circumstances.

4) SO_4^{2-} dominant or anions unselective water type with Ca^{2+} dominant, Ca^{2+} and SO_4^{2-} dominant frequently indicates a recharge water in lava and gypsiferous deposits, otherwise a mixed water or a water exhibiting simple dissolution may be indicated.

5) No dominant anion or cation; indicates waters exhibiting simple dissolution or mixing.

6) SO_4^{2-} dominant or anions unselective and Na^+ dominant, is a water type not frequently encountered and indicates probable mixing influences.

7) Cl^- and Ca^{2+} dominant, is infrequently encountered unless cement pollution is present in a well; otherwise the waters may result from reverse ion exchange of Na^+/Cl^- waters.

8) Cl^- dominant and no dominant cation indicates that the groundwater may be related to reverse ion exchange of Na^+/Cl^- waters.

9) Cl^- and Na^+ dominant frequently indicate end-point waters.

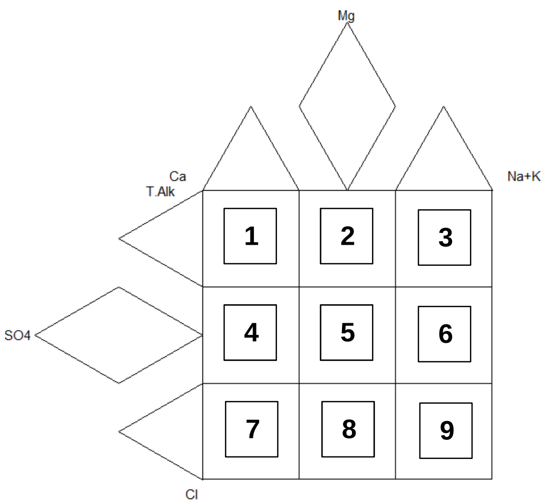

Figure 45: Explanation of expanded Durov diagram with quadrant numbering.

An expanded Durov diagram illustrating all water samples collected in the area are given in Figure 46: Expanded Durov diagram of aquifer, spring and surface water. From the data it is clear that a number water types occur in the area. These include alkalinity dominated waters, which might indicate recharge or dolomite exchange waters. Secondly, sulfate dominated water is also observed in the region and this could possibly be associated with coals in the Evergreen Formation, Bandanna formation or the early Permian Formations. Finally, chloride rich water has also been observed and can be related to the Evergreen Formation and deeper water systems in the area. Spring samples collected are presented in Table 20.

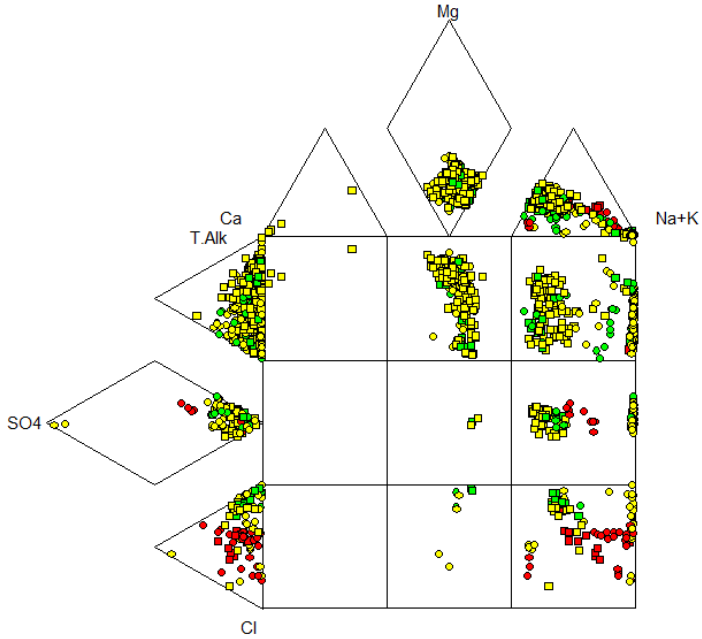

Figure 46: Expanded Durov diagram of aquifer, spring and surface water.

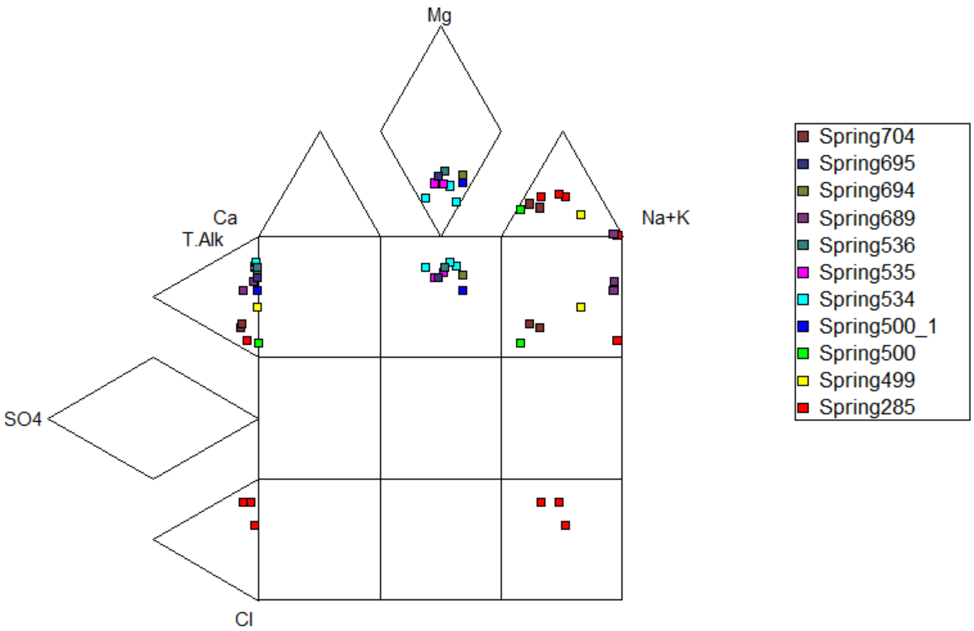

Figure 47: Expanded Durov diagram of spring vents in the study area.

Data reported for the spring vents predominantly plot in three areas. Firstly, in the alkalinity dominated area which are mostly associated with Lucky Last and Yebna 2/311 spring vents. The second group is associated with a Na/Cl water type and consist of only Spring Rock Creek vent samples. In the instance of Spring Rock Creek the impact from the Evergreen Formation is clearly recognisable (KCB, 2012). The Lucky Last and Yebna 2/311 spring vents have a more complicated distribution as there is a magnesium dominated group (spring vent 500.1, 534, 535, 536 and 694) and a sodium dominated group (499, 500, 689 and 704). Interestingly, is seems that there is a correlation between the water type and spatial distribution of the vents.

Table 20: Hydrochemical parameters for spring vent samples.

Vent Number	Date	pH	TAlk	Cl	SO_4	Ca	Mg	K	Na	TDS	EC
535	9/07/2013	8.15	247	31	0.5	44	18	4	52	341	575
536	9/07/2013	7.51	105	11	0.5	16	9	2	19	153	219
695	9/07/2013	8.26	165	24	0.5	30	14	5	30	205	366
704	9/07/2013	7.29	94	36	12	20	6	4	38	184	326
287	10/07/2013	7.8	329	41	24	13	1	7	175	898	733
689	10/07/2013	7.53	176	32	16	3	0.5	0.5	102	307	485
285	10/07/2013	7.75	221	236	18	35	25	3	153	593	1150
534	10/07/2013	7.73	258	21	2.5	38	16	6	50	328	546
689	19/03/2013	7.65	256	40	7	4	0.5	3	142	663	683
287	19/03/2013	6.58	142	0.5	0.5	3	0.5	1	81	580	368
704	7/02/2013	6.48	85	35	12	17	5	3	40	239	327
499	7/02/2013	6.63	82	24	0.5	6	3	3	43	203	244
500.1	7/02/2013	7.33	94	19	0.5	15	8	2	27	188	252
534	7/02/2013	7.97	147	14	3	29	8	14	37	397	372
694	7/02/2013	7.44	124	17	0.5	18	12	5	32	237	315
535	7/02/2013	8.07	173	25	1	37	14	7	33	311	450
285	7/02/2013	7.96	205	333	12	38	30	6	204	761	1330
534	19/06/2011	8.08	153	15	3	35	8	11	23	238	351
500	19/06/2011	7.58	304	169	0.5	72	15	5	117	566	1044
285	17/04/2011	7.7	280	145	27	4	0.5	3	230	689	1000
285	17/04/2011	6.93	224	241	40	59	27	10	153	754	1224
689	19/03/2013	7.65	256	40	7	4	0.5	3	142	663	683
499	12/02/2013	6.63	82	24	0.5	6	3	3	43	203	244
500.1	12/02/2013	7.33	94	19	0.5	15	8	2	27	188	252
535	12/02/2013	8.07	173	25	1	37	14	7	33	311	450
694	12/02/2013	7.44	124	17	0.5	18	12	5	32	237	315
704	12/02/2013	6.31	85	35	12	17	5	3	40	239	327
285	12/02/2013	7.96	205	333	12	38	30	6	204	761	1330
534	12/02/2013	7.97	147	14	3	29	8	14	37	397	372

Units for chemical analytes are in mg/L, EC uS/cm and pH in pH units.

12.2 MCA Assessment Background

12.2.1 Key Features of MCA

Multiple criteria analysis establishes preferences between options by reference to an explicit set of objectives that the decision making body has identified, and for which it has established measurable criteria to assess the extent to which the objectives have been achieved. In simple circumstances, the process of identifying objectives and criteria may alone provide enough information for decision-makers. However, where a level of detail broadly akin to cost base analysis (CBA) is required, MCA offers a number of ways of aggregating the data on individual criteria to provide indicators of the overall performance of options.

A key feature of MCA is its emphasis on the judgement of the decision making team, in establishing objectives and criteria, estimating relative importance weights and, to some extent, in judging the contribution of each option to each performance criterion. The subjectivity that pervades this can be a matter of concern. Its foundation, in principle, is the decision makers' own choices of objectives, criteria, weights and assessments of achieving the objectives, although 'objective' data such as observed prices can also be included. MCA can bring a degree of structure, analysis and openness to classes of decision that lie beyond the practical reach of CBA.

12.2.2 Advantages of MCA over Informal Judgement

MCA has many advantages over informal judgement unsupported by analysis:

- It is open and explicit.
- The choice of objectives and criteria that any decision making group may make are open to analysis and to change if they are felt to be inappropriate.
- Scores and weights, when used, are also explicit and are developed according to established techniques. They can also be cross-referenced to other sources of information on relative values, and amended if necessary.
- Performance measurement can be sub-contracted to experts, so need not necessarily be left in the hands of the decision making body itself
- It can provide an important means of communication, within the decision making body and sometimes, later, between that body and the wider community.
- Scores and weights are used which provides an audit trail.

12.2.3 Stages of MCA Analysis

A full application of multiple criteria analysis normally involves eight steps which can be summarised as follows:

1) Establish the decision context.
    a. Establish aims of the MCA, and identify decision makers and other key players.
    b. Design the socio-technical system for conducting the MCA.
    c. Consider the context of the appraisal.
2) Identify the options.
3) Identify the objectives and criteria that reflect the value associated with the consequences of each option.
    a. Identify criteria for assessing the consequences of each option.
    b. Organise the criteria by clustering them under high-level and lower-level objectives in a hierarchy.

4) Describe the expected performance of each option against the criteria.
   a. Describe the consequences of the options.
   b. Score the options on the criteria.
   c. Check the consistency of the scores on each criterion.
5) 'Weighting'. Assign weights for each of the criteria to reflect their relative importance to the decision.
6) Combine the weights and scores for each of the options to derive and overall value.
   a. Calculate overall weighted scores at each level in the hierarchy.
   b. Calculate overall weighted scores.
7) Examine the results.
8) Conduct a sensitivity analysis of the results to changes in scores or weights.
   a. Conduct a sensitivity analysis: do other preferences or weights affect the overall ordering of the options?
   b. Look at the advantage and disadvantages of selected options, and compare pairs of options.
   c. Create possible new options that might be better than those originally considered.
   d. Repeat the above steps until a 'requisite' model is obtained.

The general approach outlined above will be followed in the remainder of this section to assist Santos in assessing possible prevention or mitigation options at the spring complexes.

12.2.4 Multiple Criteria Analysis Matrix

A standard feature of multi-criteria analysis is a performance matrix, or consequence table, in which each row describes an option and each column describes the performance of the options against each criterion. The individual performance assessments are often numerical, but may also be expressed as bullet point scores, or colour coding. In a basic form of MCA this performance matrix may be the final product of the analysis. The decision makers are then left with the task of assessing the extent to which their objectives are met by the entries in the matrix. Such intuitive processing of the data can be speedy and effective, but it may also lead to the use of unjustified assumptions, causing incorrect ranking of options. In analytical MCA techniques the information in the basic matrix is converted into consistent numerical values which are the basis of the current MCA approach. This analytical approach is taken with criteria and weights for the analysis matrix as defined in Table 21 and Table 22.

Table 21: Criteria of definitions as it relates to the importance of the decision.

Intensity of Importance	Definition	Intensity of Importance	Definition
0	Trivial	6	Quite important
1	Unimportant	7	Very important
2	Not very important	8	Very much important
3	Somehow important	9	Extremely important
4	Relatively important	10	Critical
5	Important		

Table 22: Criteria of weights assigned to prevention or mitigation options.

Options Performance	Definition	Options Performance	Definition
0	Extremely poor	6	Good
1	Very poor	7	Quite good
2	Poor	8	Very good
3	Somehow poor	9	Extremely good
4	Slightly poor	10	Absolutely good
5	Neutral		

To effectively perform the MCA a cumulative index for each of the proposed options were prepared; the reasoning for this approach was to incorporate a robust assessment that could not adversely be affected by a single parameter.

A three tier methodology was applied to assign criteria weight. The first level consisting of implementation criteria, second level regulatory acceptability and physical constraint and finally social and environmental impact as it relates to acceptability and environmental footprint of proposed methods. All assessment criteria were important but in order to find an acceptable solution a grading approach for the criteria weights were used (Table 23).

Tier 1: The criteria weights were prioritised to include effectiveness of solution and likelihood of long term implementation. Without either of these options the viability of the prevention or mitigation options would not be feasible and other alternatives would have to be sought.

Tier 2: The cost and timing of implementing the prevention or mitigation options were evaluated as an effective method was required that could be executed within reason. Timing requirements were especially critical since the prevention or mitigation option should be sufficiently simple to develop within a specific timeframe and implement for the respective spring complex. It is expected that some background investigations will be required to develop a suitable prevention or mitigation option. Finally, regulatory acceptability would be required if the selected option should be applied.

Tier 3: Social acceptability and environmental impacts associated with prevention or mitigation options were considered. Social acceptability will play a major role in the success of the prevention or mitigation option as community buy-in would be required for the long term sustainability of the proposed options. The environmental impacts of the prevention or mitigation option were included to minimise the effect of the possible infrastructure development and future impacts associated with the selected options.

Table 23: Criteria type and assigned criteria weighting.

	Schedule or Timing	**Likelihood of Successful Implementation**	**Cost**	**Social Acceptability**
Criteria Weight	5	8	6	4
	Environmental Impact	**Long Term Effectiveness and Liability**		**Regulatory Acceptability**
Criteria Weight	10	4		5

12.3 URS Report

Report

Spring Mitigations Option Assessments and Selection - EPMOR

Ecological Assessment

13 JUNE 2013

Prepared for

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Executive Summary

The Queensland Water Commission (QWC) prepared the Underground Water Impact Report (UWIR) for the Surat Cumulative Management Area (SCMA) in response to expansion of coal seam gas production involving multiple developers adjacent to one another in the Surat and southern Bowen Basins.

As a condition of the UWIR, Santos is required to prepare and submit an Evaluation of Prevention or Mitigation Options Report (EPMOR) for three spring complexes, namely the Yebna/311, Spring Rock Creek, and Lucky Last complexes.

URS was engaged by Santos Ltd (Santos) to undertake an ecological assessment of the aforementioned spring complexes to complement the surface water and groundwater studies for the EPMOR.

An initial field assessment (the first of four proposed in 2013) was conducted in April-May 2013. The field assessment sought to survey 31 spring vents across the three complexes. Of the 31 vents, 29 were assessed, with details such as flora present, condition, presence of water and habitat values recorded. In addition, at a number of vents, photomonitoring stations were established to allow for future comparison of conditions.

The field assessment determined that most of the vents were impacted by cattle and weeds, with pig damage evident at a number. Despite this, a large variety of aquatic plants were recorded, including *Eriocaulon carsonii* (salt pipewort) (listed as Vulnerable under the Commonwealth *Environment Protection and Conservation Biodiversity Act 1999* and the Queensland *Nature Conservation Act 1999*) at the Lucky Last complex. The tusked frog (*Adelotus brevis*), listed as Vulnerable under the *Nature Conservation Act 1992.* Overall vent and associated wetland habitat values were degraded, yet values for native fauna and flora were present.

The Queensland Water Commission has developed a regional groundwater flow model to predict the impacts of groundwater extraction by petroleum and gas activities in the Surat Basin. Based upon the results of this groundwater flow model, an estimate was made of the potential impacts to spring ecosystems from drawdown. This ecology study determined that should the maximum predicted pressure head impacts occur, alterations to the flows and hence ecosystems at each of the spring vents could occur.

Introduction

1.1 Introduction

The Underground Water Impact Report (UWIR), released by the Queensland Water Commission (QWC, July 2012), identified numerous spring complexes in the Surat Catchment Management Area (CMA) that have the potential of being impacted by the extraction of groundwater (referred to as associated water) during coal seam gas (CSG) production. As a condition of the UWIR, Santos is required to prepare and submit by 1 September 2013, an Evaluation of Prevention or Mitigation Options Report (EPMOR) for three spring complexes, namely the Yebna/311, Spring Rock Creek, and Lucky Last complexes. These springs exist in the Santos Gladstone LNG (GLNG) project, Fairview tenement and have been identified in the UWIR for further study as the potentiometric level drawdown impacts have been predicted to exceed 0.2 m.

URS Australia (URS) was engaged by Santos to undertake an ecological assessment of the Yebna/311, Spring Rock Creek, and Lucky Last spring complexes to complement the surface water and groundwater studies also being conducted for the EPMOR. These spring vents are depicted on Figure 1-a and Figure1-b.

1.2 Aims and Objectives

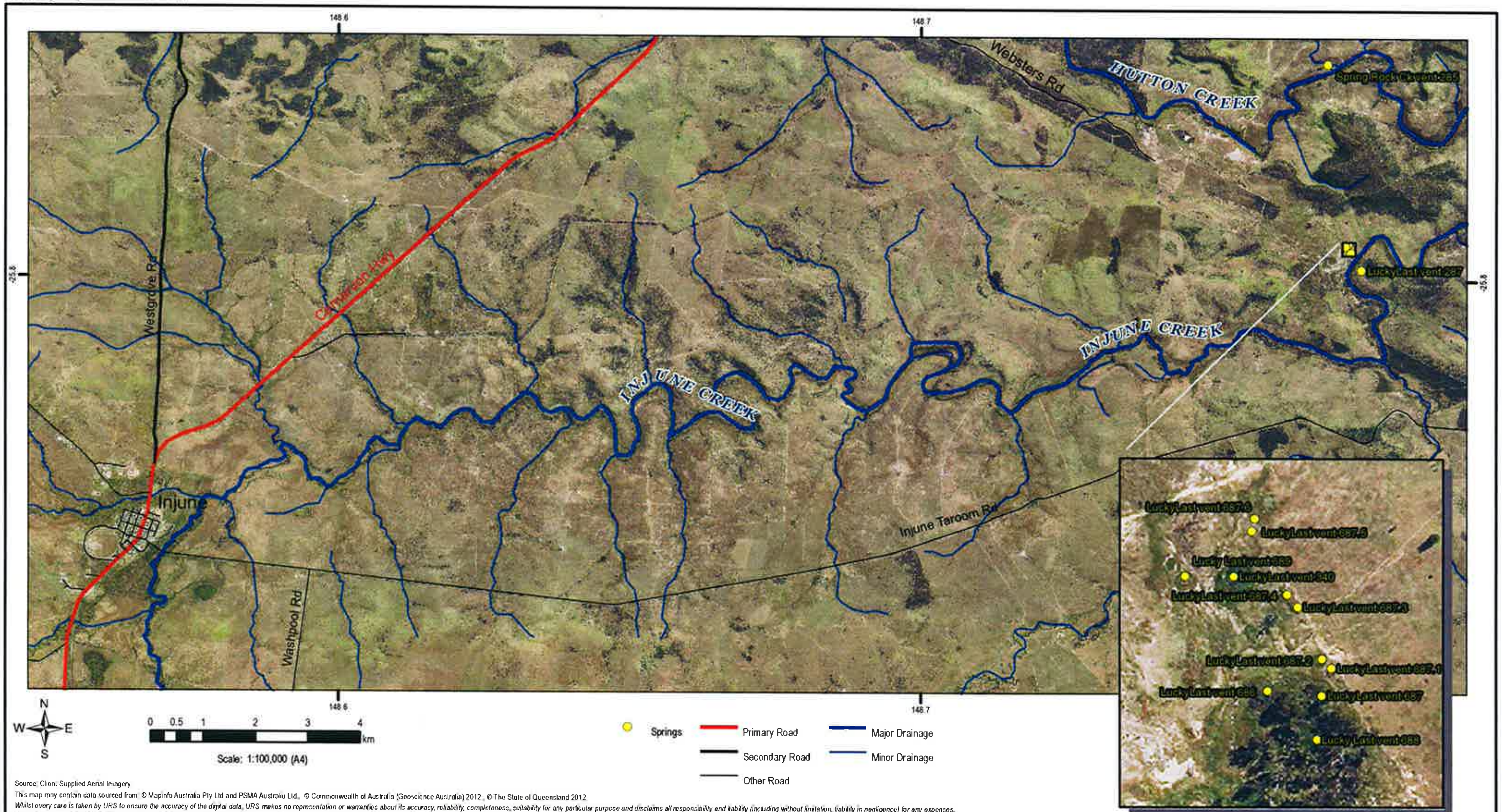
The overall aims of the ecology component of the spring assessment are to characterise each spring or spring complex, ascertain potential impacts of drawdown and provide mitigation options.

Santos has highlighted several objectives for the ecology study. These are:

- Determine the ecological stability of the spring ecosystems;
- Identify the impacts to the ecosystem flora resulting from decreased water supply;
- Determine the vulnerability of the springs to a drop of 0.21 m (311/Yebna) or 1.2 m head (Lucky Last);
- Define the point where drawdown impacts to springs may be non-reversible; and
- Identify and rationalise use of monitoring equipment recommended for assessing impact to springs.

To achieve these objectives, the following tasks have been identified:

- Undertake ecological surveys every three months for one year to determine and monitor :
  - Extent of wet area (zone of influence of water regime for dependent flora);
  - Flora and fauna species diversity and abundance;
  - EPBC species presence and variability; and
  - Representative sites for ongoing surveys.
- Assess the vulnerability of spring ecosystems in terms of:
  - Spring resilience to dry periods;
  - Flora root zone; and
  - Resilience to a lower water level;
- Quantify the vulnerability of spring ecosystems in view of maximum predicted water level decline at Yebna/311 and Lucky Last; and
- Determine the minimum water level decline for impact to be manifested.



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SPRING MITIGATIONS OPTION ASSESSMENTS AND SELECTION - EPMOR

SPRING ECOLOGICAL ASSESSMENTS (WEST)

URS | **ECOLOGICAL ASSESSMENT**

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Figure: 1a | Rev.A | A4

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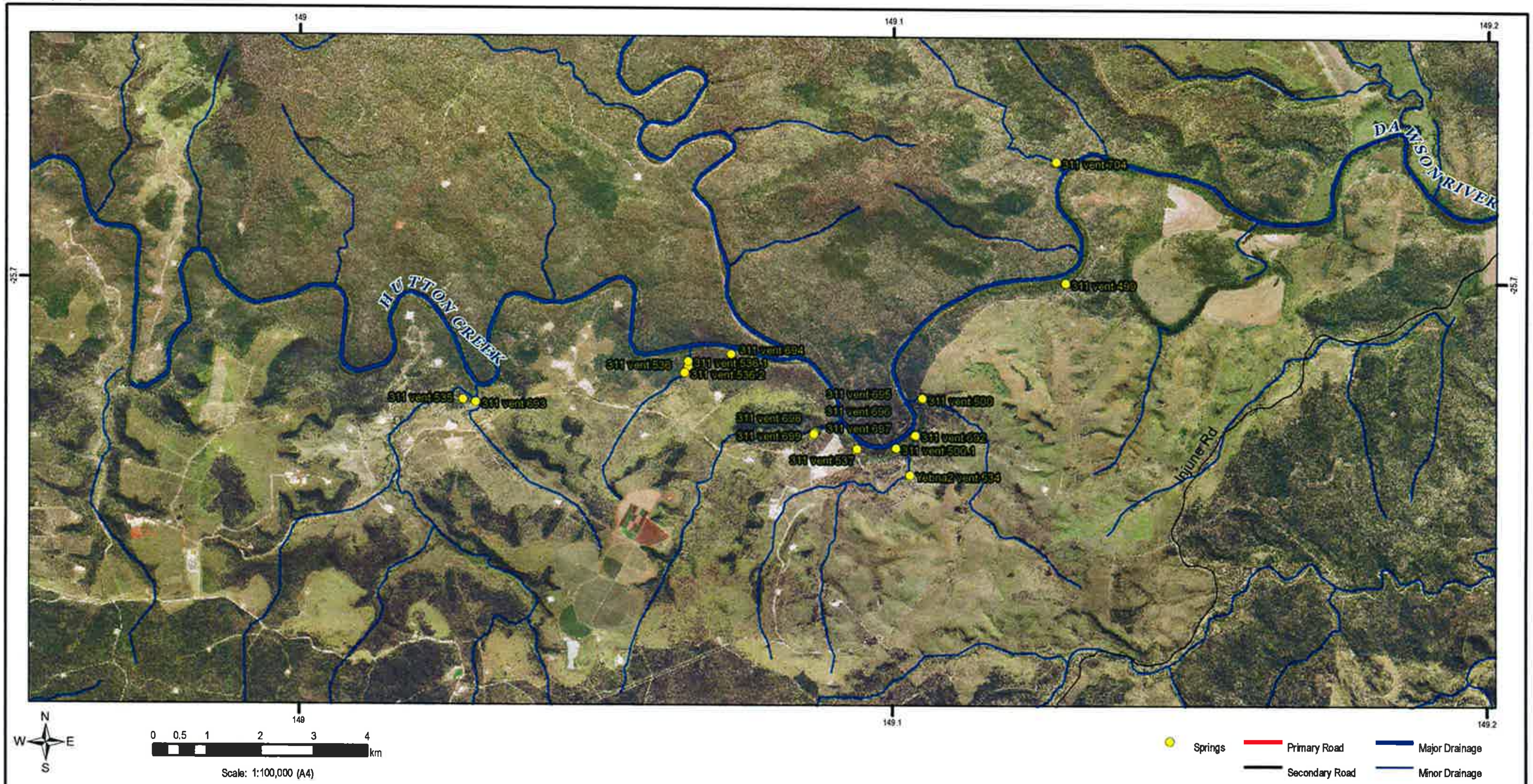

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SPRING MITIGATIONS OPTION ASSESSMENTS AND SELECTION - EPMOR

SPRING ECOLOGICAL ASSESSMENTS (EAST)

URS

ECOLOGICAL ASSESSMENT

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Figure: 1b

Rev. A | A4

Background

This section presents a high-level summary of spring geomorphology and ecology with specific reference to the spring complexes studied as part of this project.

2.1 Great Artesian Basin

The groundwater feeding the springs and spring complexes assessed is sourced from the Great Artesian Basin (GAB). The GAB is a vast (~ 1.7 million square kilometres) hydrogeological basin that consists of several interconnected geological basins. It straddles arid and semi-arid areas of Queensland, Northern Territory, South Australia and New South Wales (Fensham *et al.,* 2010, DSEWPaC, 2012). The GAB is a confined groundwater system fed by rainwater entering the basin predominantly along its eastern margin (Radke *et al.,* 2000 in Fensham *et al.,* 2010), where the aquifer sediments outcrop as sandstone or are buried beneath freely draining material.

2.2 Surat Basin

The Surat Basin is a sub-basin of the GAB, approximately 280,000 km^2 in area. It comprises a sequence of generally south-westerly dipping Jurassic and Cretaceous sediments. USQ (2011) note that the Surat Basin sediments overlie the Bowen Basin and that both basins comprise a multi-layered alternating sequence of water-bearing permeable sandstones (aquifers) and low permeability siltstones and mudstones (confining units – aquitards). None of the low permeability units are considered to be so completely impermeable as to totally prevent groundwater flow between adjacent aquifers, hence the confining beds are all considered to provide some degree of leakage when subjected to hydraulic stresses from depressurisation of the coal seam.

Natural discharge occurs within the Surat Basin as outflow from springs, discharge to the regional water table through fractures or matrix flows and sub-surface discharge to neighbouring sedimentary basins. Outflow from springs is commonly associated with geo-structural features such as faults, fractures and the abutment of aquifers against impervious basement rocks.

2.3 Spring Definition

Springs are located where groundwater discharges to the surface naturally (USQ, 2011). Further, Fensham *et al.* (2011) define a spring vent as a permanent natural surface expression of groundwater, and a spring wetland as an area of ground that is permanently maintained in a damp condition by a spring vent or multiple vents. GAB springs are regionally clustered and referred to as spring Super-groups (Fairfax and Fensham, 2003). The springs assessed as part of this study are within the Springsure Super-group. A spring complex is defined In Queensland as a group of springs where no adjacent pair of springs is more than 6 km apart and all springs within the complex are in a similar geomorphic setting (Fensham & Fairfax 2003). In some situations the total area of a complex may extend more than 6 km. Complexes can contain both active and inactive springs.

2.4 Springs in the Surat CMA

The UWIR (QWC, 2012) notes that there are six basic types of springs in the Surat CMA as defined by hydrogeological characteristics (some springs can display a mix of these characteristics):

(a) A spring can form where there is a change in the geology within the landscape. This type of spring is often referred to as a contact spring. Where a higher permeability formation overlies a lower permeability formation, there is a restriction to flow across the boundary. As a result, water tends to flow laterally and may find expression at the surface as a spring.

(b) Permeability can vary within an individual aquifer. In an aquifer, there can be layers of higher and lower permeability. Water restricted by a lower permeability layer can flow laterally through a higher permeability layer as a perched watertable, and may find expression at the surface as a spring. This type of spring typically occurs within outcropping aquifers and forms in a similar way to a contact spring described under (a).

(c) A geologic structure, such as a fault can provide a path to the surface along which water can flow. If an underlying aquifer is confined by impermeable material and the water pressure in the aquifer is high enough, water can flow to the surface as a spring.

(d) A thinning of a confining layer can provide a path to the surface along which water can flow. If the pressure in the aquifer is high enough, water can flow to the surface as a spring.

(e) Where an aquifer outcrops high in the landscape, such as in Carnarvon Gorge, Expedition Ranges and the Great Dividing Range, a spring can form where there is a change in the slope of the ground surface.

(f) Where an outcropping aquifer has been eroded to create a depression in the surface of sufficient depth to reach the water table, a spring can form. This type of spring is generally associated with creeks and streams, and is referred to as a watercourse spring (also sometimes referred to as baseflow springs) in the UWIR.

Based on the preliminary findings of the Groundwater component of the EPMOR, the spring types that are the subject of this study could include any of those defined above except for (e) (G Steyl, pers. comm. 2013). Further descriptions of the springs assessed are presented in Section 4.0 and Appendix A.

2.5 The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin

The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin is an EPBC-listed Threatened Ecological Community (TEC). This TEC can be described as "Spring wetlands fed by discharge of GAB groundwater except where springs occur within outcrop areas of the following sandstone formations on the eastern margins of the GAB: Adori, Boxvale, Clematis, Expedition, Gilbert River, Griman Creek, Gubberamunda, Hampstead, Hooray, Hutton and Precipice sandstones, the Bulimba, Glenidal, Moolayember, Piliga, Rewan, Wallumbilla and Westbourne formations, and the Helby and Ronlow Beds" (Fensham *et al.,* 2010).

Springs which are not included in this community are generally associated with outcropping sandstone, which can form rugged landscapes with springs often situated in gullies and providing the source for streams (Fensham *et al.,* 2010).

All springs assessed during this project derive water from the GAB, however only the 12 vents in the Lucky Last and single vent in the Yebna 2 complexes are identified as being part of the EPBC TEC. The source aquifers for these complexes are the Evergreen Formation and Precipice Sandstone (QWC, 2012). The remaining vents assessed are associated with outcropping of sandstone, primarily in creeks and gullies. These springs typically provide baseflow for waterways such as Hutton Creek and Dawson River within the study area.

Methods

3.1 Desktop Review

A range of relevant reports and papers were reviewed to gain an understanding of the general hydrogeology and ecology of the study area, as well as the specific ecological and hydrogeological character of each of the spring complexes or vents. Key documents utilised are summarised below.

Underground Water Impact Report for the Surat Cumulative Management Area

The Underground Water Impact Report for the Surat Cumulative Management Area (UWIR) (QWC, 2012) provides a comprehensive description of groundwater resources in the Surat Cumulative Management Area (Surat CMA) and greater region, regional landscape and geology, historic and current groundwater extraction, predictions of groundwater impacts, a Water Monitoring Strategy and a Spring Impact Management Strategy (SIMS).

The SIMS describes the nature of the springs and identifies the potentially affected springs in the Surat CMA. The SIMS defines a potentially affected spring if it overlies a GAB aquifer where the long-term predicted impact on water pressures at the location of the spring resulting from the extraction of water by petroleum tenure holders exceeds 0.2 m. In addition, the SIMS includes high value springs that are located up to 10 km beyond the 0.2 m limit to allow for the limitations associated with modelling very small changes in water pressure.

In 2010, the QWC commissioned surveys of springs that met the following criteria:

- Springs that had not previously been fully surveyed, and are located on a petroleum tenure or within 20 km of a petroleum tenure; and
- Springs known to be associated with EPBC Act listed species and the listed ecological community, 'the community of native species dependent on the discharge of groundwater from the GAB', regardless of their prior survey status.

The findings of the surveys of the identified springs are presented in Fensham *et al.* (2011), a synopsis of which is presented below.

The UWIR is the primary driver for the Evaluation of Mitigation Options Report (EPMOR), of which the current spring survey is a component.

Ecological and Botanical survey of springs in the Surat Cumulative Management Area

The Queensland Herbarium conducted a survey of springs within the SCMA in 2011 (Fensham *et al.*, 2011). The purpose of the spring survey was to assist the QWC in the development of the SIMS. In particular, the information collated as part of this project aimed to assist with the following activities:

- Characterising the springs in relation to ecological attributes;
- Characterising springs in relation to condition;
- Providing a current record of the presence or absence of Commonwealth listed species and the listed ecological community '*The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin*';
- Providing a current record of the presence of State listed species;
- Providing guidance on where additional investigations are required in the future;
- Guiding the development of targeted monitoring and mitigation strategies under the SIMS; and

- Providing a basis for coal seam gas and petroleum proponents to meet their obligations under the Commonwealth conditions of approval under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

Fensham *et al.* (2011) conducted a survey of 95 Surat CMA springs between March and September 2011. Twenty-two of these were assessed during the current survey.

The results of this survey formed an important resource to support fieldwork during the current survey.

Spring Impact Prevention or Mitigation Options Desktop Analysis Summary Report

Halcrow (2013) undertook a desktop analysis of the Lucky Last, Spring Rock Creek and 311/Yebna2 Spring Complexes that included the following key tasks:

- Site Characterisation: A review of all available information and an assessment of the hydrogeological regime and confirmation of the source aquifer;
- Summary of Predicted Impacts: A summary of the predicted impacts on groundwater level at each of the spring vents, based on modelling undertaken by GHD (2012);
- Evaluation of Potential Spring Mitigation Options: Undertaken by:
  - Identification of the spring vent source aquifer and associated GAB groundwater management unit;
  - Identification of registered bores within 5 km of each spring vent;
  - Calculation of the potential cumulative impact from groundwater abstractions; and
  - Evaluation of the feasibility of relocation, surrender or substitution of groundwater entitlements allocated to registered bores within 5 km of a spring vent.

Recovery plan for the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin

This recovery plan is for '*The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin*'. The community is listed as 'Endangered' under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The overall objective of the plan is to maintain or enhance groundwater supplies to Great Artesian Basin discharge spring wetlands, maintain or increase habitat area and health, and increase all populations of endemic organisms (Fensham *et al.*, 2010; DSEWPaC, 2013).

Within this document, the Lucky Last complex (a target of the current survey) has been noted to support *Eriocaulon carsonii* (salt pipewort), an EPBC-listed plant species.

Preliminary Assessment of Cumulative Drawdown Impacts in the Surat Basin Associated with the Coal Seam Gas Industry

The overarching aim of this report was to collate and present the existing groundwater modelling data to provide both the Government and the public with a greater level of understanding and confidence regarding the cumulative groundwater impacts from the development of CSG projects within the Surat Basin.

The key objectives of this preliminary study were to:

- Determine the groundwater areas expected to be impacted by depressurisation of the Walloon Coal Measures by the four major CSG company projects in the Surat Basin; and

- Compile a package of information and data to be provided to the QWC to assist its modelling consultants in developing a regional groundwater model for the Surat Basin.

Recovery plan for salt pipewort Eriocaulon carsonii 2007–2011

This recovery plan (Fensham, 2006) was developed to prevent further decreases in numbers, populations and habitat of the salt pipewort and to increase numbers, populations and habitat where possible.

Salt pipewort is listed as 'Endangered' under the EPBC Act and under the Queensland Nature Conservation Act 1992 (NC Act). The recovery plan details biological information on the salt pipewort relevant to identifying the potential threat from drawdown and ability to recover should flow be restored.

Other pertinent reports reviewed include:

- Water Resource Assessment for the Surat Region (Smerdon and Ransley, 2012);
- Assessment of the impacts of future climate and groundwater development on Great Artesian Basin springs (Miles *et al.*, 2012);
- Risk Assessment Process for Evaluating Water Use Impacts on Great Artesian Basin Springs (Green *et al.*, 2013);
- Hydrogeological Attributes Associated with Springs in the Surat Cumulative Management Area (Klohn Crippen Berger, 2012a); and
- Desktop Assessment of the Source Aquifer for Springs in the Surat Cumulative Management Area (Klohn Crippen Berger, 2012b).

3.2 Field Study

Prior to commencing fieldwork, summary information for target spring vents was provided by Santos that included a summary of spring data such as locations, brief descriptions and notes. A Santos prioritisation of spring vents for field assessment was also provided. The spreadsheet was used as a reference guide whilst undertaking fieldwork.

A digital form of the above summary information was uploaded to a hand-held GPS device (Trimble Nomad) supporting Discover Mobile (a mobile MapInfo platform) that can be interrogated in the field. Other data layers utilised included Santos tracks, waterways, roads, vegetation communities and geology.

A field assessment was undertaken at 29 targeted sites by a team of two ecologists for a period of three days between 30 April 2013 and 2 May 2013.

3.2.1 Vent Assessments

Table 3-1 below lists the vents targeted for assessment, the priority for study and if actual assessment took place. The vents are depicted on Figure 1-1 and Figure 1-2.

3 Methods

Table 3-1 Spring vents targeted for assessment

Complex Number	Complex Name	Vent Number	Priority for Ecological work	Assessed
311	311	499	Low	Yes
311	311	500	Medium	Yes
311	311	500.1	High	Yes
311	311	535	High	Yes
311	311	536	Medium	Yes
311	311	536.1	Medium	Yes
311	311	536.2	High	Yes
311	311	537	Medium	Yes
311	311	692	Medium	Yes
311	311	693	High	Yes
311	311	694	Low	**No**
311	311	695	High	Yes
311	311	696	High	Yes
311	311	697	High	Yes
311	311	698	High	Yes
311	311	699	High	Yes
311	311	704	Medium	**No**
230	Lucky Last	287	High	Yes
230	Lucky Last	340	High	Yes
230	Lucky Last	686	High	Yes
230	Lucky Last	687	High	Yes
230	Lucky Last	687.1	High	Yes
230	Lucky Last	687.2	Medium	Yes
230	Lucky Last	687.3	Medium	Yes

230	Lucky Last	687.4	Medium	Yes
230	Lucky Last	687.5	Medium	Yes
230	Lucky Last	687.6	High	Yes
230	Lucky Last	688	High	Yes
230	Lucky Last	689	High	Yes
561	Spring Rock Creek	285	High	Yes
591	Yebna2	534	High	yes

As depicted in Table 3-1, above, 31 spring vents were identified as targets for the ecological survey. Of these, 19 vents were recognised as High Priority, 10 as Medium and two as Low Priority. Two spring vents (694 and 704) were not accessed due to access and safety concerns. These were labelled as Low and Medium Priority respectively. As shown, all High Priority vents were surveyed. The priority ranking was developed by Santos and was based on EPBC listing, potential predicted impacts, proximity to construction and other factors.

At each vent, a range of attributes were recorded, including (but not restricted to):

- Location/ Complex Name/ Vent Number;
- Description of geomorphology and vent;
- Presence of, and form of moisture (dampness or standing water);
- General description of landscape and vegetation surrounding each vent;
- An inventory of all spring-dependent (aquatic) plants;
- Faunal usage of the site;
- Disturbance to the vent and local area;
- Weeds present; and
- Recommendations for local management.

A range of general photos were taken for the site and surrounds.

3.2.2 Photo-monitoring Points

Photo-monitoring points were established at most of the sites (refer to Appendix A). Photo-monitoring will be conducted at selected vents in June 2013, as well as during spring and summer in 2013 to assess seasonal variability in flows and conditions. The establishment of photomonitoring points involved the installation of a painted wooden stake at a location adjacent to the vent and taking a photo (or photos). Selected vents will be revisited

As cattle were frequenting the majority of the springs, the potential for disturbance to stakes was high. In these places, where available, an adjacent existing tree or sapling was used as the reference point. At some sites a monitoring reference stake was not installed due to the lack of suitable ground to place the stake or where multiple similar vents were in close proximity.

3 Methods

3.2.3 Flora Survey

At each vent and immediately downstream of each vent, a comprehensive inventory of aquatic plant species were undertaken. Although dominant flora in the local terrestrial environment were also recorded, aquatic plants were the focus of the study as, in the event of drawdown, these species would initially indicate that drawdown-related impacts are occurring and the loss of these species could predict the loss of the ecosystem on the whole. Where possible, aquatic plants were identified at the time of survey. When they could not be positively identified, samples were taken and forwarded to the Queensland Herbarium for identification.

A flora list is presented in Appendix B. In the appendices as well as the main body of the report, the asterisk symbol (*) has been used to denote exotic plant or animal species.

3.2.4 Fauna Observations

Opportunistic observational records of vertebrate fauna were taken during the field survey. Although this was not a focus of the field assessment, faunal usage can be a good indicator of habitat quality and ecosystem functionality.

Results and Discussion

Twenty-nine spring vents (out of a possible 31) were assessed for ecological values, flora species, disturbance levels and other attributes. Table 3-1 details the vents that were assessed. A discussion of the results is presented below. A profile description for each vent is presented in Appendix A. The location of spring vents is presented on Figure 1-a and Figure 1-b.

4.1 Study Area and General Characteristics

The study area is located to the north-east of Injune in south-central Queensland (refer to Figure 1-a and Figure 1-b). It is located within the southern portion of the Fairview CSG field. The study area comprises 31 vents of three spring complexes within an area of approximately 590 km^2. These spring complexes are identified as Yebna/311, Spring Rock Creek, and Lucky Last complexes.

The landscape of the southern Fairview CSG field has previously been described as within "...an extensive belt of predominantly coarse sandstones that form the north-eastern margin of the Great Artesian Basin. These have been partly dissected to form an undulating to hilly surface with areas of deep valleys and gorges. Soils are predominantly coarse, with deep sands or with deep sandy-surfaced texture contrast soils on less steep areas. A mixed eucalypt woodland or forest, usually with a shrubby understorey, is the most widespread vegetation type, the dominant tree being narrow-leaved ironbark (*Eucalyptus crebra*), spotted gum (*Corymbia citriodora*) and bloodwoods (*Corymbia* spp.). Cypress pine (*Callitris glaucophylla*) is common on the deeper soils of undulating areas, whereas rusty gum (*Angophora leiocarpa*) is common in valleys" (Sattler and Williams, 1999).

A number of waterways are found within the study area, with the Dawson River a prominent feature. Hutton Creek and a range of ephemeral waterways feed into the Dawson River, with many of these supplying baseflow from the springs investigated.

The land uses within the study area historically have been grazing and forestry. As such, much of the native woodlands have been cleared and pastures have been improved with introduced grasses such as buffel grass (*Pennisetum ciliare**). More recently, CSG production has become prominent in the area.

4.2 Spring Characteristics

The springs assessed as part of this study appear to be of two primary types: mound springs and watercourse springs (baseflow springs). Watercourse springs occur where an outcropping aquifer has been eroded to create a depression in the surface of sufficient depth to reach the water table. This type of spring is generally associated with creeks and streams (QWC, 2012). The mound springs are a particular type of spring formation that conforms to the definition of the EPBC-listed TEC *The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin.*

However, preliminary findings from the Groundwater component of the EPMOR suggest that there are compound geological settings present leading to uncertainty regarding the hydrogeology at the Lucky Last complex. In other areas, some of the watercourse springs may actually be sourced from local ephemeral groundwater discharge instead of being sourced from an aquifer.

For the purposes of this report, existing spring classifications (watercourse or mound springs) and groupings will be used as defined within the Queensland Herbarium's Surat CMA spring database (Pennay and Drimer, 2011).

Many of the watercourse springs are seeps from the base of exposed banks along creeks, or from within cracks in sandstone slabs and boulders on the creek fringe. Others exist as outlets in deeply incised gullies where dense exotic grasses, fallen timber and flood debris are concealing the actual vent. Water flow from vents was typically a slow seep; rarely it was a significant flow of water. It is likely that seasonal conditions will influence spring flow. Monthly rainfall data for the Injune Post Office Station (Number 43015) shows that well above average rainfall fell in the area in 2008, 2010 and 2011 with 2010 recording 1343.9 mm (mean 640.5) (BoM, 2013). The influence of the groundwater stemming from this rainfall is potentially still being displayed at some vents.

Most 'mound' springs displayed a degree of surface mounding, although some had limited to no mounding. Generally the larger springs displayed mounding to around 1-2 metres above surrounding ground level. The size of the mound vents varied considerably. The smallest mound vents were around one metre in diameter. The largest mound, Four Dog at the Lucky Last complex, was approximately 40 metres in diameter. The largest mound springs comprised a wetland 'tail' downstream of the mound. This was only evident where spring outflow exceeded evaporation and transpiration. Wetland size was variable from non-existent/minuscule to over 50 metres long (Four Dog). The wetland tail at Lucky Last vent 688 is shown on Plate 4-3.

Nearly all the springs, except those located in steeply incised gullies, were heavily impacted by cattle through trampling, grazing and fouling. Use by pigs for wallows and the presence of exotic and non-endemic native flora were also common.

4.3 Spring Flora

An inventory of flora using the wet portions of each vent was undertaken. For mound springs this included the mound, the damp or wet circumference of the mound, and the downstream wetland where this was present. For watercourse vents, the damp and wet creek bed and banks were surveyed in the vicinity of the vents. The survey recorded true aquatic and semi-aquatic flora (those species that are dependent upon the presence of water for at least part of their life cycle), along with terrestrial species that had colonised the damp areas. In addition, shrubs and trees were recorded where present. A general description of the surrounding terrestrial environment was also recorded.

The flora survey results are presented in Appendix A (vent profiles) and Appendix B (species list). One conservation significant flora species *Eriocaulon carsonii* (salt pipewort) was recorded from the Lucky Last complex. This had previously been recorded from this site (Fensham, 2006; Fensham *et al.*, 2010; Fensham *et al.*, 2011). It is listed as Endangered under the Commonwealth EPBC Act and the Queensland NC Act.

At the time of the survey (April-May 2013), cooler conditions were causing grasses to 'brown-off'. This, in conjunction with grazing impacts, meant that fertile material on many grass, sedge and herb species was absent which precluded positive identification of all species.

The Lucky Last complex exhibited growth of a large number of *Eucalyptus tereticornis* (forest red gum) at various stages of growth. Mature specimens, probably greater than 100 years of age, were growing within and around the spring complex and associated wetlands. Also present were a large number of saplings of the species.

Forest red gum is known to prefer alluvial flats subject to occasional flooding in drier areas. It does not tolerate waterlogging (Boland *et al.*, 2006). That *Eucalyptus tereticornis* is growing, germinating and apparently thriving in and around the damp and wet conditions of the Lucky Last complex tends to indicate that the vents may have undergone periods of drying in the recent past. During these periods, soil and sub-soil conditions may have been dry enough to enable the growth of trees. Plate 4-1 shows a moderately sized forest red gum growing on the verge of vent 687. The area around this tree is very boggy, and it is assumed that much of the root area is within very damp soil. A number of healthy saplings are also present adjacent to the vent.

Plate 4-1 ***Eucalyptus tereticornis*** **growing adjacent to Lucky Last vent 687**

Plate 4-2 shows a circle of approximately 30 *Eucalyptus tereticornis* saplings around vent 686 of the Lucky Last complex. The vent mound is dry, but 'floats' on the mud beneath and the surrounds are damp. This tends to indicate a recent change in moisture regime. It is possible that the spring and surrounding soil is drying out, thereby allowing saplings to colonise the site whereas some time ago the area was waterlogged.

Plate 4-3 shows that *Eucalyptus tereticornis* of a variety of ages are actively growing in the wetland tail of vent 688 of the Lucky Last complex. The soil surface at this site has water flowing over it and moisture extends through the soil profile for some depth. Mature tree mortality has occurred in this area but it is speculated that this is primarily due to the boggy soils not being able to support the excessive tree mass with subsequent tree fall. That trees of a range of ages are actively growing in this very wet area again suggests that conditions have changed, or the springs are highly vulnerable to seasonal changes in flow with the drying and wetting cycles mimicking natural creek flooding events to enable *Eucalyptus tereticornis* to prosper. It is difficult to estimate the time period in which the changes have been occurring. However, given the age of the saplings present, it appears that there have been cycles of wetting and drying over the last 20 years at least. Certainly, the spring vents would be dynamic over geological time in terms of location and flows. It may be possible that a dendrochronologist may be able to sample the tree core to facilitate an understanding of moisture regimes over time in the vicinity of the Lucky Last vents.

Plate 4-2 Ring of *Eucalyptus tereticornis* saplings around vent 686 of the Lucky Last complex

4.4 Spring Wetland Regional Ecosystems

The Department of Environment and Heritage Protection (EHP) use Regional Ecosystems (REs) to describe the relationships between vegetation communities and the environment at the bioregional scale. REs are derived from linking vegetation mapping units recognised at a scale of 1:100,000 to land zones that represent major environmental variables, in particular geology, rainfall and landform.

During the recent Queensland Herbarium ecological and botanical survey of springs within the Surat CMA, Fensham *et al.* (2011) attributed spring wetland communities to one of the two applicable spring RE codes: RE 11.10.14 and RE 11.3.22. These are detailed in Table 4-1, below.

Table 4-1 Spring Regional Ecosystems

RE	Description	VM Act class	Biodiversity status
11.10.14	Springs. Associated with quartzose sandstone ranges.	Of Concern	Endangered
11.3.22	Springs. Associated with recent alluvia, but also including those on fine-grained sedimentary rocks (shale), basalt, ancient alluvia and metamorphic rocks.	Of Concern	Endangered

The current survey did not reassess these REs but did confirm them visually during the assessments. The RE of each spring (as determined by Fensham *et al.*, 2011) is noted on the vent profiles presented in Appendix A.

4.5 Spring Condition

The ecological condition of each spring is considered to be relatively poor. This is primarily the result of current impacts from cattle congregating around and using these reliable water sources.

Impacts observed included trampling of vegetation, grazing of herbage to ground level, hoof impressions in waterlogged soil and fouling of the watercourses and vents. In many cases the levels of damage precluded an absolute identification of vent expression and inventory of flora present. In a number of springs pig rooting and wallows were also evident, further reducing the condition. Weeds and pasture species were also common within and around the springs and spring wetlands.

4.6 Weeds

A number of weeds were recorded at the spring vents and associated wetlands. Species commonly recorded include *Cirsium vulgare** (spear thistle), *Conyza sumatrensis** (tall fleabane), *Chloris virgata** (feathertop Rhodes grass), *Gomphocarpus fruticosis** (narrow-leaf cotton bush), *Megathysus maximus** (green panic) and *Xanthium pungens** (Noogoora burr). *Opuntia stricta** (prickly pear) and *O. tomentosa** (velvety tree pear), both rarely observed, were the only weed species declared under the Queensland *Land Protection (Pest and Stock Route Management) Act 2002* recorded. The tall native grass *Phragmites australis* (common reed) was present at a number of vents in the Lucky Last complex. This species is often regarded as a pest of wetlands and can proliferate in the right conditions (such as after removal of stock (Fensham, 2006)).

Weed levels at the spring complexes were generally low and consisted of agricultural weeds typical of the area. At present the threat of weeds appears minimal compared to that provided by cattle and pigs. However, weeds (including *Phragmites*) should be monitored to ensure that new infestations do not occur and current species do not expand their range.

4.7 Native Faunal Usage

Free water emanating from vents provides significant resources for native fauna, not only as a source of water for drinking, but also for the shelter the dense plant growth provides and as a source of food items. During drought or in the absence of artificial water sources, springs become more important as a water resource in the region.

Whilst not a focus of the current study, a range of mammals, birds, reptiles and amphibians were observed utilising spring habitats during the field assessment. The loss of water flow could have an impact on localised faunal populations, particularly animals with limited range such as amphibians, small reptiles and small ground mammals. It is possible that local extinctions of these faunal assemblages could occur at the vent surrounds should drawdown result in the loss of free standing water.

The loss of dense wetland vegetation from wetlands downstream of the vents (e.g. Lucky Last complex, vent 688; see Plate 4-3, below) would impact on species that utilise such habitat including the rufous bettong (*Aepyprymnus rufescens*) and snake species such as the red-bellied black snake (*Pseudechis porphyriacus*). This may need to find alternative habitat elsewhere which could leave them open to predation or competition for resources.

Plate 4-3 Wetland downstream of Lucky Last vent 688

4.8 Conservation Significant Species and Communities

A number of conservation significant flora and fauna species and communities were identified during the springs survey:

- *The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin* is listed as an Endangered TEC under the EPBC Act. This community is present at the vents of the Lucky Last Complex and a single vent of the Yebna complex.
- *Eriocaulon carsonii* (salt pipewort) is an herbaceous perennial plant that inhabits spring complexes in South Australia, Queensland and New South Wales. The GAB sustains the wetlands with salt pipewort populations in the study area (Fensham, 2006). It is listed as Endangered under the Commonwealth EPBC Act and the Queensland NC Act. It is ranked as a high priority under the Department of Environment and Heritage Protection *Back on Track* species prioritisation framework. It was recorded at Lucky Last vents 287, 340, 787, 687.1, 687.4, 687.6 and 689.
- The tusked frog (*Adelotus brevis*) was identified from calls at numerous vents and spring wetlands during the survey. The tusked frog is listed as Vulnerable under the Queensland NC Act. It was identified at the following complexes/vents:
  - Yebna/311 vents 500, 535, 536;
  - Lucky Last vents 287, 689; and
  - Spring Rock Creek vent 285.

4.9 Threats to Springs

A range of threats have been identified that have the potential to impact on springs and associated communities. DSEWPaC (2013) note a number of threats, including livestock farming and grazing and extraction of artesian water resources that are relevant to the springs within the study area. Fensham *et al.* (2010) notes the following threats as barriers to the recovery of springs:

- Aquifer drawdown from bores and mining, coal seam gas extraction and geothermal mining;
- Excavation of springs;
- Exotic plants, in particular the following, have been recorded as pest flora at various springs:
  - *Urochloa mutica** (para grass);
  - *Hymenachne amplexicaulis** (hymenachne);
  - *Phoenix dactylifera** (date palms);
  - Bamboo* (species unknown);
  - *Tamarix aphylla** (athol pine);
  - *Parkinsonia aculeata** (parkinsonia);
  - *Acacia nilotica** (prickly acacia); and
  - *Cryptostegia grandiflora** (rubber vine)[1].
- Stock and feral animal disturbance, in particular grazing and trampling and pig rooting;
- exotic aquatic animals such as mosquito fish (*Gambusia holbrooki**);
- tourist visitation; and
- Impoundments.

Aquifer drawdown is discussed in more detail in Section 4.9.1, below. Weeds are discussed further in Section 4.7.

Management of impacts from cattle, pigs and weeds should be considered as part of the long-term management of the spring complexes.

4.9.1 Drawdown

During CSG production, groundwater is pumped from the CSG wells to lower the water pressure in the coal seam so that the gas is released. CSG production is therefore dependent on groundwater extraction to facilitate recovery of the gas from the coal seams (USQ, 2011).

Drawdown of groundwater has been identified as threat to springs and their ecology (Fensham, 2006; Fensham *et al.*, 2010; Fensham *et al.*, 2011; DSEWPaC, 2013). Fensham *et al.* (2010) detail local extinction of endemic species as a result of drawdown at a range of springs. In addition, it is noted that the area of habitat of many specialised plants and animals has been reduced at locations where springs are still active[2].

It has also been identified that reductions in spring flow can result in changes to water quality in the spring surface water environment by increasing salinity, exposing sediments and triggering acid sulphate conditions (Green *et al.*, 2013).

The UWIR (QWC, 2012) notes that "The 'Lucky Last' spring complex is expected to be the site that is most affected. Impacts in the source aquifer at the location of the spring complex are not expected to

[1] None of these species were recorded during the current study.
[2] Primarily as a result of drawdown stemming from free-flowing artesian bores. The effect of drawdown from CSG activities could have a similar impact.

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exceed more than 0.2 m until 2017 and the maximum impact is expected to be less than 1.3 m. Impacts at the other sites are expected to be smaller and occur later. Impacts at the other sites are expected to be smaller and occur later".

Risks to springs from aquifer drawdown are dependent on:

- the extent of drawdown at the spring;
- the relationship between spring flow and aquifer hydraulic pressure; and
- sensitivity of spring surface environment and spring ecosystems to flow reduction (Green *et al.*, 2013).

Therefore, each spring may react differently to drawdown and even related vents within the same complex may behave in diverse ways.

Without knowing the exact magnitude of the drawdown for each vent it is difficult to establish how it might be affected. However, drawdown generally is going to be expressed as the 'drying-up' of the vent and associated spring wetland. With regards to the springs subject to the current study, four scenarios could eventuate as drawdown progresses (disregards other factors such as change in water quality):

a) No change to presence and quantity of free standing water and moisture levels;
b) Free standing water disappears but soil moisture levels are retained at the surface;
c) Soil moisture not evident at surface but is present below surface; or
d) Soil moisture drops below useable depth for aquatic and semi-aquatic plants (but may be accessible by deep-rooted species such as trees).

These are explored further below. Seasonal variation in vent flow, the area of standing water and soil moisture levels is likely irrespective of CSG activities; this may play a greater role in flow fluctuations than drawdown. Seasonal variation is not considered in the scenarios below as these are not yet understood. The spring vents and associated wetlands at the Lucky Last complex have been used as an example due to the diversity of habitat types and the extent of the wetland systems.

Scenario A – No impact

This scenario will eventuate if there is no impact on a vent and surface conditions remain stable. That is, there may be little or no impact on the springs from a reduction in groundwater pressure. Wetland functionality will be retained and flora diversity will be maintained. There would be significant benefits in managing cattle and other impacts at the vents for positive biodiversity and amenity outcomes.

Scenario B - Loss of free standing water

In this scenario the vent would cease having value as a drinking water source for cattle and native fauna. The soil moisture levels would result in the retention of some aquatic and semi-aquatic flora although it is highly likely that flora assemblages would change with plants requiring higher water regimes being replaced with those needing less water. In the case of a mound spring it is likely that the extent of the trailing wetland (if present) would contract. The area would remain as habitat for fauna species that require shelter, although it would not support the same abundance and diversity.

Scenario C - Loss of surface soil moisture

Scenario C would see the spring and wetland flora assemblages change further, with shallow-rooted herbs and forbs disappearing and only deeper-rooted plants remaining. The wetland extent would retract further leaving a reduced area supporting semi-aquatic plants. Terrestrial herbs and grasses would invade the formerly damp area.

Shrubs and trees intolerant of anoxic soils may also establish, although the wetter soil at depth may restrict their growth and they may be short-lived. Many fauna species that utilised the area would not remain except for those tolerant of change. Assemblages will depend on the nature and form of the vegetation that replaces the wetland ecosystem.

Scenario D – Lowering of sub-surface soil moisture

This scenario would result in the complete disappearance of wetland plants that rely on permanent water, although some hardy species such as rice sedge (*Cyperus difformis*) may remain in overland flow paths. Grasses and other terrestrial species will invade and dominate. Shrubs and trees would become well established, although growth would be determined by depth of the water influence.

4.9.2 Potential Impacts at the Spring Complexes

Table 4-2 details the predicted maximum levels of drawdown at each of the spring complexes as modelled in the UWIR. Based on these levels of drawdown some inferences can be made as to the impacts at each of the spring complexes.

However, given that the parallel hydrogeological study is still in preparation, and a more refined knowledge of potential drawdown is not available, these inferences are preliminary and conservative. Advice has been given that an assessment of the potential impact on the springs (mostly Lucky Last) is problematic due to complex geological settings (G. Steyl pers. comm., 2013).

Table 4-2 Spring Complexes Identified for Potential Mitigation

Spring Complex	Spring Complex Number	No of Vents in Complex	Primary Source Aquifer	Predicted Maximum Impact (year)	Year when impact exceeds 0.2 m
311/Yebna 2	311/591	17	Precipice Sandstone	0.21 m (2066)	2062
Lucky Last	230	12	Precipice Sandstone	1.43 m (2071)	2017
Spring Rock Creek	561	1	Precipice Sandstone	1.23 m (2063)	2017

4.9.2.1 Yebna/311

A 0.2 metre drop in water level as predicted for the Yebna/311 springs may cause many of the springs to stop flowing, although there may be some moisture retained at the vent mouth. It is possible that much of the baseflow contribution to the Dawson River may slow or stop, thus potentially impacting on downstream receiving habitat. It is possible however that as the pressure head changes, the point of groundwater egress might shift and continue flowing, depending upon the individual vent circumstances. It is possible that the vents in the Yebna/311 complex may ultimately cease flowing but retain moisture, equating to Scenario B. However, given the number of vents in the complex in different locations and situations, it is likely that a number of states might eventuate.

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4.9.2.2 Lucky Last

A 1.43 m maximum drop in groundwater pressure, if this is expressed as a 1.43 m lowering of the water at the surface, will probably result in the loss of the wetland systems at the Lucky Last complex. This aligns with Scenario D, above. If this eventuates, it is possible that all aquatic and semi-aquatic herbs, grasses and sedges will be replaced over time with non-wetland species as found in the surrounding landscape. *E. carsonii* may well disappear from this complex.

As the predicted drawdown will take many years, there will be a gradual change in the floristic and structural nature of the site. *Eucalyptus tereticornis* (forest red gum), especially mature specimens, will be retained as their root system will enable water extraction from greater depths.

The alteration of ecosystem type may have a profound impact on faunal assemblages. Many fauna species dependent or partially dependent upon water and associated dense habitat will be forced to search for alternative sites. Some species may become locally extinct. Prey populations may be modified with prey substitution occurring.

4.9.2.3 Spring Rock Creek

As with the Yebna/311 springs, a 1.23 m drop in water level at this site could cause the water flow to stop, or at the very least, slow. This will probably result in the drying of the pool at this point if not supplemented by rainfall contribution. Currently the pool formed by this spring is providing water for cattle and native fauna. Both groups, especially fauna, will be impacted by the loss of water at this point. Fish noted in the pool would be affected by loss of this habitat. Aquatic plants are scarce at this site due to the rocky substrate and depth of the water. Therefore, it is considered that there will be no significant loss of an aquatic plant community. Riparian vegetation at this site, such as *Casuarina cunninghamiana* (river oak) would be likely to persist due to their extensive root system.

4.9.2.4 Summary of Potential Impacts

The analysis of drawdown impacts shows that in the worst case, springs are likely to stop flowing with resulting impacts to aquatic ecosystems and flora and fauna. Without further hydrogeological analysis and input, it is difficult to ascertain the level of drawdown where spring and wetland ecosystem functionality will not be significantly impaired.

For the Lucky Last complex, a smaller drawdown may result in the loss of smaller vents while the larger vents that feed the wetlands may continue functioning. This may still enable the retention of wetland flora and habitat, albeit with a restricted extent. This may also apply to the Yebna/311 and Spring Rock Creek vents.

Table 4-3 below summarises the ecological aspects of concern and estimated vulnerability of each vent assessed.

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Table 4-3 Ecological values and vulnerability for all vents assessed

Complex Number	Complex Name	Vent Number	Ecological Aspects of Concern	Potential Ecological Vulnerability (Scenario A, B, C or D)
311	311	499	Significant baseflow into the Dawson River	B
311	311	500	Deep pool, quality habitat, few impacts. Tusked frog recorded here.	B
311	311	500.1	Some baseflow, few ecological values.	B
311	311	535	Some baseflow, few ecological values. Tusked frog recorded here.	B
311	311	536	Provides some baseflow. Tusked frog recorded here.	B
311	311	536.1	Minor contribution to baseflow.	B
311	311	536.2	Significant cattle damage, few values. Pool of water present.	B
311	311	537	Minor contribution to baseflow.	B
311	311	692	Moderate contribution to baseflow. Few values.	B
311	311	693	Large undisturbed wetland flowing into large pools. Good aquatic habitat.	B
311	311	694	Not assessed	B?
311	311	695-699	Series of vents providing moderate baseflow. Reasonable fauna habitat but cattle impacts present.	B
311	311	704	Not assessed	B?
230	Lucky Last	287	Very large mound, good habitat, significant cattle damage. Tusked frog recorded here. *Eriocaulon carsonii* present.	D
230	Lucky Last	340	Small mound with little standing water, cattle damage. *Eriocaulon carsonii* present.	D
230	Lucky Last	686	Significant cattle damage, little standing water. Ring of *Eucalyptus tereticornis* saplings around mound of interest.	D
230	Lucky Last	687	Raised mound with some standing water. Some habitat in dense vegetation.	D

Complex Number	Complex Name	Vent Number	Ecological Aspects of Concern	Potential Ecological Vulnerability (Scenario A, B, C or D)
230	Lucky Last	687.1	Small mound, little standing water. *Eriocaulon carsonii* present.	D
230	Lucky Last	687.2	Dominated by weeds, little habitat.	D
230	Lucky Last	687.3	Dominated by weeds, little habitat.	D
230	Lucky Last	687.4	Cattle damage and standing water present. *Eriocaulon carsonii* recorded.	D
230	Lucky Last	687.5	Small mound, little standing water.	D
230	Lucky Last	687.6	Small mound, little standing water. *Eriocaulon carsonii* present.	D
230	Lucky Last	688	Large mound heavily degraded. Significant water flow into large wetland area below. Very good habitat values.	D
230	Lucky Last	689	Standing water obvious. Significant cattle and pig damage. Tusked frog recorded here. *Eriocaulon carsonii* present.	D
561	Spring Rock Creek	285	Large pool of water, fish present. Tusked frog recorded here.	D
591	Yebna2	534	Small mound heavily degraded by cattle.	B

? – no assessment so this ranking is assumed

4.10 Recovery of Spring Ecosystems

There is potential for partial or complete recovery of springs affected by drawdown, depending upon location, species present, proximity to other vents, seasonal flow variation and duration of water loss.

In the event that drawdown is to maximum predicted levels, it is likely that the floral assemblage present prior to drawdown will change significantly and aquatic plants will be replaced by terrestrial species. Upon return of flows to pre-drawdown levels, the wetland may resume functionality but may never regain the same suite of species, which will depend on viability of seeds and propagules in the soil seed bank, vectors available for re-introduction of fertile material and competition with and resilience of species that have colonised the area in the interim.

Four species recorded during the current surveyed have been researched for life cycle and seed/ propagule viability to determine the likelihood of persistence or reintroduction. These are used as indicator species to investigate the potential for recovery. Again, the Lucky Last complex has been used as an example.

The species selected are:

- *Schoenoplectus mucronatus;*
- *Eriocaulon carsonii;*

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- *Isachne globosa;* and
- *Cyperus difformis.*

Schoenoplectus mucronatus

Schoenoplectus mucronatus (bog bulrush) is a native rhizomatous perennial sedge that grows in streams and other damp situations. It was found at Yebna/311 vents 695-696, 500, 534, 536, 536.1 and 693; Lucky Last vent 688. This species was selected as an indicator species as it was found in both watercourse and mound spring situations.

S. mucronatus reproduces through seed, rhizomes, and stolons. The root produces several stolons that end with round, dark tubers. When constantly submerged, the tubers will sprout new plants; however, during a draw-down or drought, the tubers will become dormant until conditions are more favourable for growth (Holm *et al.*, 1997 in WSNCB, 2007). It is also likely that seeds are eaten by waterfowl and probably carried between sites on their feet and feathers (Swearingen *et al.*, 2010). A study on the capacity of eight Mediterranean wetland seeds to be internally dispersed by common teal (*Anas crecca*) showed that 54% of *S. mucronatus* seeds ingested were evacuated in a viable condition (Brochet *et al.*, 2010). Endozoochorous transport by Australian equivalent duck species may be an effective dispersal mechanism for this species.

Given the reproductive mechanisms available to *S. mucronatus*, the ability of tubers to maintain dormancy, the proximity of nearby populations and the dispersal vectors available, it is considered likely that *S. mucronatus* will re-establish in spring wetlands should flow to springs be restored.

Eriocaulon carsonii

The *Eriocaulon carsonii* (salt pipewort) is an herbaceous perennial typically forming mat-like colonies in spring wetlands fed by permanent groundwater (Fensham, 2006). It was recorded from six vents, all EPBC springs: Lucky Last vents 287 (Four Dog), 340, 687, 687.1, 687.4 and 687.6. It was chosen as an indicator species due to its listing as Endangered under the Commonwealth EPBC Act and the Queensland NC Act.

Fensham (2006) notes that *E. carsonii* produces abundant tiny seeds that germinate readily and is capable of colonising suitable habitat within complexes where it is known to occur and also to disperse over considerable distances. The salt pipewort is also capable of vegetative spread. Fatchen & Fatchen (1993, 1999 in NSWNPWS, 2003) suggest that seed or vegetative material transported by grazing animals or birds may be responsible for the spread of the species between mounds at Hermit Hill Springs in South Australia.

Davies (2000 in NSWNPWS, 2003) speculates that dispersal of *E. carsonii* seed between springs may be assisted by its small size (800 x 500 mm), hard nature, ability to withstand desiccation, and the release of the seed enclosed within two boat-shaped scarious sepals which would enable transport by flood waters and possibly by the wind. Studies of the soil seed bank has shown that seeds persist up to 6 cm below the surface and are unlikely to remain viable for more than a decade.

It appears that *E. carsonii* possesses a range of mechanisms that will enable it to either remain viable for short periods in springs affected by drawdown or to recolonise affected springs.

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Isachne globosa

Isachne globosa (swamp millet) is an aquatic or semi-aquatic perennial grass. It usually grows in and beside fresh water (Jacobs and Hastings, 2013). Reproduction is by seeds and vegetatively (Oswaldasia, 2013). Little information is available on this species regarding seed viability in the soil seed bank or vectors of dispersal. However, as trials on a range of native and introduced grasses in western Queensland showed that grass seed viability was less than three years, it could be expected that *I. globosa* seed might not survive extended dry periods at the springs before flows are restored. It is therefore likely that this species, and other grasses, might become locally extinct. Vectors such as birds, wind and surface water flow do have the capacity to reintroduce the grass from other sources.

Cyperus difformis

Cyperus difformis (rice sedge) is a native tufted annual found in shallow stationary waterbodies and associated wetlands. It completes a cycle of growth from seedling to flowering in less than two months and can produce about 50,000 seeds with a germination percentage of 60% (Sainty and Jacobs, 2003). It is thought to form large, persistent seed banks (Kloot, 1979; Cox, 1984 in Ravindran *et al.*, 1999). *C. difformis* is not drought tolerant and requires standing water for germination (Ravindran *et al.*, 1999).

It is likely that *C. difformis* seed can survive for periods without water as long as moisture is present in the soil. However, it will not germinate without standing water. Tyndall (1983) notes that "The widespread distribution of *Cyperus difformis* in the southeastern United States could be due, at least partially, to transport by bird". It therefore has the potential to be reintroduced to wetlands through this vector. It is possible that restoration of flows would result in the re-establishment of this species.

Conclusions and Recommendations

The ecological assessment of springs has described and assessed 29 spring vents of 3 complexes in the Fairview CSG field that may be impacted by drawdown. The assessment showed that while impacts from cattle and pigs in particular were impacting significantly on flora and habitat values, a range of aquatic plants were still present and thriving. This included the Endangered plant *Eriocaulon carsonii*.

An analysis of potential drawdown and species present determined that the predicted maximum drawdown has the potential to impact significantly on wetland flora and ecosystems. However, it is unclear at this stage whether the actual drawdown will reflect the predicted figure. This is partly due to the complex geology and hydrogeology present and uncertain connectivity between aquifers and vents. Should drawdown occur and loss of wetland habitat occur, there is potential for recovery of the wetland should flows recommence. It is likely however that flora assemblages will consist of a different suite of species to pre-drawdown conditions.

The engagement of a dendrochronologist for sampling of forest red gum cores at the Lucky Last complex may provide further detail on seasonal or cyclic wetting and drying regimes at these vents. This may enable a better understanding of how and when natural fluctuations in water flow occur.

As listed in Table 5-1 below, 16 vents have been selected for ongoing monitoring. This is based on values present, initial priority for assessment and presence of a photomonitoring point.

Table 5-1 Springs proposed for ongoing monitoring

Complex Number	Complex Name	Vent Number	Monitoring point established
311	311	500	Yes
311	311	535	No
311	311	536	No
311	311	536.1	No
311	311	536.2	Yes
311	311	693	No
311	311	695-699	Yes
230	Lucky Last	287	Yes
230	Lucky Last	340	Yes
230	Lucky Last	686	Yes
230	Lucky Last	687	Yes
230	Lucky Last	687.1	No
230	Lucky Last	687.4	No
230	Lucky Last	688	Yes
561	Spring Rock Creek	285	Yes
591	Yebna2	534	Yes

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Appendix A Vent profiles

Complex	Yebna / 311 Vent 499
Type of Spring	Watercourse
Waterway	Gully flowing into Dawson River
Spring RE	11.10.14
Description Narrow gully through sandy soil adjoining Dawson river. Significant water flows were observed. No shrub layer was present, but a dense ground layer of weeds dominated by *Megathyrsus maximus** (green panic) and *Conyza sumatrensis** (tall fleabane) almost obscured the vent. Other ground layer species observed included *Sida* sp*. and *Cirsium vulgare** (spear thistle). Fallen timber was located over the vent further reducing accessibility. Canopy species nearby included *Eucalyptus tereticornis* (forest red gum) and *Casuarina cunninghamiana* (river oak). *Spirodela* sp. (duckweed) was floating on the pool at the vent outlet. No cattle impacts were observed within the gully and immediately surrounding the vent.	
Aquatic species present	*Spirodela* sp.
Monitoring Point available.	No monitoring photo – no suitable point
Impacts	weeds

Plate_Appendix 1. Pool at outlet of vent 499. Note *Spirodela* sp. on surface

Complex	Yebna / 311 Vent 500
Type of Spring	Watercourse
Waterway	Tributary of Dawson River
Spring RE	11.10.14
Description	

Vent in a deeply incised creek channel with sandstone substrate flowing into the Dawson River.

The channel and immediate surrounds contains a high proportion of sandstone boulders, exposed tree roots and large woody debris. Although a single vent feeding a main pool was identified, a number of seeps were located nearby, probably adding to base flow. Boulders within the watercourse were covered in mosses and ferns near the additional seeps.

Canopy species present within the channel include *Eucalyptus tereticornis* (forest red gum), *Casuarina cunninghamiana* (river oak), and *Angophora floribunda* (rough-barked apple). Other canopy species present on upper slopes included *Eucalyptus melanophloia* (silver-leaved ironbark) and *Callitris glaucophylla* (white cypress pine). Shrubs present include *Dodonaea* sp. (a hopbush), *Grewia latifolia* (dysentery bush) and *Acacia decora* (pretty wattle). The ground layer consisted predominantly of *Imperata cylindrica* (blady grass) and *Pennisetum ciliare** (buffel grass) with *Rubus parvifolius* (native raspberry), *Verbena aristigera** (Mayne's pest), *Alternanthera denticulata* var. *denticulata* (lesser joyweed), *Cirsium vulgare** (spear thistle), *Cynodon dactylon** (couch) and *Lomandra longifolia* (long-leaved matrush) also present.

Cattle grazing and damage was minimal in the immediate vicinity of the spring, possibly due to the limited accessibility of the site and the surrounding steep banks. Upstream and downstream from the spring demonstrated significant cattle damage.

A range of birds were observed and frogs, including *Adelotus brevis* (tusked frog), were heard calling from the stream and pools.

Aquatic species present	*Cyperus difformis*
	Cyperus flavidus
	Juncus prismatocarpus
	Juncus usitatus
	Ludwigia octovalvis
	Ludwigia peploides ssp. *montevidensis*
	Schoenoplectus mucronatus
Monitoring Point	Orange painted stake on edge of creek (149.1049, -75.7195). Photos bearing 140° of seep and across creek.
Impacts	Minimal

Plate_Appendix 2. Watercourse showing spring baseflow at Yebna/311 vent 500

Complex	Yebna 311	Vent 500.1
Type of Spring	Watercourse	
Waterway	Gully on Dawson River	
Spring RE	11.10.14	

Description

A small vent feeding into an incised gully draining into the Dawson River. The surrounding banks are densely vegetated with weeds. Very little instream vegetation is present around the vent. A significant amount of flood debris has been deposited near the site, including a poly water pipe (pictured).

Vegetation on the banks surrounding the vent is dominated by *Megathyrsus maximus** (green panic). Other species present include *Conyza sumatrensis** (tall fleabane), *Xanthium pungens** (Noogoora burr), *Ludwigia octovalvis* (willow primrose), *Ludwigia peploides* ssp. *montevidensis* (water primrose), *Cirsium vulgare** (spear thistle), *Verbena bonariensis** (purpletop), *Sida rhombifolia** (Paddy's lucerne), *Lepidium bonariense** (Argentine peppercress), *Juncus usitatus* (common rush), *Cynodon dactylon** (couch), *Alternanthera denticulata* var. *denticulata* (lesser joyweed) *Verbena aristigera** (Mayne's pest) and *Persicaria hydropiper* (water pepper).

A number of grasses were not able to be identified due to the lack of fruiting bodies and flowers.

Aquatic species present	*Ludwigia peploides* ssp. *montevidensis*
	Juncus usitatus
	Ludwigia octovalvis
	Persicaria hydropiper

Monitoring Point

Photo monitoring point established at 149.1004, -25.7282 (marked with an orange painted stake opposite the vent), bearing 24° from stake towards vent. The stake is likely to be washed away in a significant rain event.

Impacts	Weeds, flood debris, erosion

Plate_Appendix 3. Vent 500.1 (top centre-right) with flood deposited poly pipe

Complex	Yebna 311 Vent 535
Type of Spring	Watercourse
Waterway	Tributary of Hutton Creek
Spring RE	11.10.14

Description

Single vent located at base of steep side gully draining into tributary of Hutton Creek. The seep is arising from the base of a sandstone slab. The channel within the tributary is densely vegetated and features abundant water that appears to be residual from previous flows or is spring-fed. The vent is located approximately 15 m downstream from where the provided GPS point indicates. The vent is significantly impacted by trampling and grazing of cattle.

Riparian canopy species include *Eucalyptus tereticornis* (forest red gum) and *Angophora floribunda* (rough-barked apple). Groundcover species in the vicinity of the vent include *Imperata cylindrica* (blady grass), *Juncus continuus* (sand rush) and *Leersia hexandra* (swamp rice grass) and *Schoenoplectus tabernaemontanus* (softstem bulrush).

The tusked frog (*Adelotus brevis)* was heard calling nearby.

Aquatic species present	
	Juncus continuus
	Leersia hexandra
	Schoenoplectus tabernaemontanus

Monitoring Point

No photo monitoring point established.

Impacts	Cattle, weeds

Plate_Appendix 4. Vent 535 outlet showing cattle damage

Complex	Yebna / 311 Vent 536
Type of Spring	Watercourse
Waterway	Tributary of Hutton Creek
Spring RE	11.10.14

Description

A broadening of the creek downstream from vent 536.1. The vent itself is located above the creek on the eastern bank beneath tree roots. Large woody debris is present adjacent to the vent.

The canopy is dominated by *Eucalyptus tereticornis* (forest red gum) and *Angophora floribunda* (rough-barked apple). Other canopy and shrub species present include *Callitris glaucophylla* (white cypress pine), *Acacia leiocalyx* (early-flowering black wattle), *Acacia decora* (pretty wattle) and *Acacia salicina* (sally wattle).

Ground cover was dominated by *Imperata cylindrica* (blady grass), *Themeda triandra* (kangaroo grass) and *Sida** sp. Many of the ground covers were unidentifiable due to the degree of trampling and damage by cattle, combined with the lack of fruiting/flowering bodies.

Tusked frog (*Adelotus brevis*) was heard calling from the stream and wetland vegetation.

Significant cattle damage was observed along creek banks and within the spring vent.

Aquatic species present	*Centella asiatica*
	Cyperus exaltatus
	Cyperus polystachyos var. polystachyos
	Fimbristylis depauperata
	Ludwigia octovalvis
	Schoenoplectus mucronatus
	Typha sp.
Monitoring Point	No photo monitoring point established
Impacts	Cattle, weeds

Plate_Appendix 5. Wetland below vent 536.

Complex	Yebna / 311	Vent	536.1
Type of Spring	Watercourse		
Waterway	Tributary of Hutton Creek		
Spring RE	11.10.14		

Description

Multiple seeps from fissures in sandstone rock face overhang. In-stream vegetation consists mainly of grasses growing in cracks in sandstone substrate. General surrounding vegetation pattern is consistent with found upstream (vents 536 and 536.2). Mosses are present on the rock face where water was observed.

Grazing impacts are significant on surrounding banks and within stream bed. Impacts are consistent with those observed upstream.

Aquatic species present	*Schoenoplectus mucronatus*
	Ludwigia peploides ssp. *montevidensis*
	Ludwigia octovalvis
	Cyperus exaltatus
	Cyperus flavidus
Monitoring Point	No monitoring points at this site.
Impacts	Cattle, weeds

Plate_Appendix 6. Vent 536.1 - primary seep from rock fissure.

Complex	Yebna / 311 Vent 536.2
Type of Spring	Watercourse
Waterway	Tributary of Hutton Creek
Spring RE	11.10.14

Description

A relatively constrained creek channel feeding into Hutton Creek. Two vents were observed (only one marked previously at this point) stemming from the base of an eroded high bank of outside bend in creek channel. Substrate primarily comprised of sandstone slabs and boulders. Evidence of erosion and significant disturbance from cattle present. Residual water from last rainfall flow event was observed upstream from the vents.

Canopy species present on banks included *Angophora floribunda* (rough-barked apple) and *Eucalyptus tereticornis* (forest red gum). Shrub layer was dominated by *Gomphocarpus fruticosis** (narrow-leaf cotton bush) with no other shrub species observed at the vent area. The ground layer was highly disturbed by cattle. Despite this, the grass layer comprised *Imperata cylindrica* (blady grass), *Megathyrsus maximus** (green panic), *Conyza sumatrensis** (tall fleabane), *Sida** sp., *Cynodon dactylon** (couch), *Cirsium vulgare** (spear thistle) and *Dichanthium sericeum* (Queensland blue grass). Many of the ground cover species present were not able to be identified due to significant damage from grazing and trampling.

Cattle grazing damage was observed at the location of the vents as well as upstream and downstream from the vents. Grazing is heavy and trampling impacts are high. Fouling of the watercourse is heavy.

Aquatic species present	*Cyperus exaltatus*
	Cyperus nutans var. *eleusinoides*
	Schoenoplectus mucronatus
	Ludwigia octovalvis
	Ludwigia peploides ssp. *montevidensis*

Monitoring Point

Orange painted stake beneath tree root, overlooking vent (149.0647, -25.7156). Photos bearing 242° across creek and 90° towards vent.

Impacts	Weeds, cattle

Plate_Appendix 7. Cattle damage at vent 536.2.

Complex	Yebna 311 Vent 537
Type of Spring	Watercourse
Waterway	Dawson River
Spring RE	11.10.14
Description A small seep from sandstone slab on the banks of the Dawson River. Riparian vegetation was dominated by *Eucalyptus tereticornis* (forest red gum) and *Casuarina cunninghamiana* (river oak) with *Melaleuca viminalis* (weeping bottlebrush) prominent in the shrub layer. Ground covers are sparse due to the high proportion of bare rock. Ground cover species identified included *Cynodon dactylon** (couch), *Juncus usitatus* (common rush), *Persicaria hydropiper* (water pepper) and *Alternanthera denticulata* var. *denticulata* (lesser joyweed). Other small herbs and grasses were present but were not able to be identified due to lack of fruiting bodies/fertile material. No impacts were observed at the location of the vent due to the surrounding rock, but adjacent grazing and trampling impacts from cattle were observed.	
Aquatic species present	*Juncus usitatus*
	Persicaria hydropiper
Monitoring Point Photo monitoring point established at 149.0941, -25.7284 (Orange marked *Casuarina cunninghamiana*) bearing 180°. Photo taken from tree towards vent.	
Impacts	Cattle

Plate_Appendix 8. Rock seep at Vent 537

Complex	**Yebna 311**	**Vent**	**692**
Type of Spring	Watercourse		
Waterway	Dawson River		
Spring RE	11.10.14		

Description

A vent feeding directly into the Dawson river. The vent itself was obscured from view by a very large flood debris pile. Water was observed emerging from beneath the debris pile. Cattle damage is evident, but not severe and restricted mainly to trampling along a cattle pad leading down to the river.

Flood debris is widespread and significant in size and volume. Canopy species at this site comprise of *Eucalyptus tereticornis* (forest red gum), *Casuarina cunninghamiana* (river oak) and *Angophora floribunda* (rough-barked apple). *Melaleuca viminalis* (weeping bottlebrush) was common on the raised gravel bars around the vent.

Ground covers identified include *Verbesina encelioides** (crownbeard), *Megathyrsus maximus** (green panic), *Xanthium pungens** (Noogoora burr), *Lomandra longifolia* (long-leaved matrush), *Conyza sumatrensis** (tall fleabane), *Zinnia peruviana** (Peruvian zinnia), *Verbena aristigera** (Mayne's pest), *Bidens pilosa** (cobbler's pegs), *Sida** sp. *Cynodon dactylon* (couch) and *Cirsium vulgare** (spear thistle).

Instream species were uncommon and included *Ludwigia peploides* ssp. *montevidensis* (water primrose) and *Juncus usitatus* (common rush).

Aquatic species present	*Ludwigia peploides ssp. montevidensis*
	Juncus usitatus

Monitoring Point

Photo monitoring point established at 149.1095, -25.7257 (Orange painted stake) bearing 70°. Photo taken from stake towards outlet.

Impacts	Cattle, weeds

Plate_Appendix 9. Pile of flood debris surrounding vent 692.

Plate_Appendix 10. Vent 692 outlet at base of debris pile.

Complex	Yebna 311 Vent 693
Type of Spring	Watercourse
Waterway	Tributary to Hutton Creek
Spring RE	11.10.14

Description

A large wetland area (approximately 60 m x 8 m) of residual water was identified, with a small seepage at the base of a sandstone formation. It is unclear if this seepage is the sole vent feeding the storage area or if the water is residual storage from previous flows. Due to the volume of water and the density of ground cover species, it was not possible to determine if further vents were located in the storage area. The storage area feeds into a large water hole.

Cattle damage is minimal and restricted mainly to the fringes of the banks. The site is generally in good condition and provides good habitat values. Riparian trees and shrubs include *Angophora floribunda* (rough-barked apple), *Acacia decora* (pretty wattle) and *Eucalyptus tereticornis* (forest red gum). Groundcovers present include *Heteropogon contortus* (black speargrass), *Dianella* sp. (a flax lily), *Conyza sumatrensis** (tall fleabane), *Melinis repens** (red Natal grass), *Rubus parvifolius* (native raspberry), *Themeda triandra* (kangaroo grass) and *Lomandra longifolia* (long-leaved matrush).

Plants growing within the wetland include *Schoenoplectus mucronatus* (bog bulrush), *Imperata cylindrica* (blady grass), *Verbena bonariensis** (purpletop), *Leersia hexandra* (swamp rice grass), *Ludwigia peploides* ssp. *montevidensis* (water primrose) and *Persicaria hydropiper* (water pepper).

Aquatic species present	*Schoenoplectus mucronatus*
	Ludwigia peploides ssp. *montevidensis*
	Persicaria hydropiper

Monitoring Point

No photo monitoring point established as it was unable to be determined where the main vent was occurring.

Impacts	Minor cattle and weed impacts

Plate_Appendix 11. Large wetland in the vicinity of Vent 693

Complex	Yebna / 311 Vents 695-699
Type of Spring	Watercourse
Waterway	Tributary of Dawson River
Spring RE	11.10.14

Description

Small tributary of the Dawson River. Sandstone slab substrate with series of pools and riffles. Upstream section of study site is a boggy pool with dense cover of emergent aquatic plants.

Adjacent banks and slopes have been impacted by grazing and clearing. Canopy species present include *Callitris glaucophylla* (white cypress pine), *Eucalyptus melanophloia* (silver-leaved ironbark), *Angophora floribunda* (rough-barked apple) and *E. tereticornis* (forest red gum). Shrubs present include *Acacia decora* (pretty wattle), *A. harpophylla* (brigalow), *Alectryon diversifolius* (scrub boonaree) and *Brachychiton australis* (broad-leaved bottletree). The ground layer comprised of species including *Lomandra longifolia* (long-leaved matrush), *Imperata cylindrica* (blady grass), *Cirsium vulgare** (spear thistle), *Pennisetum ciliare** (buffel grass), *Cynodon dactylon** (couch) and *Xanthium pungens** (Noogoora burr). As the ground layer has been disturbed by cattle and many grasses were not holding fertile material, not all species, particularly grasses, could be identified.

This series of vents feed baseflow into the creek at multiple points. At the time of survey it was very difficult to differentiate between individual vents due to the number of seeps and extensive cattle damage. As such, it was not possible to accurately identify the individual vents with precision. Due to the homogenous nature of the spring complex, it was described as a single site.

Due to the presence of water, cattle had grazed, trampled and fouled much of the watercourse and vent locations, thereby reducing the biodiversity values at this site. However, a range of birds were observed drinking from the creek and frogs were heard calling from the denser stream vegetation.

Aquatic species present	*Scheonoplectus mucronatus*
	Ludwigia peploides ssp. *montevidensis*
	Ludwigia octovalvis
	Cyperus exaltatus
	Cyperus flavidus
	Eleocharis cylindrostachys
	Fimbristylis bisumbellata
	Juncus continuus
	Schoenoplectus tabernaemontanus
Monitoring Point	Orange painted stake located at top of bank above seep (-25.7255, 149.0867). Photos bearing 154° of streambed and close up of seep pool.
Impacts	Cattle, weeds

Plate_Appendix 12. Watercourse showing spring baseflow at Yebna/311 vents 695-699

Complex	Lucky Last	Vent	287 (Four Dog)
Type of Spring	Mound		
Waterway	Adjacent Injune Creek		
Spring RE	11.3.22		

Description

Very large mound spring approximately 1-2 m high and 50 m across. Significant impacts from cattle were observed that include trampling and grazing. The mound surface was damp and spongy with areas of standing water, particularly in cattle hoof depressions.

A very large wetland area extended beyond the downslope edge of the mound for approximately 50.0 m toward Injune Creek. This was noted to be heavily impacted by cattle and pigs.

The vegetation cover on the mound was extensive with species present including *Phragmites australis* (common reed), *Sida rhombifolia** (Paddy's Lucerne), *Imperata cylindrica* (blady grass), *Centella asiatica* (Indian pennywort), *Ranunculus plebeius* (buttercup), *Chloris virgata** (feathertop Rhodes grass), *Schoenoplectus tabernaemontanus* (softstem bulrush), *Carex* sp., *Xanthium pungens** (Noogoora burr), *Bidens bipinnata** (bipinnate beggartick), *Cirsium vulgare** (spear thistle), *Cenchrus purpurascens** (swamp foxtail), *Sesbania cannabina* (sesbania), *Isachne globosa* (swamp millet), *Verbena bonariensis** (purpletop), *Eriocaulon carsonii* (salt pipewort), *Sorghum nitidum** (brown sorghum), *Cyperus difformis* (rice sedge), *Citrullus lanatus** (watermelon) and *Maireana microphylla* (small-leaf bluebush).

The tusked frog (*Adelotus brevis*) was heard calling from within the mound.

Aquatic species present	*Fimbristylis dichotoma*
	Centella asiatica
	Cyperus difformis
	Cyperus sanguinolentus
	Eleocharis cylindrostachys
	Persicaria decipiens
	Phragmites australis
	Schoenoplectus tabernaemontanus
	Bacopa monnieri
	Carex sp.

Monitoring Point

Photo monitoring point established at 148.7751, -25.7978 (marked on tree – *Eucalyptus populnea*), bearing 108°. Photo taken from base of tree towards mound.

Impacts	Cattle, pigs, weeds

Plate_Appendix 13. Vent 287 looking upstream at wetland towards mound

Complex	Lucky Last	Vent	340
Type of Spring	Mound spring		
Waterway	Adjacent Injune Creek		
Spring RE	11.3.22		

Description

Mound spring located in a cleared paddock on an undulating, low hill. Portions of the mound are raised and dry whereas other areas are soaked and boggy. Areas around the perimeter of the mound are influenced by seepage and were observed to be boggy.

Ground cover species varied with the localised water availability and impacts. Areas with standing water were dominated by sedges, *Cenchrus purpurascens** (swamp foxtail) and *Phragmites australis* (common reed) with *Chloris virgata** (feathertop Rhodes grass) located throughout the mound. Some grasses and ground covers were not able to be identified due to the lack of flowering/fruiting bodies and the extent of the damage from cattle.

Cattle damage was extensive throughout the spring and was more prominent (due to trampling) in wetter areas around the perimeter of the spring.

Aquatic species present	*Bacopa monnieri*
	Carex sp.
	Centella asiatica
	Cyperus difformis
	Cyperus sanguinolentus
	Eleocharis cylindrostachys
	Eriocaulon carsonii
	Isachne globosa
	Fimbristylis dichotoma
	Phragmites australis
	Schoenoplectus tabernaemontanus

Monitoring Point

Photo monitoring point established in rocky outcrop overlooking mound. Orange painted stake next to log at 148.7729, -25.7938. Bearing 110° towards spring. Additional photo taken at spring towards photo monitoring point at 148.7732, -25.7940 bearing 290°.

Impacts	Cattle, weeds

Plate_Appendix 14. Mound of vent 340

Complex	Lucky Last	Vent	686
Type of Spring	Mound		
Waterway	Adjacent Injune Creek		
Spring RE	11.3.22		
Description A small slightly raised spring vent approximately 7 m diameter. Trampling damage is evident throughout the mound with a small amount of free standing water in the hoof depressions. *Eucalyptus tereticornis* saplings have grown around the edge of the mound. This recent growth of *E. tereticornis* saplings could indicate a decrease in the moisture levels surrounding the spring, allowing the saplings to colonise the fringes of the previously waterlogged area. Ground cover is substantial, although disturbed by cattle. Species include *Phragmites australis* (common reed), *Eleocharis cylindrostachys* (drooping spikerush), *Carex* sp., *Cirsium vulgare** (spear thistle), *Centella asiatica* (Asian pennywort), *Schoenoplectus tabernaemontanus* (softstem bulrush) and *Fimbristylis dichotoma*. A number of grasses were unable to be identified due to the lack of fruiting bodies/flowers.			
Aquatic species present	*Phragmites australis*		
	Eleocharis cylindrostachys		
	Carex sp.		
	Fimbristylis dichotoma		
	Juncus prismatocarpus		
	Schoenoplectus tabernaemontanus		
	Juncus continuus		
	Centella asiatica		
	Eriocaulon carsonii		
Monitoring Point Photo monitoring point (paint on sapling) established at 148.7734, -25.7978, bearing 223°.			
Impacts	Cattle, weeds		

Plate_Appendix 15. Vent 686 with circle of saplings

Complex	Lucky Last	Vent	687
Type of Spring	Mound		
Waterway	Adjacent Injune Creek		
Spring RE	11.3.22		

Description

A large mound spring approximately 19 m in diameter. Well vegetated on top but heavily impacted by trampling and grazing. Canopy species in the area primarily consist of *Eucalyptus tereticornis*. Juvenile *E. tereticornis* plants are growing in a ring around the edge of the mound with a single large *E. tereticornis* on the southern verge.

Ground cover is substantial, although disturbed by cattle. *Phragmites australis* (common reed) dominates the mound, with other species present including *Centella asiatica* (Indian pennywort), , *Bacopa monnieri* (water hyssop), *Chloris virgata** (feathertop Rhodes grass), *Eriocaulon carsonii* (salt pipewort), *Cirsium vulgare** (spear thistle), *Xanthium pungens** (Noogoora burr), *Sesbania cannabina* (sesbania), *Ranunculus plebeius* (forest buttercup) and *Cenchrus purpurascens** (swamp foxtail).

Aquatic species present	*Bacopa monnieri*
	Carex sp.
	Cyperus nutans var. eleusinoides
	Cyperus sanguinolentus
	Eriocaulon carsonii
	Fimbristylis dichotoma
	Juncus prismatocarpus
	Phragmites australis

Monitoring Point

Photo monitoring point established at 148.7737, -25.7948 bearing 40°. Marked on a tree.

Impacts	Cattle, weeds

Plate_Appendix 16. Vent 687 showing *E. tereticornis* on verge and *Phragmites australis* on mound

Complex	Lucky Last	Vent	687.1
Type of Spring	Mound		
Waterway	Adjacent to Injune Creek		
Spring RE	11.3.22		

Description

A small circular vent approximately 4 m in diameter slightly raised in centre. Trampling damage is evident around the perimeter of the mound with free standing water in the hoof prints. Vegetation is less disturbed in the centre of the mound.

Ground cover is substantial, although disturbed by cattle. Species include *Cyperus difformis* (rice sedge), *Chloris virgata** (feathertop Rhodes grass), *Eriocaulon carsonii* (salt pipewort), *Aster subulatus** (wild aster), *Bacopa monnieri* (water hyssop), *Cynodon dactylon** (couch) and *Centella asiatica* (Asian pennywort).

Aquatic species present	*Bacopa monnieri*
	Centella asiatica
	Cyperus difformis
	Cyperus nutans var. eleusinoides
	Cyperus sanguinolentus
	Eriocaulon carsonii
	Fimbristylis dichotoma
	Juncus prismatocarpus
	Juncus continuus

Monitoring Point

No photo monitoring point established

Impacts	Cattle, weeds

Plate_Appendix 17. Vent 687.1 showing large mat of *Eriocaulon carsonii* in centre

Complex	Lucky Last	Vent	687.2
Type of Spring	Mound		
Waterway	Adjacent Injune Creek		
Spring RE	11.3.22		

Description
A small circular mound with some free standing water in the middle. Minor damage from trampling and grazing of cattle is present, especially on the fringe of the vent.

Ground cover is dominated by *Chloris virgata** (feathertop Rhodes grass) with *Centella asiatica* (Indian pennywort), *Phragmites australis* (common reed), *Fimbristylis dichotoma* (common fringe-sedge), *Cyperus difformis* (rice sedge), *Isachne globosa* (swamp millet), *Juncus prismatocarpus* (branching rush) and *Juncus continuus* (*sand* rush).

Aquatic species present	*Centella asiatica*
	Cyperus difformis
	Cyperus nutans var. *eleusinoides*
	Cyperus sanguinolentus
	Eleocharis cylindrostachys
	Fimbristylis dichotoma
	Juncus prismatocarpus
	Juncus continuus
	Phragmites australis
Monitoring Point	No photo monitoring point established.
Impacts	Cattle, weeds

Plate_Appendix 18. Vent 687.2 showing dense groundcover

Complex	Lucky Last	Vent	687.3
Type of Spring	Mound		
Waterway	Adjacent Injune Creek		
Spring RE	11.3.22		

Description

A small vent (approximately 6 m x 4 m) with the appearance of a 'floating' surface. No discernible mound. Some cattle damage through hoof marks and grazing. Lack of significant surface water has probably reduced the usage of the vent by cattle with an associated reduction in damage. *Chloris virgata** (feathertop Rhodes grass) dominates the vent with *Cyperus difformis* (rice sedge) and *Cynodon dactylon** (couch).

Two additional small vents were located nearby with similar species composition and low flows. One of the vents, located due south of vent 687.3, supported *E. carsonii*.

Aquatic species present	*Cyperus difformis*
	Cyperus sanguinolentus
	Fimbristylis dichotoma
	Leersia hexandra
	Bacopa monnieri

Monitoring Point

No photo monitoring points established.

Impacts	Cattle, weeds

Plate_Appendix 19. Dense groundcover at Vent 687.3

Complex	Lucky Last	Vent	687.4
Type of Spring	Mound		
Waterway	Adjacent Injune Creek		
Spring RE	11.3.22		
Description Small vent that is slightly mounded and heavily disturbed around the edge. Central area of mound is very wet and relatively undisturbed. The top of the mound had the appearance of floating and would 'bounce' when pressure was applied. Approximately 10 m x 4 m. Species present include *Centella asiatica* (Asian pennywort), *Eriocaulon carsonii* (salt pipewort), *Cynodon dactylon** (couch), *Chloris virgata** (feathertop Rhodes grass), *Bacopa monnieri* (water hyssop), *Cyperus difformis* (rice sedge), *Carex* sp. and *Cenchrus purpurascens** (swamp foxtail).			
Aquatic species present	*Cyperus difformis*		
	Cyperus exaltatus		
	Fimbristylis dichotoma		
	Bacopa monnieri		
	Carex sp.		
	Centella asiatica		
	Cyperus sanguinolentus		
	Eriocaulon carsonii		
Monitoring Point No photo monitoring point established			
Impacts	Cattle, weeds		

Plate_Appendix 20. Vent 687.4 showing cattle hoof marks

Complex	Lucky Last Vent 687.5
Type of Spring	Mound
Waterway	Adjacent Injune Creek
Spring RE	11.3.22
Description Very small vent (approximately 2 m x 2 m) with very little water observed. The lack of water appears to have reduced attractiveness to cattle and pigs and as such trampling and other impacts are less evident. Groundcover regeneration appears to have occurred as a result. Dense ground cover layer with species similar to adjacent mound springs. Dominated by *Chloris virgata** (feathertop Rhodes grass) and *Cynodon dactylon** (couch).	
Aquatic species present	*Cyperus difformis*
	Eleocharis cylindrostachys
	Fimbristylis bisumbellata
	Fimbristylis dichotoma
Monitoring Point No photo monitoring point established due to likelihood of disturbance from cattle.	
Impacts	Cattle, weeds

Plate_Appendix 21. Small area of Vent 687.5

Complex	Lucky Last	Vent	687.6
Type of Spring	Mound		
Waterway	Adjacent Injune Creek		
Spring RE	11.3.22		

Description

A very small mound (approximately 1.5 m x 2 m) located in the same vicinity as vents 689 and 340. Small pools of water and muddy areas surround the mound.

Similar flora species mix to nearby vents (689 and 340). Cattle damage through trampling and grazing was apparent.

Aquatic species present	*Fimbristylis dichotoma*
	Bacopa monnieri
	Eriocaulon carsonii
	Cyperus sanguinolentus
	Juncus continuus

Monitoring Point

No photo monitoring point established due to likelihood of disturbance.

Impacts	Cattle, weeds

Plate_Appendix 22. Disturbed nature of Vent 687.6

Complex	Lucky Last	Vent	688
Type of Spring	Mound		
Waterway	Adjacent Injune Creek		
Spring RE	11.3.22		

Description

Large raised mound approximately 14.0 m in diameter. The mound is heavily impacted from cattle grazing and trampling. Standing water is present in hoof depressions. Much of the vegetation has been flattened by cattle except for clumps of *Schoenoplectus tabernaemontanus* (softstem bulrush) and *Sesbania cannabina* (sesbania) which have been protected by fallen timber.

Water seepage extends downhill for approximately 40 m across a wide area. This area is dominated by *Carex* sp. in dense clumps within very boggy areas. This area is not heavily impacted by cattle as they do not appear to forage on the *Carex* sp. which possesses saw-like leaf blades. The canopy is dominated by live and dead specimens of *Eucalyptus tereticornis* (forest red gum). Many of these trees are mature with hollows. A number of mature *E. tereticornis* trees have fallen, or are in the process of falling, possibly due to the root system not being able to sustain the weight of the tree in the waterlogged soil. A number of *E. tereticornis* saplings are present on the wetland fringes.

Ground cover species include *Schoenoplectus tabernaemontanus* (softstem bulrush), *Carex* sp., *Centella asiatica* (Asian pennywort), *Xanthium pungens** (Noogoora burr), *Sesbania cannabina* (sesbania), *Persicaria decipiens* (slender knotweed), *Chloris virgata** (feathertop Rhodes grass), *Ludwigia peploides* ssp. *montevidensis* (water primrose), *Cyperus difformis* (rice sedge) and *Schoenoplectus mucronata* (bog bulrush).

Aquatic species present	*Schoenoplectus tabernaemontanus*
	Schoenoplectus mucronata
	Carex sp.
	Cyperus difformis
	Isachne globosa
	Spirodela sp.
	Ludwigia peploides ssp. montevidensis

Monitoring Point

Photo monitoring point established at 148.7738, -25.7951, bearing 194°.

Impacts	Cattle, weeds

Plate_Appendix 23. Edge of mound at Vent 688 showing significant cattle trampling

Complex	Lucky Last	Vent	689
Type of Spring	Mound spring		
Waterway	Adjacent Injune Creek		
Spring RE	11.3.22		

Description

Mound spring located in a cleared paddock on an undulating, low hill. Smaller in area than vent 340 but with more visible water. Central raised area was very damp. Perimeter of mound was holding water.

Extensive cattle damage was observed with churned mud. Three feral pig (*Sus scrofa**) wallows were identified within the spring perimeter. Tusked frog (*Adelotus brevis*) was heard calling from within the mound. Similar flora species mix to vent 340 present, including *Bacopa monnieri* (water hyssop), *Cenchrus purpurascens** (swamp foxtail), *Centella asiatica* (Asian pennywort) and *Chloris virgata** (feathertop Rhodes grass).

Aquatic species present	*Schoenoplectus tabernaemontanus*
	Centella asiatica
	Bacopa monnieri
	Cyperus sanguinolentus
	Eleocharis cylindrostachys
	Isachne globosa
	Fimbristylis dichotoma

Monitoring Point

Photo monitoring point established in rocky outcrop overlooking mound (as for vent 340. Orange painted stake next to log at 148.7729, -25.7938. Bearing 200° towards spring. Additional photo taken at spring towards pho monitoring point bearing 20°.

Impacts	Cattle, pigs, weeds

Plate_Appendix 24. Vent 689 displaying cattle and pig damage

Complex	Spring Rock Creek Vent 285
Type of Spring	Watercourse
Waterway	Spring Rock Creek
Spring RE	11.3.22

Description

Seepage from soil profile in a large isolated billabong on Spring Rock Creek.

Canopy species consist of *Eucalyptus tereticornis* (forest red gum) and *Casuarina cunninghamiana* (river oak) along the creek bank. Surrounding vegetation has been largely cleared resulting in significant gully erosion leading towards the creek. This erosion has caused bank instability above the vent and a number of bank collapses have occurred. The vent is located at the foot of the bank at the upstream point. Cattle damage is severe with grazing and trampling evident along the course of the creek and at vent outlet as well as fouling within the waterbody.

Species present along the banks include: *Dichanthium sericeum* (Queensland bluegrass), *Cynodon dactylon** (couch), *Callitris glaucophylla* (white cypress pine), *Acacia decora* (pretty wattle), *Eragrostis brownii* (Brown's lovegrass), *Bothriochloa bladhii* ssp. *glabra** (forest bluegrass) and *Heteropogon contortus* (black speargrass).

Species present in the stream, or along the edge of the stream include: *Juncus continuus* (sand rush), *Imperata cylindrica* (blady grass) and *Cladium procerum* (leafy twigrush).

The tusked frog (*Adelotus brevis*) was heard calling from within the creek.

Aquatic species present	*Cladium procerum*
	Cyperus sanguinolentus
	Juncus continuus
Monitoring Point	Photo monitoring point established at 148.7695, -25.7627 (marked on tree), bearing 294°. Photo taken from base of tree towards vent.
Impacts	Cattle, weeds

Plate_Appendix 25. Vent (foreground) at Spring Rock Creek showing significant cattle damage and slumping at outlet

Complex	Yebna 311	Vent	534
Type of Spring	Mound		
Waterway	Tributary of Dawson River		
Spring RE	11.10.14		

Description

A small mound spring (approximated 5 m x 4 m) located in the bed of a small drainage line that feeds into the Dawson River. The watercourse was mostly dry, with only a little water retained in deeper holes. Canopy species around the spring include *Eucalyptus tereticornis* (forest red gum), *Acacia harpophylla* (brigalow), *Angophora floribunda* (rough-barked apple) and *Eucalyptus populnea* (poplar box).

Significant cattle damage in the form of grazing, fouling and trampling was observed in and around the vent. Standing water was present within a small waterhole adjacent and in hoof depressions.

Ground cover at the vent included *Schoenoplectus tabernaemontanus* (softstem bulrush), *Xanthium pungens** (Noogoora burr), *Schoenoplectus mucronatus* (bog bulrush), *Persicaria hydropiper* (water pepper), *Cyperus polystachyos* var. *polystachyos*), *Ludwigia octovalvis* (willow primrose), *Juncus usitatus* (common rush) and *Imperata cylindrica* (blady grass).

Other species present around the mound and on the banks of the drainage feature included *Cynodon dactylon** (couch), *Pennisetum ciliare** (buffel grass), *Dichanthium sericeum* (Queensland bluegrass), *Verbena aristigera** (Mayne's pest), *Sida* sp*., *Cirsium vulgare** (spear thistle), *Lepidium bonariense** (Argentine peppercress), *Maireana microphylla* (small-leaf bluebush) and *Cymbopogon refractus* (barb-wire grass). Other grass species were present but unable to be identified due to lack of fruiting/flowering bodies and trampling from cattle.

Aquatic species present	*Schoenoplectus tabernaemontanus*
	Schoenoplectus mucronatus
	Cyperus polystachyos var. *polystachyos*
	Juncus prismatocarpus
	Juncus usitatus
	Ludwigia octovalvis
	Persicaria hydropiper

Monitoring Point

Photo monitoring point established at 149.1078, -25.7327 (Orange painted stake) bearing 282°. Photo taken from base of tree towards mound.

Impacts	Weeds, cattle

Plate_Appendix 26. Small mound at Vent 534. White surveyor's stake in front of mound.

B

Appendix B Flora Species List

Scientific name	Common name	Form	Status	Aquatic plant	Vent																								
					695-699	500	499	536.2	536.1	536	340	689	687.6	687.5	687.4	687.3	687	687.2	687.1	686	688	285	287	500.1	534	692	537	693	535
Acacia decora	pretty wattle	Shrub	LC		Y	Y				Y												Y						Y	
Acacia harpophylla	brigalow	Shrub	LC		Y																				Y				
Acacia leiocalyx	early-flowering black wattle	Shrub	LC							Y																			
Acacia salicina	sally wattle	Shrub	LC							Y																			
Alectryon diversifolius	scrub boonaree	Shrub	LC		Y																								
Alternanthera denticulata var. *denticulate*	lesser joyweed	Herb	LC			Y				Y	Y													Y			Y		
Angophora floribunda	rough-barked apple	Tree	LC		Y	Y		Y		Y															Y	Y		Y	Y
Aster subulatus	wild aster	Herb	*								Y						Y		Y										
Bacopa monnieri	water hyssop	Herb	LC	Y							Y	Y	Y		Y	Y	Y		Y				Y						
Bidens bipinnata	bipinnate beggar tick	Herb	*		Y																		Y						
Bidens pilosa	cobbler's pegs	Herb	*																							Y			
Bothriochloa bladhii ssp. *glabra*	forest bluegrass	Grass	*		Y	Y																Y							
Brachychiton australis	broad-leaved bottletree	Tree	LC		Y																								
Callitris glaucophylla	white cypress pine	Tree	LC		Y	Y				Y												Y							
Carex sp.		Sedge	LC	Y							Y				Y		Y			Y	Y		Y						
Casuarina cunninghamiana	river oak	Tree	LC			Y	Y	Y		Y												Y		Y		Y	Y		
Cenchrus purpurascens	swamp foxtail	Tree	*	Y								Y			Y		Y						Y						
Centella asiatica	Asian pennywort	Herb	LC	Y						Y	Y	Y			Y		Y	Y	Y	Y	Y		Y						
Chloris virgata	feathertop Rhodes grass	Grass	*								Y	Y	Y	Y	Y	Y	Y	Y	Y		Y		Y						
Christella dentata	binung	Fern	LC	Y		Y																							
Cirsium vulgare	spear thistle	Herb	*		Y	Y	Y	Y			Y						Y			Y			Y	Y	Y	Y			
Citrullus lanatus	watermelon	Vine	*																										
Cladium procerum#	leafy twigrush	Sedge	LC	Y																		Y							
Conyza sumatrensis	Tall Fleabane	Herb	*				Y	Y															Y	Y		Y		Y	
Crotalaria sp.	a rattlepod	Herb	LC		Y																								
Cymbopogon refractus	barb-wire grass	Grass	LC																						Y				
Cynodon dactylon	couch	Grass	I		Y	Y		Y			Y	Y	Y	Y	Y	Y			Y			Y		Y	Y	Y	Y		
Cyperus difformis	rice sedge	Sedge	LC	Y		Y					Y			Y	Y	Y		Y	Y		Y		Y						
Cyperus exaltatus	tall flat-sedge	Sedge	LC	Y	Y			Y	Y	Y																			
Cyperus flavidus	yellow flat-sedge	Sedge	LC	Y	Y	Y			Y																				
Cyperus nutans var. *eleusinoides*	flatsedge	Sedge	LC	Y	Y			Y									Y	Y	Y										
Cyperus polystachyos var. *polystachyos*	a sedge	Sedge	LC	Y						Y											Y				Y				
Cyperus sanguinolentus	dark flat-sedge	Sedge	LC	Y							Y	Y	Y		Y	Y	Y	Y	Y		Y	Y	Y						
Cyperus trinervis	a flat sedge	Sedge	LC	Y																							Y		
Dianella sp.	a flax lily	Herb	LC																									Y	
Dichanthium sericeum	Queensland bluegrass	Grass	LC					Y														Y			Y				
Dodonaea sp.	a hopbush	Shrub	LC			Y																							
Echinochloa crus-galli	barnyard grass	Grass	*														Y			Y	Y		Y					Y	
Echinochloa colona	awnless barnyard grass	Grass	*																							Y			
Echinochloa inundata	marsh millet	Grass	LC	Y																					Y				
Eleocharis cylindrostachys	drooping spikerush	Sedge	LC	Y	Y						Y	Y		Y				Y		Y			Y						
Eragrostis brownie	Brown's lovegrass	Grass	LC																			Y							
Eriocaulon carsonii	salt pipewort	Herb	E	Y							Y	Y	Y		Y		Y		Y				Y						

Scientific name	Common name	Form	Status	Aquatic plant	Vent																								
					695-699	500	499	536.2	536.1	536	340	689	687.6	687.5	687.4	687.3	687	687.2	687.1	686	688	285	287	500.1	534	692	537	693	535
Eucalyptus melanophloia	silver-leaved ironbark	Tree	LC		Y	Y																							
Eucalyptus populnea	poplar box	Tree	LC																						Y				
Eucalyptus tereticornis	forest red gum	Tree	LC		Y	Y	Y	Y		Y								Y		Y	Y	Y		Y	Y	Y	Y	Y	Y
Fimbristylis bisumbellata	a fringe-sedge	Sedge	LC	Y	Y									Y															
Fimbristylis depauperata	a fringe-sedge	Sedge	LC	Y						Y																			
Fimbristylis dichotoma	common fringe-sedge	Sedge	LC	Y							Y	Y	Y	Y	Y	Y	Y	Y	Y	Y			Y						
Geijera salicifolia	wilga	Tree	LC		Y																								
Gomphocarpus fruticosis	narrow-leaf cotton bush	Herb	*					Y																					
Grewia latifolia	dysentery bush	Shrub	LC		Y	Y																							
Heteropogon contortus	black speargrass	Grass	LC																			Y						Y	
Imperata cylindrica	blady grass	Grass	LC		Y	Y		Y	Y	Y	Y	Y										Y	Y		Y			Y	Y
Isachne globosa	swamp millet	Grass	LC	Y							Y	Y					Y	Y			Y		Y						
Juncus prismatocarpus	branching rush	Sedge	LC	Y		Y											Y	Y	Y	Y					Y				
Juncus continuus	sand rush	Sedge	LC	Y	Y								Y					Y	Y	Y		Y							Y
Juncus usitatus	common rush	Sedge	LC	Y		Y																		Y	Y	Y	Y		
Lachnagrostis filiformis	blown grass	Grass	LC			Y																							
Leersia hexandra	swamp rice grass	Grass	LC													Y												Y	Y
Lepidium bonariense	Argentine peppercress	Herb	*																					Y	Y				
Lomandra longifolia	long-leaved matrush	Herb	LC		Y	Y																				Y		Y	
Ludwigia octovalvis	willow primrose	Herb	LC	Y	Y	Y		Y	Y	Y														Y	Y				
Ludwigia peploides ssp. *montevidensis*	water primrose	Herb	LC	Y	Y	Y		Y	Y												Y			Y		Y		Y	
Maireana microphylla	fine-leaved bluebush	Herb	LC		Y																		Y		Y				
Megathysus maximus	green panic	Grass	*				Y	Y																Y		Y			
Melaleuca viminalis	weeping bottlebrush	Shrub	LC	Y																						Y	Y		
Melinis repens	red Natal grass	Grass	*																									Y	
Opuntia stricta	prickly pear	Shrub	*			Y																							
Opuntia tomentose	velvety tree pear	Shrub	*			Y																							
Paspalum scrobiculatum	ditch millet	Grass	LC	Y					Y	Y																			
Pennisetum ciliare	buffel grass	Grass	*		Y	Y																			Y				
Persicaria decipiens	slender knotweed	Herb	LC	Y																	Y		Y						
Persicaria hydropiper	water pepper	Herb	LC	Y																				Y	Y		Y	Y	
Phragmites australis	common reed	Grass	LC	Y							Y						Y	Y		Y			Y						
Phyla canescens	lippia	Herb	*														Y												
Ranunculus lappaceus	common buttercup	Herb	LC	Y						Y																			
Ranunculus plebeius	forest buttercup	Herb	LC								Y	Y					Y						Y						
Rubus parvifolius	native raspberry	Vine	LC			Y																						Y	
Sacciolepis indica	Indian cupscale grass	Grass	LC							Y																			
Schoenoplectus mucronatus	bog bulrush	Sedge	LC	Y	Y	Y		Y	Y	Y											Y				Y			Y	
Schoenoplectus tabernaemontanus	softstem bulrush	Sedge	LC	Y	Y						Y	Y								Y	Y		Y		Y			Y	Y
Sesbania cannabina	sesbania pea	Herb	LC								Y						Y				Y		Y						
Sida cordifolia	flannel weed	Herb	*																					Y					
Sida rhombifolia	Paddy's lucerne	Herb	*																		Y		Y						
Sida sp.		Herb	*		Y	Y	Y	Y		Y							Y								Y	Y			

Scientific name	Common name	Form	Status	Aquatic plant	Vent																								
					695-699	500	499	536.2	536.1	536	340	689	687.6	687.5	687.4	687.3	687	687.2	687.1	686	688	285	287	500.1	534	692	537	693	535
Sorghum nitidum	brown sorghum	Grass	*																				Y						
Spirodela sp.	a duckweed	Herb	LC	Y			Y														Y								
Sporobolus creber	slender rat's tail grass	Grass	LC																			Y							
Themeda triandra	kangaroo grass	Grass	LC	Y	Y					Y																		Y	
Typha sp.	cumbungi	Sedge	LC	Y						Y																			
Verbesina encelioides	crownbeard	Herb	*																							Y			
Verbena aristigera	Mayne's pest	Herb	*		Y	Y																	Y	Y	Y	Y			
Verbena bonariensis	purpletop	Herb	*																				Y	Y				Y	
Xanthium pungens	Noogoora burr	Herb	*		Y						Y	Y	Y	Y			Y	Y	Y		Y		Y	Y	Y	Y			
Zinnia peruviana	Peruvian zinnia	Herb	*																							Y			

Key to table symbols

- not confirmed

LC – least concern under the *Nature Conservation Act 1992* (NC Act)

E – Endangered under the NC Act and *Environment Protection and Biodiversity Conservation Act 1999.*

* – Introduced

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Report Signature Page

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APPENDIX A

Limitations

LIMITATIONS

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