Lake Eyre Basin Springs Assessment

Ecohydrological conceptual models of springs in the western Lake Eyre Basin, South Australia

DEWNR Technical report 2016/02

Government of South Australia
Department of Environment, Water and Natural Resources

Funding for these projects has been provided by the Australian Government through the Bioregional Assessment Programme.

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February 2016

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Foreword

The Department of Environment, Water and Natural Resources (DEWNR) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEWNR's strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

Sandy Pitcher
CHIEF EXECUTIVE
DEPARTMENT OF ENVIRONMENT, WATER AND NATURAL RESOURCES

Acknowledgements

The Lake Eyre Basin Springs Assessment (LEBSA) project received valuable guidance from the project Technical Reference Committee members made up of members from various offices, departments and groups and of diverse backgrounds, including the Department of Environment (DE), Bureau of Meteorology (BoM), Geoscience Australia (GA), Queensland Department of Science, Information Technology, Innovation, and the Arts (DSITIA), the SAAL NRM Board and the South Australian Department of Environment, Water and Natural Resources (DEWNR).

The LEBSA project has been delivered concurrently and in-conjunction with an equivalent project run by DSITIA, of which Keryn Oude-egberink (DSITIA LEBSA PM) has been instrumental in providing feedback to the TRC and SA LEBSA project, and guidance to the many DSITIA staff working on the project.

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Acronyms

AWMSGAB - Allocating Water and Maintaining Springs in the Great Artesian Basin (AWMSGAB) project under the NWC

BDBSA – Biological database of South Australia

BOM – Bureau of Meteorology

BTEX - Benzene, Toluene, Ethylbenzene, and Xylenes (chemicals that can be a by-product of unconventional gas production)

CSG – coal seam gas

DEWNR – the South Australian Department of Environment, Water and Natural Resources

dGPS – differential Global Positioning System

DO – dissolved oxygen

DSITIA – the Queensland Department of Science, Information, Technology and Innovation

EC – electrical conductivity

GAB – Great Artesian Basin

GABSI – Great Artesian Basin Sustainability Initiative

GDE – groundwater dependent ecosystem

IESC – Interim Expert Scientific Committee (on Coals Seam Gas and Large Coal Mining Development)

LEBRM – Lake Eyre Basin Rivers Monitoring project

LEBSA – Lake Eyre Basin Springs Assessment project

ORP– Oxidation Reduction Potential

PAE - Preliminary Assessment Extent

NWC – National Water Commission

SAAL – South Australian Arid Lands (Natural Resources Management region)

SAGEODATA – South Australian government dataset containing spatial and geochemical records.

SDE – South Australian government dataset containing all other spatially explicit data not housed by SAGEODATA, HYDSTRA, or BDBSA.

SEA – Social and Ecological Assessment (c. 1986)

UCG – underground coal gasification

Summary

This report is part of a series of studies forming part of the Lake Eyre Basin Springs Assessment (LEBSA) project. The LEBSA project is one of three water knowledge projects being undertaken by the South Australian Department of Environment, Water and Natural Resources (DEWNR) to inform the Bioregional Assessment Programme in the Lake Eyre Basin (LEB). A key aim of the LEBSA project was to improve data knowledge through field investigations to inform future decision making and management for the South Australian portion of the LEB and areas overlying the Arckaringa and Pedirka (coal) Basins (the LEBSA project area). Ultimately the LEBSA project outcomes will inform the storage of spring data, leading to consistent data capture and management across South Australia and Queensland.

An assessment was done of all relevant datasets containing Great Artesian Basin (GAB) springs information known to exist for the focus area. The scope of assessment was broad, including among other data general survey data and photo points, hydrological, birds, vegetation, fish, geological, and water chemistry, from private and public sources, from raw datasets to published papers and plans, and mostly generated through specific projects and / or a specific legislative requirement. The assessment also identified relevant datasets already digitised and located in corporate structures.

A gap analysis was conducted on the then current knowledge base, with the priority to address and fill gaps given first to springs in the vicinity of proposed coal developments, or that could potentially be impacted by coal developments (DEWNR, 2015). This was followed by springs that had yet to be mapped or had poor elevation data. Core attribute data was then collected for all spring complexes within the identified study area.

This report documents a field survey study conducted from July 2014 to January 2015, consisting of five individual field trips, each targeting the following spring complexes: Dalhousie, Billa Kalina, Mt Denison, Allandale, Peake Creek and Lake Cadibarrawirracanna. The surveys captured data in three broad categories; morphological, biodiversity and hydrogeological (including hydrochemical data analysed by an independent National Accredited Testing Association accredited laboratory). Captured data were then adopted into state government corporate data structures. While this study did not include for significant additional broadscale analysis of datasets, these types of analyses are now possible with the updated and aligned data capture and storage processes across state jurisdictions. The results from the field survey are summarised by Section 5 of this report.

The LEBSA project has further integrated the amassed South Australian springs knowledge into a series of conceptual models that describe the specific spring types identified for the western South Australian Lake Eyre Basin (SA LEB). Hydrogeological models are detailed in Keppel *et al.* (2015a) while ecohydrological models are presented in this report (Section 4). Keppel *et al.* (2015) define five hydrogeological conceptual models (1a through 4 below) for describing the variations of structural architecture responsible for spring formation within the study area, noting that further localised geomorphological, structural or hydrological factors that may influence spring formation are largely regarded as secondary influences (i.e. to be included only where significant and appropriate). In addition to the five models defined by Keppel *et al.* (2015a), the Dalhousie anticline model has been included (refer model 5 below) as previously described by Kreig (1989) and Wolaver *et al.* 2013. The hydrogeological conceptual models discussed within are:

- Conceptual model 1a Basin margin, structure (fracture zone)
- Conceptual model 1b Basin margin, structure (fault zone)
- Conceptual model 2 Basin margin, sediment thinning
- Conceptual model 3 Basin margin, structure / sediment thinning combination
- Conceptual model 4 Astrobleme
- Conceptual model 5 Dalhousie anticline

Eight spring types were identified to describe South Australian springs and diagrammatical conceptual models developed for each:

- Travertine mounds
- Astrobleme
- Sand mounds
- Flat depressions
- Abutment springs
- Thermal mounds
- Rocky seeps and terraces
- Diffuse discharge (scald).

The models summarise natural and human induced drivers and impacts, hydrogeological connectivity, chemistry and critical knowledge gaps in the context of coal mining and unconventional gas development, for each of the following types. The conceptual models of spring types, presented in Section 4, coupled with evidence base tables (Appendices B and C) and linked to supporting published literature (Appendix D), provide the most current understanding of GAB spring complexes in the South Australian LEB. The relationship between models and types is further explored in the evidence tables presented in Appendices B and C.

The field study provided a much needed expansion on the baseline of information held for spring complexes in the South Australian area of the Lake Eyre Basin. Baseline information was amassed in relation to morphological, biodiversity and hydrogeological characteristics of these springs and led to the development and refinement of the conceptual understanding of their function and of associated risk and vulnerabilities. Importantly, the LEBSA project has allowed SA and QLD to collect consistent spring attribute data using consistent data capture methods across state boundaries so that datasets will become more easily comparable across the broader LEB (DEWNR, 2015). The analysis of datasets at a regional level may permit further examination of cumulative impacts, and the development of appropriate, measured management approaches.

Future work on SA GAB springs should consider the following key points raised within the body of this report:

- The hydrogeological conceptual models for 1a (basin margin / fracture structures), 3 (basin margin / sediment thinning and structure combination) and 4 (astrobleme) identify springs with these hydrogeological characteristics are at greatest risk from groundwater pressure changes that would be anticipated from future coal development activities. This is related to the potential for groundwater connectivity between aquifers within the GAB, and those of the underlying Arckaringa Basin afforded by regional deformation structures, such as fracture and fault zones associated with the margins of the Arckaringa Basin.
- The travertine mound, abutment and rocky seep and terracing types are among the most at risk spring types from coal developments due to the extra risk of sulfation in response to groundwater pressure changes. Rapid changes in pH and conductivity have proven to be lethal for spring endemic flora and fauna in the past. Drying cycles are expected to be more common for springs in the zone of influence of prolonged groundwater drawdown (i.e. as potentially associated with any future mining development in the arid zone).
- Springs in the Toondina, Peake Creek and Mt Dutton complexes are the most vulnerable to developments in the Arckaringa Basin, due to their proximity to sizeable coal deposits and associated types and functionality.
- For potential future developments in the Pedirka Basin, a better understanding of the amount of water and temperature inputs that are derived from the Pedirka Basin at Dalhousie Springs is required.

Springs on the western margin of the Great Artesian Basin are currently impacted by low flows, high grazing pressure and high nutrient loads. Future assessment, monitoring and management needs to be inclusive of more than groundwater pressure impacts alone. A holistic management approach should be utilised that addresses the cumulative impacts of these pre-existing stressors as well as groundwater impacts. Tailored management plans should be developed for spring groups likely to be impacted by coal developments, to ensure the springs are properly managed and impacts eliminated or mitigated. These management plans need to be fit for purpose and inclusive of the management of all identified impacts to site (i.e. from tourism through to potential large scale groundwater extraction), and tailored to a level appropriate to the associate risks and vulnerabilities of that particular type.

1 Introduction

1.1 Independent Expert Scientific Committee and the Bioregional Assessment Programme

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (the IESC) is a statutory body under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) which provides scientific advice to Australian governments on the water-related impacts of coal seam gas and large coal mining development proposals.

Under the EPBC Act, the IESC has several legislative functions to:

- Provide scientific advice to the Commonwealth Environment Minister and relevant state ministers on the water-related impacts of proposed coal seam gas or large coal mining developments.
- Provide scientific advice to the Commonwealth Environment Minister on:
    - bioregional assessments being undertaken by the Australian Government, and
    - research priorities and projects commissioned by the Commonwealth Environment Minister.
- Publish and disseminate scientific information about the impacts of coal seam gas and large coal mining activities on water resources.

The Bioregional Assessment Programme is a transparent and accessible programme of baseline assessments that increase the available science for decision making associated on potential water-related impacts of coal seam gas and large coal mining developments. A bioregional assessment is a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential direct, indirect and cumulative impacts of coal seam gas and large coal mining development on water resources. This Programme draws on the best available scientific information and knowledge from many sources, including government, industry and regional communities, to produce bioregional assessments that are independent, scientifically robust, and relevant and meaningful at a regional scale.

For more information on bioregional assessments, visit <http://www.bioregionalassessments.gov.au

1.2 Lake Eyre Basin Springs Assessment project

This report documents one of a series of studies forming the Lake Eyre Basin Springs Assessment (LEBSA) project. The LEBSA project was one of three water knowledge projects undertaken by the South Australian Department of Water, Environment and Natural Resources (DEWNR) to inform the Bioregional Assessment Programme in the Lake Eyre Basin (LEB). The three projects were:

- Lake Eyre Basin Rivers Monitoring (LEBRM)
- Arckaringa Basin and Pedirka Basin Groundwater Assessment
- Lake Eyre Basin Springs Assessment (LEBSA)

The LEBSA project was delivered by DEWNR for the South Australian (SA) areas of the LEB, with a similar project being run in parallel by the Queensland Government Department of Science, Information Technology, Innovation and the Arts (DSITIA) for Queensland (QLD) areas of the LEB.

The primary aim of the LEBSA project was to ensure that advice provided by the IESC and decisions made by regulators about water-related impacts are informed by substantially improved science. The Groundwater Dependent Ecosystem (GDE) products that have been developed under the LEBSA project will be made available through state databases and the Bureau of Meteorology's National GDE Atlas. This information will ultimately support the IESC in its assessment of any future CSG and coal proposal.

The LEB presents unique challenges to assessing and managing the risks that may arise from CSG and coal mining developments. It is characterised by a high degree of hydro-climatic variability and unpredictability, with patterns of water availability occurring over annual and decadal scales. There are considerable knowledge gaps regarding the hydrology and ecology of surface water assets and their vulnerabilities during different phases of the hydro-climatic cycle. The LEBSA project addressed these knowledge gaps for priority areas providing valuable information to the IESC about the water-related resources and potential impacts and risks from CSG and coal mining activities.

The Lake Eyre Basin includes the Bioregional Assessment Programme sub-regions of the Galilee, Cooper, Pedirka and Arckaringa geological basins (see Figure 1-1). The LEBSA project captured essential water asset information on ground water dependent ecosystems (GDEs), including Great Artesian Basin (GAB) springs in Arckaringa, Pedirka, Galilee and Cooper Basins in aligned SA and QLD datasets. A suite of consistent springs and GDE conceptual models for the LEB were produced as part of the project. The SA and Qld datasets, maps, and conceptual models will be used to support the National GDE Atlas (with delivery via the Bioregional Assessment Information Platform).

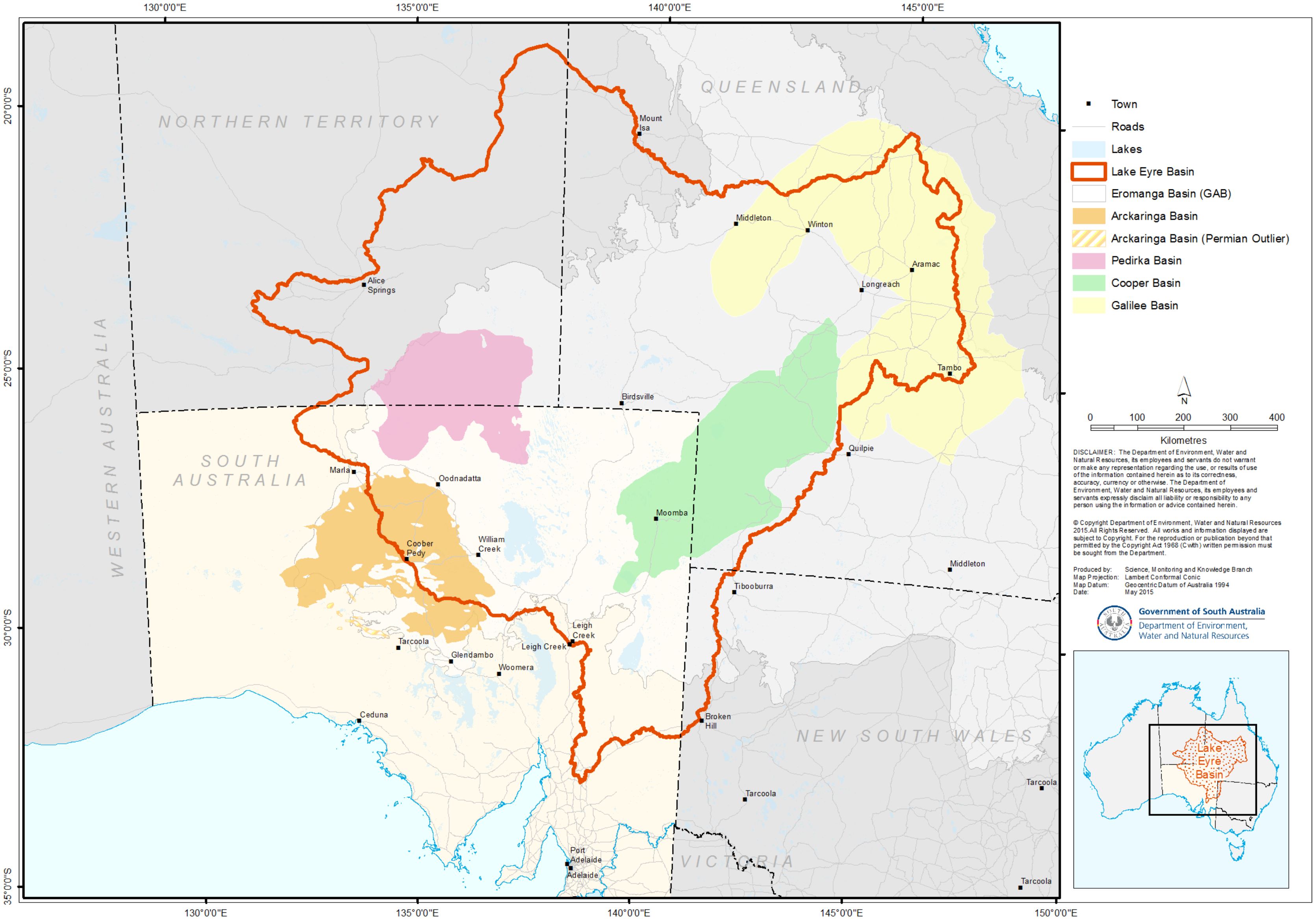


Figure 1-1 Lake Eyre Basin, the Great Artesian Basin and coal-bearing Permo-Carboniferous basins that occur within the vicinity

1.3 South Australian LEBSA project

The South Australian LEBSA project provided to the Australian Government consistent, standardised products on groundwater dependent ecosystems (GDE) assets (including springs) focussing on the GDES of the Pedirka and Arckaringa Preliminary Assessment Extents[1] (PAE, the project area). These products consist of aligned and attributed datasets, maps, and conceptual models for GDEs in the project area in SA.

Due to the low rainfall in the area very few permanent non-artesian springs exist within the LEBSA project area. The only known one is Edith Springs in the Davenport Ranges. This is a significant difference from the LEB in Queensland where there are numerous tertiary springs as well.

South Australia is quite advanced in the mapping of GAB springs within the LEB (Gotch 2013). However much of this information was spread across numerous databases or is held on individual laptops or hard drives. Prior to the LEBSA project consolidated knowledge of the location, ecology and hydrology of the GAB springs in the project area was limited. There was particularly poor understanding of the responses and potential impacts on springs from the water extraction activities of coal mining and coal seam gas extraction. These information gaps placed significant constraints on the capacity of governments to manage environmental risks associated with both the cumulative and individual impacts of CSG and coal mining developments. An initial step to addressing information gaps is the establishment of baseline survey data and the interpretation of such data for spring groups, ultimately to inform decision making regarding cumulative development pressures. This report outlines a study undertaken from a technical perspective to address identified knowledge gaps for the SA LEB and the Bioregional Assessment programme.

Other LEBSA studies included:

- A hydrogeological baseline characterisation of springs in the Neales River Catchment and Lake Cadibarrawirracanna regions, Lake Eyre Basin, South Australia (Keppel *et al.* 2015a)
- SA Springs Assessment Data Management (DEWNR 2015)
- Remote sensing – 'GAB wetland area mapping, flow estimation' (White *et al.* 2015) and 'GAB wetland diffuse discharge' (Turner *et al.* 2015)
- Mapping and conceptual models of shallow GDEs (Miles and Costelloe 2015)
- A hydrogeological and ecological characterisation of springs in the vicinity of Lake Blanche (Keppel et al. 2016).

In particular, this study is closely linked to the first two listed above.

1.4 Overview of key tasks

The broad aim of this study was to gather information to inform the development of the LEBSA technical data component, including field work to address the outcomes of the gap analysis. The tasks for this study were:

- Refinement of survey methodology
- Site selection (regional prioritisation based on potential coal development)
- Field survey program
- Information gap filling and alignment of datasets (across the GAB)
- Conceptual modelling of common spring types.

[1] A PAE is the geographic area associated with a Bioregional Assessment subregion in which potential water-related impacts of coal resource assessment on assets are assessed.

2 Preliminary data assessment: prioritisation, gap analysis and integration

A detailed description of the initial data analysis, prioritisation and gap analysis conducted for the LEBSA project is provided by (DEWNR 2015). The following provides a brief summary only, providing context to this technical report.

2.1 Data identification

An assessment was done of all relevant South Australian datasets containing GAB springs information and known to exist for the study area (see section 3.1) through consultation with technical experts in the field. The scope of the data assessed was broad and included:

- General survey data (e.g. location, size, number of vents, spring group complexes, elevations, flows, chemistry);
- Photo points
- Aerial imagery and
- Technical datasets (e.g. hydrological, flow data, avian, fish, social, flora, geological, cultural, invertebrates, amphipods, general spring vegetation and threatened flora species).

The data identified included private and public sources, ranging from raw datasets to published papers and plans, and was mostly generated through specific projects or a specific legislative requirement. The assessment also identified relevant datasets already stored in corporate structures.

The assessment identified:

- 23 separate datasets sitting outside of the corporate data structure that required integration (reports, research, raw datasets, access databases)
- 3 corporate databases already housing springs data including SA Geodata (spatial, geochemical, water chemistry, yield and quality), BDBSA (biological including flora and fauna, but excluding macroinvertebrates) and SDE (remaining spatially explicit data) and
- Remotely sensed imagery.

Separate datasets identified outside of corporate data structures were located where possible, and prioritised for integration.

2.2 Identification of core springs attributes and consistency of datasets

GAB Springs data from South Australia and Queensland was compared to identify gaps in each data set from the two jurisdictions. From this, the data needed to undertake an assessment on springs were identified in the event of a future coal development triggering an IESC approval process. This approach ensured that data collected on springs in South Australia would have the same attributes and be compatible with data collected in Queensland. Consistency in the units and the methods used to derive the data was also achieved through consultation with project stakeholders across borders, furthering the alignment of datasets in South Australia and Queensland. This important step has made it possible for data from both states to be collated into one National GAB Springs Database with agreed national attributes accommodating the multiple spatial scales (e.g. vent, complex) at which springs can be recorded, should this be desired by the Australian Government at a later date.

2.3 Gap analysis

The South Australian data gap analysis was based on project requirements, consideration of cross state integration (common attributes and methods employed) and the need to standardize collected datasets.

South Australia had strong datasets around the spatial locations and elevations of springs. It also had good hydrogeological information with data going back to the start of the 20th century. There was good floristic data but only limited fauna data. For the latter elements the level of detail depended on location. General morphology data on springs was lacking in South Australia.

2.4 Prioritisation for LEBSA field investigations

Priority to fill gaps was given first to springs in the vicinity of proposed coal developments or that could potentially be impacted by future coal developments due to proximity to known viable deposits (i.e. the Preliminary Assessment Extent or study area). This was followed by springs that had yet to be mapped or had poor elevation data. Core attribute data were collected for a number of springs within this priority area.

The broad prioritisation process to infill the gaps involved the following activities:

1. Identify the geographic locations of the gaps:
   - Identify focus area
   - Identify number of vents (e.g. 123 spring groups were identified)
   - Identify gaps in data for spring groups: Spatial data was available for 117 spring groups; 55 spring group vents had data for some attributes; and 5 spring group vents had no attribute data.
2. Identify the key attributes that should be collected:
   - Based on the SA /QLD aligned attribute list (DEWNR 2015).
3. Develop field program to fill in the gaps:
   - Vent locations
   - Which attributes required.

Given the broad extent of the LEB, locations of field investigations were chosen based on the following:

- knowledge gaps identified after initial data audit;
- geology of the basin, critical knowledge gaps and location of potential impact sites;
- The need for a thorough data set to be developed for the most 'at risk' sites where CSG or Coal mining exploration has or is expected to occur;
- Availability and priority of existing datasets for all sites within the PAE to be uploaded in corporate databases and
- Logistical considerations, including resources and time during which spring locations could be safely accessed.

3 Springs survey methodology

3.1 Site selection

The Preliminary Assessment Extent (PAE) developed for the Arckaringa investigations is 228,046 km²and contained most of the springs in the Lake Eyre Supergroup and all of the springs in the Dalhousie Supergroup. The zones of interest (the study area) is a subset of this larger region chosen to reflect the locations of potential coal developments and known barriers created by Basement outcrops such as the Davenport and Dennison Ranges (Figure 3-1), and the paucity of available data on the springs of interest. Springs outside this area were not investigated as part of this study but have been previously investigated as part of the NWC funded Allocating Water and Maintaining Springs of the Great Artesian Basin project, other investigations within the South Australian Arid Lands (SAAL) Natural Resources Management (NRM) region and a subsequent LEBSA study (Keppel *et al.* 2016).

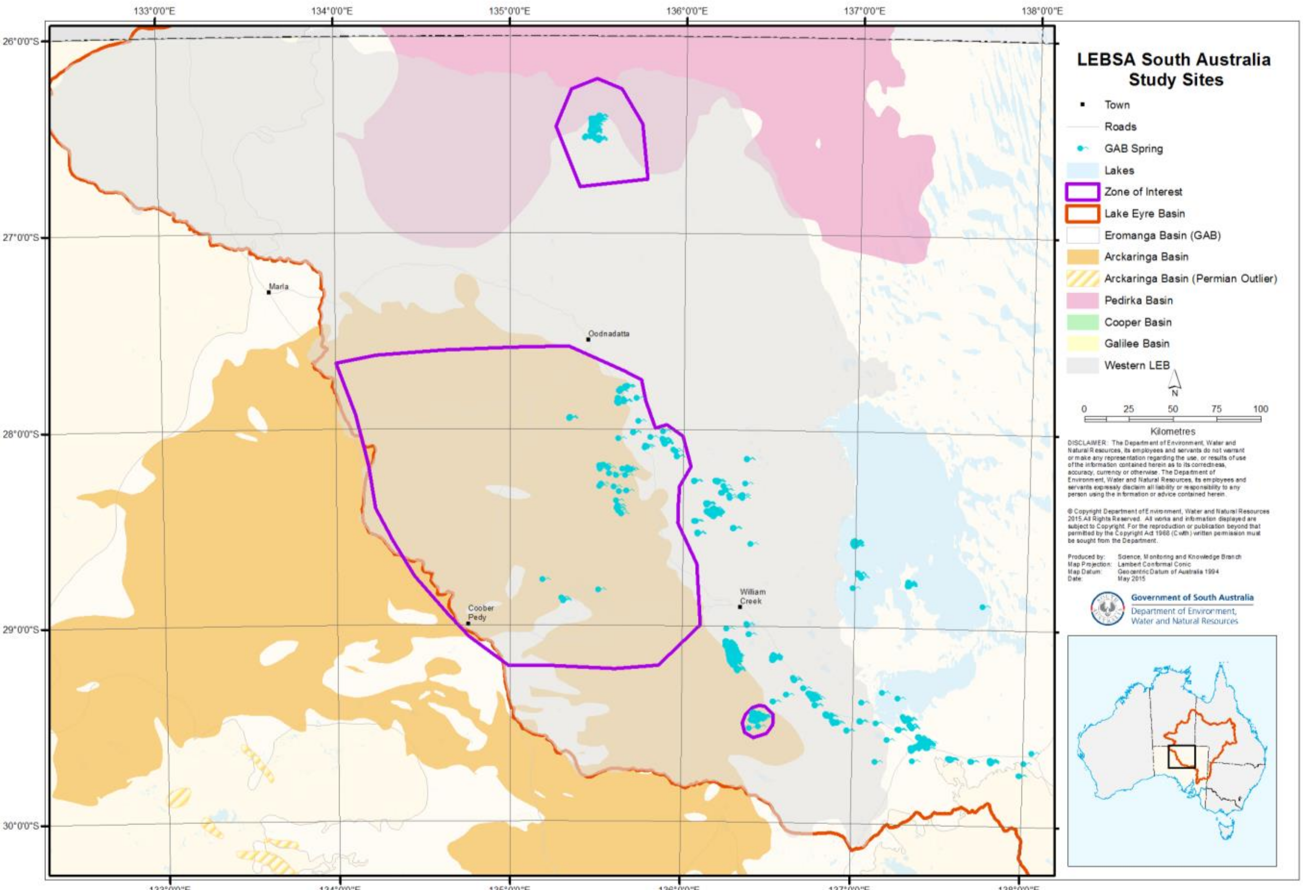


Figure 3-1: Map of study sites (springs in the targeted zones of interest)

3.2 Regional setting

The study area is located in northern South Australia and extends from Dalhousie Springs in the north to Billa Kalina Springs in the south-east. It covers 30,567 km^2 and includes springs on Allandale, Nilpinna, The Peake, Anna Creek and Billa Kalina stations as well as springs at Dalhousie in Witjira National Park. Most of these sites lie to the west and north of the Davenport and Denison Ranges. The exception to this is the Billa Kalina Spring Group to the south-east which was included due to its proximity the Arckaringa Basin and the speculation that there may be some groundwater linkage between this basin and the overlying GAB. There are 7 Spring Complexes containing 61 Spring Groups in this survey (Gotch, 2013). They include Dalhousie, Mt Dutton, Toondina, Peake Creek, Mt Denison, Lake Cadibarrawirracanna and Billa Kalina Springs. None of the spring groups represented here are thought to directly discharge water from the Arckaringa Basin. All are thought to be supported by water and pressure from the overlying Great Artesian Basin (Gotch, 2013). A few exceptions exist; water from the Permian Pedirka Basin supporting some of the discharge at Dalhousie Springs, and the possibility of some Mt Toondina Formation (Arckaringa Basin) water discharging at Toondina Springs.

The climate in this area is generally arid, with weather patterns dominated by persistent high pressure systems. Rainfall in the area is infrequent and unpredictable but is largely driven by weak winter cold fronts from the south and west and by sporadic monsoonal lows from the north-west and/or north-east. Rainfall averages for the region are around 150 mm/y but can vary significantly from year to year (BOM, 2015). This area is mainly in the Stony Plains Bioregion but also includes areas of dune fields and saline adapted species in low lying areas (DEH, 2009).

The Davenport and Denison Ranges (also referred to as the (Peake and Dennison inlier)) form the eastern boundary to the study area. They are an outcrop of Proterozoic and Archaean basement sequences that are generally interpreted to be the northern extension of the Adelaide Geosyncline (Preiss, 1987). These inliers were enveloped by the GAB and have several spring groups forming near them most likely in response to stresses created by their presence on the overlying confining layers. The western boundary is delimited by the artesian pressure contour for the GAB (Gotch, 2013). The northern boundary includes Dalhousie Springs. Impacts on this spring group could occur due to coal developments in either the Arckaringa or Pedirka Basins.

Preliminary data analysis, as discussed in Sections 2 and 3 of the LEBSA data management report, identified the differences and deficiencies of the South Australian and Queensland datasets (DEWNR, 2015). The field program was developed to address these differences and gaps. Three data themes were developed, morphology, biodiversity and hydrogeology. Individual vents were surveyed at each spring group. For morphological and biological assessments each vent was surveyed. For the hydrogeological assessment representative samples were taken at each spring group within the study area except for Dalhousie and Allandale. Significant hydrogeological investigations had been carried out at each of these sites during the NWC Allocating Water and Maintaining Springs of the GAB (AWMSGAB) project. Equally the biological investigations for Dalhousie Springs were constrained to fish only as detailed flora and macroinvertebrate work had already been undertaken at this site. Significant work was also conducted in the areas of data capture and storage, with the SA and QLD datasets being deliberately aligned and with agreement gained on data capture methods across state boundaries so that datasets will become more easily comparable across the broader LEB (DEWNR, 2015). It is hoped that the alignment of datasets may encourage future regional level examination of cumulative impacts, and the development of appropriate, measured management approaches.

3.3 Field program

The field program was conducted from July 2014 to January 2015 and consisted of five field trips each of two weeks average duration (Table 3.1). The field team is listed in Appendix A.

Table 3.1 Summary of LEBSA field trips

Date	Locations (complexes)	Field trip type
July 2014	Dalhousie Springs	Fish and water quality (pH, Temp, EC and DO) survey
August 2014	Billa Kalina/ Lake Cadibarrawirracanna	Elevation, morphology, water quality (pH, Temp, EC), and species richness survey
October 2014	Peake Creek, Mt Denison	Elevation, morphology, water quality (pH, Temp, EC), and species richness survey
November 2014	Allandale, Peake Creek, Lake Cadibarrawirracanna, Mt Denison	Elevation, morphology, water quality (detailed), species richness, geophysics, Aboriginal history
January 2014	Dalhousie Springs	Morphology, Aboriginal history

3.4 Study area climate

Weather stations are separated by several hundred kilometres in this region and representative data for the areas in between stations may not exist. The weather stations used to provide climatic data for the field trip period are Coober Pedy Airport, Oodnadatta Airport, Marree Aerodrome and Roxby Downs (Olympic Dam) Aerodrome (BOM, 2015). The weather during the field campaign was mostly dry and cool in the winter months and hot during the summer months. A large localised rainstorm resulted in the abandonment of the Billa Kalina survey in August 2014 and the delay of the subsequent trips by a month. Total monthly rainfall at Billa Kalina Springs is unavailable, however William Creek received over 40 mm and Stuart Creek Station recorded over 60 mm at several of their gauges (D. Khan (ODT Australis), pers. comm., 2014, 1 September). Marree and Roxby Downs also recorded reasonable rainfall at this time (Figure 3-2).

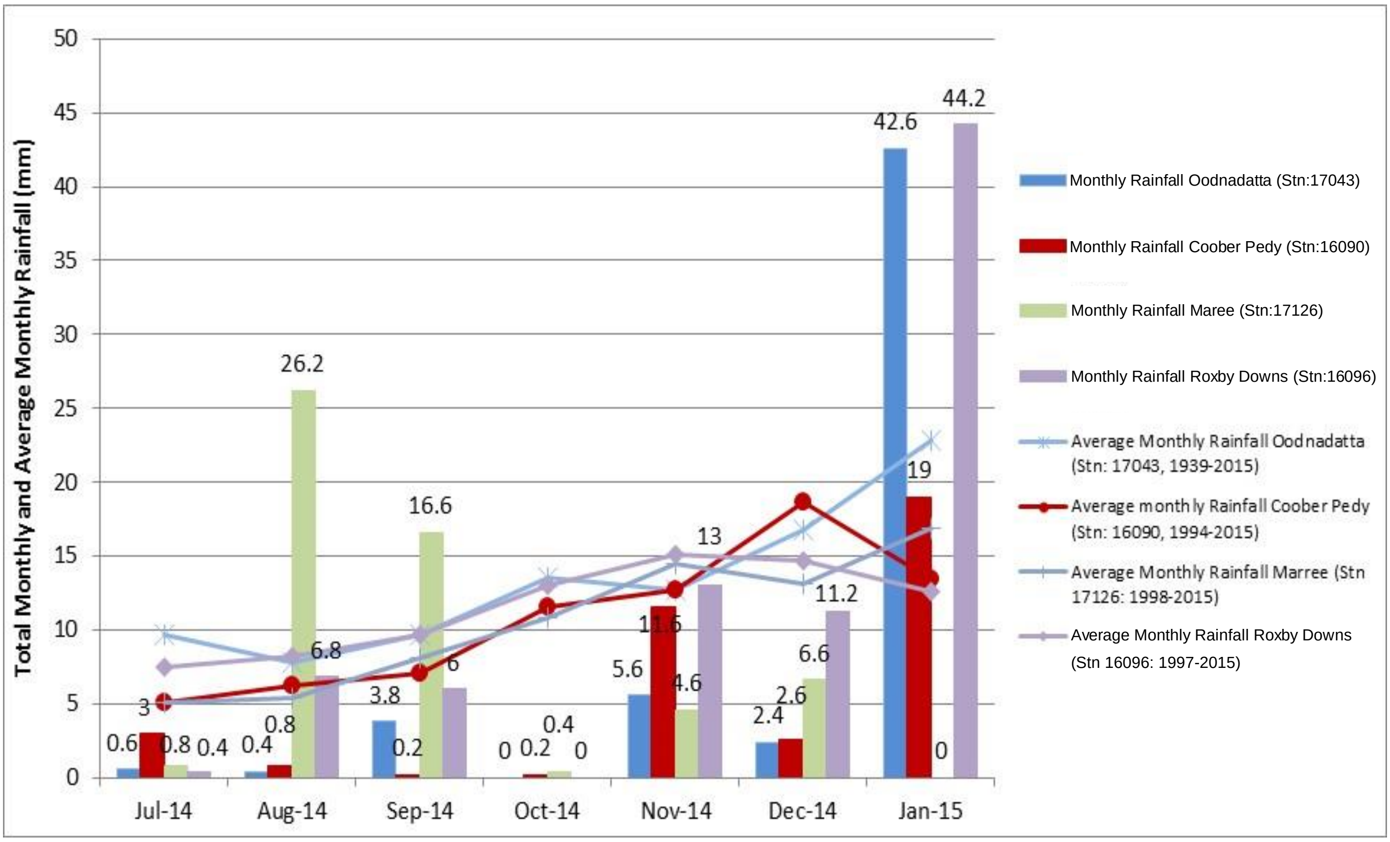


Figure 3-2 Rainfall data during the field campaign (presented as monthly totals with monthly averages per station)

3.5 Field data collection and methods

Data collected can be broadly defined into three categories: morphological, biodiversity and hydrogeological. Data sheet templates are provided for reference in Appendix A.

Spring vent locations and elevations were recorded using a Trimble® R8 real time kinematic differential GPS (RTK dGPS), as per the methods described in Gotch (2013). The location of other site specific data were recorded using a handheld Garmin® E-Trex GPS. Photos were taken with various hand held digital cameras.

3.5.1 Morphological

This consisted of basic descriptive data about the location, size, shape and type of springs surveyed. It also included qualitative measures of disturbance such as grazing, pugging, excavation and sulfation.

The geomorphological setting was described, including overall land form and land system, topography, connectivity to surface water drainage systems, and context in the broader landscape. Individual springs were described by recording mound length, width and height (where relevant), ascribed a type based on the identification of key characterising features collected in a detailed site description, and examined for surface expression of water (Fatchen and Fatchen, 1993). The presence of sulfur crystals were noted together with a description of the size and location of the sulfation zone. Disturbance factors were described including grazing, pugging (Fatchen and Fatchen, 1993), and excavation (e.g. bore casings, fencing and tracks) (Gotch, 2013). Photographs were catalogued for each spring complex visited.

3.5.2 Biodiversity

The presence of spring flora and fauna were recorded at each spring vent and grouped up to the spring complex level. Flora species were distinguished as native or introduced, and estimates taken of cover and abundance (Fatchen and Fatchen, 1993). Fauna species presence or inferred presence (e.g. through the observation of indirect evidence such as tracks, scats and other traces), was recorded for all native and introduced species. Species presence was measured by taking continuous observations down the transect (of various lengths, depending on spring size) from the vent to the spring tail. Fauna groups recorded included birds, fish, crustaceans, molluscs, arachnids, insects and microbial mats (stromatolites and thrombolites).

Voucher specimens of several faunal groups likely to be short-range endemic species, including hydrobiid snails, isopods, amphipods and ostracods, were collected for DNA analysis at a later date (beyond the scope of this study). Voucher specimens of any other unusual flora or fauna species observed were also collected.

Species were classified for their significance to the system; i.e. significant species being those that are either endemic spring biota or locally rare species or species that are disjunct from their normal habitat. Examples of these relicts include Cutting Grass (*Gahnia trifida*) and Bare Twig-rush (*Baumea juncea*). These are common in coastal areas or in southern swamp and wetlands. Typically they don't exist in the arid zone except on springs. Genetic studies of several of these species have shown very little gene flow between the different spring populations or with more distant populations (Clarke *et al.* 2013). Essentially they are isolated species and dependent on the long term stability of the springs for their local survival.

3.5.3 Hydrogeological

The hydrogeological parameters collected varied across each survey. A detailed hydrogeological assessment including basic parameters, hydro chemistry and geophysics was undertaken at four key sites only (Cootanoorina, Old Nilpinna, Lake Blanche and Reedy Springs). Basic parameters (pH, electrical conductivity (EC) and temperature (℃) as well as dissolved oxygen (DO) at Dalhousie) were collected at all spring vents with sufficient water present to sample them. Basic parameters (alkalinity, oxidation-reduction potential (ORP)) and hydrochemistry data (cations and anions, trace elements, water quality and total carbon, stable isotopes, strontium 87/86) were collected at representative springs for each spring group in the study area. Whilst nutrients are identified as important water chemistry variables in the GAB spring model (Table 4.1), collection of accurate nutrient data in the field was not feasible.

A detailed report on the hydrogeological assessment methods can be found in Keppel *et al.* (2015a).

3.6 Post field data processing

The dGPS survey data were post-processed using a control point network created by Gotch (2013) which is based from static observations derived from zero-order horizontal and third-order vertical survey benchmarks supplied by the Office of the Surveyor General of South Australia.

Data collected during the field program were entered into various corporate databases (predominantly SA Geodata for hydrological, hydrochemical and geomorphological data and photographs and BDBSA for biological data). The data will be made available to the Australian and Queensland Governments.

Detailed data analysis was not part of the scope of this project. However, the new data has enabled the development and or refinement of detailed conceptual hydrogeological and ecohydrological models (refer Section 4) and supporting evidence base tables (refer Appendices B and C) describing each spring or GDE type commonly associated with spring complexes in the South Australian GAB.

4 Results: spring conceptualisations

Technical expert knowledge, together with the outcomes of the LEBSA field survey program, have informed the development of a series of conceptual models that describe each of the eight spring types identified for the South Australian section of the LEB. The following chapter presents the outcomes of the conceptual modelling phase of this project.

4.1 Hydrogeological conceptual models

The report "*A hydrogeological baseline characterisation of springs in the Neales River Catchment and Lake Cadibarrawirracanna regions, Lake Eyre Basin, South Australia*" by Keppel *et al.* (2015a) details the hydrogeological investigations of the Peake Creek, Lake Cadibarrawirracanna, Mt Toondina and Mt Denison spring complexes and is considered representative of the study area. This report identifies several common features that apply to all of the hydrogeological conceptual models.

All springs surveyed are artesian and primarily fed by the GAB.

Using the definitions in the National Recovery Plan (Fensham *et al.*, 2007) all springs in the South Australian section of the LEB are classified as discharge springs, characterised by:

- A thin / weakened confining bed or aquifer abutting impervious basement rock
- Spring flows that are not dependent on recent rainfall, but that may fluctuate in size with seasonal changes, as such. flows are generally permanent and water levels relatively constant
- Waters that have been subject to long aquifer residence times, usually alkaline and with high levels of dissolved solids
- Springs complexes that are located in areas relatively remote from recharge zones, and general in isolation from other spring complexes (leading to a concentration of specialised endemic species).

Quaternary to recent stream erosion across many areas has led to greater exposure of GAB aquifers and the creation of topographical lows that are favourable for spring formation. Furthermore, reduction of overburden has increased the likelihood of elevated groundwater pressure relative to the land surface.

Within the study area the majority of springs are located near the margin of the Arckaringa Basin, where either large changes in basement architecture occur or where hydrostratigraphic units thin and ultimately pinch out. This suggests that the underlying basement architecture is the major control on spring formation. Additionally, the eastern extent of the basin margin in many instances is coincident with the margin of GAB artesian groundwater. Keppel *et al*. (2015a) refers to the basinal areas surrounding the Peake and Denison and Mount Woods inliers as basin margins despite their location within the GAB boundary. With respect to the underlying Arckaringa Basin, the Peake and Denison and Mount Woods inliers represent important structural features; the Peake and Denison inlier represents the eastern margin of the Arckaringa Basin whereas both inliers represent important piercement structures that either disrupt or thin overlying sediment. In both cases, the hydrogeology of overlying sediments is greatly influenced by their presence, particularly with respect to the location of confining units and the extent of artesian groundwater. For this reason they act similarly to basin margins and are thus described accordingly.

Keppel *et al*. (2015a) defines five conceptual models as appropriate for describing spring formation within the study area (refer models 1a through 4 below). At some springs there are further localised geomorphological, structural or hydrological factors that can influence spring formation but these are regarded as secondary influences and only included where appropriate.

The sixth model, the Dalhousie anticline (refer model 5 below), was originally proposed by Kreig (1989) and further developed by Wolaver *et al.* (2013) as part of the NWC AWMSGAB project. This original model suggests that the Dalhousie Springs were originally formed through a low broad dome or upwarp of rock formations, with the crest of the dome breached or removed by erosion. Further erosion of the strata over time has then exposed the deepest layers of the GAB leaving the aquifer very close to the ground surface in the vicinity of the anticlinal axis (Kreig, 1989). An alternative to model 5 was suggested by Karlstrom *et al.* (2013), which interpreted the Dalhousie Anticline to be oppositely facing monoclines over a horst structure resulting from an inversion of a Proterozoic graben (model 6 below). To confirm which of the two models (5 or 6) is correct would require a more detailed seismic and matching interpretation study to be undertaken. Under a future development scenario, both models (5 and 6) have equal levels of risk for Dalhousie springs with respect to shallower groundwater (e.g.

GAB), but with respect to impacts on deeper groundwater (e.g. Pedirka Basin and fracture rock/crystalline basement aquifers), the springs are likely to be at greater risk if model 6 applies compared with model 5 (M. Keppel, Senior Hydrogeologist, DEWNR, pers. com. 8/10/15). For the purposes of this report, only the Dalhousie anticline model (5) is discussed further.

The LEBSA spring conceptual model set therefore includes:

- **Conceptual model 1a** Basin margin, structure (fracture zone)
- **Conceptual model 1b** Basin margin, structure (fault zone)
- **Conceptual model 2** Basin margin / sediment thinning and outcropping aquifer unit
- **Conceptual model 3** Basin margin / sediment thinning and structure combination
- **Conceptual model 4** Astrobleme
- **Conceptual model 5** Dalhousie anticline
- **Conceptual model 6** Dalhousie oppositely facing monoclines (not discussed further in this report).

4.2 Spring conceptual models

The GAB Springs of South Australia are complex and relatively unique ecosystems. They extend in a disjunct arc of over 5000 spring vents across the south-western margin of the GAB and LEB. Because of the number, complexity and diversity of springs in this area there is a need to categorise these springs into different types and to simplify the current knowledge of the functions of these systems. The creation of conceptual models enables this while identifying the key processes, drivers and values of the system to better facilitate the future monitoring and assessment of these springs.

The underlying process that drives spring function is groundwater pressure. Simply put, if there is sufficient pressure to bring the water to the surface naturally and without intervention, a spring may develop. For GAB springs in South Australia, an accepted convention is that this is further defined as sufficient water coming to the surface to sustain permanent wetland vegetation. There are several hydrogeological processes and pathways by which springs can form (Keppel *et al.,* 2015a). Equally there are several different types of GAB spring that can form at the surface. An analysis of common surface types has resulted in the development of only two generalised ecohydrology models with supporting evidence base tables:

- GAB spring model (covering the specific types of travertine mounds, astrobleme, sand mounds, flat depressions, abutment springs, thermal mounds and rocky seeps and terraces)
- Diffuse discharge (scald) model (a separate type that does not fit into the above GAB spring model).

The different spring types are described in a series of conceptual diagrams and the relationships and variations from the generalised models are detailed in the associated evidence base tables (Appendices B and C). The spring type conceptual models represent an integration of the hydrogeological models provided in Keppel *et al.* (2015a) with the ecological knowledge collated from this and other referenced studies throughout this report.

4.3 Generalised GAB spring model

The generalised GAB spring model graphically demonstrates the processes underlying the different types of springs identified within the study area and supports this with a detailed evidence base. The model shown in Figure 4.1 identifies the relationship between each of the key drivers, the agents of change and the values represented by the ecosystem. The impacts of the agents of change on the drivers and values on the springs are shown in greater detail in the supporting evidence base tables (refer Appendices B and C).

Key drivers include hydrogeological, climate, geomorphology and water quality parameters. Agents of change are external factors that impact on the drivers and values, changing them in either a positive or negative direction. In this context the agents of change are treated as distinct from the driver due to their anthropogenic origin as per Harding (2014). Values are groupings of the features of the springs that have been identified as important in spring function or health, they include vegetation communities, endemic species, ecosystem services and cultural values. The parameters and drivers of the generalised spring model are shown in Table 4.1.

Table 4.1 Variables used in the generalised GAB spring model, with justification for parameter choice

Hydrogeology	
Groundwater Temperature	Temperature of the groundwater at the discharge point. The temperature of the groundwater is a key factor in the maintenance of spring microhabitats, particularly in hot springs (discharge temp exceeds 24°C).
Groundwater Pressure	Groundwater (aquifer) pressure at the spring. This parameter is modelled as it is impossible to definitively measure the aquifer pressure for every spring.
Groundwater Chemistry	The actual chemistry of the groundwater in the aquifer as measured at the discharge point, including anions, cations, pH, conductivity, stable isotopes, trace elements, ORP, water quality, total carbon, strontium 87/86.
Climate	
Atmospheric Pressure	Atmospheric pressure can have a significant impact on spring flow. Extreme low pressure systems have been observed to cause the spring wetted area to increase to nearly double the average area (Gotch personal observation).
Evapotranspiration	The combination of evaporation and transpiration. High evapotranspiration can in extreme situations result in the complete drying up of all free water in a spring. This occurs at numerous low flow springs across the arid regions of the LEB.
Rainfall	Sudden influxes of fresh water into spring habitats from localised flooding can result in spring macroinvertebrates going hyperosmotic and literally rupturing internally (N. Murphy (The University of Adelaide) pers. comm. 2007, 1 September). This has resulted in localised extinctions of the isopod *Phreatomerus latipes* at McLachlan Springs (T. Fatchen (Fatchen and Fatchen) pers comm. to Gotch August 1999). Rainfall events that result in localised flooding can also increase the connectivity between springs in a spring groups, and in extreme events, connectivity between spring complexes providing a potential vector for species dispersal (Gotch *et al.*, 2008).
Physical setting	
Spring Elevation	Spring elevation is the measurement of the spring discharge point above mean sea level (Gotch 2013). The elevation relative to the potentiometric head is the principal variable in determining spring flow. Spring groups with low variation in elevation are at higher risk of drawdown extinction than spring groups with a larger elevation range (Green *et al.* 2013).
Local Geology and Soils	The interlaying material between the aquifer and the surface has a strong influence on the water chemistry at the discharge site. In the northern and western portions of the Lake Eyre Supergroup the high accumulation of sulfides may be a result of local geology and soils
Topography and Geomorphology	The local geomorphology and topography will influence the types of springs that form in them and the long term stability of the spring habitat.
Hydrology and spring structure	
Flow Rate	The actual flow rate at the point of discharge. This can be a discrete point where it can be measured easily or it can be based on the flow rate against vegetated wetland area equations developed by White *et al.* (2015) when the discharge is diffused over a large area.
Spring Wetland Area	The vegetated wetland area of the spring. This uses the 50% cover limit to define the edge of the wetland vegetation.
Wetland Connectivity	Connection of spring vents through the wetlands they support. This may be an outcome of other drivers (e.g. rainfall, groundwater pressure) or it may be an inherent property of the spring.
Mound Building Rate	The rate of carbonate deposition and/or the rate of accumulation of windblown sand in the wet vegetation.
Vent Pool	Depending on the type of spring and the morphology of the spring a vent pool can develop. These pools are often the most critical and stable habitats within the spring. They can be just a few cm across up to 160 m long.
Water chemistry	
pH	Critical to the deposition and erosion of mound carbonates and to the overall health of the spring. Can range from 1.5 to 9 (Shand *et al.*, 2013; Gotch unpublished data). Rapid fluctuations result in local die-offs and potential extinction of spring flora and fauna.
Conductivity	Self-explanatory. Rapid fluctuations result in local die-offs and potential extinction of spring flora and fauna.
Dissolved Oxygen	Typically very low immediately at discharge point then rapidly reaching saturation. Not a significant parameter except in thermal mounds such as at Dalhousie where it can have a significant role in vent pool fish distributions.
Nutrients	Inputs of nutrients such as nitrogen and phosphorus into springs mainly from grazing animals but can also be caused by other disturbances such as excavation and erosion.

Turbidity	Not a significant parameter except in thermal mounds such as at Dalhousie where water depths can exceed 10 m. Can be an issue in excavated springs such as Toondina and Finniss Well.
Values	
Spring Vegetation Communities	Vegetation communities dependent on spring discharge to survive.
Spring Endemic and Relict Flora	Flora that is either endemic to GAB springs (endemic flora) or that is disjunct from its normal population distribution and only survives in the region due to the presence of the spring (relict flora).
Spring Endemic and Significant Fauna	Fauna that is either endemic to GAB springs (endemic fauna) or that is disjunct from its normal population distribution and only survives in the region due to the presence of the spring (relict fauna).
Stromatolites	Stromatolites and thrombolites, these are symbiotic microbial communities that contain cyanobacteria on the outer upper layers that photosynthesise and other microbial populations in the lower layers, some of which precipitate carbonate in the spring. They are a critical component in the development of travertine mounds.
Ecosystem Services	Springs provide water, habitat and food sources for non-aquatic organisms as well. In the absence of any other water source in the region the springs are critical in maintaining these organisms.
Aboriginal Culture	The springs are important culturally to the aboriginal peoples who shared the landscape. Consequently the springs have significant stories, songs (Ularaka for Arabana or Tjukurpa for the Lower Southern Arrente) and numerous artefacts associated with them.
Social Values	Includes tourism, aesthetic, spiritual (non Aboriginal) social and amenity values placed on springs.
Agents of change	
Groundwater Extraction	The key driver of drawdown (the reduction in potentiometric head of an aquifer) which is the major cause of spring extinction.
Groundwater Contamination	Groundwater contamination can result from a number of pathways both natural and anthropogenic in origin. For example, fracking chemicals can potentially get into aquifers where coal seams are either within an aquifer or immediately adjacent to one. Also fracking release BTEX compounds (benzene, toluene, ethyl-benzene, and xylenes) from coal seams as they are depressurised or during underground coal gasification (UCG). Also salt contamination from non-GAB aquifers as a result of pressure differentials generated from drawdown. Changes in pH or oxygen concentration can mobilise or lock up metals dissolved in the aquifer or bound to aquifer sediments.
Spring Excavation	Springs have been excavated in the past to increase the volumes of vent pools, direct he flow of water down a channel, increase flows from springs and to create "better" pastures for grazing animals (ponded pastures). Excavation can take the form of physical digging or dredging, screening sediments or insertion of bore casing into springs to localise and increase flow.
Grazing	Grazing includes domestic animals such as cattle and sheep as well as feral grazers such as camels and donkeys and native grazing animals. It also includes pugging (the trampling of springs by animals) and the introduction of nutrients from animal faeces.
Feral Animals	Feral animals includes exotic pests such as Mosquitofish, Feral Cats as well as feral grazers.
Weeds	Major weeds in springs in the study area include Annual Beard-grass (*Polypogon monspeliensis*), date palms (*Phoenix dactylifera*) and bamboo (*Bambusa vulgaris*)
Tourism	Tourists can impact springs by eroding springs when swimming in them, introduce toxic chemicals from sun screen and mosquito repellent, driving into them and getting bogged and changing water courses from tracks in soft scald areas.
Exploration	Exploration activities are well regulated. Impacts are only likely if non-compliance with the regulations takes place. Impacts can include, driving on springs, spring tails or into the scald areas around them. Failures in drilling could result in drawdown events occurring in close proximity to springs. Waste from exploration if improperly disposed of could contaminate springs. Drilling muds not contained could contaminate springs. Improper completion of exploration drill holes can result in leaking bores.
Fencing	Fencing of springs to exclude stock requires a detailed management plan to be implemented that may require intervention for up to 20 years. This is mostly to control the rapid regrowth of *Phragmites* sp. In response to the removal of grazing pressure and the increased nutrient load from animal manure. Fenced areas need to be regularly checked to prevent holes in the fence and to remove animals that may climb the fences.
Natural long term change	Natural long term change is an element of the driver groundwater pressure. The western margin of the GAB currently receives very little to no recharge with the entirety of the study site being naturally in decline (i.e. natural discharge rates exceed recharge rates) (Rousseau-Gueutin *et al.,* 2013). Artificial water extractions may further enhance this natural long term decline.

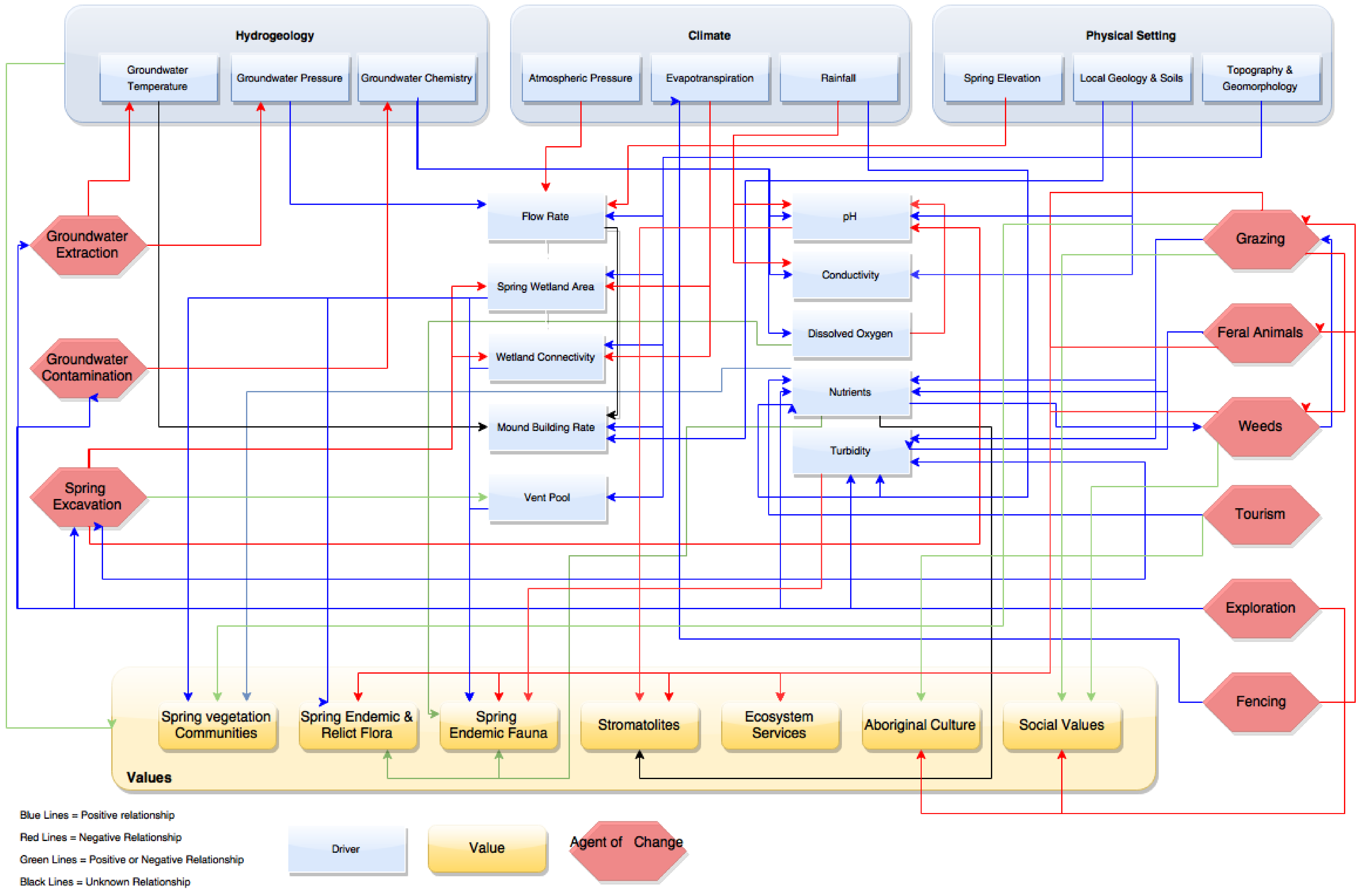


Figure 4-1: Generalised GAB spring model (box and line)

4.3.1 Spring type conceptual diagrams

Spring groups can contain several different types with each type having some variation in response or resilience to drawdown impacts. Many of the drivers and impacts are common between the spring types. The types show the current state of the springs and susceptibilities to coal development. Due to issues of scale and resolution some impacts appear larger than they potentially are. Most obvious here is the impact from fracking and pollution arising from CSG, Shale and underground gasification practices. For the former two practices these impacts are likely to be very low, however the latter practice has the potential to cause significant pollution issues within aquifers and potentially the springs (Verma *et al.,* 2014).

The GAB Spring Model encompasses the following types: travertine mounds, astrobleme, sand mounds, flat depressions, abutment springs, thermal mounds and rocky seeps and terraces.

Travertine mound springs

Travertine mound springs typically form distinct carbonate domes of travertine and tufa, containing a core of soft black silt and sand. Spring water flows up and out of a vent located at the top of the mound, and either pools or, if flow is sufficient, runs down the side of the mound to form a wetland tail. Travertine mounds are often hundreds of thousands of years old, very fragile and can accumulate high concentrations of sulfides, heavy metals and metalloids. Because of their age, travertine mound springs typically have very high biodiversity values and numerous short-range endemics. Groundwater is primarily sourced from the Great Artesian Basin. The mounds are usually located in extensive diffuse discharge (scald) zones. Significant examples in the Preliminary Assessment Extent include Billa Kalina, Big Cadnaowie, and Cardajalburrana Springs.

Travertine vent showing sulfate accumulation (Strangways Springs)

Travertine mound (Billa Kalina Springs)

Natural drivers

- Groundwater pressure
- Groundwater chemistry
- Local geology
- Low spring connectivity
- Influence of atmospheric pressure and lunar tidal cycle on spring flow
- Evapotranspiration

Impacts

- Maintains ecosystem integrity (spring flow, connectivity and biodiversity)
- Increased short-range endemism due to isolation
- Temporal and spatial variation of spring flow and wetland extent

Human induced drivers

- Aquifer drawdown from current developments (e.g. pastoral bores, mining and town water supplies)
- Grazing pressure, and trampling by domestic and feral animals
- Tourism pressure
- Introduced weeds and pests

Impacts

- Reduction and fragmentation of habitat
- Reduced biodiversity
- Increased risk of extinctions
- Increased salinity and acid sulfate hazard
- Damage to spring structure
- Changes in community ecology

Potential impacts of coal mining and unconventional gas activity

- Significant decrease in aquifer pressures, due to groundwater extraction
- Reduction in wetland area and increase in habitat fragmentation
- Increased acid sulfate hazard and spring mound erosion
- Increased risk of extinction of short-range endemics
- Contamination of groundwater
- Structural destabilisation of aquifers and aquitards amplifying drawdown impacts
- Reduced biological values

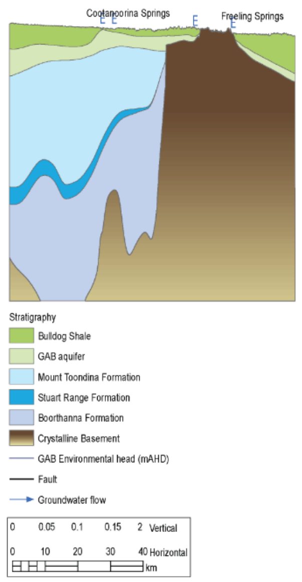
Connectivity

Relatively low connectivity between individual vents and mounds. Most mounds are isolated from each other, except during periods of extremely low atmospheric pressure and large rain events. Exceptions occur in groups with high flows.

Critical chemistry

Sulfides, heavy metals and metalloids (e.g. Arsenic) accumulate in anoxic mounds. If spring flow decreases and deposits dry out, sulfides can oxidise into sulphates. If the mound rewets, as a result of pressure recovery or rainfall, the sulfates dissolve into the water creating sulfuric acid. Acidification can dissolve the carbonate mound structure and mobilise toxic metals into the water, impacting spring fauna.

Structural geology model for Cootanoorina Springs



Knowledge gaps

- Connectivity between aquifer and springs
- Sensitivity of springs to aquifer drawdown
- Limited species distribution information
- Sulfides, heavy metal and metalloid accumulation and mobilisation in springs
- Degree to which spring ecosystems have been affected by post-European disturbance

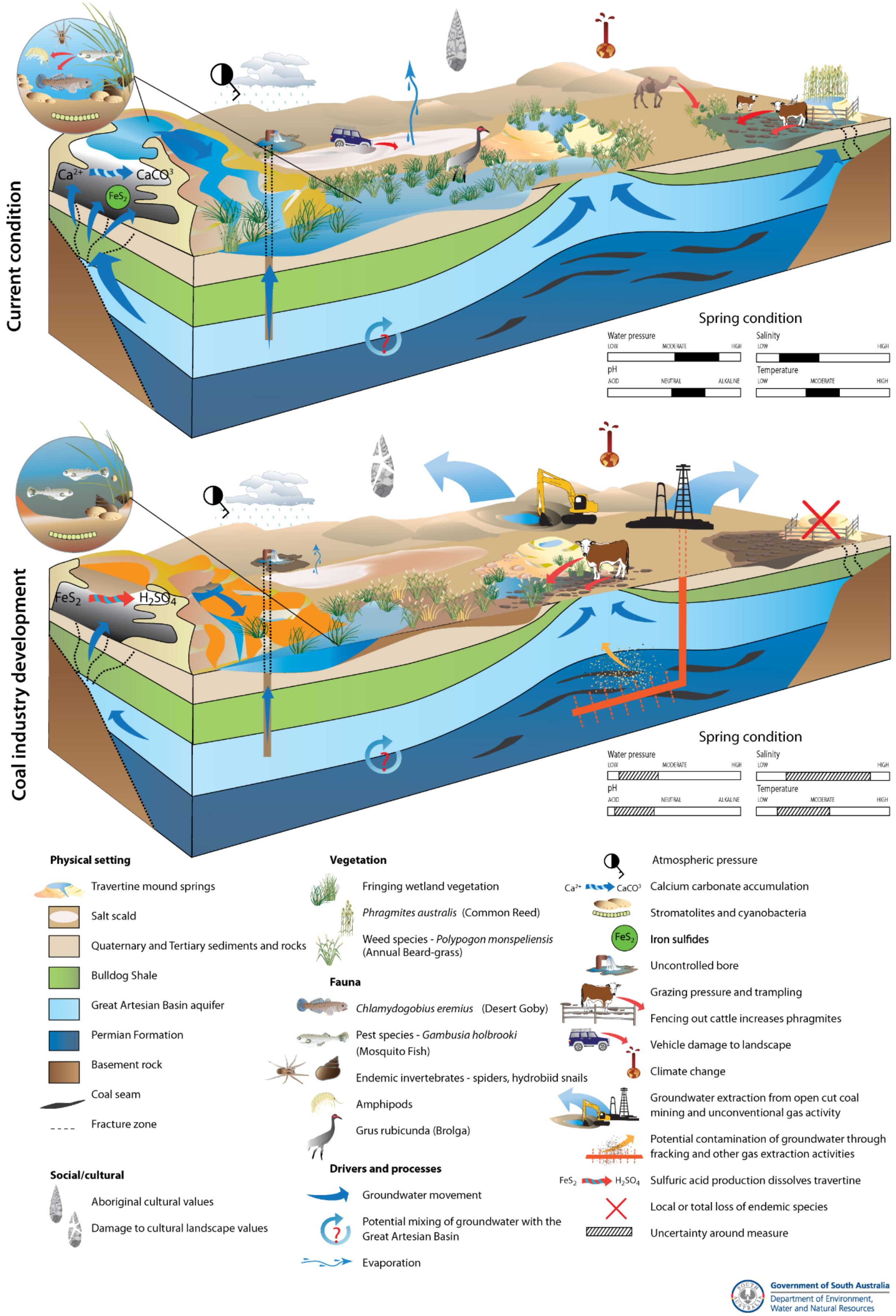


Figure 4-2 GAB generalised model for travertine mounds

Astrobleme

An astrobleme is an eroded remnant of the crater made by a meteorite impact. A meteorite strike leaves an impact zone of hardened sediments, which withstands weathering and erosion better than the surrounding landscape, resulting in the formation of a low hill at the site of the impact. At Mt Toondina, springs have formed around an astrobleme, at stress points created from the impact of a meteorite some time after the formation of the aquifer. The meteorite also caused significant changes in the local geology, resulting in the exposure of lower sequence coal deposits at the surface.

The Mt Toondina springs are predominantly very low-flow and dry up most periodically. *Phragmites australis* (Common Reed) is only supported at several points around the edge of the astrobleme. One vent has permanent water, but has been excavated to provide water for cattle. This spring contains a low diversity of spring-dependent species. Mt Toondina has very strong cultural values because of the unique nature of the astrobleme and the presence of permanent water.

Looking west from the centre of Toondina Astrobleme

Excavated vent at Toondina Springs

Natural drivers

- Groundwater pressure
- Groundwater chemistry
- Local geology
- Low spring connectivity
- Influence of atmospheric pressure and lunar tidal cycle on spring flow
- Evapotranspiration

Impacts

- Maintains ecosystem integrity (spring flow, connectivity and biodiversity)
- Increased short-range endemism due to isolation
- Temporal and spatial variation of spring flow and wetland extent

Human induced drivers

- Aquifer drawdown from current developments (e.g. pastoral bores, mining and town water supplies)
- Grazing pressure, and trampling by domestic and feral animals
- Introduced weeds and pests
- Past excavation of spring

Impacts

- Reduction and fragmentation of habitat
- Reduced biodiversity
- Increased risk of extinctions
- Increased salinity and acid sulfate hazard
- Damage to spring structure
- Changes in community ecology

Potential impacts of coal mining and unconventional gas activity

- Significant decrease in aquifer pressures, due to groundwater extraction
- Loss of flow to small ephemeral springs, reduction in wetland area and increase in habitat fragmentation
- Increased acid sulfate hazard and spring mound erosion
- Increased risk of extinction of short-range endemics
- Contamination of groundwater
- Structural destabilisation of aquifers and aquitards amplifying drawdown impacts
- Reduced biological values

Connectivity

Very low connectivity between individual vents on the south-west margin of the astrobleme. In periods of flow, some of these vents would link. The larger, permanent vent remains isolated from the other spring vents at all times.

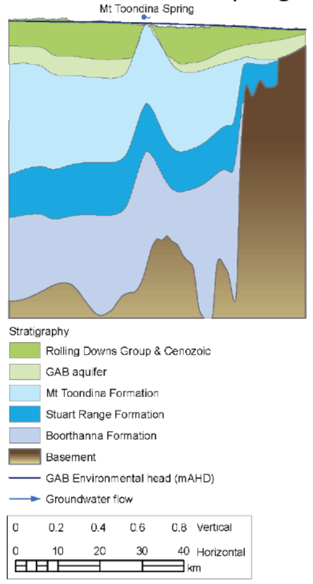
Critical chemistry

Unknown.

Knowledge gaps

- Connectivity between aquifer and springs
- Sensitivity of springs to aquifer drawdown
- Limited species distribution information
- Sulfides, heavy metal and metalloid accumulation and mobilisation in springs
- Degree to which spring ecosystems have been affected by post-European disturbance
- Impacts of excavation of spring

Structural geology model for Mt Toondina Spring



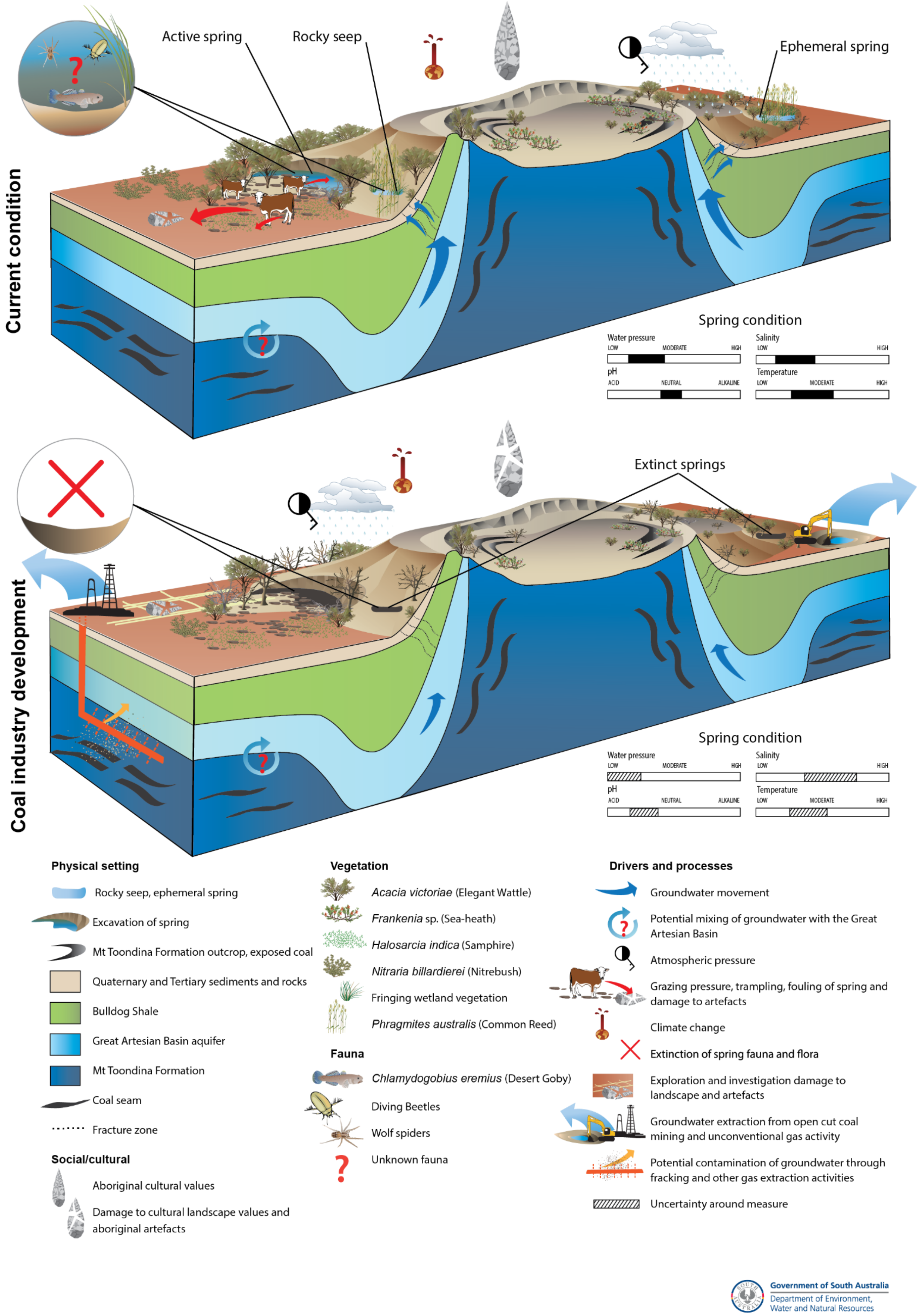


Figure 4-3 GAB generalised model for astrobleme

Sand mound springs

Springs of this type form low mounds of wind-accumulated sand. While sand is the predominant component of the mound, springs in areas with carbonate-containing water, will produce some travertine. Vegetation coverage is often low in diversity and is dominated by *Phragmites australis* and *Cyperus gymnocaulis*. Significant examples in the Preliminary Assessment Extent include South Well and Georgyana Springs.


Sand mounds at West Finniss Springs surrounded by diffuse discharge scalds

Natural drivers
- Groundwater pressure
- Groundwater chemistry
- Local geology
- Low spring connectivity
- Influence of atmospheric pressure and lunar tidal cycle on spring flow
- Evapotranspiration

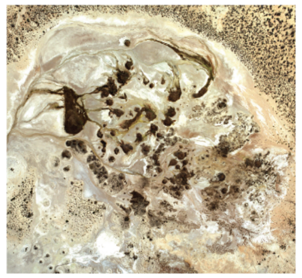
Impacts
- Maintains ecosystem integrity (spring flow, connectivity and biodiversity)
- Increased short-range endemism due to isolation
- Temporal and spatial variation of spring flow and wetland extent

Human induced drivers
- Aquifer drawdown from current developments (e.g., pastoral bores, mining, town water supplies)
- Grazing pressure and trampling by domestic and feral animals
- Introduced weeds and pests

Impacts
- Reduction and fragmentation of habitat
- Reduced biodiversity
- Increased risk of extinctions
- Increased salinity and acid sulfate hazard
- Damage to spring structure
- Changes in community ecology


Sand mound surrounded by diffuse discharge

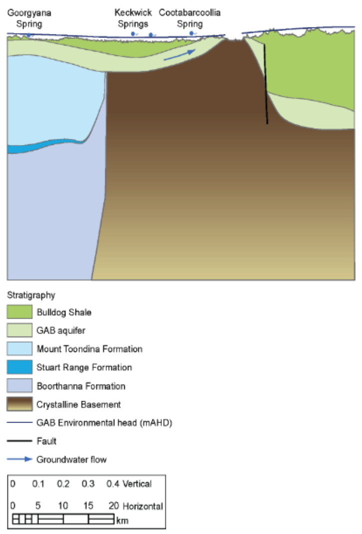
Potential impacts of coal mining and unconventional gas activity
- Significant decrease in aquifer pressures, due to groundwater extraction
- Reduction in wetland area and increase in habitat fragmentation
- Increased acid sulfate hazard and spring mound erosion
- Increased risk of extinction of short-range endemics
- Contamination of groundwater
- Structural destabilisation of aquifers and aquitards amplifying drawdown impacts
- Reduced biological values


Aerial view of sand mound connectivity at West Finniss Springs

Connectivity
Very low connectivity between individual vents located in the Preliminary Assessment Extent. Most vents are isolated from each other, except during extremely low atmospheric pressure events and large rain events. In springs outside of the Preliminary Assessment Extent, there are sand mound groups, which exhibit high levels of connectivity between vents.

Critical chemistry
Sand mound springs often have higher than average salinity, due to low flow rates and their geomorphological setting.

Structural geology model for Cootabarcoollia Springs



Knowledge gaps
- Connectivity between aquifer and springs
- Sensitivity of springs to aquifer drawdown
- Limited species distribution information
- Sulfides, heavy metal and metalloid accumulation and mobilisation in springs
- Degree to which spring ecosystems have been affected by post-European disturbance

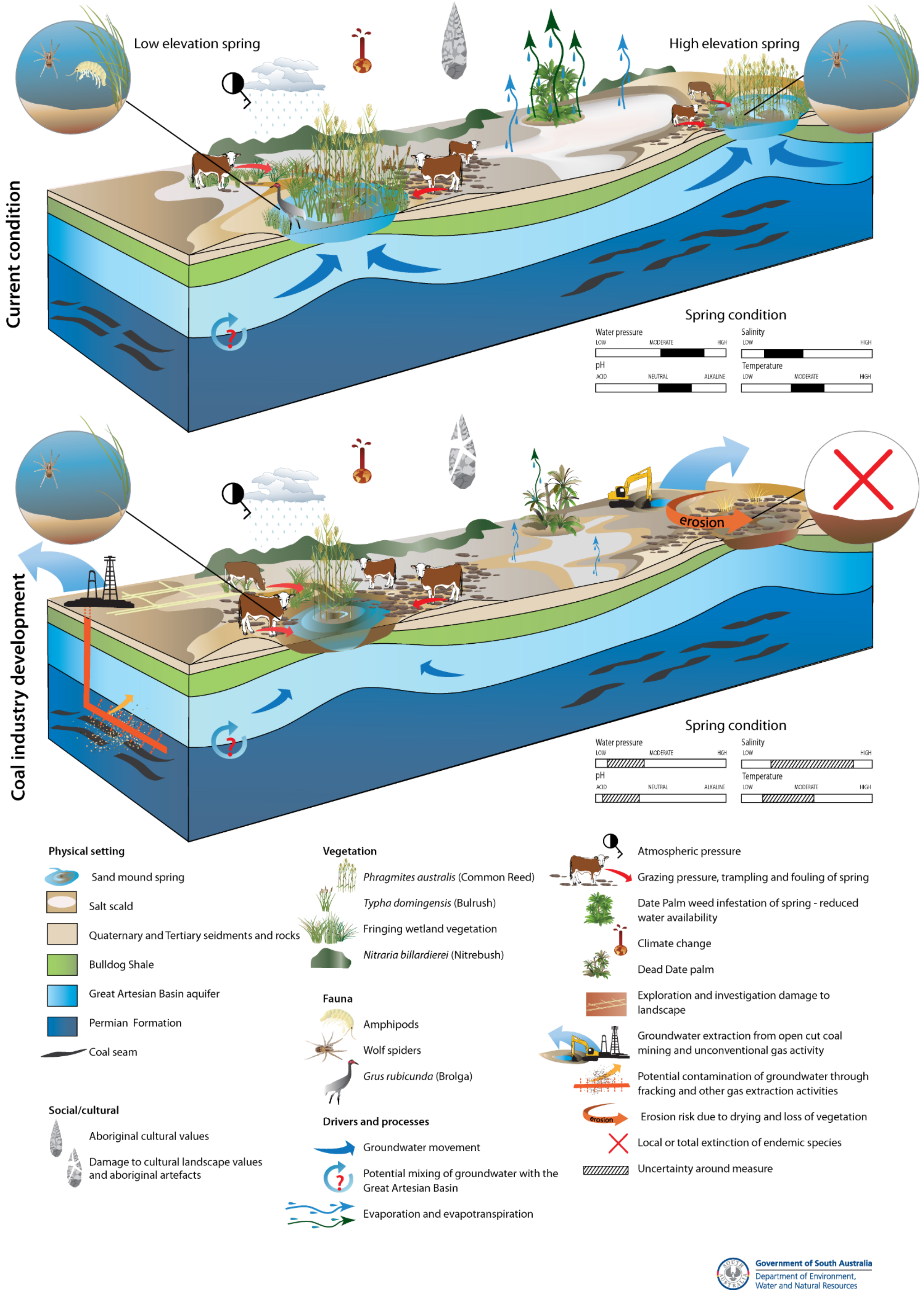
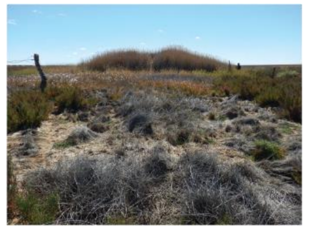


Figure 4-4 GAB generalised model for sand mounds

Flat depression springs

Springs of this type occur in low depressions in the surrounding landscape. Many of the springs are predominantly sand based, but some produce travertine. Some springs that previously produced low travertine mounds are no longer present, due to sulfation or erosion from cattle. These springs are often low in invertebrate diversity, due to flooding following large rain events. Significant examples in the Preliminary Assessment Extent include Oolgelima and Mole Hill (part) Springs.



Oolgelima Springs

Depression spring at Oolgelima is situated lower than the surrounding landscape with nowhere for water to run off

Natural drivers

- Groundwater pressure
- Groundwater chemistry
- Local geology
- Low spring connectivity
- Influence of atmospheric pressure and lunar tidal cycle on spring flow
- Evapotranspiration

Human induced drivers

- Aquifer drawdown from current developments (e.g. pastoral bores, mining and town water supplies)
- Grazing pressure, and trampling by domestic and feral animals
- Introduced weeds and pests

Impacts

- Maintains ecosystem integrity (spring flow, connectivity and biodiversity)
- Increased short-range endemism due to isolation
- Temporal and spatial variation of spring flow and wetland extent

Impacts

- Reduction and fragmentation of habitat
- Reduced biodiversity
- Increased risk of extinctions
- Increased salinity and acid sulfate hazard
- Damage to spring structure
- Changes in community ecology

Potential impacts of coal mining and unconventional gas activity

- Significant decrease in aquifer pressures, due to groundwater extraction
- Reduction in wetland area and increase in habitat fragmentation
- Increased acid sulfate hazard and spring mound erosion
- Increased risk of extinction of short-range endemics
- Contamination of groundwater
- Structural destabilisation of aquifers and aquitards amplifying drawdown impacts
- Reduced biological values

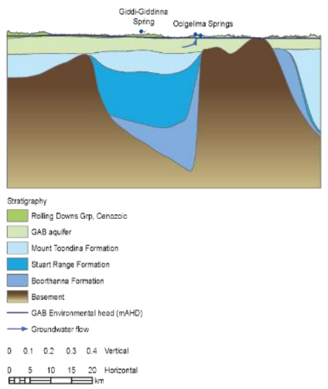
Connectivity

Reletively low connectivity between individual vents. Most vents are isolated from each other, except during periods of extremely low atmospheric pressure and large rain events.

Critical chemistry

Sulfides, heavy metals and metalloids (e.g., Arsenic) accumulate in anoxic mounds. If spring flow decreases and deposits dry out, sulfides can oxidise into sulfates. If the mound rewets, as a result of pressure recovery or rainfall, the sulfates dissolve into the water creating sulfuric acid. Acidification can dissolve the carbonate mound structure and mobilise toxic metals into the water, impacting spring fauna.

Structural geology model for Oolgelima Springs



Knowledge gaps

- Connectivity between aquifer and springs
- Sensitivity of springs to aquifer drawdown
- Limited species distribution information
- Sulfides, heavy metal and metalloid accumulation and mobilisation in springs
- Degree to which spring ecosystems have been affected by post-European disturbance

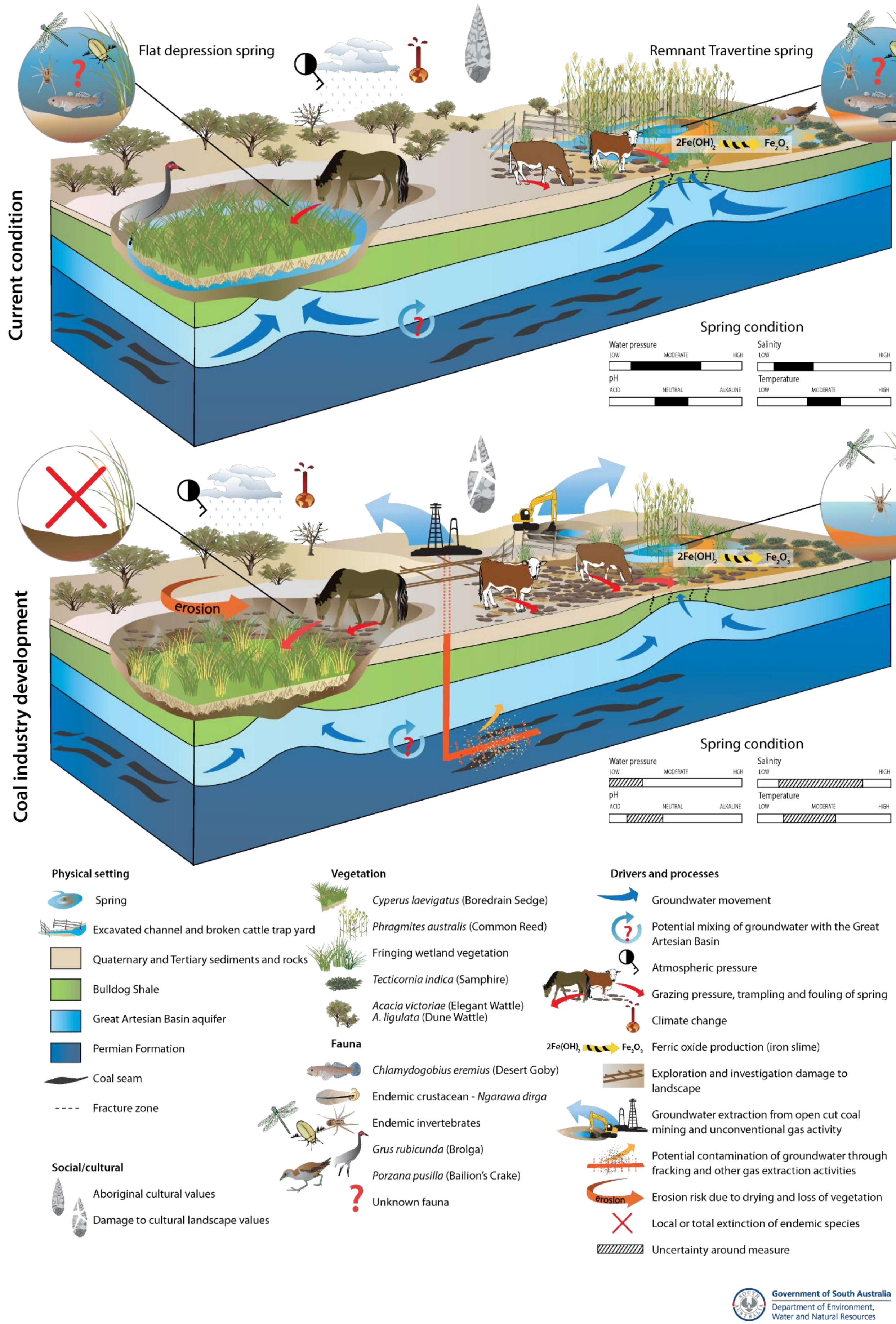
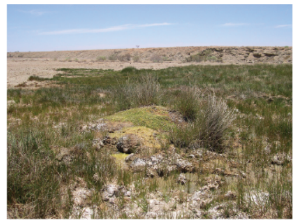


Figure 4-5 GAB generalised model for flat depressions

Abutment

In some instances, basement rocks protrude through the Great Artesian Basin, creating a zone of weakness in the aquitard (confining layer). If pressure is sufficient, springs can form in this area. Typically, springs will be distributed along the edge of the abutment and down an elevation gradient, with the low-flow rate springs located higher than the high-flow rate springs. The springs mostly form rocky vents and terraces, but may also form travertine mounds. These spring typologies are often very old and fragile, and are often very sensitive to groundwater drawdown. Many are now extinct, due to drawdown from pastoral bores over the past 150 years. Abutment springs are typically of very high biodiversity value, and in the case of Freeling Springs, have the highest biodiversity value of any spring group, other than Dalhousie in South Australia. Significant examples in the Preliminary Assessment Extent include Freeling, North Freeling, Kerlatroabooantallinna, Coppertop, Sandy, Willparoona and Blind Springs.



Abutment springs at Petermorra Springs. Vent is a soft, spongy, "pimple" of wet silt and organic matter held together by roots of the spring's vegetation.

Abutment springs at Hermit Hill Springs

Natural drivers

- Groundwater pressure
- Groundwater chemistry
- Local geology
- Low spring connectivity
- Influence of atmospheric pressure and lunar tidal cycle on spring flow
- Evapotranspiration

Human induced drivers

- Aquifer drawdown from current developments (e.g. pastoral bores, mining and town water supplies)
- Grazing pressure, and trampling by domestic and feral animals
- Introduced weeds and pests

Impacts

- Maintains ecosystem integrity (spring flow, connectivity and biodiversity)
- Increased short-range endemism due to isolation
- Temporal and spatial variation of spring flow and wetland extent

Impacts

- Reduction and fragmentation of habitat
- Reduced biodiversity
- Increased risk of extinctions
- Increased salinity and acid sulfate hazard
- Damage to spring structure
- Changes in community ecology

Potential impacts of coal mining and unconventional gas activity

- Significant decrease in aquifer pressures, due to groundwater extraction
- Reduction in wetland area and increase in habitat fragmentation
- Increased acid sulfate hazard and spring mound erosion
- Increased risk of extinction of short-range endemics
- Contamination of groundwater
- Structural destabilisation of aquifers and aquitards amplifying drawdown impacts
- Reduced biological values

Connectivity

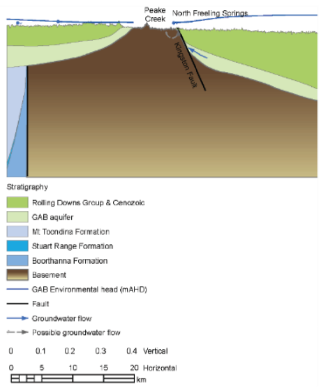
Relatively low connectivity between individual vents, although in some springs, such as the lower terraces of Freeling Springs, several vents can be permanently connected. Most vents are isolated from each other, except during periods of extremely low atmospheric pressure and large rain events. Exceptions occur in spring groups with high flows, outside the Preliminary Assessment Extent.

Critical chemistry

The structure of these springs is critically dependent on the presence of carbonate in the water and stromatolites and thrombolites in the vents and tails. The latter organisms can be seriously impacted by the presence of cattle.

Sulfides, heavy metals and metalloids (e.g., Arsenic) accumulate in anoxic mounds. If spring flow decreases and deposits dry out, sulfides can oxidise into sulfates. If the mound rewets, as a result of pressure recovery or rainfall, the sulfates dissolve into the water creating sulfuric acid. Acidification can dissolve the carbonate mound structure and mobilise toxic metals into the water, impacting spring fauna.

Structural geology model for North Freeling Springs



Knowledge gaps

- Connectivity between aquifer and springs
- Sensitivity of springs to aquifer drawdown
- Limited species distribution information
- Sulfides, heavy metals and metalloid accumulation and mobilisation in springs
- Degree to which spring ecosystems have been affected by post-European disturbance

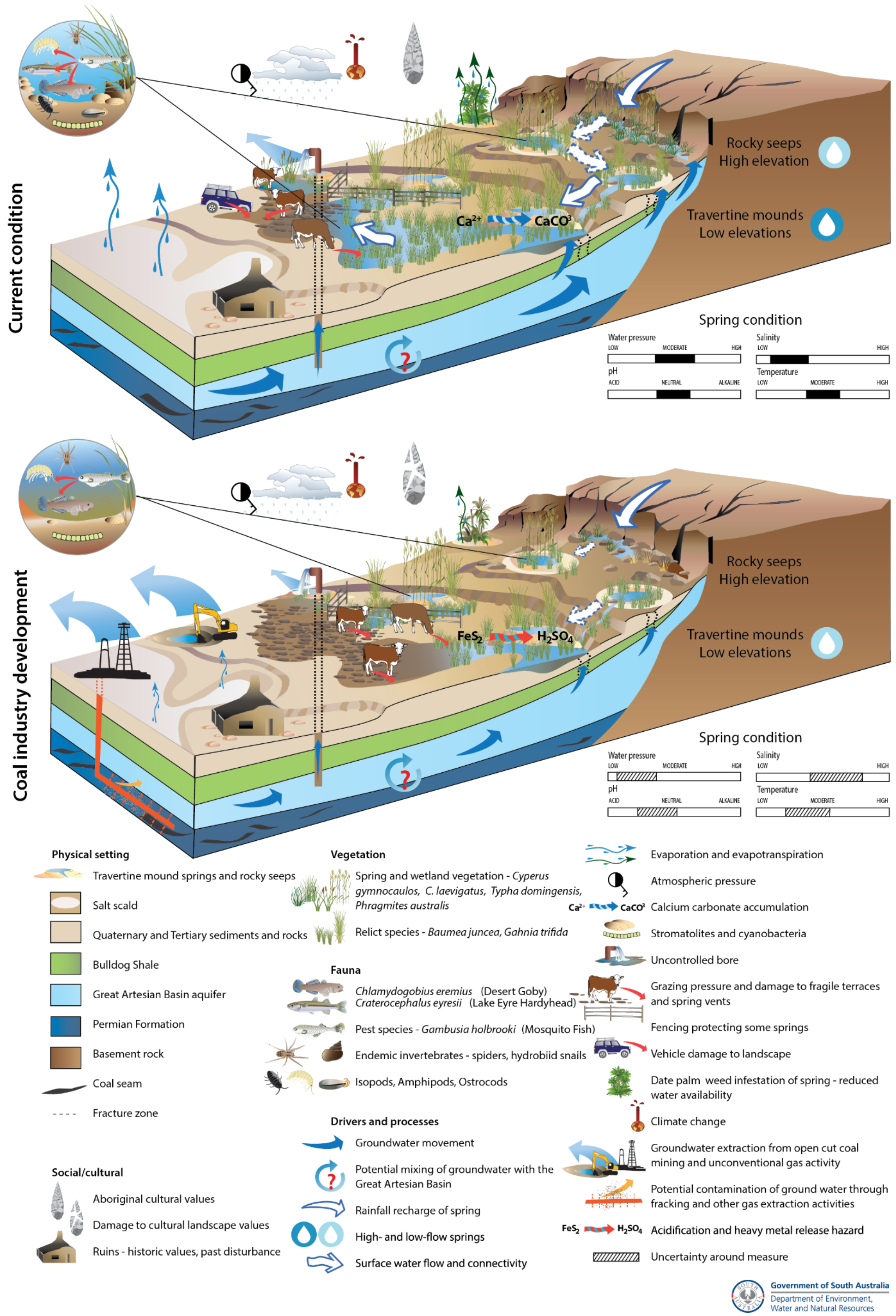


Figure 4-6 GAB generalised model for abutment

Thermal mound springs

In South Australia, thermal mounds only occur at Dalhousie Springs. The springs form thermal mounds in the landscape, and typically have flows in excess of 2 ML/day. They are often associated with large, deep vent pools and extensive outflow channels and wetlands that can be several kilometres long and several hundred hectares in area. Because the associated wetlands are very large, atmospheric pressure influences on the springs are mitigated. The water at the discharge site is warm, as it flows from great depth along a hot granite anticline before reaching the surface. These springs are estimated to have been discharging for 1-2 million years, longer than any of the other known springs. Typically these mounds have the greatest diversity of flora and fauna, as well as the largest diversity of short-range endemic species. At Dalhousie, the springs have distinct vent vegetation, often dominated by an overstorey of *Melaleuca glomerata* and/or *Phragmites australis*, and an understory of plants usually found in more tropical climates, such as *Imperata cylindrica*. Large wetland areas exist and are mostly dominated by *P. australis*, *Cyperus laevigatus* and *C. gymnocaulos*. The presence of typically tropical flora is due to microclimates created by large volumes of warm water from the spring vents, which also supports an abundance of endemic fauna, with 16 species currently recognised as only occurring at Dalhousie Springs.

Thermal mound spring vent at Dalhousie Springs

Natural drivers

- Groundwater pressure
- Groundwater chemistry
- Local geology and isolation
- Large spring flows
- High water temperature
- Evapotranspiration
- Influence of lunar tidal cycle on spring flow

Impacts

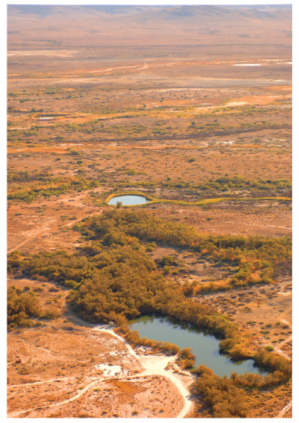
- Maintains ecosystem integrity (spring flow, connectivity and biodiversity)
- Maintains water temperature at outflow
- Increased short-range endemism due to isolation
- Temporal and spatial variation of spring flow and wetland extent

Human induced drivers

- Aquifer drawdown from current developments (e.g. pastoral bores, mining and town water supplies)
- Grazing pressure, and trampling by domestic and feral animals
- Tourism pressure
- Introduced weeds and pests

Impacts

- Reduction and fragmentation of habitat
- Reduced biodiversity
- Increased risk of extinctions
- Increased salinity and reduced water temperatures
- Damage to spring structure
- Changes in community ecology



Thermal mound springs and tails at Dalhousie. The mound and pool in the foreground discharges >10 ML/day.

Potential impacts of coal mining and unconventional gas activity

- Significant decrease in aquifer pressures, due to groundwater extraction
- Reduction in wetland area and increase in habitat fragmentation
- Significant change in water temperature
- Increased risk of extinction of short-range endemics
- Contamination of groundwater
- Structural destabilisation of aquifers and aquitards amplifying drawdown impacts
- Reduced biological values

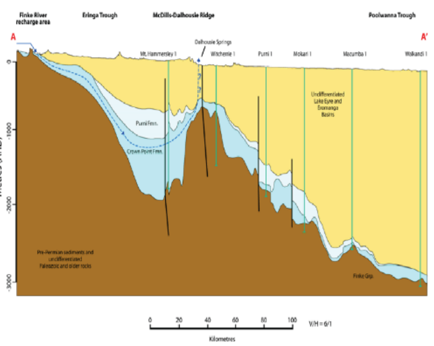
Connectivity

Spring vents are very connected with several vents forming wetlands >200 ha. Isolation exists between unconnected vents with limited dispersal of species between isolated wetlands.

Critical chemistry

Springs are mostly fresh with low conductivity and dissolved oxygen, and moderate levels of carbonate. Water temperature is critical to ecosystem function and supports a diverse range of endemic and relict flora and fauna.

Structural geology model for Dalhousie Springs



Aerial map of Dalhousie Springs

Knowledge gaps

- Sensitivity of springs to drawdown, particularly the springs in the centre of the complex that have low potentiometric heads
- Aquifer-spring connectivity, particularly groundwater inputs from the Pedirka basin
- Limited species distribution information
- Sulfides, heavy metal and metalloid accumulation and mobilisation in springs
- Long-term impacts of weeds, particularly *Polypogon monspeliensis*
- Degree to which spring ecosystems have been affected by post-European disturbance

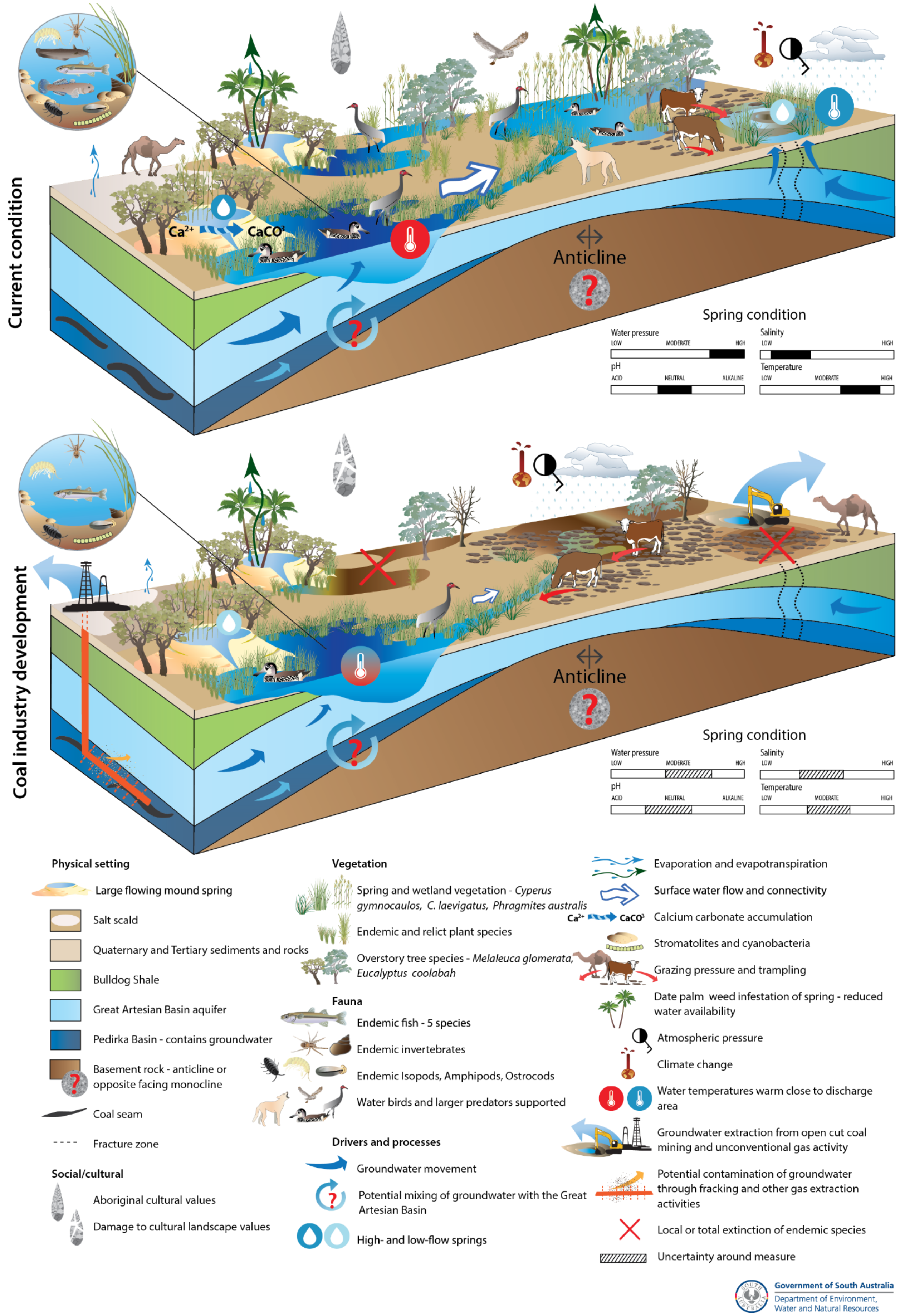


Figure 4-7: GAB generalised model for thermal springs

Rocky seeps and terraces

Where travertine mounds do not form distinct mound structures, small rock vents and low travertine terraces may be formed. Low travertine rock vents may be isolated, or more often occur within travertine terraces, which may form a part of a larger travertine structure. The vent pools are often small, shallow and rarely more than 5m across, with free water flowing over carbonate terraces in a braided pattern. As carbonate is precipitated, the course of the water changes, resulting in the formation of a broad flat terrace. Vegetation on these terraces is often sparse, however the wet areas often contain stromatolites and foraging crustaceans and molluscs. These terraces and rocky vents can be hundreds of thousands of years old and are very fragile. Because of their age, the small rocky vents often have very high biodiversity values and numerous short-range endemics. Significant examples in the Preliminary Assessment Extent include Allandale, Wild Dog, Weedina, Edadurruna, Little Cadnaowie, Wangarranna and the lower terraced components of Freeling Springs.

Rocky seep at Elizabeth Springs, SA

Small rocky vent at Weedina Springs

Natural drivers

- Groundwater pressure
- Groundwater chemistry
- Local geology
- Low spring connectivity
- Influence of atmospheric pressure and lunar tidal cycle on spring flow
- Evapotranspiration

Impacts

- Maintains ecosystem integrity (spring flow, connectivity and biodiversity)
- Increased short-range endemism due to isolation
- Temporal and spatial variation of spring flow and wetland extent

Human induced drivers

- Aquifer drawdown from current developments (e.g. pastoral bores, mining and town water supplies)
- Grazing pressure, and trampling by domestic and feral animals
- Tourism pressure
- Introduced weeds and pests

Impacts

- Reduction and fragmentation of habitat
- Reduced biodiversity
- Increased risk of extinctions
- Increased salinity and acid sulphate hazard
- Damage to spring structure
- Changes in community ecology

Potential impacts of coal mining and unconventional gas activity

- Significant decrease in aquifer pressures, due to groundwater extraction
- Reduction in wetland area and increase in habitat fragmentation
- Increased acid sulfate hazard and spring mound erosion
- Increased risk of extinction of short-range endemics
- Contamination of groundwater
- Structural destabilisation of aquifers and aquitards amplifying drawdown impacts
- Reduced biological values

Connectivity

Relatively low connectivity between individual vents, although in some springs, such as the lower terraces of Freeling Springs, several vents can be permanently connected. Most vents are isolated from each other, except during periods of extremely low atmospheric pressure and large rain events. Exceptions occur in spring groups with high flows, outside the Preliminary Assessment Extent.

Critical chemistry

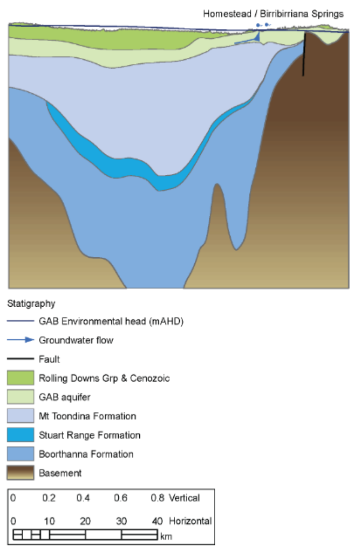
The structure of these springs is critically dependent on the presence of carbonate in the water and stromatolites and thrombolites in the vents and tails. The latter organisms can be seriously impacted by the presence of cattle.

Sulfides, heavy metals and metalloids (e.g. Arsenic) accumulate in anoxic mounds. If spring flow decreases and deposits dry out, sulfides can oxidise into sulfates. If the mound rewets, as a result of pressure recovery or rainfall, the sulfates dissolve into the water creating sulfuric acid. Acidification can dissolve the carbonate mound structure and mobilise toxic metals into the water, impacting spring fauna.

Knowledge gaps

- Connectivity between aquifer and springs
- Sensitivity of springs to aquifer drawdown
- Limited species distribution information
- Sulfides, heavy metal and metalloid accumulation and mobilisation in springs
- Degree to which spring ecosystems have been affected by post-European disturbance

Structural geology model for Birribirriana Springs



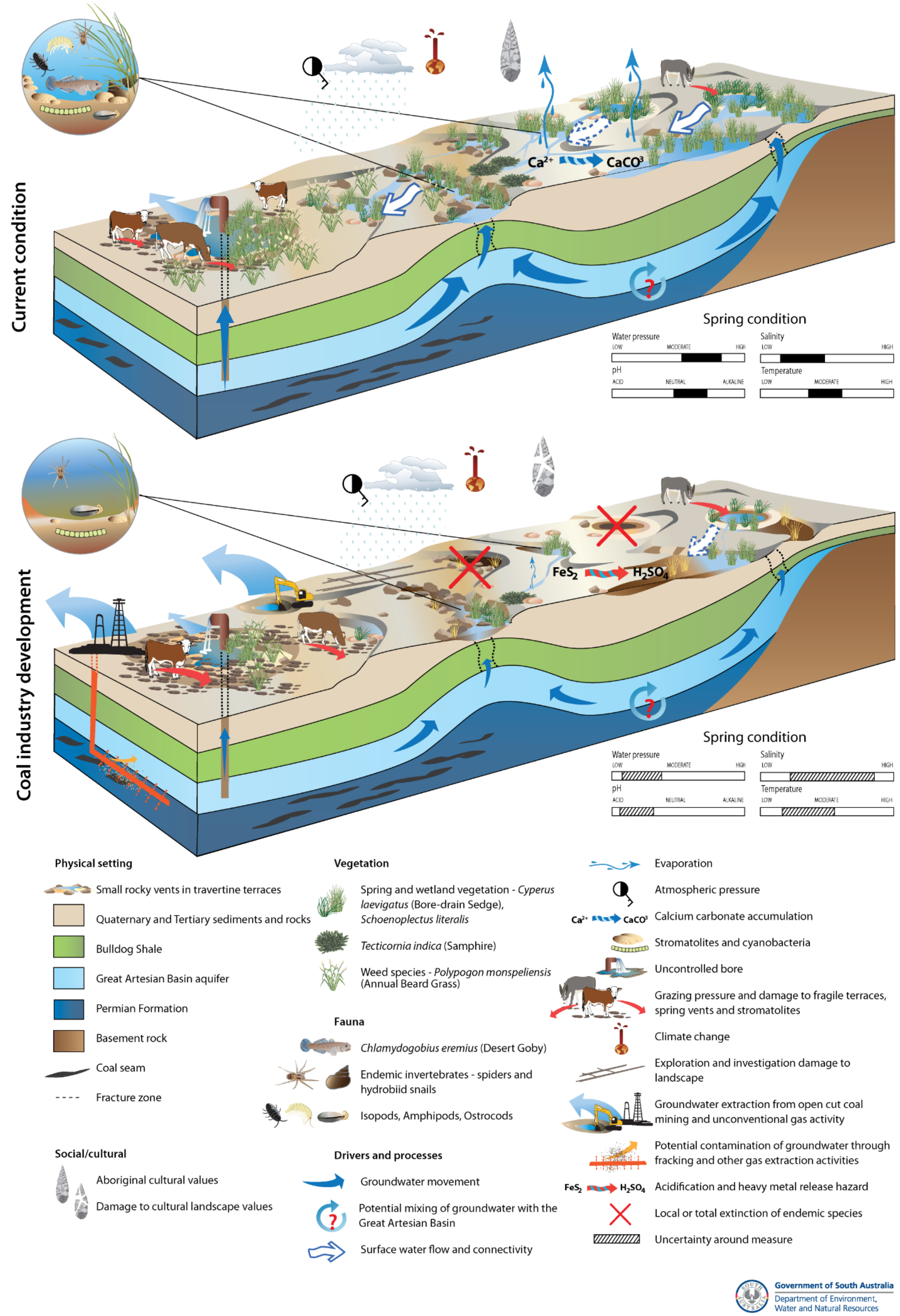


Figure 4-8 GAB generalised model for rocky seeps and terraces

4.4 Diffuse discharge (scald) model

The generalised diffuse discharge (scald) model graphically demonstrates the processes underlying the different types of habitats identified within this spring type in the study area. Whilst not considered a spring *per se*, the diffuse discharge or scald model describes a functioning GDE that can often be found in association with GAB springs, and one that can further improve the inter-connection of nearby springs through saturated soils thus allowing colonisation by salt tolerant wetland species. Key drivers include hydrogeological, climate, geomorphology and water quality parameters. Agents of change are external factors that impact on the drivers and values, changing them in either a positive or negative direction. Values are groupings of the features of the springs that have been identified as important in spring function or health. They include vegetation communities, endemic species, ecosystem services and cultural values. A detailed explanation of the parameters relevant to the diffuse discharge scald model can be found in Table 4.2.

The described processes are supported by a detailed evidence base (Appendix D). The model shown in Figure 4-9 identifies the relationship between each of the key drivers, the agents of change and the values represented by the ecosystem. The impacts of the agents of change on the drivers and values on the springs are shown in greater detail in the supporting evidence base tables (refer Appendix D).

Table 4.2 Variables used in the diffuse discharge (scald) model, with justification for parameter choice

Hydrogeology	
Groundwater Pressure	Groundwater (aquifer) pressure at the discharge site. This parameter is modelled as it is impossible to definitively measure the aquifer pressure for every spring.
Spring Discharge	Nearby spring discharge can infiltrate back into shallow water table and help sustain scald habitat
Climate	
Atmospheric Pressure	Atmospheric pressure can have a significant impact on discharge. Extreme low pressure systems have been observed to cause GAB spring wetted area to increase to nearly double the average area (Gotch pers. obs.).
Evaporation	Evaporation cools the substrate and surface temperatures. Capillary action from this helps to draw moisture to the surface.
Rainfall	Sudden influxes of fresh water into spring habitats from localised flooding can result in spring macroinvertebrates going hyperosmotic and literally rupturing internally (N. Murphy (The University of Adelaide) pers. comm. 2007). This has resulted in localised extinctions of the isopod *Phreatomerus latipes* at McLachlan Springs (Fatchen (Fatchen & Fatchen Consultants) pers comm. to Gotch 1999). Rainfall events that result in localised flooding can also increase the connectivity between springs in a spring groups, and in extreme events, connectivity between spring complexes providing a potential vector for species dispersal (Gotch *et al.*, 2008).
Physical setting	
Local Geology and Soils	The interlaying material between the aquifer and the surface has a strong influence on the water chemistry at the discharge site. In the northern and western portions of the Lake Eyre Supergroup the high accumulation of sulfides may be a result of local geology and soils
Substrate Temperature	The cool substrates are the refugia habitat for a number of scald endemic species
Hydrology	
Sub Surface Flow Rate	This is the discharge rate from the aquifer to the shallow water table
Shallow Water Table Level	The depth to total saturation in the shallow water table
Drainage Channel Pool Depth	Deeper pools remain cooler and persist longer. Typically they remain less saline for longer periods of time
Drainage Channel Pool Temperature	Cooler pools are able to sustain more biota and more biodiverse systems
Water chemistry	
pH: Substrate	Unknown factor but likely to affect scald biota
pH: Shallow Water Table	Unknown factor but likely to affect scald biota
pH: Drainage Channel	Fish species very sensitive to changes in pH
Conductivity: Substrate	Unknown factor but likely to affect scald biota
Conductivity: Shallow Water Table	Unknown factor but likely to affect scald biota

Conductivity: Drainage Channel	Flora and fauna of drainage channel pools tend to be regulated by conductivity. Changes in conductivity lead to changes in structure and function of the ecological community. This varies from species to species
Values	
Vegetation Communities	Vegetation communities dependent on scald discharge to survive
Scald Endemics Species	Flora or fauna that is either endemic to scalds
Aboriginal Culture	Some scalds are important culturally to the aboriginal peoples who shared the landscape. Consequently the scalds have significant stories, songs (Ularaka for Arabana or Tjukurpa for the Lower Southern Arrente) and numerous artefacts associated with them
Other Fauna	Drainage channel pools and other scald habitats are utilised by non-wetland species either as foraging areas, nesting sites or after rain events temporary water sources
Agents of change	
Groundwater Extraction	The key driver of drawdown (the reduction in potentiometric head of an aquifer) which is the major cause of scald contraction
Groundwater Contamination	Groundwater contamination can occur as a result of external inputs of chemical into the water, i.e. BTEX chemicals generated during fracking or released from coal seams either from depressurising seams or from underground coal gasification (UCG). BTEX from fracking is unlikely to be a problem due to the tiny concentrations generated relative to the large volumes of water however UCG has the potential to contaminate large areas if a critical failure was to occur. Other sources of contamination include inputs from non-GAB aquifers as a result of pressure differentials generated from drawdown.
Physical Disturbance	Physical disturbance on a scald can change the surface hydrology and impact on drainage channel pools and .sub surface flow.
Grazing	Grazing includes domestic animals such as cattle and sheep as well as feral grazers such as camels and donkeys and native grazing animals. It also includes pugging (the trampling of scalds by animals) and the introduction of nutrients from animal faeces.
Natural long term decline	Natural long term change is an element of the driver groundwater pressure. The western margin of the GAB currently receives very little to no recharge with the entirety of the study site being naturally in decline (i.e. natural discharge rates exceed recharge rates) (Rousseau-Gueutin *et al.,* 2013). Artificial water extractions may further enhance this natural long term decline.

Diffuse Discharge (Scald) Model

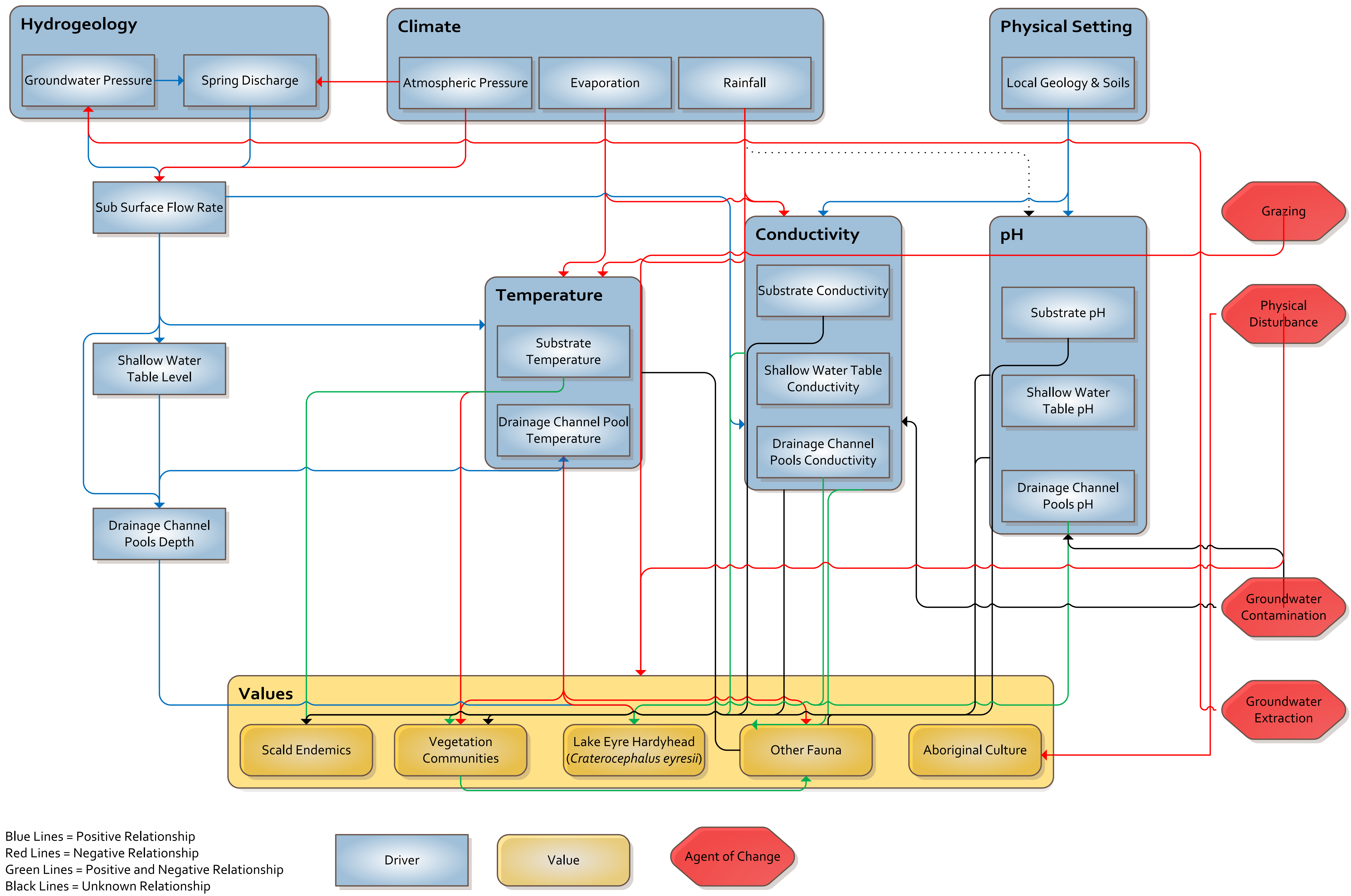


Figure 4-9 Generalised diffuse discharge (scald) GDE model (box and line)

Diffuse discharge zones (scalds)

Diffuse discharge zones or scalds are highly saline, wet to damp areas associated with diffuse groundwater discharge from the Great Artesian Basin (GAB), through vertical leakage or leakage associated with fractures supporting springs. Water from the GAB infiltrates and recharges the local shallow unconfined water table, and is drawn to the surface by the osmotic potential created from extreme evaporation rates in the area. Diffuse discharge zones can be found adjacent to springs or in isolation. Despite having no free-flowing surface discharge, these areas remain damp to moist all year round. Due to the extreme nature of the saline habitat, unique fauna and flora has evolved, including an endemic onisicidian. Flora adapted to saline conditions like *Frankenia* sp. and *Tecticornia* sp. grow at the margins to the scalds and provide habitat to other species, including an endemic bee, *Lasioglossum frankenia*.

Small diffuse discharge scald forming on Lake Frome (salt lake) adjacent to mound springs

Small spring vent surrounded by diffuse discharge scald at Lake Warrangarrana

Natural drivers

- Groundwater pressure
- Groundwater chemistry
- Local geology and geomorphology
- Influence of atmospheric pressure and lunar tidal cycle on spring flow
- Evapotranspiration (particularly evaporation)

Impacts

- Maintains ecosystem integrity (spring flow, connectivity and biodiversity)
- Isolation and extreme habitat driving endemism
- Variation of supporting flows from tides and atmospheric pressure
- Wet area changes from evapotranspiration
- Spatial variation in surface temperature due to evaporation

Human induced drivers

- Aquifer drawdown from current developments (e.g. pastoral bores, mining and town water supplies)
- Grazing pressure, and trampling by domestic and feral animals
- Tourism pressure
- Introduced weeds and pests

Impacts

- Reduction and fragmentation of habitat
- Reduced biodiversity
- Increased risk of extinctions
- Increased salinity and acid sulfate hazard
- Damage to spring structure
- Changes in community ecology

Potential impacts of coal mining and unconventional gas activity

- Significant decrease in aquifer pressures, due to groundwater extraction
- Increased risk of extinction of short-range endemics
- Contamination of groundwater
- Structural destabilisation of aquifers and aquitards amplifying drawdown impacts
- Reduced biological values

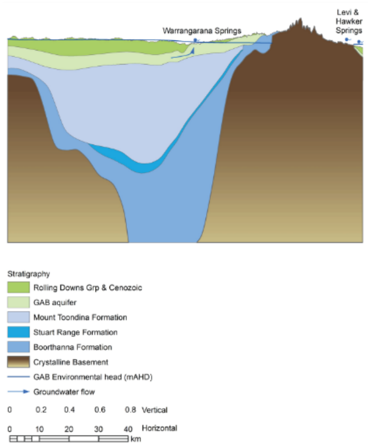
Connectivity

Diffuse discharge zones or scalds vary in size and can be linked by saline drainage channels that occur naturally within the landscape. Scalds facilitate the connectivity of nearby springs, as the substrate is already close to saturation. Some scalds are quite isolated due to local geomorphology of the area.

Critical chemistry

Largely unknown. However it is possible for sulfides and heavy metals (e.g. Arsenic) to accumulate in anoxic substrates below the surface.

Structural geology model for Warrangarrana Springs



Knowledge gaps

- Connectivity between aquifer and scalds
- Sensitivity of scalds to aquifer drawdown
- Limited biodiversity and species distribution information
- Effects or likelihood of sulfide and heavy metal accumulation in scald areas

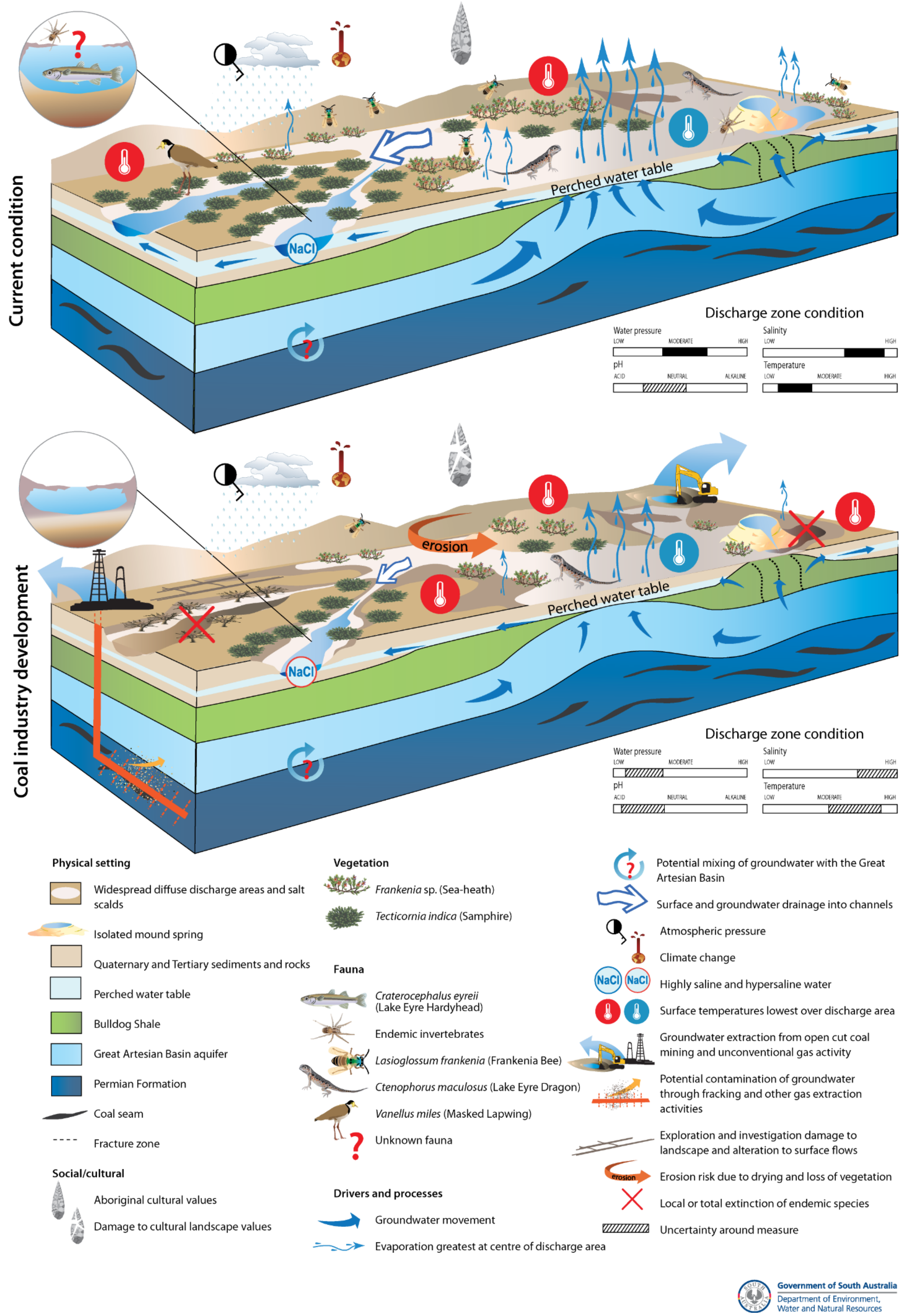


Figure 4-10 Diffuse discharge (scald) model

5 Results: springs complex summaries

A total of 7 spring complexes (including 63 spring groups) were visited or were attempted to be visited during the 7 month field program. Spring types were characterised within each spring complex, as summarised by Table 5.1. Refer to Section 4 and Appendices B and D for a detailed descriptions of SA GAB spring types discussed herein. Note that all GAB springs in SA are listed as threatened ecological communities under the EPBC Act (Fensham et al. 2007).

Table 5.1 Surveyed spring complexes, spring groups and associated types

				Spring types								
Spring complexes	**Spring groups**	**Visited[1]**	**Surveyed**	**Travertine mounds**	**Astrobleme**	**Sand mounds**	**Flat depressions**	**Abutment springs**	**Thermal mounds**	**Rocky seeps terraces**	**Diffuse discharge (scald)**	**Notes[2]**
Dalhousie (13 spring groups)	Bananas	✓	✓	✓					✓		✓	
	Blind Fish	✓	✓						✓		✓	
	Cadni Dreaming	✓	✓	✓						✓	✓	
	Dalhousie Proper	✓	✓	✓					✓		✓	
	Donkey Flat	✓	✓	✓					✓		✓	
	Errawanyera	✓	✓	✓					✓		✓	
	Frog Dreaming	✓	✓							✓	✓	
	Ilpikwa	✓	✓						✓		✓	
	Kingfisher	✓	✓	✓					✓		✓	
	Loveheart	✓	✓						✓		✓	
	Main Pool	✓	✓						✓		✓	
	Mt Jessie	✓	✓	✓							✓	
	Witcherrie	✓	✓						✓		✓	
Mt Dutton (6 spring groups)	Allandale									✓		NWC
	Big Cadna-owie			✓							✓	NWC
	Little Cadna-owie			✓						✓	✓	NWC
	Ockenden Old	U									✓	Unable to locate[3]
	Ockenden Proper			✓								NWC
	Wandillinna						✓					NWC
Mt Toondina	Mt Toondina				✓							
Peake Creek (22 spring groups)	Balyaweelbanyana	✓		✓							✓	Extinct
	Birribirriana	✓	✓	✓			✓				✓	
	Boundary Camp	✓	✓			✓					✓	Only bore flows now
	Cardajalburrana	✓	✓	✓							✓	
	Coorandatana	✓	✓				✓				✓	Date Palm only
	Cootabarcoollia	✓	✓			✓						
	Cootanoorina	✓	✓	✓			✓				✓	Mole Hill
	Edadurrana	✓	✓							✓		
	Goorgyana	✓				✓				✓		
	Keckwick	✓	✓	✓								
	Little Piabullina	U										Unable to locate
	Old Nilpinna (Homestead)	✓	✓				✓			✓		
	One Mile Bore						✓					Bore in spring

Spring complexes	Spring groups	Visited[1]	Surveyed	Spring types: Travertine mounds	Astrobleme	Sand mounds	Flat depressions	Abutment springs	Thermal mounds	Rocky seeps terraces	Diffuse discharge (scald)	Notes[2]
	Oodloodlana	✓	✓							✓		Only bore flows now
	Oortookoolana	✓								✓		Extinct
	Saline	U										Unable to locate
	South Well	✓	✓			✓						
	Tidnamurkuna	U										Formerly located in Mt Denison Complex
	Warrangarrana	✓	✓							✓	✓	
	Weedina	✓	✓							✓	✓	
	Weedina North	U										Unable to Locate
	Wintro Warduna	U										Unable to Locate
Mt Denison (9 spring groups)	Breakneck	U										Extinct and unable to locate
	Blind	U										Extinct and unable to locate
	Coppertop	✓		✓				✓				Extinct
	Freeling North	✓	✓					✓				
	Freeling	✓	✓					✓		✓		
	Murra murrana	✓		✓				✓				Extinct
	Mud	✓						✓				Extinct
	Sandy Creek	U						✓				Extinct Unable to locate
	Tidnamurkuna	U										Unable to locate
	Wilparoona	✓								✓		No Free water not surveyed during site visit
Lake Cadibarrawirracanna (10 spring groups)	Castine	U										Large saline waterhole
	Eurilyna	✓										Unable to locate
	Giddi-Giddinna	✓										Extinct
	Giddiphantom North	✓										Not a spring
	Giddiphantom South	✓										Not a spring
	Lake Cadibarrawirracanna	U										Unable to locate
	Oolgelima	✓	✓				✓			✓		
	Oolgelima West	✓	✓				✓					
	Widigiedona	U										Unable to locate
	Wirracanna	U										Unable to locate
Billa Kalina (3 spring groups)	Billa Kalina	✓	✓	✓								
	McEwins	✓		✓								NWC
	Welcome	✓		✓								NWC

1 U = searched for but unable to locate.
2 NWC = surveyed by the recent National Water Commission project (2013), so not surveyed by the LEBSA project.
3 Old Ockenden was unable to be located during field surveys. Subsequent to the field survey examinations of pastoral board data and maps show reference to a blind spring at this site. This term has been used in the past to describe an area of wet ground that doesn't fully form a spring. This term has fallen into disuse over the past 40 years and may have been the source of the confusion around Old Ockenden during the 1996 Lake Eyre South Spring Survey, which was the only previous mention of this spring.

The following sub-sections summarise the results of the field survey program by spring complex.

5.1 Dalhousie Springs Complex

Dalhousie Springs is the only spring complex located in the Dalhousie Supergroup. The springs are located almost 1000 km north–north-west of Adelaide in Witjira National Park. The complex contains 148 active vents spread amongst 13 spring groups (Figure 5-1). Another spring group, Bees Spring, is extinct and is likely to have been so for over 60 years.

The Lower Southern Arrente, Wangkangurru and Arabana Aboriginal peoples have an association with Dalhousie Springs that extends back thousands of years.

The springs were first discovered by Europeans in 1870 by a group of workers on the overland telegraph line. Three men are variously attributed with the discovery and naming of the springs, though it is possible all three were present at the time. In 1893 Christopher Giles told HC Talbot he was the first to see and name them the Lady Edith Ferguson Springs (Manning, 2006). Richard Randall Knuckey, a surveyor on the Overland Telegraph Line, was reported as being a part of a group that found the springs and makes a detailed description of the springs in Richards (1914). He also gives an account that the group had decided that the most important discovery they made would be named after Lady Edith Ferguson, who had been a major benefactor of the expedition workers. In a later letter published in the Royal Geographical Society Proceedings, Vol. 62 pp 42-43 he states – "*It was my luck, with Mr C. Giles, to find the Dalhousie Springs* ...". The other person credited with the discovery is Albert T Woods, the Overland Telegraph Line overseer at the time, in Cockburn (1908). Irrespective of who found and named the springs, Lady Ferguson requested the springs be named after her father, the Marquis of Dalhousie.

A significant number of studies have been undertaken at this site due to the size and uniqueness of these springs. An important body of work has been captured and summarised in Zeidler and Ponder (1989), which covers early investigations on history, geology, hydrogeology, flora and fauna. Another significant body of knowledge can be found in the seven volume *Allocating Water and Maintaining Springs in the Great Artesian Basin* series of reports published in 2013. Smaller but no less significant investigations into weeds (Gotch *et al.* 2005; Noack, 1994, 2002) and fish (Kodric-Brown & Brown 1993; Kodric-Brown *et al*. 2007) further describe the ecology and condition of Dalhousie Springs.

As part of this study fish communities were sampled, as were flora and hydrological parameters including temperature, pH, dissolved oxygen and conductivity. Other elements of the standard survey are not included as they had been documented in previous works.

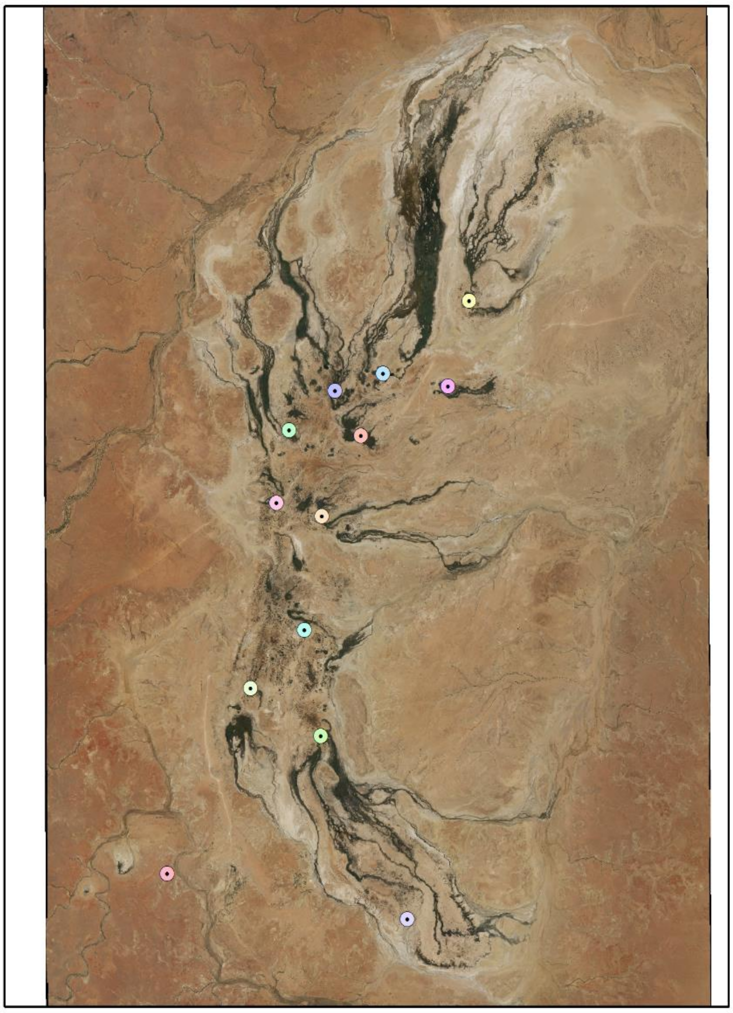
5.1.1 Geomorphology, geology, hydrogeology and hydrochemistry

Dalhousie Springs occurs in a depression running almost north–south along its length. This depression is approximately 45 km long and 35 km wide. The spring complex within the depression is approximately 20 km long and 8 km wide (Figure 5-1). The surrounding landscape is gibber plain, largely devoid of perennial vegetation except at creek lines. Upper drainage lines are vegetated with Gidgee (*Acacia cambageii*) while lower drainage areas will be dominated by samphire (*Tecticornia* spp.). The spring area is predominately Dalhousie landsystem around the springs and perennial wetlands in the springs.

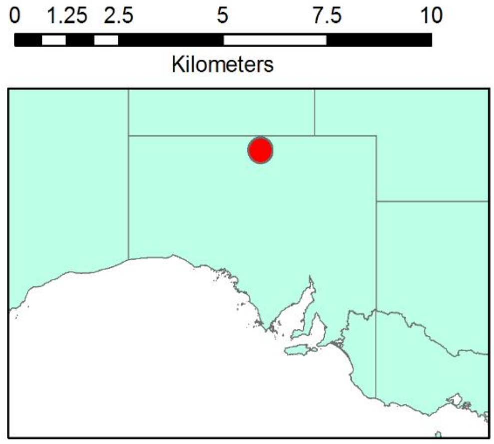
The most accepted view of the geological structural drivers of this complex is that the depression is the exposed core of the Dalhousie Anticline (Krieg, 1989). Karlstrom *et al.,* (2013) proposed an alternative theory to the Anticline model one with oppositely facing monoclines above a horst structure that resulted from an inversion of a Proterozoic graben. On the basis of existing seismic data, this concept warrants further investigation.

Kreig (1989) ascribes the flow from Dalhousie as originating GAB aquifers, however recent investigations by Wolaver *et al.* (2013) show a strong likelihood that Permian aquifers, most likely those of the Pedirka Basin, may also be contributing to the flows at Dalhousie and in the maintenance of the water temperatures. Development of resources that target the Pedirka Basin therefore are potentially going to have an impact at Dalhousie. Further investigation is required to address this critical knowledge gap.

For a detailed examination and revision of the hydrogeology and hydrochemistry at Dalhousie Springs and a conceptual model of the hydrogeological drivers for the springs function refer to Wolaver *et al.* (2013) and Karlstrom *et al.* (2013).



Spring Group Codes	DBA, DEA, DFA, DDB, DGA, DDA, DGB, DCC, DAA, DCD, DCA, DHA, DCB
Number of Vents	148
Field Alkalinity	93-235 $CaCO_3$ mg/L
Temperature	30.2-42 °C
Elevation range	104.5 – 136.8 mAHD
EC range	1067-13151 µS/cm
pH range	6.3-8.41
ORP	Not available
Significant species count:	32 (16 endemic)



Points displayed represent centroids of spring groups

Figure 5-1: Dalhousie Spring Complex summary

5.1.2 Spring types

The different spring types observed in the Dalhousie Complex include:

- Thermal mounds
- Travertine mounds
- Rocky seeps and terraces.

The majority of springs at Dalhousie fit into the thermal mound type but also present are a number of smaller travertine mounds and to the south a number of cooler rocky seeps.

Section 5 and Appendices B and D provide a detailed description of the spring types supported by associated references (Appendix D).

5.1.3 Project surveys; reassessment and knowledge in-fill

Relative to the majority of springs within South Australia Dalhousie is one of the most studied and understood of the spring complexes. Numerous studies have occurred here beginning with White (1914) and most recently the NWC AWMSGAB project.

Existing data were collated, reviewed and uploaded into the relevant Government of South Australia databases. A specific investigation of endemic fish populations and parameters likely to influence them were undertaken here as part of this study. The parameters included water temperature, depth, location in the spring (i.e. vent pool, channel or tail), pH, conductivity, DO, vegetation structure and composition, litter depth and shading. The information collected as part of this study has been incorporated into BDBSA.

5.1.4 Biological values

Dalhousie Springs is the oldest and most biodiverse of all of the GAB Springs in Australia (Priestley *et al.*, 2013; Gotch 2005). It contains over 16 species endemic to Dalhousie and numerous sub-tropical and/or coastal floral relicts (Figure 5-2). Significantly there are five endemic fish species as well as another more widespread species along with endemic crustaceans, molluscs and arachnids. Dalhousie also is one of the few GAB springs in South Australia to support frogs (the other is Freeling Springs). Over 100 plant species have been recorded from the springs (Mollemans, 1989; Noack, 1994). Witjira-Dalhousie Springs was listed on the National Heritage List on 4 August 2009.

A number of potential impacts on the spring biota as a result of drawdown from coal development activities both within the Arckaringa and Pedirka Basins are possible:

- Drawdown resulting in reduced flows will reduce habitat areas and free water areas that will negatively impact on aquatic species and will result in increased competition for resources with Phragmites for many of the rarer plant species
- Drop in temperature from drawdown in the Pedirka Basin that could have catastrophic impacts on spring endemic species, particularly those species of mollusc, crustaceans and plants located around hot vent pool areas. The current hydrogeological models for Dalhousie Springs identify the Pedirka as the principal source of heat for the water discharged at Dalhousie (Wolaver *et al.*, 2013). Ergo a reduction in pressure in the Pedirka could result in less water from this basin mixing with GAB waters, and thus a drop in temperatures at Dalhousie Springs.

Dalhousie Springs is the most ecologically and biologically intact spring group in South Australia. Despite overgrowth of Phragmites in response to a reduction in grazing animals, and the (up until now) lack of reintroduction of traditional Aboriginal management practices, the springs are in very good condition (Roberts, 2013, Kodric *et al.*, 2007). Some reduction in flow has been observed in some of the southern springs however this may be as a result in changes in tail hydrology and pathways rather than as a result in a decline in actual flow. This is currently being investigated as part of the Australian Government funded Caring for Country "Desert Jewels" project.

5.2 Mt Dutton Spring Complex

Located approximately 60 km SSE of Oodnadatta around Mt Dutton, the Mt Dutton complex of springs comprises of six spring groups and contains a total of 37 spring vents. One of the spring groups, Old Ockenden, has only ever been located by a set of GPS points in the 1996 Lake Eyre South Spring Survey conducted by WMC (now BHP Billiton) in 1996. No springs were ever found in this location and further investigation reveals these points were scaled from an old map. Within 2 km of this point is a diffuse discharge scald. Examination of pastoral inspection maps from 1960 show this area as having a blind spring present at this site. The term blind spring is misleading and was used locally to describe an area that remains wet but without a discrete spring vent—a diffuse discharge scald. This can lead to confusion in the present day as the term is no longer used. It is unlikely that Old Ockenden was anything other than a scald with a confusing name on a map. The other springs in this group are all flowing and in reasonable to poor condition (D. Niejakle unpublished data for the Lake Eyre Spring South Survey, and T. Gotch, pers. observation, 1999–2015).

The springs in this complex have important significance to the Arabana. A large grave site exists in the sandhills around Big Cadna-owie of people who died as a result of an influenza outbreak in 1919 and care needs to be taken when working in the vicinity of these springs. The Arabana name for Mt Dutton "Kadnjawi" translates literally to hill-water, i.e. a hill with springs (Hercus & Sutton, 1985). The first Europeans to enter this area was John McDouall Stuart and his party who first moved through this area during his 3rd expedition on the 5 January 1860. He describes this area as having plentiful grass and freely flowing water (McDouall Stuart & Hardman (ed), 1986).

5.2.1 Geomorphology, geology, hydrogeology and hydrochemistry

The springs in this complex are located around Mt Dutton which is the northern-most surface expression of the Peake and Dennison Inlier, and as such forms part of the constraining eastern boundary of the Arckaringa Basin. This area is slightly to the north of the Neales River floodplain and is bounded by the Plantation sand hills to the north and northwest. The hill itself is roughly 10 km long and 5 km wide. Much of the hill is exposed Bulldog Shale, particularly on the north-western side. Spring groups occur on the northern, north-western, south-western and south-eastern sections of the hill. The largest spring in the complex is the main vent at Big Cadna-owie which is a fast flowing seep that has created a small mound on a hill side which then flows down and across a gypsum flat.

The majority of the other springs at this site are small springs located on the northern and southern edges of the hill. An outlying spring occurs several kilometres to the east of Big Cadna-owie, Ockenden Spring. This spring shows differing hydrochemistry to the other spring groups within the complex (Keppel *et al.* 2015a). More detailed investigations of this complex were undertaken during the NWC funded AWMSGAB project. Hydrogeologically Keppel *et al.* (2015a) have assigned conceptual model 2: Basin margin, sediment thinning as the most likely driver for Big Cadna-owie, and model 1b: Basin margin, structure (fault zone) for Ockenden spring. They did not visit the other springs in the complex but based on the proximity to the outcropping basement they are likely to best fit model 3: Basin margin structure/sediment thinning combination.

Figure 5-2 provides a summary of the hydrogeological data collected for the Mt Dutton Springs Complex.

5.2.2 Spring types

The majority of the springs present here are abutment springs, there are a selection of rocky seeps present within the Little Cadna-owie, and Allandale groups while Ockenden Spring displays the sand mound type. Old Ockenden has been removed from the SA GAB Spring Master List for reasons outlined above.

Section 5 and Appendices B and D provide a detailed description of the spring types supported by associated references (Appendix D)

5.2.3 Project surveys; reassessment and knowledge in-fill

The springs in this complex with the exception of Old Ockenden were surveyed in detail during the NWC AWMSGAB project in July 2011. These investigations included geology, hydrogeology, hydrochemistry, flora fauna and spring mapping and elevation survey. At this time a total of 37 spring vents in 6 spring groups are present. Of these 18 have free water present, four were saturate at the time of sampling and the remaining 15 were capable of sustaining wetland vegetation.

Effort was made to locate Old Ockenden however this again proved unsuccessful.

5.2.4 Biological values

Springs in this complex exhibit three vegetation community types. They are either dominated by reeds (*Phragmites* spp., *Typha domingensis*) or Spiny Flat-sedge (*Cyperus gymnocaulos*) at the vent. Tail vegetation is typically composed of Bore-drain Sedge (*C. laevigatus*) and Salt Couch (*Sporobolus virginicus*). Other vegetation species include algae (*Chara* spp.), *Schoenoplectus subulatus* and various samphire (*Tecticornia* spp.) species.

Overall, this spring complex has low to moderate diversity of significant species (Figure 5-2). Notable species include the endemics *Fonscochlea zeidleri*, *Ngarawa dirga*, *Venatrix fontis*, *Chlamydogobius eremius* and an unidentified snail species that was collected from Wandillina spring. Significant flora species recorded at this site include Bare Twig-rush (*Baumea juncea*) and Sea Rush (*Juncus krausii*) both of which are new records for these plants at this site. Two springs in the Wandillina group are supporting three well established River Red Gum (*Eucalyptus camaldulensis*) trees. These trees are locally rare and it is very unusual to see them on springs.

Several introduced species are present at this complex and have the potential to have significant impacts on the springs they include Mosquitofish (*Gambusia holbrooki*), Date Palm (*Phoenix dactylifera*), Annual Beard-grass (*Polypogon monspeliensis*) and Buffel Grass (*Cenchrus ciliaris*).

Other impacts on the biological values of the springs here include the excavation of two springs at Little Cadna-owie and the insertion of bore casing into a number of spring vents.

A number of potential impacts on the spring biota as a result of drawdown from coal development activities both within the Arckaringa and Pedirka basins are possible.

- Drawdown resulting in reduced flows will reduce habitat areas and free water areas that will negatively impact on aquatic species and will result in increased competition for resources with Phragmites for many of the rarer plant species.
- Loss of habitat area will result in significant pressure on aquatic fauna and significant plant species. Due to the small size of many of these springs even a minor reduction in flow could result in individual springs drying up.

Spring Group Codes	UAS, UBC, ULC, UOP, UOS, UWS
Number of Vents	37
Field Alkalinity	197-221 $CaCO_3$ mg/L
Temperature	Not Available
Elevation range	68.6 – 107.8 mAHD
EC	1040-10532 µS/cm
pH	6.11-8.2
ORP	Not available
Significant species count:	7 (4 endemics)

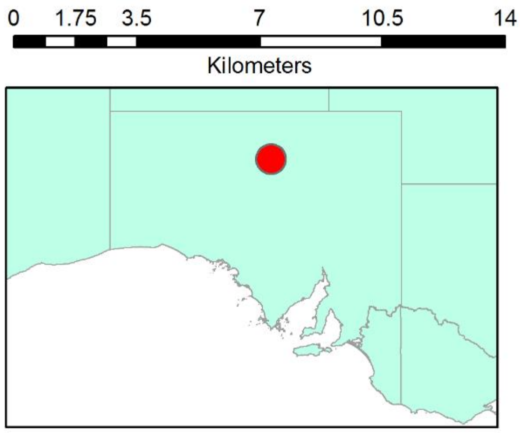


Figure 5-2 Mt Dutton Spring Complex summary

5.3 Mt Toondina Spring Complex

Mt Toondina Spring Complex is located west of the Peake and Dennison Inlier approximately 35 km from the nearest basement outcrop at Mt Dutton. A number of small damp to dry springs and one flowing spring occur around the margins of Mt Toondina. Until 1976 this site was thought to be a salt dome or diapir but this was challenged by Youles (1976) who proposed its origin was from an impact. This has been supported since by a number of geological and geophysical investigations (Plescia *et al*., 1994; Dressler, 2010; Keppel *et al.,* 2015a).

The astrobleme sits in the middle of a large, relatively flat gibber plain and is an obvious high point in the surrounding landscape. It is fringed with Broughton Willow (*Acacia salicinia*) and Elegant Wattle (*A. victoriae*) and the centre plateaux vegetation comprises a very sparse cover of Salt Bush (*Atriplex* spp.) and samphire (*Tecticornia* spp.). The centre plateaux has very complex geology discussed below.

This site is important to the Arabana and is an important part of the Kangaroo history. Numerous sites and places exist here, and vehicles should not drive on the top of the astrobleme. It is unknown who the first Europeans were to observe this site.

5.3.1 Geomorphology, geology, hydrogeology and hydrochemistry

As mentioned above Mt Toondina is an astrobleme from an impact that had to have occurred in the last 110 million years. Since then it has been heavily eroded so only the hard impact site remains as a low hill in the landscape. The outcrop geology at Mt Toondina is complex, consisting of Mt Toondina Formation, JK aquifer, Bulldog Shale and quaternary sediments.

Regional groundwater flow and hydrochemistry suggests a source from the west or north-west of the springs. Groundwater is currently thought to be primarily sourced from the GAB. Modelling by Dressler (2010) suggests that Mt Toondina formation sediments at the centre of the structure are less porous and permeable than the GAB aquifer rocks at this location. Added to this Dressler (2010) hypothesised that groundwater flow within the Mt Toondina Spring Complex is controlled by advective flow from the subsurface to the ring of vegetation around the springs, but also that the central portion of the impact crater is influenced by free convective processes. This is discussed in detail in Keppel *et al. (*2015a). The hydrogeological conceptualisation for this spring complex is 4: astrobleme.

5.3.1 Spring types

There is only one type for this site, astrobleme. There were two flowing free water vents present here in 2014, one large heavily modified and excavated vent and another small seep. There are several small ephemeral spring discharges on the southern and northern margins that periodically support wetland vegetation. At the time of the spring surveys they were all dry and the wetland vegetation was nearly all dead.

Section 5 and Appendices B and D provide a detailed description of the spring types supported by associated references (Appendix D).

5.3.2 Project surveys: reassessment and knowledge in-fill

Mt Toondina has been visited in the past mainly for geological and hydrogeological investigations (Youles, 1976; Plescia *et al.*, 1994; Dressler, 2010; Keppel *et al.* 2015a). It was investigated in 1984 as part of the Heritage of the Mound Springs Survey and by Gotch in 2002 investigating mound spring wolf spider populations (Framenau *et al.* 2006; Gotch *et al.* 2008). Field investigations of this site to address spring locations and elevations as well as data gaps were undertaken in November 2014.

5.3.3 Biological values

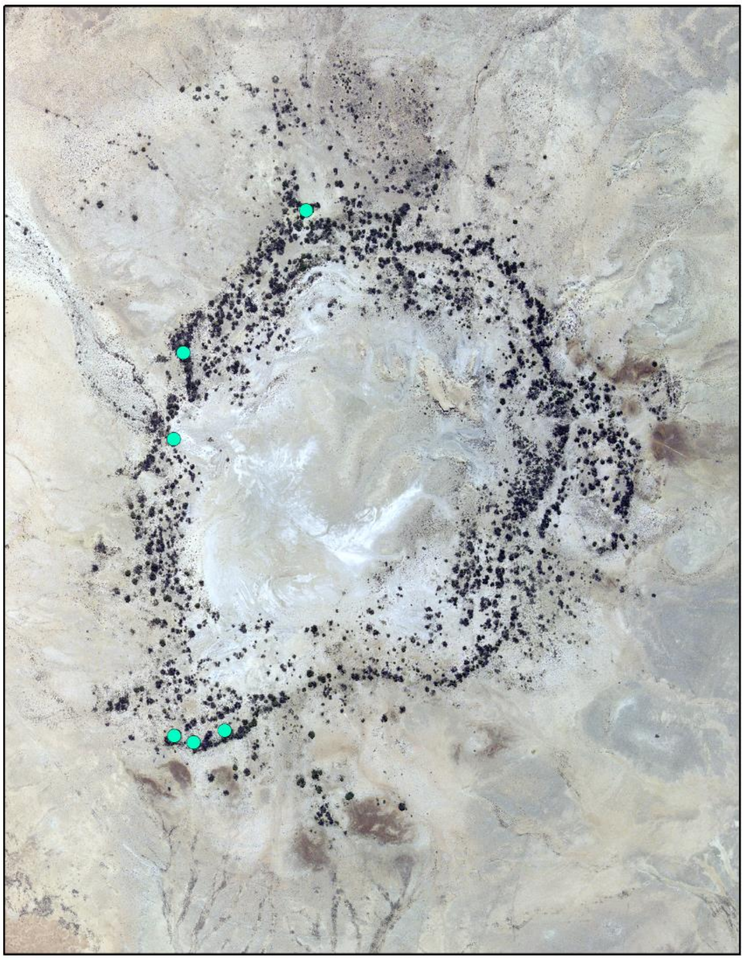
At the time of this survey there were only two flowing springs at this site (Figure 5.3). This marks a decline since 2002 when several small seeps supporting wetland vegetation were noted around the margins of the astrobleme. These had declined to only supporting wetland vegetation during the 2009 visit. The largest vent at this site has been heavily modified and was excavated some time during the late 1990s. It now functions as a small deep waterhole which despite no obvious runoff remains fresh and of reasonable quality. The other flowing vent is extremely low flow and supports very little wetland vegetation due to its rocky substrate.

Glover investigated this spring for fish sometime between 1970 and 1984 and has recorded the presence of Lake Eyre Hardyheads at the main spring (McLaren *et al.*, 1985) however they were not located here by Gotch in 2002, 2009 or in 2014 as part of this survey. This could be due to the disturbance created at this spring when it was excavated, or due to insufficient sampling effort.

In 2002 this spring maintained a large abundance of algae (*Chara* sp.) however this had declined in 2014 most likely in response to cattle. Spring wolf spiders (*V. fontis* and *Artoria howquaensis*) have both been observed here in moderate numbers on all visits and there are numerous unidentified Dytiscid beetles and unidentified Odonata (dragonflies and damselflies) present as well.

Vegetation at the now-dry seep is predominantly Common Reed (*Phragmites* spp.) as well as a small, dead patch of bulrush (*T. domingensis*).

Toondina springs are very vulnerable to drawdown from coal developments. There high elevation relative to the local potentiometric head, combined with the direct inputs of water from the Permian Arckaringa formation, mean they could be significantly affected.



Spring Group Codes	UTS
Number of Vents	6
Field Alkalinity	Not available
Temperature	Not available
Elevation range	103.2-107.8 mAHD
EC	Not available
pH	Not available
ORP	Not available
Significant species count:	2

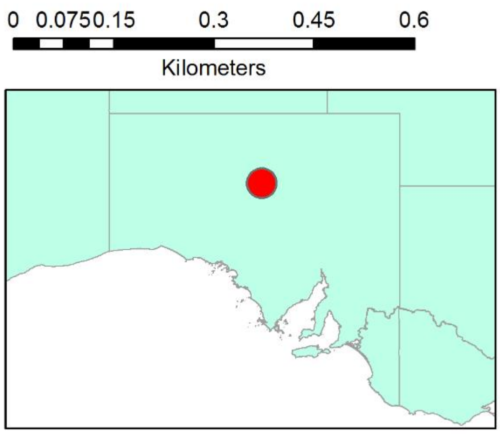


Figure 5-3 Mt Toondina Spring Complex summary

5.4 Peake Creek Spring Complex

Springs in the Peake Creek Complex are located west of the Dennison Ranges and in the vicinity of the Peake and Weedina Creeks. This complex consists of 21 groups, 9 of which are either extinct, had flows reduced to only supporting dry wetland vegetation or were no longer able to be located and presumed extinct (Table 5.1).

John McDouall Stuart passed through this area in 1859, however many of the springs initially remained undiscovered for some time. The first Europeans to see these springs are unknown but are likely to be the early lease holders taking up the pastoral runs and later workers on the overland telegraph line and the North-South Railway (now known as the Ghan Railway). Pastoral lease maps from 1885 identify several of the springs in this complex (SA Pastoral Board Station Dockets). The Outback Areas Authority Burial Register (2006) identify a number of graves associated with sites in the area, including the grave of Robert Bowden who was buried at Old Cootanoorina (currently known as Mole Hill) in 1891.

This area is culturally significant to Aboriginal peoples, especially the Arabana, but it also contains sites and stories associated with the Lower Southern Arrente and Thirrari peoples. There are numerous artefact sites associated with the springs in the regions, and the areas of diffuse discharge around Mole Hill and Cardajalburrana are of considerable importance as a part of the story explaining the creation of Kati Thanda-Lake Eyre.

5.4.1 Geomorphology, geology, hydrogeology and hydrochemistry

Springs in this complex occur west of the Dennison and Davenport Ranges and mainly along the Peake and Weedina Creeks. This area is part of the Stony Plains Bioregion and is predominantly gibber plains with large ephemeral creek systems. There are some sand dune areas in the north eastern part of the complex which contain some springs as well. Large diffuse discharge scalds are present in this area particularly along the Weedina Creek.

The Peake Creek Complex does not fully align with the definitions of a complex as described in Gotch (2013). Keppel *et al* (2015a) identify three possible conceptual drivers for springs within this complex with different spring groups tending to one or more of the proposed models. The models proposed in Keppel *et al.* (2015a) for this complex are 1a: basin margin, structure (fracture zone), 2: basin margin, sediment thinning, and 3: basin margin, structure/sediment thinning combination. The different models align with two regions, with one region to the east more likely influenced by sub surface structuring and the region to the west largely driven by thinning of the confining layers due to erosion from water flow along the Peake and Weedina Creeks.

Hydrochemical examination of most of the flowing springs in this area were undertaken along with detailed geophysics assessment at Old Nilpinna and Cardajalburrana Springs. The hydrochemical work is fully explained in Keppel *et al.* (2015a), and summarised by Figure 5-4.

5.4.2 Spring types

A large diversity of spring types are present within this complex, they include:

- Travertine mounds
- Sand mounds
- Flat depressions
- Rocky seeps and terraces

There are also large areas of diffuse discharge scalds present both in isolation from springs and in and around spring groups. The types vary from north to south with sand mounds and flat depressions being more common in the north-east and travertine mounds and terracing occurring more commonly along the western edge of the Weedina Fault where the confining layers have thinned and in some cases the aquifer its self is exposed.

Section 5 and Appendices B and D provide a detailed description of the spring types supported by associated references (Appendix D).

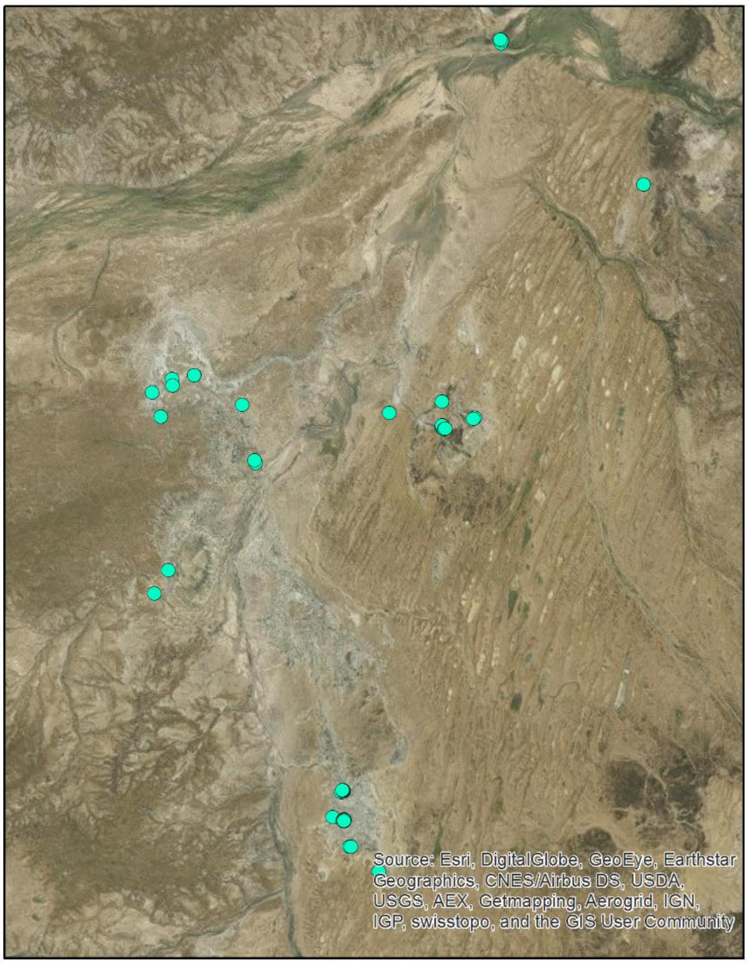
5.4.3 Project surveys: reassessment and knowledge in-fill

Many but not all of these springs were surveyed as part of the 1986 Social and Ecological Assessment (SEA) of the Heritage of the Mound Springs. Since then they have been partially investigated as part of the NWC funded AWMSGAB study and for spring wolf spiders (Gotch *et al.*, 2008). Many springs previously surveyed or mapped were unable to be located despite extensive searching from the ground and the air. Some of these are presumed to have become extinct; others with further investigation have been shown to be incorrectly mapped, for example One Tree Spring which has been reported in the vicinity of One Tree Bore (Williams, 1979; Habermehl 1982). Ground searches of this area failed to find any signs of spring activity and it was presumed to have been lost. Recent discussions with Luise Hercus and investigation of her field notes show that this spring is most likely Pitha-palithanha spring (PCN001) and has been confused with the bore. Pitha-palithanha translates from Arabana as One Box Tree Spring and this is the likely source of confusion around the naming of the spring. Also the current lease holders at Nilpinna refer to the springs in this area as Mole Hill rather than its original name Old Cootanoorina to help distinguish it from the "New" Cootanoorina ruins which are closer to One Tree Bore. Early pastoral board records show One Tree Spring to be located near Old Cootanoorina which further supports the removal of One Tree Bore as having a spring classification. PCN001 still has the remnant box tree growing from the middle of the vent. This tree is in poor health and is subject to damage from cattle.

Another spring, Tidnamurkuna, has been previously listed as part of the Mt Denison Spring Complex however its location on the western side of the Peake and Denison inlier means that hydrogeologically it is a part of the Peake Creek Complex rather than the Mt Denison Complex. This spring was unable to be located as part of this study however it was visited by Hercus in 1984 and was recorded as flowing then.

Keckwick Spring is incorrectly mapped as occurring on Nilpinna, the actual spring is on Allandale Station and is referred to as Peake Creek Springs in the SEA reports. The location mapped on the Pastoral board paddock plans for Nilpinna is a 'claypan/soak/ephemeral waterhole' around some sand dunes adjacent to the Weedina Creek.

Data was collected to fill gaps in the spring records for this area and to look at changes in the springs here since the 1986 SEA surveys.



Spring Group Codes	PBA, PBB, PBI, PCN, PCR, PCS, PCT, PES, PGS, PKS, POM, POS, PSS, PSW, PUA, PUB, PWA, PWD, PWE, PWN, PWO, PWW EUC
Number of Vents	46 (not including groups not located)
Field Alkalinity	206-238 $CaCO_3$ mg/L
Temperature	22-27 °C
Elevation range	45.8 – 87.8 mAHD
EC range	3292-4999 µS/cm
pH range	7.4 – 8.1
ORP	Not available
Significant species count:	10

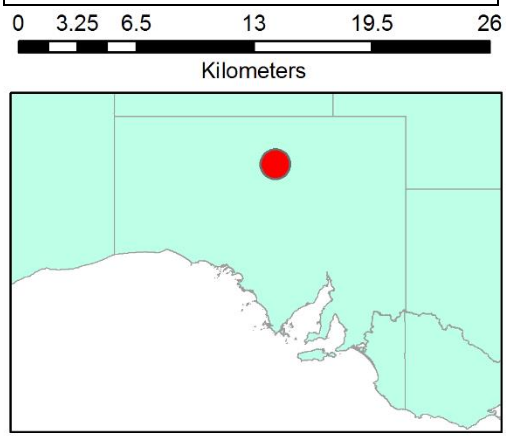


Figure 5-4 Peake Creek Spring Complex summary

5.4.4 Biological values

The floristic diversity of the springs in this complex tends to be low compared to other springs. Many are so overgrazed that they show very little of the previously reported plant diversity. One unusual feature on several springs in this complex is the growth of Broughton Willow (*Acacia salicinia*) on mounds and around vents. This is relatively unusual and has provided protection to the integrity of the mounds on which it grows on. Particularly at Keckwick Springs where it helps hold the mounds together in the event of flooding, and at Cardajalburrana Springs where it partially protects the springs from cattle. Where grazing pressure was low enough for vegetation to be assessed the springs tend to be dominated by reeds (*Phragmites* sp.) or bulrush (*T. domingensis*) at the vent and Spiny Flat-sedge (*C. gymnocaulos*) and Bore-drain Sedge (*C. laevigatus*) on the tails. Other wetland species present include *Schoenoplectus subulatus*, Salt Club-rush (*Bolboschoenus caldwellii*), Fennel Pondweed (*Potamogeton pectinatus*), algae (*Chara* sp.) and Sea Rush (*Juncus krausii*). A number of weed species are also present. Most widespread is Annual Beard-grass (*P. monspeliensis*). This weed was only present at Cootabarcoollia Spring during the SEA survey, however it is now present on nearly all of the flowing springs in the complex. Date Palms (*P. dactylifera*) are also present at Old Nilpinna and Goorgyana Springs as well as Common Bamboo (*Bambusa vulgaris*) at Old Nilpinna and Birribirriana respectively.

Figure 5-5 Travertine erosion as a result of cattle impacts at Edadurrana Springs (Peake Creek)

The springs in this complex have some of the lowest faunal diversity of any springs in the South Australian portion of the Lake Eyre Basin (Figure 5-4). This may be due to post European impacts in the area, but equally the location of most of these springs in areas prone to flooding could be a significant factor in the low diversity of these springs. The 1985 SEA survey reported only one spring in this complex (Keckwick, identified in the report as Peake Creek Spring) as having populations of amphipods (*Austrochiltonia* sp.), hydrobiids (*Fonscochlea aquatica*) and isopods (*Phreatomerus latipes*). This tends to support post European impacts on the springs driving the low diversity as this spring is located right on the northern edge of the Peake Creek. It is however relatively high in the surrounding landscape and may act as an island refuge during large flood events. At the time of this survey none of the previously reported endemic species were observed. Birribirriana Springs previously supported a population of the endemic snail *Fonscochlea aquatica* but it was also not observed during this survey. Several other springs in the complex (Keckwick, Weedina, South Well and Cootanoorina) have populations of the endemic Ostracod, *Ngarawa dirga*. Other significant fauna in the springs include the wolf spider, *V. fontis* and the more wide spread (but rare in SA mound springs) pond snail (*Lymnaea lessoni*) which was previously only reported at Old Nilpinna (Social and Ecological Assessment, 1986) but also found at Weedina Springs during this survey. There are a number of springs supporting fish species, mainly desert gobies (*Chlamydogobius eremius*) and Lake Eyre hardyhead (*Craterocephalus eyresi*). At Old Nilpinna the previously reported Hardyheads were not seen and viable habitats were occupied by the introduced mosquito fish (*G. holbrooki*). Also there is a record of a Dalhousie catfish (*Neosilurus gloveri*) being collected at Old Nilpinna however the collector of that specimen has questioned the veracity of this record and this species has never otherwise been observed at this site (McLaren *et al.*, 1985). It is considered by the authors that this was an error and that the Dalhousie Catfish was never present at this site.

The springs in this complex have seen the greatest level of degradation and impact from drawdown and cattle impacts of any of the spring complexes, in this study, since both the 1985 SEA surveys and the more recent visits including Gotch in 2002–03 and the NWC funded AWMSGAB projects in 2009–12. This survey has been undertaken in a period of relatively good conditions for cattle so numbers have been higher than normal however the damage exhibited on some springs in this group is very high. The travertine mounds in this complex have been very badly affected by cattle grazing and pugging and in many cases are being eroded away. Pugging and eutrophication by cattle is also seriously impacting the presence of stromatolites and thrombolites which is resulting in very little carbonate deposition and the effective erosion of many travertine mounds (Figure 5-5).

The Peake Creek Complex along with Mt Toondina are the most vulnerable to impacts from coal developments. Many of the viable deposits are located directly beneath the western most springs in this complex and it is currently being investigated for both open cut operations and underground coal gasification. Due to the currently stressed state of the majority of springs in this complex and the corresponding reduction in resilience small impacts from drawdown and other coal derived impacts may have a greater than predicted impact. Also further investigation into the absent endemic species is required confirm if they have become locally extinct.

5.5 Mt Denison Spring Complex

Springs in the Mt Denison Complex are located on the eastern side of the Denison Ranges part of the Peake and Denison inlier with the exception of Tidnamurkuna Spring. This spring has been reclassified to be a part of the Peake Creek Complex as it is hydrogeologically impossible to be a part of the Mt Denison Complex. While not likely to be directly affected by current coal activity, the springs of the Mt Denison Complex have been included as they will be the first affected if drawdown impacts extend past the Peake and Denison Inlier also as the spring complex is east of the ranges they do not overly or intersect the Arckaringa Basin at all. This spring complex abuts the eastern side of the Denison ranges. Most of the spring groups in this complex are extinct and have been for over 30 years. The major spring group in this complex is Freeling springs which is located near the Old Peake Repeater Station ruins, part of the Overland Telegraph Line. Freeling Springs is biologically one of the most significant spring groups in all of the GAB. With 14 significant species recorded including the one of the two populations of the endangered hydrobiid snail, *Trochidrobia inflata* (Ponder, 1996) the other population is located at the nearby Freeling North Springs (Figure 5-6).

The springs here are also very important to the Arabana and are a part of the Two Snakes, The Old Man and the Rain History song-lines among others. The Arabana have several stories relating to springs in the area that were not reported by the early explorers but are no longer flowing now. The first Europeans to see the springs in this complex were John McDouall Stuart and his party in June of 1859. At the time he mentions passing many flowing springs beginning with Blythe Springs, later known as Murra Murrana springs, now extinct. Upon arriving at Freeling he describes them as *"… the largest springs I have yet seen. The flow of water is immense, coming in numerous streams …"* (McDouall Stuart 1865). Since this time the flow has reduced considerably however they remain along with Francis Swamp as the most biologically significant spring groups in the Lake Eyre Supergroup.

5.5.1 Geomorphology, geology, hydrogeology and hydrochemistry

The springs in this complex form as abutment springs along the eastern margin of the Denison Ranges. The ranges themselves are the outcropping Peake and Denison Inlier and are predominantly Precambrian in origin (Karlstrom *et al.* 2013). The Peake and Denison's rise abruptly from the surrounding plains which at the surface are mostly alluvial sediments washed out of the range. Three flowing spring groups still exist within the complex Freeling, Freeling North and Wilparoona. Wilparoona is located on the north side of the Peake Creek, Freeling North is right on the southern edge of the Peake creek along the eastern edge of the ranges. The main spring vent at Freeling North services a permanent waterhole which is a key refugia habitat (and Freeling springs is further south along the edge of the ranges. The springs in the complex are all located on the eastern and south eastern margins of the ranges and derive some of their water from localised mountain system recharge (Wohling *et al.,* 2013). A detailed study of the geology and hydrogeology of the area was undertaken as part of the AWMSGAB projects and is presented in Volumes I, II and III of the reports (Karlstrom *et al.,* 2013; Wohling *et al.,* 2013; Crossey *et al.*, 2013).

Hydrogeologically the Mt Denison Complex best fits conceptual model 1b: basin margin, structure (fault zone).

5.5.2 Spring types

The types represented in this complex are:

- Abutment mounds
- Travertine mounds
- Small rocky seeps and terraces.

The majority of the spring groups in this complex are extinct, many were unable to be located despite extensive searching during both the AWMSGAB project and this one.

Section 5 and Appendices B and D provide a detailed description of the spring types supported by associated references (Appendix D).

5.5.3 Project surveys: reassessment and knowledge in-fill

These springs were surveyed during the AWMSGAB project from 2009–13 and during the SEA surveys in the early 1980s. During this survey searching was undertaken to find springs that had previously been unable to be located. Three flowing springs were located and mapped as part of the Freeling North group, these correspond with Kuyiri, Ilantja and Palku-wintjininha springs described in Hercus & Sutton (1985). Springs were also assessed to address data gaps for the nationally aligned spring data set.

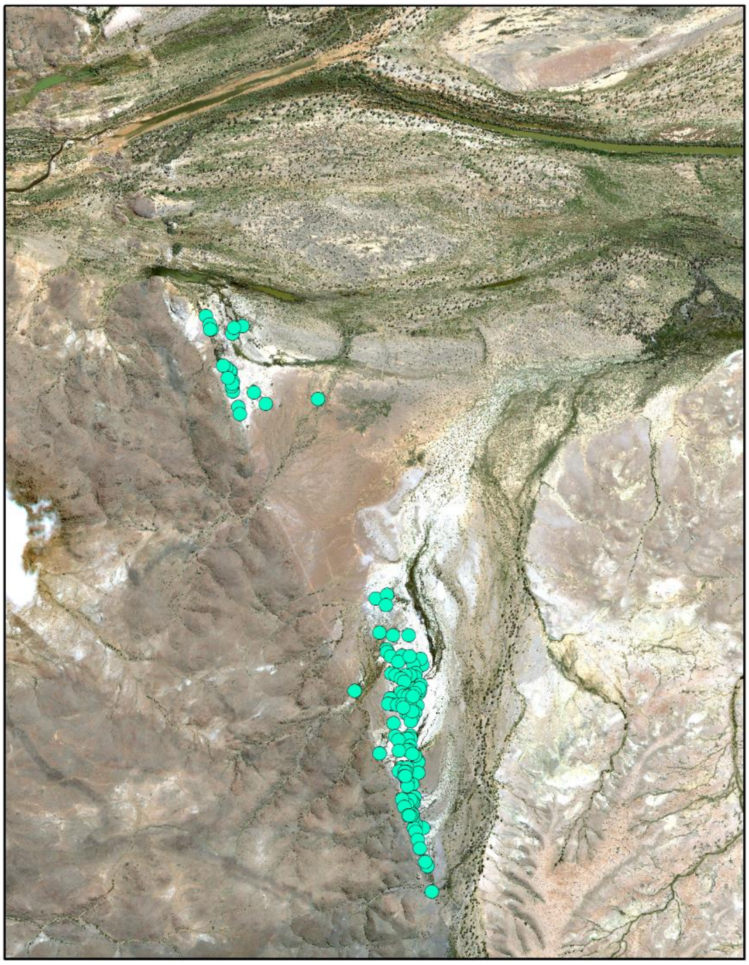
5.5.4 Biological values

Of the three groups that remain flowing only Freeling and Freeling North have any free water present. Wilparoona maintains some wetland vegetation (*S. virginicus* and some dry *Phragmites* sp.) but no aquatic fauna. Freeling Springs and Freeling North Springs are very diverse springs and contain numerous species not normally found in this part of the Lake Eyre Supergroup. They are also genetically diverse and significant evidence indicates these springs are a critical evolutionary refuge for spring species (Gotch, 2008; Guzik and Murphy, 2013; Murphy *et al.,* 2013). There are 9 spring endemic species here including the endangered locally endemic *T. inflata*, four other hydrobiid snails (*Fonscochlea expandolabra*, *F. aquatica, F. zeidleri* and *Trochidrobia minuta*), one amphipod (*Austrochiltonia* sp., Murphy *et al.,* in press), one ostracod (*N. dirga*), one isopod (*P. latipes* soon to be reclassified as a new species restricted to the Mt Denison complex, Murphy, pers com June 2015) and one spider (*V. fontis*) (Figure 5-6). In addition to the endemic species, there are three significant fauna present; desert gobies (*Chlamydogobius eremius*), Lake Eyre Hardyhead (*C. eyresi*) and the Desert Tree Frog (*Litoria rubella*) as well as four relict plant species, Cutting Grass (*G. trifida*), Sea Rush (*J. krausii*), Fine Twig Rush (*Baumea arthrophylla*) and Bare Twig-rush (*B. juncea*). Freeling Springs is the only spring group other than at Dalhousie which has *B. arthrophylla* present.

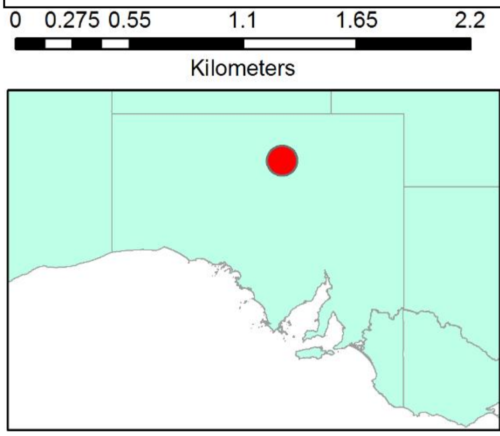
The majority of the springs at Freeling are excluded from grazing by a non-binding agreement between the lessees Kidman & Co. pastoral company and the Friends of Mound Springs. As a consequence the springs are still in relatively good condition. Springs are Freeling North are still subjected to grazing pressure however this has been relatively moderate over the past 15 years.

There are some significant weed species present at Freeling Springs and Freeling North. A clump of Date Palms (*P. dactylifera*) is present on a spring vent near the ruins and Annual Beard-grass (*P. monspeliensis*) has been found at Freeling North. Also the Mosquitofish (*G. holbrooki*) is present in large numbers at Freeling North.

The springs in this complex are not connected to the Arckaringa Basin and so will not be directly impacted by coal development activities occurring there. However any significant impacts into the GAB could potentially affect the springs in this location. This complex would most likely be the first impacted to the east of the Peake and Denison Inliers.



Spring Group Codes[1]	EBN, EBS, ECS, EFN, EFS, EMM, EMS, ESC, EWS
Number of Vents	123
Field Alkalinity	208-227 $CaCO_3$ mg/L
Temperature	Not available
Elevation range[2]	53.4 – 73.3 mAHD
EC range	3750-4259 µS/cm
pH range	7.8-7.9
ORP	n/a at time of draft
Significant species count:	15 (9 spring endemics)



1 Spring groups EBN, EBS, ECS, EMM, EMS & ESC are extinct, Spring group EWS has yet to be surveyed,
2 Elevation is calculated from spring groups EFN and EFS only

Figure 5-6 Mt Denison Spring Complex summary

5.6 Lake Cadibarrawirracanna Spring Complex

The springs of the Lake Cadibarrawirracanna Complex are located around the lake itself which sits at the eastern edge of the Moon Plain and is the terminus for a number of ephemeral rivers and creeks in the area. There were 10 spring groups in this complex at the beginning of this study. Two of these were found not to be springs but were persistent vegetation at ephemeral waterholes. One is confirmed extinct (Giddi-Giddinna), several were unable to be located and are presumed extinct (Wirracanna, Widigiedona, Eurilyna and Lake Cadibarrawirracanna). Of the remainder Castine Spring is a large persistent saline waterhole that is most likely spring fed and Oolgelima and Oolgelima West are still flowing springs.

The springs at Oolgelima and Giddi-Giddinna were once used as a water supply for the early Coober Pedy township (D. Davidson, pers. comm., 23rd March 2015). Prior to this it is unclear who the first Europeans were to see them, Stuart passed 10–20 km to the south of the springs in 1858 but he makes no mention of either the springs or Lake Cadibarrawirracanna. These springs are an important site for the Western Arabana, a sub dialect of Arabana, and are a part of the Whirlwind History. The springs here are also part of the Arabana Rain History and have many artefact sites located near them.

5.6.1 Geomorphology, geology, hydrogeology and hydrochemistry

The environment here varies from gypseous gibber plain (Moon Plain country) to sand hills and swale. Many of the springs are located in the vicinity of creek and drainage lines and it is likely this erosion has assisted in the development of the springs. This area is also a small "island" of artesian pressure as its low elevation enables the GAB to return to artesian conditions. The pressure in this area has been reduced considerably over the past 150 years and of the 10 spring groups in the complex only three springs are still flowing.

Hydrogeologically the springs in this complex best fit conceptual model 3: basin margin, structure/sediment thinning combination. Keppel *et al.* (2015a) identify the margin of the major trench structure near the Mt Woods Inlier as the structure creating the fractures that allow the springs to form at this complex. This is supported with recent seismic data that shows no definitive evidence for faulting in this area.

5.6.2 Spring types

Of the remaining springs at Lake Cadibarrawirracanna the types present are:

- Flat depressions
- Rocky seeps and terraces

Oolgelima Spring is basically a flat depression however some travertine exists in the centre of the spring. It is difficult to assign a type to this spring as it has been excavated and modified in the past. Oolgelima West in a flat depression. Giddi-Giddinna showed some evidence of travertine deposits interspersed through Bulldog Shale. Given it has been extinct for over 40 years (Williams, 1979) it was unable to be classified into a type.

Section 5 and Appendices B and D provide a detailed description of the spring types supported by associated references (Appendix D).

5.6.3 Project surveys: reassessment and knowledge in-fill

Springs in the Lake Cadibarrawirracanna complex have been surveyed in the past however the location is extremely remote and difficult to access. As a consequence previous surveys have largely been incomplete or have not been able to locate all of the springs. Hydrogeological investigations were carried out during the late 1970s by Williams (1979). They were also investigated by Wolfgang Zeidler and Winston Ponder as part of the early assessment for the Olympic Dam Mine (Roxby Management Services, 1984) and later as part of the Lake Eyre South Springs Survey (Niejalke unpublished data). Some of the springs were visited during the SEA surveys in 1984 (Hercus & Sutton, 1984; McLaren *et al.*, 1985) and they were investigated for their spider fauna in 2003 (Gotch, 2008). Zeidler and Ponder (Roxby Management Services, 1984) located Eurilyna spring but it was unable to be relocated during the SEA surveys. They were unable to locate Wirracanna and Widigiedona during this period and report them most likely extinct. Williams (1979) reported the water level at Giddi-Giddinna and at Oolgelima to be 1 m below the land surface in 1975 however free water was observed in the 1984 SEA survey and the wetland was reported as 5000 m^2. The 1996 LESS survey data reports free water only at Oolgelima, Oolgelima West and Castine. Others in the complex were visited by Phil Gee however no free water was reported and for Giddi-Phantom North and South he expressed doubts they were true springs (pers. comm. to Gotch February, 2003).

This project addressed data deficiencies in the previous surveys and collected location and elevation data at springs in the Oolgelima and Oolgelima West spring groups. Attempts to locate the other springs in the complex were made on three occasions, once by air and twice on the ground. Considerable effort was made to locate these springs but this was unsuccessful and it is considered likely that these are extinct and taking into consideration current pressure scenarios unlikely to recover.

5.6.4 Biological values

Of the three springs still active Castine is a large saline waterhole it has some Spiny Flat-sedge (*C. gymnocaulos*), Fennel pondweed (*P. pectinatus*) and *Tecticornia* spp. present. No fish or other macroinvertebrates were observed. Oolgelima is the largest flowing spring. It has a vent dominated by reeds (*Phragmites* sp.) and bulrush (*T. domingensis*). The tail contains Bore-drain Sedge (*C. laevigatus*), Spiny Flat-sedge (*C. gymnocaulos*), *Schoenoplectus subulatus* and *Tecticornia* spp. This spring has been heavily modified in the past having been used as a trap yard for cattle and being modified to facilitate water collection during the early days of the Coober Pedy township. The Oolgelima Spring group was excavated some time in 2002-03 with an excavator to increase flow. It contains a population of the spring endemic ostracod *N. dirga* (Figure 5-7) as well as the spring wolf spider *V. fontis*. Oolgelima West is a small flat depression spring that has an unusual floating mat of *Cyperus laevigatus* dominating the spring. The spring endemic ostracod *N. dirga* is present here as well. At the time of the survey this spring was in very good condition and had very little impact from cattle or feral grazers.

These springs are in an area of decreasing pressure and as such are very vulnerable to extinction from drawdown. The springs are not badly affected by grazing and pugging. This region is difficult to muster in, receives little rainfall and has poor feed. As a consequence of this stocking levels in this area have been low for well over a decade. The direct risk to the springs in this complex from coal developments is low given the distance from currently known coal deposits. However more exploration for coal is scheduled for this area and it needs to be noted that even minor drawdown in this area could be catastrophic.

Spring Group Codes	XCS XES, XGG, XLC, XOS, XOW, XPN, XPS, XWC, XWS
Number of Vents	6 (21 historically)
Field Alkalinity	Not Available
Temperature)	Not Available
Elevation range	102.07-106..47 mAHD
EC range	6500-10410 µS/cm
pH range	6.59-6.9
ORP	Not Available
Significant species count:	1

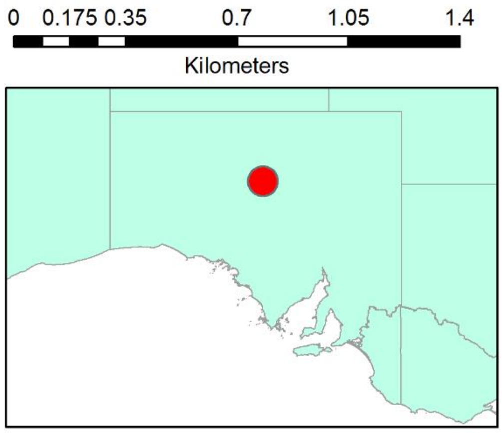


Figure 5-7 Lake Cadibarrawirracanna Spring Complex summary

5.7 Billa Kalina Spring Complex

Billa Kalina Springs Complex is a large spring group on the Margaret Creek in the northern end of Billa Kalina Station. This site is a considerable distance from known coal deposits in the Arckaringa Basin, however Billa Kalina was included as it represented a significant gap in the knowledge base of the Lake Eyre Supergroup. There are two significantly smaller spring groups in this complex—McEwins and Welcome.

It is unclear who the first European to see these springs was. Warburton passed close by in 1858 and certainly found springs in the complex north of Billa Kalina, but his letters to the South Australian Parliament make no mention of travelling in this part of the Margaret Creek The overland telegraph survey passed through the area in 1870–72 and one of the surveyors, John Ross, was contracted in 1873 to assess the land south of the complex for its suitability to grazing (Gee, 2000), and it may have been him, or one of the pastoralists, who followed soon after that found the springs.

The springs are culturally important to the Arabana and Kuyani as they are the last permanent water for peoples travelling south-west from here (Hercus & Sutton 1984). There are few documented stories in the public literature but they are associated with the Dog History and other springs in the complex are associated with the Two Snakes song-line.

5.7.1 Geomorphology, geology, hydrogeology and hydrochemistry

The springs at Billa Kalina sit on a large (5 km x 2 km) flat diffuse discharge scald on the western edge of the Margaret Creek. To the west is stony tablelands and sand dunes, and to the east and south is stony tablelands and breakaway country. There are over 600 spring vents mapped to date and an expected 150 still to be mapped. The vast majority of springs appear to be extinct. However the springs in this complex are travertine mounds that often have water within them that is periodically exposed.

At Welcome Spring the mound was thought to be extinct but when the nearby Welcome Bore was rehabilitated and the flow reduced, as part of GABSI, the spring began to flow and endemic *Phreatomerus* sp. isopods were found in the spring discharge. These macroinvertebrates had been surviving in cracks in the travertine for over 10–20 years. Many of the mounds at Billa Kalina are similar and thus it is difficult to determine how many of these mounds are sustaining spring-endemic species. This area was not investigated hydrogeologically as part of this study but reviewing other studies (Enesar Consulting, 2006; Keppel *et al.,* 2013) show the most likely hydrogeological conceptualisation for these springs is 3: basin margin, structure/sediment thinning combination.

5.7.2 Spring types

The springs in the Billa Kalina Complex are all Travertine Mound types.

Section 5 and Appendices B and D provide a detailed description of the spring types supported by associated references (Appendix D).

5.7.3 Project surveys: reassessment and knowledge in-fill

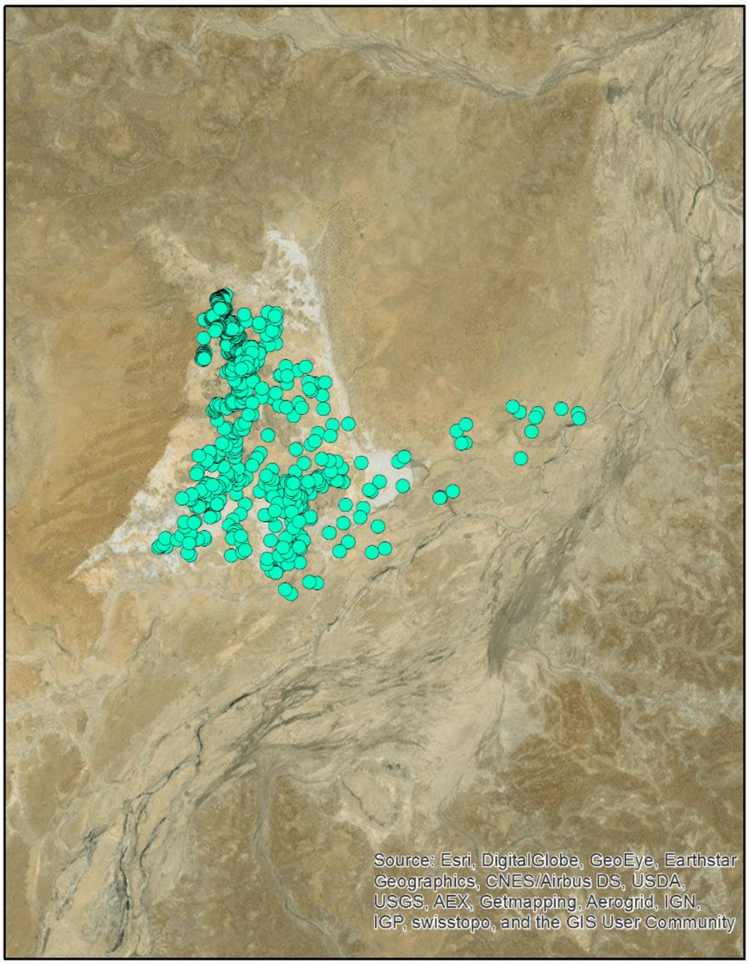
These springs have been extensively surveyed in the past (SEA, 1986; Roxby Management Services, 1984; Niejalke, unpublished data; Gotch 2013, Keppel *et al.,* 2013). This project aimed to address data gaps and to complete the mapping of the spring vents that had previously been abandoned due to rain. The mapping of the springs had to be abandoned again because of heavy rainfalls and hail during the field survey. This final part of the mapping and survey remains incomplete as of July 2015.

5.7.4 Biological values

Billa Kalina is a species rich spring complex containing an extremely diverse spring endemic fauna (Figure 5 8). There are four hydrobiid snails (*F. aquatica, F. billakalina, F. zeidleri* and *T. smithi*), one amphipod (*Austrochiltonia* sp.), one isopod (*P. latipes* soon to be reclassified as a new short range endemic Murphy pers com June 2015), the ostracod (*N. dirga*) and the spring wolf spider (*V. fontis*). Also present are desert gobies (*C. eremius*) and Lake Eyre hardyheads (*C. eyresi*). Floristically the springs at Billa Kalina have relict populations of Sea Rush (*J. krausii*) as well as the ubiquitous Bore-drain Sedge (*C. laevigatus*) and reeds (*Phragmites* spp.). In addition to the spring specific flora and fauna, McEwins Spring is a Brolga nesting site, regularly having up to six pairs of Brolga on the spring tail.

The springs at Billa Kalina vary in quality, some are targeted by cattle and can be extremely degraded while others are almost untouched by any sign of disturbance. Also the springs are cryptic; they can look extinct but upon climbing the mound they can have small vent pools supporting 2–3 endemic species.

These springs are at risk from drawdown, many have already been sealed off and appear extinct. However their distance from coal deposits means they are at a low risk of impacts from current or forecast coal developments.



Spring group codes	KBK, KME, KWS
Number of vents	665 (approximately 150 unsurveyed)
Field Alkalinity	431 $CaCO_3$ mg/L
Temperature	Not Available
Elevation range	36.84–55.43 mAHD
EC	5330-11390 µS/cm
pH	6.65-7.9
ORP	n/a at time of draft
Significant species count:	10

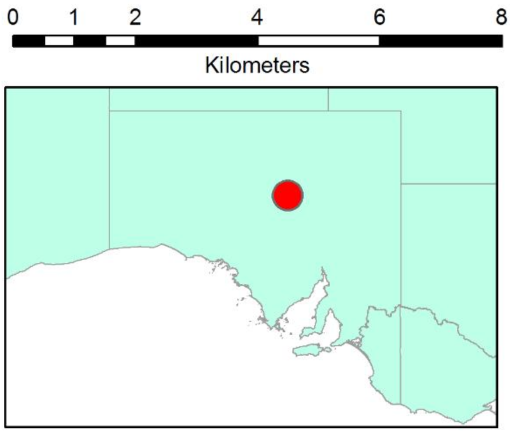


Figure 5 8: Billa Kalina Spring Complex summary

6 Discussion and conclusions

This report, together with associated reports from the broader Bioregional Assessment Programme (as listed in Section 1.3), describes the technical processes and field programs undertaken to identify and fill the information gaps for spring complexes in South Australian portion of the Great Artesian Basin.

The program has resulted in the development of baseline of information that can be used to assess the potential impacts of coal developments on the spring complexes in the identified zones of interest (in the PAE) established for the Arckaringa coal deposits (Figure 3-1). The resulting set of conceptual models, which represent an assimilation of baseline information for each common spring type of the region, provide a basis from which general risks may be identified and predictions about likely impacts made. The generic nature of these models mean that they may be taken and applied to specific springs or spring complexes, used to identify and direct where further investigations are necessary, and expanded and adapted to suit the development at hand.

6.1 Risks to springs

Springs in the Toondina, Peake Creek and Mt Dutton complexes are the most vulnerable to coal developments in the Arckaringa Basin. Dalhousie Springs is vulnerable to any development that will reduce groundwater pressure or temperature within the Pedirka Basin, a potential impact from any major development in the basin requiring a secure water source. With the exception of the Peake Creek complex, most of these springs have moderate to high levels of short range endemic diversity. Critically, this means that the potential extinction of a spring group or complex could lead to the extinction of multiple species.

The major risks to springs and scalds are identified in tables 8-2 through to 8-7 in Appendices C, D, and E respectively. Some of the more significant risks are discussed below.

6.1.1 Aquifer Drawdown

The principal risk to springs is aquifer drawdown, the reduction in groundwater pressure as a result of anthropogenic extraction of water. This results in reduced flows that can have potential catastrophic impacts on spring communities up to and including cessation of flow and the total extinction of spring dependent species. The limited distribution and genetic diversity of spring flora and fauna maker them particularly vulnerable to any drawdown activities.

The impacts of direct extraction from the GAB aquifer are understood however assessing and predicting these impacts on GAB springs remain difficult. The impacts of extraction from adjacent aquifers is much less understood. Keppel *et al.* (2015a) identified hydrogeological conceptual models 1a (basin margin, structure (fracture zone)), 3 (basin margin, structure/sediment thinning combination) and 4 (astrobleme) as having the greatest risk from future coal development activities. This is related to the potential for groundwater connectivity between aquifers within the GAB, and those of the underlying Arckaringa Basin afforded by regional deformation structures, such as fracture and fault zones associated with the margins of the Arckaringa Basin. The nature of connectivity between the GAB and underlying aquifers, and what this means with respect to groundwater supply to springs, is still largely unknown (Keppel *et al.*, 2015a). Springs in 1b (basin margin, structure (fault zone)) and 2 (basin margin, sediment thinning) are also at risk though and each development will need careful and considered examination.

Drawdown affects all spring types to varying degrees and diffuse discharge scalds are also at risk as they are likely being maintained by low pressures. The area of salt scald may be a useful future metric in monitoring changes in groundwater pressure before impacts on springs can be detected. This metric could further be monitored remotely via analysis of aerial imagery (Turner *et al.*, 2015).

6.1.2 Groundwater Contamination

Groundwater contamination is a risk identified frequently in the media and is mainly attributed to fracture stimulation (fracking). However contamination can also occur via a number of pathways both natural and anthropogenic in origin. Groundwater contamination resulting from fracking is recognised as a low level risk for the GAB, Arckaringa and Pedirka basins

(DSD, 2014). Fracking utilises a number of additives that act as lubricants to facilitate transport of the sand into the fracture, biocides to inhibit the growth of bacteria in the well and fracture, to increase permeability near the well, to clean and prevent scaling in the well and to inhibit corrosion in the well. These additives are present in low concentrations and the majority are removed and reused (DSD, 2014). Depressurising the coal seam to allow gas to flow can release BTEX compounds (benzene, toluene, ethyl-benzene, and xylenes) from the coal however most of these are removed with the gas. Groundwater contamination from underground gasification can potentially cause large scale pollution to surrounding aquifers (Verma *et al*, 2014) including the release of BTEX compounds and is potentially a greater risk, particularly in the Arckaringa and western GAB, as underground gasification has been proposed as a potential method for exploiting the Arckaringa coal deposits. Other vectors for groundwater contamination include changes in water chemistry, resulting from leakage from other groundwater resources, in response to pressure differentials generated by drawdown. Introduction of bacteria into aquifers from poor hygiene practices can contaminate groundwater and result in changes to pH and dissolved oxygen as well.

6.1.3 Sulfide accumulation in springs

Many springs on the western margin of the GAB contain very high concentrations of sulfides locked in wet anoxic spring sediments (Shand *et al.* 2013). These sediments can also contain high concentrations of minerals associated with the sulfur compounds (i.e. Arsenic) (Shand *et al.* 2013). If these springs dry out then these sediments will be oxidised from sulfides to sulfates. When the spring then re-wets, the sulfates create sulfuric acid, dissolving the mound and releasing any accumulated metals into the local spring ecosystem. Sulfates can also precipitate around the edges of the vent area where they can be washed into the spring after rain, generating a pH change down the tail sufficient to kill wetland vegetation and spring endemics (Gotch personal observation, January 2012, and Figure 6-1). When these events occur only fauna located in the vent area are likely to survive due to the inputs of fresh groundwater. These impacts will be amplified with declining groundwater pressure. Equally temporary pressure reductions from drawdown events will trigger spring acidification once extractions cease and local pressures recover. Drying cycles are expected to be more common for springs in the zone of influence of prolonged groundwater drawdown (i.e. as potentially associated with any future mining development in the arid zone) and as a result of climate change. Travertine mound, abutment and rocky seep and terraces are among the most at risk types from coal developments due to the extra risk of sulfation.

Figure 6-1: Effects of acidification on spring vegetation following a rain event in 2012

6.1.4 Indirect Risks

The springs on the western margin of the GAB are currently at various levels of stress due to a number of non-coal related activities and impacts. These include excavation, grazing, invasive species, tourism and fencing. These stressors need to be considered during the assessment process as they can compound (and be compounded by) the effects of reduced flows. Evaluation and monitoring of coal or unconventional gas projects needs to include these indirect risks and identify mitigation strategies to protect springs. Travertine mounds in particular are quite fragile, as the carbonate travertine structure is soft and easily eroded by anthropogenic disturbances (cattle, tourism, exploration and vehicles). The mound itself is a shell of carbonate rock that often contains a core of soft black silts and sands where the water flows up and out the mound. If flow rates are low, spring vents can be blocked by wind deposited sands. Where this occurs, carbonates can precipitate in these sands eventually sealing off the mound. This is very common in springs in the Billa Kalina and Francis Swamp spring groups.

The size of the wetland is not static, in many springs it can vary in response to changes in atmospheric pressure, lunar cycles and local evapotranspiration rates. In extreme low pressure events springs have been observed to double the temporary wetland area while in extreme high pressure events in summer some springs have been observed to almost dry up (Gotch personal observations over multiple years C. 1990s, 2000s and 2010s). Understanding how these factors interact with drawdown is critical to protecting springs in the long term.

6.2 Critical knowledge gaps

The investigations underpinning this report addressed several knowledge gaps that were identified in NWC (2013), however other knowledge gaps remain unaddressed and the investigations also identified several new knowledge gaps summarised below. The Evidence Base Tables provided in Appendices D and E detail many of the key knowledge gaps and potential areas to target for future investigations (as well as capturing the current knowledge about springs).

6.2.1 Aquifer connectivity

Despite detailed investigations in Keppel *et al.* (2015a) and NWC (2013) the actual connectivity pathways between springs and aquifers are relatively poorly understood for the majority of GAB Springs in South Australia. Equally the interactions between aquifers and the potential implications for springs warrants further investigation. A key knowledge gap regarding source aquifers is at Dalhousie Springs. At present the role of the Pedirka basin in maintaining both flow and water temperature is poorly understood. The flora and fauna at Dalhousie Springs is dependent on the temperature of the water to maintain the microhabitats that they occupy (Zeidler and Ponder, 1989, Kodric-Brown and Brown, 1993, Kodric *et al.*, 2007). As most of the heat is thought to come from the Pedirka Basin (Wolaver *et al.,* 2013), even if flow is maintained, any cooling of the aquifer or changes that impact on the outflow temperature could result in a major shift in spring character and condition. To further investigate this issue, it is recommended that a nested bore be installed near the springs that will permit samples to be collected from all aquifers without cross contamination. Signatures of these water samples could then be analysed so that the level of input from the Pedirka Basin can be properly quantified, and thus a preliminary assessment made on the sensitivity of this environment to future proposed development.

6.2.2 Sensitivity of spring types and associated ecosystems to drawdown

Different spring types respond differently to drawdown. For some type these variations are understood, for example travertine springs and rocky terraces that accumulate sulfides are at much greater risk to partial drawdowns than are sand mounds and flat depression springs. Equally spring groups with low elevation range standard deviations are more likely to have all vents go extinct in the event of localised drawdown than would spring groups with a lot of variation in their elevation range (Green *et al.,* 2013). However, for the majority of spring types little is known as to the specifics of how they will respond to drawdown.

6.2.3 Spring formation and biochemical interactions

A detailed study into the formation of travertine mound springs was undertaken by Keppel (2013) however very few other studies of this nature have been undertaken for the other spring types. The way springs form and ultimately change is important for predicting future impacts arising from changes in ground water pressure of chemistry. It has been suggested in the past (Fatchen & Fatchen 1993) that sand mounds are possibly precursors to travertine mounds however this has never been investigated. . Further to this the whole of wetland chemical and biochemical processes need to be better understood. Examples are the stromatolite like Oncoids occurring in many springs which have an important role in mound formation but are very sensitive to changes in water chemistry and surface disturbance.

6.2.4 Spring resilience and cumulative spring impacts

Understanding the resilience of different spring types to non-drawdown impacts and the cumulative impacts of all other agents of change affecting the springs is critical for undertaking suitably rigorous evaluations of any coal or unconventional gas proposal. For example, a spring endemic fauna could be stressed from over grazing that has caused the only clean water suitable for the species to be an area as small as 0.5 metres diameter around the vent. In this scenario, a slight reduction in groundwater pressure leading to only a minor reduction in spring flow rate could cause a dramatic decrease in the area of clean water such that the spring endemic can no longer survive. Ignoring cumulative impacts could result in extinctions of springs and entire species, however the relationships between impacts is not understood beyond theoretical discussions. In addition to grazing, other common impacts include spring excavation and invasive species. Understanding the relationships between these impacts and drawdown could enable mitigation work to be undertaken to protect these species while still allowing sustainable exploitation of the resource. These impacts are detailed in tables 4-1 and 8-1 through 8-7.

6.2.5 Limited species distribution information

Due to the isolated nature of springs in the western GAB many of the species present have genetically diverged to varying degrees. For less mobile species this has resulted in significant short range endemism (Guzik & Murphy, 2013). Many species groups remain to be investigated and it is probable that the number of spring endemic species reported to date is under representative. Investigations into existing high likelihood endemic species groups and other spring fauna needs to continue to enable objective evaluation of coal or unconventional gas projects.

6.2.6 Diffuse Discharge Scalds

Very little is known about the associated geology, hydrology and hydrogeology of diffuse discharge scalds; equally very few studies have investigated the flora and fauna that are dependent on them. The role these groundwater-dependent systems have in maintaining the surrounding ecosystem is not understood. A tool was developed to map the extent of diffuse discharge scald areas (Turner *et al* 2015) and further work could be undertaken to develop this into a tool suitable for monitoring changing groundwater pressures impacts on surface flows and have developed a tool to map this.

6.3 Key Recommendations

The Lake Eyre Basin Springs Assessment in conjunction with the Arckaringa and Pedirka Basin Assessments have provided a solid platform from which bioregional assessments can be undertaken. There have been a number of critical information gaps identified during this process though and it is recommended these receive priority for future investigations or as part of assessments for coal and unconventional gas development proposals. The expansion of baseline knowledge to address these identified gaps will better inform the assessment of the management of these assets into the future.

An analysis of common spring surface types has resulted in the development of two system ecohydrology models, the generalised GAB spring, and the diffuse discharge (scald) model, under which the common types are described; travertine mounds, astrobleme, sand mounds, flat depressions, abutment springs, thermal mounds, rocky seeps and terraces and diffuse discharge (scald). These conceptual models should be used as the basis for future assessments.

Individual management plans need to be developed at the group level for springs likely to be impacted on by coal developments to ensure the springs are properly managed and impacts eliminated or mitigated. Currently management plans are usually prepared at the spring complex or super group level and do not necessarily address management of key attributes and characteristics identified by this report. Management plans need to be fit for purpose at the spring group level and incorporate analysis of the impacts specific to each spring group (i.e. management of tourist based impacts versus management of groundwater drawdown impacts as associated with major development).

The critical message for assessors is that the springs on the western margin of the Great Artesian Basin are in a stressed state from low flows, high grazing pressure and high nutrient loads. Future assessment, monitoring and management needs to be inclusive of more than groundwater pressure impacts alone. A holistic approach that includes these pre-existing stressors needs to be utilised, including a look at cumulative regional impacts that include not just groundwater but also surface interactions as well.

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8 Appendices

A. Field personnel

DEWNR: Travis Gotch (Technical Leader/Ecologist, TG), Danny Brock (Ecologist, DB), Dave Armstrong (Ecologist, DA), Sam Gitahi (Ecologist, SG), Dr Mark Keppel (Hydrogeologist, MK), Peter Kretschmer (Hydrogeologist, PK), Dean Ah Chee (Senior Cultural Ranger Dalhousie, DAC), Kent Inverarity (Geophysicist, KI), Daniel Harrison (Field Tech Geophysicist, DH).

SARDI: Dr Dale McNeil (Fish Ecologist, DM), Rupert Mathwin (Fish Ecologist, RM)

CSIRO: Dr Chris Wilcox (Ecologist, CW), Dr Denise Hardesty (Ecologist, DH).

Bush Heritage Australia: Dr Adam Kerezsy (Fish Ecologist, AK).

Arabana Aboriginal Corporation: Sam Stuart (Arabana Cultural Officer, SS.

RMIT Melbourne: Brad Baldessare (Hydrologist, BB),

Table 8.1 Summary of LEBSA field trip personnel

Date	Locations (complexes)	Personnel
July 2014	Dalhousie Springs	TG, AK, CW, DH, DM, RM, BB
August 2014	Billa Kalina/ Lake Cadibarrawirracanna	TG, DB, DA
October 2014	Peake Creek, Mt Denison	TG,
November 2014	Allandale, Peake Creek, Lake Cadibarrawirracanna, Mt Denison	TG, SG, SS, MK, PK, KI, DH
January 2014	Dalhousie Springs	TG, DAC

B. Field datasheet templates

LEBSA Field Data - Geomorphology

Spring Code		**Easting**	
Site Name		**Northing**	
Date and time		**Zone**	
		Collected by	

General Morphology:

Field Data		**Field Data**	
Excavation Proportion (sq m)		Mound Length (m)	
Excavation Type		Mound Width (m)	
Disturbance Level		Relative Mound Height (m)	
Disturbance Type		Morphological Type	
Bore Casing Present/Absent		Surface Expression	
Pugging Level		Sulphate Status	
Pugging Area (%)		Sulphation Area (sq m)	
Grazing Level		Photo Taken	
Grazing Area (%)		Photo ID's	

Notes:

LEBSA Field Data - Biological Data

Spring Code		**Easting**	
Site Name		**Northing**	
Date and time		**Zone**	
Sample Point		**Collected by**	

Comments:

Spring Flora	Presence	% Cover	Collected	Notes
Bambusa sp				
Baumea arthrophylla				
Baumea juncea				
Bolboshoenus cardwellii				
Cyperus gymnocaulos				
Cyperus laevigatus				
Eliocharus geniculata				
Eliocharus pallens				
Eriocaulon carsonii				
Fimbristylis dichotoma				
Fimbristylis ferruginea				
Fimbristylis seiberiana				
Gahnia trifida				
Imperata cylindrica				
Myoporum acuminatum				
Phoenix dactylifera				
Phragmites australis				
Polypogon monspeliensis				
Samolus repens				
Senecio cuninghamii				
Shoenoplectus littoralis				
Sonchus hydrophilus				
Spergularia rubra				
Sporoboulous virginicus				
Tecticornia sp				
Typha domingensis				
Utricularia fenshamii				
Wilsonia backhousei				

Spring Fauna	Presence	Abundance	Collected	Notes
(ARACH) Artoria sp				
(ARACH) Hogna sp				
(ARACH) Tetralycosa sp				
(ARACH) Venatrix sp				
(CRUST) Amphipods				
(CRUST) Isopods				
(CRUST) Ostracods				
(MOLL) Hydrobiids				
(PISC) Chlamydogobius eremeus				
(PISC) Chlamydogobius gloveri				
(PISC) Craterocephalus dalhousiensis				
(PISC) Craterocephalus eyresi				
(PISC) Craterocephalus gloveri				
(PISC) Leiopotherapon unicolor				
(PISC) Mogurnda thermophilla				
(PISC) Neosilurus gloveri				
(STROM) Stromatolites (Oncoids)				

LEBSA Field Data - Hydrogeology					
Spring Code		**Easting**			
Site Name		**Northing**			
Date and time		**Zone**			
Sample Point		**Collected by**			
Distance to vent (m)					
Equipment used:					
Comments:					
Field Data		**Sample Type**	**Collected**	**Volume**	**Field Prep**
Field Alkalinity (mg/L)		Anion		125	F
Temperature (°C)		Cation		125	F/A pH<2 HNO_3
		Trace			F/A pH<2 HNO_3
EC (μS/cm)		Stable Isotopes			UF
TDS (mg/L)		Carbon-13 (separate to ^{14}C)			F
pH		Carbon-14		1000	UF
DO (mg/L)		Chlorine-36		500	UF
ORP		Sulphur-34		1000	F/A pH<4 HCl
		Strontium-87/86		1000	F
		Radon			PET/DIR HH:MM
Photo Taken		CFC			UF
Photo ID's		SF6			UF
		Tritium		1000	UF
		Copper tubes (noble gas)			UF
		Diffusion cell (noble gas)			UF
		Bromide-81 & Chloride-37		1000	UF
		Uranium (234/238)		5000	F/A pH<1 HCl/HNO_3
		Archive		1000	F
Flow Data					
Spring Flow Rate Qualitative					
Spring Flow Rate Quatitative					
Quantitative Flow Rate Method					
Notes:					

C. Generalised GAB spring model evidence base tables

The following evidence base tables with associated reference are presented for the generalised GAB spring model; hydrology (Table 8.1), water chemistry (Table 8-3) and water quality, and disturbance (Table 8-4). References for all three tables are provided in Appendix E).

Table 8-2 Generalised GAB spring model evidence base table – Hydrology

Values	Ecosystem Response to Impacts				
Spring Types	**Reduced Flow**	**Reduced Wetland Area**	**Reduced Wetland Connectivity**	**Reduced Groundwater Temperature**	**Contamination of Groundwater**
Travertine Mound	• Increased likelihood of spring vent being filled by aeolian deposits resulting in vent closure (1) • Exposure and oxidation of sulfides decreasing pH to extremely acidic conditions (2, 16) • Potential mobilisation of accumulated heavy metals (2, 16) • Wetland area reduced proportionally to flow reduction (3, 26) • Loss of open water habitat and vent pools (1)	• Loss of habitat (1, 4) • Loss of habitat resilience to extreme climatic events (1)	• Reduced habitat function (1, 4) • Restriction in intra-spring colonisation and dispersal (6, 8, 13, 18) • Potential for species loss (1, 6, 8)	• Different temperatures change the composition and structure of carbonate precipitates (5)	• NA
Astrobleme (Toondina)	• Spring extinction due to low pressure/flow at this site (1) • Exposure and oxidation of sulfides decreasing pH to extremely acidic conditions (2, 16) • Potential mobilisation of accumulated heavy metals (2, 16) • Wetland area reduced proportionally to flow reduction (3, 26) • Loss of open water habitat and vent pools (1)	• Loss of habitat (1, 4) • Loss of habitat resilience to extreme climatic events (1)	• Reduced habitat function (1, 4) • Restriction in intra-spring colonisation and dispersal (6, 8, 13, 18) • Potential for species loss (1, 6, 8)	• NA	• NA
Sand Mound	• Exposure and oxidation of sulfides decreasing pH to extremely acidic conditions (2, 16) • Potential mobilisation of accumulated heavy metals (2, 16) • Wetland area reduced proportionally to flow reduction (3, 26) • Loss of open water habitat and vent pools (1)	• Loss of habitat (1, 4) • Loss of habitat resilience to extreme climatic events (1)	• Reduced habitat function (1, 4) • Restriction in intra-spring colonisation and dispersal (6, 8, 13, 18) • Potential for species loss (1, 6, 8)	• NA	• NA

Values	Ecosystem Response to Impacts				
Spring Types	**Reduced Flow**	**Reduced Wetland Area**	**Reduced Wetland Connectivity**	**Reduced Groundwater Temperature**	**Contamination of Groundwater**
Flat Depressions	• Exposure and oxidation of sulfides decreasing pH to extremely acidic conditions (2, 16) • Potential mobilisation of accumulated heavy metals (2, 16) • Wetland area reduced proportionally to flow reduction (3, 26) • Loss of open water habitat and vent pools (1)	• Loss of habitat (1, 4) • Loss of habitat resilience to extreme climatic events (1)	• Reduced habitat function (1, 4) • Restriction in intra-spring colonisation and dispersal (6, 8, 13, 18) • Potential for species loss (1, 6, 8)	• NA	• NA
Abutment	• Exposure and oxidation of sulfides decreasing pH to extremely acidic conditions (2, 16) • Potential mobilisation of accumulated heavy metals (2, 16) • Wetland area reduced proportionally to flow reduction (3, 26) • Loss of open water habitat and vent pools (1)	• Loss of habitat (1, 4) • Loss of habitat resilience to extreme climatic events (1)	• Reduced habitat function (1, 4) • Restriction in intra-spring colonisation and dispersal (6, 8, 13, 18) • Potential for species loss (1, 6, 8)	• Different temperatures change the composition and structure of carbonate precipitates (5)	• NA
Thermal mounds (Dalhousie)	• Exposure and oxidation of sulfides decreasing pH to extremely acidic conditions (2, 16) • Potential mobilisation of accumulated heavy metals (2, 16) • Wetland area reduced proportionally to flow reduction (3, 26) • Loss of open water habitat and vent pools (1)	• Loss of habitat (1, 4) • Loss of habitat resilience to extreme climatic events (1)	• Reduced habitat function (1, 4) • Restriction in intra-spring colonisation and dispersal (6, 8, 13, 18) • Potential for species loss (1, 6, 8)	• Different temperatures change the composition and structure of carbonate precipitates (5) • Reduction in temperature will change species composition and may result in extinction of endemic fauna and loss of relict flora (1)	• NA
Small Rocky Seeps and Terraces	• Increased likelihood of spring vent being filled by aeolian deposits resulting in vent closure (1) • Exposure and oxidation of sulfides decreasing pH to extremely acidic conditions (2, 16) • Potential mobilisation of accumulated heavy metals (2, 16) • Wetland area reduced proportionally to flow reduction (3, 26) • Loss of open water habitat and vent pools (1)	• Loss of habitat (1, 4) • Loss of habitat resilience to extreme climatic events (1)	• Reduced habitat function (1, 4) • Restriction in intra-spring colonisation and dispersal (6, 8, 13, 18) • Potential for species loss (1, 6, 8)	• Different temperatures change the composition and structure of carbonate precipitates (5)	• NA

Values	Ecosystem Response to Impacts				
Spring Types	**Reduced Flow**	**Reduced Wetland Area**	**Reduced Wetland Connectivity**	**Reduced Groundwater Temperature**	**Contamination of Groundwater**
Vegetation Community					
Phragmites spp	• Reduced inundation, depth and duration (1) • Loss of habitat with wetland drying out and transitioning to Diffuse Discharge Scald or terrestrial environment (3, 26) • Declining condition (19, 20) • As flow decreases *Phragmites* will out compete many other spring species and is usually the last species remaining (1) • Shifts from emergent vegetation to dry vegetation	• Loss of habitat (1,3,19) • Loss of resilience (1) • Decrease in habitat complexity (1) • As area decreases *Phragmites* will out compete many other spring species and is usually the last species remaining (1, 19) • Loss of habitat supporting dispersal of aquatic species (1)	• Reduced habitat function (1) • Restriction too intra-spring colonisation and dispersal (19)	• Unknown impact / Knowledge Gap (1)	• Phragmites is resilient to contamination and performs well in a variety of conditions so magnitude of impact is likely to be lower than with other species (19)
Typha domingensis	• Reduced inundation, depth and duration (1) • Loss of habitat with wetland drying out (3, 26) • Transition of habitat to *Phragmites* dominated reed beds as inundation period reduced (1	• Loss of habitat (1, 3, 19) • Loss of resilience (1) • Decrease in habitat complexity (1) • Loss of habitat supporting dispersal of aquatic species (1) • Reduction in propagule source (1)	• Reduced habitat function (1) • Restriction too intra-spring colonisation and dispersal (1)	• Unknown impact / Knowledge Gap (1)	• Unknown impact / Knowledge Gap (1)
Melaleuca glomerata	• Loss of habitat with wetland drying out (3, 26) • Local extinction of species (1) • Increased impact of Date palms (1, 21)	• Loss of habitat (1, 3) • Loss of resilience (1) • Decrease in habitat complexity (1) • Loss of habitat supporting dispersal of aquatic species (1) • Reduction in propagule source (1)	• Reduced habitat function (1) • Restriction too intra-spring colonisation and dispersal (1)	• Unknown impact / Knowledge Gap (1)	• Unknown impact / Knowledge Gap (1)
Eriocaulon carsonii	• Loss of habitat with wetland drying out (3)	• Loss of habitat (1, 20) • Loss of resilience (1) • Decrease in habitat complexity (1) • Local extinctions (1, 20) • Reduction in propagule source (1) • Increased competition for space with *Phragmites* spp (20)	• Reduced habitat function (1) • Restriction too intra-spring colonisation and dispersal (1)	• Unknown impact / Knowledge Gap (1)	• Unknown impact / Knowledge Gap (1)
Common Sedges (*Cyperus laevigatus, Cyperus gymnocaulos*)	• Loss of condition (1, 20) • Loss of habitat area (3, 20, 26)	• Loss of habitat (1, 20) • Loss of resilience (1) • Decrease in habitat complexity (1) • Local extinctions (1, 20) • Reduction in propagule source (1)	• Reduced habitat function (1) • Restriction too intra-spring colonisation and dispersal (1)	• Unknown impact / Knowledge Gap (1)	• Unknown impact / Knowledge Gap (1)

Values	Ecosystem Response to Impacts				
Spring Types	**Reduced Flow**	**Reduced Wetland Area**	**Reduced Wetland Connectivity**	**Reduced Groundwater Temperature**	**Contamination of Groundwater**
Relict Sedges (*Gahnia, Juncus, Baumea*)	• Loss of condition (1, 20) • Loss of habitat area (3, 20, 26)	• Loss of habitat (1, 20) • Loss of resilience (1) • Decrease in habitat complexity (1) • Local extinctions (1, 20) • Reduction in propagule source (1) • Species richness correlates with number of vents rather than total wetland area As Wetland area declines so will the number of vents resulting in species loss (20)	• Reduced habitat function (1) • Restriction too intra-spring colonisation and dispersal (1)	• Unknown impact / Knowledge Gap (1)	• Unknown impact / Knowledge Gap (1)
Dalhousie Relicts (*Imperata, Senecio, Eleocharis* etc)	• Loss of condition (1, 20) • Loss of habitat area (3, 20)	• Loss of habitat (1, 20) • Loss of resilience (1) • Decrease in habitat complexity (1) • Local extinctions (1, 20) • Reduction in propagule source (1)	• Reduced habitat function (1) • Restriction too intra-spring colonisation and dispersal (1)	• Reduction in habitat area as microclimate is maintained by heat from groundwater (1)	• Unknown impact / Knowledge Gap (1)
Spring Endemic Species					
Hydrobiids	• Reduction in aquatic habitat area (3, 26) • Loss of condition (1) • Cessation of flow will result in extinction of endemic species (1)	• Reduction in habitat area (3, 26) • Loss of resilience (1) • Reduced foraging area (1) • Local extinctions (6, 7, 8)	• Reduced habitat function (1) • Restriction too intra-spring colonisation and dispersal (6, 7, 8,11,13,18) • Increased chance of extinction from stochastic event (6)	• Some species at Dalhousie likely to be temperature dependent so loss of groundwater temp could result in species decline or extinction (1)	• Unknown but likely to be sensitive to chemical contaminants. Knowledge Gap (1)
Isopods/Amphipods/ Ostracods	• Reduction in aquatic habitat area (3, 26) • Loss of condition (1, 22) • Cessation of flow will result in extinction of endemic species (1)	• Reduction in habitat area (3, 26) • Loss of resilience (1) • Reduced foraging area (1) • Local extinctions (6, 7, 8)	• Reduced habitat function (1, 22) • Restriction too intra-spring colonisation and dispersal (6, 7, 8, 9, 10, 12, 13,14,15,17,18) • Increased chance of extinction from stochastic event (6)	• Some species at Dalhousie likely to be temperature dependent so loss of groundwater temp could result in species decline or extinction (1)	• Unknown but likely to be sensitive to chemical contaminants. Knowledge Gap (1)
Lycosidae	• Reduction in aquatic habitat area (3, 26) • Loss of condition (1)	• Reduction in habitat area (3, 26) • Loss of resilience (28) • Reduced foraging area (1) • Local extinctions (27, 28)	• Reduced habitat function (1) • Restriction too intra-spring colonisation and dispersal (27)	• Unknown impact / Knowledge Gap Unlikely to be a critical issue(1)	• Unknown impact / Knowledge Gap Unlikely to be a critical issue(1)
Fish	• Reduction in aquatic habitat area (3, 26) • Loss of condition (1) • Cessation of flow will result in extinction of endemic species (1)	• Reduction in habitat area (3, 26) • Loss of resilience (1) • Reduced foraging area (1) • Local extinctions (32, 33) • Loss of competitive refuges resulting in increasing competition with introduced species (31, 32)	• Reduced habitat function (1) • Restriction too inter and intra-spring colonisation and dispersal (31, 32) • Critical genetic diversity loss (31, 32) • Increased chance of extinction from stochastic event (6)	• Some species at Dalhousie are temperature dependent (*Mogurnda* and *Neosilurus*) so loss of groundwater temp could result in species decline or extinction (1)	• Unknown but unlikely to occur at levels that will cause problems. However fish species are likely to be sensitive to chemical contaminants which could cause lethal and sub lethal impacts reducing population resilience or interfering with breeding. (31) • Knowledge Gap (1)

Values	Ecosystem Response to Impacts				
Spring Types	**Reduced Flow**	**Reduced Wetland Area**	**Reduced Wetland Connectivity**	**Reduced Groundwater Temperature**	**Contamination of Groundwater**
Other Fauna					
Stromatolites	• Reduction in habitat area (3, 26) • Reduced flows may lead to drying out and loss of "Propagule source"	• Increased exposure to effects of pugging (1) • Loss of suitable habitat (1)	• Reduced habitat function (1) • Restriction too intra-spring colonisation and dispersal (6, 7, 8)	• Unknown impact / Knowledge Gap (1)	• Unknown impact / Knowledge Gap (1)
Ducks and Swans	• Reduction in habitat area (3, 26)	• Decrease in species diversity (23, 24, 25) • Decrease in spatial and temporal habitat availability (23, 24, 25) • Loss of foraging and nesting sites(23)	• Decrease in spatial and temporal habitat availability (23, 24, 25)	• Unknown impact / Knowledge Gap Unlikely to be a critical issue(1)	• Unknown impact / Knowledge Gap (1)
Waders (Stilts / Snipes)	• Reduction in habitat area (3, 26)	• Decrease in species diversity (23, 24, 25) • Decrease in spatial and temporal habitat availability (23, 24, 25) • Loss of foraging and nesting sites(23)	• Decrease in spatial and temporal habitat availability (23, 24, 25)	• Unknown impact / Knowledge Gap Unlikely to be a critical issue(1)	• Unknown impact / Knowledge Gap (1)
Cryptic Birds (Crakes / Rails)	• Reduction in habitat area (3, 26)	• Decrease in species diversity (23, 24, 25) • Decrease in spatial and temporal habitat availability (23, 24, 25) • Loss of foraging and nesting sites(23) • Exposure to predators (26)	• Decrease in spatial and temporal habitat availability (23, 24, 25)	• Unknown impact / Knowledge Gap Unlikely to be a critical issue(1)	• Unknown impact / Knowledge Gap (1)
Other Birds (Grass Owls / Lapwings / Brolga)	• Reduction in habitat area (3, 26)	• Decrease in species diversity (23, 24, 25) • Decrease in spatial and temporal habitat availability (23, 24, 25) • Loss of foraging and nesting sites(23) • Exposure to predators (26)	• Decrease in spatial and temporal habitat availability (23, 24, 25)	• Unknown impact / Knowledge Gap Unlikely to be a critical issue(1)	• Unknown impact / Knowledge Gap (1)
Ecosystem Services					
Permanent Water Point	• Reduction in water available for terrestrial species (1) • Impact on local agriculture as water levels decline (1)	• Loss of foraging site for terrestrial species (1) • Loss of shelter for smaller species exposing them to predation (1)	• NA	• Unknown impact / Knowledge Gap Unlikely to be a critical issue(1)	• Unknown impact / Knowledge Gap (1)
Culture					
Aboriginal	• Reduction in health of important cultural sites (29,30) • Loss of cultural sites (29,30)	• Reduction in health of important cultural sites (29,30) • Loss of cultural sites (29,30)	• Reduction in health of important cultural sites (29,30)	• Reduction in health of important cultural sites (29)	• Reduction in health (real or perceived) of important cultural sites creating distress among traditional owners(29)
European	• Reduction in tourism for the region (1) • Negative impact on iconic sites (1)	• Reduction in tourism for the region (1) • Negative impact on iconic sites (1)	• NA	• Major impact at Dalhousie springs due to tourists making use of hot springs for bathing	• Impact on tourism as clean "pristine" environment perception is lost (1)

Table 8-3 Generalised GAB spring model evidence base table – Water chemistry and quality

Values	Ecosystem Response to Impacts				
	Decreasing pH	**Changing Conductivity**	**Change in DO**	**Increased Nutrients**	**Increased Turbidity**
Spring Types					
Travertine Mound	• Acidification of springs (2, 16) • Loss of biodiversity values (2, 16) • Extinction of short range endemic species (1) • Loss of travertine and structural collapse of mounds (1)	• Loss of biodiversity values (1)	• Spring source water very low in DO then rapidly approaches saturation due to surface area and depth (1)	• Increased growth of wetland veg, particularly *Phragmites* spp resulting in increased transpiration and reduced wetland area and free water habitat (1)	• Not likely to be a major issue due to water depth (1)
Astrobleme (Toondina)	• Acidification of springs (2, 16) • Loss of biodiversity values (2, 16) • Extinction of short range endemic species (1)	• Loss of biodiversity values (1)	• Spring source water very low in DO then rapidly approaches saturation due to surface area and depth (1)	• Increased growth of wetland veg, particularly *Phragmites* spp resulting in increased transpiration and reduced wetland area and free water habitat (1)	• Reduced light penetration to vents (1) • Reduction in littoral zone area(1) • Loss of habitat (1) • Reduction in habitat resilience (1)
Sand Mound	• Acidification of springs (2, 16) • Loss of biodiversity values (2, 16) • Extinction of short range endemic species (1)	• Loss of biodiversity values (1)	• Spring source water very low in DO then rapidly approaches saturation due to surface area and depth (1)	• Increased growth of wetland veg, particularly *Phragmites* spp resulting in increased transpiration and reduced wetland area and free water habitat (1)	• Not likely to be a major issue due to water depth (1)
Flat Depressions	• Acidification of springs (2, 16) • Loss of biodiversity values (2, 16) • Extinction of short range endemic species (1)	• Loss of biodiversity values (1)	• Spring source water very low in DO then rapidly approaches saturation due to surface area and depth (1)	• Increased growth of wetland veg, particularly *Phragmites* spp resulting in increased transpiration and reduced wetland area and free water habitat (1)	• Not likely to be a major issue due to water depth (1)
Abutment	• Acidification of springs (2, 16) • Loss of biodiversity values (2, 16) • Extinction of short range endemic species (1) • Loss of travertine and structural collapse of mounds (1)	• Loss of biodiversity values (1)	• Spring source water very low in DO then rapidly approaches saturation due to surface area and depth (1)	• Increased growth of wetland veg, particularly *Phragmites* spp resulting in increased transpiration and reduced wetland area and free water habitat (1)	• Not likely to be a major issue due to water depth (1)
Thermal Mounds (Dalhousie)	• Acidification of springs (2, 16) • Loss of biodiversity values (2, 16) • Extinction of short range endemic species (1) • Loss of travertine and structural collapse of mounds (1)	• Loss of biodiversity values (1)	• Spring source water very low in DO then rapidly approaches saturation due to surface area and depth (1) • Large vent pools have low DO levels	• Increased growth of wetland veg, particularly *Phragmites* spp resulting in increased transpiration and reduced wetland area and free water habitat (1)	• Reduced light penetration to vents (1) • Reduction in littoral zone area(1) • Loss of habitat (1) • Reduction in habitat resilience (1)
Small Rocky Seeps and Terraces	• Acidification of springs (2, 16) • Loss of biodiversity values (2, 16) • Extinction of short range endemic sprecies (1) • Loss of travertine and structural collapse of mounds (1)	• Loss of biodiversity values (1)	• Spring source water very low in DO then rapidly approaches saturation due to surface area and depth (1)	• Increased growth of wetland veg, particularly *Phragmites* spp resulting in increased transpiration and reduced wetland area and free water habitat (1)	• Not likely to be a major issue due to water depth (1)

Values	Ecosystem Response to Impacts				
	Decreasing pH	**Changing Conductivity**	**Change in DO**	**Increased Nutrients**	**Increased Turbidity**
Vegetation Community					
Phragmites spp	• *Phragmites* relatively tolerant of low pH but ultimately will be lost on extreme acid springs (1, 19)	• Tolerant of a wide range of salinities up to around 27.2mS/cm (19) • Tolerant of fluctuating conductivity (1)	• NA	• *Phragmites* spp positively benefits from elevated nutrients. This results in increased density, increased litter deposition and increased transpiration rates (1)	• Increased turbidity can impact on propagule success in deeper water pools (1)
Typha domingensis	• Intolerant of low pH resulting in species loss (1)	• As Conductivity increases *Typha* will be replaced by *Phragmites* (20)	• NA	• *Typha domingensis* spp positively benefits from elevated nutrients. This results in increased density, increased litter deposition and increased transpiration rates (1)	• Increased turbidity can impact on propagule success in deeper water pools (1)
Melaleuca glomerata	• Intolerant of low pH resulting in species loss (1)	• Unknown/Knowledge gap (1)	• NA	• Likely to respond positively to elevated nitrogen however phosphorus can have a negative impact on some species of Myrtaceae (Knowledge gap) (1) • Can be out competed by *Phragmites* spp (1)	• NA
Eriocaulon carsonii	• Intolerant of low pH resulting in species loss (1, 33)	• Unknown/Knowledge gap (1)	• NA	• *Eriocaulon* spp positively benefits from elevated nutrients.(33) However it competes poorly against aggressive species such as *Phragmites* so will be reduced in area and/or pushed to spring margins when occurring with these species (20)	• NA
Common Sedges (*Cyperus laevigatus, Cyperus gymnocaulos*)	• *Cyperus laevigatus is* intolerant of low pH resulting in species loss (1) • *C. gymnocaulos* relatively tolerant of low pH but ultimately will be lost on extreme acid springs (1)	• As Conductivity increases *Cyperus laevigatus* will be replaced by *C. gymnocaulos* (1)	• NA	• *Cyperus* spp positively benefits from elevated nutrients. This results in increased density and increased transpiration rates (1) • When present with *Phragmites* spp these species are likely to be pushed to the margins or down the tail to more variable wetted areas (1)	• NA
Relict Sedges (*Gahnia, Juncus, Baumea*)	• Intolerant of very low pH resulting in species loss (1)	• Unknown/Knowledge gap (1)	• NA	• Response to elevated nutrients Unknown/Knowledge gap (1) • Will be negatively impacted by increased *Phragmites* density (1)	• NA
Dalhousie Relicts (*Imperata, Senecio, Eleocharis* etc)	• Intolerant of low pH resulting in species loss (1)	• Unknown/Knowledge gap (1)	• NA	• Unknown/Knowledge gap (1)	• NA

Values	Ecosystem Response to Impacts				
	Decreasing pH	**Changing Conductivity**	**Change in DO**	**Increased Nutrients**	**Increased Turbidity**
Spring Endemics					
Hydrobiids	• Extremely sensitive to changes in pH (1)	• Rapid fluctuations in conductivity will result in large scale mortality of endemic specie in this group (1, 22) • Tolerant of moderate salinities – up to 6mS/cm (1)	• Minimal impacts due to water depths (1)	• Direct response to elevated nutrients Unknown/Knowledge gap (1) • Reduction in open free water habitat will negatively impact on the abundance of species (1) • Increased leaf litter from *Phragmites* negatively impacts species (1)	• Reduction in littoral zone area(1) • Loss of habitat (1) • Reduction in habitat resilience (1)
Isopods/Amphipods/ Ostracods	• Extremely sensitive to changes in pH (1)	• Rapid fluctuations in conductivity will result in large scale mortality of endemic specie in this group (1, 22) • Tolerant of moderate salinities – up to 6mS/cm (1)	• Minimal impacts due to water depths (1)	• Direct response to elevated nutrients Unknown/Knowledge gap (1) • Reduction in open free water habitat will negatively impact on the abundance of species (1) • Increased leaf litter from *Phragmites* negatively impacts species (1)	• Reduction in littoral zone area(1) • Loss of habitat (1) • Reduction in habitat resilience (1)
Lycosidae	• Some species very sensitive to changing pH others more tolerant (28)	• Rapid fluctuations in conductivity likely to impact on resilience of Lycosids (1)	• NA	• Direct response to elevated nutrients Unknown/Knowledge gap (1) • Reduction in open free water habitat will negatively impact on the abundance of species (1) • Increased leaf litter from *Phragmites* negatively impacts species (1)	• NA
Fish	• Extremely sensitive to changes in pH (1, 31, 32)	• Rapid fluctuations in conductivity will result in large scale mortality of endemic species in this group excluding Hardyheads (31) • Short term exposure to changing conductivity might be tolerable but not in the long-term(31) • Knowledge gap (32)	• Fish populations can be effected by fluctuating DO at large vent pools at Dalhousie (1, 31, 32) • Eutrophication from nutrients in low flow springs can cause a rapid decline in DO impacting on local fish populations (31)	• Reduction in open free water habitat will negatively impact on the abundance of species and/or localised extinctions (1, 31, 34, 35) • Increased leaf litter from *Phragmites* negatively impacts species (1, 35) • Decreased pH (32)	• Reduction in littoral and limnetic zone area(1) • Loss of habitat (1) • Reduction in habitat resilience for fish populations(1)
Other Fauna					
Stromatolites	• Extremely sensitive to pH lower than 6 (1)	• Unknown/Knowledge gap (1)	• NA	• Unknown/Knowledge gap (1) • Increased vegetation will negatively impact on stromatolite abundance (1)	• NA
Ducks and Swans	• Loss of food source due to low pH reduces likelihood of these species being present (1, 23) • Elevated risk of uptake of metals mobilised in low pH springs (1, 16)	• Loss of food source due to fluctuating pH reduces likelihood of these species being present (1, 23)	• NA	• Reduction in open free water habitat will negatively impact on the abundance of species (23)	• Reduction in foraging sites will negatively impact on these species in large vent pools

Values	Ecosystem Response to Impacts				
	Decreasing pH	**Changing Conductivity**	**Change in DO**	**Increased Nutrients**	**Increased Turbidity**
Waders (Stilts / Snipes)	• Loss of food source due to low pH reduces likelihood of these species being present (1,23) • Elevated risk of uptake of metals mobilised in low pH springs (1, 16)	• More tolerant of fluctuating conductivities than most bird groups but ultimately loss of food source due to fluctuating pH reduces likelihood of these species being present (1, 23)	• NA	• Loss of spring margin habitat due to increased transpiration will negatively impact these species (1, 23) • Reduction of food source for these species may result in reduced abundance (1)	• NA
Cryptic Birds (Crakes / Rails)	• Loss of shelter and food source due to low pH reduces likelihood of these species being present (1,23) • Elevated risk of uptake of metals mobilised in low pH springs (1, 16)	• Loss of food source due to fluctuating pH reduces likelihood of these species being present (1, 23)	• NA	• Denser vegetation may benefit these species from an increase in nesting sites (1, 23)	• NA
Other Birds (Grass Owls / Lapwings / Brolga)	• Loss of nesting sites due to low pH reduces likelihood of these species being present (1,23) • Elevated risk of uptake of metals mobilised in low pH springs (1, 16)	• Unknown/Knowledge gap (1)	• NA	• Denser vegetation may benefit these species from an increase in nesting sites (1, 23)	• NA
Ecosystem Services					
Permanent Water Point	• Mobilisation of accumulated heavy metals eliminates spring as a water point and could result in severe penalties for pastoralists (1)	• Fluctuating conductivity or increased conductivity will reduce value of spring as a watering point (1)	• NA	• Loss of water quality reduces the value of springs as a watering point (1)	• NA
Culture					
Aboriginal	• Reduction in health of important cultural sites (29,30) • Loss of cultural sites (29,30)	• Reduction in health of important cultural sites (29,30) • Loss of cultural sites (29,30)	• NA	• Reduction in health of important cultural sites (29,30)	• Reduction in health of important cultural sites (29,30)
European	• Reduction in tourism for the region (1) • Negative impact on iconic sites (1)	• Reduction in tourism for the region (1) • Negative impact on iconic sites (1)	• NA	• Reduction in tourism for the region (1) • Negative impact on iconic sites (1)	• Reduction in tourism for the region (1) • Negative impact on iconic sites (1)

Table 8-4 Generalised GAB spring model evidence base table – Disturbance

Values	Ecosystem Response to Impacts				
	Grazing and Pugging	**Invasive Species**	**Physical Disturbance (Excavation, exploration impacts etc)**	**Fencing**	**Tourism**
Spring Types					
Travertine Mound	• Loss of vegetation biomass and diversity (36, 37 • Erosion and breaking down of travertine (1) • Increased nutrient loading into springs from faecal matter (1) • Change in habitat (36) • Loss of habitat quality (1, 36) • Change in vegetation community structure (36) • Dispersal of weeds (1)	• Grazing pressure from introduced herbivores (1) • Predation by feral predators (1) • Reduction in resilience (1) • Reduced flows from transpiration by weeds (39) • Introduction of nutrients to the system (1) • Dispersal of weeds (1)	• Erosion and breaking down of travertine (1) • Exposure of sulfides to oxidation resulting in acidification and mobilisation of metals (2, 16) • Damage to spring habitats (1, 36) • Changes to flow regime (1) • Loss of endemic species (1) • Loss/creation of vent pools (1) • Dispersal of weeds (1)	Small scale fencing can result in • Increased *Phragmites* growth (1) • Loss of habitat complexity (1) • Change in habitat structure (1) • Loss of species(1) • Protection of mounds (1) Larger scale fencing or fences with implemented management plans • Initial increased *Phragmites* growth (1) • Protection of grazing sensitive plants(1) • Improved habitat complexity and health (1) • Protection of mounds (1)	• Erosion of travertine and/or mound (1) • Compaction of spring vegetation (1) • Dispersal of weeds (1) • Swimming in vent pools erodes the structure of the pool and potentially introduces contaminants to springs (1)
Astrobleme (Toondina)	• Loss of vegetation biomass and diversity (36, 37 • Increased nutrient loading into springs from faecal matter (1) • Change in habitat (36) • Loss of habitat quality (1, 36) • Change in vegetation community structure (36) • Dispersal of weeds (1)	• Grazing pressure from introduced herbivores (1) • Predation by feral predators (1) • Reduction in resilience (1) • Reduced flows from transpiration by weeds (39) • Introduction of nutrients to the system (1) • Dispersal of weeds (1)	• Damage to spring habitats (1, 36) • Changes to flow regime (1) • Loss of endemic species (1) • Significant excavation damage exists at Toondina and has resulted in the loss of fish and crustacean species (1) • Dispersal of weeds (1)	Small scale fencing can result in • Increased *Phragmites* growth (1) • Loss of habitat complexity (1) • Change in habitat structure (1) • Loss of species(1) • Protection of mounds (1) Larger scale fencing or fences with implemented management plans • Initial increased *Phragmites* growth (1) • Protection of grazing sensitive plants(1) • Improved habitat complexity and health (1) • Protection of mounds (1)	• No Public Access

<table>
<tr><th>Values</th><th colspan="5">Ecosystem Response to Impacts</th></tr>
<tr><th></th><th>Grazing and Pugging</th><th>Invasive Species</th><th>Physical Disturbance (Excavation, exploration impacts etc)</th><th>Fencing</th><th>Tourism</th></tr>
<tr><td>Sand Mound</td><td>• Loss of vegetation biomass and diversity (36, 37
• Increased nutrient loading into springs from faecal matter (1)
• Change in habitat (36)
• Loss of habitat quality (1, 36)
• Change in vegetation community structure (36)
• Dispersal of weeds (1)</td><td>• Grazing pressure from introduced herbivores (1)
• Predation by feral predators (1)
• Reduction in resilience (1)
• Reduced flows from transpiration by weeds (39)
• Introduction of nutrients to the system (1)
• Dispersal of weeds (1)</td><td>• Damage to spring habitats (1, 36)
• Changes to flow regime (1)
• Loss of endemic species (1)
• Exposure of sulfides to oxidation resulting in acidification and mobilisation of metals (2, 16)
• Loss/creation of vent pools (1)
• Dispersal of weeds (1)</td><td>Small scale fencing can result in
• Increased Phragmites growth (1)
• Loss of habitat complexity (1)
• Change in habitat structure (1)
• Loss of species(1)
• Protection of mounds (1)

Larger scale fencing or fences with implemented management plans
• Initial increased Phragmites growth (1)
• Protection of grazing sensitive plants(1)
• Improved habitat complexity and health (1)
• Protection of mounds (1)</td><td>• Erosion of travertine and/or mound (1)
• Compaction of spring vegetation (1)
• Dispersal of weeds (1)
• Swimming in vent pools erodes the structure of the pool and potentially introduces contaminants to springs (1)</td></tr>
<tr><td>Flat Depressions</td><td>• Loss of vegetation biomass and diversity (36, 37
• Increased nutrient loading into springs from faecal matter (1)
• Change in habitat (36)
• Loss of habitat quality (1, 36)
• Change in vegetation community structure (36)
• Dispersal of weeds (1)</td><td>• Grazing pressure from introduced herbivores (1)
• Predation by feral predators (1)
• Reduction in resilience (1)
• Reduced flows from transpiration by weeds (39)
• Introduction of nutrients to the system (1)
• Dispersal of weeds (1)</td><td>• Damage to spring habitats (1, 36)
• Changes to flow regime (1)
• Loss of endemic species (1)
• Exposure of sulfides to oxidation resulting in acidification and mobilisation of metals (2, 16)
• Loss of vent pools (1)
• Dispersal of weeds (1)</td><td>Small scale fencing can result in
• Increased Phragmites growth (1)
• Loss of habitat complexity (1)
• Change in habitat structure (1)
• Loss of species(1)
• Protection of mounds (1)

Larger scale fencing or fences with implemented management plans
• Initial increased Phragmites growth (1)
• Protection of grazing sensitive plants(1)
• Improved habitat complexity and health (1)
• Protection of mounds (1)</td><td>• Erosion of travertine and/or mound (1)
• Compaction of spring vegetation (1)
• Dispersal of weeds (1)</td></tr>
</table>

Values	Ecosystem Response to Impacts				
	Grazing and Pugging	**Invasive Species**	**Physical Disturbance (Excavation, exploration impacts etc)**	**Fencing**	**Tourism**
Abutment	• Loss of vegetation biomass and diversity (36, 37 • Erosion and breaking down of travertine (1) • Increased nutrient loading into springs from faecal matter (1) • Change in habitat (36) • Loss of habitat quality (1, 36) • Change in vegetation community structure (36) • Dispersal of weeds (1)	• Grazing pressure from introduced herbivores (1) • Predation by feral predators (1) • Reduction in resilience (1) • Reduced flows from transpiration by weeds (39) • Introduction of nutrients to the system (1) • Dispersal of weeds (1)	• Erosion and breaking down of travertine (1) • Exposure of sulfides to oxidation resulting in acidification and mobilisation of metals (2, 16) • Damage to spring habitats (1, 36) • Changes to flow regime (1) • Loss of endemic species (1) • Loss/creation of vent pools (1) • Dispersal of weeds (1)	Small scale fencing can result in • Increased *Phragmites* growth (1) • Loss of habitat complexity (1) • Change in habitat structure (1) • Loss of species(1) • Protection of mounds (1) Larger scale fencing or fences with implemented management plans • Initial increased *Phragmites* growth (1) • Protection of grazing sensitive plants(1) • Improved habitat complexity and health (1) • Protection of mounds (1)	• Erosion of travertine and/or mound (1) • Compaction of spring vegetation (1) • Dispersal of weeds (1) • Swimming in vent pools erodes the structure of the pool and potentially introduces contaminants to springs (1)
Thermal Mounds (Dalhousie)	• Loss of vegetation biomass and diversity (36, 37 • Erosion and breaking down of travertine (1) • Increased nutrient loading into springs from faecal matter (1) • Change in habitat (36) • Loss of habitat quality (1, 36) • Change in vegetation community structure (36) • Dispersal of weeds (1)	• Grazing pressure from introduced herbivores (1) • Predation by feral predators (1) • Reduction in resilience (1) • Reduced flows from transpiration by weeds (39) • Introduction of nutrients to the system (1) • Critical risk to Dalhousie fish populations (32) • Dispersal of weeds (1)	• Erosion and breaking down of travertine (1) • Exposure of sulfides to oxidation resulting in acidification and mobilisation of metals (2, 16) • Damage to spring habitats (1, 36) • Changes to flow regime (1) • Loss of endemic species (1) • Loss of vent pools (1) • Dispersal of weeds (1)	Larger scale fencing or fences with implemented management plans • Initial increased *Phragmites* growth (1) • Protection of grazing sensitive plants(1) • Improved habitat complexity and health (1) • Protection of mounds (1)	• Erosion of travertine and/or mound (1) • Compaction of spring vegetation (1) • Dispersal of weeds (1) • Swimming in vent pools erodes the structure of the pool and potentially introduces contaminants to springs (1)

Values	Ecosystem Response to Impacts				
	Grazing and Pugging	**Invasive Species**	**Physical Disturbance (Excavation, exploration impacts etc)**	**Fencing**	**Tourism**
Small Rocky Seeps and Terraces	• Loss of vegetation biomass and diversity (36, 37 • Erosion and breaking down of travertine (1) • Increased nutrient loading into springs from faecal matter (1) • Change in habitat (36) • Loss of habitat quality (1, 36) Change in vegetation community structure (36) Dispersal of weeds (1)	• Grazing pressure from introduced herbivores (1) • Predation by feral predators (1) • Reduction in resilience (1) • Reduced flows from transpiration by weeds (39) • Introduction of nutrients to the system (1) • Dispersal of weeds (1)	• Erosion and breaking down of travertine (1) • Exposure of sulfides to oxidation resulting in acidification and mobilisation of metals (2, 16) • Damage to spring habitats (1, 36) • Changes to flow regime (1) • Loss of endemic species (1) • Loss/creation of vent pools (1) • Dispersal of weeds (1)	Small scale fencing can result in • Increased *Phragmites* growth (1) • Loss of habitat complexity (1) • Change in habitat structure (1) • Loss of species(1) • Protection of mounds (1) Larger scale fencing or fences with implemented management plans • Initial increased *Phragmites* growth (1) • Protection of grazing sensitive plants(1) • Improved habitat complexity and health (1) • Protection of mounds (1)	• Erosion of travertine and/or mound (1) • Compaction of spring vegetation (1) • Dispersal of weeds (1)
Vegetation					
Phragmites spp.	• Performs better than most other species to grazing pressure, can be benefited by selective grazing targeting other species (1) • Responds well to nutrients from faecal matter (1, 19) • Extreme grazing will result in loss of biomass and impaired sexual reproduction (1, 19))	• Grazing impacts from feral herbivores (1) • Can be excluded by introduced plants such as Date Palms, Athol Pine and Bamboo (1)	• Loss of habitat area (1) • Changes to flow paths can result in loss of wetland habitat (1) • Dispersal of seed to springs without *Phragmites* on machinery (1)	• Positive effect, exclusion from grazers and high nutrient levels result in aggressive growth of *Phragmites* • Deposition of thick (up to 3m) litter	• Dispersal of seed to springs without *Phragmites* (1)
Typha domingensis	• Targeted species for grazers (1) • Loss of cover from overgrazing and pugging (1) • Spread of seed (1)	• Grazing impacts from feral herbivores (1) • Can be excluded by introduced plants such as Date Palms, Athol Pine and Bamboo (1)	• Loss of habitat area (1) • Changes to flow paths can result in loss of wetland habitat (1) • Dispersal of seed to springs without *Typha* on machinery (1)	• Positive effect, exclusion from grazers and high nutrient levels result in aggressive growth of *Typha*	• Dispersal of seed to springs without *Typha* (1)
Melaleuca glomerata	• Not targeted by grazing (1) • Seedlings impacted by pugging (1)	• Trampling impacts from feral herbivores (1) • Can be excluded by introduced plants such as Date Palms, Athol Pine and Bamboo (1)	• Clearing of trees for tracks and access (1) • Changes to flow paths can result in loss of wetland habitat (1)	• Moderately positive effect from exclusion of grazers, this can be neutralised by aggressive growth of *Phragmites* or weeds (1)	• Collection of wood for fires (1)

Values	Ecosystem Response to Impacts				
	Grazing and Pugging	**Invasive Species**	**Physical Disturbance (Excavation, exploration impacts etc)**	**Fencing**	**Tourism**
Eriocaulon carsonii	• Very sensitive to grazing and pugging (20)	• Grazing impacts from feral herbivores (1) • Can be excluded by introduced plants such as Date Palms, Athol Pine and Bamboo (1)	• Loss of habitat area (1) • Changes to flow paths can result in loss of wetland habitat (1) • Exposure of sulfides in soil will result in local extinction of *Eriocaulon* (1, 20)	• Overgrowth of *Phragmites* in response to fencing pushes *Eriocaulon* to the margins resulting in more exposure to grazing (20)	• NA
Common Sedges (*Cyperus laevigatus, Cyperus gymnocaulos*)	• Performs better than most other species to grazing pressure, can be benefited by selective grazing targeting other species (1) • Responds well to nutrients from faecal matter (1, 19) • Extreme grazing will result in loss of biomass and impaired sexual reproduction (1, 19))	• Grazing impacts from feral herbivores (1) • Can be excluded by introduced plants such as Date Palms, Athol Pine and Bamboo (1)	• Loss of habitat area (1) • Changes to flow paths can result in loss of wetland habitat (1) • Exposure of sulfides in soil will result in local extinction of *Cyperus* spp. (1, 20)	• Moderately positive effect from exclusion of grazers, this can be neutralised by aggressive growth of *Phragmites* or weeds (1)	• Dispersal of seed (1)
Relict Sedges (*Gahnia, Juncus, Baumea*)	• Targeted species for grazers (1) • Loss of cover from overgrazing and pugging (1)	• Grazing impacts from feral herbivores (1) • Can be excluded by introduced plants such as Date Palms, Athol Pine and Bamboo (1)	• Loss of habitat area (1) • Changes to flow paths can result in loss of wetland habitat (1) • Exposure of sulfides in soil will result in local extinction of *Cyperus* spp. (1, 20)	• Moderately positive effect from exclusion of grazers, this can be neutralised by aggressive growth of *Phragmites* or weeds (1)	• NA
Dalhousie Relicts (*Imperata, Senecio, Eleocharis* etc)	• Loss of cover from overgrazing and pugging (1) • Unknown/Knowledge Gap	• Grazing impacts from feral herbivores (1) • Can be excluded by introduced plants such as Date Palms, Athol Pine and Bamboo (1)	• Loss of habitat area (1) • Changes to flow paths can result in loss of wetland habitat (1)	• positive effect from exclusion of grazers (1)	• Some trampling of plants adjacent to public access areas • Erosion of spring banks undercutting and dislodging locally rare *Eleocharis and Baumea* spp.
Spring Endemic					
Hydrobiids	• Loss of habitat (1) • Loss of habitat condition (1) • Reduced population numbers (1) • Potential species extinction (1)	• Weeds such as Date palms can suppress phytoplankton crashing the food web and resulting in localised extinctions (39) • Pugging from herbivores reduces abundance and can lead to local extinctions (1) • *Gambusia* predate on Hydrobiids (1)	• Exposure of sulfides in soil will result in local extinctions • Loss of habitat (1) • Loss of habitat condition (1) • Reduced population numbers (1) • Potential species extinction (1)	• Overgrowth of *Phragmites* in response to fencing pushes Hydrobiids to the margins resulting in more exposure to grazing pressure (1)	• Potential dispersal vector (1) • Compaction of edge sediments (1) • Compaction of foraging areas (1)
Isopods/Amphipods/ Ostracods	• Loss of habitat (1) • Loss of habitat condition (1) • Reduced population numbers (1) • Potential species extinction (1)	• Weeds such as Date palms can suppress phytoplankton crashing the food web and resulting in localised extinctions (39) • Pugging from herbivores reduces abundance and can lead to local extinctions (1) • *Gambusia* predate on crustaceans (1)	• Exposure of sulfides in soil will result in local extinctions • Loss of habitat (1) • Loss of habitat condition (1) • Reduced population numbers (1) • Potential species extinction (1)	• Overgrowth of *Phragmites* in response to fencing pushes crustaceans to the margins resulting in more exposure to grazing pressure (1)	• Potential dispersal vector (1) • Compaction of edge sediments (1) • Compaction of foraging areas (1)

Values	Ecosystem Response to Impacts				
	Grazing and Pugging	**Invasive Species**	**Physical Disturbance (Excavation, exploration impacts etc)**	**Fencing**	**Tourism**
Lycosidae	• Moderate grazing is beneficial for Lycosidae (27, 36) • Pugging reduces refuge sites and destroys burrows of spring margin dwelling Lycosids (27, 36) • Extreme grazing results in loss of cover and refuge sites ex[posing spiders to predation (27, 36)	• Grazing impacts (1) • Weeds such as Date palms can suppress phytoplankton crashing the food web and resulting in localised extinctions (39)	• Loss of habitat (1) • Loss of habitat condition (1) • Reduced population numbers (1) • Potential species extinction (1)	• Overgrowth of *Phragmites* in response to fencing changes habitats to less favourable types and pushes Lycosids to the margins resulting in more exposure to grazing pressure (1)	• Potential dispersal vector (1) • Compaction of edge sediments (1) • Compaction of foraging areas (1)
Fish	• Turbidity, loss of DO from sediment disturbance (31) • Spawning substrate loss (31) • Open water habitat loss (1) • Fouling of eggs (31) • Physical squashing and isolation of benthic fish like goby (31) • Changing internal architecture of springs (32)	• *Gambusia holbrookii* represent a major threat to GAB Spring fish and are the largest risk to endemic fish communities at Dalhousie. Impacts include predation on juveniles, harassment of adults and egg predation that can lead to local or species wide extinctions (31, 38) • *Polypogon monspeliensis* (weed) results in habitat modification, loss of habitat, loss of foraging sites (1) • Potential new introductions that could have serious impacts on endemic fish include red claw, sleepy cod and tropical aquarium fish (31, 32, 38) • Introduced disease from poor sampling hygiene during fish surveys or with tourists (1) • Trampling and pugging by feral herbivores damaging habitats (1)	• Sediment runoff (1) • Changing pathways of connectivity to rivers (31 32) • Fish sensitive to vibration potential impact from seismic Knowledge Gap (31, 32)	• Overgrowth of *Phragmites* in response to fencing changes habitats to less favourable types for fish (31) • Trophic changes resulting from habitat disturbance (31)	• introduction of contaminants • habitat disturbance • Introduction of disease or pest species by tourists (1)
Other Fauna					
Stromatolites	• Severe impact on Stromatolites. Stromatolites disappear when pugging levels exceed moderate (1)	• Unknown/Knowledge Gap (1)	• Severe impact on Stromatolites	• Overgrowth of *Phragmites* in response to fencing changes habitats pushing Stromatolites to the margins	• Habitat disturbance (1) • Habitat compaction (1)
Ducks and Swans	• Loss of nesting sites (1, 23)	• Predation by feral cats (1)	• Presence of people and equipment will drive away avifauna (1) • Creation of open water habitat beneficial to these species (1, 23)	• Reduction in open water habitat detrimental to species (1)	• Disturbance by people will drive avifauna away (1)
Waders (Stilts / Snipes)	• Heavy grazing and pugging damages feeding areas (1, 23) • Moderate grazing opens up more sites for foraging (1, 23)	• Predation by feral cats (1) • Grazing impacts (1)	• Presence of people and equipment will drive away avifauna (1) • Creation of open water habitat beneficial to these species (1, 23)	• Reduction in open water habitat detrimental to species (1)	• Disturbance by people will drive avifauna away (1)

Values	Ecosystem Response to Impacts				
	Grazing and Pugging	**Invasive Species**	**Physical Disturbance (Excavation, exploration impacts etc)**	**Fencing**	**Tourism**
Cryptic Birds (Crakes / Rails)	• Loss of nesting sites (1, 23) • Exposure of birds to predators (1, 23)	• Predation by feral cats (1) • Grazing impacts (1)	• Presence of people and equipment will drive away avifauna (1) • Loss of Refugia habitat (1, 23)	• Overgrowth of *Phragmites* in response to fencing increases cover and nesting sites (1)	• Disturbance by people will drive avifauna away (1) • Walking I spring wetlands may disturb nesting sites (1)
Other Birds (Grass Owls / Lapwings / Brolga)	• Loss of nesting sites (1, 23) • Loss of foraging sites (1, 23) • Overall degradation of habitat (1, 23)	• Predation by feral cats (1) • Grazing impacts (1)	• Presence of people and equipment will drive away avifauna (1)	• Overgrowth of *Phragmites* in response to fencing increases cover and nesting sites (1)	• Disturbance by people will drive avifauna away (1)
Ecosystem Services					
Permanent Water Point	• Over stocking can result in polluted water point (1)	• Predation of stock by dogs (1) • Competition for resources by Feral herbivores (1)	• Presence of people and equipment will disturb stock (1)	• Protection of vent from stock damage	• Presence of people and equipment will disturb stock (1)
Culture					
Aboriginal	• Reduction in health of important cultural sites (29,30) • Loss of cultural sites (29,30)	• Reduction in health of important cultural sites (29,30) • Loss of cultural sites (29,30)	• Reduction in health of important cultural sites (29,30) • Loss of cultural sites (29,30)	• Fencing can provide protection to cultural sites but a lack of management plan can result in damage offering due aggressive regrowth of *Phragmites* (1, 29,30)	• Vandalism of cultural sites (29,30) • Loss of cultural sites (29,30) • Inappropriate use of cultural sites (29, 30) • Education opportunity for tourists and non-aboriginals (1, 29, 30)
European	• Reduction in tourism for the region (1) • Negative impact on iconic sites (1)	• Reduction in tourism for the region (1) • Negative impact on iconic sites (1)	• Reduction in tourism for the region (1) • Negative impact on iconic sites (1)	• Fencing can provide protection to cultural sites but a lack of management plan can result in damage offering due aggressive regrowth of *Phragmites* (1)	• Education opportunity for tourists and non-aboriginals (1) • Damage to springs from over use (1)

D. Diffuse discharge (scald) model evidence base tables

The following evidence base tables with associated reference are presented for the generalised GAB diffuse discharge (scald) model; hydrology (Table 8-5), and water chemistry, quality and disturbance (Table 8-6). References for all three tables are provided in Appendix E).

Table 8-5 Diffuse discharge (scald) model evidence base table – Hydrology

Values	**Ecosystem Response to Impacts**				
Habitat Types	**Reduced Open Water Habitat Area**	**Reduced Scald Area**	**Reduced Wetland Connectivity**	**Increased Ground Temperature**	**Contamination of Groundwater**
Damp Salt Flats	• NA	• Scald area related to groundwater flow, wetted area reduced proportionally to flow reduction (40) • Reduced habitat area for scald dependent flora and fauna (1, 22, 33)	• Reduced habitat function (1, 4) • Restriction in intra-scald colonization and dispersal (1, 22) • Potential for species loss (1, 22, 33)	• Scald dependent fauna strongly dependent on cooling effects of evaporating moisture to survive otherwise extreme conditions (1, 40)	• Unknown impact / Knowledge Gap (1)
Open Water Channels	• Reduced habitat area for free water dependent flora and fauna (1, 22, 23, 33) • Loss of open water habitat (1)	• NA (1)	• Reduced habitat function (1, 4) • Restriction in intra-scald cononizaltion and dispersal (1, 22) • Potential for species loss (1, 22, 33)	• Increased pool temperatures reduce DO in pools and negatively impact on open water living species	• Unknown impact / Knowledge Gap (1)
Vegetation Community					
Frankenia sp. (*Frankenia* sand flats)	• NA	• Loss of habitat (1,40) • Loss of resilience (1) • Decrease in habitat complexity (1) • Loss of habitat supporting scald species (1)	• Reduced habitat function (1, 4) • Restriction in intra-scald colonization and dispersal (1) • Potential for species loss (1, 22, 33)	• Obligate pollinator bee needs cool temperatures provided by evaporating moisture to survive, increased temperatures will ultimately result in loss of pollinators and loss of local populations (1) • Unknown impact on the plant / Knowledge Gap (1)	• Unknown impact / Knowledge Gap (1)
Samphire	• Open water habitats support Samphire populations around the margins of the channel reduction in these habitats will negatively impact on the Samphire habitat area	• Loss of habitat (1,40) • Loss of resilience (1) • Decrease in habitat complexity (1) • Loss of habitat supporting scald species (1)	• Reduced habitat function (1, 4) • Restriction in intra-scald colonization and dispersal (1, 22) • Potential for species loss (1, 22, 33)	• Unknown impact / Knowledge Gap (1)	• Unknown impact / Knowledge Gap (1)
Scald Endemic Species					
Tetralycosa sp (Salt Lake Wolf Spiders)	• NA	• Loss of habitat for foraging and burrowing (1,40) • Loss of resilience (1) • Increased competition from non-scald Lycosids (1)	• Reduced habitat function (1, 4) • Restriction in intra-scald colonization and dispersal (1) • Potential for species loss (1)	• *Tetralycosa* strongly dependent on cooling effects of evaporating moisture to survive otherwise extreme conditions (1)	• Unknown impact / Knowledge Gap Unlikely to be a critical issue(1)

Values	Ecosystem Response to Impacts				
Habitat Types	**Reduced Open Water Habitat Area**	**Reduced Scald Area**	**Reduced Wetland Connectivity**	**Increased Ground Temperature**	**Contamination of Groundwater**
Fish	• Reduction in aquatic habitat area (3, 26) • Loss of condition (1) • Cessation of groundwater support will result in extinction of endemic species (1)	• NA	• Reduced habitat function (1) • Restriction too inter and intra-spring colonization and dispersal (31, 32) • Critical genetic diversity loss (31, 32) • Increased chance of extinction from stochastic event (6)	• NA	• Unknown but unlikely to occur at levels that will cause problems. However fish species are likely to be sensitive to chemical contaminants which could cause lethal and sub lethal impacts reducing population resilience or interfering with breeding. (31) • Knowledge Gap (1)
Lasioglossum frankenia (Frankenia Bee)	• NA	• Loss of habitat for foraging and burrowing (1,40) • Loss of resilience (1) • Knowledge Gap (1)	• Reduced habitat function (1, 4) • Restriction in intra-scald colonization and dispersal (1) • Potential for species loss (1) • Knowledge Gap (1)	• *Lasioglossum frankenia* are likely to be strongly dependent on cooling effects of evaporating moisture to survive otherwise extreme conditions (1) • Knowledge Gap (1)	• Unknown impact / Knowledge Gap Unlikely to be a critical issue(1)
Oniscidean Isopods	• NA	• Loss of habitat for foraging and burrowing (1,40) • Loss of resilience (1, 22)	• Reduced habitat function (1, 4, 22) • Restriction in intra-scald colonization and dispersal (1) • Potential for species loss (22)	• Onicidians are strongly dependent on cooling effects of evaporating moisture to survive otherwise extreme conditions (1, 22)	• Unknown impact / Knowledge Gap (1)
Other Fauna					
Lake Eyre Dragon	• NA	• Loss of habitat for foraging and burrowing (1,40) • Loss of resilience (1, 23)	• Reduced habitat function (1, 4, 23) • Restriction in intra-scald colonization and dispersal (1) • Potential for species loss (23)	• *Ctenophorus maculosus* is dependent on cooling effects of evaporating moisture to survive otherwise extreme conditions (1, 23)	• Unknown impact / Knowledge Gap (1)
Ducks	• Reduction in habitat area (3, 26) • Loss of resting sites (23) • Reductions in food availability (macrophytes and invertebrates) (23) • Reduction in open water habitat will reduce likelihood of ducks landing and occupying these sites (23)	• NA	• Decrease in spatial and temporal habitat availability (23, 24, 25)	• NA	• Unknown impact / Knowledge Gap (1)
Waders (Stilts / Snipes)	• Reduction in habitat area particularly for Red Capped Dotterels, Black Fronted Dotterels and Red Kneed Dotterels(3, 23, 26) • Loss of resting sites (23) • Reductions in food availability (macrophytes & invertebrates) (23) • Loss of deeper pools will negatively impact on Red Necked Avocets (23)	• NA	• Decrease in spatial and temporal habitat availability (23, 24, 25)	• Unknown impact / Knowledge Gap (1)	• Unknown impact / Knowledge Gap (1)
Other Birds (Lapwing etc.)	• Reduction in foraging habitat area (23, 26) • Decrease in spatial and temporal habitat availability (23, 24, 25) • Loss of foraging sites(23) • Exposure to predators (26)	• Decrease in species diversity (23, 24, 25) • Decrease in spatial and temporal habitat availability (23, 24, 25) • Loss of foraging sites(23) • Exposure to predators (26)	• Decrease in spatial and temporal habitat availability (23, 24, 25)	• Unknown impact / Knowledge Gap Unlikely to be a critical issue(1)	• Unknown impact / Knowledge Gap (1)

Values	Ecosystem Response to Impacts				
Habitat Types	**Reduced Open Water Habitat Area**	**Reduced Scald Area**	**Reduced Wetland Connectivity**	**Increased Ground Temperature**	**Contamination of Groundwater**
Culture					
Aboriginal	• Reduction in health of important cultural sites (29,30) • Loss of cultural sites (29,30)	• Reduction in health of important cultural sites (29,30) • Loss of cultural sites (29,30)	• Reduction in health of important cultural sites (29,30)	• Reduction in health of important cultural sites (29)	• Reduction in health (real or perceived) of important cultural sites creating distress among traditional owners(29)
European	• NA	• NA	• NA	• NA	• Impact on tourism as clean "pristine" environment perception is lost (1)

Table 8-6 Generalised GAB spring model evidence base table – Water chemistry, quality and disturbance

Values	Ecosystem Response to Impacts					
Spring Types	**Change in pH**	**Changing Conductivity**	**Grazing and Pugging**	**Physical Disturbance (Excavation, exploration impacts, tourism etc.)**	**Fencing**	**Increased Turbidity**
Damp Salt Flats	• Possible acidification of scalds (1) • Knowledge Gap (1)	• Knowledge Gap (1)	• Loss of vegetation biomass and diversity (1) • Erosion and breaking down of habitat (1) • Compaction of habitats especially in proximity to springs (1) • Loss of habitat quality (1) • Dispersal of weeds (1)	• Increased erosion (1) • Changes to broader flow regime (1) • Dispersal of weeds (1)	• Protection of grazing sensitive plants(1) • Protection of plants sensitive to trampling (1)	• NA
Open Water Channels	• Acidification of scalds could result in acid pulses into pools and channels during rain events (1) • Knowledge Gap (1)	• Knowledge Gap (1)	• Loss of vegetation biomass and diversity (1) • Increased nutrient loading into channels from faecal matter (1) • Change in habitat (36) • Loss of habitat quality (1, 36) • Change in vegetation community structure (1) • Dispersal of weeds (1) • Damage to channel structure (1)	• Damage to channel habitats (1) • Changes to flow regime (1) • Loss of channel dependent species (1) • Damage to nesting sites (23) • Dispersal of weeds (1)	• Protection of grazing sensitive plants(1) • Protection of plants sensitive to pugging (1)	• Reduced light penetration to pools (1) • Reduction in littoral and limnetic zone area(1) • Loss of habitat (1) • Reduction in habitat resilience (1)
Vegetation Community						
Frankenia sp.	• Knowledge Gap (1)	• Range of salinity tolerance is unknown (1) • Tolerant of fluctuating conductivity (1)	• *Frankenia* sp are very sensitive to trampling excessive trampling results in loss of propagule's (1)	• Loss of habitat area (1) • Changes to flow paths can result in loss of scald habitat (1) • *Frankenia* sp are very sensitive to disturbance ultimately resulting in loss of propagule's (1)	• Positive effect, protection from trampling (1)	• NA
Samphire	• Knowledge Gap (1)	• Tolerant of extreme saline conditions (1) • Tolerant of a wide range of salinities (1)	• Not grazed (1) • Pugging can impact existing and propagule success (1)	• Loss of habitat area (1) • Changes to flow paths can result in loss of wetland habitat (1)	• Positive effect, protection from trampling (1)	• NA
Scald Endemic Species						

Values	Ecosystem Response to Impacts					
Spring Types	**Change in pH**	**Changing Conductivity**	**Grazing and Pugging**	**Physical Disturbance (Excavation, exploration impacts, tourism etc.)**	**Fencing**	**Increased Turbidity**
Tetralycosa sp	• Knowledge Gap (1)	• Rapid fluctuations in conductivity likely to impact on resilience of Lycosids (1)	• Pugging reduces refuge sites and destroys burrows of scald dwelling Lycosids (27, 36)	• Loss of habitat (1) • Loss of habitat condition (1) • Reduced population numbers (1) • Changes in flow paths from road diversions may locally dry out scald areas (1) • Potential species extinction (1)	• Positive effect, protection from trampling (1)	• NA
Fish	• Extremely sensitive to changes in pH (1, 31, 32)	• *Craterocephalus eyrsii* tolerant of fluctuating conductivity (31)	• Turbidity, loss of DO from sediment disturbance (31) • Spawning substrate loss (31) • Open water habitat loss (1) • Fouling of eggs (31) • Changing internal architecture of channels (32)	• Sediment runoff (1) • Changing pathways of connectivity to rivers (31 32)	• Reduction in impacts from pugging (31, 32)	• Reduction in littoral and limnetic zone area(1) • Loss of habitat (1) • Reduction in habitat resilience for fish populations(1)
Frankenia Bee	• Knowledge Gap (1)	• Knowledge Gap (1)	• Pugging reduces refuge sites and destroys burrows of scald dwelling bees (1) • Knowledge Gap (1)	• Vehicle traffic reduces refuge sites and destroys burrows of scald dwelling bees (1) • Changes in flow paths from road diversions may locally dry out scald areas (1) • Knowledge Gap (1)	• Knowledge Gap (1)	• NA
Onicidians	• Extremely sensitive to changes in pH (1)	• Rapid fluctuations in conductivity likely to result in large scale mortality of endemic species in this group (1, 22)	• Damage to habitat (1) • Loss of habitat condition (1) • Reduced population numbers (1) • Potential species extinction (1)	• Changes in flow paths from road diversions may locally dry out scald areas (1) • Loss of habitat (1) • Loss of habitat condition (1) • Reduced population numbers (1) • Potential species extinction (1)	• Knowledge Gap (1)	• NA
Other Fauna						
Lake Eyre Dragon (*Ctenophorus maculosus*)	• Knowledge Gap (1)	• Knowledge Gap (1)	• Pugging reduces refuge sites and destroys burrows of scald dwelling reptiles (1, 23)	• Loss of habitat (1) • Loss of habitat condition (1) • Reduced population numbers (1) • Changes in flow paths from road diversions may locally dry out scald areas (1) • Potential species extinction (1)	• Positive effect, protection from trampling (1)	• NA

Values	Ecosystem Response to Impacts					
Spring Types	**Change in pH**	**Changing Conductivity**	**Grazing and Pugging**	**Physical Disturbance (Excavation, exploration impacts, tourism etc.)**	**Fencing**	**Increased Turbidity**
Ducks	• Loss of food source due to low pH reduces likelihood of these species being present (1, 23)	• Loss of food source due to fluctuating conductivity reduces likelihood of these species being present (1, 23)	• Loss of nesting sites (1, 23)	• Presence of people and equipment will drive away avifauna (1) • Changes in flow paths from road diversions may locally dry out channels negatively impacting on these species (1, 23)	• Positive effect, protection of nesting sites from trampling (1)	• Reduction in foraging sites will negatively impact on these species in large pools
Waders (Stilts / Snipes)	• Loss of food source due to low pH reduces likelihood of these species being present (1,23)	• More tolerant of fluctuating conductivities than most bird groups but ultimately loss of food source due to fluctuating conductivity reduces likelihood of these species being present (1, 23)	• Heavy grazing and pugging damages feeding areas (1, 23) • Loss of nesting sites (1, 23) • Moderate grazing opens up more sites for foraging (1, 23)	• Presence of people and equipment will drive away avifauna (1) • Changes in flow paths from road diversions may locally dry out channels negatively impacting on these species (1, 23)	• Positive effect, protection of nesting sites from trampling (1)	• NA
Other Birds (Lapwing etc)	• Loss of nesting sites due to low pH reduces likelihood of these species being present (1,23)	• Unknown/Knowledge gap (1)	• Loss of nesting sites (1, 23) • Loss of foraging sites (1, 23) • Overall degradation of habitat (1, 23)	• Presence of people and equipment will drive away avifauna (1)	• Positive effect, protection of nesting sites from trampling (1)	• NA
Culture						
Aboriginal	• Reduction in health of important cultural sites (29,30) • Loss of cultural sites (29,30)	• Reduction in health of important cultural sites (29,30) • Loss of cultural sites (29,30)	• Reduction in health of important cultural sites (29,30) • Loss of cultural sites (29,30)	• Reduction in health of important cultural sites (29,30) • Loss of cultural sites (29,30)	• Fencing can provide protection to cultural sites (1)	• Reduction in health of important cultural sites (29,30)
European	• Reduction in tourism for the region (1) • Negative impact on iconic sites (1)	• Reduction in tourism for the region (1) • Negative impact on iconic sites (1)	• Reduction in tourism for the region (1) • Negative impact on iconic sites (1)	• Reduction in tourism for the region (1) • Negative impact on iconic sites (1)	• Fencing can provide protection to cultural sites (1)	• NA

E. Evidence base tables reference list

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