Department of Natural Resources and Mines

Office of Groundwater Impact Assessment

Springs in the Surat Cumulative Management Area

A summary report on spring research and knowledge

June 2016

Queensland Government

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Abbreviations

AETG	Aquatic Ecosystems Task Group
CMA	cumulative management area
CQCHM	Central Queensland Cultural Heritage Management
CSG	coal seam gas
EPA	Environmental Protection Agency
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
ET	evapotranspiration
GAB	Great Artesian Basin
GDE	groundwater-dependent ecosystem
GWi	groundwater inflow
GWo	groundwater outflow
OGIA	Office of Groundwater Impact Assessment
P&G	petroleum and gas
Pr	precipitation
QWC	Queensland Water Commission
SWi	surface water inflow
SWo	surface water outflow
UWIR	underground water impact report

1 Introduction

1.1 Context

Coal seam gas (CSG) production involves the extraction of gas and water from underground coal seams, which can affect groundwater within and near the CSG production area. In areas of concentrated CSG development, the impacts on groundwater pressure resulting from CSG activities by individual petroleum tenure holders may overlap. In these situations, the Queensland Government may prescribe an area to be a Cumulative Management Area (CMA) which allows for a cumulative approach to the assessment and management of groundwater impacts from these activities. The Surat CMA (Figure 1-1) was established in response to existing and proposed CSG development in the Surat and southern Bowen basins.

In the Surat CMA, the Office of Groundwater Impact Assessment (OGIA) is responsible for assessing cumulative groundwater impacts from CSG activities and for developing appropriate water monitoring and spring management strategies. The assessment includes modelling regional groundwater flow and developing integrated management arrangements. OGIA assigns responsibility to individual tenure holders for implementing specific parts of the strategies.

The collective assessments and management arrangements are established in an Underground Water Impact Report (UWIR). Under the legislative framework, the UWIR is required to be updated every three years. This approach ensures that any changes in petroleum and gas (P&G) development scheduling, and new knowledge about the groundwater system and monitoring approaches, are appropriately considered within the management arrangements.

The first UWIR for the Surat CMA (‘the UWIR 2012’) came into effect in December 2012 and provided:

- an assessment of the predicted groundwater impacts from petroleum and CSG water extraction activities in the Surat CMA
- integrated management arrangements, including a water monitoring strategy and a **spring impact management strategy**
- assignment of responsibility to individual tenure holders for implementing monitoring and mitigation activities.

The spring impact management strategy relates to all springs that overlie aquifers where impacts are predicted. In 2012, the strategy identified the location of potentially affected springs; assessed the connectivity between springs and underlying aquifers; and established a strategy for preventing or mitigating predicted impacts on springs. Importantly, in 2012 the spring impact management strategy also established a program for monitoring selected spring vents and watercourse springs.

To support the UWIR 2016, a research program was specified to improve knowledge of springs in the Surat CMA. This report presents the outcomes of the monitoring and research, and summarises the technical basis from which the UWIR 2016 was developed.

1.2 Purpose

A range of investigations, monitoring and research into springs has been completed since the implementation of the UWIR 2012. The purpose of this report is to summarise:

- the completed activities and new knowledge on springs
- the technical basis which has informed the spring strategies established under the UWIR 2016.

1.3 Location of springs in the Surat CMA

In the Surat CMA, springs predominantly receive groundwater flow from the Clematis Sandstone, the Precipice Sandstone, the Boxvale Sandstone Member of the Evergreen Formation, the Hutton Sandstone, the Gubberamunda Sandstone and the Bungil Formation. In addition to these aquifers, there are springs associated with the Tertiary volcanics and Cenozoic sediments. The location of all springs in the Surat CMA is provided in Figure 1-1.

The occurrence and distribution of springs in the Surat CMA are primarily driven by regional and local geology, topography and groundwater flow regimes. Most springs are located along and near the northern and central outcrop areas of the Surat and Bowen basins and are associated with the Gubberamunda, Hutton, Clematis and Precipice sandstones.

In addition to topography, structures such as faults influence the occurrence and distribution of springs. Regional faulting features such as the Hutton Wallumbilla Fault and the Leichhardt-Burunga Fault are associated with springs in the central area of the Surat CMA, including the Lucky Last and Boggomoss spring complexes. At a more local scale, small fractures provide pathways for the groundwater to flow to the surface at many locations, including Scott’s Creek and Dawson River 8.

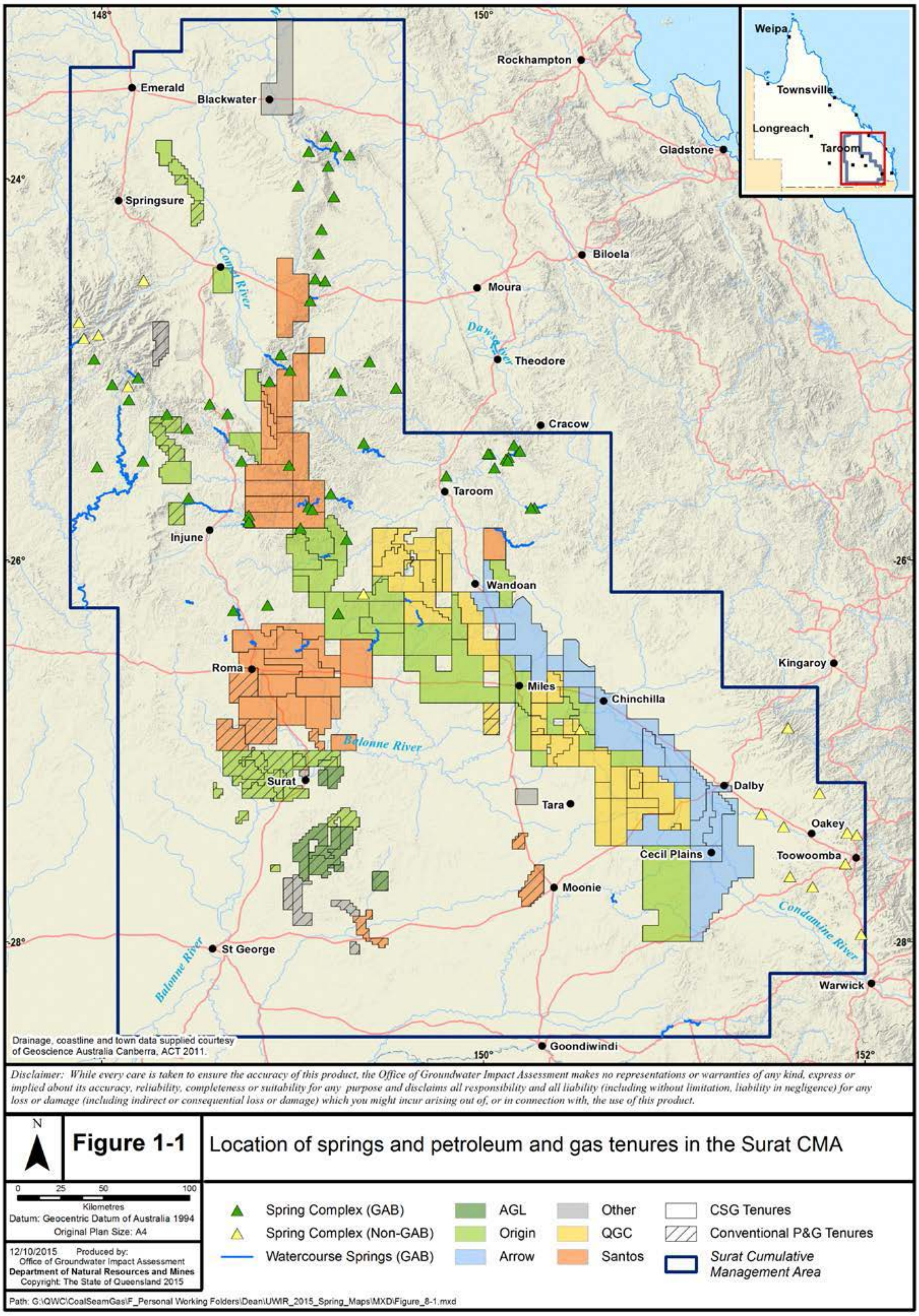

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Figure 1-1 Location of springs and petroleum and gas tenures in the Surat CMA

1.4 Terminology

1.4.1 Potentially affected springs

A spring is defined as the land to which water rises naturally from below the ground and the land over which water then flows. The *Water Act 2000* requires that the UWIR assess the potential groundwater impacts of petroleum and gas activities on all ‘potentially affected springs’. A potentially affected spring is defined as one that overlies a Great Artesian Basin (GAB) aquifer where the modelled long-term predicted impact on water pressure in any underlying aquifer exceeds 0.2 metres.

In common practice, and for the purposes of the UWIR, the GAB springs are further subdivided as ‘spring vents’ and ‘watercourse springs’. The term ‘spring complex’ is used to group spring vents. The meanings of these terms are set out in Table *1-1*.

Table 1-1 Spring terminology

Term	**Description**	**Quantity in the Surat CMA**
Spring vent	A single point in the landscape where groundwater is discharged at the surface. A spring vent can be mounded or flat and can also be represented by wetland vegetation, with no visible water at the location of the spring.	387
Spring complex	A group of spring vents located close to each other. The spring vents are located in a similar geology and are fed by the same source aquifer. No adjacent pair of spring vents in the complex is more than 10 km apart.	87
Watercourse spring	A section of a watercourse where groundwater from a GAB aquifer enters the stream through the streambed. This includes waterholes and flowing sections of streams dependent on groundwater. This type of spring is also referred to as a baseflow-fed watercourse.	40

Springs in the GAB are often further classified by features such as size, location in the landscape, and regional hydrogeological setting (for example, whether they are located in recharge areas or discharge areas).

The emerging nomenclature that encompasses features traditionally referred to as springs is based on the concept of groundwater-dependent ecosystems.

1.4.2 Groundwater-dependent ecosystems

A groundwater-dependent ecosystem (GDE) is an ecosystem that needs access to groundwater permanently or intermittently to maintain its communities of plants and animals, its ecological processes and its ecosystem services (Richardson et al. 2011).

The terminology used to describe GDEs has evolved significantly over the past decade and is being used more consistently nationally. The terminology is described in the National Atlas of Groundwater Dependent Ecosystems <http://www.bom.gov.au/water/groundwater/gde/> and in the GDE toolbox (Richardson et al. 2011).

Three types of GDEs are recognised, as described by Eamus and Froend (2006):

1. Ecosystems dependent on the **surface expression** of groundwater, which refers to ecosystems that reside within wetlands, lakes, seeps, springs and river baseflow.

2. Ecosystems dependent on the **sub-surface expression** of groundwater, which refers to ecosystems associated with terrestrial vegetation accessing the water table below the natural surface.
3. **Cave and aquifer** ecosystems, which refers to ecosystems that reside within the spaces of caves and aquifers.

Within this context, a feature identified as a spring in this report would be recognised as an ecosystem dependent on the surface expression of groundwater. Figure 1-2 represents how springs align within the national GDE hierarchy.

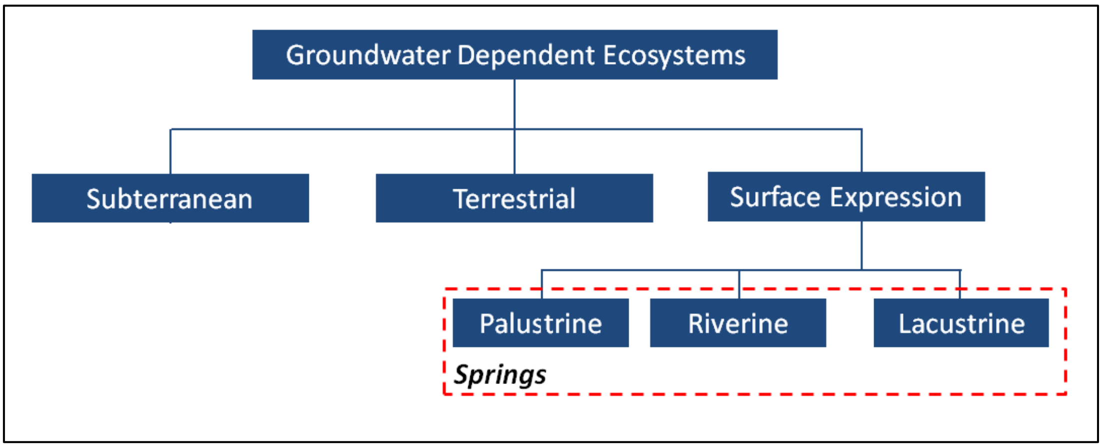


Figure 1-2 Hierarchy of groundwater-dependent ecosystems

1.5 About this report

This report summarises completed spring research activities, new knowledge and how the new understanding has informed the strategies established in the UWIR 2016. The report is structured as follows:

- Chapter 2 provides an overview of the activities completed since the UWIR 2012.
- Chapter 3 summarises the new knowledge.
- Chapter 4 describes the methodology used for assessing the risk to springs.
- Chapter 5 summarises the approach used for monitoring springs.

2 Investigations and monitoring activities

Spring monitoring and research carried out in accordance with the UWIR 2012 has provided a significant body of knowledge to inform the preparation of the UWIR 2016. The monitoring and research activities have focused on springs in locations where impacts on groundwater levels were predicted, and on springs known to host species or ecological communities listed under the *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act).

The following section provides a summary of the activities completed following the UWIR 2012.

2.1 Monitoring spring vents

The UWIR 2012 specified requirements for tenure holders to carry out monitoring at spring vents. The objective of the monitoring was to establish an understanding of the natural variability of discharge so that any long-term impact from CSG water extraction could be detected. Sites were selected with a view to the risk of impact from CSG water extraction, the representative capacity of springs, and the general suitability of the sites. A total of 33 spring vents, comprising 10 spring complexes, were required to be monitored on a quarterly basis (Figure 2-1).

In parallel with the monitoring requirements under the UWIR 2012, under the EPBC Act the Australian Government set monitoring and other requirements on tenure holders as conditions of approval to commence CSG development. The conditions that related to monitoring required:

- an assessment of the presence or absence of EPBC Act listed species in all springs within project tenure areas and within 100 kilometres of project tenures (Section 2.3)
- where a listed species or ecological community was identified, quarterly baseline monitoring for a period of 12 months (Jacobs 2015), with six-monthly monitoring over the remaining life of the project (Halcrow Group 2013).

In response to both the Australian Government and the UWIR 2012 requirements, the tenure holders collectively completed a monitoring program as part of a joint industry plan, which ensured consistency in the way in which activities were undertaken. A summary of the attributes monitored and their relationship to the UWIR 2012 and Australian Government requirements is provided in Table *2-1*.

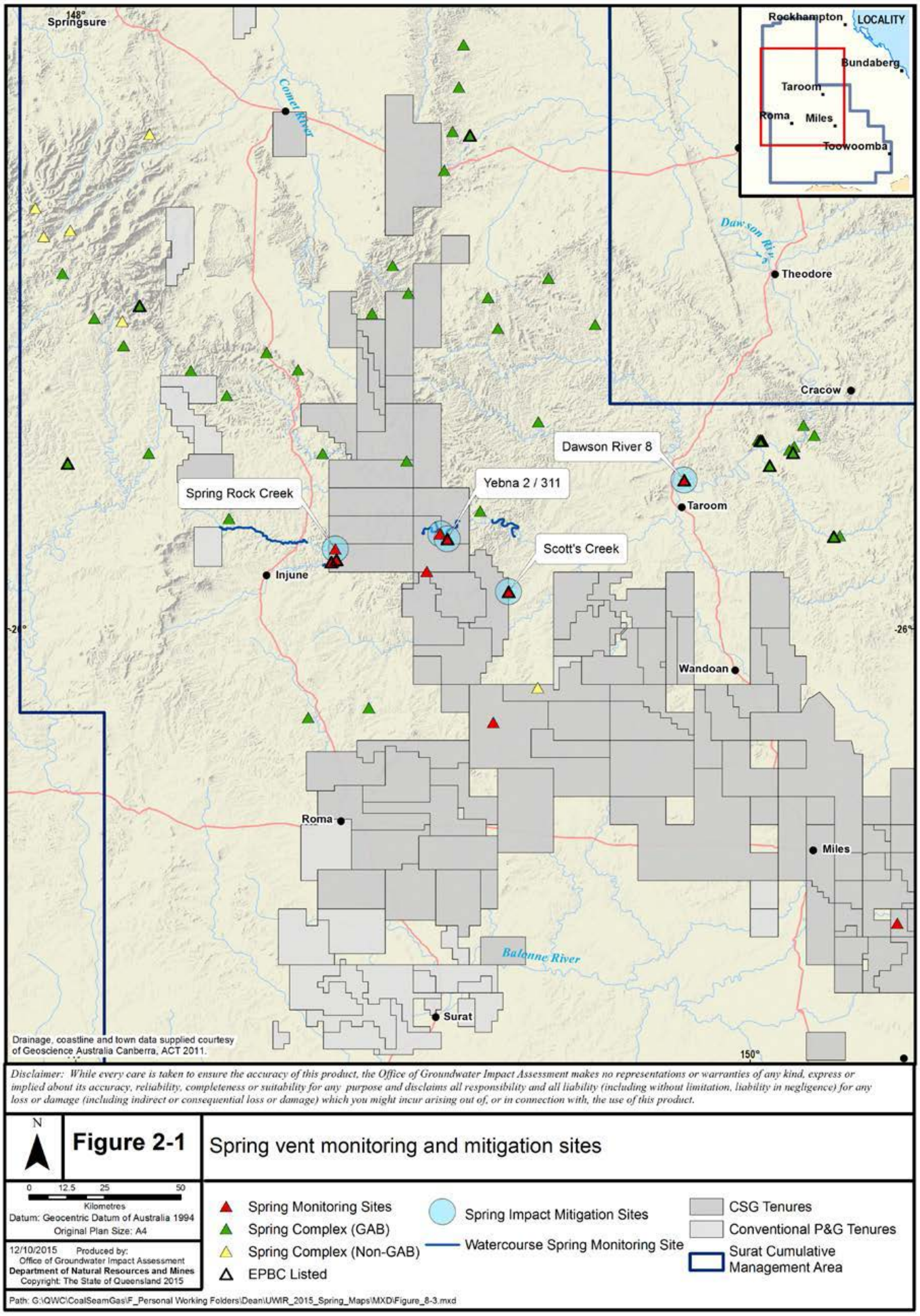


Figure 2-1 Spring vent monitoring and mitigation sites

Table 2-1 Summary of spring vent attributes monitored

Attribute	**Monitoring method**	**Requirement**	
		UWIR	**Australian Government**
Spring discharge	Measurement or estimate of discharge	✓	✓
Spring area	Measurement or estimate of wetland extent	✓	
Water chemistry	Field parameters and major ions	✓	✓
	Isotopes		✓
Condition	Visual assessment	✓	✓
Species assemblages	Flora transects and macroinvertebrates		✓

During the implementation of the monitoring program, requirements and techniques evolved in response to conditions encountered at the monitoring sites. All changes to the program were made in consultation with the Queensland Department of Environment and Heritage Protection.

The monitoring data collected was a key input to the conceptualisation of springs (Chapter 3) and the assessment of risk (Chapter 4). A database held by OGIA currently stores the monitoring data.

2.2 Monitoring watercourse springs

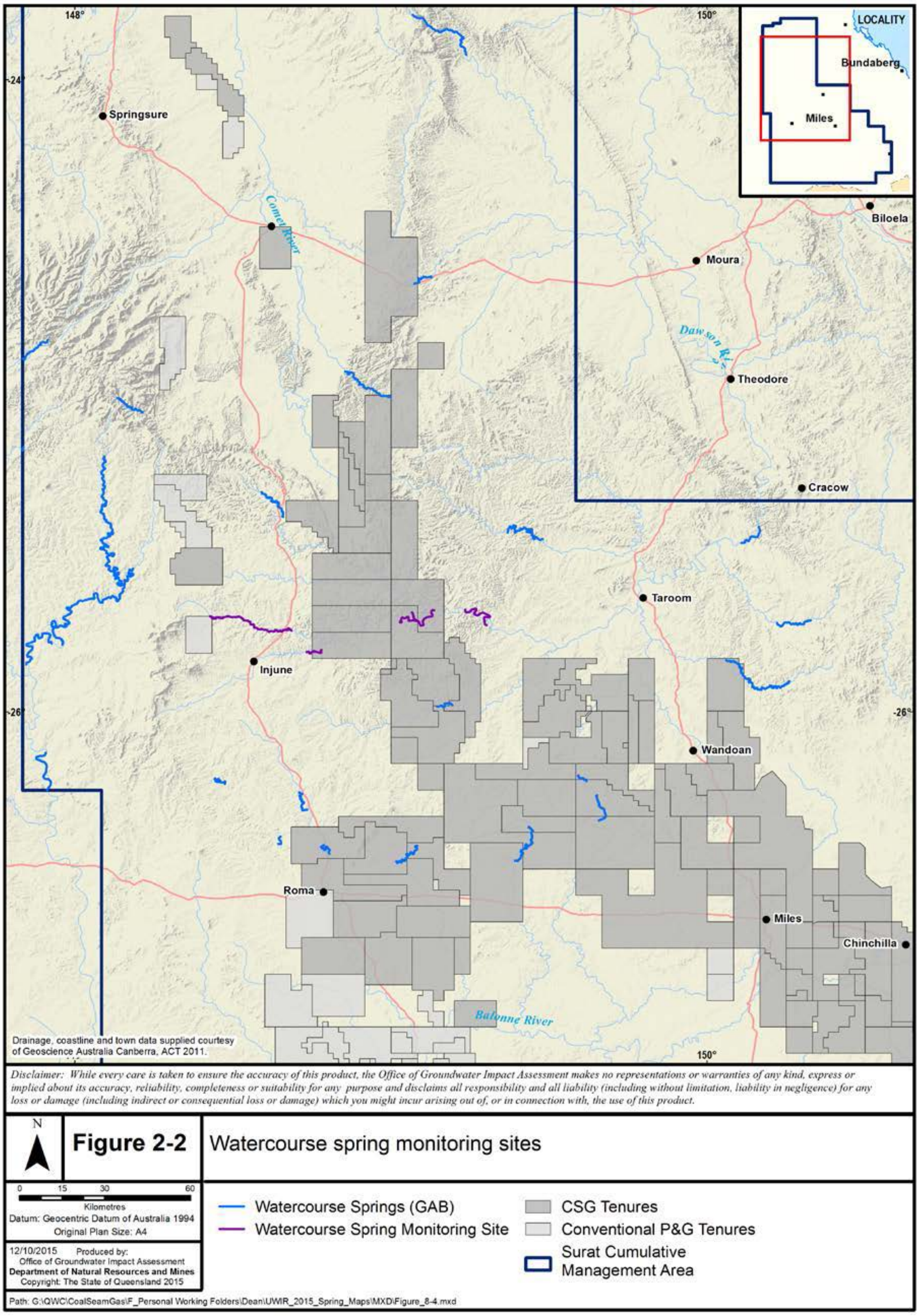
The UWIR 2012 specified requirements for tenure holders to carry out monitoring at five watercourse springs (Figure 2-2). The objectives of the monitoring program were to establish an understanding of the natural variability in stream flow along the specified reaches. Consistent with the approach for spring vents, locations were selected with a view to the risk of impact from CSG water extraction, the representativeness of the springs, and general suitability of the sites. Monitoring was required on a quarterly basis. A summary of the attributes monitored is provided in Table *2-2*.

Table 2-2 Summary of watercourse spring attributes monitored

Attribute	**Monitoring method**
Spring discharge	Measurement or estimate of discharge
Water chemistry	Field parameters and major ions

During the implementation of the monitoring program, requirements and techniques evolved in response to conditions encountered at the monitoring sites. All changes to the program were made in consultation with the Queensland Department of Environment and Heritage Protection.

The monitoring data collected was important for understanding the nature of connection between surface water and groundwater at these locations. A database held by OGIA currently stores the monitoring data.



Drainage, coastline and town data supplied courtesy of Geoscience Australia Canberra, ACT 2011.

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Figure 2-2 Watercourse spring monitoring sites

2.3 Assessing springs for EPBC-listed species

Under the EPBC Act, the Australian Government provided conditional approval for CSG projects in the Surat Basin (Section 2.1). The approval conditions required tenure holders to assess the presence or absence of EPBC Act listed species in all springs within project tenure areas and within 100 kilometres of project tenures.

In response, the tenure holders jointly commissioned a survey ('the industry survey') which geographically expanded upon the spring survey carried out to inform the preparation of the UWIR 2012. The industry survey identified potential spring sites through analysis of aerial photographs and satellite imagery. Sites were characterised with respect to potential spring type, groundwater source and likely physio-chemical characteristics. Sites were visited to validate potential new spring locations.

Details of springs newly identified through the industry survey have been incorporated into the Queensland Government dataset and into the UWIR 2016.

2.4 Evaluating options to prevent or mitigate impacts

The UWIR 2012 identified five spring complexes (comprising 38 spring vents) that are predicted to experience pressure declines of more than 0.2 metres in their source aquifers as a result of CSG water extraction (Figure 2-1). Although the predicted impacts were relatively small and were not expected until well into the future, tenure holders were required to assess options to avoid or mitigate the predicted impacts.

At two sites, the responsible tenure holder identified that relocating landholder water supply bores that were already affecting water pressure in the source aquifer could 'balance out' the predicted impact of CSG water extraction. The relocation would result in no net change to the current pressure at the spring. The tenure holder established agreements with the landholder to relocate the bores if it becomes necessary.

At the remaining three sites, the tenure holder identified that there was no opportunity to balance out the predicted impacts by relocating water supply bores; however, the initial hydrogeological assessment by the tenure holder has complemented related research carried out by OGIA to improve conceptualisation of the relationship between the springs and the pressures in underlying aquifers (Chapter 3). This improved conceptualisation has improved the methodology for assessing risk (Chapter 5) which is the basis for assessing the need for mitigation actions in the UWIR 2016.

2.5 Conceptualising and classifying springs

Over the period 2013–15, a project was undertaken to improve the conceptualisation of the relationship between springs and the water pressure in underlying aquifers. Through this project, a system of grouping springs, or 'spring typology', has been developed. The typology has led to improvements in assessing risk and provides a more systematic approach to specifying spring monitoring (Chapter 5).

As part of the project, an understanding of landscape-level and local-scale groundwater flow to 17 spring complexes was developed using hydrogeological, landscape, flora and fauna datasets. The project used existing data, recently collected monitoring data, data from investigations carried out by tenure holders, and data from field investigations carried out specifically for the project.

The targeted field investigations were:

- local-scale field geological mapping at the Lucky Last and Scott's Creek complexes

- a ground geophysical survey at the Lucky Last complex
- drilling investigations and installation of nested piezometers at the Lucky Last complex
- the installation of shallow piezometers at the Scott's Creek complex.

The spring typology developed through the project is described in Section 3.2 and is based on the Australian National Aquatic Ecosystem classification framework (AETG 2012). Reports detailing the analysis of conceptual options at each of the 17 sites, and summarising the conclusions drawn, have been prepared.

2.6 Improving monitoring techniques

Spring monitoring is carried out to build understanding of the natural variability of spring flow and the way variability is related to local hydrogeological settings. This improved understanding will enable any significant changes in flow associated with CSG water extraction to be more clearly identified.

Monitoring spring flow can, however, be difficult; in most cases it must be measured indirectly using other spring attributes which can themselves be affected by a range of non-groundwater related influences including surface water flows, land-use changes, livestock grazing, and feral animals.

Over the past decade, there has been some standardisation of spring monitoring techniques. These techniques were specified in the UWIR 2012 for use in monitoring required to be carried out by tenure holders. Due to the significant challenges involved in monitoring springs and the continuing development of techniques by spring experts, a project to update the specification of monitoring techniques for the UWIR 2016 was carried out (Section 3.5). The project comprised a literature review and an expert workshop.

Learnings from the project are described in Section 3.5 and have been incorporated into the required monitoring techniques specified in the UWIR 2016. A further outcome of the project was the preliminary design of a pilot to test possible new techniques that may be useful in the Surat CMA. The pilot will be implemented over several years, starting in 2016.

2.7 Identifying watercourse springs

Watercourse springs, as well as spring vents, have the potential to be affected by CSG water extraction; however, the location of watercourse springs are not as well identified as spring vents. Discharge can be diffuse, it can move over time and, where discharge is semi-permanent, the springs can be confused with surface water flow. The UWIR 2012 identified potential watercourse springs using desktop methods and identified the need to better define the existence of watercourse springs.

In the Dawson, Mackenzie and Comet river catchments, work to identify terrestrial GDEs (groundwater-dependent ecosystems) has been completed. As described in Section 1.4, terrestrial GDEs are ecosystems associated with terrestrial vegetation that accesses the watertable below the natural ground surface. Techniques have been applied in the Surat CMA to better identify the existence of watercourse springs. Where terrestrial GDEs are identified, a connection between shallow groundwater and nearby creeks and rivers is likely.

Additional information on the approach to mapping and classifying GDEs is available at: http://wetlandinfo.ehp.qld.gov.au/resources/static/pdf/facts-maps/gde/gde-mapping-classification-methodology.pdf.

The knowledge revealed through this project is described in Section 3.6. The outcomes have been considered in selecting the locations for monitoring springs and water pressure. In conjunction with risk, the outcomes have also assisted in specifying locations for future research into watercourse springs.

3 New knowledge

This chapter summarises the new knowledge since 2012, which has informed the UWIR 2016.

3.1 Classifying springs

3.1.1 The evolution of GAB spring classification

Springs in the Great Artesian Basin (GAB) were first classified in the 1954 report *Artesian water supplies in Queensland,* which divided springs into four groups (Whitehouse 1954):

- streams issuing from sandstones where stream erosion has cut below the watertable
- springs issuing from outcropping sediments where recharge water is unable to enter the groundwater system (often termed ‘rejected recharge’)
- springs occurring where wide and flat valleys have eroded away to reduce the vertical distance between the ground surface and aquifer level
- mound springs where water, under pressure, discharges through overlying clay.

Since these initial conceptual understanding and groupings, new classifications have emerged to accommodate new knowledge and to meet specific management needs. A commonly used grouping for GAB springs is based on the mechanism by which groundwater flows to a spring. Under this system, a spring is either a recharge spring or a discharge spring.

Recharge and discharge springs occur in a variety of landscapes; however, the two share common characteristics. For example, a discharge spring receives groundwater flow from a confined aquifer, the groundwater generally having travelled a significant distance within the aquifer. In contrast, a recharge spring receives groundwater which has travelled a short distance from the recharge area within an unconfined aquifer.

This high-level classification system has been the basis of many protection and management arrangements for springs in the GAB. Expanding upon the recharge and discharge classification, the UWIR 2012 (QWC 2012) identified six mechanisms by which springs occur in the Surat CMA:

- a change in geology
- a perched watertable
- geological structures
- thinning of a confining layer
- a change in slope
- a window into the watertable.

Since 2012, in addition to hydrogeological mechanisms such as faults, the focus on classifying springs in relation to their surface characteristics, such as their substrate and position in the landscape, has been increased. These characteristics better relate to a spring’s function and how the spring is likely to respond to changes in the groundwater regime.

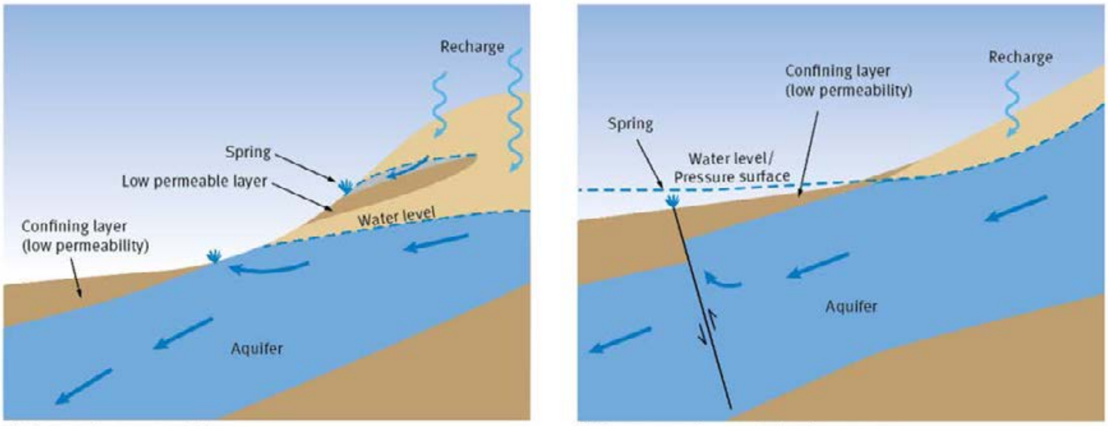
3.1.2 Mechanisms by which springs occur

In the Surat CMA, there are three basic hydrogeological mechanisms by which springs occur. Individual springs can occur due to more than one of these mechanisms. The three mechanisms are described below and are represented diagrammatically in Figure 3-1.

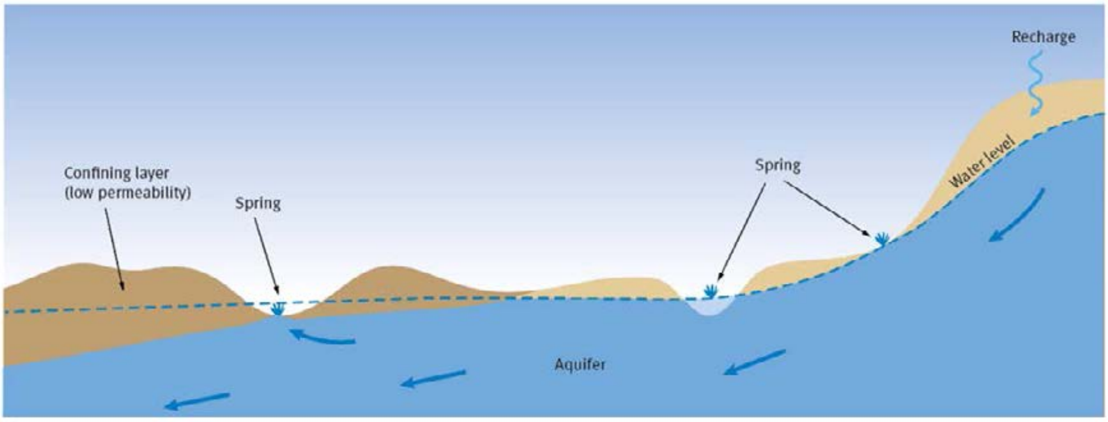
a) A spring can form where there is a change in the hydraulic properties of the geology within the landscape. Such a spring is often referred to as a contact spring. Where a higher permeability layer overlies a lower permeability layer, flow across the boundary is restricted. As a result, water tends to flow laterally and may reach the surface as a spring. This can occur where there is a change in permeability within a single aquifer or where there is a change in geology.

b) 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.

c) Erosion and dissection of the landscape by surface water flows can provide opportunities for groundwater to reach the surface. This can occur where an outcropping aquifer has been eroded to create a depression of sufficient depth to reach the watertable. This situation is generally associated with creeks and streams. In other areas, a confining unit may be dissected, resulting in a reduction in the thickness of the confining unit and providing an opportunity for groundwater to flow to the surface.



a) Change in permeability **b)** Presence of a geological structure



c) Erosion of the surface geology

Figure 3-1 The hydrogeological mechanisms by which springs occur in the Surat CMA

3.1.3 Classifying springs in the Surat CMA

For the purposes of the UWIR 2016, all identified springs have been described using attributes that are consistent with the Australian National Aquatic Ecosystem classification framework (AETG 2012) and the Queensland wetland habitat classification scheme (EPA 2005). The attributes relate to the springs' settings and the processes that influence ecological functioning at the associated wetlands.

Section 2.5 refers to the data collected at 17 spring complexes. These sites were selected for detailed study as they are representative of other springs and were recognised as being at higher risk. The new wetland typology described in Section 3.2 was applied using data from these 17 sites.

3.2 New spring wetland typology

For the purpose of consistency with the emerging nomenclature (Section 1.4), springs and watercourse springs are identified as 'wetlands' regardless of where they occur in the landscape.

A wetland typology has been developed by OGIA for the purposes of the UWIR that groups wetlands based on common features with common management needs, such as monitoring. The typology is based on the dominant processes that form the wetlands. For each type, attributes describe how the wetlands occur within the landscape and how they will respond to changes in the groundwater regime connected to the wetland.

The attributes are:

- landscape setting
- geomorphology
- groundwater flow system
- regolith
- water regime
- ecology (flora and macroinvertebrates).

Four wetland types, and two sub-types, have been defined:

Type 1: **Permanent** fresh-to-brackish, **palustrine** wetlands with **well-developed peat wetland soils**, dense vegetation coverage, mainly connected to **regional and local groundwater systems**. There are two subtypes:

Type 1a: Wetlands located in off-stream environments, mainly along floodplains.

Type 1b: Wetlands located at the interface between floodplain and riverine environments and influenced by surface water flows.

Type 2: **Semi-permanent** brackish, **palustrine** wetlands with **minor wetland soils** and minor vegetation cover, mainly connected to **regional groundwater systems**. Cockatoo Creek is an example.

Type 3: **Permanent to semi-permanent riverine** wetlands with minor wetland soils and moderate vegetation cover, sourced from **local and regional groundwater systems** and **significantly influenced by surface water flows**.

Type 4: **Semi-permanent** fresh **riverine-to-palustrine** wetlands with minor wetland soils and moderate vegetation cover, mainly connected to **local groundwater systems**. There are two subtypes:

- Type 4a: Wetlands located within riverine environments with deep, sandy, alluvial deposits (non-GAB).
- Type 4b: Wetlands located within riverine-to-palustrine environments with shallow-to-nil consolidated material. These wetlands can form in areas of significant topography (GAB).

A summary of the key characteristics of each wetland type is provided Table *3-1*.

The landscape settings for the dominant hydrological processes for each wetland type are presented in Figure 3-2. The four wetland types are described in more detail in the following sections.

Table 3-1 A summary of the wetland typology

Wetland attributes		Type 1a	Type 1b	Type 2	Type 3	Type 4a	Type 4b
Landscape setting		Palustrine and floodplain	Floodplain/riverine interface	Palustrine	Riverine	Riverine	Palustrine/riverine
Geomorphology		Low-lying landscapes; topographic lows; or gently sloping land, often associated with floodplains	Lower slopes adjacent to watercourses	Broad and flat break of slope impacted by surface erosion	Active watercourse with only minor accumulation of wetland soil on exposed sandstone bedding planes	Active watercourse within alluvial deposits	Very subtle ephemeral drainage lines; no visible alluvial deposits
Groundwater flow system		Receives groundwater from both regional and local flow systems	Receives groundwater from both regional and local flow systems	Receives groundwater from the regional flow system	Receives groundwater from both regional and local flow systems	Receives groundwater predominantly from local flow system	Receives groundwater predominantly from local flow system; includes perched systems
Regolith		Deep weathered clay regolith, overlain by organic rich wetland soil with mounding	Moderate to minor regolith development Can be associated with outcropping sandstone and minor mounding	Deep highly weathered clay regolith, overlain by thin sodic wetland soils	Little to no regolith development, predominantly within exposed sandstone	Deep, sandy alluvial deposits, overlain by minor to nil wetland soil	Shallow, weathered alluvial / colluvium deposits, overlain by minor wetland soil
Water regime	**Nature of the wetland discharge**	Permanent discharge, dominated by diffuse discharge and ET Seasonally induced, free-flowing wetland discharge Pooling can occur depending on the wetland shape	Permanent discharge, dominated by diffuse discharge and ET Seasonally induced, free-flowing wetland discharge Pooling can occur depending on the wetland shape	Semi-permanent diffuse discharge, with only minor ET demand and pooling	Permanent to semi-permanent free-flowing wetland discharge with minor ET Pooling can occur depending on the wetland shape	Permanent to semi-permanent discharge dominated by free flow with minor ET	Permanent to semi-permanent discharge dominated by free flow with minor ET.
	Salinity	Fresh-brackish (TDS < 1000)	Fresh-brackish (TDS < 1000)	Saline (TDS 1000–2000)	Fresh (TDS < 500)	Fresh (TDS < 300)	Fresh (TDS < 300)
	Frequency of inundation	Aseasonal Intermittent to ephemeral	Seasonal to aseasonally intermittent	Aseasonal Ephemeral	Seasonal	Seasonal	Aseasonal. Ephemeral
Flora		Major coverage of wetland vegetation, including large woody vegetation	Moderate coverage of wetland species	Minor vegetation, dominated by terrestrial species; often bare wetlands with exposed soil	Minor coverage of wetland and terrestrial vegetation due to the lack of substrate	Minor vegetation due to the lack of substrate and dynamic landscape; can contain wetland species	Minor vegetation due to the lack of substrate and dynamic landscape; can contain wetland species
Macroinvertebrates		Aquatic habitat suitable for tolerant species	Aquatic habitat suitable for tolerant and sensitive species	Very poor aquatic habitat	Aquatic habitat suitable for sensitive species	Aquatic habitat suitable for sensitive species	Aquatic habitat suitable for sensitive species

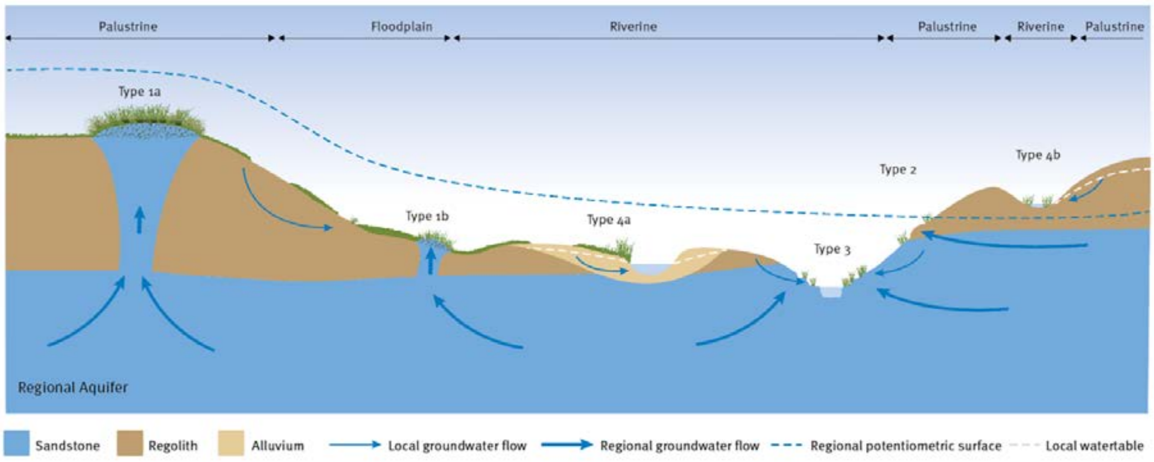


Figure 3-2 Wetland setting and dominant landscape process for each spring/wetland type

3.2.1 Type 1 wetlands

Type 1 wetlands are palustrine, located within topographic lows, gently sloping landscapes and occasionally on floodplains. They are supported by groundwater inflows from both regional and local groundwater systems, and predominantly occur over deep regolith profiles.

The permanent supply of groundwater enables the significant development of peaty wetland soil, vegetation and mounding. The wetlands are characterised by central cores of aquatic vegetation with very discrete and disconnected wetlands around them.

The wetland water balance (Section 3.5.1) is dominated by diffuse discharge and evapotranspiration. During cooler months, wetlands may flow freely due to lower evapotranspiration, and pooling can occur. The wetlands are influenced by seasonal and long-term changes in climate and groundwater regime. A positive relationship exists between the magnitude of wetland discharge and the condition of aquatic vegetation and macroinvertebrates.

A conceptual model for Type 1 wetlands is presented in Figure 3-3.

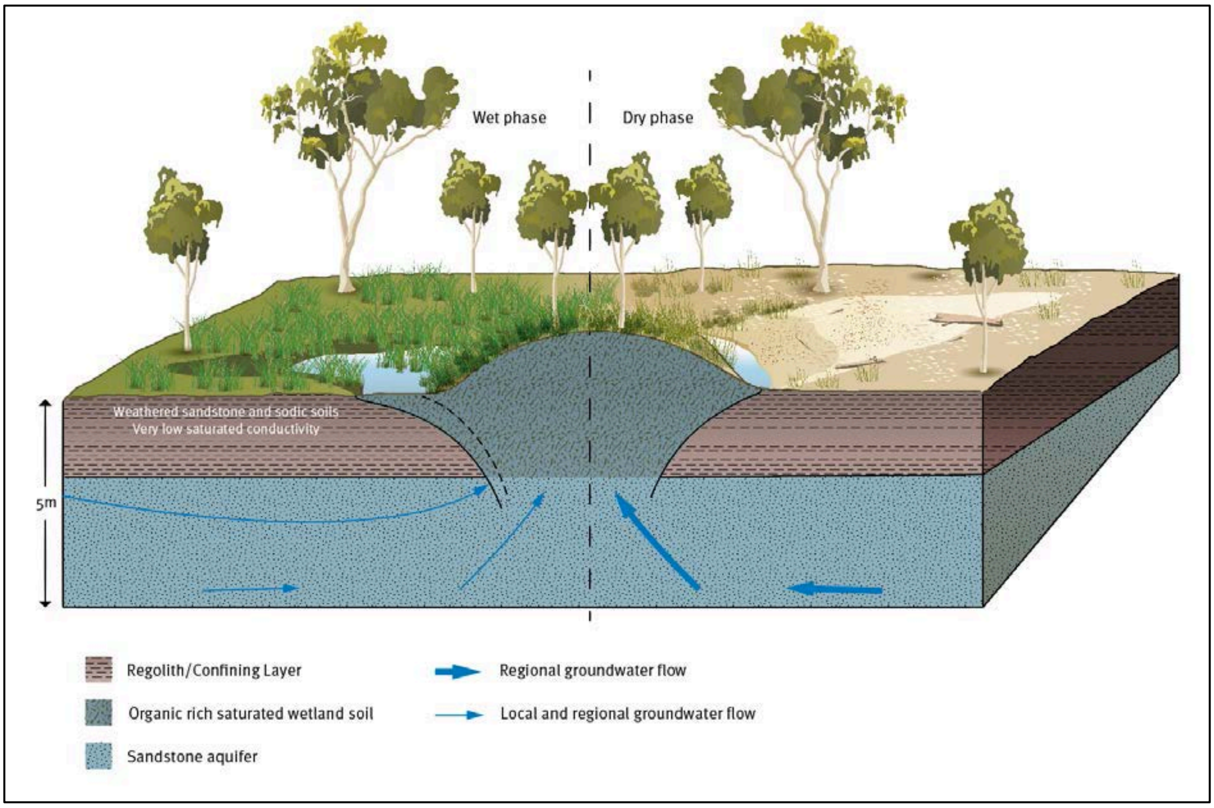


Figure 3-3 Type 1 wetlands – conceptual model

Type 1 wetlands have two subtypes based primarily on their position in the landscape: Type 1a wetlands (for example, Lucky Last) are located along low-lying hill slopes or floodplains; in contrast, Type 1b wetlands (for example, Scott's Creek) occur at the interface between the floodplain and riverine settings. As a result, Type 1b wetlands have relatively thin regolith and wetland soil development. They are also closer to the underlying source aquifers. They may receive surface water during high stream-flow events and are physically influenced by surface water during high stream-flow events.

Figure 3-4 Type 1a wetlands

Figure 3-5 Type 1b wetlands

Groundwater maintains the wetland and its aquatic vegetation and macroinvertebrates. It permanently saturates the wetland cores and seasonal local groundwater flow creates additional discharge, forming extensive wetland tails.

The environmental values are maintained by the permanent supply of groundwater discharge which is enough to keep the underlying regolith saturated, preventing oxidation of peaty wetland soils, and to provide a permanent water source for wetland vegetation, including large woody vegetation. The groundwater discharge rate and volume must exceed evapotranspiration for water to pool and discharge tails to develop. Additional seasonal input from local groundwater systems to the wetland helps regulate the wetland salinity.

Type 1b wetlands are connected to ephemeral and perennial surface water sources, such that the stream water provides additional habitat for macroinvertebrates and is, therefore, part of the wetland water balance.

For Type 1a wetlands, short-term changes in the groundwater regime beyond historical variability are likely to reduce the flow of water to wetlands, cause changes in the floristic composition, and increase the salinity. The severity of this change will be determined by the available pressure above ground.

For Type 1b wetlands, minor changes in groundwater regime may be offset by additional water from surface water flow events that inundate the wetlands. Where the wetlands are in grazing areas, the vegetation fringing the wetlands may become compacted and altered.

3.2.2 Type 2 wetlands

Type 2 wetlands are palustrine, located within topographic lows or gently sloping landscape settings. They receive groundwater mainly from regional groundwater systems. In comparison to Type 1, these wetlands occur on highly weathered profiles and the wetland water balance is dominated by semi-permanent diffuse regional groundwater discharge. During extended dry periods, the wetlands may cease to flow. Examples of this type of wetland in the Surat CMA are the Cockatoo Creek and Abyss complexes (Figure 3-6).

Figure 3-6 Type 2 wetlands (Abyss complex)

Type 2 wetlands are relatively small and are dominated by terrestrial vegetation, with little-to-no habitat (free water) for macroinvertebrates. The semi-permanent connection to the groundwater system inhibits the development of distinct wetland soils. The wetlands are often associated with a broader saline discharge zone that is actively eroding. The wetlands are commonly characterised by 'flowing sands' that create small non-vegetated mounds. Changes in the subsoil allow for more discrete discharge zones (wetlands) to occur, initiating quick flow conditions of sediment which develop 'mud springs'.

A conceptual model for Type 2 wetlands is presented in Figure 3-7.

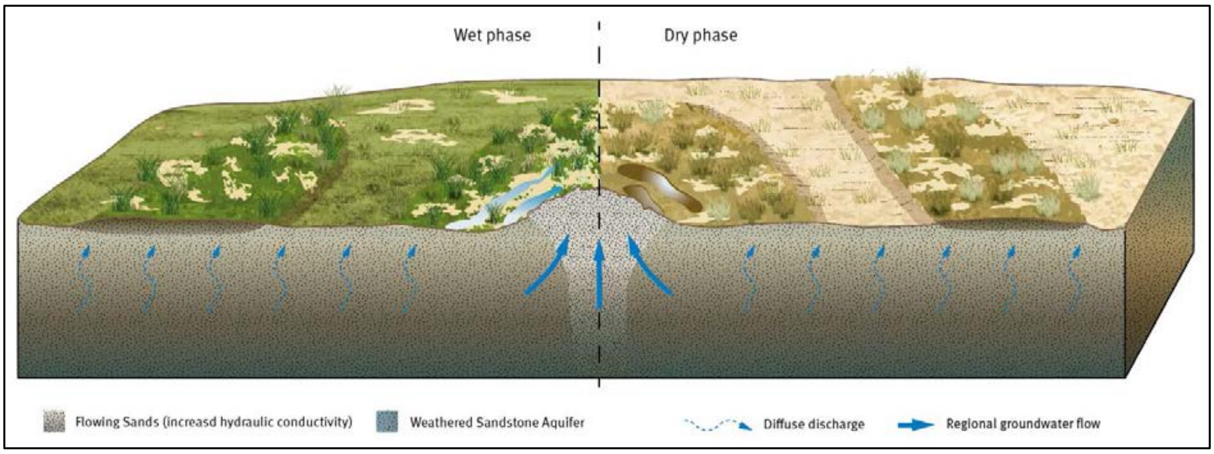


Figure 3-7 Type 2 wetlands – conceptual model

The wetland water balance is dominated by groundwater discharge; however, it is rarely at a rate where considerable discharge occurs at the surface. This may reflect the low hydraulic gradient and/or the low permeability of the source aquifer.

The environmental values are maintained by a supply of groundwater discharge during extended dry periods and sufficient groundwater discharge (rate and volume) to keep the underlying regolith saturated, providing a seasonal water supply for wetland vegetation.

Type 2 wetlands are not considered permanent features of the landscape. Therefore, they are likely to be more resilient to short- and long-term changes. Prolonged changes in the groundwater regime will, however, reduce wetland vegetation to such an extent that the wetland may be difficult to distinguish from terrestrial vegetation.

The dominant anthropogenic influences on these wetlands are grazing and changes in adjacent land use, which have allowed unstable soils to be exposed and considerable sheet and rill erosion to occur across the landscape.

3.2.3 Type 3 wetlands

Type 3 wetlands are located within or near riverine environments and, typically, receive regional and local-scale groundwater discharge from exposed sandstone aquifers. These wetlands are predominantly actively discharging, with little soil water storage or evapotranspiration demand. The shape and size of the wetlands are controlled by the nature of the exposed sandstone and by the erosion and dynamics of in-stream sediments. Examples of this type of wetland are the Yebna, Barton and 311 complexes (Figure 3-8). Traditionally, wetlands of this type have been termed ‘watercourse springs’ or ‘gaining streams’.

Figure 3-8 Type 3 wetlands (Barton (left) and 311 (right))

A dominant influence on these wetlands is surface water flow, which can alter the wetland form during high flow events. Therefore, the wetlands contain only minor wetland vegetation due to lack of substrate. The constant flow of low salinity groundwater to the wetland provides habitat for aquatic vegetation and aquatic macroinvertebrate assemblages. Changes to the wetland area are controlled by large-scale, high flow surface water events rather than groundwater discharge.

A conceptual model for Type 3 wetlands is presented in Figure 3-9.

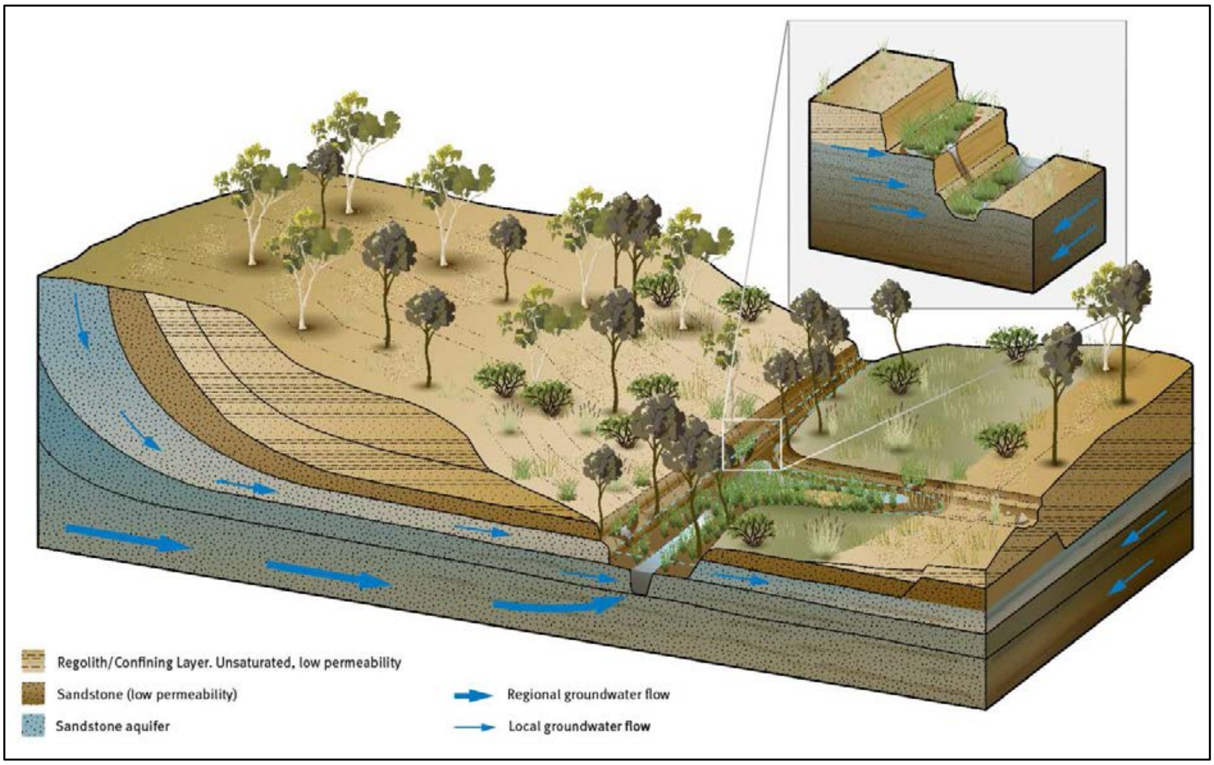


Figure 3-9 Type 3 wetlands – conceptual model

The environmental values associated with these wetlands are maintained by a permanent supply of groundwater discharge and a groundwater discharge rate sufficient to maintain a free-flowing wetland. The wetlands are connected to ephemeral and perennial surface water sources which provide additional habitat for macroinvertebrates.

Short-term changes in the groundwater regime may be offset by surface water flows that inundate the wetlands; however, changes in the medium- to long-term may be exacerbated by a reduction in the surface water flow, particularly when both stream flow and the wetland are dependent on the same aquifer.

3.2.4 Type 4 wetlands

Type 4 wetlands occur within active watercourses along regional- or local-scale sandy alluvial deposits. They receive groundwater inflows from local groundwater systems. Groundwater discharge is fresh and watercourses are free-flowing. The Wambo complex is an example (Figure 3-10).

These wetlands contain an irregular distribution of vegetation due to the lack of substrate and a dynamic landscape where the form of the wetland can be altered by stream bank erosion. They are subtle features, only distinguishable from the surrounding landscape during dry periods due to greener vegetation, fluctuating in extent and area. They are generally in good ecological condition, with balanced macroinvertebrate species.

Type 4 has two subtypes, 4a and 4b, based on their position in the landscape with respect to river reach. Type 4b occurs in the upper catchment, within drainage lines and sandstone escarpments that have little surface water flow. Their locations often coincide with the headwaters of large, more defined watercourses. The significant difference between the two subtypes is that, for Type 4b, no distinct channel has developed within the drainage line, such that the wetlands occur as broad areas of saturation within only minor wetland soil development.

Figure 3-10 Type 4a wetlands (Wambo complex)

Figure 3-11 Type 4b wetlands (Ponies complex)

Conceptual models for Type 4a and Type 4b wetlands are presented in Figure 3-12 and Figure 3-13 respectively.

Local groundwater flow from alluvial aquifers is forced to flow to the Type 4a wetlands due to the presence of a less-permeable layer, and discharges in the banks of the watercourse.

Type 4b wetlands have formed due to local groundwater flow systems overlying a less permeable, weathered substrate. Lateral, gravity-driven flow paths result in point discharge zones (wetlands) in the valley floors or at breaks in slopes.

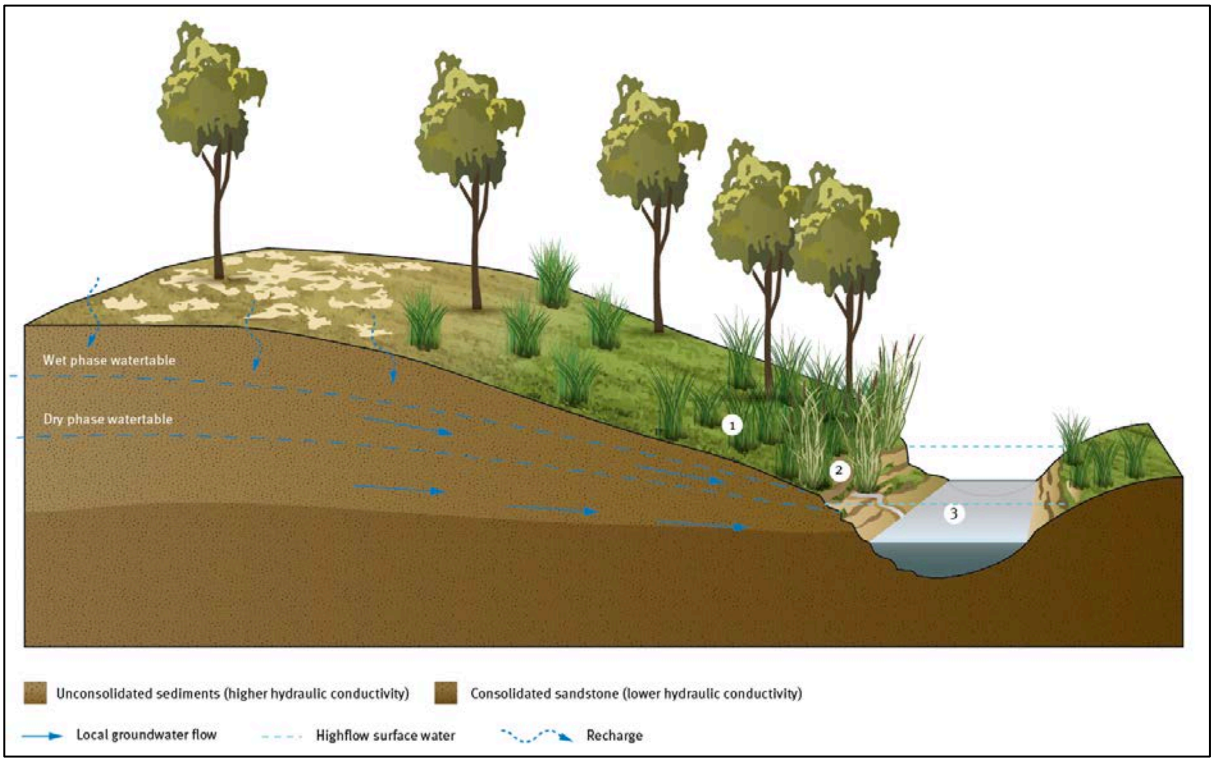


Figure 3-12 Type 4a wetlands – conceptual model

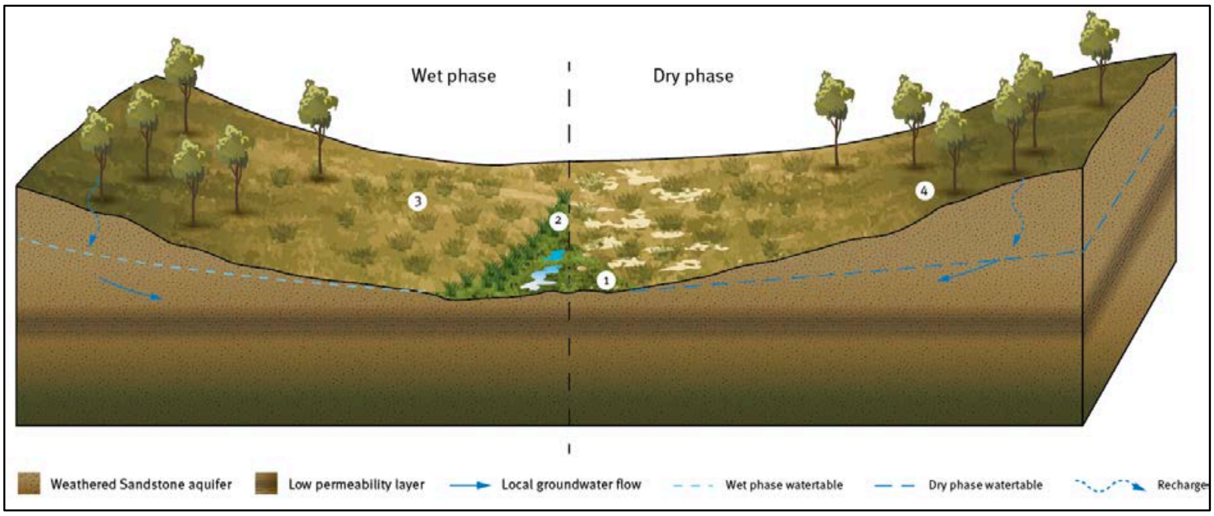


Figure 3-13 Type 4b wetlands – conceptual model

Seasonal changes in groundwater discharge and climate appear to have little impact on Type 4a wetlands. The sandy substrate and low water-holding capacity of the immediate area of the wetland allows groundwater to discharge at different rates without affecting the wetland vegetation. In contrast, seasonal changes in Type 4b wetlands occur when recharge results in increases in discharge from the wetland, expanding the wetted area and discharge rate.

The wetland water balance is a combination of groundwater discharge, river-bank storage from inundation during flood events, and adjacent semi-permanent watercourses, depending on the wetland's landscape setting. Type 4 wetlands support minor coverage of wetland vegetation and an aquatic habitat suitable for a dynamic population of macroinvertebrate species. During heavy rain and flood events, the source aquifer is likely to be recharged from surface water.

The environmental values associated with these wetlands are maintained by:

- a supply of groundwater discharge that may not be permanent
- a groundwater discharge rate sufficient to maintain a free-flowing wetland, maintaining the connection with water in the watercourse
- over-bank storage and supply of water during and following flood events.

The wetlands are connected to ephemeral and perennial water sources such that the stream water provides additional habitat for macroinvertebrates. As such, this connectivity is part of the wetland's water requirements.

3.3 Identifying spring source aquifers

The OGIA regional groundwater flow model provides information about the likelihood of water pressure at spring locations being affected by CSG water extraction. To assess the consequences for a spring of changes in pressure in aquifers underlying the spring, the dominant source aquifer feeding the spring needs to be identified.

Which aquifer is the source aquifer depends upon the spring's hydrogeological setting and the mechanism through which groundwater flows to the surface. The source aquifer could be the same geological formation in which the spring occurs, or it could be a deeper formation from which groundwater flows through fractures or faults to the spring.

The identification of the source aquifer for each spring in the Surat CMA has been inferred from a range of secondary information about the spring; local- and regional-scale geology, hydrogeology and hydrochemistry. The most common source aquifers for the springs are the Clematis Sandstone, Precipice Sandstone, the Boxvale Sandstone Member of the Evergreen Formation, the Hutton Sandstone and the Gubberamunda Sandstone. Many springs are dependent on discharge from basalt and Cenozoic aquifers; some also receive flow from multiple sources, including a combination of local and regional groundwater systems. The number of springs associated with each source aquifer is provided in Table *3-2*.

Table 3-2 Spring source aquifers in the Surat CMA

Aquifer	**Number of spring complexes (vents)**		**Number of watercourse springs**
Bungil/Mooga/Orallo Sandstone	-		7
Gubberamunda Sandstone	3	(10)	6
Hutton Sandstone	12	(42)	14
Evergreen Formation (Boxvale Sandstone Member)	8	(29)	1
Precipice Sandstone	22	(151)	8
Clematis Sandstone	17	(58)	4
Cenozoic and Basalts	25	(97)	Unknown
Total	**87**	**(387)**	**40**

The Lucky Last spring complex is an important site because of its high ecological value and the potential impact of CSG water extraction on underlying formations. At the time the UWIR 2012 was prepared, the Precipice Sandstone was inferred to be the dominant source aquifer for the spring complex. Subsequent detailed investigations have found that the Boxvale Sandstone Member of the Evergreen Formation is the dominant source aquifer. Research supporting this conclusion is detailed in the UWIR 2016.

Detailed conceptualisation has enabled attribution of the dominant source aquifers to be refined. It has made clear that for some springs the source aquifers are local flow systems. For these springs, the distance between recharge and discharge is, typically, less than five kilometres; they respond rapidly to changes in recharge; and they display seasonality. Local flow systems that are disconnected from regional groundwater flow systems are not at risk from CSG water extraction from regional aquifers.

Some springs are subject to both local and regional groundwater flow systems in which more constant background rates of groundwater discharge are overlain by seasonally fluctuating groundwater discharge.

All of the above factors have been incorporated into the risk assessment presented in Chapter 4.

3.4 Understanding spring dynamics

3.4.1 Overview

The monitoring and research completed has provided insights into the dynamics over time of spring wetlands in the Surat CMA. In general, discharge rates and associated areas of saturation within spring wetlands are influenced by seasonal and longer-term trends in climate, groundwater pressure and surface flow.

The seasonal variation in discharge and wetland area was observed through the mapping of the extent of wetland vegetation and wetted area during spring monitoring. Long-term variation was identified through the analyses of historical imagery (OGIA 2014) and the presence of landscape features that indicated wetting or drying phases of the wetland area, such as dead trees, salt-scalded soil, collapsed spring vents, and spring vents that have stopped flowing.

The spring wetland typology provides a framework to describe the dynamic nature of discharge that influences the nature of the flora and fauna associated with the springs (Table *3-1*). A summary of the wetland dynamics for each wetland type is provided below:

- **Type 1a** spring wetlands are permanent discharge zones that create wetlands with extensive regolith zones, providing habitat for wetland vegetation. Groundwater discharge is generally dominated by diffuse discharge, largely from evapotranspiration from the wetland area. Groundwater flow to the wetland is from regional and local groundwater systems. Depending upon the local hydrogeological setting and topography, significant changes in the rate of discharge and spring wetland area can occur. Seasonally, these wetlands can develop large discharge tails that grow and shrink depending on seasonal climatic conditions and local groundwater flow contributions to the spring.

  These wetlands are supported by varying levels of artesian pressure. The higher the artesian pressure, the more resilient the wetland is to changes in the regional and local groundwater system. Changes to the regional groundwater system are likely to influence the core wetland area, reducing the long-term area of the aquatic environment. Changes to the local groundwater system will influence the seasonal discharge component and the extent of the discharge tail.

- **Type 1b** spring wetlands are similar to Type1a; the primary difference is that Type 1b wetlands are located adjacent to or within riverine environments. The wetland area and discharge rate is significantly influenced by surface flow events which can increase the area of saturated soil and/or change the shape of the wetland.
- **Type 2** spring wetlands are semi-permanent and dominated by diffuse discharge, predominantly from evapotranspiration. These springs experience minor seasonal changes in discharge; however, evidence suggests they are also affected by long-term climatic and groundwater pressure changes.

  These wetlands are supported by low levels of artesian pressure, such that small changes in the groundwater system can cause the spring to stop flowing.
- **Type 3** spring wetlands are permanent to semi-permanent free-flowing springs. They receive flow from both regional and local groundwater flow systems. Deep pools can form depending upon the shape of the wetland. These spring wetlands occur within outcropping sandstone and are confined to watercourse areas. As a result, evapotranspiration is a minor component of the wetland water balance.

  Changes in climate and/or groundwater pressure affect the discharge rate (reducing surface flow), rather than decreasing the area of the wetland.
- **Type 4a** spring wetlands are permanent to semi-permanent free-flowing springs. They receive flow from local groundwater systems. Consequently, these springs show significant seasonality in response to changes in climate and recharge. These springs are located adjacent to riverine environments and are influenced by ephemeral surface flow events that can increase the area of saturated soil. These spring wetlands have developed within groundwater systems that have naturally varying rates of groundwater discharge.
- **Type 4b** spring wetlands are similar to those of Type 4a, except they are not located adjacent to riverine environments. These spring wetlands have developed within groundwater systems that have naturally varying rates of groundwater discharge.

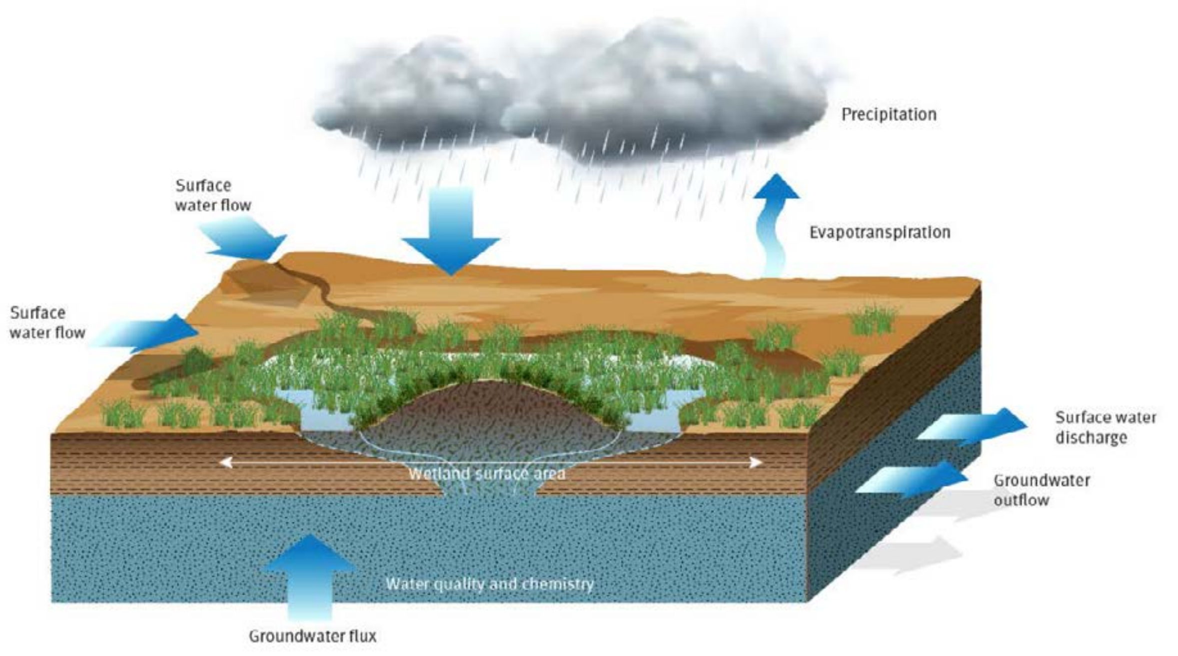


Figure 3-14 Conceptual model – wetland water balance

Analysing and interpreting the time-series data and establishing the typology have provided new insights into the dynamics of these systems. Under natural conditions (prior to private groundwater development, and petroleum and gas activities), the ecology and processes that occur within a spring are intrinsically linked to the maintenance of the spring wetland water balance.

Variations in wetland discharge, wetland area and major inflows and outflows (Figure 3-14) are natural water balance components for a wetland. In addition to these natural influences on the wetland water balance, non-groundwater-related stressors (private groundwater extraction, land use, and petroleum and gas extraction) influence the water balance and, therefore, the observed dynamics.

3.4.2 Observed trends and interpretations

Understanding the drivers of spring dynamics is critical for determining appropriate monitoring methods and for understanding how changes in groundwater pressure could affect wetland ecosystems. Below are some examples from the analyses of data relating to spring dynamics.

3.4.2.1 The influence of climate on wetland area

Understanding the variability associated with groundwater is a significant challenge because of the lack of monitoring of groundwater pressure near the wetlands. However, the measured seasonal variation in the wetted areas of wetlands is considered to be much greater than the seasonal variation in the source regional groundwater systems (OGIA 2015). Changes in evapotranspiration and in local groundwater inflows at some locations are plausible underlying causes of observed seasonal variation.

Wetland area and rainfall data for the Lucky Last and Scott's Creek complexes are shown in Figure 3-15 and Figure 3-16, illustrating some of the seasonal and long-term variability in wetland area. The wetlands shown are Type 1 wetlands. The extent of wetland vegetation and variability was assessed for the period 1948–2013 from aerial photographs (OGIA 2014). The data for 2013–15 was physically measured in the field during monitoring by the tenure holder (SKM 2014).

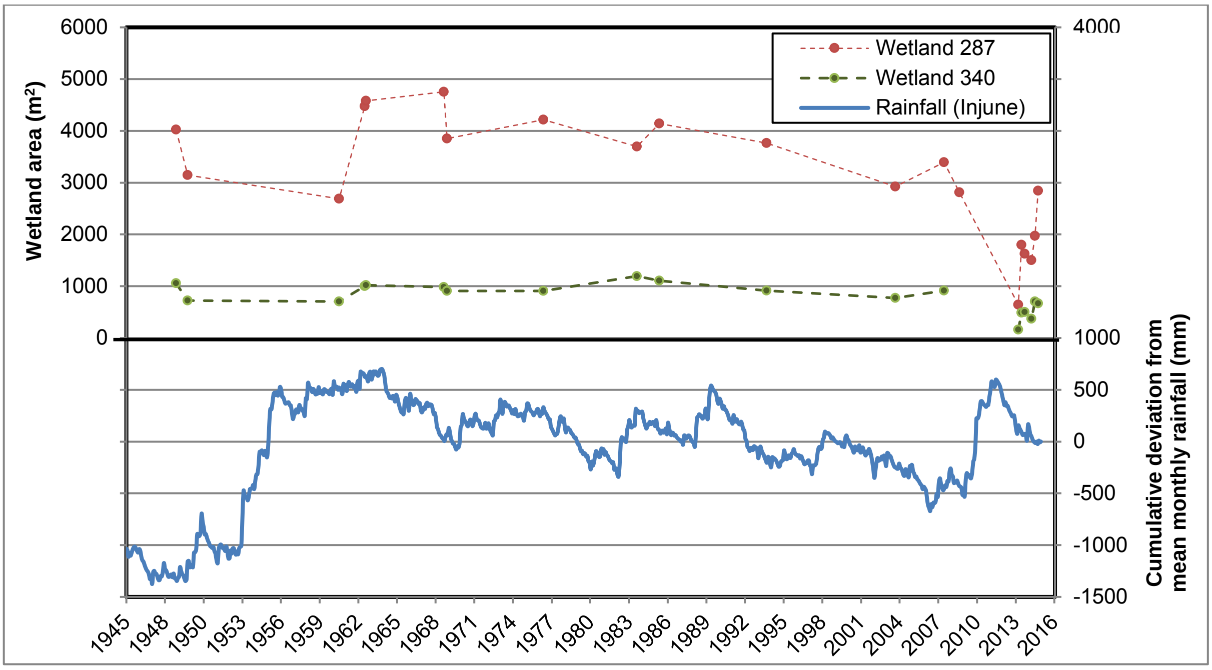


Figure 3-15 Wetland area and long-term rainfall (Lucky Last)

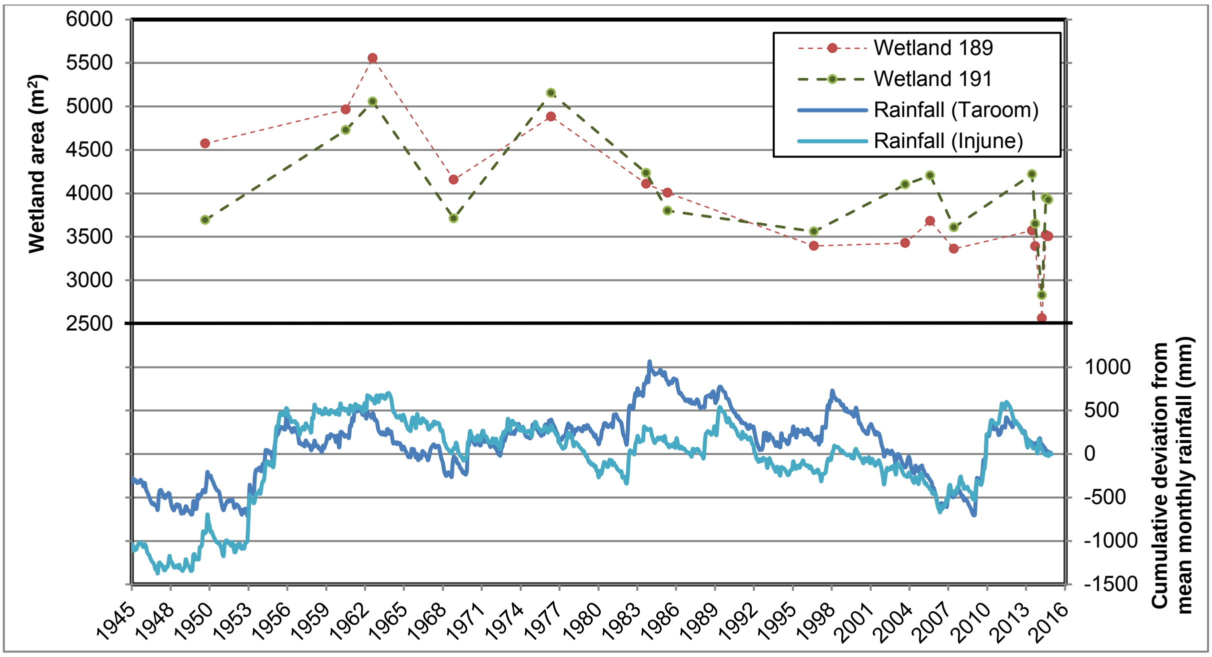


Figure 3-16 Wetland area and long-term rainfall (Scott's Creek)

Over the period of available data, both spring wetlands show an overall trend of decline in wetland area, indicating a correlation with the cumulative deviation from mean monthly rainfall and, likely, associated recharge events. Injune had below-average rainfall from 1960 to 2010. This is generally reflected in the declining trends observed in wetland area. From 2011, there were multiple years of significantly above-average rainfall. At both spring complexes, there appears to be a lag of several years before the wetland area responded to the above-average rainfall, suggesting these wetlands are supported by regional and local flow groundwater systems.

The observed extent of the spring wetland areas has generally been declining over the period of record, particularly at Scott's Creek. This is interpreted to be caused by climatic influences in addition to the expansion of groundwater development in the Hutton Sandstone during the period 1960–2005 in the Surat Basin.

3.4.2.2 The distribution of plant species in wetlands

Corresponding with changes in wetland extent, the dominance and distribution of wetland versus terrestrial vegetation species within the wetland is also interpreted to have changed, particularly along the periphery of the wetland. Figure 3-17 shows data collected along vegetation transects during tenure holder monitoring at Wetland 340 in the Lucky Last spring complex (Type 1).

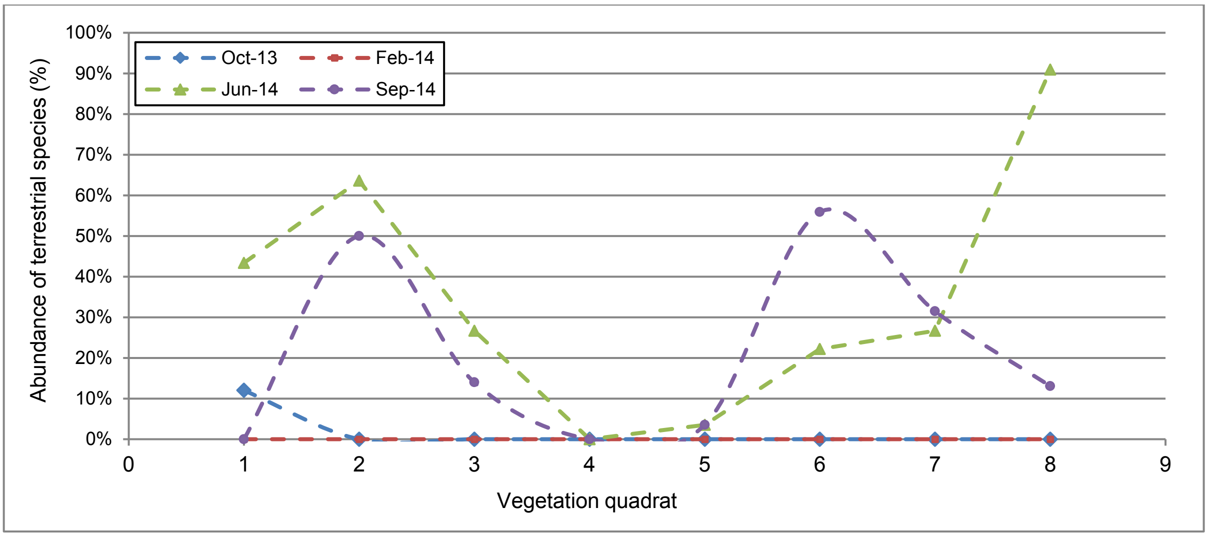


Figure 3-17 Vegetation transect data for Wetland 340 (Lucky Last)

The vegetation transect data was collected from one side of the wetland, across the central part of the wetland to the opposite side, during four monitoring periods over a single year. The saturated extent of the wetland and associated wetland conditions correlate with the dominant vegetation type. An observed spatial and temporal variability of wetland soil saturation influences the preferred habitat for each vegetation type.

Where the wetland remains permanently saturated (within the wetland core), aquatic species dominate. Where the level of saturation varies (around the periphery), terrestrial species are able to co-exist with aquatic species. The seasonal variability in spring wetlands is illustrated by the four rounds of surveyed wetland at the Lucky Last complex (Figure 3-18).

During dry periods, the central core of the wetland remains saturated and is dominated by aquatic vegetation. Over the dry period, the extent of saturated soil and aquatic vegetation are similar. During cooler and wet periods, wetland discharge increases, which results in an increased wetland area, and which may result in free-flowing water to inundate downslope areas. During these periods, the extent of saturated soil and aquatic vegetation may be different.

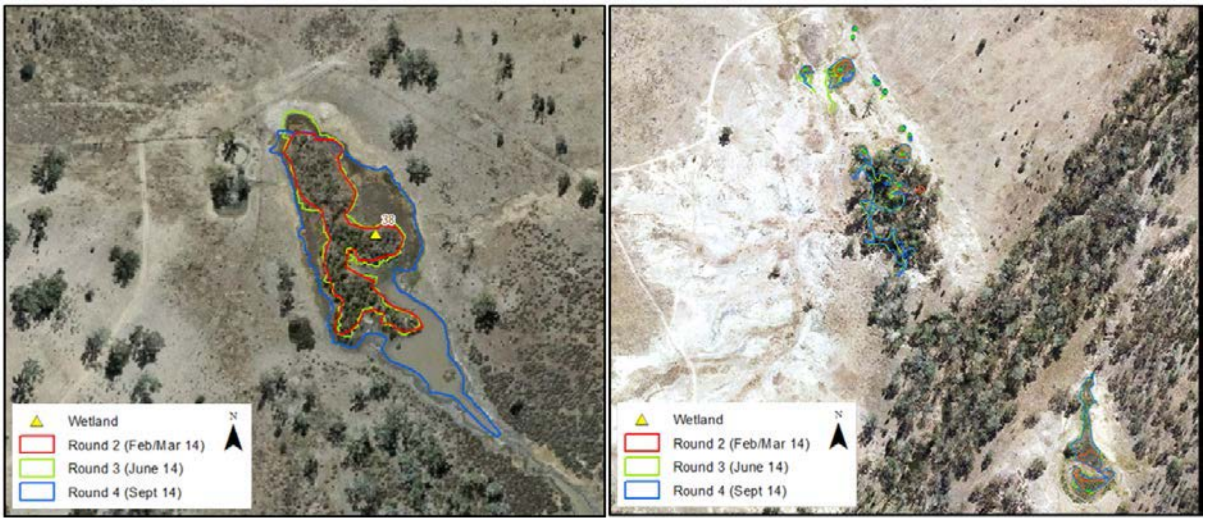


Figure 3-18 Seasonal variation in wetland area (Dawson River 8 and Lucky Last)

At the Dawson River 8 wetland, in contrast to other wetlands in the Surat CMA, terrestrial vegetation (*Melaleuca viminalis* and *Duma florulenta*) dominates in the core of the wetland within the mound. At this location, there is limited groundwater pressure above ground. As a result, at the higher points within the wetland there is limited pressure driving groundwater into the wetland. In combination with evapotranspiration, this has resulted in reduced saturation within the high, central area of the wetland. In response, the roots of terrestrial plant species are able to remain aerated and have, therefore, colonised this area. The slightly lower area of the spring wetland is dominated by *Phragmites australis* and other wetland species, including *Eleocharis* sp.

The relationship between changes in spring wetland area and dominant vegetation type is less obvious in wetland types 2 and 3. Generally, the rate of wetland discharge at Type 2 wetlands is insufficient to maintain a saturated wetland core to allow for the permanent colonisation of aquatic vegetation. Therefore, these wetlands are generally dominated by terrestrial vegetation. The changes in groundwater discharge rates and how they change the wetland area are best identified through observing the extent of the wetted area.

Type 3 spring wetlands occur in outcropping sandstone within watercourses. Changes in groundwater pressure may not result in significant changes in the area of discharge and, thus, the area of aquatic vegetation. The changes in groundwater discharge rates and how they change the wetland area are more accurately determined through measurement of the rates of groundwater discharge (using stream gauges) and of the depth of pools during periods of low flow.

3.4.2.3 The influence of evapotranspiration and local flows on water chemistry

Wetland water chemistry varied significantly across the monitoring period. This variability is interpreted to be due to the seasonal influence of surface water inflows; local groundwater inflow contributions to the wetland; and evaporation. Figure 3-19 shows the data for two wetlands at the Lucky Last complex.

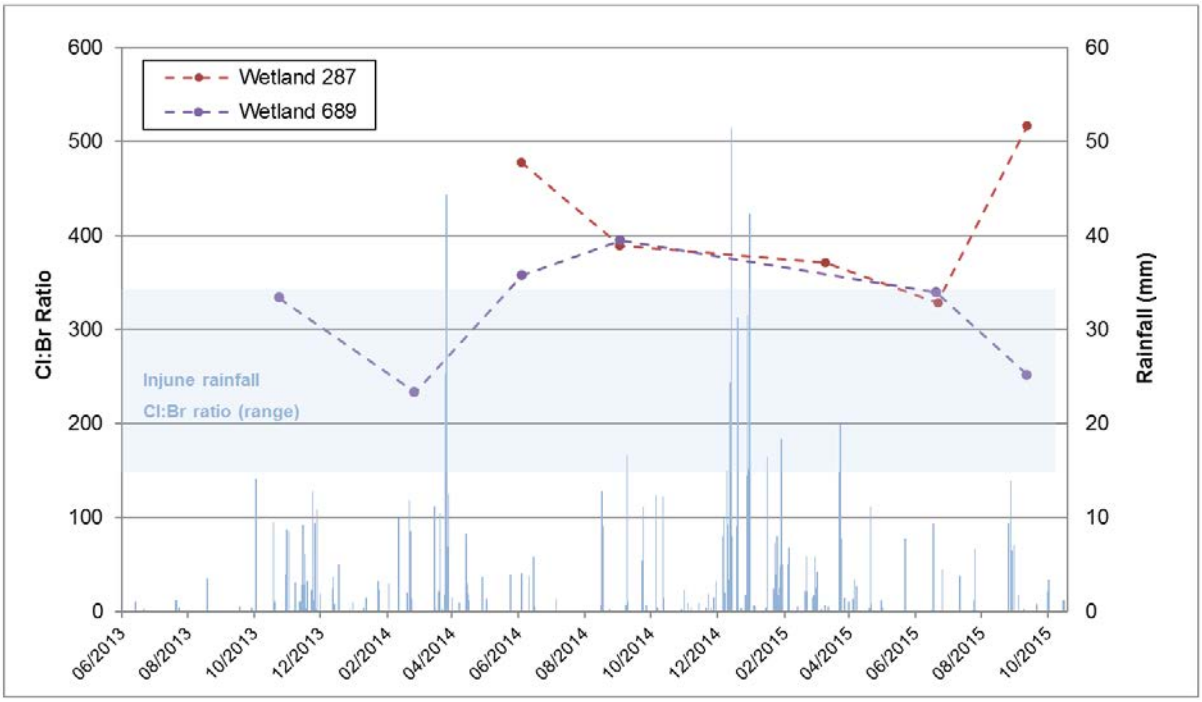


Figure 3-19 Variations in the Cl:Br ratio over the monitoring period (Lucky Last)

Cl: Chloride
Br: Bromide

At this location, water is interpreted to be evaporated from the wetland during the drying phase. Evaporation leaves salt (sodium chloride) at the surface and within the shallow subsoil surrounding the wetland. During periods of low evaporation demand and/or local groundwater inflows, this salt is carried into the wetland by the additional groundwater discharge.

This process results in peaks and troughs in the chloride-to-bromide ratio and in the salinity of the wetland. Concentrations of both chloride and bromide are altered mainly by physical processes (i.e. evapotranspiration, dilution) rather than biological and or soil-related processes.

In a wetland with a single source of water, the chloride-to-bromide ratio would remain fairly constant. For the ratio to change, an additional source of water (other than the source aquifer) with a different ratio would need to be introduced to the wetland, and/or evaporation and precipitation would need to occur, adding or removing chloride.

Wetland 287 is characterised by regional groundwater flow with minor local groundwater contribution. In contrast, Wetland 689 is located within significant regolith and alluvial development, and receives both regional and local groundwater flows. Both wetlands show peaks and troughs in their chloride-to-bromide ratios; however, the ratio for Wetland 287 is much higher than that of Wetland 689 (mean concentrations of 520 vs 340). The higher ratio is interpreted to be due to the influence of regional groundwater flow concentrations of chloride compared to the relatively lower concentrations of chloride in the local flow system supporting Wetland 689.

At both wetlands, the chloride-to-bromide ratio is high during cooler months when evapotranspiration is lowest. This causes comparatively higher concentrations of chloride to be retained within the wetland waters and, therefore, higher ratios are observed.

3.4.2.4 The influence of land use on the condition of wetlands

At many locations, changes in land use are observed to significantly affect the overall condition of the wetlands. This in turn influences the seasonal and long-term dynamics of spring wetlands. The observed effects of grazing activities include compaction, disturbance and changes in the wetland water chemistry. Pugging around the edges of mounded spring wetlands can create small drains which alter the area of saturated soil. Grazing of wetland vegetation alters the balance between evaporation and transpiration within the wetland. The indirect effects of changes in land use can have long-term impacts on wetland area and condition.

As an example, aerial imagery analyses for the Scott’s Creek wetland (Figure 3-20) identified significant historical changes in land use adjacent to the wetlands. These land-use changes are likely to have caused an increase in overland flow and may have led to erosion of the soil adjacent to the wetland, altering the area of saturated soil. Changes in vegetation abundance and soil degradation can change recharge and surface flow patterns, influencing the form and degree of saturation of the wetland area. These land-use changes have corresponded with a general decline in the extent of the area of the spring wetlands.

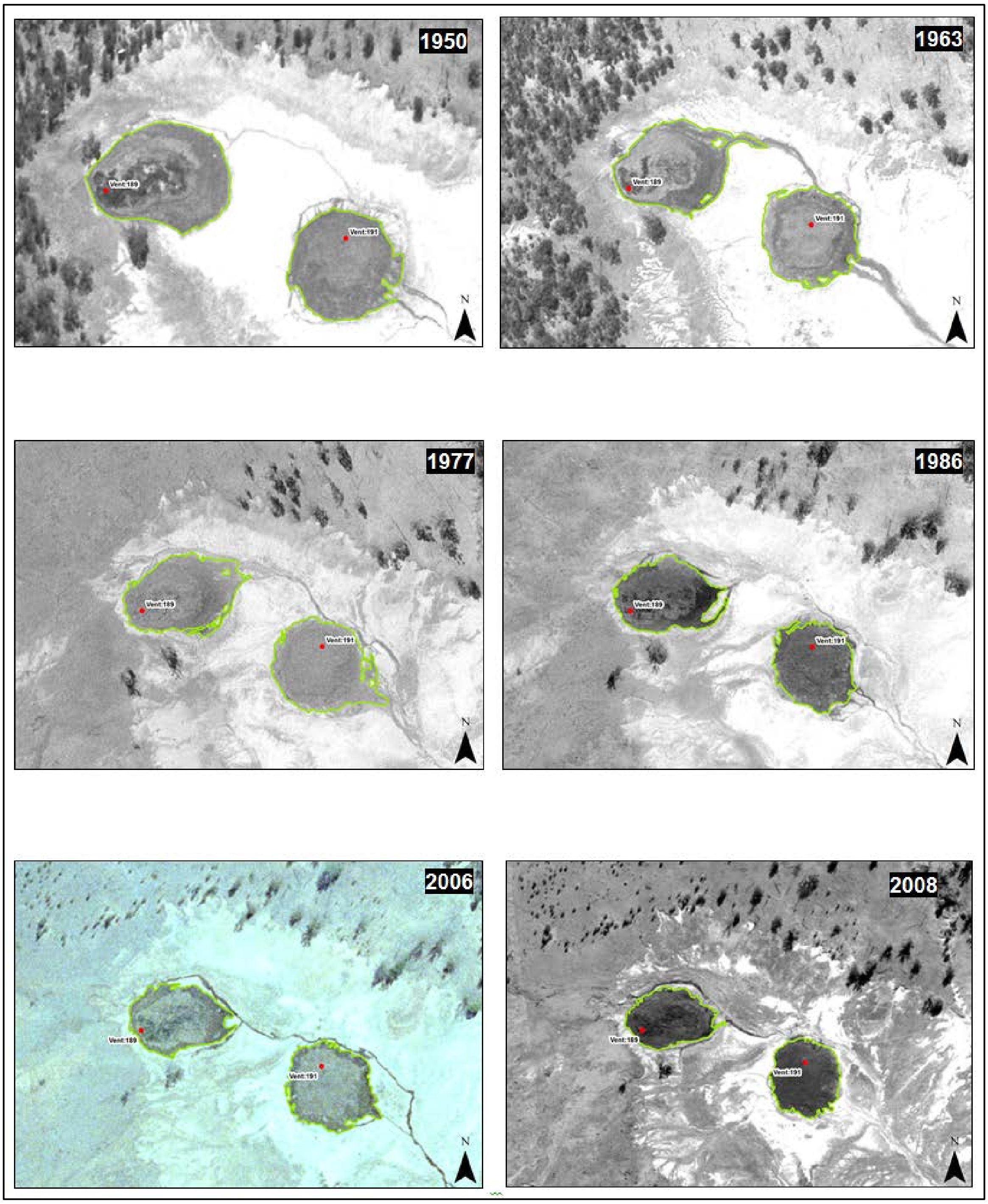


Figure 3-20 Land-use changes and wetland area extent, 1950–2008 (Scott's Creek)

Longer-term changes in spring wetland areas are often expressed in the adjacent soil and vegetation. Tree mortality and generations of emergent saplings can reflect the phases of increasing and decreasing wetland saturation. In Figure 3-21, the 1950 image shows variability in woody vegetation, indicating longer-term shifts in wetland hydrology. Large established trees, saplings and dead trees occur within the same wetland. By 1986, the wetlands had stopped flowing due to declining seasonal rainfall.

Figure 3-21 Evidence of long-term changes in wetlands

3.4.3 Conclusions

The ecology and processes that occur within wetlands are intrinsically rely on the spring water balance being maintained. Quantifying the dynamics within the water balance is difficult and requires site-specific data for each component of the water balance. The detailed work completed has identified several indirect observation datasets that can be used as surrogates to observing changes in the water balance of wetlands. These datasets will become components of long-term monitoring in the Surat CMA and will assist in further understanding the dynamics of the wetland systems.

The long-term and seasonal changes in wetland area are physically expressed differently for each wetland type. The main aspects of the wetland dynamics for each wetland type are described below:

Type 1a

Type 1a spring wetlands are sourced from regional and local groundwater systems. The sources of water can be identified through changes in the water chemistry of the wetland. The extent of the spring wetland area and the dominant vegetation type are influenced by seasonal and long-term changes in climate and groundwater levels. Seasonal changes in wetland discharge can be observed in the changing ratio of aquatic to terrestrial vegetation. Longer-term changes in the wetland area (due to changes in climate and groundwater pressure) can be interpreted from the presence of dead trees, sapling recruitment and soil features indicative of wetting and drying.

These spring wetlands are susceptible to changes in the regional and local groundwater systems. Changes in the regional groundwater systems will impact the wetland core, with changes in the local flow systems impacting the seasonal variability of the wetland area.

Type 1b

Type 1b spring wetlands are similar to Type 1a; however, they are also influenced by ephemeral stream-flow events.

Type 2

Type 2 spring wetlands are sourced from regional groundwater systems. Groundwater flow to the wetlands is low volume and semi-permanent. Due to their semi-permanence, there is limited wetland soil development and the wetlands are dominated by terrestrial species. Long-term and seasonal changes in the wetland area can be observed by measuring the total area of wetland discharge, as opposed to the area occupied by aquatic vegetation.

These spring wetlands are susceptible to small changes in the regional groundwater systems which can stop the wetland from flowing.

Type 3

Type 3 spring wetlands are sourced from regional and local groundwater systems. They are spatially confined to outcropping sandstone stretches of watercourses. Seasonal and longer-term changes to the spring wetland can be measured by changes in stream flow and, in some cases, the depth of the in-stream pool.

These spring wetlands are susceptible to changes in the regional and local groundwater systems.

Type 4a

Type 4a spring wetlands are sourced from local groundwater systems. Groundwater flow to the spring wetland creates free-flowing discharge which may not be permanent. Seasonal and longer-term changes in the spring wetland area can be observed by measuring the wetland and wetted area.

Type 4b

Type 4b spring wetlands are similar to Type 4a except that they are not located adjacent to riverine environments.

3.5 Monitoring techniques

During spring monitoring (Sections 2.1 and 2.2), the methods for monitoring evolved to accommodate new spring knowledge, available technologies, varied seasonal conditions and logistical challenges.

In parallel, a project to improve the selection of techniques for spring monitoring was completed (Section 2.6) which highlighted the importance of measuring components of the spring water balance in addition to stressors. The project identified attributes to be monitored and measuring techniques. The following sections summarise the key improvements in knowledge about monitoring techniques.

3.5.1 The spring water balance

Under natural conditions, the ecology and processes that occur within a spring intrinsically rely on the spring water balance being maintained. The water balance includes all major inflows to the spring and outflows from the spring, and provides a basis for the selection of attributes for monitoring. The major components of the spring water balance are shown in Figure 3-22.

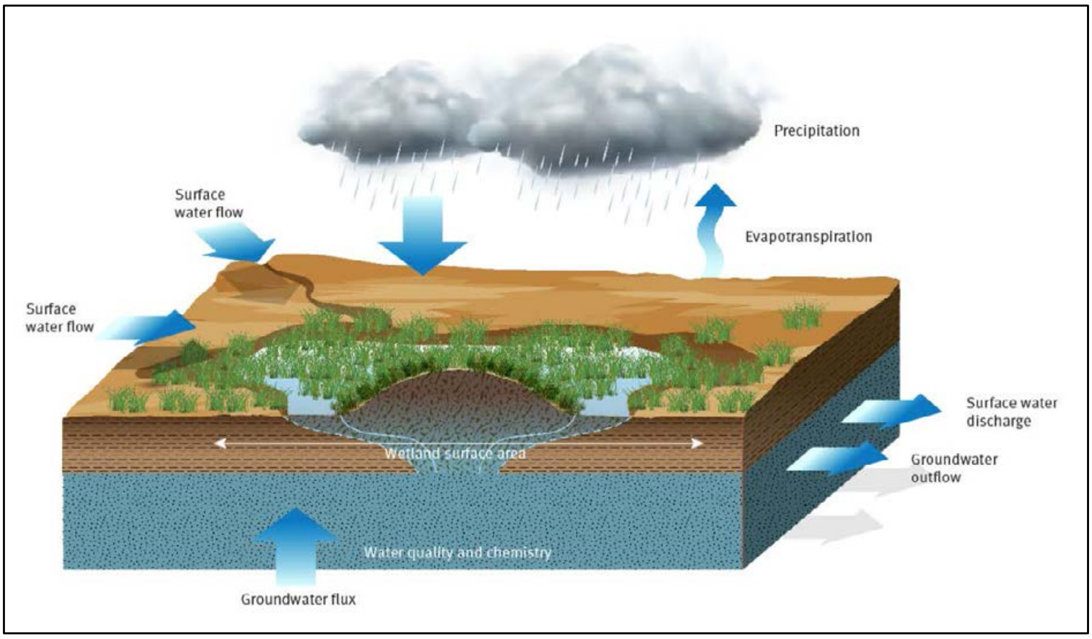


Figure 3-22 Spring water balance – a conceptual model

The spring water balance can also be expressed as follows:

$$(Pr + GWi + SWi) – (ET + GWo + SWo) = \Delta S \text{ (saturated and unsaturated)}$$

where Pr = precipitation, GWi = groundwater inflow, SWi = surface water inflow, ET = evapotranspiration, SWo = surface water outflow, GWo = groundwater outflow, ∆S: change in wetland storage (saturated and unsaturated storage).

Many of the spring water balance components can be difficult to measure and quantify. The project identified that a number of hydrological indicators can be used to monitor the water balance components at a spring. The indicators adopted for an individual spring will depend on the physical attributes of the spring. Table *3-3* gives the range of hydrological indicators and the associated water balance components.

Table 3-3 Components of the spring water balance and hydrological indicators

Water balance components		Hydrological indicators
Inflows	Surface water inflow (SWi)	Stream flow
		Water chemistry
	Groundwater inflow (GWi)	Groundwater pressure (regolith, shallow, deep)
		Wetland temperature
		Wetland area, biomass, vigour, extent, depth
		Wetland discharge (stream flow, evapotranspiration)
		Wetland chemistry
	Precipitation (Pr)	Rainfall
Outflows	Surface water outflow (SWo)	Stream flow
		Water chemistry
	Plant water use / ET	Evapotranspiration rate
	Groundwater outflow (GWo)	Groundwater pressure (regolith, shallow, deep)
Storage	Wetland storage (∆S)	Wetland area, biomass, vigour, extent, depth

Source: Adapted from SKM, 2013

From Table *3-3* it can be seen that four hydrogeological indicators can measure multiple components of the spring water balance: groundwater pressure, wetland area, discharge and water chemistry. These are the key hydrogeological indicators that have been incorporated into the UWIR 2016.

Non-hydrogeological indicators of changes in the water balance—referred to as 'ecological endpoints'—have also been identified. Ecological endpoints (Gross 2003) represent key physical, biological and chemical elements of the spring wetland which are primarily influenced by groundwater discharge and include indicators such as the extent of wetland vegetation that is dependent on groundwater discharge. A change in the wetland extent, for example, may be an indicator of a change in the groundwater regime.

The above hydrogeological indicators and ecological endpoints have been adopted in the specification of spring monitoring techniques in the UWIR 2016. More details about the monitoring approach are provided in Chapter 5.

3.5.2 Non-P&G influences on springs

Monitoring at springs to assess changes in the groundwater regime can be difficult due to the range of non-groundwater-related stressors influencing a spring's condition and ecological functioning. A range of stressors were observed during the implementation of the spring monitoring program (see Sections 2.1 and 2.2).

Table *3-4* provides a summary of the key stressors and potential implications for a spring's condition and for the water balance.

Table 3-4 Non-P&G influences on spring condition

Stressor	Implications
Groundwater extraction	Depending on the location, magnitude and duration of extraction, groundwater extraction from aquifers connected to springs may influence the volume of water flowing to, and discharging from, a spring. A reduction in discharge may result in: • a reduction in the wetland extent • a reduction in the occurrence of a spring tail (where applicable) • reduced depth of pooling (where applicable) • changes in the wetland water chemistry.
Cattle grazing and feral animals	Grazing within and adjacent to a spring may result in: • compaction of wetland soils, resulting in additional runoff • a reduction in wetland extent • disturbance resulting in weed colonisation • changes in the wetland water chemistry • sedimentation and erosion of the wetland area.
Excavation	Excavation of a spring may result in: • alteration of the wetland extent • changes in the wetland water chemistry.

Stressor	Implications
Local vegetation clearing	Clearing vegetation in areas adjacent to a spring may result in: • increased overland flow • increased sedimentation of the wetland area • increased erosion of the area surrounding the wetland • reduced wetland stability • reduced local aquifer recharge.
Regional vegetation clearing	Clearing vegetation in higher catchment areas may result in: • increased frequency of high flow and inundation events • increased sedimentation of the wetland area • increased erosion of the area surrounding the wetland • reduced wetland stability.

Non-groundwater-related influences on the components of the water balance are relevant to the assessment of risk associated with CSG water extraction. If a spring is heavily and permanently degraded from other stressors, then the consequence of any CSG water extraction on the water balance would be less than in the absence of the degradation. This factor is incorporated into the risk assessment methodology described in Chapter 4.

3.6 Identifying terrestrial groundwater-dependent ecosystems

As detailed in Section 2.7, there is an established methodology in Queensland for mapping groundwater-dependent ecosystems (GDEs). The Queensland Herbarium has applied the methodology in the Surat CMA (2012). Mapping has been completed for the eastern Murray–Darling Basin (2012) and the Dawson, Mackenzie and Comet river catchments in the northern Surat CMA. The combined outputs from these two processes are presented in Figure 3-23. Only GDEs associated with the GAB and identified with high or moderate confidence are shown.

The new information has been incorporated into the design of monitoring strategies presented in the UWIR 2016. In addition, the GDE dataset developed as part of this process will assist OGIA and industry in targeting future research and investment into GDEs.

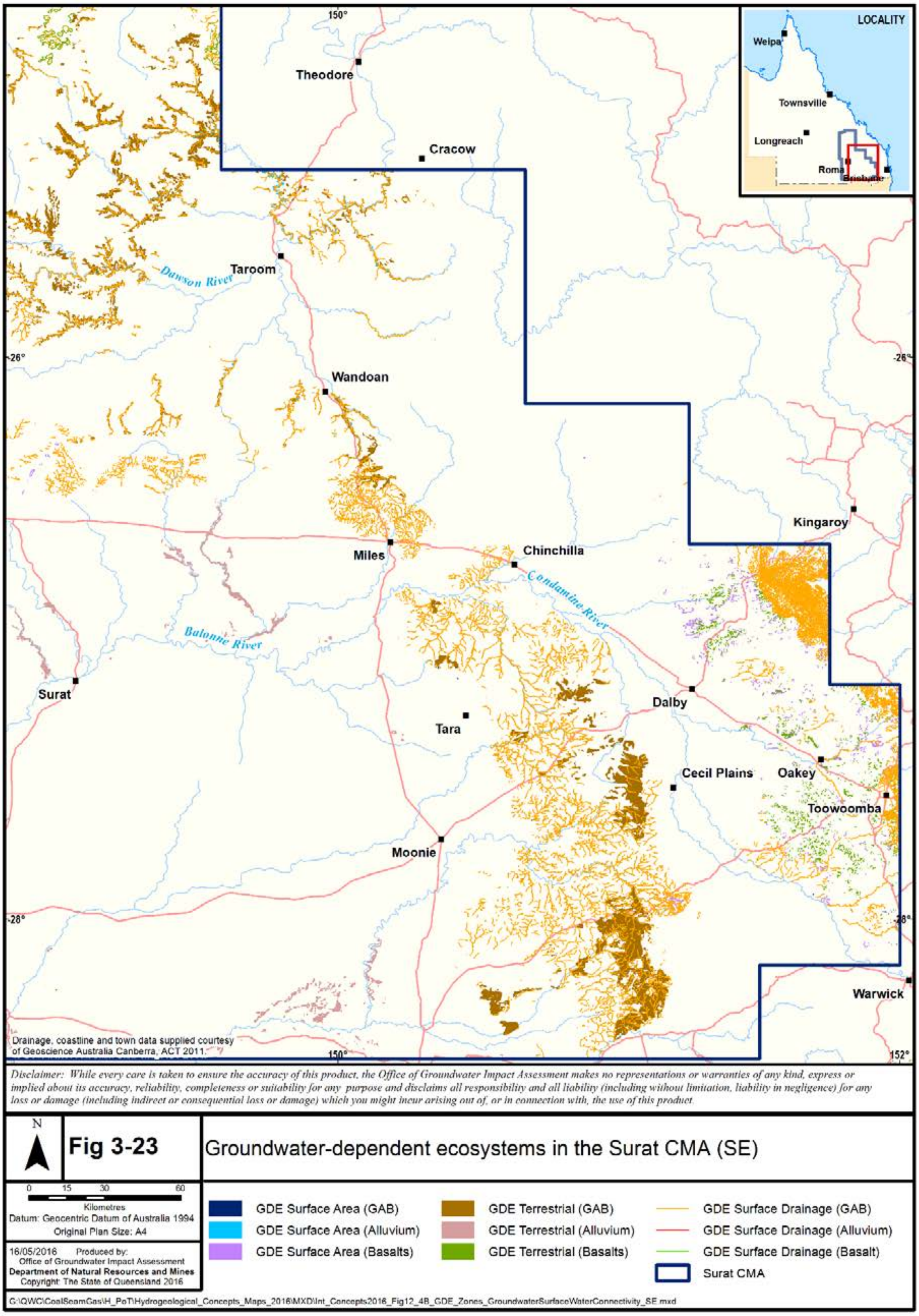


Figure 3-23 Groundwater-dependent ecosystems in the south-east of the Surat CMA

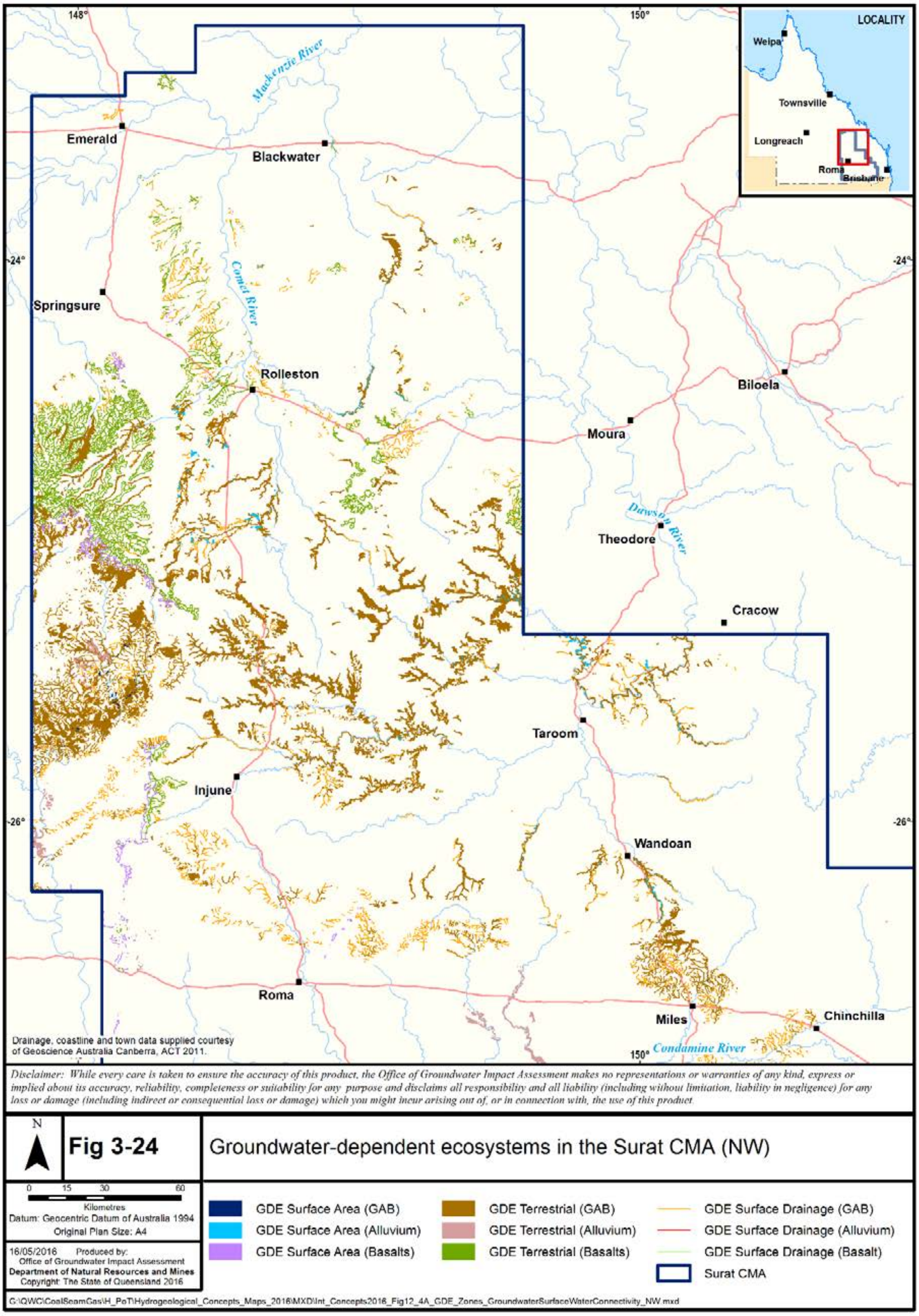


Figure 3-24 Groundwater-dependent ecosystems in the north-west of the Surat CMA

3.7 Updated spring dataset

New spring locations have been identified through research activities (Sections 2.1, 2.3 and 2.7). In places with limited access, such as Carnarvon Gorge, additional spring locations have been identified by the Queensland Parks and Wildlife Services and other non-P&G researchers. These spring locations have been considered in the development of the UWIR 2016. The following section provides an overview of the ecological and cultural values associated with the dataset.

3.7.1 Ecological values

Ecological value is described as the perceived importance of an ecosystem, which is underpinned by the living and/or non-living components and processes that characterise the ecosystem (AETG 2012).

A number of springs are known to provide unique ecological habitats and contain rare and threatened species. In addition to these known ecological assemblages, groundwater discharge from many springs sustains nearby waterholes, creeks and rivers, which is particularly important during extended periods of low surface-water flow. These sites are often referred to as baseflow springs or watercourse springs (see Section 3.2, Type 3 springs). Groundwater pressure provides the necessary groundwater flux to the surface water system to maintain ecosystem functions and processes.

The ecological values of the springs in the Surat CMA were first collated in 2012 by the Queensland Herbarium. This included determining the presence of **listed ecological communities** under the EPBC Act (the community of native species dependent on natural discharge of groundwater from the GAB) and their **conservation rankings**. This system has since been used in the legislative framework for the management of springs. The latest conservation significance and rankings informed the strategies provided in the UWIR 2016.

Springs and their associated species have been recognised under two statutes: the EPBC Act and the *Nature Conservation Act 1992*. These statutes recognise and list both individual species and ecological communities associated with the GAB springs. Table *3-5* shows the numbers of springs in the Surat CMA that are recognised for their conservation significance under these statutes.

Table 3-5 Ecological values associated with springs in the Surat CMA

Listed species / community	**Conservation status**		**Number of springs associated with the listing in the Surat CMA**
	EPBC Act	***Nature Conservation Act 1992***	**Spring complexes (Spring vents)**
The community of native species dependent on natural discharge of groundwater from the GAB	Endangered	-	14 (112)
Eriocaulon carsonii	Endangered	Endangered	5 (18)
Myriophyllum artesium	-	Endangered	1 (5)
Arthraxon hispidus	Vulnerable	Vulnerable	1 (18)
Phaius australis	Endangered	Endangered	2 (2)
Thelypteris confluens	-	Vulnerable	1 (2)
Livistona nitida	-	Near threatened	3 (7)

The importance of springs for conservation varies considerably. Some springs provide habitat for endemic species. Other springs have been heavily degraded and colonised by more common species that can tolerate the degraded habitat. Applying the **conservation ranking** to springs in the Surat CMA highlights the wetlands that are critically important for conserving species and places less importance where habitat has been degraded. This approach provides an opportunity to highlight ecological values not recognised under statute for their relative importance.

The ranking procedure is intentionally conservative: where a spring has not been surveyed for ecological assemblages, it is possible that the spring may contain an unknown organism, which may also be endemic. This circumstance is considered to be unlikely in heavily degraded habitats, but is possible in spring wetlands that contain undisturbed habitat without other known biological values.

The conservation rankings applied in the UWIR 2016 are listed in Table *3-6*.

Table 3-6 Conservation ranking used for GAB spring wetlands

Conservation ranking	**Description**
Category 1a	Contains at least one GAB endemic species not known from any other location beyond this spring complex.
Category 1b	Contains endemic species known from more than one spring complex; or has populations of threatened species listed under state or federal legislation that do not conform to Category 1a.
Category 2	Provides habitat for populations of plant and/or animal species not known from habitat other than spring wetlands within 250 km.
Category 3	Spring wetland vegetation without isolated populations (Category 2) with at least one native plant species that is not a widespread coloniser of disturbed areas.
Category 4a	Spring wetland vegetation comprised of exotic and/or only native species that are widespread colonisers of disturbed areas.
Category 4b	The original spring wetland is destroyed by impoundment or excavation. The probability of important biological values being identified in the future is very low.
Category 5	All springs inactive.

Source: Queensland Herbarium, 2015

The conservation ranking captures the ecological and conservation significance of the spring and is relevant to the assessment of risk associated with CSG water extraction. At those sites known to host endemic species, or where the wetland is in good physical condition, the consequence of a predicted impact on the spring is greater than for a spring that has been modified through excavation or impoundment (Category 4). This factor is incorporated into the risk assessment methodology described in Chapter 4.

3.7.2 Cultural heritage values

Springs are inherently associated with cultural heritage values. Unlike ecological values, cultural heritage values are not often documented, for a range of reasons. Over the past decade, a number of studies have sought to document cultural heritage values associated with springs and other water bodies in the Surat CMA.

These studies include:

- a report detailing the cultural heritage values of springs in the Queensland GAB, to support the development of the *Water Resource (Great Artesian Basin) Plan 2006* (CQCHM 2005)
- a cultural heritage assessment report prepared to inform the review of the *Water Resource (Great Artesian Basin) Plan 2006*
- a report detailing the cultural heritage values of the Maranoa, Balonne and Condamine catchments prepared for the federal government's Bioregional Assessment Programme
- a report on the impacts of groundwater extraction on Indigenous people's access and use of water resources in the central Condamine Alluvium.

These studies varied in terms of purpose and spatial extent; however, the descriptions of the cultural heritage values associated with springs generally align with the categories identified in the CQCHM report (2005) which identified the following four categories:

- Mythological associations: the linkage between a spring and its water, and mythological events and/or creator beings or other beings.
- Ritual and ceremonial associations: the role that a spring and its water played in the conduct of various ceremonies. This may also be linked to the mythological associations.
- Economic and subsistence associations: the role that a spring or group of springs, and the water available therefrom, played in the patterns of seasonal, economic and subsistence activities of particular Aboriginal groups.
- Major or personal historical events: this includes events such as births, massacres, and long-term camping and habitation.

In addition to the above reports, specific investigations, and environmental impact statements for CSG and other resource development activities have identified cultural heritage values as part of their legislative and project approval requirements. Where cultural heritage values are identified, they are recorded in the Aboriginal and Torres Strait Island Cultural Heritage Register ('the register').

Similar to the UWIR 2012, for the UWIR 2016 a search of the register was completed to identify registered cultural heritage sites that are in close proximity to springs. The presence of these sites may be linked to the presence of a permanent water source. The listings are summarised in Table *3-7*.

Table 3-7 Cultural values associated with springs in the Surat CMA

Type of record	**Number of records**		
	Within 500 m of springs	**Within 1.5 m of springs**	**Within 3 km of springs**
Artefact scatter	246	845	1242
Burial site	18	34	54
Contact site	0	1	2
Cultural site	0	5	14
Dwelling	0	1	4
Earthen arrangement	0	2	2
Engraving	11	34	62

Type of record	Number of records		
	Within 500 m of springs	Within 1.5 m of springs	Within 3 km of springs
Grinding groove	9	33	53
Hearth/Oven	4	8	11
Historical place	1	1	1
Isolated find	7	48	122
Landscape feature	7	19	30
Painting	62	178	322
Pathway	0	8	14
Quarry	11	17	23
Resource area	7	11	19
Scarred/Carved tree	26	73	118
Shell midden	11	22	23
Stone arrangement	0	2	4
Story place	0	4	4
Well	0	1	3
Total	**420**	**1347**	**2127**

The entries in the register do not comprise a comprehensive assessment of the cultural heritage values associated with springs, as the entries were made as a result of activities such as infrastructure development or mining, rather than as a result of a focused assessment of cultural heritage values associated with springs.

The register has been used to show the linkages between springs and cultural heritage. Given the incompleteness of the register, all springs are assumed to be associated with cultural heritage.

4 Risk assessment

4.1 Overview and purpose

A risk assessment of springs has been completed to ensure the strategies in the spring impact management strategy are commensurate with the risk to springs from predicted groundwater impacts.

The assessment is focused on the risk to springs from changes in groundwater levels due to CSG water extraction. The outcomes have been used in the UWIR 2016 to:

- prioritise the selection of sites for ongoing monitoring
- inform the selection of sites for which mitigation activities are required
- inform the location of targeted pressure monitoring and surface water monitoring.

The risk assessment includes both likelihood and consequence criteria. The likelihood of impact on a spring's source aquifer is assessed using the predicted impacts on the spring's source aquifer at the location of the spring. The consequences for the spring are evaluated using a combination of factors, such as the magnitude of pressure in the spring's source aquifer above ground and the known ecological values.

As detailed in previous sections, since 2012 there has been significant investment in monitoring and research at springs (Chapter 2). The new knowledge has been integrated into the risk assessment. In parallel with improvements in knowledge, several other risk assessments of springs in the GAB have been conducted, including:

- the initial assessment of risks and potential consequences to springs in the Surat CMA which informed the development of the UWIR 2012 (QWC 2012)
- an assessment of the impacts of future climate and groundwater development on springs, prepared as a component of the CSIRO GAB Water Resource Assessment (Miles et al. 2012)
- a risk assessment process for evaluating water-use impacts on GAB springs, prepared for the National Water Commission (Green et al. 2013).

These assessments are consistent with the international standard ISO 31000:2009, Risk Management – Principles and guidelines (Australian Standards 2009). These standards and assessments were reviewed during the risk assessment applied under the UWIR 2016.

4.2 Methodology

The framework and methodology adopted for the risk assessment is consistent with the standard. The level of risk is primarily a function of the likelihood and the consequence of an event occurring (Figure 4-1), and can be expressed as a score, a probability or a qualitative descriptor (Green et al. 2013). For this assessment, the level of risk is expressed as a score.

The standard provides guidance on identifying, analysing and evaluating risks and applying risk treatments within a risk framework. To ensure effective risk management, the standard recommends monitoring and periodic review of the framework to maintain validity. This is consistent with the approach applied to inform the UWIR.

All springs in the Surat CMA have been evaluated and scored for both likelihood and consequences of groundwater impacts from CSG activities. The outcomes from the risk assessment are provided in the UWIR 2016.

		Consequence		
		Lower	**Medium**	**Higher**
Likelihood	**Lower**	Very Low	Low	Medium
	Medium	Low	Medium	High
	Higher	Medium	High	Very High

Figure 4-1 Risk assessment matrix

For each spring, a risk level between ‘1’ (very low) and ‘5’ (very high) was assigned on the basis of:

- the likelihood of reductions in the flow of water at the spring as a result of CSG water extraction
- the consequences to the spring, which are a product of the sensitivity of the spring to changes in groundwater flow and the environmental values maintained at the spring.

The following sections detail the criteria that were applied in the assessment.

4.2.1 Assessing the likelihood of risk

The likelihood assessment is used to evaluate the chance of an event occurring. For the purposes of the UWIR, this is the likelihood of a spring being subject to a change in the groundwater regime because of CSG water extraction.

Under the UWIR 2012, the springs risk assessment applied a ‘multiple lines of evidence’ approach to assess the likelihood of impact at springs. Three equally weighted criteria were applied:

- the magnitude of the predicted impact on aquifers underlying a spring
- the horizontal proximity of the spring to a CSG production tenure
- the vertical proximity of the spring’s source aquifer to a target CSG and petroleum formation.

In 2012, only initial source aquifer assessments had been completed and some uncertainty remained. The multiple-criteria approach reflected this uncertainty; however, a key limitation of this approach was the double-accounting of the likelihood measure. For example, if an impact was predicted in the source aquifer, the risk was captured under both the first and third criteria.

The 2016 assessment has been designed to minimise double-accounting. An alternative approach to the assessment of likelihood has been applied which reflects the improvements in spring knowledge. There is increased confidence in the identification of the spring’s source aquifer and, consequently, the predictions of impact.

The predicted reduction in groundwater pressure in the springs’ source aquifers was assessed using the regional groundwater flow model, which provides details of the magnitude and timing of the predicted impact.

The likelihood score was based on the maximum modelled impact in the source aquifer at the location of the spring. If no impacts on groundwater pressure were predicted, then a score of ‘1’ was assigned. If the maximum modelled impact on groundwater pressure was greater than one metre, then a score of ‘5’ was assigned, as shown in Table *4-1*.

Table 4-1 Likelihood criteria (L1) – Impact on the spring’s source aquifer – scoring scheme

Likelihood	Description	Score (L1)
Highly likely	> 1 metre predicted drawdown in the spring’s source aquifer at the location of the spring at any time in the future.	5
Likely	0.5–1 metre predicted drawdown in the spring’s source aquifer at the location of the spring at any time in the future.	4
Possible	0.2–0.5 metres predicted drawdown in the spring’s source aquifer at the location of the spring at any time in the future.	3
Unlikely	0–0.2 metres predicted drawdown in the spring’s source aquifer at the location of the spring at any time in the future.	2
Rare	No predicted drawdown in the spring’s source aquifer at the location of the spring at any time in the future.	1

4.2.2 Assessing the consequence of risk

The consequence assessment relates to a measure of impact on the ecological functioning of the spring which may result if the predicted decrease in pressure was to occur. This includes the sensitivity of the spring to changes in groundwater flow and the ecological values of the spring.

Springs are subject to a range of groundwater-related and non-groundwater-related influences that may affect their condition and ecological functioning. Within the context of the UWIR 2016, only consequences resulting from changes in the groundwater flow regime are assessed.

The overarching principle is that changes in groundwater pressure will affect groundwater flow to springs, which is necessary to maintain the integrity of the associated ecosystems. Three equally weighted criteria have been applied to assess the consequence of a reduction in pressure in a spring’s source aquifer:

- Criterion C1 – the percentage change in available pressure above ground, which is used as a surrogate for the potential change in flow to the spring
- Criterion C2 – the spring typology (Section 3.2), which captures the nature of the groundwater flow system supporting the spring
- Criterion C3 – the conservation ranking (Section 3.7.1) for the spring, which is used as a measure of the ecological value of the spring.

These criteria bring together the range of attributes which influence the consequence of an impact on pressure and flow at the spring. Additional details on the criteria are provided in the following sections.

Criterion C1 – The percentage change in available pressure

Groundwater pressure above ground in the spring’s source aquifer at the location of a spring provides a hydrogeological measure of the magnitude and continuity of flow to the spring.

Where there is significant available pressure above ground, it is likely that a small change in pressure will reduce flow, but some continuity of discharge will be maintained. In this situation, the change may have comparatively minor consequences. In contrast, where a spring has minimal available pressure above ground, a small change in pressure may diminish flow and may lead to discontinuous discharge with potentially significant consequences. At these locations, the spring is considered more vulnerable to a change in pressure.

A percentage change in available pressure above ground has been calculated to provide a measure of relative change. The available pressure for each spring and the maximum predicted reduction in groundwater pressure are combined to calculate the change in available pressure. The scoring scheme for the criterion in presented in Table *4-2*.

Table 4-2 Consequence criterion (C1) – Change in available pressure above ground – scoring scheme

Description	**Score (C1)**
> 80% change	5
50%–80% change	4
20%–50% change	3
>0%–20% change	2
No change	1

Criterion C2 – Spring typology

The intent of the typology developed for springs in the Surat CMA (Section 3.2) is to describe the dominant processes that influence the occurrence of the springs. Key attributes are selected that describe how the springs occur within the landscape and how they are likely to respond to changes in the groundwater regime. In terms of assessing consequences, the typology captures the following elements:

- Landscape setting – whether the spring is located within a palustrine or riverine setting. This setting provides an indication of the interaction between the spring and surface water systems. In terms of consequences, a reduction in groundwater flow to a spring isolated from surface water systems and supported by regional groundwater discharge will have greater consequences compared to a spring supported by both surface water and groundwater.
- Groundwater flow system – the nature of the groundwater flow system supporting flow to the spring. This defines if the spring is fed by local, intermediate, regional or nested groundwater flow regimes and the permanency of groundwater discharge. In terms of consequences, springs reliant on regional groundwater flow systems are comparatively more susceptible to changes in pressure in the regional systems than those that are wholly or partially reliant on local or nested groundwater systems.

This criterion includes elements, not covered by the two other consequence criteria, that are important in considering the sensitivity of a spring to changes in groundwater pressure. The scoring scheme for this criterion is presented in Table *4-3*.

Table 4-3 Consequence criterion (C2) – Spring typology – scoring scheme

Spring type	Description	Score (C2)
	These springs are entirely reliant on regional groundwater flow. There is no additional groundwater or surface water flows supporting these springs.	5
Type 1a	Type 1a (e.g. Lucky Last) – Permanent fresh-to-brackish, **palustrine** wetlands with well-developed peat wetland soils and dense vegetation coverage, connected to **regional groundwater systems**.	
Type 1b	Type 1b (e.g. Scott's Creek) – **Permanent** fresh-to-brackish, **palustrine** wetlands with well-developed peat wetland soils and dense vegetation coverage, predominantly connected to **regional groundwater systems**.	
Type 2	Type 2 (e.g. Abyss) – Semi-permanent brackish, **palustrine** wetlands with minor wetland soils and minor vegetation cover, predominantly connected to **regional groundwater systems**.	
	These springs are reliant on regional groundwater flow but are also supported by local groundwater contributions or nearby surface water flows.	4
Type 1a	Type 1a– Permanent fresh-to-brackish, **palustrine** wetlands with well-developed peat wetland soils and dense vegetation coverage, connected to both **local and regional groundwater systems**.	
Type 1b	Type 1b (e.g. Scott's Creek (riverine)) – Permanent fresh-to-near-**riverine** wetlands with well-developed peat wetland soils and dense vegetation coverage, predominantly connected to local and regional groundwater systems. These wetlands are **periodically inundated**. Discharge supports **minor stream flows**.	
Type 3	Type 3 (e.g. 311) – **Permanent to semi-permanent** riverine wetlands, with minor wetland soil development and moderate vegetation cover, sourced from **regional groundwater systems** (GAB) with major discharge to surface water systems.	3
	These springs are reliant on regional groundwater flow but are also supported and significantly influenced by surface water flows. These springs are semi-permanent.	2
Type 2	Type 2 (e.g. Merlin) – Semi-permanent brackish, **palustrine** wetlands with minor wetland soils and minor vegetation cover, predominantly connected to **local groundwater systems**.	
Type 3	Type 3 (e.g. Barton) – **Permanent to semi-permanent** riverine wetlands, with minor wetland soil development and moderate vegetation cover, sourced from **local groundwater systems** (GAB) with minor discharge to surface water flows.	

Type 4a/b	These springs are disconnected from the regional groundwater flow systems. Type 4a/b (e.g. Wambo, Carnarvon vents) – Semi-permanent **palustrine** wetlands, with minor wetland soil development and moderate vegetation cover, predominantly connected to **local groundwater systems**.	1

Criterion C3 – Conservation ranking (known ecological values)

The conservation ranking highlights the spring wetlands that are critically important for conservation and downgrades the importance of springs with degraded habitat. The use of the conservation ranking provides an opportunity to highlight ecological values not recognised under statute for their relative importance.

For this criterion, the highest conservation ranking for any individual spring within each spring complex was applied to all springs in the complex. This is consistent with the approach applied in the UWIR 2012. This principle is applied regardless of the condition and associated values of the remaining springs in the complex. Where a spring has not been surveyed, a score of ‘5’ is applied as a precautionary approach. The scoring scheme for this criterion is presented in Table *4-4*.

Table 4-4 Consequence criterion (C3) – Conservation ranking – scoring scheme

Conservation ranking	Description	Score (C3)
Category 1a	Contains at least one GAB endemic species not known from any other location beyond this spring complex.	5
Category 1b	Contains endemic species known from more than one spring complex, or has populations of threatened species listed under state or federal legislation which do not conform to Category 1a.	
Unsurveyed	A spring which has not been surveyed.	
Category 2	Provides habitat for populations of plant and/or animal species not known from habitat other than spring wetlands within 250 km.	4
Category 3	Spring wetland vegetation without isolated populations (Category 2) with at least one native plant species that is not a widespread coloniser of disturbed areas.	3
Watercourse springs	Sections of streams, creeks and rivers that receive intermittent or permanent baseflow from groundwater.	
Category 4a	Spring wetland vegetation comprised of exotic and/or only native species that are widespread colonisers of disturbed areas.	2
Category 4b	The original spring wetland has been destroyed by impoundment or excavation. The probability of important biological values being identified in the future is very low.	1
Category 5	All springs are inactive.	0

Watercourse springs have not been explicitly evaluated for conservation significance; however, it is recognised that these springs are likely to provide baseflow to some streams and provide refugial waterholes for species during extended dry periods. For this reason, watercourse springs have been assigned a moderate conservation ranking.

4.2.3 Assessing overall risk

The purpose of the risk assessment is to prioritise sites for both mitigation and monitoring actions at individual springs. For each spring included in the assessment, a risk score for each criterion ranging from ‘1’ (lower) to ‘5’ (higher) was assigned.

Total scores for the likelihood and for the consequence of impact were then calculated as follows:

Likelihood of impact (max. 5) = L1

Consequence of impact (max. 15) = C1 + C2 + C3

The matrix presented in Figure 4-2 was then applied to assign overall risk to each spring.

			Consequence				
			0–3	**4–7**	**8–9**	**10–12**	**13–15**
			Very low	**Low**	**Moderate**	**High**	**Very high**
Likelihood	**1**	**Rare**	Very low (1)	Very low (1)	Low (2)	Low (2)	Low (2)
	2	**Unlikely**	Very low (1)	Low (2)	Moderate (3)	Moderate (3)	Moderate (3)
	3	**Possible**	Low (2)	Low (2)	Moderate (3)	High (4)	High (4)
	4	**Likely**	Low (2)	Moderate (3)	High (4)	High (4)	Very high (5)
	5	**Highly likely**	Low (2)	Moderate (3)	High (4)	Very high (5)	Very high (5)

Figure 4-2 Risk assessment matrix - scoring

The results from the risk assessment are presented in the UWIR 2016 and have informed the priorities for monitoring and mitigation and the selection of some pressure monitoring locations under the water monitoring strategy.

5 Principles for monitoring springs

The UWIR 2016 spring monitoring requirements incorporate the new knowledge developed since 2012. This improved understanding has refined the monitoring objective, the design of monitoring requirements and the assessment of the implications of changes in the groundwater regime.

5.1 Monitoring objectives

The objective of the spring monitoring is to understand the natural variations in components of the spring water balance (Section 3.5.1). Spring monitoring indicators are used to estimate fluxes and to determine relationships between components of the water balance, and the physical characteristics of the wetland.

Although the monitoring objective has not significantly changed from that of the UWIR 2012, the underlying principle of monitoring components of the water balance is an important modification. The objective more clearly links to the conceptual understanding of how springs function. This provides a more robust base for improving hydrogeological understanding and for evaluating a spring's likely response to any predicted impacts on the associated groundwater regime.

5.2 Selecting monitoring sites

Springs vary considerably in their ecological value and physical condition. For this reason, the springs risk assessment (Chapter 4) has been used to inform the selection of monitoring sites. This ensures the highest priority for monitoring is assigned to springs with higher conservation values and at locations with less physical modification. The sites selected for the spring monitoring program are listed in the UWIR 2016.

5.3 Spring monitoring indicators

This section provides additional detail on the five indicators identified for ongoing monitoring (Section 3.4). The indicators and measurement techniques estimate the flux components of the spring water balance. At some locations, more than one indicator or technique is required to provide a 'multiple lines of evidence' approach to monitoring the spring.

In addition to monitoring indicators, which are described below, photographs of the sites are required to facilitate assessment of non-groundwater-related influences on the data collected.

1. Groundwater pressure

   Groundwater pressure is the primary driver of flow to a spring and is a direct measure of change in the groundwater flow regime. Depending on the spring, pressure monitoring may be required in both the consolidated and the regolith aquifers.

   Measuring this indicator provides the following information:

   - available groundwater pressure and variability (due to seasonality or pumping)
   - a basis for estimating groundwater flux
   - a basis for linking and isolating changes in the wetland with other parameters (i.e. rainfall, evapotranspiration and wetland area).

   Measurement techniques specified in the UWIR 2016 include piezometers and push tubes.

2. Wetland area and discharge extent

   At springs where the flow of groundwater is relatively small, discharge can be almost exclusively consumed by evapotranspiration. At these sites, physically measuring discharge is not possible but measuring the wetland area and wetted extent can be a useful surrogate for estimating discharge.

   Measuring this indicator provides the following information:

   - a basis for estimating groundwater flux
   - a basis for linking and isolating changes in the wetland with other parameters (i.e. rainfall, groundwater pressure, anthropogenic influences and evapotranspiration).

   Measurement techniques vary from physical measurement of the extents to remote sensing. Techniques specified in the UWIR 2016 are measuring the area using a differential global positioning system, estimating the area from in the field, and estimating the area from aerial photographs.

3. Wetland discharge

   At some locations there is significant discharge from springs. Measuring the physical discharge can provide a direct measurement of the outflow component of a spring's water balance. This indicator is most commonly suitable for watercourse springs, or springs with significant volumes of discharge. This indicator is necessary for measuring groundwater flux through the spring.

4. Wetland chemistry

   The groundwater chemistry of springs varies considerably due to the nature of the groundwater sources mixing with local aquifers and, in some cases, surface water flows. Measuring groundwater chemistry is critical for spring characterisation; however, within individual springs, changes in the baseline groundwater chemistry may indicate changes in components of the wetland water balance. The UWIR 2016 requires that field parameters and major ions be measured at some locations.

5. Ecological endpoints

   Ecological endpoints are the key physical, biological and chemical elements of the springs that are primarily influenced by changes in the wetland water balance. For example, in addition to groundwater pressure, the extent of wetland vegetation dependent on groundwater discharge can be used as a surrogate for changes in groundwater discharge. Ecological endpoints may include:

   - wetland vegetation extent and wetted extent
   - the ratio of aquatic to terrestrial vegetation at the boundary of the wetland
   - the physical elements of the spring (mentioned above).

   Under the UWIR 2016, wetland extent and vegetation transects are required for monitoring.

5.3.1 Monitoring indicators and the spring typology

The landscape setting, geomorphology and flow regime significantly influence the applicability of the indicators described above. The spring typology (Section 3.2) provides a useful framework for specifying the applicability of monitoring indicators by spring type. A summary of the applicability of the monitoring indicators by spring type is provided in Table *5-1*.

Table 5-1 The applicability of monitoring indicators by spring type

Spring type	**Applicability of indicators of a change in the groundwater regime**				
	Groundwater pressure	**Wet/wetland extent**	**Physical discharge**	**Wetland chemistry**	**Ecological endpoint**
Type 1a	✓ (consolidated and unconsolidated aquifer)	✓	✕	✓	Groundwater pressure Wetland and wet extent Ratio of aquatic to terrestrial vegetation at the boundary of the wetland
Type 1b	✓ (consolidated aquifer)	✓	✕	✕	Groundwater pressure Wetland and wet extent (site dependent)
Type 2	✓ (consolidated aquifer)	✓	✕	✕	Groundwater pressure Wet extent
Type 3	✓ (consolidated aquifer)	✕	✓	✓	Groundwater pressure Wetland chemistry Physical discharge
Type 4a	✓ (unconsolidated or perched aquifer)	✓	✕	✕	Groundwater pressure Wetland chemistry Physical discharge
Type 4b	✓ (consolidated or perched aquifer)	✕	✕	✕	Groundwater pressure

5.3.2 Linkages with the water monitoring strategy

Given the nature of regional groundwater systems, there can be a significant lag time between groundwater impacts due to CSG water extraction and influences on springs located some distance from the production areas. In addition, depending on the magnitude of the impacts, by the time a change at the spring is detected there is unlikely to be sufficient time for management intervention.

Therefore, in addition to monitoring at springs, the UWIR 2016 specifies groundwater monitoring locations for the specific purpose of evaluating impacts on springs.

Pressure monitoring is specified at the following sites:

- Between high risk springs and CSG production tenures. The purpose of these monitoring sites is to improve future groundwater model calibration which will lead to increased confidence in the predicted impacts on springs' source aquifers. These monitoring sites are specified in the water monitoring strategy.
- In the springs' source aquifers within the immediate vicinity of the springs. The purpose of these monitoring sites is to improve conceptual understanding of available pressure, natural variability and seasonal aquifer responses, which will increase the ability to evaluate the consequences of any impact predicted by the groundwater model. These pressure monitoring sites are specified in the spring impact management strategy.

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Glossary

Alluvium: Deposits of clay, silt, sand, gravel, or other particulate material that has been deposited by a stream or other body of running water in a streambed, on a flood plain, on a delta, or at the base of a mountain.

Aquifer: A saturated underground geological formation, or group of formations, that can store water and yield it to a bore or spring. A saturated formation that will not yield water in usable quantities is not considered an aquifer.

Aquitard: A geological formation that prevents significant flow of water because of its low permeability (due to, for example, clay layers or tight deposits of shale).

Basement (geological): Generally low permeability hard-rock strata of igneous or metamorphic origin which lie below sedimentary rocks or sedimentary basins. In the same way, the sediments or sedimentary rocks on top of the basement can be called a ‘cover’ or ‘sedimentary cover’.

Basin (geological): An area in which the rock strata dip from the margins toward a common centre; the site of accumulation of a large thickness of sediments.

Basin (groundwater or hydrogeological): A groundwater system made up of multiple aquifers; may be equivalent to a geological basin.

Confined aquifer: A saturated aquifer bounded between low permeability materials such as clay or dense rock.

Depressurisation: The extraction of groundwater by pumping to decrease pressure in the groundwater system or reduce groundwater head.

Drawdown (noun): The difference between the groundwater pressure before and after pumping or depressurisation.

Erosion: The wearing down or washing away of the soil and land surface by the action of water, wind, or ice.

Fault (geological): A break in a geological formation along which some measurable movement or displacement has occurred, typically due to tectonic movement and uplift of the earth's crust (see also ‘Fracture’).

Formation (geological): A sediment or rock, or group of sediments or rocks. Geologists often group rocks of similar types and ages into named formations; for example, the Hooray Sandstone of the Great Artesian Basin.

Fracture (geological): A minor break in a geological formation with no measurable movement or displacement (see also ‘Fault’).

Groundwater: Also known as underground water. Water found in the cracks, voids, pores or other spaces between particles of clay, silt, sand, gravel or rock within the saturated zone of a geological formation.

Groundwater flow model: A set of equations, which, subject to certain assumptions, quantify the physical processes active in a groundwater system. While a model cannot simulate the detailed reality of the groundwater system, its behaviour approximates that of the actual system and is used to simulate that behaviour.

Head (groundwater): Groundwater level or pressure.

Hydraulic gradient: The difference in water pressure or water level across one or more formations over a unit distance. The hydraulic gradient indicates which direction groundwater will flow, and how rapidly.

Lacustrine: Formed in lakes or ponds. Most of a lacustrine wetland area is open water.

Lithology: The physical characteristics of rock, with reference to qualities such as colour, composition and texture.

Outcrop (noun): A geological formation or rock strata exposed at the ground surface.

Palustrine: Palustrine areas are non-channel environments.

Permeable: Capable of transmitting water through porous rock, sediment or soil.

Permeability: A property of a soil, sediment or rock indicating how easily water will be transmitted through it under a hydraulic gradient.

Petroleum tenure holder: An entity that holds an authority to prospect and/or a petroleum lease under the *Petroleum and Gas (Production and Safety) Act 2004*.

Potentially affected spring: A spring where the water level in the underlying aquifer is predicted to fall by more than 0.2 metres at any time in the future.

Production area: The area from which petroleum and gas is planned to be produced.

Recharge: The process of water flowing into an aquifer.

Regolith: A layer of loose, heterogeneous material covering solid rock; largely a product of weathering.

Responsible tenure holder: The petroleum tenure holder identified as being responsible for specific activities, such as monitoring and mitigating the impact of water extraction on springs.

Riverine: Within a stream or river channel environment.

Sediment: Material suspended in water or deposited from suspension. The plural form, sediments, is applied to all kinds of deposits from the waters of streams, lakes and seas.

Sedimentary basin: A geological basin containing a sequence of mainly sedimentary rocks.

Spring complex: A group of spring vents located close to each other. The vents are located in a similar geology and are fed by the same aquifer. No adjacent pair of spring vents in the complex is more than 10 kilometres apart.

Spring vent: A single point in the landscape where groundwater is discharged at the surface. A spring vent can be mounded or flat and can also present as wetland vegetation, with no visible water at the location of the spring.

Unconfined aquifer: An aquifer with no overlying low permeability layers that restrict water movement into the aquifer. The water level in an unconfined aquifer is known as the watertable.

Unconsolidated aquifer: An aquifer comprised of material that has not been turned into rock, such as sand.

Watercourse spring: A section of a watercourse where groundwater enters the stream from an aquifer. Also referred to as a baseflow-fed watercourse.