REPORT

Great Artesian Basin Springs Conceptualisation in NSW

NSW GAB Springs Conceptualisation Report

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Executive Summary

Objective

Golder Associates were engaged by the NSW Department of Planning, Industry and Environment (DPIE) to conceptualise selected NSW Great Artesian Basin (GAB) springs from the Bourke and Bogan River Supergroups. This assessment was based on field surveys and analytical results from springs and GAB bore sampling provided by DPIE. The specific objectives of this conceptualisation were:

- To identify the typology of the selected GAB NSW springs;
- To conceptualise the groundwater dependency of these springs; and
- To potentially define their aquifer source.

Spring Conceptualisation

The springs were characterised based on their hydrogeological, structural, ecological and chemical characteristics as well as their isotopic signature. Machine Learning algorithms were also utilised to provide an alternative interpretation of comparative chemistry for the spring waters relative to bore water signatures known to come from the GAB.

Springs were grouped by typology, combining the conceptualisation of the springs into groups which share similar characteristics and through these classifications infers the origin of the spring water. A confidence level was assigned to illustrate a level of certainty of the data provided.

Spring group and typology summary

Spring	Wetland Type	Machine Learning Grouping	Inferred Spring Source	Ecological Rating	Confidence level
Bingewilpa	**1a** - Permanent, regional and local groundwater systems	**Group 2** - Transitional composition	GAB but wetland fed from adjacent bore	-	High
Colless	**2** - Semi-permanent, diffuse, sub-artesian	**Group 3** - Low compatibility with GAB bores	GAB with modern water mixing	-	Moderate
Coonbilly	**2** - Semi-permanent, diffuse, sub-artesian	**Group 3** - Low compatibility with GAB bores	GAB with abundant modern water mixing	Low	Moderate
Culla Willallee	**2** - Semi-permanent, diffuse, sub-artesian	**Group 0** - Highly compatible with GAB bores	Possibly GAB with mixing	Low	High
Gooroomero	**4b** - Semi-permanent, fresh spring, connected to local groundwater and surface water	**Group 3** - Low compatibility with GAB bores	Low potential to be GAB, has a modern signature	-	High
Lila	**2** - Semi-permanent, diffuse, sub-artesian	**Group 3** - Low compatibility with GAB bores	Low potential to be GAB, has a modern signature	-	Low
Mulyeo	**1a** - Permanent, regional and local groundwater systems	**Group 0** - Highly compatible with GAB bores	GAB but wetland fed from adjacent bores	Low	High
Native Dog	**2** - Semi-permanent, diffuse, sub-artesian	**Group 3** - Low compatibility with GAB bores	Likely evaporatively-concentrated local runoff	Low	High

Spring	Wetland Type	Machine Learning Grouping	Inferred Spring Source	Ecological Rating	Confidence level
Old Gerara	**2** - Semi-permanent, diffuse, sub-artesian	**Group 3** - Low compatibility with GAB bores	Chemistry not consistent with GAB but strong flow	Low	Moderate
Peery West	**1b** - Permanent, regional and local water systems. Surface water influence	**Group 0** - Highly compatible with GAB bores	GAB proven	High	High
Tharnowanni	-	**Group 3** - Low compatibility with GAB bores	Not GAB	-	High
Thooro Mud	**1b** - Permanent, regional and local water systems. Surface water influence	**Group 0** - Highly compatible with GAB bores	Possibly GAB source with mixing	Low	Moderate
Thully	**1b** - Permanent, regional and local water systems. Surface water influence	**Group 3** - Low compatibility with GAB bores	Possibly GAB source with mixing	Low	Low
Youltoo	**1b** - Permanent, regional and local water systems. Surface water influence	**Group 3** - Low compatibility with GAB bores	Ambiguous, maybe GAB aquitard	-	Moderate
Youngerina	**1b** - Permanent, regional and local water systems. Surface water influence	**Group 0** - Highly compatible with GAB bores	Possibly GAB with mixing	-	Low
Coolabah	**1b** - Permanent, regional and local water systems. Surface water influence	**Group 3** - Low compatibility with GAB bores	Ambiguous	Low	Moderate
Cumborah	**3** – Intermittent, regional and local groundwater systems	**Group 3** - Low compatibility with GAB bores	Ambiguous with modern signature and ionic composition which suggests not a GAB source	-	High

Analysis of the major ions and isotopes provided the clearest lines of evidence, reinforced by the outcomes of the machine learning analysis. Metals did not add significant evidence to the assessment.

Springs have predominantly been found to be of uncertain or mixed origin sources. Few springs can be confidently stated not to have a GAB source. Three locations are likely sustained by the Hooray Sandstone, the main GAB artesian aquifer in the area, two of these with an additional shallow or meteoric source.

Recommendations for additional investigations

Specific recommendations for additional investigations are provided for each spring based on the outcome of this conceptualisation and to improve the level of confidence in the conceptualisation of each spring. For most springs with mixed origin, the most practical approach would be to continue sampling during a known drought period when mixing with meteoric water is less likely.

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1.0 INTRODUCTION

1.1 Objective

The NSW Department of Planning Industry and Environment (DPIE) undertook field surveys of selected NSW Great Artesian Basin (GAB) springs between 2018 and 2019. The surveys consisted of a characterisation of the sites, spring and nearby bore sampling and ecological surveys of some of the springs. The results of this survey have been supplied to Golder for use in this assessment. The objective of the assessment is to conduct a desktop groundwater assessment to:

- identify the typology of the selected GAB NSW springs;
- conceptualise the groundwater dependency of these springs; and
- potentially define their aquifer source.

The outcomes of this conceptualisation will be used to guide the next round of GAB springs surveys and inform NSW government position on policy and regulation on management of impacts to the GAB springs.

1.2 Scope of Work

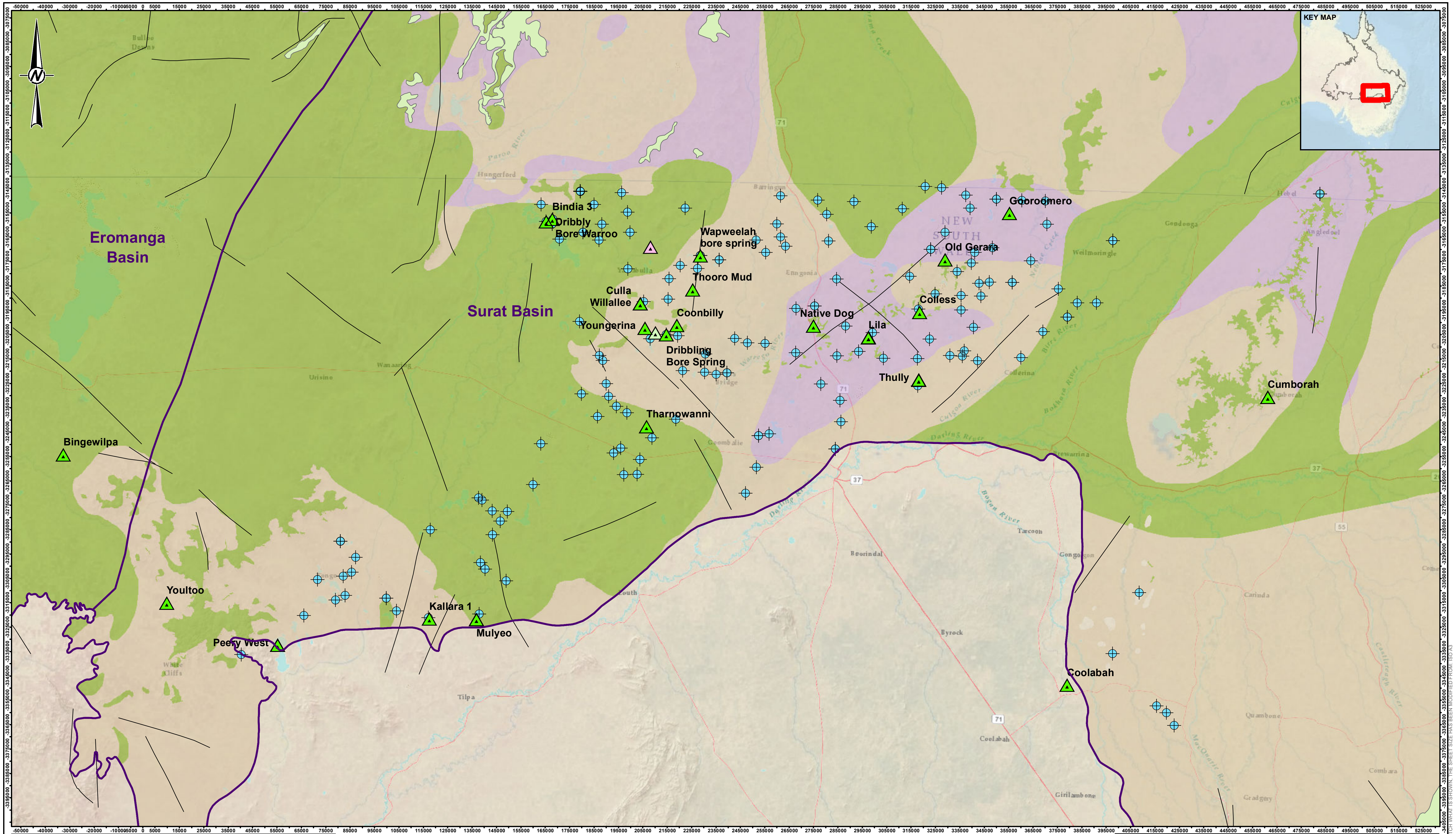
The Scope of Work (SoW) is defined in the Statement of Requirements of the Request for Quotation PRN/20-PRN/20-2158 and includes the following two main elements:

- Using the site physical features, laboratory groundwater chemistry at the springs and nearby GAB bores information, conceptualise the Great Artesian Basin (GAB) springs using typology developed by Queensland and South Australia and assess the groundwater dependency, and where possible define the aquifer source.
- Recommendations for further work to refine aquifer source, spring-bore impact relationships. The recommendations should focus on sites requiring further visits to increase the knowledge and confirm the conceptualisation. This information will be used to prioritise sites and scope the next GAB spring field survey event.

1.3 Location

The objective of this assessment is to assess the NSW GAB springs, selected by DPIE, relative to the upgradient regional NSW groundwater sources. The location of these springs and the nearby registered bores are shown on Figure 1.

Figure 1: NSW GAB Springs location map.



LEGEND

▲ spring

△ surface water

△ rainfall

⊕ bore

— GAB Major Structura lElements

🟩 PaleogeneNeogene Cover Extent

🟪 Winton Mackunda Aquifer Outcrop

▨ RollingdownsAquitard Outcrop

🟦 CadnaOwie Hooray Aquifer Outcrop

▭ GAB reporting region boundary

0 25 50
Kilometers
1:1,500,000 METRES

NOTE(S)
1.

REFERENCE(S)
1. HYDROGEOLOGICAL UNITS COPYRIGHT GEOSCIENCE AUSTRALIA GAB ATLAS

CLIENT
NSW DEPARTMENT OF PRIMARY INDUSTRIES AND ENVIRONMENT

CONSULTANT
GOLDER
MEMBER OF WSP

YYYY-MM-DD	2021-05-14
DESIGNED	KJS
PREPARED	KJS
REVIEWED	####
APPROVED	####

PROJECT
GAB SPRINGS CONSEPTUALISATION

TITLE
GAB HYDROGEOLOGICAL UNITS

PROJECT NO.	CONTROL	REV.	FIGURE
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2.0 GAB SUMMARY

Much work has been done in the GAB by Queensland, South Australian and NSW state government, CSIRO, GeoScience Australia and private petrochemical industries. Golder conducted a literature review with the purpose of identifying work completed in the GAB that is relevant to this assessment and provides additional information and methodology. The previous work completed on the Queensland and South Australian GAB springs including nomenclature, classification and typology are of particular importance and have been adopted in the methodology of this assessment. A summary review of this work and a background summary of the NSW GAB is attached in Appendix A "Literature Review".

3.0 METHODOLOGY

3.1 Data Received

Golder received spring and registered bore data from DPIE for the GAB Springs assessment which are summarised in the Appendix B and Appendix C. Included in this are field sheets from sampling and ecological surveys conducted by DPIE through 2018 and 2019 and the accompanying draft report "Draft Hydrogeology and ecology survey of the Great Artesian Basin springs in New South Wales, Results and site descriptions – Volumes 1 and 2 (DPIE, 2020b)".

Analytical data received included major ion, metal, stable and radioactive isotope data as well as physical and chemical parameters. Some locations were received with a partial data set. A rainfall sample was also included for comparison, sampling details and a location for this sample were not provided. It has been assumed to be a sample representative of the general rainfall composition across the NSW GAB.

3.2 Spring Classification

Information about each spring has been collated to enable typology classification and conceptualisation of spring source. Springs have been classified by their ecology, geomorphology, structural geology and their hydrogeological characteristics.

The GAB Springs Adaptive Management Template (Jensen et al, 2020) provides a framework for "situational analysis" of GAB springs, concentrating on the management of springs and the current physical surface condition. The purpose of this assessment is to provide a more comprehensive classification of springs in relation to the GAB groundwater resource. This framework has therefore been adapted in conjunction with the attributes used in the Queensland GAB Database, which collates a comprehensive record of springs and their attributes, including the hydrogeological, hydrogeochemical and structural characteristics.

Our ability to classify springs is limited by the type and quality of the information provided for the springs and "nearby" registered bores. Most bores are at least 10 km from the selected springs. The Spring Classification Attributes Table, attached in Appendix B, collates the information provided for each spring. The input fields are based on the type and nomenclature used in the Queensland GAB Springs Database and the table summarises the detailed typology assessment describing each spring in Section 5.0. Analytical data is tabulated separately and attached in Appendix C.

3.2.1 Spring attributes

DPIE have provided data sets for the springs and bores that may be close enough to be relevant with which to compare and group the springs. To compare the different datasets, a common set of data fields were prepared based on the attributes used in the Queensland GAB Springs Database, as presented in Table 1. Information for each spring was assessed, and the attribute information for each spring vent tabulated for comparison.

Table 1: Collated spring attributes (based on Queensland Herbarium, 2017).

Category	Description	Attributes
Nomenclature	Site name identifiers and classifications	Site Number Vent ID Supergroup name
Region	Locality of the vent and source of the groundwater.	Coordinates GAB Group Other non-GAB Tertiary springs
Surface expression	Saturation of the spring vent. If there is moisture or flow. 'Other' flow types are ephemeral or uncertain or unknown based on known or inferred information	Spring permeance Flow activity and rate Intermittent flow or inactive Wetland saturation
Detailed water chemistry	General chemistry measurements recorded in the field or samples tested in a laboratory.	pH Temperature Electrical conductivity General chemistry Isotopes
Ecology	Spring conservation rank applied at individual spring wetland/vent level.	Conservation rank
Geomorphology	Visual estimates of mound shape and dimensions. Length and width of the saturated wetland. Wetland area is for springs that have more than fifty percent wetland vegetation cover	Mound morphology Mound dimensions Erosional Landform Pattern Surface composition Water course
Region	Locality of the vent and source of the groundwater.	Coordinates GAB Other non-GAB Tertiary springs
Groundwater source	Inferred source of the spring water based on assessment of data and comparison with bore data	Inferred water source

3.3 Approach to Consideration of Water Source

Critical to grouping springs is the consideration of the water source for each. This involves reviewing the geology including geological structures, hydrogeology and water chemistry of nearby groundwater bores and comparing these characteristics with those of the GAB springs.

3.3.1 Determination of formation of nearby bores

To assess which formation each bore is screened in, or open to, we have reviewed:

- bore logs supplied by DPIE
- appreciation of drilling methods for early GAB bores
- the 3D hydrogeological ground model produced Geoscience Australia as part of the Great Artesian Basin Water Resource Assessment
- 2D cross sections from Water Sharing Plan for the NSW Great Artesian Basin - Groundwater Resource Description (DPIE, 2020a)

There were some discrepancies and limitations in this process. The bore logs were over 100 years old in some cases and the lithological descriptions sparse. It must also be considered that some drilling methods or site records may not provide accurate depth measurements of the lithology. Further, cable tool drilling might have stopped as soon as an adequate free flow of water was obtained, just touching the top of the aquifer. To supplement this data, digital datasets from the GAB Atlas (Ransley et al, 2015) and the interpreted stratigraphy of the NSW Groundwater Resource Description (DPIE, 2020a), completed by the Department of Primary Industries Office of Water, were used to define the base of the formations in the study area relative to the screened interval of the registered bores. The contour map of the base of the Hooray Sandstone in the Geoscience Australia GAB 3D hydrogeological model (Ransley et al, 2015) was found to be inconsistent with the interpreted stratigraphy of the NSW GAB Resource report. This discrepancy has been noted also in the report “Ecological and hydrogeological survey of the Great Artesian Basin springs - Springsure, Eulo, Bourke and Bogan River supergroups” (Commonwealth of Australia, 2014).

3.3.1.1 Leapfrog Model

To more accurately compare the data sources and explore the discrepancy between them, Golder combined the Geoscience Australia GAB 3D model with DPIE’s geological cross sections of the interpreted stratigraphy in the southern portion of the GAB into a Leapfrog model. The Leapfrog images were then used to assess the major formations beneath and in the vicinity of each spring, the presence and depth to any regionally and locally significant basement highs, and the structure of the GAB formation units. Where possible, this visualisation was also used to assess the screened formations of the registered boreholes.

To implement the Leapfrog visualisation, Golder extracted 1 km cell ASCII grid files from the 3D GAB model. The surfaces were imported into the 3D modelling package Leapfrog Works, where they were converted into a ‘solid’ 3D model. Groundwater bore information (including screens and screen lithologies) were incorporated into the model, with the screened lithologies compared to the regional 3D geological model. Additionally, three geological cross sections of the basin were incorporated into the 3D model. These sections were produced by DPIE and presented within their report titled “*Water Sharing Plan for the NSW Great Artesian Basin - Groundwater Resource Description*”. The results of the modelling process were summarized and presented in a 3D viewer file, readable by the free-to-download software package Leapfrog Viewer.

A discrepancy was revealed by the Leapfrog process between the base of the Hooray Formation in the GAB 3D model and the DPIE cross-section, where the two separate studies are inconsistent in the depth and shape of the base of the Hooray Formation. This inconsistency was considered in all spring source interpretations.

The Leapfrog model is considered an approximation, limited by the accuracy of the input sources, and hasn’t been refined for further use. It was used in conjunction with the resources detailed in Section 3.3.1 to determine the source aquifer for each of the registered bores considered against the springs.

3.4 Machine Learning

To better understand the hydrogeochemistry of the spring and bore samples, a statistical analysis on the major ion results has been conducted using Python scripting and machine learning algorithms to analyse the relationships between water samples. This analysis tool compliments the baseline empirical and anecdotal evidence review methods described above.

We have used a variety of machine learning algorithms to compare the components of each spring or bore dataset against the other locations. This processing has identified patterns, similarities and differences between springs and the bores, from which we can infer potential aquifer sources, providing a further line of evidence towards confirming source aquifer provenance. Details and results are discussed further in Section 4.6.

4.0 HYDROGEOCHEMISTRY

4.1 Available Data

Water chemistry information was provided by DPIE and consisted of samples collected as part of the NSW springs survey from springs, surface water and bores between March 2018 and July 2019. Some of these locations were sampled on one, two or three occasions during this period. No review of the data has been carried out as part of this assessment. It has been assumed the sampling and analytical methodologies and data tabulation have provided a dataset which is reliable and consistent between events, with the exception of anecdotal information such as rainfall and runoff observations.

DPIE provided water chemistry data for 170 bores that are part of the State-wide groundwater sampling monitoring carried out by DPIE.

In total, data from 209 samples were reviewed and consisted of:

- 27 samples from 17 springs
- 181 samples from 170 registered bores.
- one rainwater sample

All samples were analysed for:

- major ions chloride (Cl^-), sulfate (SO_4^{2-}), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}), both of which were measured as alkalinity
- fluoride (F^-), bromide (Br^-) and strontium (Sr^{2+})
- total and dissolved concentrations of selected metals and metalloids (aluminium, arsenic, cadmium, chromium, copper, iron, lithium, lead, manganese, mercury, nickel, silver, strontium, zinc)

A subset of samples were also analysed for:

- stable isotopes deuterium (^{2}H), oxygen (^{18}O) and strontium ($^{87}Sr/^{86}Sr$)
- the radioactive isotopes ^{14}C, expressed as percent modern carbon (pMC), ^{36}Cl, expressed as $^{36}Cl/Cl^-$ and tritium (^{3}H)

4.1.1 Springs

Table 2 provides a summary of the springs hydrochemistry information available. Those highlighted in grey were analysed for various isotopes.

Table 2: Summary water chemistry data from NSW Springs

Complex name	Vent	Date Sampled Round 1	Date Sampled Round 2	Date Sampled Round 3
Bingewilpa	1270_1	N/A	N/A	12/07/2019
Colless	969.2_1	N/A	23/10/2018	N/A
Coolabah	994.1_1	06/03/0218	N/A	N/A
Coonbilly	974.17_1	09/03/2018	N/A	N/A
Culla Willallee	963_1	11/03/2018	16/10/2018	17/07/2019
Cumborah	992_1	N/A	15/10/2018	N/A
Gooroomero	967.2_1	N/A	25/10/2018	N/A
Mulyeo (Kallara)	1005_2	N/A	N/A	11/07/2019
Lila	1006.3_1	N/A	25/10/2018	24/07/2019
Lila	1006.4_1	N/A	25/10/2018	24/07/2019
Mascot	-	N/A	N/A	16/07/2019
Mulyeo	1005_2	N/A	N/A	11/07/2019
Mulyeo	1005_1	N/A	N/A	11/07/2019
Native Dog	960.1_1	N/A	N/A	23/07/2019
Old Gerara	965_1	12/03/2018	N/A	N/A
Peery West	1000.200_1	07/03/2018	12/10/2018	13/07/2019
Tharnowanni	-	N/A	10/10/2018	N/A
Thooro Mud	-	N/A	N/A	16/07/2019
Thully	961.1_1	N/A	22/10/2018	25/07/2019
Thully	961.4_1	N/A	N/A	25/07/2019
Youltoo	1001_1	N/A	N/A	09/07/2019
Youngerina	973_1	N/A	N/A	18/07/2019
Rainfall	Rainfall	N/A	16/10/2018	N/A

N/A: not applicable, no sampled was collected.

4.2 Field parameters

Field parameters including temperature, pH and total dissolved solids (TDS) were measured during sample collection.

Temperature can be used as an indicator of the depth of a groundwater source when samples are taken directly from the aquifer in a strongly flowing bore. The temperature of groundwater in the Hooray Aquifer ranges between 35ºC and 48 ºC (DPIE, 2020a). Spring samples all reported temperatures below the Hooray Sandstone range at temperatures which could be indicative of ambient air. When considering groundwater or spring temperature as an indicator, the flow rate, sampling technique and location must also be considered, shallow groundwater or low flow springs would generally be expected to have water temperature within the range of ambient air temperature.

Figure 2 shows the distribution of temperature measurement from the samples collected at the springs.

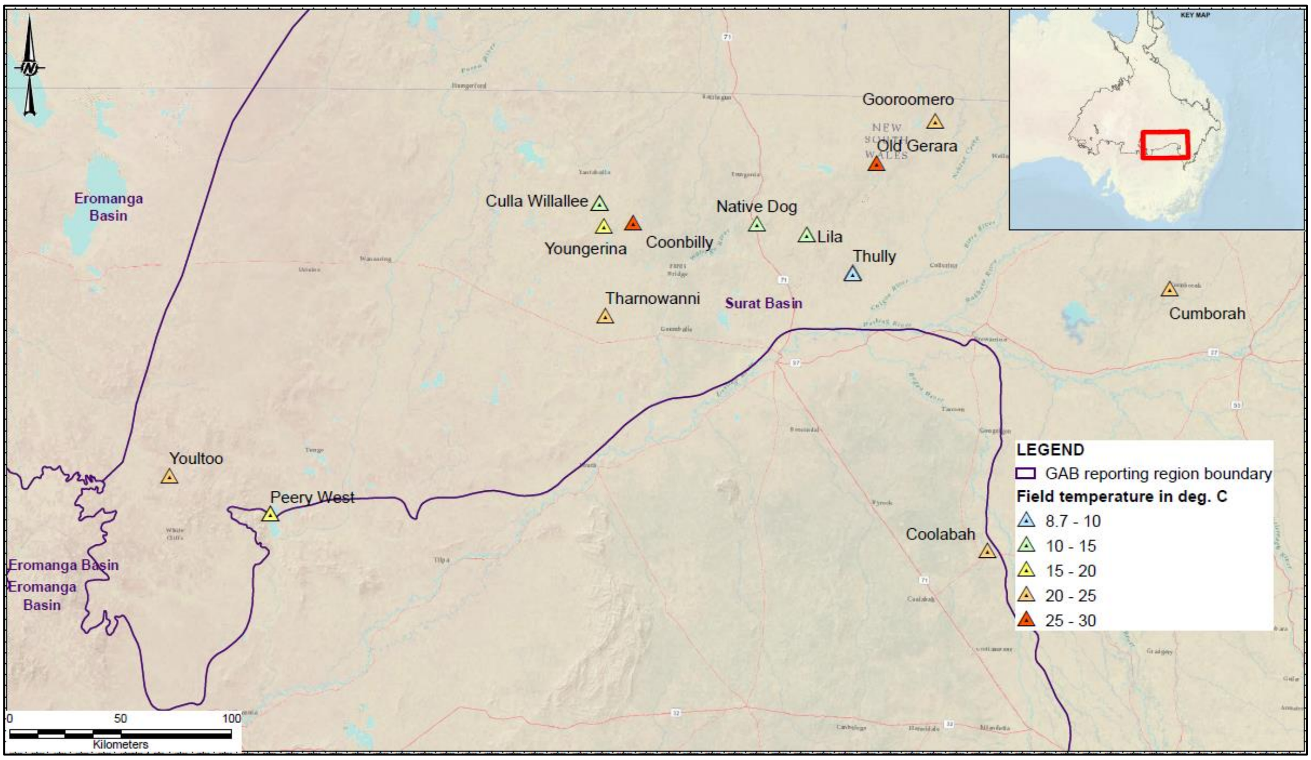

Figure 2: Field temperature distribution from springs samples

Spring salinity, measured as TDS, ranged from 21 mg/L at Lila to 3,000 mg/L in the Bingewilpa spring in the far west. Typically, groundwater TDS in the Hooray Sandstone is generally between 500 mg/L and 2,000 mg/L and in excess of 5,000 mg/L in the Rolling Downs Group (DPIE, 2020a).

Generally springs fell within the salinity range expected in the GAB, with the exceptions of Cumborah, Coonbilly, Lila, Native Dog, Thully and Youngerina which all reported TDS below 440 mg/L, and Bingewilpa which was more saline than is expected for GAB formations.

Salinity of the rainfall sample was reported as 61 mg/L, which is considered high for rainfall, and is slightly more saline than the Lila spring sample. The rainfall chemistry is not considered a diagnostic tool for spring water origins, radioactive isotopes provide a clearer indication when assessing modern water sources.

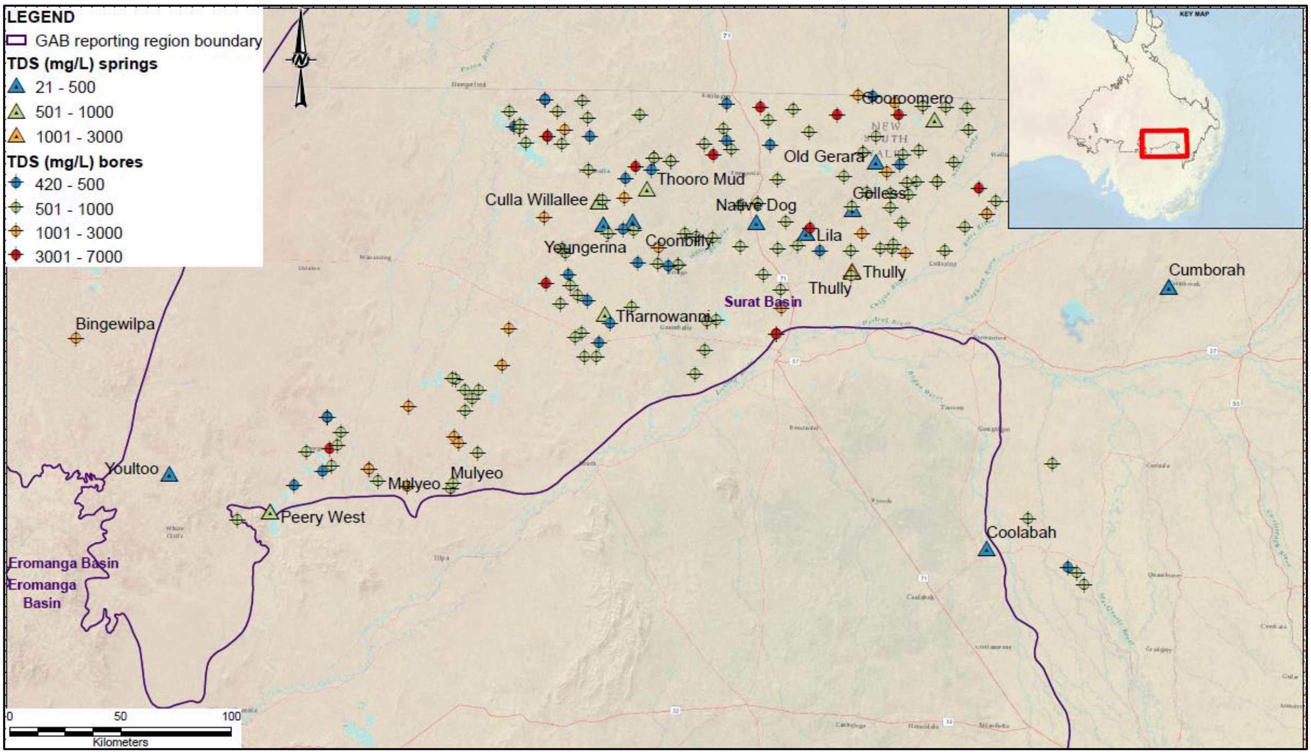

Figure 3: Field TDS distribution of springs samples and laboratory measured TDS of bores

Sample pH varied from 6.6 at Lila to 9.2 at Thooro Mud. With the exception of Thooro Mud these values around neutral pH are typical of the GAB. Rainfall pH was reported as 7, neutral, although rainfall tends towards acidity due to dissolved CO^2. Generally, pH is expected to gradually increase along the flow path through the GAB, typically falling between 6.5 and 8.5 in the Hooray Sandstone (DPIE, 2020a).

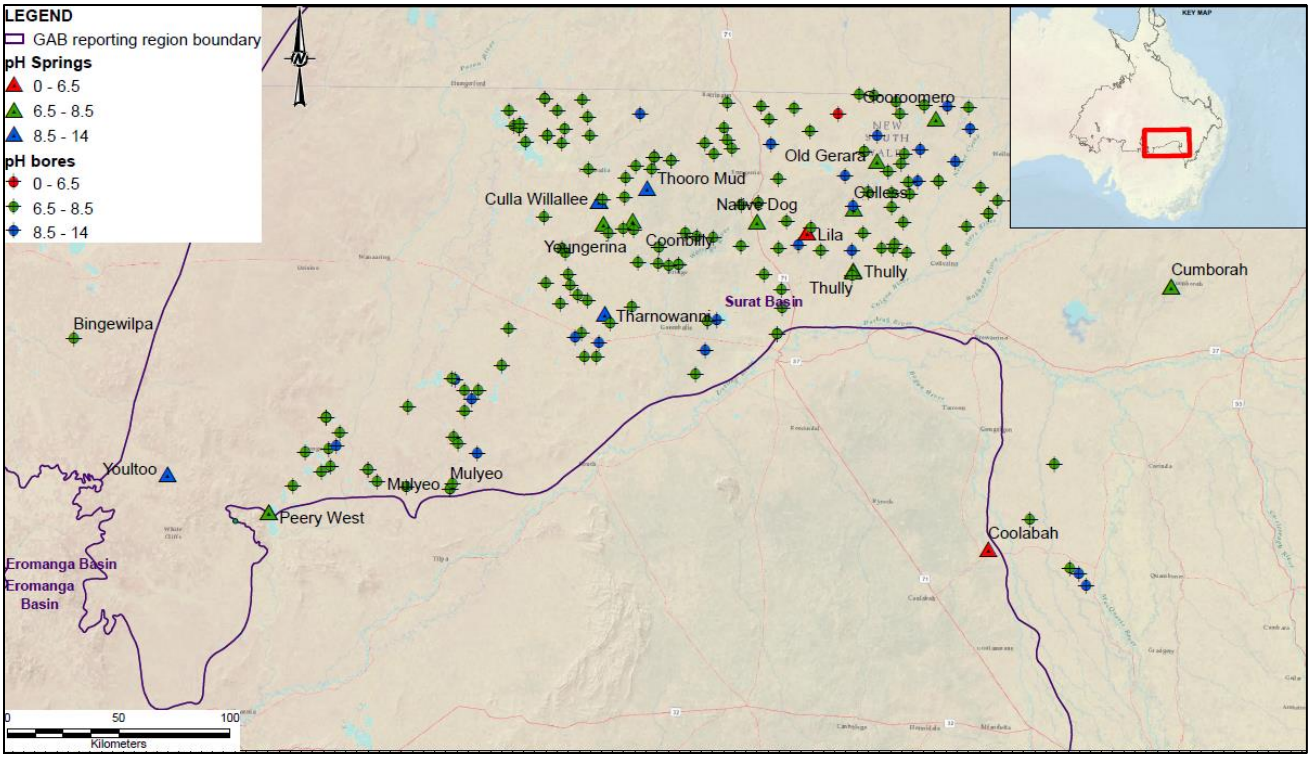

Figure 4: Field pH distribution of springs samples and laboratory measured pH of bores

4.3 Major ions

Major cations and anions data was available for the springs and the 167 bores. This information was compiled and plotted on a Piper plot for visualisation and interpretation of groundwater compositions (Figure 5). The Piper plot figure below shows all bores in blue while the springs are shown in yellow.

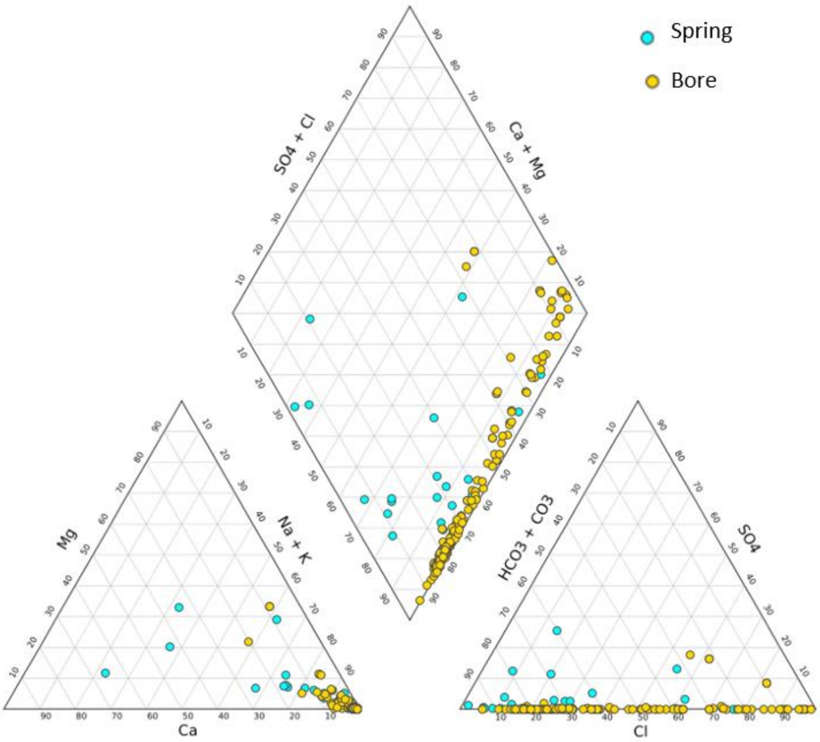

Figure 5: Piper plot of bores and springs

The following main observations are noted from the Piper plot:

- Spring samples are generally found to be of four types:
    - sodium-chloride type
    - sodium-bicarbonate type
    - magnesium bicarbonate type (rainfall sample and Youngerina)
    - mixed type (Youltoo)
- Except for a few exceptions (GW015748, GW014524, GW040866) sulfate is not present in any of the bores (or in small concentrations).
- The bores are found to be of one of two types:
    - sodium-bicarbonate type
    - sodium-chloride type

The dominance of sodium bicarbonate (with minor potassium) is seen in the majority of bore waters and is a well-known characteristic of GAB groundwater, a group of these samples trend towards higher chloride.

4.4 Metals

Springs and bores were analysed for dissolved and total metals (aluminium, arsenic, cadmium, chromium, copper, iron, lithium, lead, manganese, mercury, nickel, silver, strontium and zinc). Dissolved cadmium and silver were not found in any locations. Concentrations of the remaining metals varied widely across the springs with aluminium, iron and strontium in particular reporting concentration ranges across all bores. These results are discussed in detail for each spring in Section 5.0.

4.5 Isotope characterisation

Stable isotopes are useful tracers for assessment of flow path or differentiation of water sources. Processes involving an element in a given compound, in this case, water in aquifer systems or surface water environments, can result in varying isotopic fractionation. The isotopic signature of water varies depending on the source of the water and its current location. Water molecules with lighter isotopes of hydrogen ($\delta\,^{1}H$) and oxygen ($\delta\,^{16}O$) evaporate faster than heavier isotopes ($\delta\,^{2}H$ and $\delta\,^{18}O$) leading to a changed signature for waters that have been affected by evaporation (Craig, 1961; USGS, 2004).

Radioactive isotopes, such as ^{14}C and ^{3}H decay once removed from their source, such as when rainwater infiltrates into an aquifer. Some radioactive isotopes can be useful indicators of mixture of meteoric water and spring waters. The age of GAB aquifer water (up to millions of years) is typically too great for short half-life isotopes to occur in measurable concentrations.

Isotopic data was provided by DPIE for selected springs, the rainfall sample and a selection of groundwater bores.

4.5.1 Stable Isotopes

4.5.1.1 Hydrogen and Oxygen Isotopes

The ratios of stable isotopes of hydrogen (^{2}H, deuterium) and oxygen (^{18}O, oxygen-18) were compared with the local mean water line LMWL for Cobar (dataset downloaded from the International Atomic Energy Agency Water Isotope System) for data analysis, to assess the effects of evaporation or mixing on groundwater samples. To assess the hydrologic relationship between different sample locations, the stable isotope results for ^{2}H and ^{18}O have been plotted against each other, enabling assessment of similarities and differences between locations. Samples collected in March 2018, October 2018 and July 2019 are presented on Figure 6, Figure 7 and Figure 8 respectively.

Groundwater which has undergone evaporation or mixed with evaporated water typically plots below the LMWL as ^{2}H preferentially evaporates over ^{18}O (Craig, 1961; USGS, 2004). This evaporation signature is clear in Figures 7 to 9 (below). It is noted that the rainfall signature shows evaporative effects.

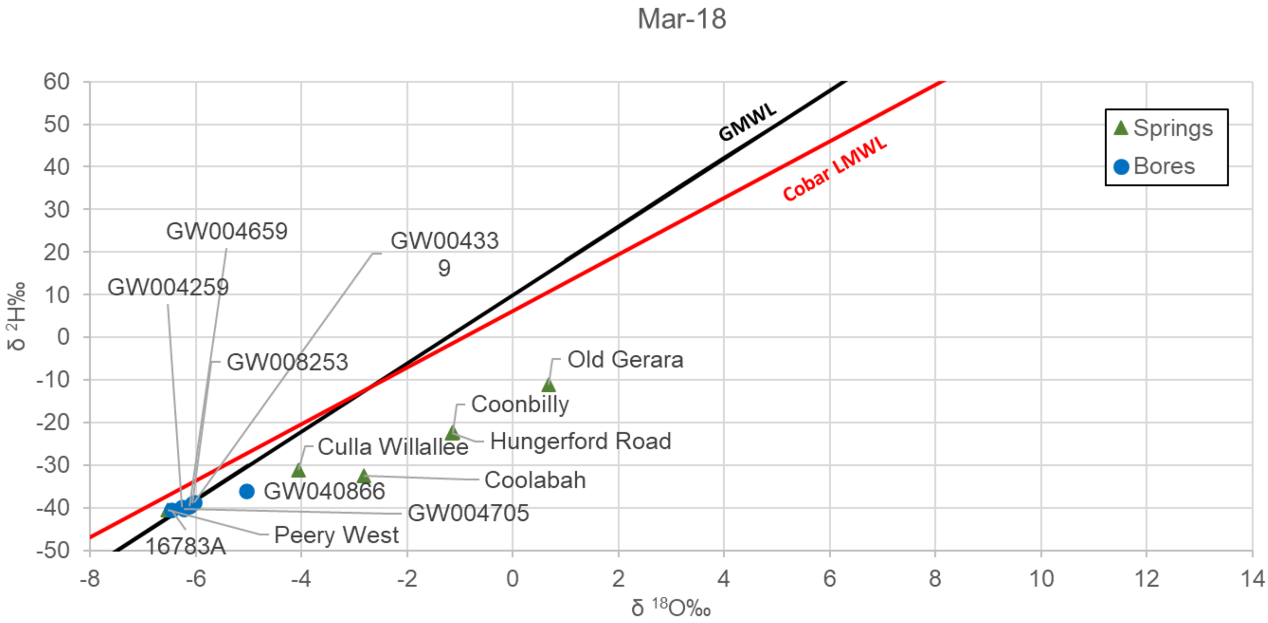

Figure 6: δ^{2}H‰ and δ^{18}O‰ for all samples collected in March 2018

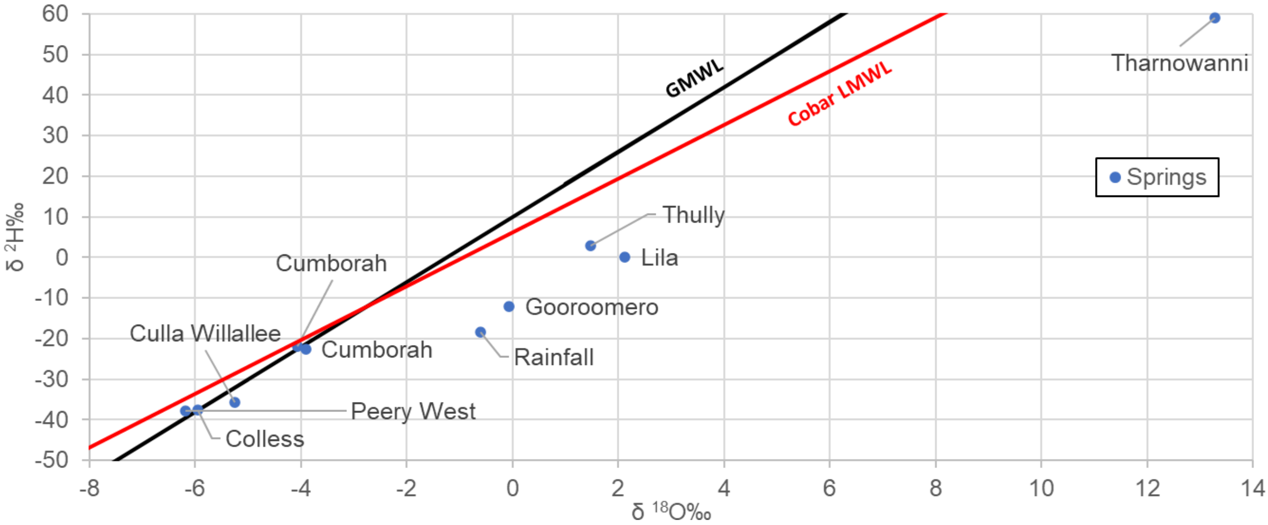

Figure 7: δ ^{2}H‰ and δ ^{18}O‰ for all samples collected in October 2018 (no bores were sampled during this sampling event)

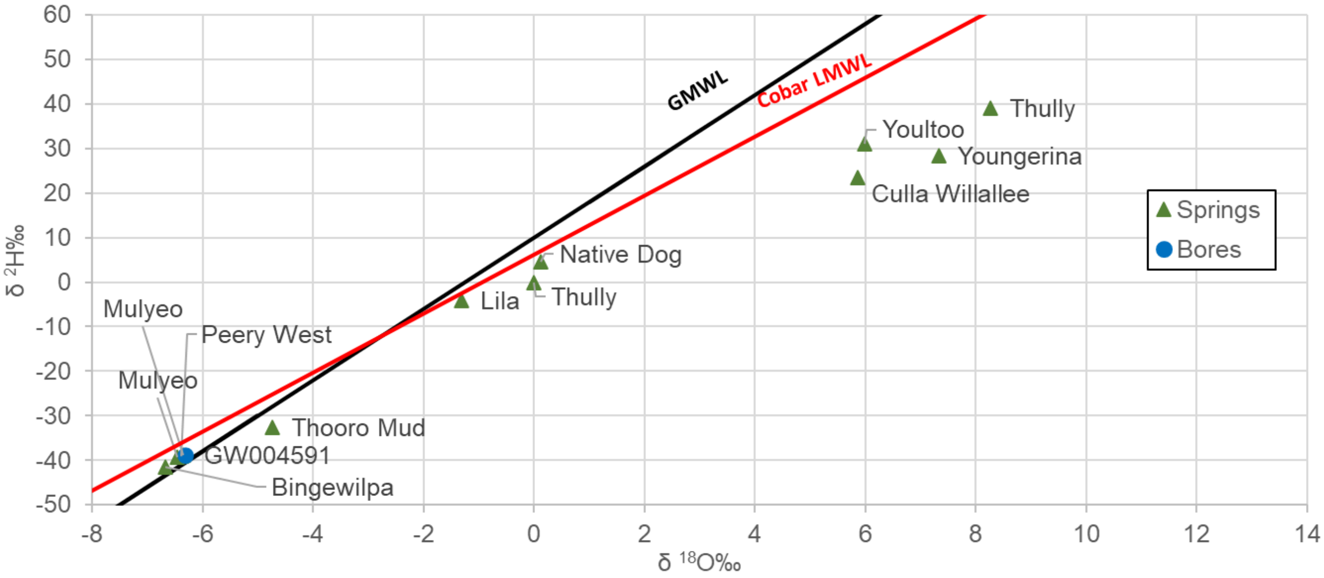

Figure 8: δ ^{2}H‰ and δ ^{18}O‰ for all samples collected in July 2019

During the March 2018 sampling event, six samples were collected from spring vents (green triangles) and seven from bores (blue circles). The results from this event show:

- The samples from three bores have similar isotopic signature and are depleted in δ^{2}H and δ^{18}O, plotting in the lower range of the LMWL. They also plot very closely to both the LMWL and the GWML suggesting minimal evaporative influence.
- A sample collected from a bore monitoring the Rolling Downs formation has a higher ratio of δ^{2}H and δ^{18}O.
- The spring samples predominantly have a wider distribution of δ^{2}H and δ^{18}O than the bores and generally plot below the LMWL and GWML suggesting common evaporative influence.
- The spring sample from Peery West plots closely to the groundwater bores from this sampling event, with a similar isotopic signature.

During the October 2018 sampling event, nine samples were collected from vents (green triangles) and one was a rainfall sample. Most of the vent samples reported low δ^{2}H/δ^{18}O ratios (- 40 and 0 for δ^{2}H‰ and -6 and 2 δ^{18}O‰), except for the sample for Tharnowanni which had a ratio of 59 δ ^{2}H‰ and 13 for δ^{18}O‰. Further discussion of each springs result is included in Section 5.0. It is noted that the rainfall sample is depleted in ^{2}H compared to the LMWL.

During the July 2019 sampling event, twelve samples were collected from vents (green triangles on Figure 8) and one from a bore inferred to be monitoring a formation below the base of the GAB (blue circle). The results from this sampling event can be divided in three groups based on their ^{2}H and ^{18}O ratios:

- Samples for Mulyeo, Peery West, Bingewilpa and Thooro Mud reported similar ratios which were close to that of the groundwater bores monitoring the GAB (Hooray and formation below Hooray) and the bore monitoring the formation below the GAB.
- The samples for Lila, Thully and Native Dog have similar ratios which are very low, close to δ^{2}H = 0 and δ^{18}O=0.
- Higher ratios of δ^{2}H and δ^{18}O were measured at Youltoo, Thully, Youngerina and Culla Willallee.

Samples were collected from Peery West and Culla Willallee during all three monitoring events. All samples from Peery West have a similar isotopic signature, indicating that the δ^2H and $\delta^{18}O$ ratios do not vary seasonally, consistent with a GAB aquifer source without mixing at, or near the surface with “evaporated” water. In addition, these ratios are similar to the samples collected from the GAB groundwater bores, suggesting a GAB groundwater source which hasn’t encountered mixing with other water sources.

The three samples from Culla Willallee, all sampled from the same vent, have a greater variety in the distribution of δ^2H and $\delta^{18}O$ ratios. Several explanations are possible:

- a GAB groundwater source which has undergone variable amounts of mixing with near-surface or meteoric water
- differences in sampling procedures, meteoric conditions or circumstances
- variation in sampling location

Further discussion is included in the conceptualisation of each spring in Section 5.0.

4.5.1.2 Strontium

The isotopic signature of strontium is determined by natural processes including the initial rainwater isotopic signature, mineralogy along the flow path, mineral dissolution, ion exchange characteristics or mixing of waters. Plotting ^{87}Sr and ^{86}Sr data against the reciprocal of Sr^{2+} enables discrimination of differing processes, such as mixing of groundwater with multiple $^{87}Sr/^{86}Sr$ signatures, evaporation, dilution, exchange or mineral precipitation (Shand et al. 2009). Such a method allows identification of end-member groundwaters, mixing trends, and the influence of mineral precipitation or evaporation.

^{87}Sr analysis was carried on 18 spring samples and just one bore sample (GW004591). The ratios of ^{87}Sr and ^{86}Sr are plotted against the reciprocal of Sr concentration as shown on Figure 9.

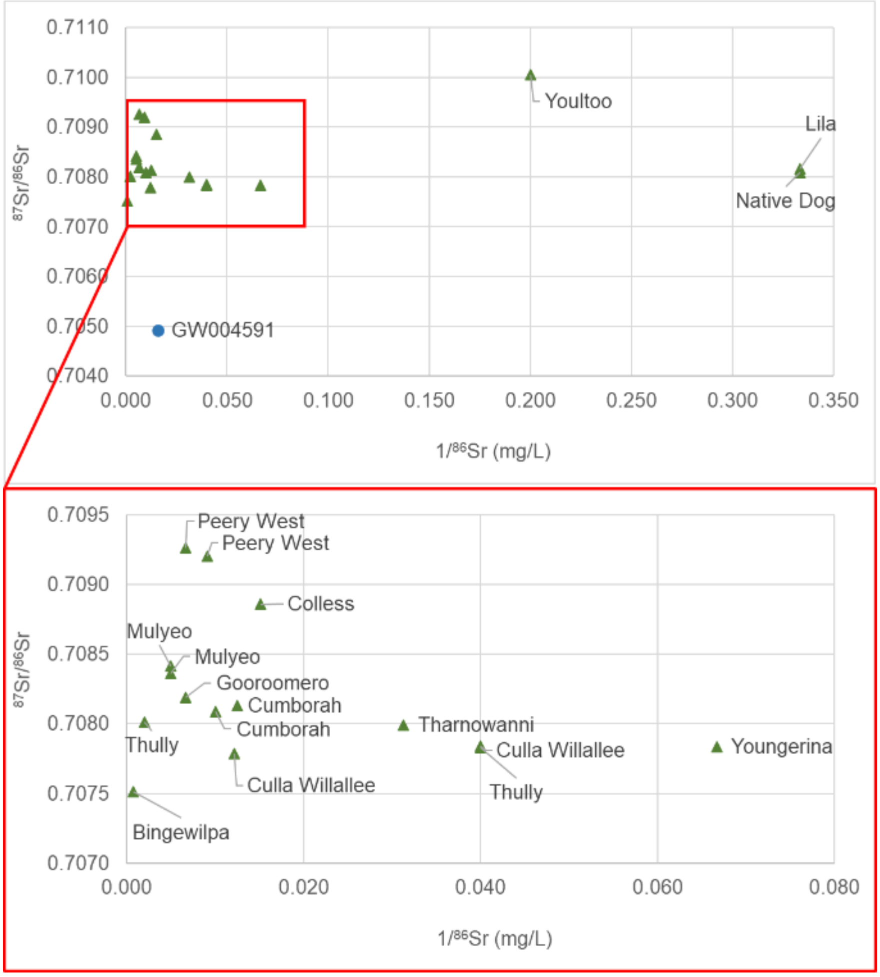

Figure 9: $^{87}Sr/^{86}Sr$ vs $1/^{86}Sr$ mg/L

The following main outcomes and groupings are observed from the $^{87}Sr/^{86}Sr$ versus $1/^{86}Sr$ distribution:

- The $^{87}Sr/^{86}Sr$ ratio from the spring samples ranges between 0.7075 (Bingewilpa) and 0.7100 (Youltoo).
- The $^{87}Sr/^{86}Sr$ ratio from the sample of bore GW004591 (likely representing the Hooray Sandstone) is lower with a ratio of 0.7049.
- Despite close similarities between some spring water and bore water parameters, the springs show a clear grouping, separate from the single bore sample. Having only one datapoint for bore water, limits the comparisons which can be made from this dataset.

4.5.2 Radioactive isotopes

Radioactive isotopes are often used to estimate the age of groundwater, with Tritium (^{3}H) useful for dating groundwater with ages younger than 60 years, radiocarbon (^{14}C) useful for waters whose age ranges between 3,000 and 45,000 years and Chlorine-36 (^{36}Cl) useful for water whose age ranges between 46,000 and 1,000,000 years. Radioactive isotopes will decay in a predictable rate into more stable isotopes. The rate of decay can be used to estimate the age of groundwater, assuming the initial value of the radioisotope in groundwater can be reasonably estimated (Plummer, 2013). “Age” is in any case a term to use with great care.

For the purpose of this study the intention is not to estimate the absolute age of the sampled water but to have an indication of the relative ages of groundwater and spring samples. Indications of “younger” spring water could be interpreted as resulting from a mixture of meteoric or very shallow (and therefore considered “young”) groundwater. GAB water would be “dead” to tritium and radiocarbon analysis.

4.5.2.1 Tritium

Tritium (^{3}H) is a useful tracer for modern groundwater due to its explicit introduction into the atmosphere during periods of atmospheric nuclear testing from 1952 to late 1970’s, and its relatively short half-life of approximately 12 years. Since the cessation of nuclear testing, the levels of tritium measured in the atmosphere have declined globally and regionally. Between 2005 and 2011, tritium has been measured in precipitation between 2.4 and 2.8 Tritium units (TU) at the closest sampling site, located 200 km west (Tadros et al. 2014). General curves for tritium concentration versus time in Australian rainfall have been derived over the decades. Other sources that could introduce tritium include contamination from landfills containing items with high levels of tritium such luminescence paint and watch dials, not sources that would affect the springs in the assessment area.

Tritium results, measured as activity in Bq/kg and typically expressed in Tritium Units (TU), were available for 17 samples from 14 springs and one groundwater monitoring bore (GW004259). Culla Willallee and Peery West were sampled twice, in October 2018 and July 2019. Two samples were collected at Mulyeo, collected from two leaking bores at the spring (further discussion included in Section 5.0)

Tritium isotope activity results are presented in Table 3. These have been divided into three groups based on their measured activity.

Table 3: Tritium results

Tritium Grouping	Locations	Tritium Isotope activity (Bq/kg)	Tritium Ratio (TU)[1]
Low	Bingewilpa, Mulyeo, GW004591	0.004	Lower than the detection limit
Medium	Colless, Culla Willalee, Gooroomero, Peery West	0.010 - 0.093	0.08 - 0.73
High	Culla Willalee, Cumborah, Native Dog, Youltoo, Youngerina, Lila, Native Dog, Tharnowanni, Thully	0.131 - 0.556	1.1- 4.67

The samples from bore GW004591 (likely monitoring the Hooray Sandstone), Peery West (July 2019), Bingewilpa and Mulyeo (location 1) reported results below the detection limit of 0.02 T.U, to be expected from the GAB groundwater or springs directly sourced from the GAB with no mixing, which would be older than the release of atmospheric tritium. All other spring water samples have higher tritium activities.

4.5.2.2 Radiocarbon

Carbon-14 (^{14}C) is a naturally occurring, isotope of carbon (^{12}C) with a half-life of approximately 5,730 years. This radioactive isotope is usually used for dating groundwater with an age range of 3,000 to 45,000 years old (Plumer, 2013). Similarly to tritium, the useful age range for radiocarbon dating is much shorter than the typical residence time for GAB waters except very close to the recharge zones.

The modern atmospheric carbon-14 content is 100 pMC (pre-nuclear test) corresponding to 13.56 dpm/gC in the year 1950 AD (Stuiver and Polach, 1977). For the purpose of this study, the intention is not to estimate an absolute age of any water sample, but to provide an indication of relative ages (distinguishing between older waters depleted of radiocarbon and younger, shallow waters that contain modern ^{14}C) and to group springs and bore samples with similar Carbon-14 isotopic signatures.

Since GAB groundwater from the Hooray Sandstone is likely to lack measurable ^{14}C, spring waters with measurable ^{14}C cannot be confirmed as partly-sourced from the GAB on this indicator alone. Measurable ^{14}C could indicate mixing with GAB water or a completely different source, such as the Tertiary alluvium that occurs in part of the study area. Waters which report measurable ^{14}C are described as “younger” for convenience in this report, although this is not a strictly correct terminology.

Radiocarbon analysis was conducted on 25 samples taken from 18 springs and 9 bore samples. Three samples were collected from Culla Willallee Spring, in March 2018, October 2018 and July 2019. Two samples were collected from Thully spring in October 2018 and July 2019. Samples from two separate vents were collected from Cumborah Spring in March 2018. Samples from two separate leaking bores were collected from Mulyeo Spring in March 2018 (further description included in Section 5.1.7).

The results are presented as percent of modern carbon (pMC) and are plotted against chloride (Cl^-) concentration on Figure 10.

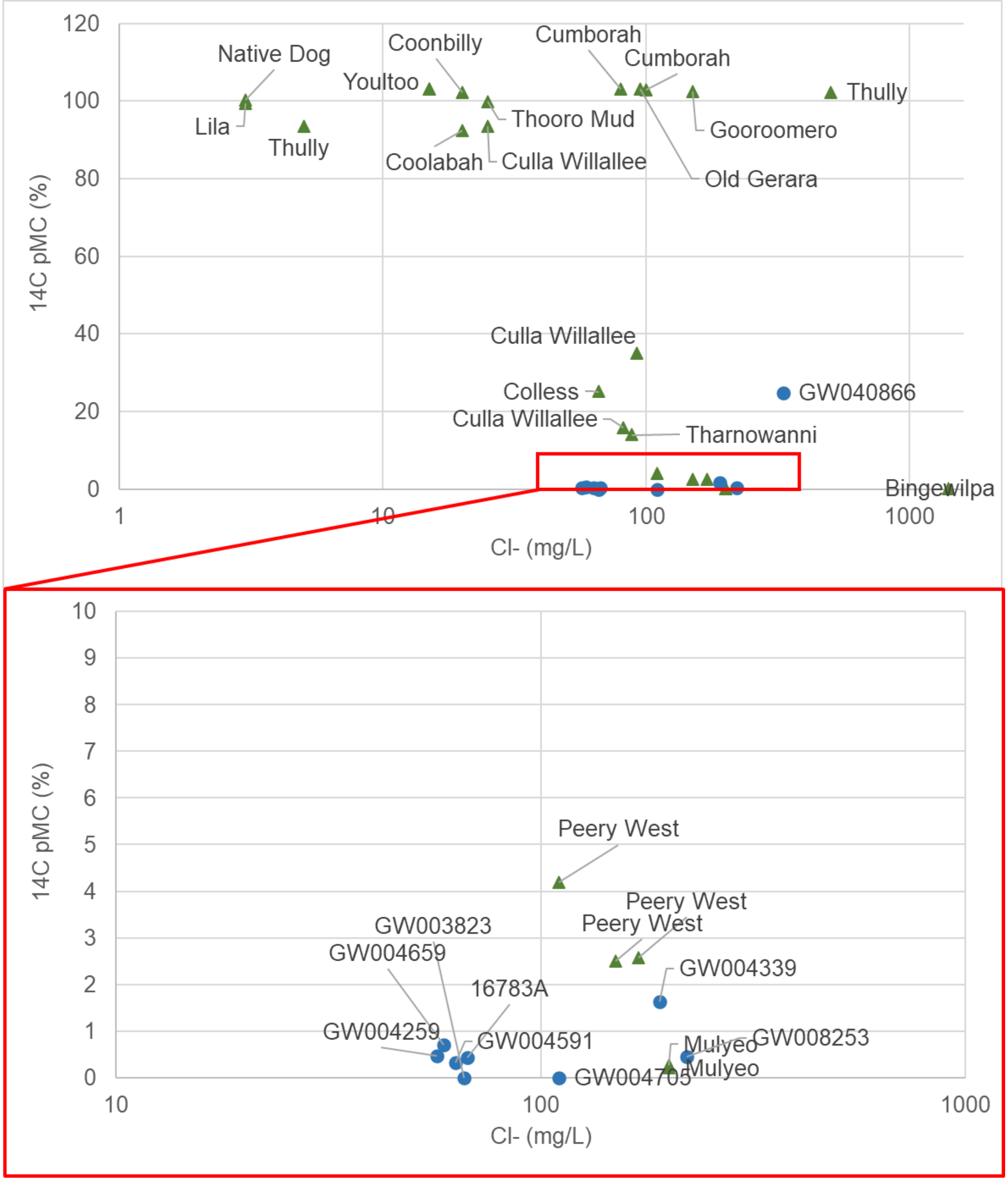

Figure 10: Percent modern carbon pMC vs chloride (Cl^- in mg/L)

The pMC versus Cl^- distribution plot identified three distinctive radiocarbon groups:

- Group 1: with practically no radiocarbon, this group includes all bores except GW040866 and Peery West and Mulyeo Springs
- Group 2: which had low ratios up to 40%, this group includes bore GW040866, Culla Willallee Spring and Colless Spring.
- Group 3: with ratios of approximately 85-100%, this group includes all the other springs.

Peery West was sampled at all three sampling events and plotted consistent pMC values in radiocarbon group 1 for all events (between 2.5 and 4%).

By contrast, the pMC value of the samples collected from Culla Willalee Spring differ for each sampling event; March and October 2018 fall in radiocarbon group 2 while the sample from July 2019 plots in radiocarbon group 3.

4.5.2.3 Chlorine-36

Chlorine-36 $^{(36}Cl)$ is a naturally occurring isotope with a half-life of approximately 300,000 years. Chlorine as chloride ion in groundwater, is a mix of isotopes and usefully a conservative solute. This radioactive isotope is typically used for dating deeper, more mature groundwater with an age range of approximately 46,000 to 1,000,000 years old, appropriate for parts of the GAB (Map 46 of Ransley et al 2015). For the purpose of this assessment, the intention is not to estimate an absolute age of water, but to have an indication of relative ages to allow identification of similarities between springs and bore samples with similar ^{36}Cl isotopic signatures.

Chlorine-36 in the atmosphere exists in a ratio of about 700 to 1000×10^{-15} relative to ^{35}Cl. Previous studies of ^{36}Cl in the GAB have identified that high ^{36}Cl values are present in all the major recharge zones. In the Eastern Recharge zone in the Great Dividing Range in NSW, ^{36}Cl ratios range between 80×10^{-15} and 150×10^{-15} (Ransley et al, 2015). Lower ^{36}Cl ratios (ranging from 0 to 80×10^{-15}) are generally found in the middle of the GAB suggesting that groundwater flow rates from the Eastern Recharge Zone towards this region of the NSW GAB are very slow, allowing time for depletion of ^{36}Cl (Ransley et al, 2015). This interpretation is consistent with most GAB analyses and publications.

Chlorine-36 analysis was carried on 23 spring samples and 9 bore samples. The ratios of $^{36}Cl/Cl^-$ are plotted against chloride (Cl^-) concentration on Figure 11. In this ration, Cl^- is the concentration of “total” dissolved chloride, a mix of both isotopes.

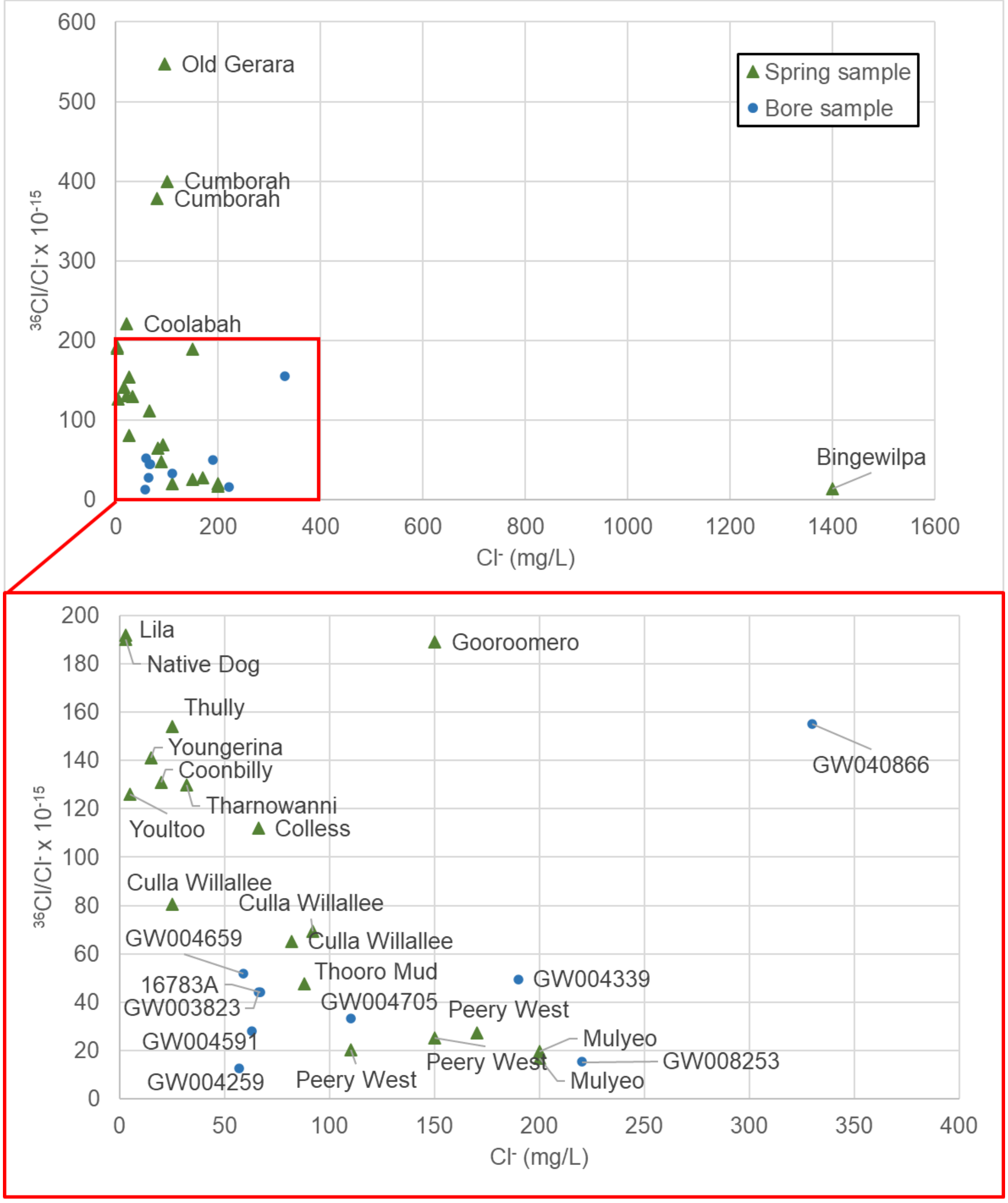

Figure 11: ^{36}Cl/Cl$^-$ x 10^{-15} versus Cl$^-$ (mg/L)

The general following outcomes and groupings are observed from the ^{36}Cl/Cl$^-$ x 10^{-15} versus Cl$^-$ distribution plot:

- Groundwater samples from GW004259, GW004659, GW004339, GW003823, GW008253, GW004705 and GW012246 ranged between 13x10^{-15} and 52x10^{-15} inferring they are representative of GAB groundwater. These bores are all located in the middle portion of the NSW GAB and are likely to be screened in the Hooray Sandstone. Their ^{36}Cl/Cl$^-$ isotopic ratio corresponds well with examples of older GAB groundwater in that area (Ransley et al, 2015).
- Bore GW040866, located on the southern margin of the GAB and understood to be monitoring the Rolling Downs formation, has a ^{36}Cl/Cl$^-$ ratio of 155x10^{-15}. This is slightly higher than the ^{36}Cl/Cl$^-$ ratios for the GAB in that area (Ransley et al, 2015).
- The springs can be grouped in three groups:

- The spring samples from Peery West, Mulyeo and Thooro Mud all plot close to the groundwater bores and have lower $^{36}Cl/Cl^-$ ratios (between 17 x10^{-15} and 48x10^{-15}) suggesting similar $^{36}Cl/Cl^-$ ratios to the bores likely monitoring the Hooray and previous sampling from the Hooray aquifer in that area (Ransley et al, 2015).
- The spring samples from Coolabah, Culla Willallee, Native Dog, Gooroomero, Thully, Coonbilly, Colless, Youltoo, Tharnowanni and Youngerina show $^{36}Cl/Cl^-$ ratio ranging between 65x10^{-15} and 221x$10^{-15.}$ This is higher than the $^{36}Cl/Cl^-$ ratio for the groundwater bores and the Hooray aquifer in that area (Ransley et al, 2015). It may be indicative of some mixing with shallower groundwater.
- The spring samples for Old Gerara and Cumborah (collected at two separate vents) were both collected in March 2018 and have relatively high ratios, ranging from 378x10^{-15} to 547x$10^{-15.}$ This range is slightly lower than atmospheric ratios suggesting younger water when compared to GAB groundwater.

Further discussion is provided for each spring in Section 5.0.

4.6 Machine learning

Various machine learning algorithms were utilised to provide an alternative interpretation of comparative chemistry for the spring water relative to bore water known to come from the GAB aquifer provenance for the group of springs.

Principal Component Analysis (PCA) was primarily used to reduce the large number of water quality parameters to a few principal components that explain the variance between individual samples and groups of samples. This machine learning algorithm is very useful to identify water quality "signatures" and group those samples with similar and opposing water chemistry signatures. For this assessment, PCA was complemented with K means cluster analysis (KCA), which is an algorithm that also determines the relatedness between individual samples and groups of samples.

The machine learning algorithms were deployed within a "multiple lines of evidence" workflow, whereby each line of evidence analysed different water quality parameters independently. The three independent lines of evidence used to assess spring provenance included:

1. Clustering of physico-chemical and major ion chemistry
2. Clustering of minor "indicator" ions
3. Reviewing the clusters against the stable isotopes.

4.6.1 Physico-chemical and Major Ion Analysis

The first line of evidence considers pH, TDS and concentrations for major cations (Na, Mg, Ca, K) and anions (Cl, HCO_3, SO_4). All springs and bores with data for these parameters were analysed using both PCA and KCA. Both algorithms identified the presence of four clear water quality groups (Figure 12):

- Group 0: This water quality group includes both spring and bores which demonstrate compatible major ion chemistry. This group includes most of the artesian bores and none of the springs.
- Group 1: This water quality group includes one anomalous bore (GW015748). The anomaly is due to a high concentration of SO_4 in this sample. Removing the SO_4 would lead to this bore clustering with Group 2.
- Group 2: This water quality group includes a majority of bores (artesian and sub-artesian) with only one spring being present in this group (Bingewilpa).

- Group 3: This water quality group is comprised predominantly of springs with only one bore analysis available (GW040866).

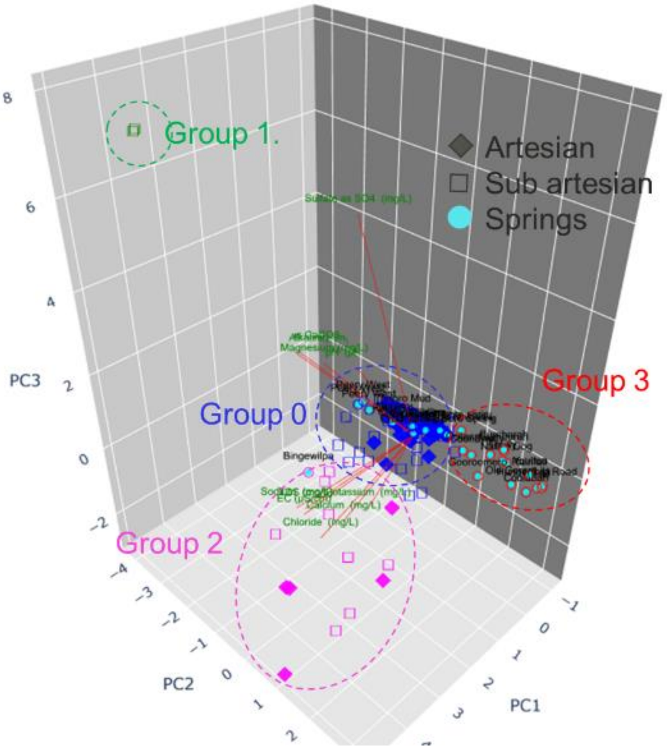

Figure 12: PCA plot presented in 3 dimensions with 4 groups identified by K-mean clustering applied to major ions.

The two water quality groups with the most springs (Group 0 and Group 3) are differentiated by pH, HCO_3 and Mg. Conversely the two water quality groups with the most bores (Group 2 and Group 0) are differentiated by Na, Ca, K, Cl and salinity.

For each individual spring, a more localised PCA was undertaken for all bores within a 25km buffer of that spring to try and identify similar water quality in springs and nearby bores. Based on these local-scale PCA assessments, each spring was categorised into three main groups, being:

- The individual spring water quality is highly compatible with the local bores suggesting a high likelihood of connection between the aquifer tapped by those bores and that spring.
- The individual spring water quality is somewhat compatible with the local bores suggesting a low to moderate likelihood of some connection between the aquifer and that spring. This transitional compatibility may be influenced by mixing of different aquifer water qualities or bores tapping multiple aquifers.
- The individual spring shows little or no water quality compatibility with the local bores. This suggests the springs are sourced from aquifers or surface water that are quite separate from the GAB sources.

Figure 13 shows a stylistic geographical distribution of the three interpreted spring categories described above (compatible, transitional and not compatible). This figure shows clear geographic distribution of the three groups. The western springs show compatibility with local bores and support aquifer provenance for those springs. The eastern springs show no compatibility with local samples groundwater. The intermediate springs show a transitional compatibility.

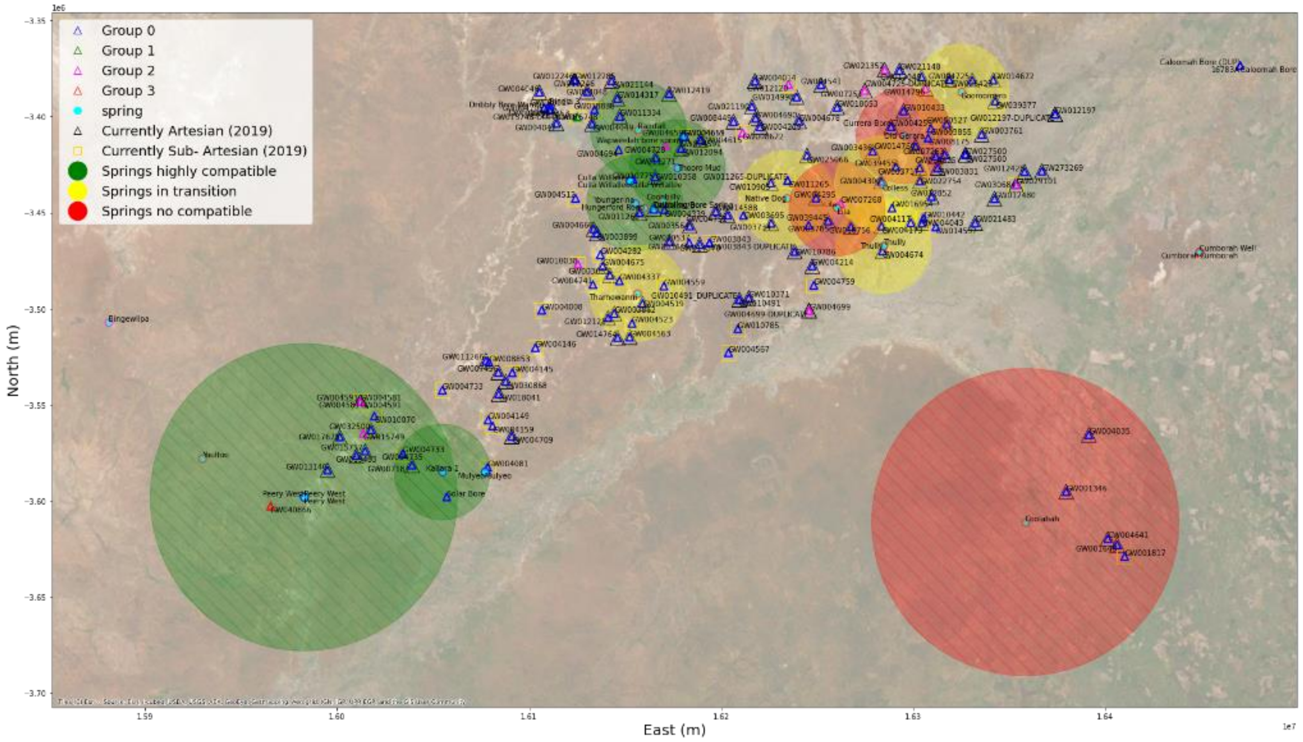

Figure 13: Spatial distribution of the spring buffers according to the compatibility with the groundwater.

4.6.2 Minor Ion Analysis

The second line of evidence considers concentrations of indicator minor ions (Sr, Zn, Mn, F, Br and Li). The indicator ions were selected by first creating a unique histogram for each minor ion and grouping by spring and bores. These histograms showed that most minor ions contained very low concentrations for these minor ions with a dominance of below detection limit (i.e. rounded zeros) concentrations. Only the six minor ions described above had sufficiently high concentrations for both bores and springs to allow for meaningful interpretation. All springs and bores with data for these six parameters were analysed again using both PCA and KCA. As shown on Figure 14, both algorithms reaffirmed the presence of the three clear water quality groups described with the major ions (i.e. groups 0, 2 and 3). Considering only the select minor ions, the anomalous Group 1 sample now clustered with Group 2. The differentiation between Group 0 (springs and bores compatible) and Group 3 (springs with only one bore) is principally related to variance in F, Zn and Mn. The differentiation of groundwater associated with springs (Group 0) and groundwater not associated with springs (Group 2) was principally related to variability with Sr and Br.

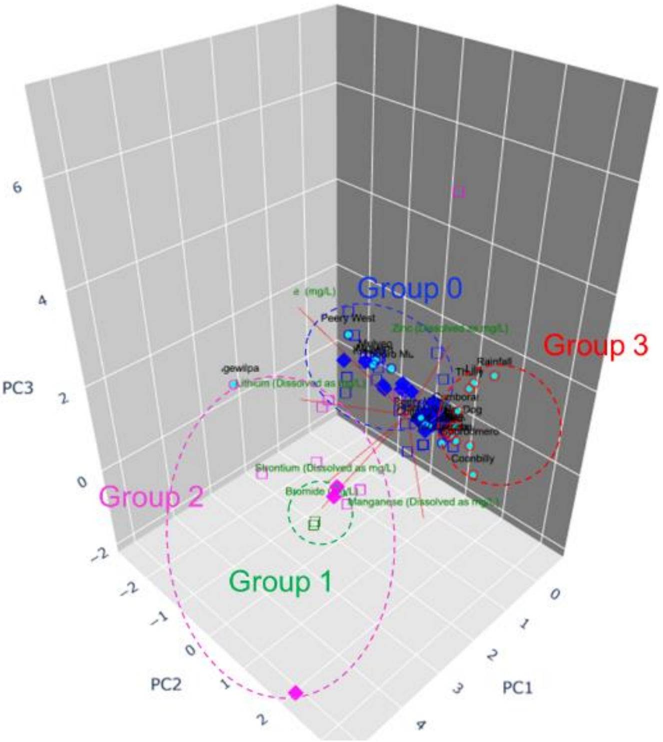

Figure 14: PCA plot presented in 3 dimensions with 4 groups identified by K-mean clustering applied to minor ions.

4.6.3 Machine Learning Approach Contrasted with Stable Isotopes

The third line of evidence integrated with the machine learning outputs was to assess the stable isotopes (^{2}H and ^{18}O) signature for the three types of springs identified using local scale PCA on major ion chemistry within the 25km buffer of each spring (i.e. compatible, transitional and not compatible).

Figure 15 presents a plot of ^{2}H versus ^{18}O with each bore and spring sample labelled by spring provenance as per the major ion analyses (see Figure 12). The majority of groundwater bores sampled for isotopes show a strong affiliation with the "compatible" springs in terms of a depleted isotope signature. This signature is often associated with cooler inland climates at the time of recharge. Conversely the incompatible and most of the transitional springs show potential fractionation trends that could indicate evaporative losses during recharge. As examples, this may indicate a source from either surface water or groundwater from shallow alluvium. Two springs from the compatible group (Culla Willallee and Youngerina) show an anomalous isotopic signature that is more affiliated with the eastern springs that weren't compatible with any groundwater samples.

This third line of evidence again shows a clear segregation between the compatible (i.e. similar to local groundwater) and incompatible springs.

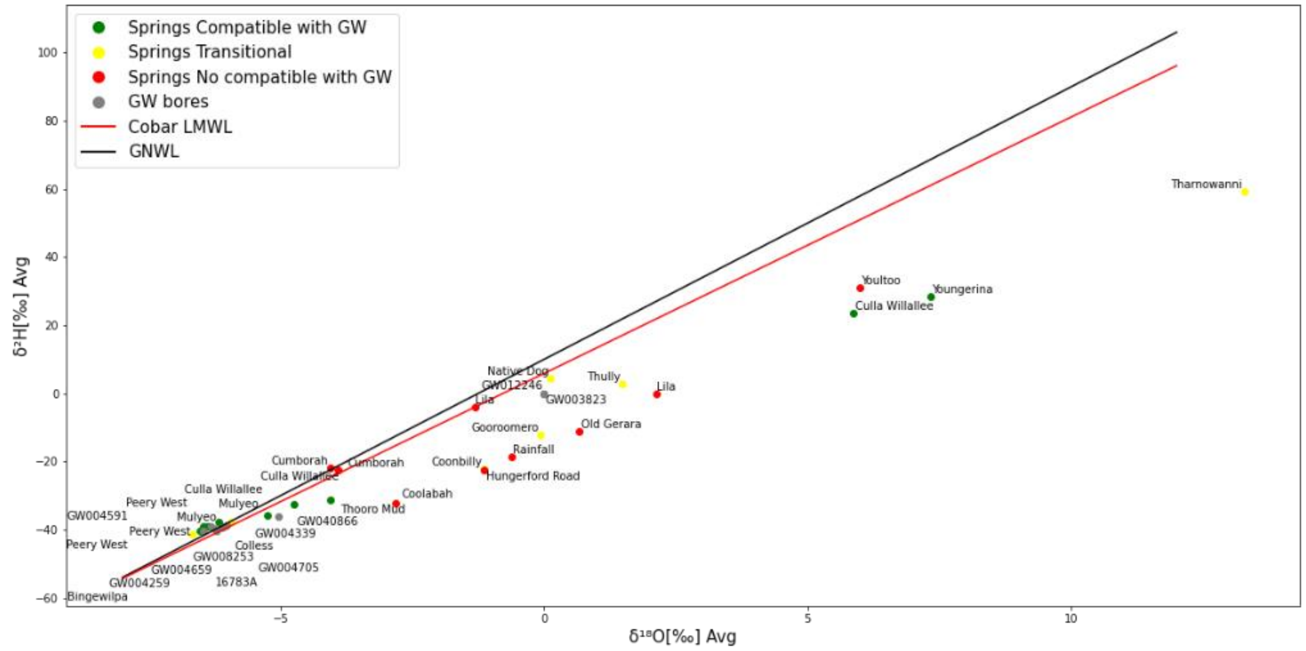

Figure 15: Isotope plot contrasted with labels obtained from machine learning outcomes.

4.6.4 Summary of Machine Learning Approach

Machine learning applied to three independent lines of evidence has demonstrated a consistency in outputs that provides support for determining the aquifer provenance of springs. Major ion chemistry, minor ion chemistry and stable isotopes all affirmed that the western springs have a strong chemical affiliation with local groundwater bores. Conversely, the eastern springs showed little to no affiliation with local groundwater bores and suggests other processes are accounting for spring occurrence. There are a group of intermediate springs with some chemical compatibility with local groundwater, although there are likely to be other processes (i.e. mixing with other aquifers or multi-aquifer samples) or reactions (geochemical reactions) that make conclusive interpretation of provenance difficult.

5.0 CONCEPTUALISATION OF SPRINGS

This section brings together the understanding, gained through this assessment, of the underlying mechanisms and expressions of each spring. These attributes have been discussed and used in the conceptualisation of each spring and its connectivity with the regional and/or local aquifers.

Water chemistry, including field parameters, major ions, isotopes and metals have been discussed. Major ion chemistry is presented on piper plots for each spring to enable comparison between springs and nearby bores. Geology has been reviewed for underlying formations and structural features. The surface geology, taken from 1:250,000 scale geology maps is presented for each spring also showing known faults taken from the GABWRA 3D model (Geoscience Australia, 2013).

All general and ecological observations discussed are based on the field observations from the DPIE spring survey (DPIE, 2020b), unless otherwise stated. Ecology has been discussed based on the available ecology surveys, no interpretation has been conducted.

The selected GAB springs have been identified as belonging to the Bourke and Bogan River Supergroups (NSW DPIE, Nov 2019).

5.1 Bourke Supergroup

5.1.1 Bingewilpa Spring

5.1.1.1 General Setting and Summary of Field Observations

Located at the western extent of the Bourke Supergroup, and 300 km west of Bourke, Bingawilpa Spring is low lying on a clay pan adjacent to undulating sand dunes. The original vent location is not visible, presumably due to earth works that together make three dams as shown on Figure 16 (DPIE, 2020b). DPIE identified a free-flowing bore nearby with overflow delivered to a small man-made dam, which appears to hold water with low turbidity relative to the adjacent dam. The excavation spoil reportedly includes white botryoidal calcareous rocks, characteristic of mound springs deposits (DPIE, 2020b).

Figure 16: Aerial photograph of Bingewilpa spring (DPIE, 2020b)

5.1.1.2 Ecology

An ecological survey was conducted at Bingewilpa, finding groundwater dependent flora present. The site has a bore free flowing into a relatively naturalised waterbody where extensive macrophytes and an abundant fish population were found. The ecology report (DPIE, 2020b) does not give an ecological value for this spring.

5.1.1.3 Geological and hydrogeological setting

Bingewilpa Spring is located on flat plains dominated by Quaternary playas, wind-blown sands and clay pans, as shown on the 1:250,000 scale surface geology map on Figure 17, Figure 18, extracted from the White Cliffs 1:250 000 Geological Sheet (Rose et al, 1964). The aerial photographs suggest fluvial deposits associated with floodplain outwash may also occur.

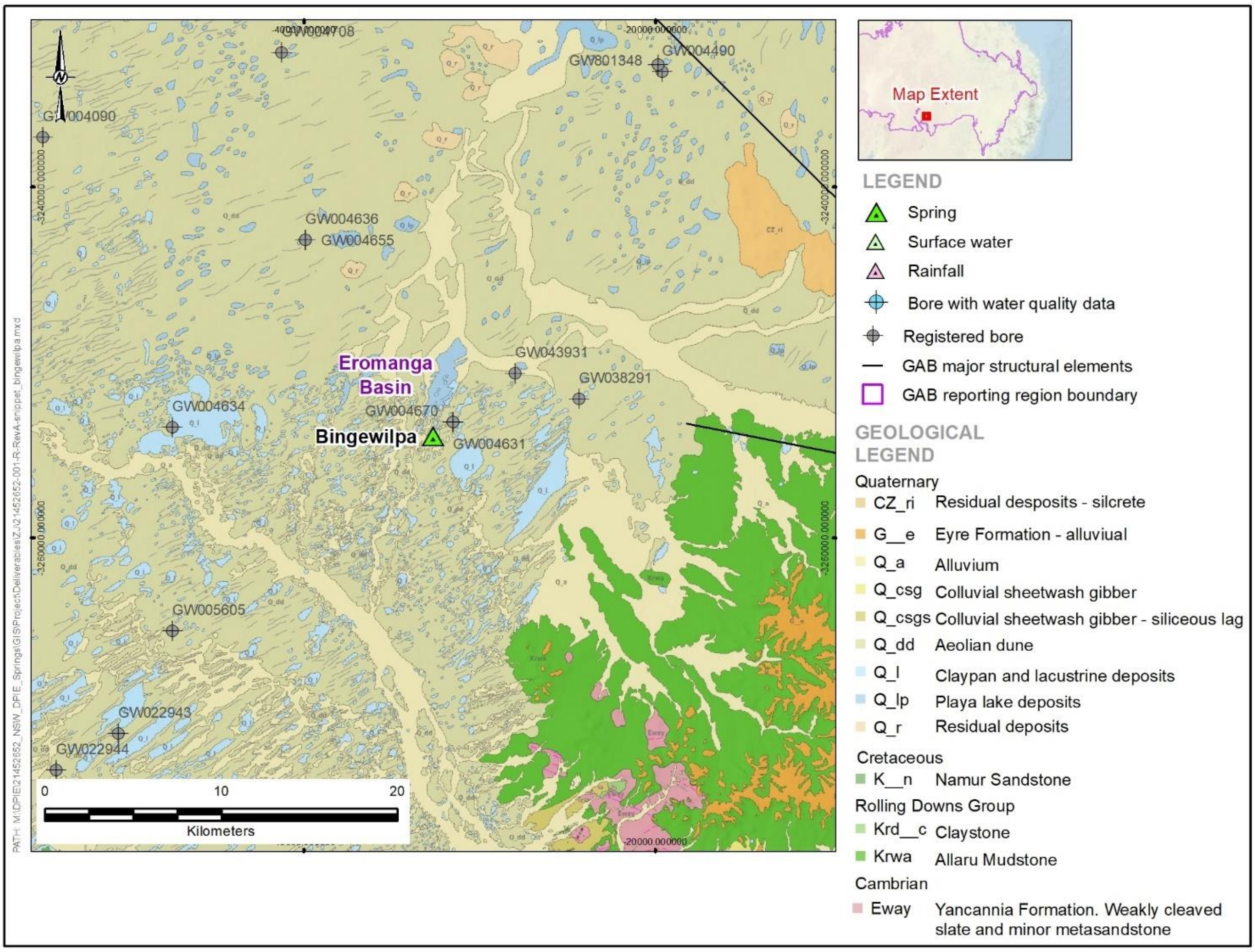

Figure 17: Bingewilpa location plan and 1:250,000 surface geology (Rose et al, 1964)

The Rolling Downs Group aquitard occurs approximately 10 km southeast of this spring. The GABWRA 3D visualisation of the GAB (Geoscience Australia, 2013) indicates the following.

- The Quaternary surface is underlain by the Hooray Sandstone or thin (and possibly inconsequential) occurrences of the Rolling Downs Group.
- The Hooray Sandstone rises from the north, at a depth of 250 m to 300 m, dipping towards the south. Here it subcrops beneath the Quaternary deposits over the margins of the high basement plateau, continuing for around 50 km to the southern edge of the GAB.
- The Rolling Downs Group thins and may not be present as the GAB formations thin over the basement high beneath these springs.
- The southern margin of the GAB is located approximately 60 km south of Bingewilpa.

Two bore logs in the vicinity of the spring, which have the same location co-ordinates, report conflicting lithology. Registered bore GW004631 (installed in 1907), indicates that sandstone predominantly dominates the geological profile to over 60 m depth while registered bore GW004670 (installed in 1927) indicates the geological profile to a similar depth is dominated by clay with occasional thin limestone bands.

A west-north-west – east-south-east, fault alignment, 15 km east of Bingewilpa spring and perpendicular to the Hooray groundwater flow is shown on Map 10 of GAB Atlas (Ransley et al, 2015). If this fault continues further west than shown on Map 7 it would likely pass within 3 or 4 km of these springs. Given the faults extent, there may be associated faults or splays although none are documented.

5.1.1.4 GAB groundwater levels/artesian conditions

Based on the information provided by DPIE and available on the online portal by Water NSW, there are no bores within 20 km with recent water level or pressure information or indication on whether they are artesian. The field observations by DPIE describe a free-flowing bore onsite (artesian), however it is unknown in what formation it is installed. This bore does not appear in the Water NSW online portal.

There is no recent information regarding water level or artesian condition from the two closest registered bores, GW004631 and GW004670. Records from 1995 indicate GW004670 is 73 m deep, with no headworks and that it showed artesian groundwater flow at that time.

5.1.1.5 Hydrogeochemistry

One water sample was collected from Bingewilpa in July 2019 and was analysed for major ions, metals and isotopes (^{2}H, ^{18}O, ^{87}Sr, ^{36}Cl, ^{14}C and ^{3}H). It is not clear whether the sample was collected directly from the bore or from one of the surface water bodies.

There are no bores with groundwater quality information within 20 km of Bingewilpa.

5.1.1.5.1 Water quality

The water sample from this vent is neutral pH (7. 6) and brackish (3000 mg/L), this is the highest salinity of all springs in the study area, and is not consistent with GAB water where lower salinities are usually measured The water is a sodium+potassium – chloride type, as shown on the Piper plot on Figure 18. This is not generally consistent with GAB water.

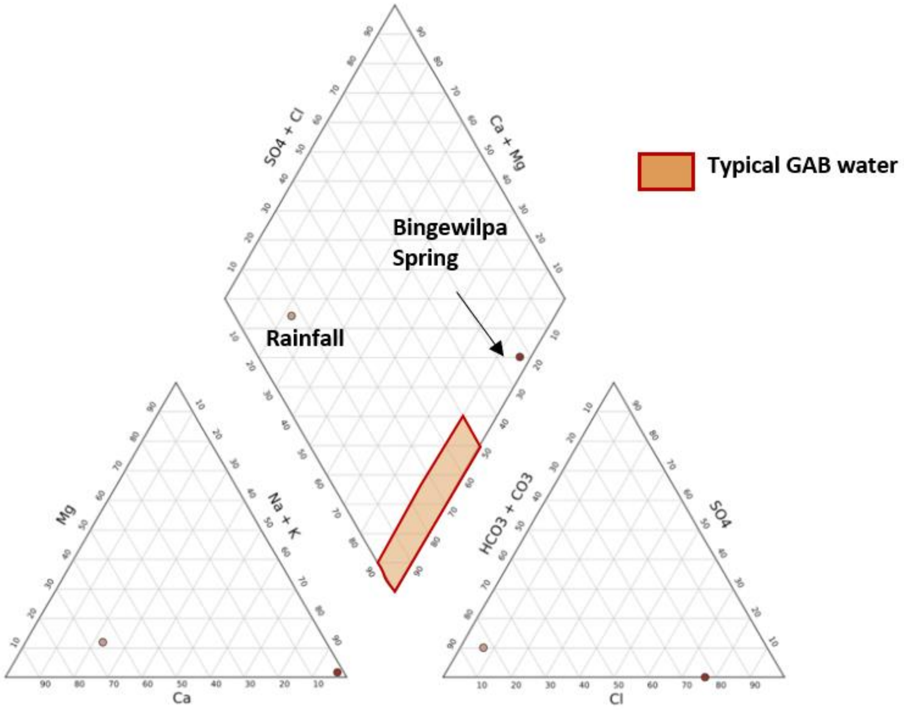

Figure 18: Piper plot Bingewilpa Spring

Most of the measured metals are under or close to the detection limits except for dissolved iron, lithium and strontium, with concentrations of 170 µg/L, 360 µg/L and 2300 µg/L respectively.

5.1.1.5.2 Isotope analysis

Based on the isotope analysis presented in Section 4.5 the following main outcomes are relevant for the conceptualisation of this spring:

- The isotopic signature of ^{2}H and ^{18}O indicate the sample has a similar signature to the groundwater bores that are understood to be monitoring the Hooray Sandstone and were sampled in March 2018.
- Tritium activity from Bingewilpa is below the limit of detection suggesting a water source without a mixture of modern meteoric or shallow groundwater.
- The sample collected shows a low pMC 0.27%, similar to the groundwater samples (from bores located between 200 km and 300 km east). This would suggest that the Bingewilpa sample is from a water source with no meteoric or shallow groundwater mixing.
- The $^{36}Cl/Cl^{-}$ ratio is 14.2×10^{-15}. This is within the range of variation of ^{36}Cl ratio for the groundwater bores in that area and in the Hooray Sandstone in that area (Map 46 of Ransley et al, 2015).

5.1.1.6 Machine Learning outcomes

According to the PCA analysis this spring is the only location within group 2 (K-mean groups). It has a higher variation in sodium, calcium and chloride ions compared to the other springs. Figure 19 shows its position in the PCA analysis.

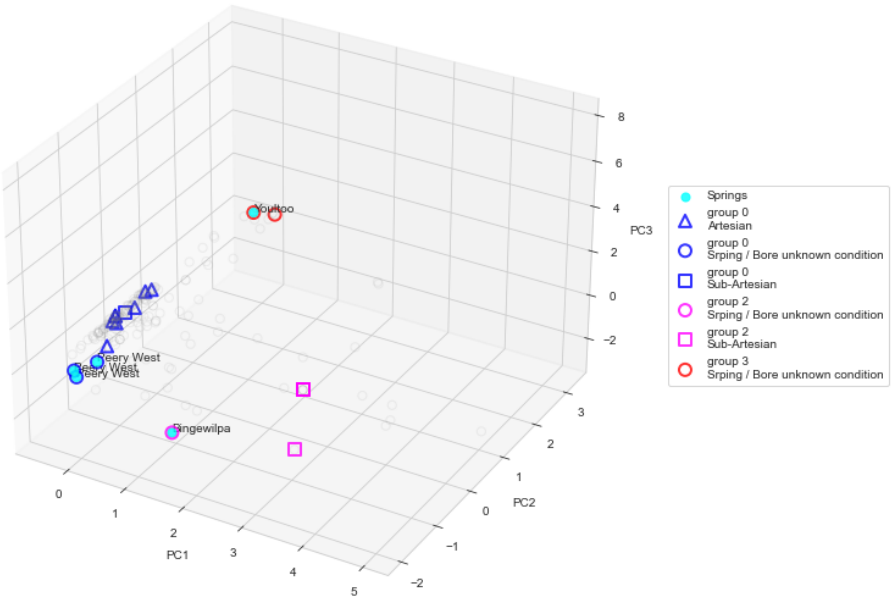

Figure 19: Relative position of spring Bingewilpa in 3 dimensional PCA plot.

5.1.1.7 Conceptualisation

The main components of the information reviewed to support the conceptualisation of the spring at Bingewilpa are summarized below:

- Based on the field observations provided by DPIE, the spring can be seen to be fed by a free-flowing artesian bore.

- The spring is located where the Hooray Sandstone is at a regional high and where the Rolling Downs Group is understood to be thinning or even absent.
- The water chemistry signature is similar to that of the bores installed in the GAB, although its chloride concentration is on the high side.
- The radioactive isotope analysis indicates the sample collected from Bingewilpa is consistent with GAB water.
- The machine learning outcome does not provide conclusive results on whether this spring is compatible with GAB water.

The water source of this spring is likely the GAB through the uncapped bore onsite.

5.1.2 Colless Spring Complex

5.1.2.1 General Setting and Summary of Field Observations

Colless Spring (Figure 21) is located on Stanbert Station approximately 30 km south of the Queensland border. DPIE identify two vents at this location, Vents 969.1 and 969.2

Vent 969.1 is an intermittently active spring. Vent 969.2, shown on the photograph on Figure 20 is described in the Queensland Herbarium (2015) as a shallow well. Vent 969.1 is described as a mound approximately 1.5 m high and 40 m in diameter. Both vents were described as being inactive by DPIE in October 2018.

DPIE collected one water sample from Vent 969.2 in October 2018, it is unclear how the vent was sampled as DPIE describe it as being inactive.

Figure 20: Colless Vent 969.2 (DPIE, 2020b)

5.1.2.2 Ecology

DPIE did not report any ecology information for this location.

5.1.2.3 Geological and Hydrogeological setting

The surface geology in the area of Colless Spring is shown on the Enngonia 1:250,000 geology map (Johnson & Menzies, 1965) which has been included in Figure 21. The surface geology suggests the Colless Spring complex is located on Quaternary sand plains and clay pans. The Rolling Downs Group, the dominant GAB formation in the area, outcrops about 3 km to the west of the complex and is unconformably underlain by Palaeozoic basement rocks. The southern margin of the GAB is located 50 km south of Colless.

Both geological sections shown on the Enngonia geological map sheet suggest that the Hooray Sandstone is not present beneath these springs. Information from registered bores drilled within 15 km of this spring and the 3D visualisation of the GAB (Geoscience Australia, 2013) suggest, to the contrary, that the Hooray Sandstone may be present in this area.

GABWRA 3D (Geoscience Australia, 2013) visualisation of the GAB also suggests the Hooray Sandstone may be present beneath these springs and appears to be thinning and pinching out about 25 km to the west. Continuity of the Hooray Sandstone across the nearby Cunnamulla Shelf to the west (and downgradient) of these springs is therefore possible but not known.

Two nearby (unnamed) faults have been mapped in the basement Cunnamulla Ridge Shelf (Ransley et al., 2015), one about 7 km southwest and oriented northwest – southeast, and the other 10 km northwest and oriented northeast – southwest. There is no evidence these faults are also present in the GAB sediments. Rade (1954) suggests spring complexes of the Bourke Supergroup may outcrop in north-west to south-east trends, parallel to fault trends.

Nearby mapped duricrust formations (Ransley et al., 2015), associated with near-surface weathered zones of the Rolling Downs Group, were regarded as possibly allowing vertical migration of pressurised groundwater from the Hutton or Hooray Sandstone through geological structures in the Rolling Downs Group aquitard (Smerdon et al, 2012).

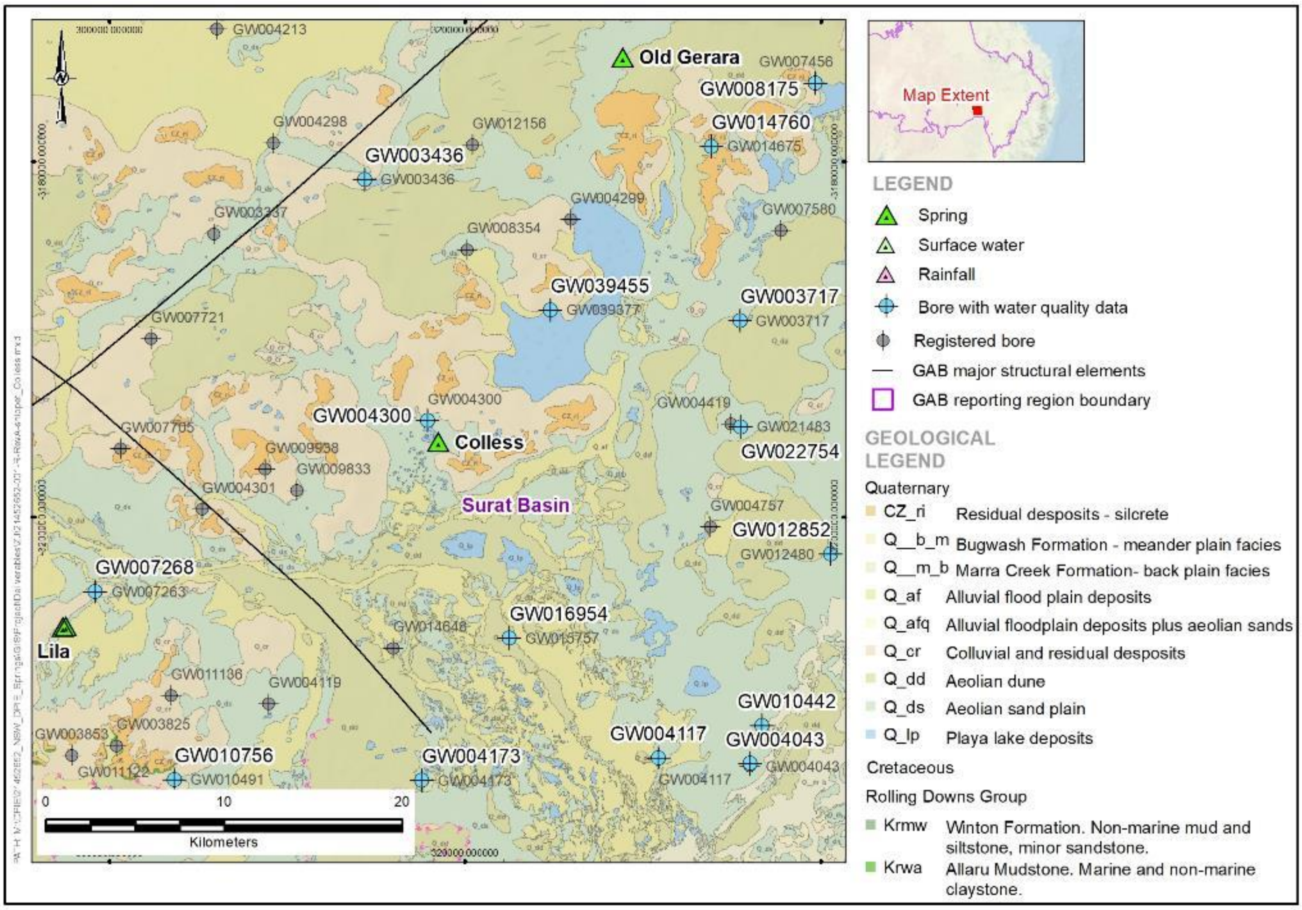

Figure 21: Colless location plan and 1:250,000 surface geology from Johnson & Menzies (1965)

5.1.2.4 GAB groundwater levels/artesian conditions

Based on the information provided by DPIE and available on the online portal by Water NSW, data from 2019 reports three bores in the vicinity (GW004300, GW003717 and GW022754 (shown on Figure 21) were artesian. The closest, GW004300, is located 1 km northwest of Colless and understood to be monitoring the Hooray Sandstone.

5.1.2.5 Hydrogeochemistry

One water sample was collected from Colless from Vent 969.2 (the shallow bore described in section 5.1.2.1) in October 2018 and was analysed for major ions, metals and isotopes (^{2}H, ^{18}O, ^{36}Cl and ^{14}C).

5.1.2.5.1 Water quality

Water from this vent is caracterized by neutral pH (7. 2) and low salinity (500 mg/L). The water is of sodium-bicarbonate type (see Piper plot on Figure 22), consistent with GAB water.

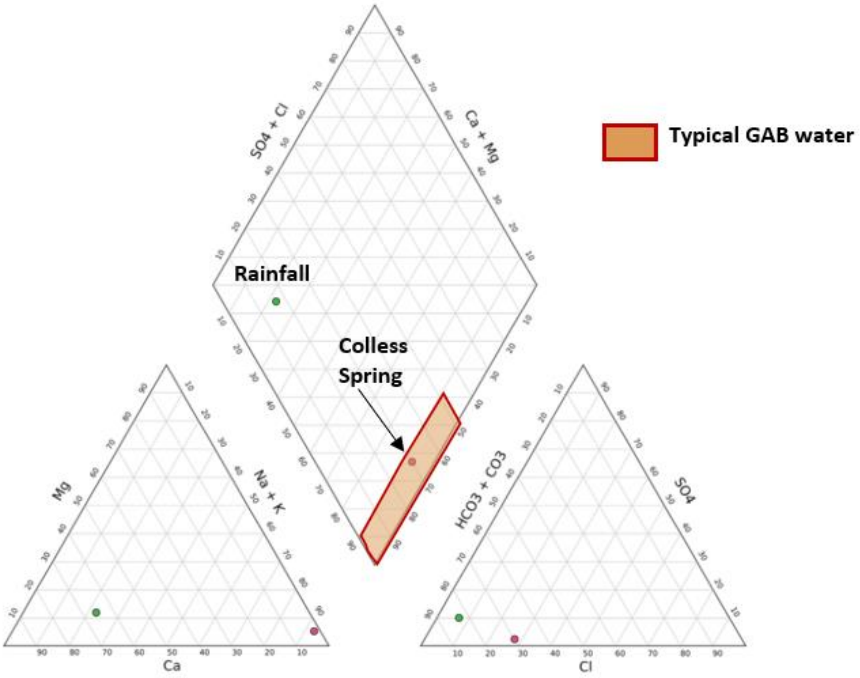

Figure 22: Piper plot Colless Spring

Most of the measured dissolved metals are under or close to the detection limit except for iron, lithium, manganese and strontium, with concentrations of 240 µg/L, 7 µg/L, 9 µg/L and 110 µg/L respectively. Similarly, most of the measured total metals are under or close to the detection limit with the exception of iron (500 µg/L), lithium (8 µg/L), lead (9 µg/L), manganese (4 µg/L) and strontium (9 µg/L). These results are all consistent with GAB groundwater.

5.1.2.5.2 Isotope information

Based on the isotope analysis presented in Section 4.5 the following main outcomes are relevant for the conceptualisation of this spring:

- the isotopic signature of ^{2}H and ^{18}O are similar to the groundwater samples (although these were sampled during different sampling events). This may suggest a similar isotopic signature as groundwater but could also be due to seasonal variation (as it was sampled at different times).
- the pMC value of 25.17% would suggest that the sample from Colless Spring is from a source with a mixture of modern meteoric water or shallow groundwater.

- the ^{36}Cl/Cl^{-} ratio of 112x10^{-15} is approximately seven times lower than the modern atmospheric ratio (of approximately 700x10^{-15}) but 10 times higher than the ratio for groundwater from the GW004259 located 25 km north and 3 times higher than the ^{36}Cl/Cl ratio in the Hooray Sandstone in that area (Map 46 of the GAB Atlas indicates ratios between 20 and 70x10^{-15} are to be expected in that area (Ransley et al, 2015)).

The isotopic analyses from Colless Spring are consistent with a GAB source mixed with modern meteoric water or shallow groundwater.

5.1.2.6 Machine Learning outcomes

According to the PCA analysis this spring is in a transitional location. That analysis suggests a low to moderate likelihood of some connection between the aquifer and the spring. Figure 23 shows its position in the PCA analysis.

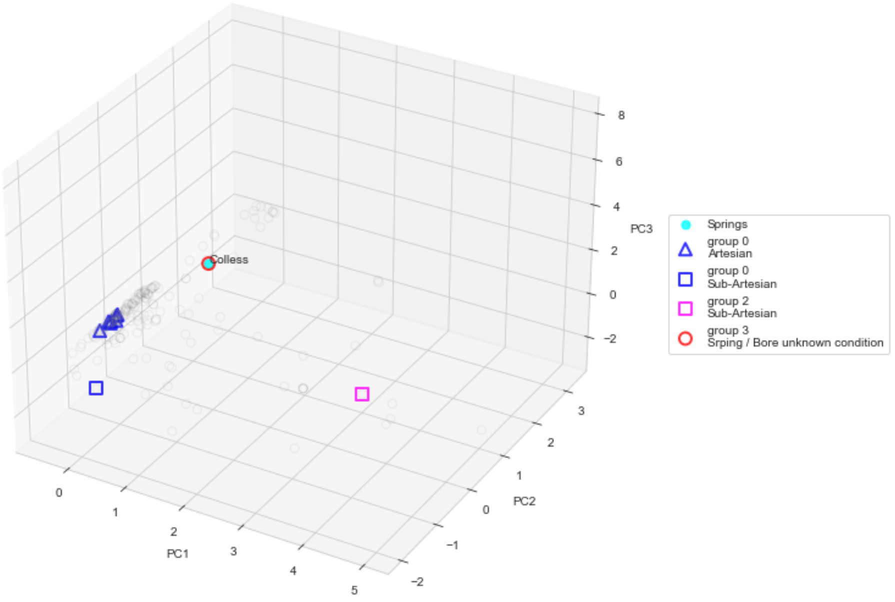

Figure 23: Relative position of spring Colless and closest bores in 3 dimensional PCA plot.

5.1.2.7 Conceptualisation and typology of Colless Spring

The main components of the information reviewed to support the conceptualisation of the spring at Colless are summarized below:

- DPIE observed that there is a remnant mound but that the water seemed to be coming from a shallow, uncapped flowing bore (although no bore depth was indicated). In addition, nearby remnant mounds are observed.
- The geological setting indicates that the area is underlain by a basement high, associated with the Lightning Ridge shelf, which could create “pinches” and discontinuities in the Hooray Sandstone. It cannot be certain that the Hooray Sandstone occurs at the site. Basement faults are identified within 10 km of the springs although it is not known whether these continue in the GAB formations. The presence of faulting at the site is not known.

- The water signature of general parameters and major ion composition is similar to GAB (i.e. neutral pH, low salinity and sodium+potassium-bicarbonate type water.
- Radioactive isotope results indicate that the water source as sampled cannot be from the GAB solely since there are clear indications of meteoric water or shallow groundwater.

The water source for this spring, although sampled from a shallow well with little information available, is likely originating from the GAB with small amounts of modern meteoric water or shallow groundwater.

5.1.3 Coonbilly Spring

5.1.3.1 General Setting and Summary of Field Observations

Coonbilly is located approximately 80 km northwest of Bourke. It is within 20 km of the Youngerina Spring, Culla Willallee Spring and Thooro Mud Spring.

Coonbilly Spring is in a low-lying area of a clay floodplain surrounded by red sandy-clay ridges with scattered iron rich rocks. At the time of DPIE's sampling, a waterline mark was observed approximately one meter from the vent water edge, the soil in this area was waterlogged. The landscape beyond the spring site was very dry and dry ephemeral creeks were noted. One sample was collected in March 2018 from Vent 974.17, however it is understood that several vents are located on site, as shown by other surface water bodies on the aerial photograph presented in Figure 24 (DPIE, 2020b). DPIE did not observed active flow or 'bubbling' from this vent.

Figure 24: Aerial photograph of Coonbilly vent (DPIE, 2020b)

Coonbilly Spring was listed in the Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources 2008, the Groundwater-dependent Ecosystems spatial database (Commonwealth GDE database) and the Queensland Spring Database (Queensland Herbarium, 2015).

5.1.3.2 Ecology

During the sampling and monitoring event, DPIE identified that groundwater dependent flora at this site was restricted to Cynodon dactylon. No Commonwealth-listed (EPBC Act 1999) or State-listed (BC Act 2016) threatened plant species were reportedly present. DPIE describe grazing disturbance and animal digging (soil disturbance) as low at the time of sampling.

Groundwater dependent fauna at the site was restricted to macroinvertebrates and amphibians. No fish were recorded, and one frog species was recorded within the aquatic zone of the spring (Cyclorana cultripes). In total, six different macroinvertebrate taxa were recorded. The most abundant macroinvertebrates were from the clam shrimp genus Limnadia (DPIE, 2020b).

Compared to other springs sampled, Coonbilly had low diversity (11% of all taxa sampled) and low abundance. No Commonwealth-listed (EPBC Act 1999) or State-listed (BC Act 2016 & Fisheries Management Act 1994) threatened fauna species were recorded. DPIE assigned a low ecological value to this spring.

5.1.3.3 Geological and Hydrogeological setting

The surface geology in the area of Coonbilly Spring is shown on the Yantabulla 1:250,000 geology map (Wallis & McEwen, 1962) included on Figure 25. This map suggests that Coonbilly Spring is situated on the Rolling Downs Group and is variably covered by Quaternary-aged wind-blown sand dunes and clay pans. Occurrences of sands, silts and silicified sedimentary boulders are irregularly present in the landscape, including within a few prominent ephemeral creeks. The southern margin of the GAB is located 80 km south of Coonbilly Spring.

The geological sections shown on the Yantabulla geological map suggest the Hooray Sandstone is not present beneath the Coonbilly Spring. Borehole logs for the two registered bores closest to this spring (GW003823 and GW004339, shown on Figure 25) drilled to 303 m indicate predominantly shale units.

GABWRA 3D visualisation (Geoscience Australia, 2013) of the GAB does suggest thin beds of the Hooray Sandstone were regarded by the authors as being present beneath this spring complex. Both the Hooray Sandstone and the underlying Injune Creek Formation unconformably overlie higher areas of the basement rocks of the Cunnamulla Shelf. IESC (2014) notes the geological log for registered bore GW804172, drilled about 35 km southeast of the spring complex, suggests it encountered the Hooray Sandstone between depths of about 332 m and 395 m. The inference from this is that it is possible that the Hooray Sandstone could occur beneath the site.

Two (unnamed) faults run 10 km northeast and 20 km southwest of Coonbilly Spring in the underlying Cunnamulla Shelf basement rocks underlying the GAB. There is no evidence whether these faults are present in the GAB sediments. However, Rade (1954) suggests spring complexes of the Bourke Supergroup may outcrop in north-west to south-east trends, parallel to fault trends. IESC (2014) also notes springs in the Yantabulla area occur along the eastern margin of a granitic basement horst, with small faults regarded as connecting Kullyna – Native Dog and Coonbilly–Youngerina springs. The nearby Culla Willallee and Youngerina spring complexes are all located in similar geological settings, including tectonic (faulting) settings. While indirect evidence, these interpretations lend support to faulting being the cause of the location of Coonbilly Spring.

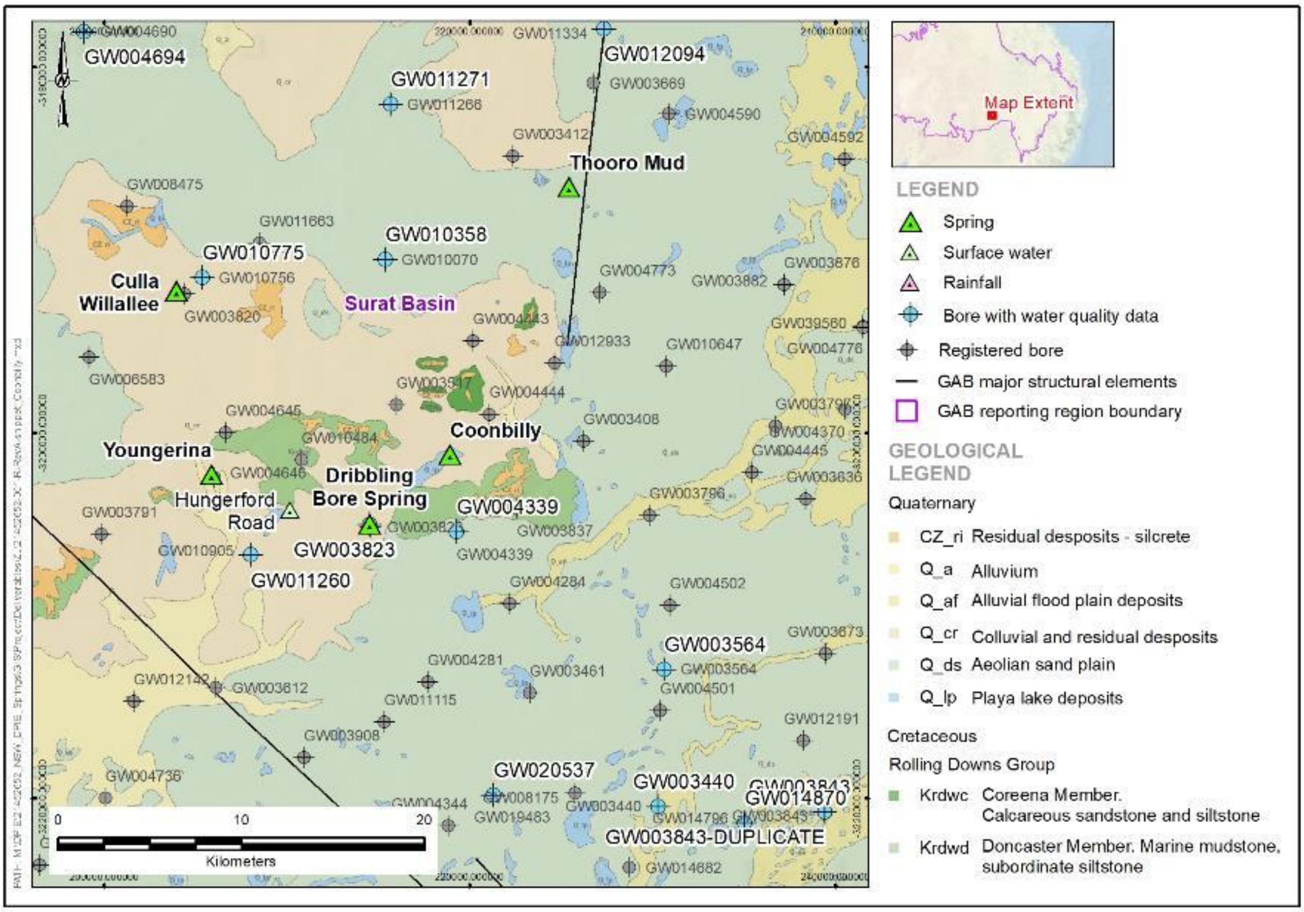

Figure 25: Coonbilly location plan and 1:250,000 surface geology from Wallis & McEwen, (1962)

5.1.3.4 GAB groundwater levels/artesian conditions

Based on the information provided by DPIE and available on Water NSW's online portal there are five bores all understood to be monitoring the Hooray Sandstone or an underlying aquifer within the GAB. with indications on whether they are under artesian condition in 2019. These are GW010358, GW003564, GW004339, GW003823 and GW011260 (see location on Figure 25). All bores except GW004339 were artesian in 2019.

5.1.3.5 Hydrogeochemistry

One water sample was collected from Coonbilly in March 2018 and was analysed for major ions, metals and isotopes (^{2}H, ^{18}O, ^{36}Cl and ^{14}C).

5.1.3.5.1 Water quality

The pH of this sample is neutral (pH 7) and salinity is low (440 mg/L). The water is of sodium-bicarbonate type (see Piper plot on Figure 26).

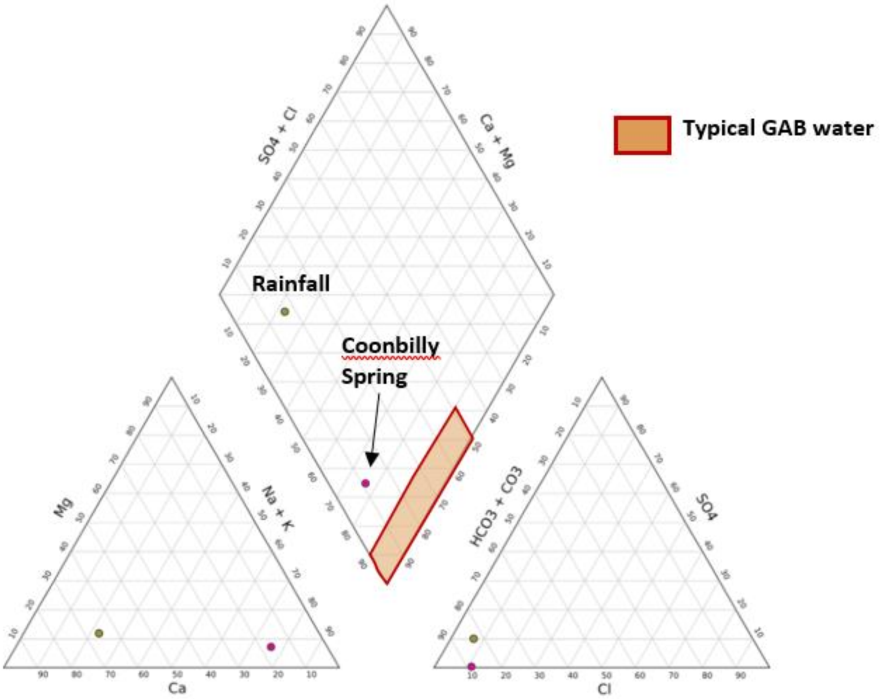

Figure 26: Piper plot Coonbilly Spring

Several dissolved metals concentrations are significantly higher than the detection limit including aluminium (2000 µg/L), iron (1200 µg/L), manganese (130 µg/L) and strontium (240 µg/L). Concentration in dissolved arsenic and lithium were slightly above the detection limit.

Similarly, several total metals concentrations are significantly higher thant the detection limit including aluminium (9600 µg/L), iron (8000 µg/L), lithium (11 µg/L) manganese (320 µg/L), strontium (300 µg/L) and zinc (23 µg/L). Concentration in total arsenic, chromium, copper, lead, lithium and nickel were slightly above the detection limit.

5.1.3.5.2 Isotope information

Based on the isotope analysis presented in Section 4.5 the following main outcomes are relevant for the conceptualisation of this spring:

- The isotopic signature of ^{2}H and ^{18}O indicate the sample falls below the GMWL. This would suggest the influence of evaporative processes. The signature is also different to the bore grouping with depleted ^{2}H and ^{18}O suggesting a different water source.
- The pMC from Coonbilly is 102%, suggesting the water is modern.
- The ^{36}Cl/Cl^{-} ratio of 131x10^{-15} is approximately 7 times lower than the atmospheric ratio but 3 times higher than the ratio of groundwater from GW004339 GW003823 and GW004659 located between 4 km and 30 km away and understood to be monitoring the Hooray Sandstone. The ^{36}Cl/Cl^{-} ratio is also approximately 3 times higher than the ^{36}Cl/Cl ratio in the Hooray Sandstone based on previous investigations (Map 45 of Ransley et al, 2015). This could imply that the spring's water source is younger than the water in the GAB and/or that the GAB is not the only water source and mixing processes are also involved.

5.1.3.6 Machine Learning outcomes

According to the PCA analysis this spring is in a transitional location. It has a high to moderate likelihood of some connection between the aquifer and that spring. Figure 27 shows its location in the PCA analysis.

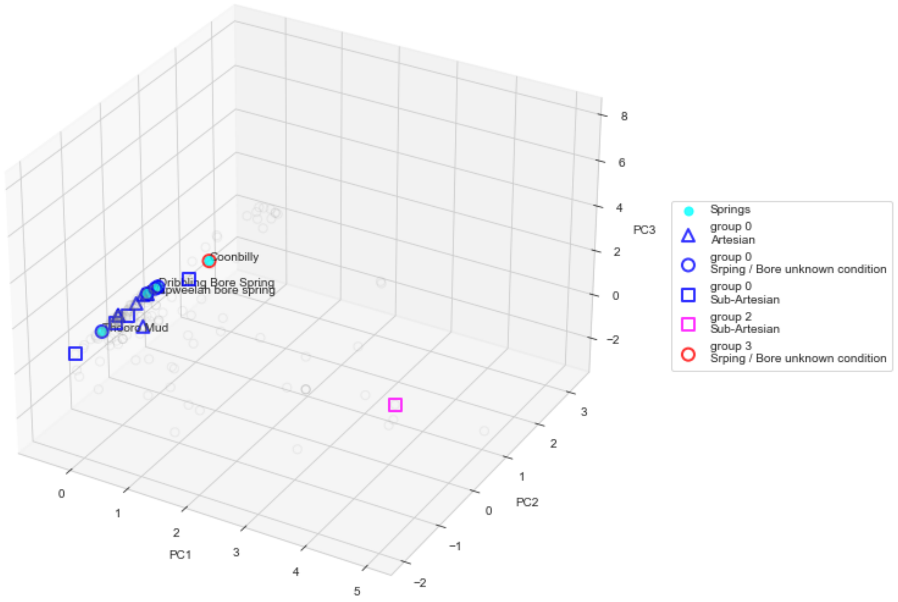

Figure 27: Relative location of Coonbilly Spring and closest bores in 3 dimensional PCA plot.

5.1.3.7 Conceptualisation and typology of Coonbilly

The main components of the information reviewed to support the conceptualisation of the spring at Coonbilly are summarized below:

- DPIE's field observations does not indicate whether there are signs of flow ('bubbling') from the spring.
- The springs are located where the Hooray Sandstone may be thin or absent, from regional data and interpretations.
- The water chemistry signature is similar to that of the bores installed in the GAB, although higher in Ca+Mg.
- The radioactive isotope analysis indicates the sample collected from Coonbilly has a different isotopic signature to the GAB. In particular, the radioactive isotope analysis suggests the water is of modern origin.
- The Machine learning analysis indicate that this spring has high to moderate likelihood of some connection between the aquifer and that spring.

The water source of this spring is likely to be the GAB with substantial mixing from meteoric water, shallow groundwater or both.

5.1.4 Culla Willalee (Mother Nosey) Spring

5.1.4.1 General Setting and Summary of Field Observation

Culla Willalee Spring is located approximately 100 km northwest of Bourke (Figure 29). This spring complex is found on the lowest local topographic point on a clay pan adjacent to flat undulating sand dunes. The Culla

Willalee spring complex forms part of the Mother Nosey Group of springs. These spring complexes are located close to each other on the same claypan.

Culla Willalee is part of the Boongunyarra Complex, which is understood to also include Black Spring and Boongunyarrah Spring (DPIE 2020). Both Black and Boongunyarra Springs were described as being inactive by DPIE.

Spring water was shallow and turbid and the edges of the spring pool were waterlogged.

DPIE visited this spring in March 2018, October 2018 and July 2019. The area of the spring was larger in July 2019 than March 2018 (see Figure 28). DPIE also note that the spring appeared more as a soak in both visits in 2018 whereas there were small bubbling water conduits flowing during the July 2019 visit.

Water sampled were collected from the same vent, Vent 963.1 for each sampling events.

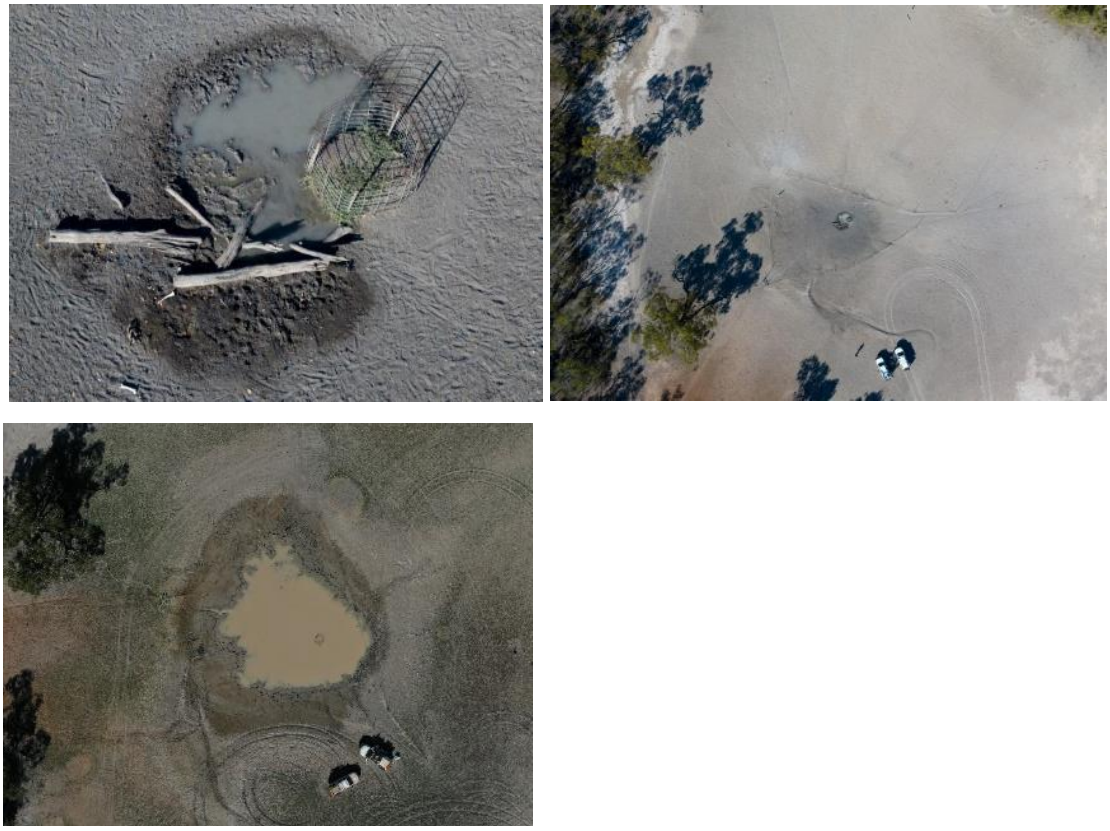

Figure 28: Low elevation aerial photograph of the spring (upper left) and 70 m aerial photographs of Culla Willallee Spring in March 2018 (upper right) and 50 m aerial photograph of spring in July 2019 (DPIE, 2020b)

5.1.4.2 Ecology

Groundwater dependent flora and fauna at this site was restricted to Glinus lotoides and eight recorded species of macroinvertebrates (DPIE, 2020b). Glinus lotoides is a native common non-endemic forb dependent on the spring water but not considered a significant species.

No commonwealth (EPBC Act 1999) or state (BC Act 2016) listed threatened plant species were present. Grazing disturbance was low and animal digging (soil disturbance) was high at the time of sampling. Compared to other springs sampled, this spring has low diversity (15% of all taxa sampled) and abundance. No Commonwealth-listed (EPBC Act 1999) or State-listed (BC Act 2016 & Fisheries Management Act 1994) threatened species were recorded.

DPIE indicate that this spring is considered to have low ecological value.

5.1.4.3 Geological and Hydrogeological setting

The Culla Willallee spring complex is situated on the Rolling Downs Group as presented on the surface geology map on Figure 29 showing the Yantabulla 1:250,000 scale geological map (Wallis & McEwen, 1962). This is variably covered by Quaternary wind-blown sand dunes and clay pans, whilst occurrences of sands, silts and silicified sedimentary boulders are irregularly present, including within a few prominent ephemeral creeks.

The geological sections on the Yantabulla geological map suggest the Hooray Sandstone is not present beneath the Culla Willallee spring complex. GABWRA’s 3D visualisation (Geoscience Australia, 2013) of the GAB, however, suggests the Hooray Sandstone is present beneath this spring complex, albeit in somewhat ‘thin’ beds typically 50 m thick or less as both it and the underlying Injune Creek Formation unconformably overlie ‘raised’ basement rocks of the Cunnamulla Shelf. GABWRA 3D visualisation. It also suggests the Hooray Sandstone may be locally absent (i.e. eroded) as the Injune Creek Formation is unconformably overlain by the Rolling Downs Group. The southern margin of the GAB is located approximately 100 km south of Culla Willallee.

Devonian granites, which also constitute basement rocks beneath the GAB in this area, are present less than 10 km west of this spring complex, potentially cropping out along a locally significant basement high which may form geological barriers to groundwater flow regimes in the GAB units.

Two (unnamed) faults in the underlying basement rocks beneath the GAB units are located in the region of the Culla Willallee spring complex (22 km east and 15 km southwest). The Youngerina, Hungerford Road, Dribbling Bore and Coonbilly spring complexes are all located within 25 km of the east of this fault. There are no known springs at similar distances to the west of this fault. It is not known whether these faults extend up into the GAB formations.

Rade (1954) suggested spring complexes at and in the vicinity of Culla Willallee may occur due to the interaction of regional groundwater flow and faulting, which is expected to be approximately perpendicular to flow in this area.

Map 16 of the GAB Atlas (Ransley et al, 2015) also shows the Culla Willallee spring complex outcrops or is close to mapped duricrust formations associated with near-surface weathered zones of the Rolling Downs Group; these are hypothesised by GAB Atlas to allow vertical migration of pressurized groundwater from the Hooray Sandstone into the Rolling Downs Group.

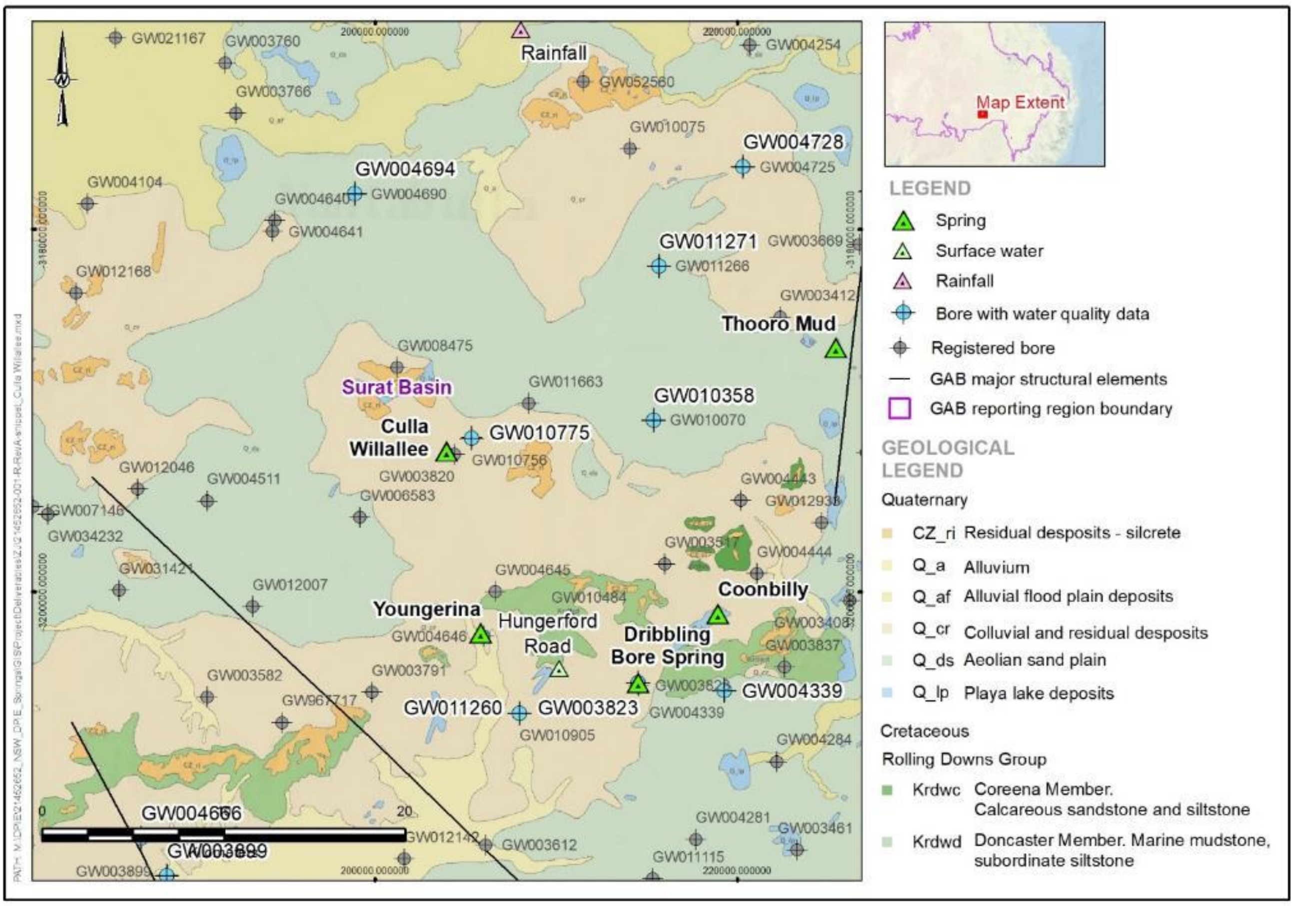

Figure 29: Culla Willalee location plan and 1:250,000 surface geology from Wallis & McEwen (1962)

5.1.4.4 GAB groundwater levels/artesian conditions

Based on the information provided by DPIE, information about artesian condition in 2019 are available for four bores within 20 km of Culla Willalee Spring. These are GW010775, GW010358, GW011271, GW003823 and GW004339, located on Figure 29. All bores except GW004339 were noted as artesian in 2019.

5.1.4.5 Hydrochemistry

Three samples were collected in total at Culla Willalee from Vent 963.1 (in March 2018, October 2018 and July 2019) and were analysed for major ions, metals and isotopes (^{2}H, ^{18}O, ^{87}Sr, ^{36}Cl, ^{14}C and ^{3}H).

5.1.4.5.1 Water quality

Water from this vent is neutral to slightly basic (between 7.7 and 8.7) and with a range of low salinity values (700-1000 mg/L). The water is of sodium-bicarbonate type (see Piper plot on Figure 5). The samples from March 2018 and October 2018 are similar in their composition of major ion while the July 2019 sample is slightly more abundant in calcium (see Piper plot on Figure 5).

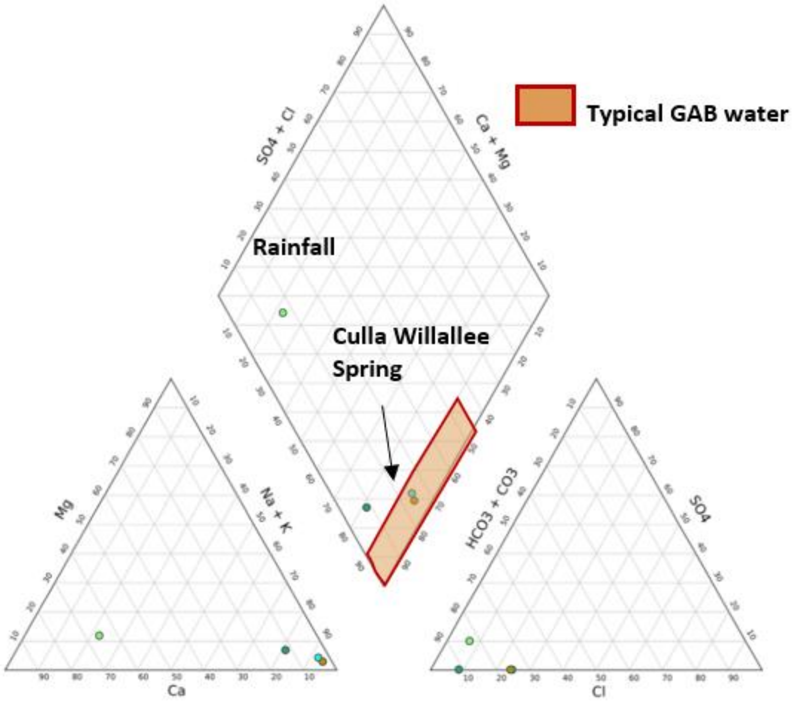

Figure 30: Piper plot Culla Willallee Spring

Aluminium and iron are the most prevalent metals with average concentrations of 36 mg/L and 19 mg/L (total metal). Strontium and Manganese are also present with average concentrations of 936 µg/L and 456 µg/L respectively. Arsenic, lithium, nickel and zinc are also observed in all samples in small concentrations. Some variability is observed between the samples, with the sample collected in March 2018 showing the highest concentration in metals.

5.1.4.5.2 Isotope information

Based on the isotope analysis presented in Section 4.5 the following main outcomes are relevant for the conceptualisation of this spring:

- the isotopic signature of ^{2}H and ^{18}O for the three rounds are distributed along and slightly below the Cobar LMWL (Figure 6, Figure 7 and Figure 8). This plot would suggest that there is seasonal variability in the isotopic ratios at that vent and that there are some evaporative influences.
- The samples collected in March 2018, October 2018 and July 2019 all show similar ^{36}Cl/Cl^{-} ratios ranging between 65x10^{-15} and 80x10^{-15}. This ratio range is slightly higher than the ^{36}Cl/Cl^{-} ratio for the groundwater bores in that area and in the GAB in that area in general (Map 45 of Ransley et al. 2015).
- Significant variability is observed in the pMC value: it was measured at 35 % in March 2018, 16% in October 0218 and 94% in July 2018. This would suggest that time-variable, or erratic mixing processes may be involved.
- Tritium was only measured in October 2019 and July 2019 and the measured tritium activity was different at each round. It was measured at 0.23 TU. in October and 1.8 TU. in July 2019. This would suggest a variable mix of water sources, similar to that shown by the pMC results. Both tritium activities are higher than the expected zero tritium activity for the GAB, suggesting the water source cannot solely be the GAB.

5.1.4.6 Machine Learning outcomes

The individual spring water quality is highly compatible with the local bores suggesting a high likelihood of connection between the aquifer tapped by those bores and that spring. Figure 31 shows its location in the PCA analysis.

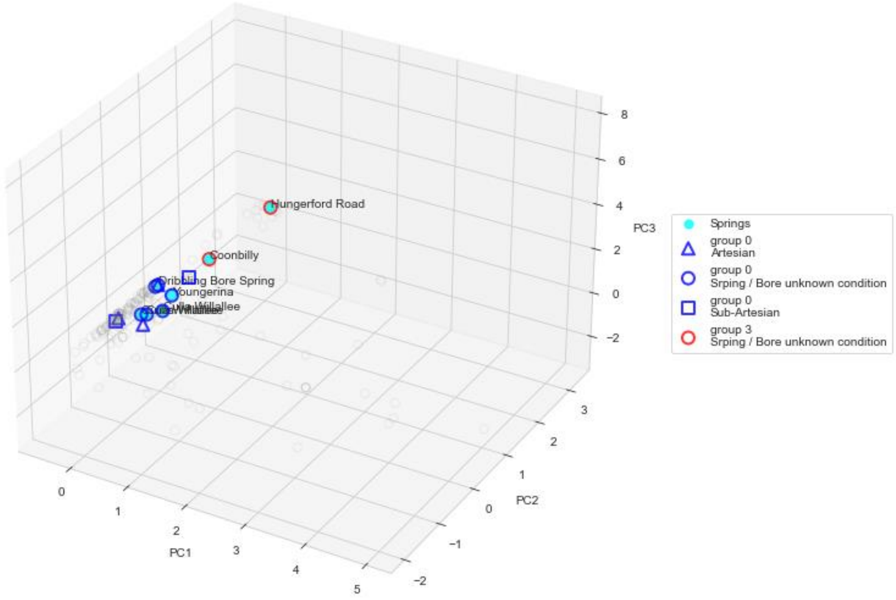

Figure 31: Relative location of Culla Willalee Spring and closest bores in 3 dimensional PCA plot.

5.1.4.7 Conceptualisation and typology

The main components of the information reviewed to support the conceptualisation of the spring at Culla Willallee are summarized below:

- Based on the field observations provided by DPIE, the spring is understood to have a very small rate of discharge. It is not possible to confirm that it never dries out but likely that it remains as a small surface feature during summer (since it is significant enough to be named).
- The spring is located where the Hooray Sandstone is at a regional high and where the Rolling Downs Formation is understood to be thinning.
- The composition in major ion is broadly similar to that of the bores installed in the GAB but with variable calcium.
- The radioactive isotope analysis would suggest seasonal variability and that evaporative processes affect the water that can be sampled, so a GAB source is not the only water at the vent.
- Machine learning outcomes spring water quality is highly compatible with the local GAB bores suggesting a high likelihood of connection between the aquifer tapped by those bores and that spring.

It seems likely that this spring is sustained by a small flow of groundwater from the GAB, the discharge is mixed with a significant proportion of shallow, young groundwater and locally infiltrating meteoric water.

5.1.5 Gooroomero Spring

5.1.5.1 General Setting and Summary of Field Observations

Gooroomero is located 130 km northeast of Bourke (Figure 32).

There were no field observations or ecology surveys made available for Gooroomero Spring. One water sample was collected from Gooroomero, but it is unclear where it was collected. Shallow groundwater was reportedly observed in the area of the spring, with water understood to be encountered within the first 0.5 m.

Previous investigations carried out in 2014 were unsuccessful in locating Gooroomero Spring (Commonwealth of Australia, 2014).

5.1.5.2 Geological and Hydrogeological Setting

Gooroomero Spring is understood to occur amongst Quaternary, silicified sandstone and conglomerate boulders set among wind-blown sands and clay pans as shown on the surface geology map on Figure 32 (extracted from 1:250,000 scale Enngonia Surface Geology sheet (Johnson & Menzies, 1965). It is underlain by the Rolling Downs Group. There is confirmation of the Hooray Sandstone occurrence in this area. Borehole logs for the two closest registered bores (GW004725 and GW025423) suggest the GAB units in this area are dominated by hard shale units, with only occasional and typically thin (less than 5 m thick) sandstones encountered to depths close to 500 m.

GABWRA's 3D visualisation (Geoscience Australia, 2013) also suggests the thickness of the Rolling Downs Group beneath this spring complex is between about 500 and 600 m. The Hooray Sandstone may therefore be present beneath these springs, the registered bores having been terminated too shallow to penetrate the formation. The southern margin of the GAB is located 90 km south of Gooroomero.

If the Hutton Sandstone is present beneath this spring, the regional data suggests it would be thinning and ultimately terminating on the eastern rise of the Cunnamulla Shelf about 20 to 30 km west and southwest of the spring.

There are no known faults within 25 km of this spring complex.

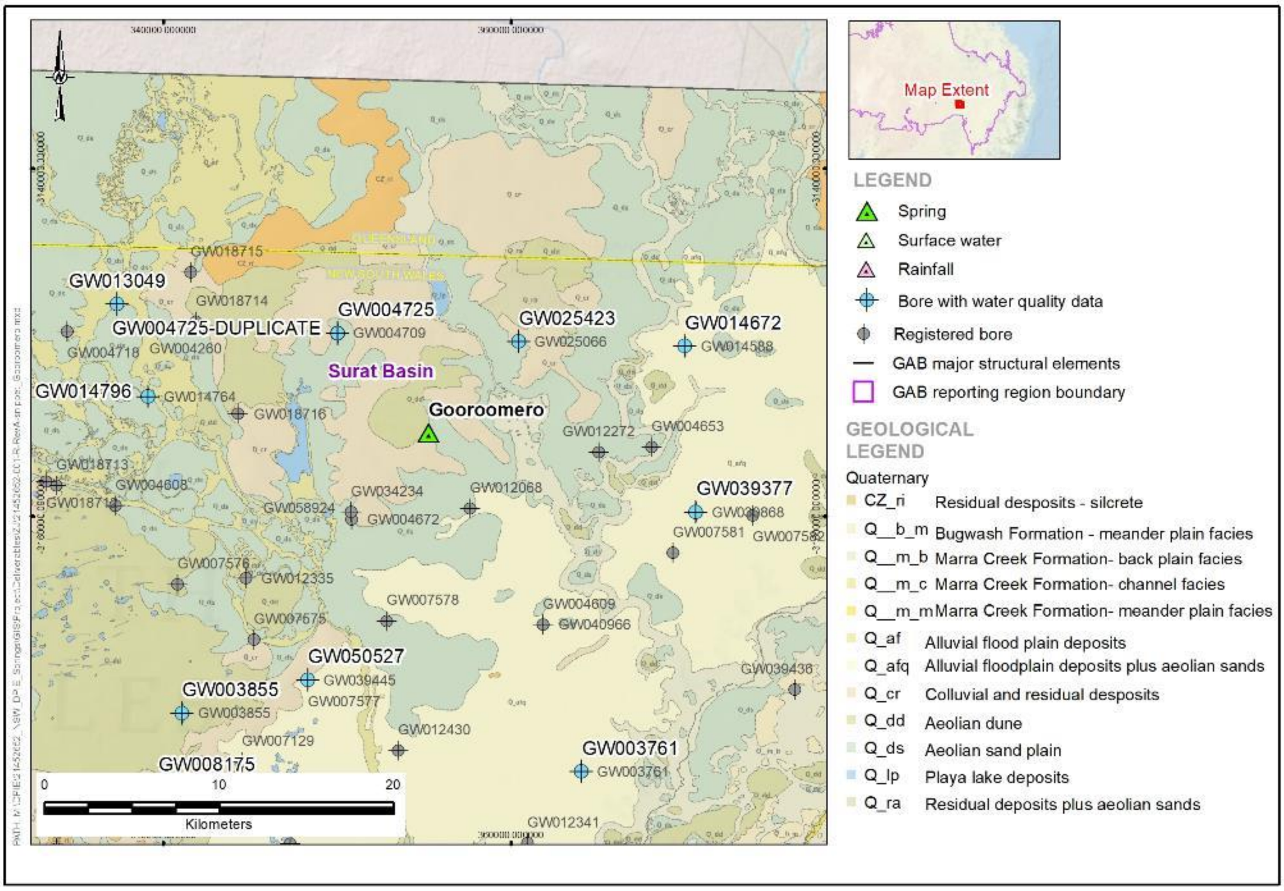

Figure 32: Gooroomero Location Plan and Surface Geology

5.1.5.3 GAB groundwater levels/artesian conditions

Based on the information provided by DPIE, information about artesian condition in 2019 are available for ten bores within 20 km of the spring formation. These are shown on Figure 32. These were all artesian when they were drilled between 1941 and 1987. All the bores, except GW003855 and GW008175 were noted as artesian in 2019.

5.1.5.4 Hydrogeochemistry

One water sample was reportedly collected at Gooroomero in October 2018 and was analysed for major ions, metals and isotopes (^{2}H, ^{18}O, ^{87}Sr, ^{36}Cl, ^{14}C and ^{2}H). The exact location of where this sample was collected was not provided.

5.1.5.4.1 Water quality

Water from the spring is characterised by neutral pH (7.5) and low salinity (520 mg/L). The water is of sodium-bicarbonate type (see piper plot on Figure 33) which is similar to GAB groundwater bores.

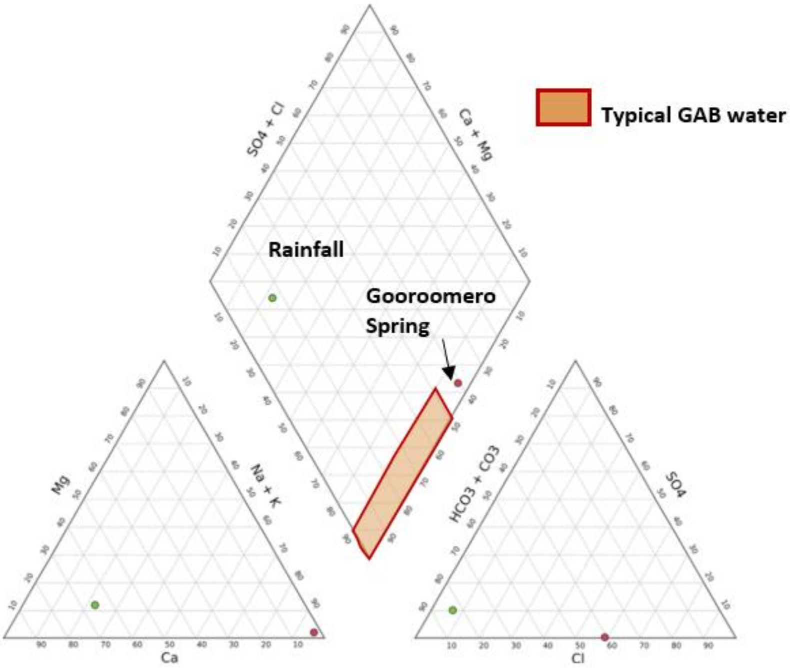

Figure 33: Piper plot Gooroomero Spring

Most of the concentrations in dissolved metals are under or close to the detection except for aluminium (20 µg/L), iron (1200 µg/L), lithium (9 µg/L), manganese (83 µg/L), strontium (27 µg/L) and zinc (10 µg/L).

Similarly, most of the concentrations in total metals are under or close to the detection except for aluminium (50 µg/L), iron (2000 mg/L), lithium (8 µg/L), lead (4 µg/L) dissolved manganese (83 µg/L), dissolved strontium (27 µg/L) and dissolved zinc (10 µg/L).

5.1.5.4.2 Isotope information

Based on the isotope analysis presented in Section 4.5 the following main outcomes are relevant for the conceptualisation of this spring:

- the isotopic signature of ^{2}H and ^{18}O plots below the LMWL, suggesting the water from the vent is subject to evaporative processes when compared to the LMWL. Its isotopic signature is similar to the rainfall sample collected during the same round (rainfall sample is of unknown origin). The sample does not plot close to the groundwater bores.
- The tritium activity is 0.78 in October 2018 grouping with the samples with low tritium activity but not as low as the groundwater bore monitoring the GAB (see 4.5.2.1). Deep groundwater in the GAB has zero tritium activity.
- The pMC values is 102% representative of modern water. Deep groundwater in the GAB expected to have a pMC close to zero.
- The ^{36}Cl/Cl^{-} ratio is 196x10^{-15}. This is sixteen times higher than the ^{36}Cl/Cl^{-} ratio of the closest groundwater bores located 50 km to the southwest and four times higher than Hooray Sandstone in that area (Map 45 of Ransley et al, 2015) also suggesting a modern water signature.

5.1.5.5 Machine Learning outcomes

According to the PCA analysis this spring is in a transitional location. It has a low to moderate likelihood of some connection between the aquifer and that spring. Figure 34 shows its location in the PCA analysis.

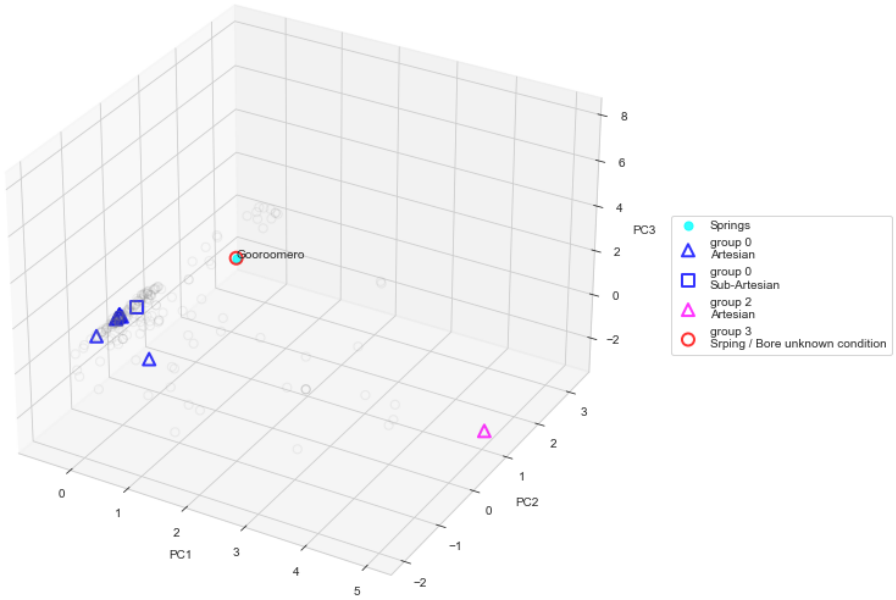

Figure 34: Relative location of spring Gooroomero and closest bores in 3 dimensional PCA plot.

5.1.5.6 Conceptualisation and typology of Gooroomero Spring

The main components of the information reviewed to support the conceptualisation of the spring at Gooroomero are summarized below:

- No current field observations were provided for Gooroomero Spring. Observations from other sources in 2014 indicate that no spring was evident at that location but that shallow groundwater is observed when digging. As noted, one sample was reportedly collected from Gooroomero by DPIE, but it is unclear where or how it was collected.
- The spring's location is in an area of Quaternary sandstone. The Rolling Downs Formation is expected to be thick at this location and there are no known faults nearby.
- The composition of major ions is similar to that of the bores installed in the GAB.
- The radioactive isotope analysis would suggest the GAB is not the only water contributing to this sample.
- Machine learning outcomes suggest that the spring water quality is highly compatible with the local bores suggesting a high likelihood of connection between the aquifer tapped by those bores and that spring.

Gooroomero Spring cannot confidently be regarded as being associated with the GAB unless it is found again and further evaluation made. The sodium bicarbonate chemistry and low salinity are in part consistent with a GAB source. Conversely, the isotopic signature would point to a 'modern' water source. It is likely that the spring is associated with Quaternary sediments. This is consistent with the field observations made by others onsite who identified shallow groundwater when trying to find the spring.

5.1.6 Lila Spring

5.1.6.1 General Setting and Summary of Field Observation

Lila Spring is a complex located 60 km northeast of Bourke, within 30 km of Native Dog Spring, Thully Spring and Colless Spring.

No field observations were made available for this spring. Two samples were collected, one in October 2018 and one in July 2019 but it is understood that they were collected from two different vents, the October 2018 sample was collected from Vent 1006.3 and the July 2019 sample was collected from Vent 1006.4. The total number of vents was not included in the data made available for this study.

Previous investigations carried out in 2014 (Commonwealth of Australia, 2014) noted that the spring was inactive at the time and had large, scalded areas created by groundwater precipitates. “Inactive” might simply mean that evaporation was exceeding the discharge rate and vents were covered at that time, for example with vegetation.

5.1.6.2 Ecology

The ecology survey found some aquatic plants and grasses.

DPIE does not provide an ecological value for the spring.

5.1.6.3 Geological and Hydrogeological setting

Lila Spring complex occurs amongst Quaternary black soils, silts and sands as shown on the Enngonia 1:250,000 scale geological map sheet (Johnson & Menzies, 1965) included on Figure 35. The Rolling Downs Group, which is the dominant GAB surface formation throughout much of this area, outcrops between about 1 and 3 km in all directions around these springs. The southern margin of the GAB is located 40 km south of Lila Spring.

The surface geology map (Johnson & Menzies, 1965) indicate the Hooray Sandstone is not present beneath this Spring. This is supported by the lithology and water-bearing zones identified on the borehole logs for three of the four bores drilled within 10 km of this spring complex. These bores report fractured shales with no notable occurrences of water-bearing sandstones reported, at least to the depths drilled (a maximum of 231 m).

GABWRA’s 3D visualisation (Geoscience Australia, 2013) of the GAB contradicts the maps referred to above, instead suggesting that the Hooray Sandstone may be thin but present, pinching out to the west as the basement rocks of the Cunnamulla Shelf rise. Two (unnamed) nearby faults in the basement Cunnamulla Shelf beneath the GAB (Ransley et al., 2015) run 7 km northeast and approximately 8 km northwest. Although there is no evidence of these faults being present in the GAB, Rade (1954) suggests spring complexes of the Bourke Supergroup may outcrop due to the interaction of regional groundwater flow paths with faulting, many of which have similar orientations as those noted above in the Cunnamulla Shelf basement rocks.

Nearby duricrust formations associated with near-surface weathered zones of the Rolling Downs Group; may cause vertical migration of pressurized groundwater from the Hooray or Hutton Sandstone via regional faulting into the Rolling Downs Group.

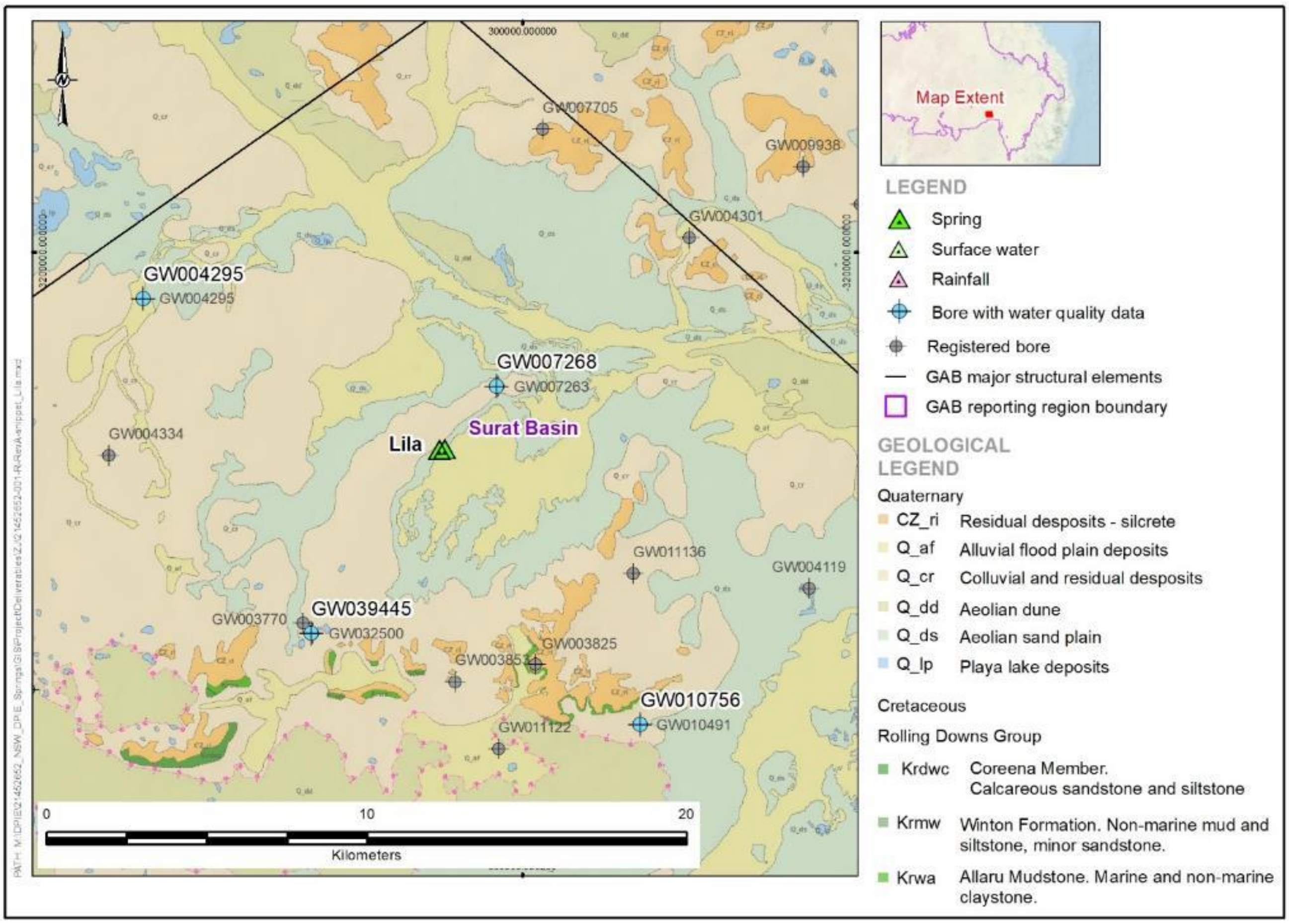

Figure 35: Lila location plan surface geology (Johnson &Menzies, 1965)

5.1.6.4 GAB groundwater levels/artesian conditions

Based on the information provided by DPIE, information about artesian condition in 2019 are available for four bores within 20 km of the spring. These are shown on Figure 35, based on the GABWRA 3D model (Geoscience Australia, 2013), GW004295 is understood to be monitoring the Hooray Sandstone while GW007268, GW010756 and GW039445 are monitoring the Rolling Downs Group (it is possible, but not defined to our knowledge, that water chemistry of permeable zones within Rolling Downs material might differ from Hooray Sandstone except near the base of the aquitard). These were all artesian when they were drilled between 1884 and 1990. All the bores, except GW007268 were artesian in 2019. GW007268 is closest and located approximately 5 km northeast of the spring.

5.1.6.5 Hydrogeochemistry

Two samples were collected in total from Lila, one in October 2018 and one in July 2019. These were collected from two different vents (1006.3 and 1006.4) although no descriptions of the vents were provided. Both samples were analysed for major ions, metals and stable isotopes (^{2}H, ^{18}O and ^{87}Sr) and only the October 2018 sample from Vent 1006.3 was analysed for radioactive isotopes (^{36}Cl, ^{14}C and ^{3}H).

5.1.6.5.1 Water quality

The pH of the October 2018 sample is near-neutral (6.6) while the July 2019 sample is slightly acidic (5.6). Both water samples have low salinity (24 mg/L). The water is of sodium/potassium-bicarbonate type (see Piper plot on Figure 36).

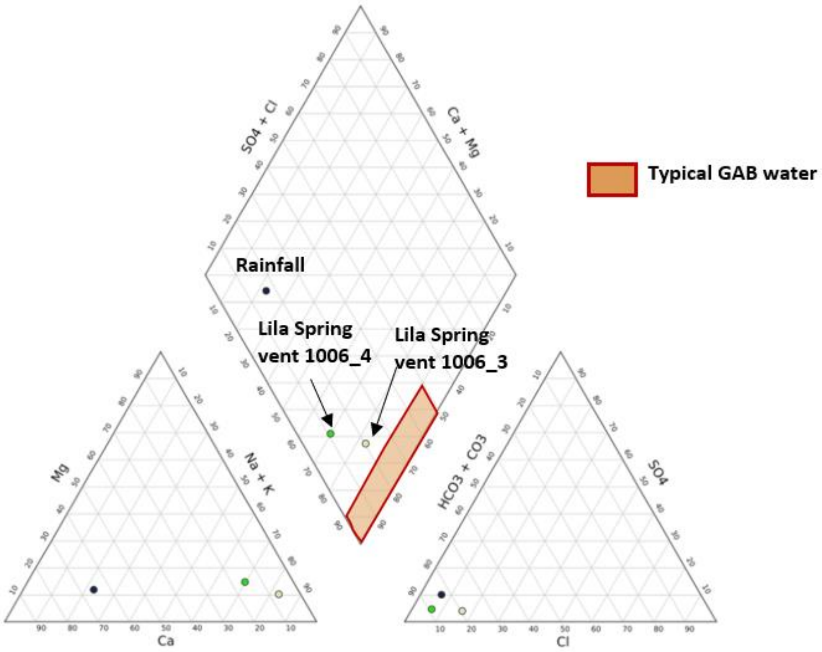

Figure 36: Piper plot Lila Spring

Both samples have similar signature in minor elements with small concentrations in dissolved and total copper, lithium, manganese, nickel, strontium and zinc.

The two samples present the following main differences:

- The July 2019 sample presents a high concentration in dissolved aluminium (1200 µg/L) while the October 2018 sample did not detect any dissolved aluminium. However, both samples have similar concentration in total aluminuim.
- The October 2018 sample has a higher concentration in total iron (2700 mg/L) than the July 2019 sample (680 mg/L) although the concentration in dissolved iron is higher in the July 2019 sample (540 µg/L) compared to the October 2018 sample (120 µg/L).
- In addition the March 2018 sample presented a small concentration in arsenic (dissoled and total), lead (total), nickel (total) that was not detected in the July 2019 sample.

These differences could be due to differences in water source but also to seasonal variability and different times of sampling relative to a major episodic rainfall event.

5.1.6.5.2 Isotope information

Based on the isotope analyses presented in Section 4.5, the following main outcomes are relevant for the conceptualisation of this spring:

- the isotopic signature of the ratios of hydrogen (δ^2H) and oxygen (δ^{18}O) vary between March 2018 and July 2019, suggesting seasonal variation or a difference in water source between the two vents. The water sample from March 2018 plot on the LMWL while the July 2019 plots below the line suggesting the vent water is subject to evaporative processes when compared to the LMWL.
- the tritium activity measured in October 2018 was 4.67 TU and is grouped with the cluster described as modern. This is higher than the average value measured in Australian precipitation in that area between 2005 and 2011 and suggests that water from this spring is surface water or shallow groundwater.

- the pMC of the October 2018 sample is 100% suggesting modern water.
- The $^{36}Cl/Cl^{-}$ ratio is 192x10^{-15}. This is sixteen times higher than the ^{36}Cl ratio for the groundwater bores in that area and over four times higher than Hooray Sandstone in that area (Map 45 of Ransley et al., 2015), suggesting modern water.

5.1.6.6 Machine Learning outcomes

The spring shows no water quality compatibility with the local bores. This analysis suggests the spring is sourced from aquifers or surface water that is not being sampled by the local bores. Figure 35 shows its location in the PCA analysis.

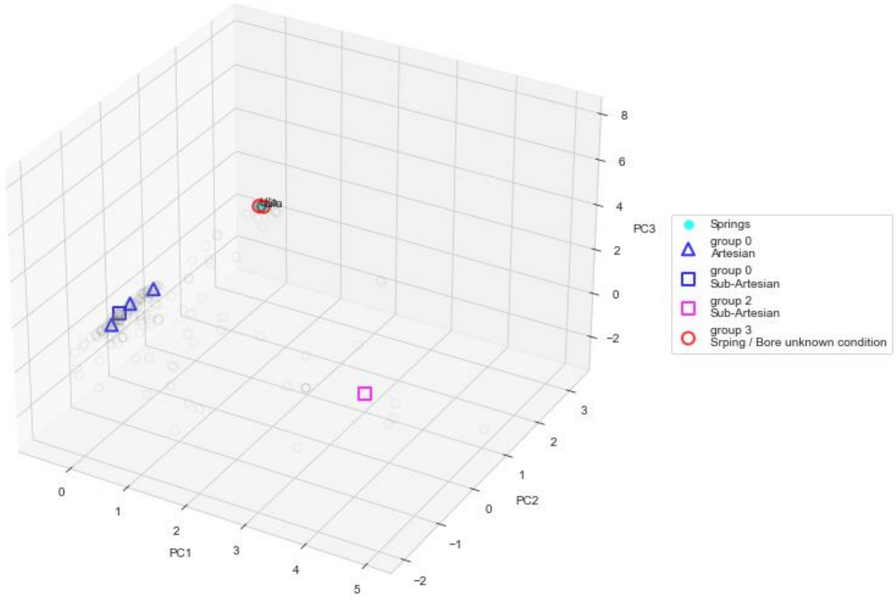

Figure 37: Relative location of Lila Spring and closest bores in 3 dimensional PCA plot.

5.1.6.7 Conceptualisation and typology of Lila Spring

The main components of the information reviewed to support the conceptualisation of the spring at Lila are summarized below:

- No current field observations were provided for Lila Spring. Observations from others in 2014 indicate that no spring is evident at that location but shallow groundwater is observed when digging. Despite the failure to find the spring, two samples have been collected from Lila reportedly from two different vents, but it is unclear where the vents are, what they look like and how the samples were collected.
- The geological review of the area indicates that at 231 m depth there is no evidence of Hooray Sandstone, although artesian flows are clearly present. There are no knowns faults close to Lila Spring.
- The composition in major ion is partly similar to GAB bores, but with low pH and unusually low salinity.
- The isotopic signature from vent 1006.4 suggests the water source for this vent is modern, in particular the tritium activity would suggest the water source to be surface water.

Lila spring cannot be regarded with any confidence as being associated with the GAB on the basis of the information provided.

The isotopic signature from Vent 1006.4. is consistent with a ‘modern’ water source, associated with Quaternary sediments and maybe a subtle topographic low zone. This interpretation is consistent with the field observations made by others onsite who identified shallow groundwater associated with the area.

5.1.7 Mulyeo Spring

5.1.7.1 General setting and summary of field observations

Mulyeo spring is located 150 km southwest of Bourke, on a clay pan, in a low-lying part of a generally topographically flat landscape. It is recorded as being an inactive mud spring which is the site of two flowing defunct, leaky artisan bores (understood to be GW096004 and GW004267). These bores have been used to water a dam used for stock as shown on Figure 38. Water samples were collected from these two bores in July 2019.

Based on DPIE’s field observations, there is no evidence of a spring at all.

Figure 38: Aerial photograph of Mulyeo displaying the spring expression extent (DPIE, 2020b)

5.1.7.2 Ecology

The ecology survey carried out by DPIE concluded that the spring has minimal native vegetation and low GDE ecological value (DPIE 2000).

5.1.7.3 Geological and Hydrogeological setting

The 1:250,000 scale surface geology extracted from the Louth map (Loudon et al, 1965) is shown on Figure 39. It shows Mulyeo Spring outcropping amongst Quaternary deposits dominated by sands, silts and clays. The only mapped GAB unit near these springs is the Rolling Downs Group about 18 km to the northwest. Quaternary silicified sandstone, quartzite, shale and conglomerate which unconformably overlie the Rolling Downs Group are present 7 km east of these springs, whilst outcrops of Devonian-aged bedrock, dominated by sandstones and conglomerates of the Mulga Downs Group, outcrop 18 km to the southeast and 22 km south of the springs. The southern margin of the GAB is located 4 km south of the bores at Mulyeo.

The Rolling Downs Group thins from north to south as the Palaeozoic and Devonian basement rocks rise to the surface along the southern boundary of the GAB. Mulyeo Spring itself is thought to be about 3 km or less from the edge of the GAB and possibly underlain by ‘thin’ occurrences of the Rolling Downs Group. Given the geological setting, the Hooray Sandstone is not expected to be present beneath or in the vicinity of these springs, rather aquifers associated with the Rollings Downs Group, possibly the Griman Creek Formation and Wallumbilla Formation.

GABWRA’s 3D visualisation (Geoscience Australia, 2013) of the GAB suggests the Hooray Sandstone and underlying Injune Creek Formation outcrop along the edge of the GAB in the vicinity of these springs.

The borehole summary for GW096004 identify shale and sandstone until 85 m depth, the water bearing unit being a sandstone 14 m deep overlain by 45 m thick shale. Differentiating between possible GAB units and those of the underlying basement units in this bore – should they have been encountered – is not straightforward though given the generic geological descriptions presented on the worksheets.

The spring complex is also situated roughly midway between the alignment of two regionally-significant faults in the underlying basement rocks beneath the GAB units, approximately 12 km to the east and west and oriented roughly north – south. There is no evidence however that these faults are observed in the GAB formations.

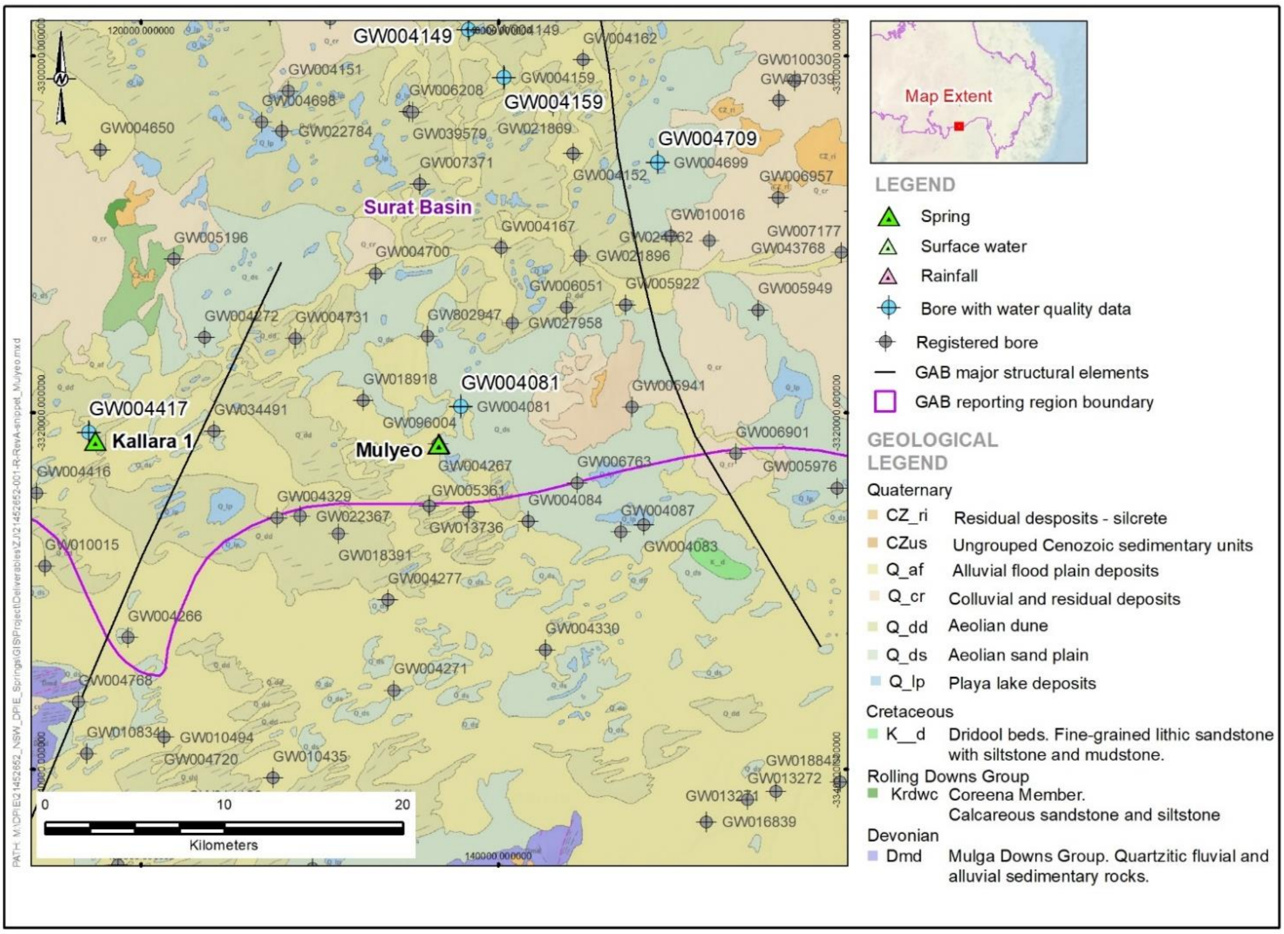

Figure 39: Mulyeo location plan and surface geology (Loudon et al, 1965)

5.1.7.4 GAB groundwater levels/artesian conditions

The two bores, GW096004 and GW004267 from which the samples were collected are installed to a depth of 85 and 76 m and are under artesian condition. As described in Section 5.1.7.3, it unclear what formation these bores are monitoring (i.e. a sandstone or fracture zone within the Rolling Downs Group or the Hooray Sandstone)

GW004081, located 2.5 km northeast of the spring and understood to be monitoring the GAB(location on Figure 39). This bore was artesian when it was installed in 1914 and was also under artesian condition in 2019.

5.1.7.5 Hydrogeochemistry

Two samples were collected from Mulyeo in total, both in July 2019. These were collected from two separate leaking bores (see description in field observations). Both samples were analysed for major ions, metals and isotopes (^{2}H, ^{18}O, ^{87}Sr, ^{36}Cl, ^{14}C and ^{3}H).

5.1.7.5.1 Water quality

The pH of both samples is neutral (average of 7.9). Both water samples have low salinity (average of 960 mg/L). The water pf both sample is of sodium/potassium-bicarbonate type (see Piper plot on Figure 5).

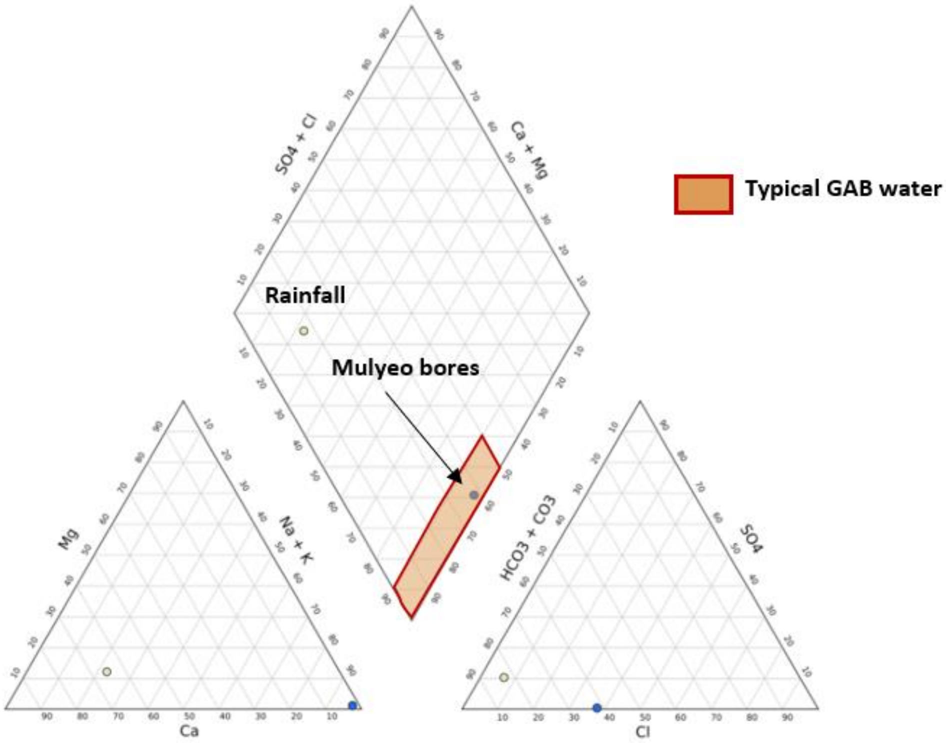

Figure 40: Piper plot Mulyeo samples

Both samples have similar signature in minor elements which includes with similar concentrations in:

- dissolved and total iron (average of 240 µg/L and 345 µg/L respectively),
- lithium (average of 29 µg/L and 29 µg/L respectively),
- strontium (average of 230 µg/L and 2305 µg/L respectively) and
- manganese (total only with an average of 5 µg/L).

The sample called 1005_2 (it is not clear from which bore) presents small concentration in dissolved and total zinc (2 µg/L and 15 µg/L), total aluminium (1200 µg/L) and total copper (7 µg/L) which was not detected in the other sample (from the other bore).

5.1.7.5.2 Isotope information

Based on the isotope analysis presented in Section 4.5 the following main outcomes are relevant for the conceptualisation of this spring:

- The ratios of ^{2}H and ^{18}O indicate that both Mulyeo samples have similar isotopic signature. They also have similar signature to the groundwater bores sampled in March 2018 and to Bingewilpa Spring (see Figure 6 and Figure 8).
- The tritium ratio measured in July 2019 was below the detection limit for one sample and slightly higher than the detection limit for the other sample. This is consistent with water from the GAB.
- The pMC values vary between 0.21 to 0.26%, suggesting this water sample is mature and is grouped with the GAB groundwater bores (see Section 4.5.2.2)
- The $^{36}Cl/Cl^{-}$ ratio vary between 17.0×10^{-15} to 19.8×10^{-15}. This is within the range of variation of ^{36}Cl ratio for the groundwater bores in that area and in the Hooray Sandstone in that area (Map 45 of Ransley et al., 2015).

5.1.7.6 Machine Learning outcomes

The individual spring water quality is highly compatible with the local bores suggesting a high likelihood of connection between the aquifer tapped by those bores and that spring. Figure 41 shows its location in the PCA analysis.

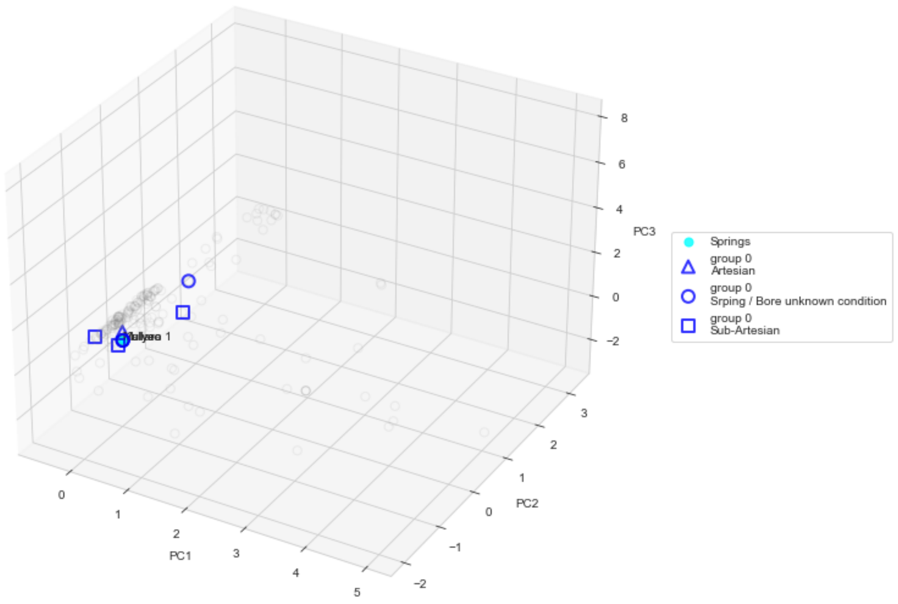

Figure 41: Relative location of Mulyeo and closest bores in 3 dimensional PCA plot.

5.1.7.7 Conceptualisation and typology

The main components of the information reviewed to support the conceptualisation of the Spring at Mulyeo are summarized below:

- The samples were collected from the two free-flowing artesian bores onsite (understood to be GW096004 and GW004267).
- The geological review of the area indicates that the “spring” is located in the margin of the GAB basin. The spring is located on Quaternary deposits but understood to be underlain by the Rolling Downs formation
- The composition in major ion is similar GAB bores.

- The isotopic signature from both bores is consistent with bores in the GAB and the radioactive isotope signature is consistent with GAB formations.

The water source from Mulyeo Spring is likely from a GAB aquifer by bore discharge to the wetland. All the information suggests that this is not a spring at all. There is not sufficient information to ascertain whether there is a discharge separate from the bores.

5.1.8 Native Dog Spring

5.1.8.1 General setting and summary of field observations

Native Dog spring complex is located 60 km north of Bourke.

During their site visit in July 2019, DPIE indicated that all Native Dog vents were inactive but that a water sample was collected from a vent with water shown on the photograph on Figure 42 (vent 960.1). No evidence of bubbling was noted, so the sample may well be remnant surface water from the last rainstorm.

Remnant springs were observed though that were lined with highly weathered calcareous white consolidated sediments. The vent is situated on a clay pan, in a low-lying part of the generally topographically flat landscape.

Figure 42: Depression filled with surface water near Native Dog (DPIE, 2020b)

5.1.8.2 Ecology

DPIE indicated that the ecology survey found only some aquatic plants and grasses (DPIE, 2020b). It is inferred from this that this spring has a low ecological value.

5.1.8.3 Geological and Hydrogeological setting

The geology, extracted from the Enngonia 1:250,000 scale geological map sheet (Johnson & Menzies, 1965) is shown on Figure 43. Native Dog Spring is observed to outcrop amongst Quaternary wind-blown sands and clay pans. The Rolling Downs Group outcrops a few hundred metres to the north, east and south of the complex.

GAB units in the vicinity of these springs comprise solely formations within the Rolling Downs Group (Johnson & Menzies, 1965) and are likely to include Coreena and Doncaster Members of the Wallumbia Formation and the Wyandra Sandstone of the Cadna-owie Formation, the lateral equivalent of the Hooray Sandstone, although it is not shown as being present beneath these springs. The southern edge of the GAB is about 50 km south and the GAB sediments are shown to thin and pinch out as the basement rocks of the Lightening Ridge Shelf rise and outcrop. The GABWRA 3D model (Geoscience, 2013) suggests that the Hooray

Sandstone may occur as thin and possibly discontinuous sandstone beds in this area, possibly ‘pinching out’ further to the west of this complex as the basement rocks of the Cunnamulla Shelf rise to equivalent depths.

More recent work by IESC (Commonwealth of Australia, 2014) suggests the Hooray Sandstone may occur in the GAB units beneath these springs at depths between 300 and 500 m. The borehole summary for a registered borehole 9 km to the north (GW011265) indicates a sandstone water supply about 50 m thick was encountered between about 286 and 335 m depth.

IESC (Commonwealth of Australia, 2014) note a basement high 15 km south, caused by a Palaeozoic granite intrusion, stating that it ‘*follows the line of the Sweetwater, Yarrongany, Kullyana and Native Dog spring complexes*’ which it considers may ‘*indicate an unmapped lineament, fault or other structural feature related to the shallow basement from which the three spring complexes may get artesian groundwater’*.

Two (unnamed) faults run 6 km southeast and 24 km northeast of the Soring in the basement rocks. There is no evidence that these faults are present in the GAB sediments however. IESC (Commonwealth of Australia, 2014) notes springs in the Yantabulla area occur along the eastern margin of a granitic basement horst, with small faults connecting Kullyna – Native Dog and Coonbilly–Youngerina springs.

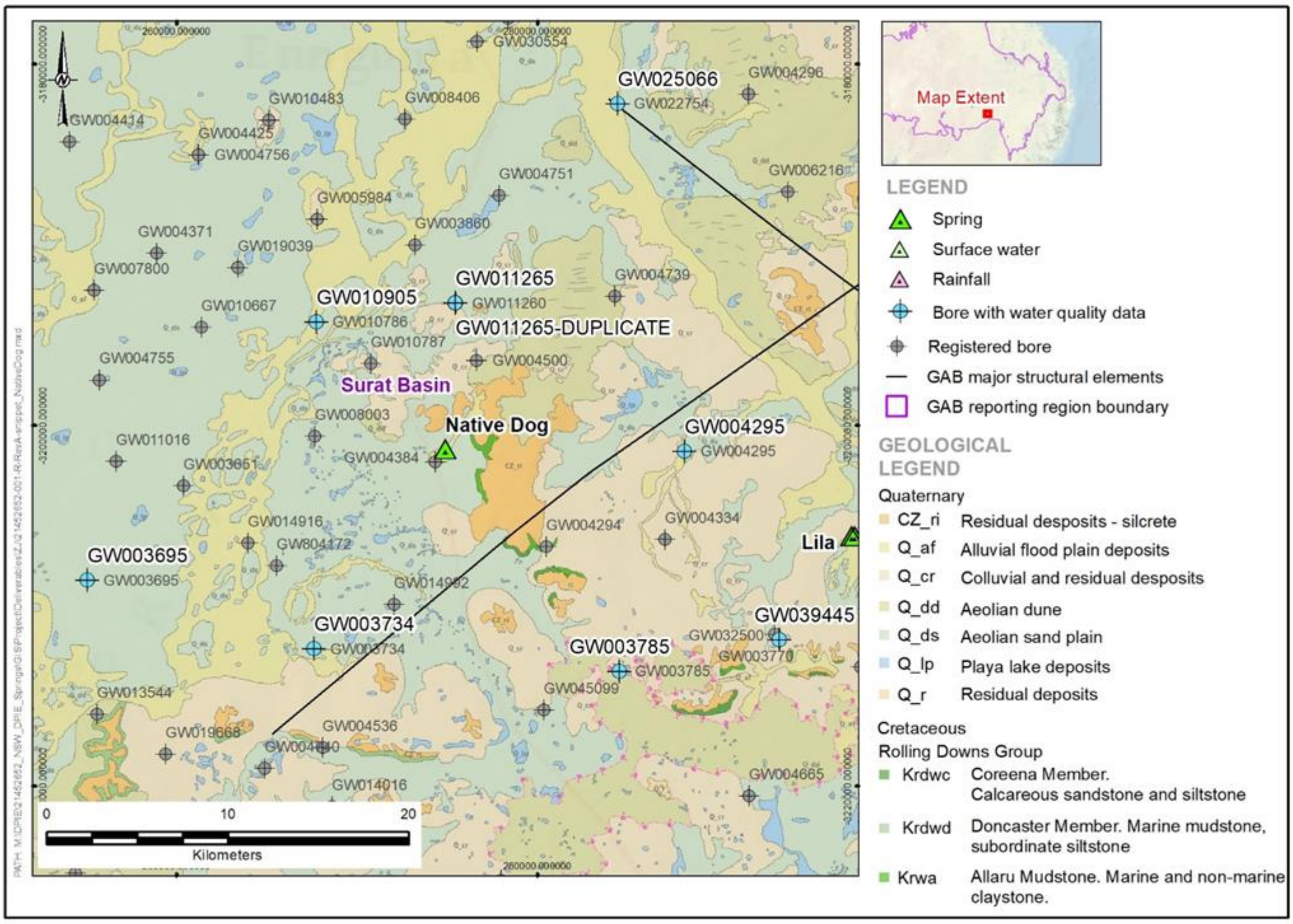

Figure 43: Native Dog location plan and surface geology (Johnson & Menzies, 1965)

5.1.8.4 GAB groundwater levels/artesian conditions

Registered bores GW003785, GW001654, GW004295, GW010905, GW011265 are all located within 20 km of the spring (location on Figure 43). These bores were all artesian when they were installed between 1884 and 1955. Based on DPIE’s records, only GW004295 and GW010905 were artesian in 2019.

5.1.8.5 Hydrogeochemistry

One sample was collected from the active vent at Native Dog in July 2019 and was analysed for major ions, metals and isotopes (^{2}H, ^{18}O, ^{87}Sr, ^{36}Cl, ^{14}C and ^{3}H).

5.1.8.5.1 Water quality

The pH of the water is neutral pH (7. 4) and the salinity is low (160 mg/L). The major ion classification is sodium/potassium – chloride type. The major ion composition of the sample from Native Dog Spring is slightly different to that of the GAB bores by having a slightly higher composition of calcium (see Piper plot on Figure 44) and being a chloride-type water not a bicarbonate type.

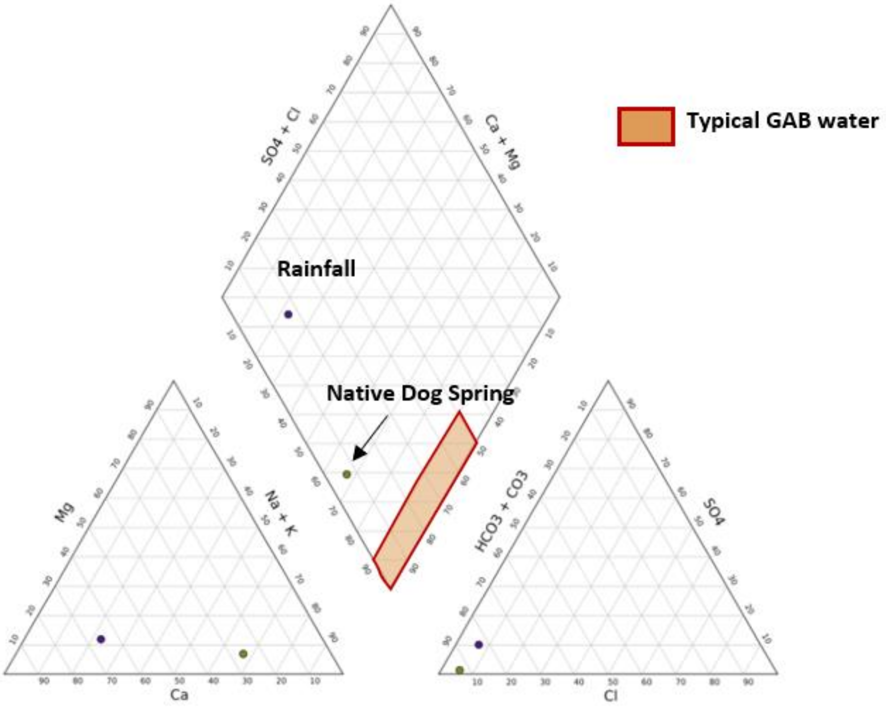

Figure 44: Piper plot Native Dog Spring

Most of the measured metals and metalloids are under or close to the detection except for dissolved aluminium and dissolved iron with concentraiton of 5.1 mg/L and 3.4 µg/L respectively.

5.1.8.5.2 Isotope information

Based on the isotope analysis presented in Section 4.5 the following main outcomes are relevant for the conceptualisation of this spring:

- the isotopic signature of the ratios of ^{2}H and ^{18}O plots close to the Cobar LMWL suggesting minimum evaporative influence. The sample does not plot close to the cluster of groundwater bores with depleted ^{2}H and ^{18}O.
- The tritium ratio of 1.37 T.U. is relatively high and suggests the water is modern, this is not consistent with water from GAB (where tritium is expected to be inexistent)
- The pMC value of 100% suggesting modern water.
- The ^{36}Cl/Cl^{-} ratio is 190x10$^{-15.}$ This is six times higher than the ^{36}Cl ratio for the groundwater bores (GW004259 and GW004339) in that area and four times higher than Hooray Sandstone in that area (Map 45 of Ransley et al., 2015), suggesting modern water.

5.1.8.6 *Machine Learning outcomes*

According to the PCA analysis this spring is in a transitional location. It has a low to moderate likelihood of some connection between the aquifer and that spring. Figure 45 shows its location in the PCA analysis.

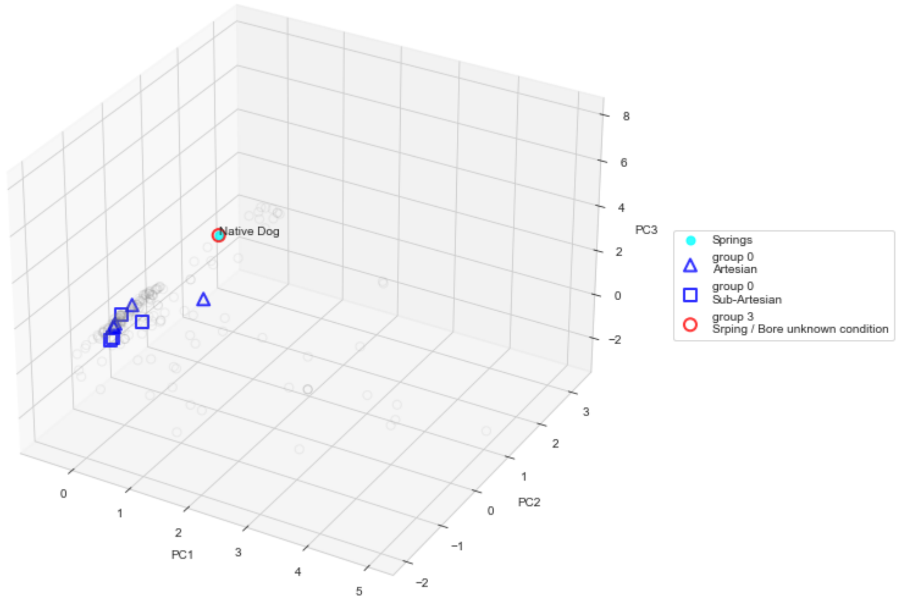

Figure 45: Relative location of Native Dog Spring and closest bores in 3 dimensional PCA plot.

5.1.8.7 *Conceptualisation and typology of Native Dog Spring*

The main components of the information reviewed to support the conceptualisation of the spring at Native Dog are summarized below:

- The vents are all understood to be inactive (DPIE, 2020b). However, a sample was collected from one vent with water. Remnant mounds are observed onsite suggesting the presence of springs in the past.
- The geological review suggests the Hooray Sandstone may be in the GAB units beneath these springs at depths between 300 and 500 m. In addition, two faults run 6 km southeast and 24 km northeast in the basement Palaeozoic rocks in the area. However, there is no evidence these faults are present in the GAB sediments.
- The water chemistry signature of major ion is different to that of the bores installed in the GAB.
- The radioactive isotope analysis indicates the sample collected from Native Dog Spring has a distinctive isotopic signature, different from the bores monitoring the Hooray sandstone aquifer in the GAB but more consistent with meteoric water, runoff from recent rainfall or shallow groundwater.
- The outcome of the machine learning process suggests that Native Dog Spring has a low to moderate likelihood of some connection between the aquifer and that spring.

Based on the above, it is unlikely that the water sample collected from the vent at Native Dog is from the GAB but rather partly evaporated runoff from a recent rainfall event that has drained into the depression and flooded the vent.

The remnant mounds suggest that there may have been GAB springs in the past. The local depressurization evidence by the loss of artesian condition from the neighbouring bores may have caused the spring to dry up.

5.1.9 Old Gerara Spring

5.1.9.1 General and summary of field observations

Old Gerara spring is located in the Ledknapper Nature Reserve, 100 km northeast of Bourke. The main vent (Vent 965) has been excavated 3 to 4 m to create a deep channel (see photograph on Figure 46). DPIE observed sandstone on the banks of the excavations to build a wall around the main vent, creating a pond. A second vent was also observed to be dry and infilled with silt from the main vent.

Water was observed to be bubbling from the active vent, with an estimated discharge rate of 200 L/hour (DPIE, 2020b).

One sample was collected form this spring in March 2018.

Figure 46: a) Old Gerara Spring showing long excavated pond and metal bar across channel, and b) aerial view of spring site (DPIE, 2020b)

DPIE identified a defunct artesian bore close to Old Gerara Spring called Gurera bore (identified as GW004259). Water flowing out of this bore was observed to be ponding nearby as shown on the photograph on Figure 47. Based on WaterNSW's online portal, this bore was drilled to 396 m but no lithological description is available.

One water sample was also collected from this bore.

Figure 47: a) head of the defunct "Gurera bore", and b) aerial view of extent of water body from defunct bore (DPIE, 2020b)

5.1.9.2 Ecology

Groundwater dependent flora at this site consisted of Alternanthera angustifolia. No commonwealth (EPBC Act 1999) or state (BC Act 2016) listed threatened plant species were present.

Groundwater dependent fauna at the site was restricted to macroinvertebrates as no fish were present. In total, seven different taxa were recorded. The most abundant were from the Corixidae genus Agraptocorixa.

Compared to other springs sampled, Old Gerara spring had low diversity (13% of all taxa sampled) and abundance. No commonwealth (EPBC Act 1999) or state (BC Act 2016 & Fisheries Management Act 1994) listed threatened species were present. Based on the collected data at the time of sampling, this spring is considered to have low ecological value (DPIE, 2020b).

The springs have significant Aboriginal cultural heritage and western cultural heritage.

5.1.9.3 Geological and Hydrogeological setting

Old Gerara Spring occurs amongst Quaternary wind-blown sands and clay pans as shown on map on Figure 48 which includes the surface geology from 1:250,000 map for Engonnia (Johnson & Menzies 1965). These Quarternary sediments are prominent for several kilometres in all directions. The Rolling Downs Group outcrops about 2 km to the east and south of these springs. A notable outlier of Tertiary silicified sandstone, quartzite, shale and conglomerate, unconformably overlying the Rolling Downs Group, is located about 1 km to the south of the springs. The southern margin of the GAB is located 70 km south of Old Gerara Spring.

The Hooray Sandstone and its equivalents are not known to be present beneath these springs. This is supported somewhat by the depth of water-bearing zones descriptions on the borehole summary for three of the four bores drilled within 10 km of this spring complex, each of which obtained groundwater supplies in fractured shales.

GABWRA’s 3D visualisation (Geoscience Australia, 2013) of the GAB suggests the Hooray Sandstone may be present beneath these springs, at less than 150 m thick across and overlying basement of the Cunnamulla Shelf which rises to equivalent depths along the western margins of the Coonamble Embayment and Surat Basin. The thickness of the Rolling Downs Group in this area is typically between 250 and 300 m. It also indicates the Hutton Sandstone may be present beneath this spring complex thinning and ultimately terminating on the eastern rise of the Lightening Ridge Shelf.

Regardless of the presence or absence of the Hooray Sandstone, GAB water does occur beneath the springs, demonstrated by the nearby Gurera Bore.

The Old Gerara springs are located about 1.5 km south of the mapped surface alignment of a fault in the basement Cunnamulla Shelf beneath the GAB (Ransley et al., 2015). There is no evidence this fault is present in the GAB sediments at Old Gerara Spring. Rade (1954) suggests spring complexes of the Bourke Supergroup may outcrop due to the interaction of regional groundwater flow paths with such faulting. It is noted Gurera bore (GW004259) is located along the inferred surface alignment of this fault. This bore reportedly encountered water-bearing zones at depths of 21, 189 and 396 m depth, however descriptions of these are not included in the borehole summary.

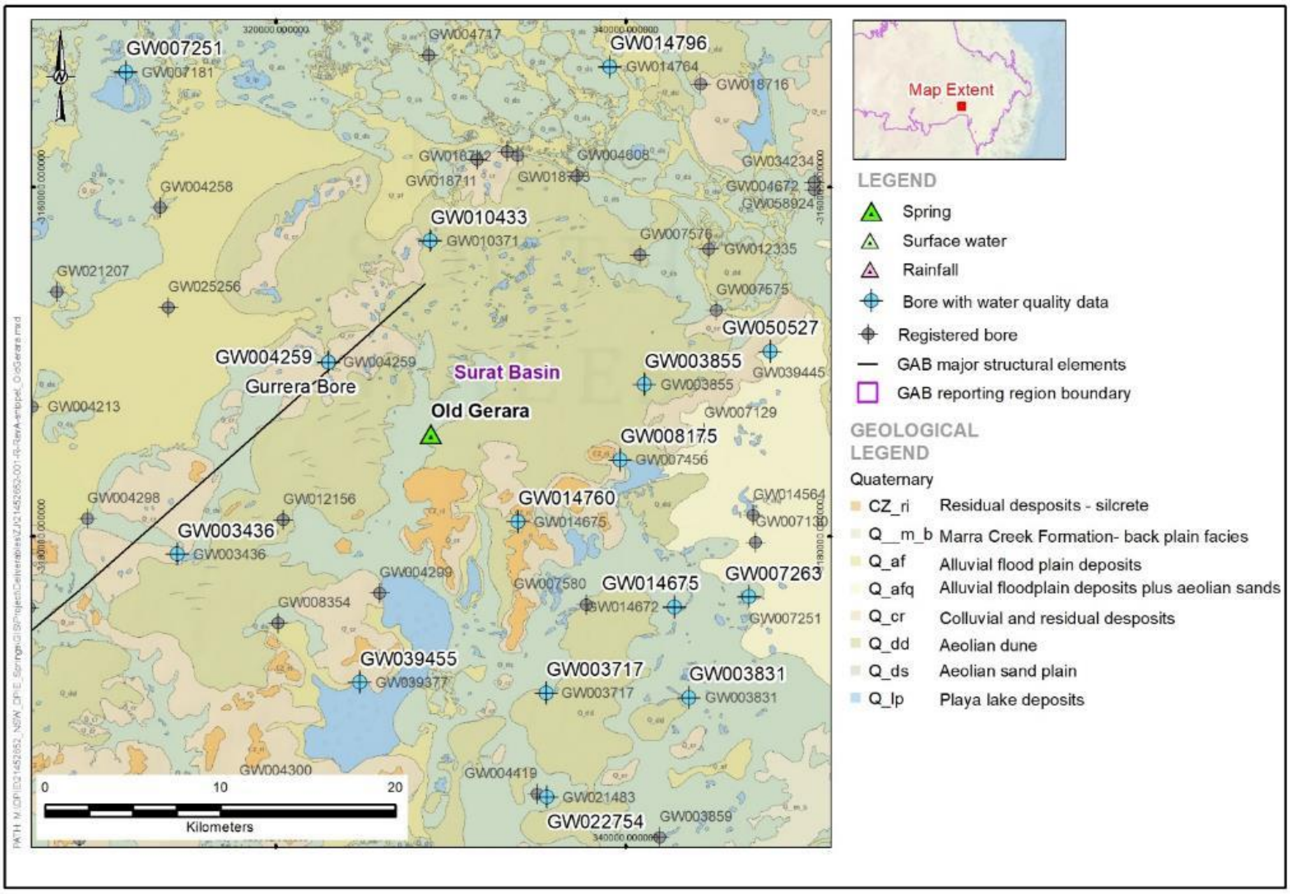

Figure 48: Old Gerara location plan and surface geology (Johnson & Menzies 1965)

5.1.9.4 GAB groundwater levels/artesian conditions

Gurera Bore (GW004259) is drilled to 396 m and observed to be artesian (see photograph on Figure 47).

In addition, GW003855, GW008175, GW050527, GW014760 and GW010433, are all located within 20 km of the spring (location on Figure 48). These were all artesian when they were installed between 1944 and 1980. Based on DPIE's records, only GW010433, GW014760 and GW050527 were artesian in 2019.

5.1.9.5 Hydrogeochemistry

One sample were collected from Old Gerara Spring and one sample was collected from the Old Gerara spring in March 2018. Both were was analysed for major ions, metals and isotopes (^{2}H, ^{18}O, ^{36}Cl and ^{14}C).

5.1.9.5.1 Water quality

Water from this Old Gerara Spring is characterised by neutral pH (6.8) and low salinity (490 mg/L). The major cation is sodium while the major anion is chloride. This chemistry is different to the typical sodium bicarbonate water in the GAB in the area.

Water from gurrera bore has a higher ph (8.3) and low salinity (580 mg/L). The major cation is sodium while the major anion is bicarbonate, consistent with GAB water.

The composition in major ions of both samples is shown on the Piper plot on Figure 49.

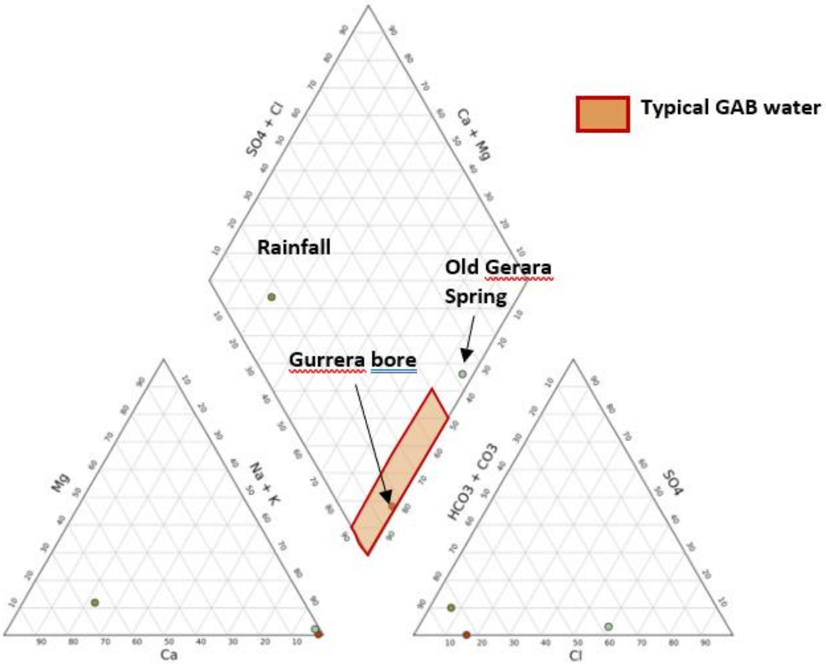

Figure 49: Old Gerara Piper plot

Most of the measured metals and metalloids at Old Gerara Spring are under or close to the detection except for dissolved aluminium and total aluminium with concentration of 100 µg/L and 2800 µg/L respectively. A low concentration of arsenic was also detected in this spring (uniquely, as arsenic was not detected in any of the other springs).

5.1.9.5.2 Isotope information

Based on the isotope analysis presented in Section 4.5 the following main outcomes are relevant for the conceptualisation of this spring:

- the isotopic signature of ^{2}H and ^{18}O plots below the Cobar LMWL which would suggest the influence of evaporative processes. The isotopic signature is different to the group of groundwater bores.
- The sample from Old Gerara Spring is included in the cluster of samples with high pMC (103%), indicative of modern water.
- The ^{36}Cl/Cl^{-} ratio is 547x10$^{-15.}$ This is 42 times higher than the ^{36}Cl ratio for the groundwater bores in that area and twelve times higher than Hooray Sandstone in that area (Map 45 of Ransley et al, 2015), suggesting modern water.

5.1.9.6 Machine Learning outcomes

The spring shows no water quality compatibility with the local bores. This suggests the spring is sourced from aquifers or surface water that is not being sampled by the local bores. Figure 50 shows its location in the PCA analysis.

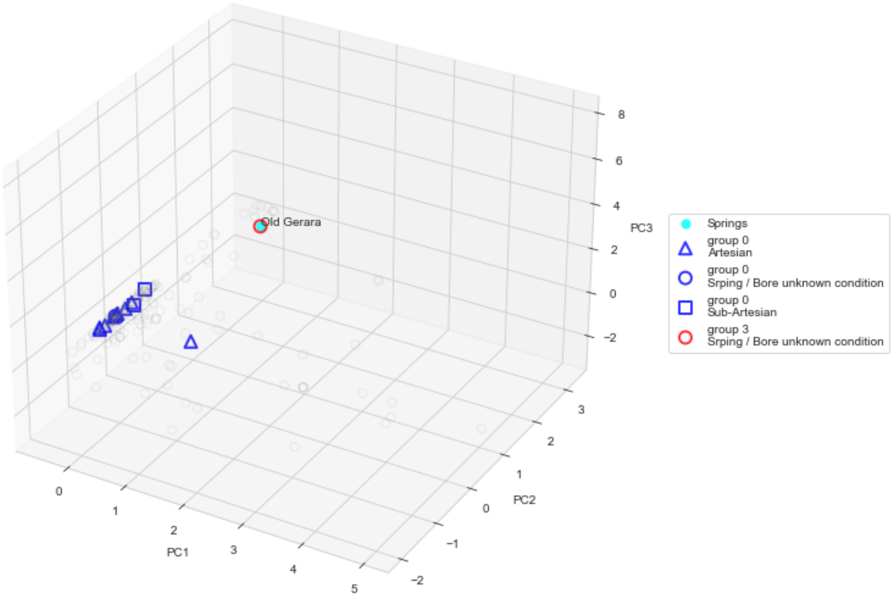

Figure 50: Relative location of Old Gerara Spring and closest bores in 3 dimensional PCA plot.

5.1.9.7 Conceptualisation and typology of Old Gerara Spring

The main components of the information reviewed to support the conceptualisation of the spring at Old Gerara are summarized below:

- Old Gerara Spring was observed by DPIE to consist of one active vent, Vent 965.
- The geological review indicates the Spring is located on Quaternary sediment (although the thickness of it is not known), underlain by the Rolling Downs Group (expected thickness of up to 300 m). The Hooray Sandstone is expected to be underlying the Rolling Downs Group. The Spring is located 1.5 km from a basement fault. However, it is unclear if this fault is observed in the GAB. In addition, information from nearby bores indicates the GAB is under artesian condition in this area.
- The composition in major ions is different to the groundwater bores within 20 km of the spring and different to Gurera bore (GW004259) with chloride dominant over bicarbonate yet a lower salinity than the bore water.
- The isotope analysis indicates the sample collected from Old Gerara has a distinctive isotopic signature to the groundwater bores within 20 km of the spring and not consistent with the GAB. The isotopic signature is more consistent with meteoric water, runoff from recent rainfall or shallow groundwater.

The water source of Old Gerara Spring is likely not solely from the GAB, it is unclear whether its flow can be supported by meteoric water, surface runoff or non-GAB water in the Tertiary sediments.

5.1.10 Peery West Spring

5.1.10.1 General setting and summary of field observations

The Peery Spring complex is located 240 kilometres southwest of Bourke, along the western edge of the Peery Lake floodplains of the Paroo River. The Peery Lake spring complex consists of eight active discharge spring vents, some of which are occasionally inundated by Peery Lake when the Paroo River floods.

The main spring vent (Vent 1000.200_1) was observed to be free flowing from the top of the mound, flowing along a tail and dissipating towards the fringe of Peery Lake (DPIE, 2020b) as shown on Figure 51. In July 2019, the vent was reported to reduce to a seeping mound, scaled with salt, while a nearby mound was reported to become more active.

Queensland Herbarium (2015) states that the main Peery Spring vent, which DPIE Water surveyed, was the only spring site developed into a watering point in the historical pastoral runs. Maps of the historical pastoral runs dating back to 1881 (Momba Pastoral Run 1881, reported by Queensland Herbarium 2015) record this as a historical watering point which can be seen by the line of remnant wooden posts leading to the main spring vent.

Samples were collected from vent 1000.200 in March 2018, October 2018 and July 2019.

Figure 51: Vent 1000.200 sampled in March 2018 (left) and aerial photo of Peery West vent taken in March 2018 (right) (DPIE, 2020b)

5.1.10.2 Ecology

Groundwater dependent flora present at this site included Cynodon dactylon, Cyperus gymnocaulos, Cyperus laevigatus, Cyperus squarrosus and an Utricularia spp. Whilst comprehensive sampling was not carried out on other vents within the Peery Complex, it was noted that there was an established population of the endangered (EPBC Act 1999) Salt Pipewort Eriocaulon carsonii on at least one nearby vent. No state (BC Act 2016) listed threatened plant species were present. A medium level of grazing disturbance was evident at the time of sampling. Groundwater dependent fauna at the site was restricted to macroinvertebrates as no fish were present, twenty different taxa were recorded. The most abundant were from the micro crustacean family and Sididae and Cypridopsidae. Compared to other springs sampled, Peery had high diversity (39% of all taxa sampled) and abundance.

No commonwealth (EPBC Act 1999) or state (BC Act 2016 & Fisheries Management Act 1994) listed threatened species were present. Based on the collected data at the time of sampling, this spring is considered to have high ecological value (DPIE, 2020b).

5.1.10.3 Geological and Hydrogeological setting

The Peery spring complex is shown on Figure 52 which include the 1:250,000 surface geology from the White Cliffs geological sheet (Rose et al, 1964). The spring complex outcrops amongst Quaternary playas and clay pans surrounded by aeolian dune, the latter very notable along the eastern margin of Perry Lake. These overlie GAB formations of the Eromanga Basin to the north and southwest of these springs as well as Precambrian basement rocks of the Mulga Downs Group which outcrop along the western margin of Perry Lake and form localised topographic highs. Occurrences of residual and colluvial deposits also occur sporadically throughout the region whilst fluvial deposits are present to the north and south of these springs delineating nearby floodplains, outwash areas and drainage flats of the Paroo River.

The closest mapped GAB formation is the Rolling Downs Group which outcrops about 5 km to the northwest.

The surface geology indicates the basement units beneath the GAB are dominated by the Devonian Mulga Downs Group which has locally-significant folding around 2 km west and to the south and southwest of these springs. IESC (Commonwealth of Australia, 2014) notes these may influence groundwater flow paths and occurrence in the area.

GABWRA's 3D visualisation (Geoscience Australia, 2013) of the GAB indicates the Hooray Sandstone is present, with a typical thickness of around 100 m, beneath the Rolling Downs Group which is around 20 m thick. It gently rises from north to south as the GAB formations overlie the rising basement rocks and east to west along the western margin of the White Cliffs GAB embayment. Groundwater flow direction here in the Hooray Sandstone is understood to be from northeast to southwest, essentially flowing into the White Cliffs GAB embayment and potentially outcropping along the nearby edges of the GAB.

The underlying Injune Creek Formation is also shown to be outcropping around the margins of the GAB.

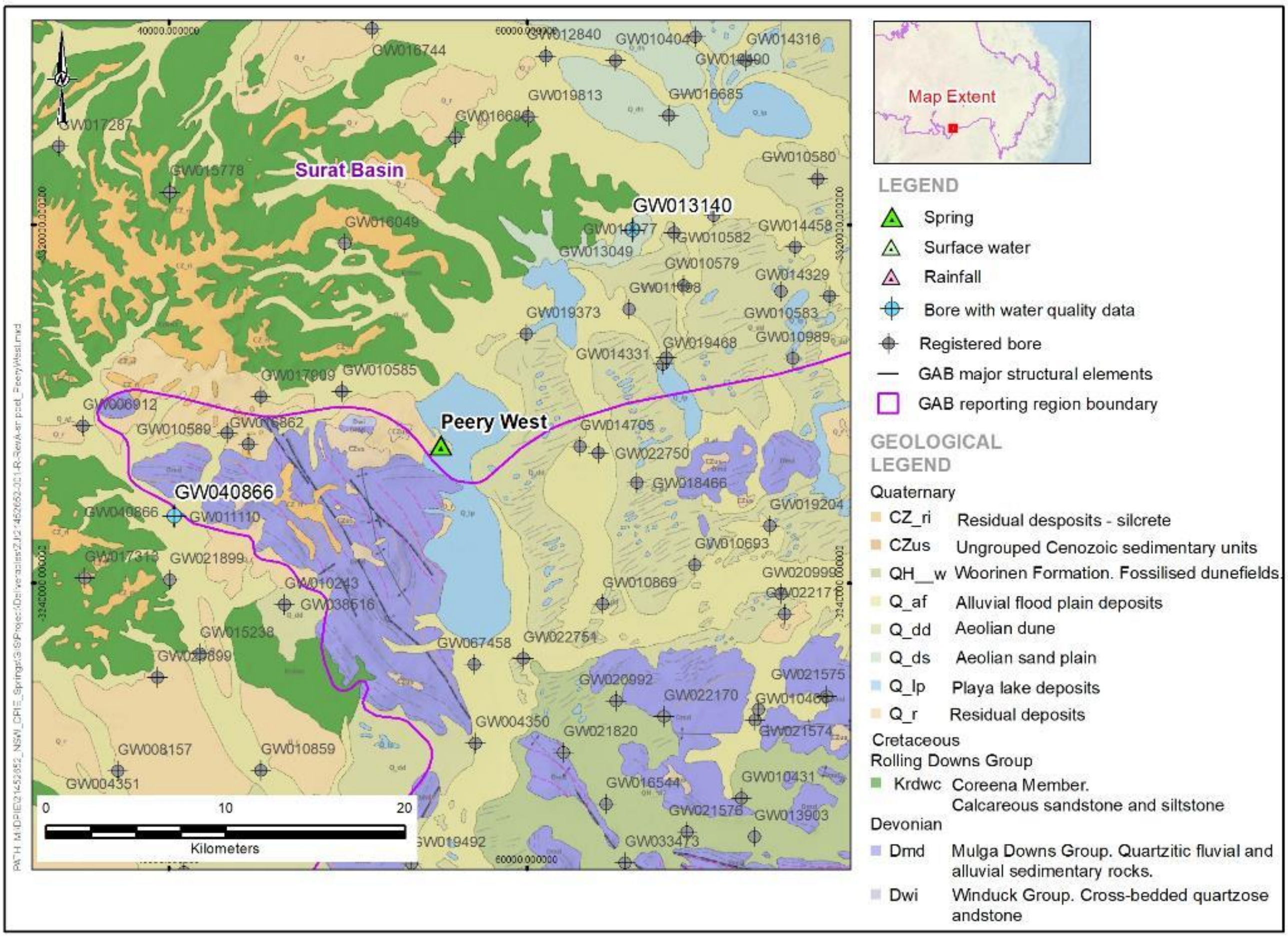

Figure 52: Peery West location plan and surface geology (Rose et al, 1964)

5.1.10.4 GAB groundwater levels/artesian conditions

GW013140 and GW040866, are all located within 20 km of the spring (location on Figure 52). Based on GAWRA's 3D model, GW013140 is understood to be installed the base of the GAB while GW040866 is understood to be monitoring the Rolling Downs Group. These were all artesian when they were installed in

1957 and 2002 respectively. Based on DPIE's records GW013140 is still artesian while no information is available for GW040866.

5.1.10.5 Hydrochemistry

Three samples were collected from Peery West (vent 1000.200) in total in March 2018, October 2018 and July 2019. These were all collected from vent 1000.200. The samples were analysed for major ions and isotopes (^{2}H, ^{18}O, ^{87}Sr, ^{36}Cl, ^{14}C and ^{3}H).

5.1.10.5.1 Water quality

The ph of all three samples is neutral pH (7.6-8.3) and slightly saline (1500-1700 mg/L). The composition in major ions is shown on the Piper plot on Figure 53. The water is of sodium-bicarbonate type generally similar to the GAB groundwater bores, but different to GW040866, located 15 km west and understood to be monitoring the Roling Downs Group (based on GABWRA's 3D model).

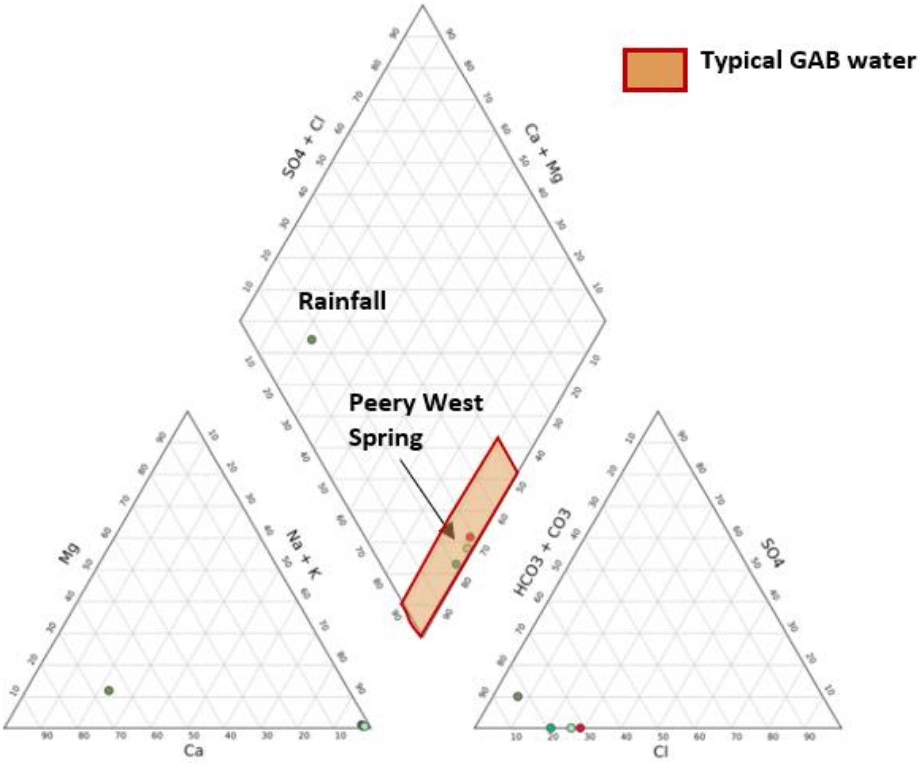

Figure 53: Piper plot Peery West Spring complex

The three samples collected from Peery West vent show similar concentration of lithium (70 µg/L exclusively in dissolved form), strontium (396 µg/L total strontium and 310 µg/L dissolved strontium), manganese (13 µg/L in total form) and zinc (3 µg/L total zinc). All the three samples show significant concentration of aluminium (375 µg/L, mostly as total aluminium) and iron (330 mg/L, mostly as total iron), although the concentration for both metals in the March 2018 sample is 10 times higher.

5.1.10.5.2 Isotope information

Based on the isotope analysis presented in Section 4.5 the following main outcomes are relevant for the conceptualisation of this spring:

- The isotopic signature in ^{2}H and ^{18}O of the samples collected in March 2018, October 2018 and July 2019 indicate all three samples have similar isotopic signature. They also have similar signature to the groundwater bores (see Figure 6, Figure 7 and Figure 8).
- The tritium activity was measured to be below the detection limit in July 2019 and slightly higher than the detection limit in March 2018. This is consistent with water from the GAB.
- The pMC values vary between 2.5 to 4.2%, suggesting the water is mature and is grouped with the GAB groundwater bores.
- The ^{36}Cl/Cl^{-} ratio vary between 20x10^{-15} to 28x10^{-15}. This is within the range of variation for the groundwater bores in that area and in the Hooray Sandstone in that area (Map 45 of Ransley et al., 2015).

5.1.10.6 Machine Learning outcomes

The individual spring water quality is highly compatible with the local bores suggesting a high likelihood of connection between the aquifer tapped by those bores and that spring. Figure 54 shows its location in the PCA analysis.

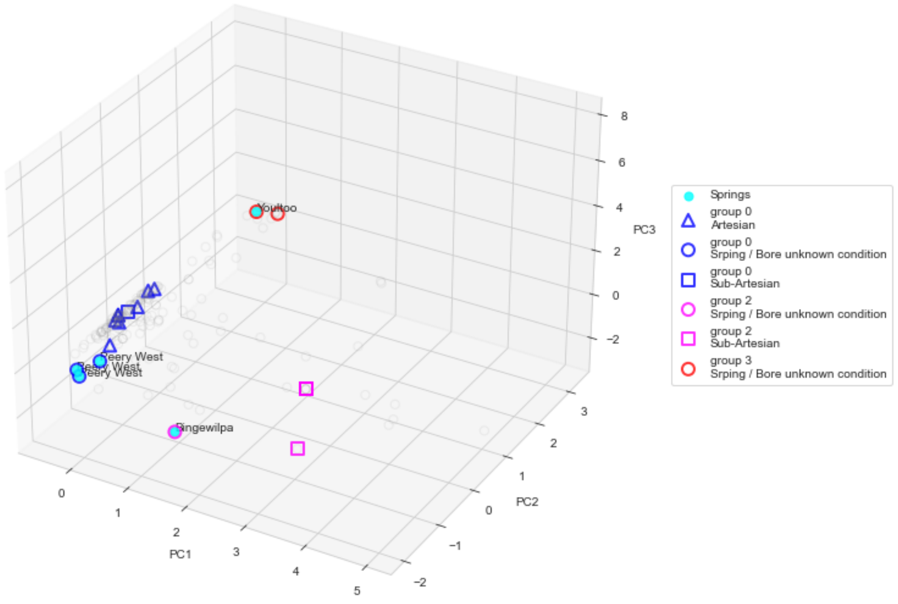

Figure 54:: Relative location of Peery West Spring and closest bores in 3 dimensional PCA plot.

5.1.10.7 Conceptualisation and typology

The main components of the information reviewed to support the conceptualisation of the Spring at Peery West are summarized below:

- The field observations indicate that the Peery Lake spring complex consists of eight active discharge spring vents, some of which are occasionally inundated by Peery Lake when the Paroo River floods. The main spring vent (1000.200_1) was observed to be free flowing from the top of the mound, flowing along a tail and dissipating towards the fringe of Peery Lake (DPIE, 2020b).
- The spring complex lies on the southern margin of the Eromanga Basin where the Hooray Sandstone is relatively close to the surface.

- The composition in major ions is similar to that of groundwater bores monitoring the GAB, but different to that of a nearby bore monitoring the Rolling Downs Group (GW04086).
- The isotopic signature is consistent with GAB water and the radioactive isotope signature is consistent with GAB formations.
- The machine learning outcome suggest a high likelihood of connection between the GAB and Peery West Spring.

GAB aquifers present in the region, and likely source aquifers for the springs, include the Hooray Sandstone and the Wyandra Sandstone Member of the Cadna-owie Formation. Stratigraphic information for the area is limited and it is likely that the deeper GAB aquifers do not extend to the edge of the Basin.

Based on the local geological setting it is likely that the structural model is of a basin margin with sediments thinning (structural conceptual model 2). It is unclear however if faults and outcropping Devonian sediments influence this structural setting.

The water source from Peery Lake Spring (vent 1000.200) is likely from a GAB aquifer. This interpretation is consistent with the outcome of the 2014 conceptualisation (Commonwealth of Australia, 2014).

5.1.11 Tharnowanni

5.1.11.1 General setting and summary of field observations

The site called Tharnowanni is located 80 km west of Bourke.

The site was originally included in DPIE's spring monitoring study as historical record indicated a spring was present. However, only a 20 m diameter excavated dam was encountered at that location (as presented on Figure 55). This site was subsequently removed from the spring survey as it was not considered to be a spring although it is understood that a mound was observed.

A water quality sample was nonetheless collected from this dam and included in the field report (DPIE, 2020b).

Figure 55: Excavated dam found at Tharnowanni (DPIE, 2020b)

5.1.11.2 Ecological survey

No ecological survey was provided.

5.1.11.3 Geological and Hydrogeological setting

Tharnowanni is located among flat plains dominated by Quaternary silicified sandstone and conglomerate boulders as shown on the 1:250,000 surface geology map extracted from Yantabulla 1:250,000 scale map sheet

(Wallis & McEwen, 1962) (see Figure 56). This location is unconformably underlain by the Rolling Downs Group which outcrops about 25 km south-south-east (Wallis & McEwen, 1962). The GABWRA 3D visualisation (Geoscience Australia, 2013) suggests the Hooray Sandstone is also present below the Rolling Downs Group. The southern margin of the GAB is located 45 km south of Tharnowanni.

Basement faults are located at distances between 10 and 30 km to the northwest, north, east and southeast of Tharnowanni. It is not known however whether these faults are present in the underling basement rocks only or continue into the GAB units in this area.

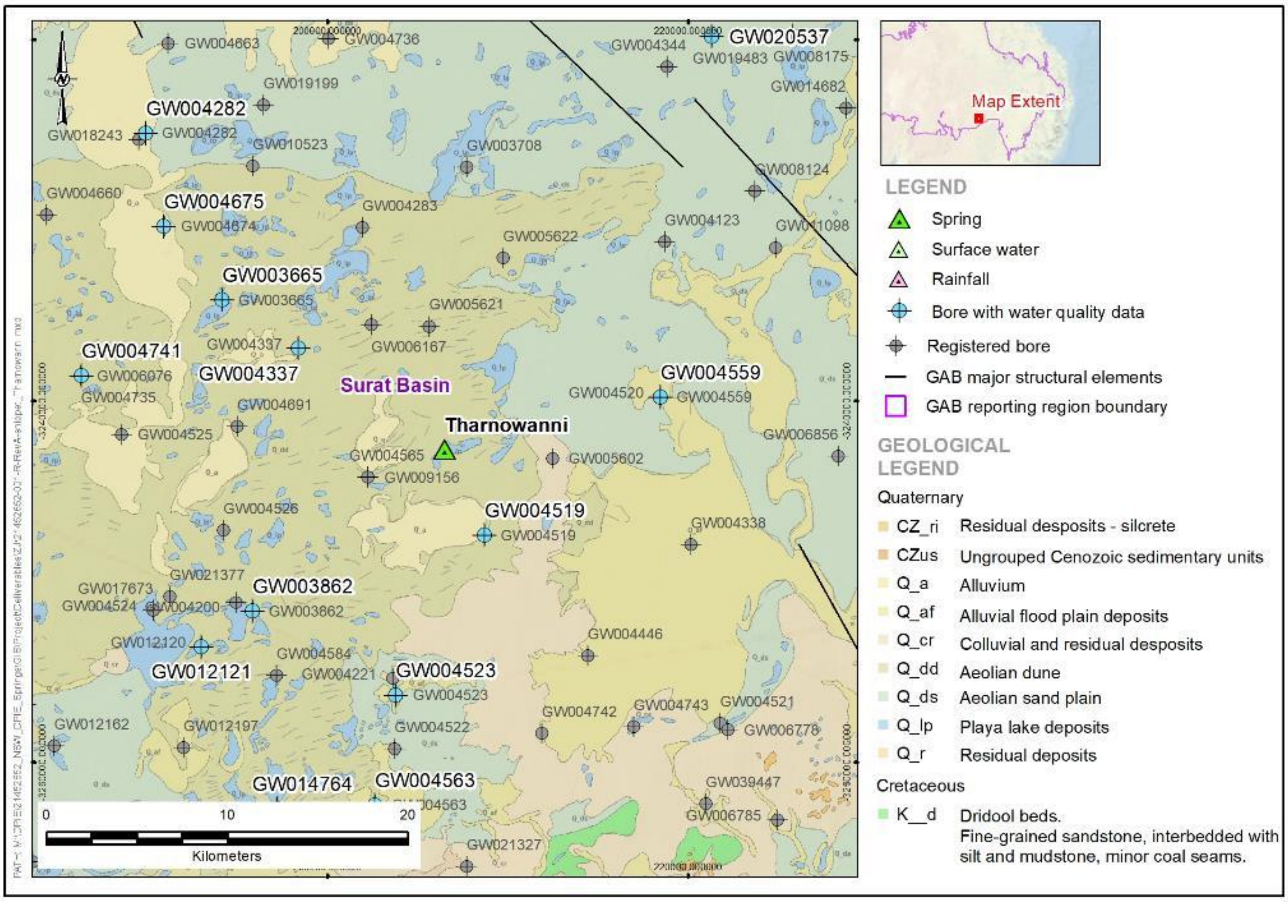

Figure 56: Tharnowanni location plan and surface geology (Wallis & McEwen, 1962)

5.1.11.4 GAB groundwater levels/artesian conditions

Based on the information provided by DPIE, information about artesian condition in 2019 are available for twelve bores within 20 km of Culla Willallee Spring (see location on Figure 56). All bores except GW004282, GW004337, GW004523, GW004559 and GW004741 were artesian in 2019.

5.1.11.5 Hydrogeochemistry

One water sample was collected from the excavated dam at Tharnowanni in October 2018 and was analysed for major ions, metals and isotopes (^{2}H, ^{18}O, ^{87}Sr, ^{36}Cl, ^{14}C and ^{3}H).

5.1.11.5.1 Water quality

The water from the dam is slightly basic (pH of 8.5) with low salinity (640 mg/L). The water is of sodium, potassium-bicarbonate type, similar to GAB water (see Piper plot on Figure 57).

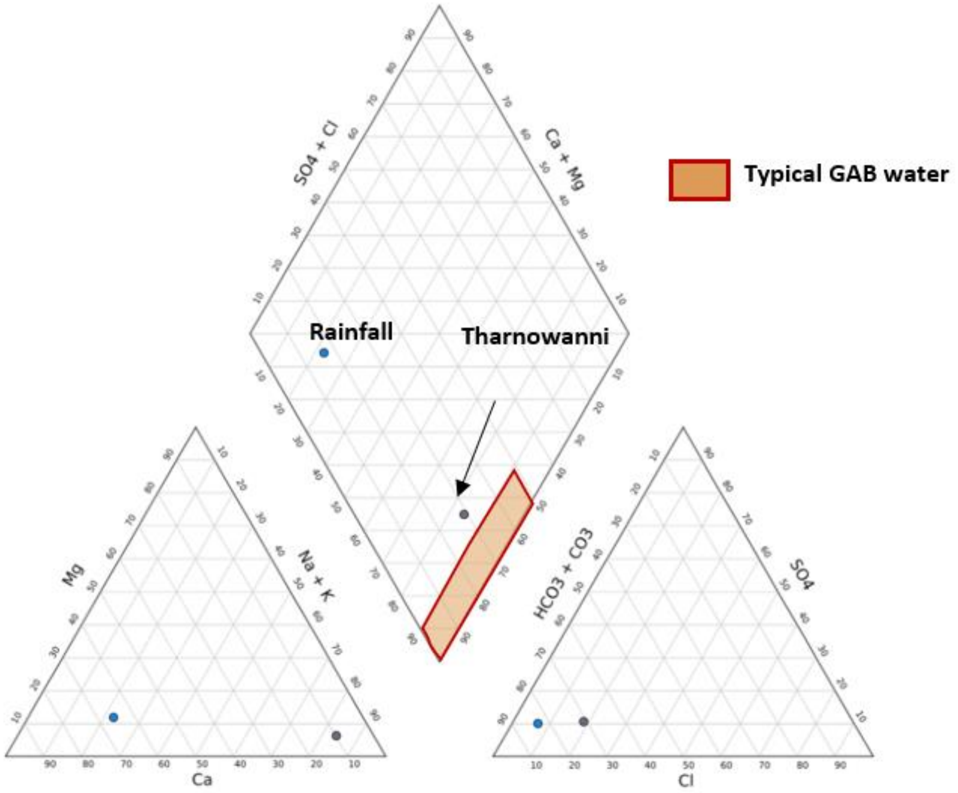

Figure 57: Piper plot Tharnowanni sample

The concentration in metals and metalloids of the sampe collected at Tharnowanni dam is different to the groundwater bores as no dissolved iron and aluminium are measured. In addition, small concentration of copper and chromium are measured which is unlike the groundwater bores in the GAB.

5.1.11.5.2 Isotope information

Based on the isotope analysis presented in Section 4.5 the following main outcomes are relevant to describe this sample:

- the isotopic signature of ^{2}H and ^{18}O is highly enriched when compared to the other spring samples and bores.
- The measured ^{3}H activity is 3.2 TU suggesting modern water.
- The ^{36}Cl/Cl^{-} ratio is 130x10$^{-15.}$ This is over double the ^{36}Cl/Cl^{-} ratio of the Hooray Sandstone in that area (Map 45 of Ransley et al 2015), suggesting modern water.

5.1.11.6 Machine Learning outcomes

According to the PCA analysis this water sample is in a transitional location. It has a low to moderate likelihood of some connection between the aquifer and the sample. Figure 58 shows its location in the PCA analysis.

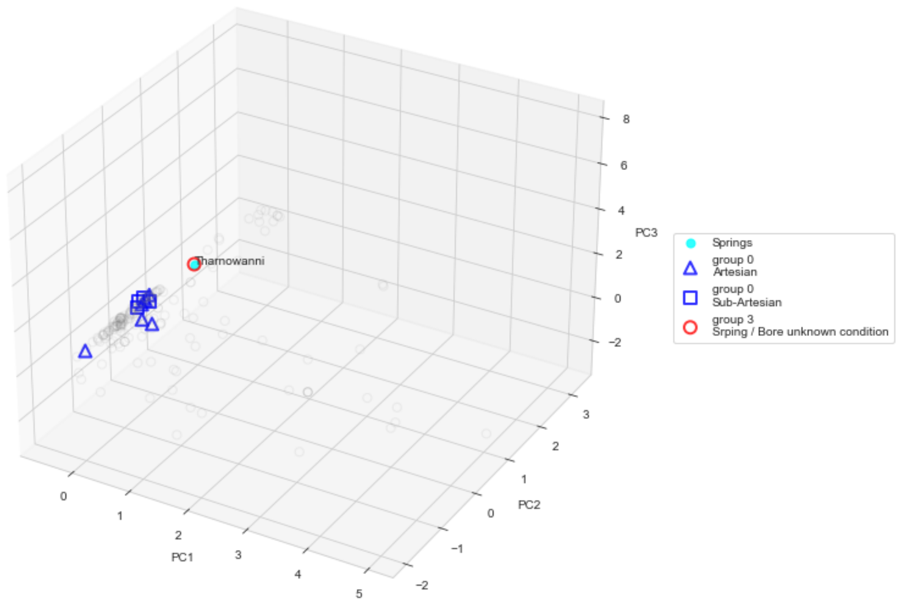

Figure 58: Relative location of Tharnowanni dam sample and closest bores in 3 dimensional PCA plot.

5.1.11.7 Summary

The main components of the information reviewed to support the conceptualisation of the spring at Youngerina are summarized below:

- DPIE describe Youngerina Spring as being an inactive spring site. In addition, numerous remnant mound spring vents are reported nearby. Mound Springs alone provide strong evidence for GAB water emerging at the site.
- One water sample was collected from the surface water storage (the springs are dry).
- The geological review indicates the Rolling Downs Group occur at the spring to a depth of approximately 50 m and that it is underlain by the Hooray Sandstone.
- The composition in major ions is magnesium-bicarbonate type, different from any of the groundwater bores sampled and different from the typical major ion composition of the GAB. The pH is slightly basic (unlike the GAB) with low salinity (similar to the GAB).
- The isotopic signature is not consistent with the GAB but more consistent with meteoric water, runoff from recent rainfall or shallow groundwater.

There has not been an indication that there is a spring at this site, the water source is likely to be from local surface water and not from the GAB.

5.1.12 Thooro Mud Spring

5.1.12.1 General setting and summary of field observation

Thooro Mud Spring is located approximately 100 km north-west of Bourke.

DPIE describe Thooro, Thooro Mud and Mascot (‘Tanawanta Mud’) to be part of a same group due to their proximity to each other. Thooro Mud was described as active while Thooro and Mascot were described as inactive.

Thooro Mud Spring consists of 12 active and 8 inactive spring vents. The mud depressions (as the one shown on Figure 59 b) and small mounds of the Thooro Mud springs are found in a low-lying part of the landscape and are scattered across three topographically low clay pans. Low lying sand dunes, alluvium and historic creek beds surround the springs.

The active springs are predominantly muddy depressions without vegetation. Few vents have free flowing water. Vent 976.24 at Thoroo Mud was noted to be an active spring with waterlogged, iron-rich mud on the edge of the clay pan area (shown on Figure 59a). One sample was collected from this vent.

DPIE include a photograph of the claypan where Thooro is located filled with rainfall after a rain event, although they do not mention the date or amount of rainfall (see shown on Figure 59a).

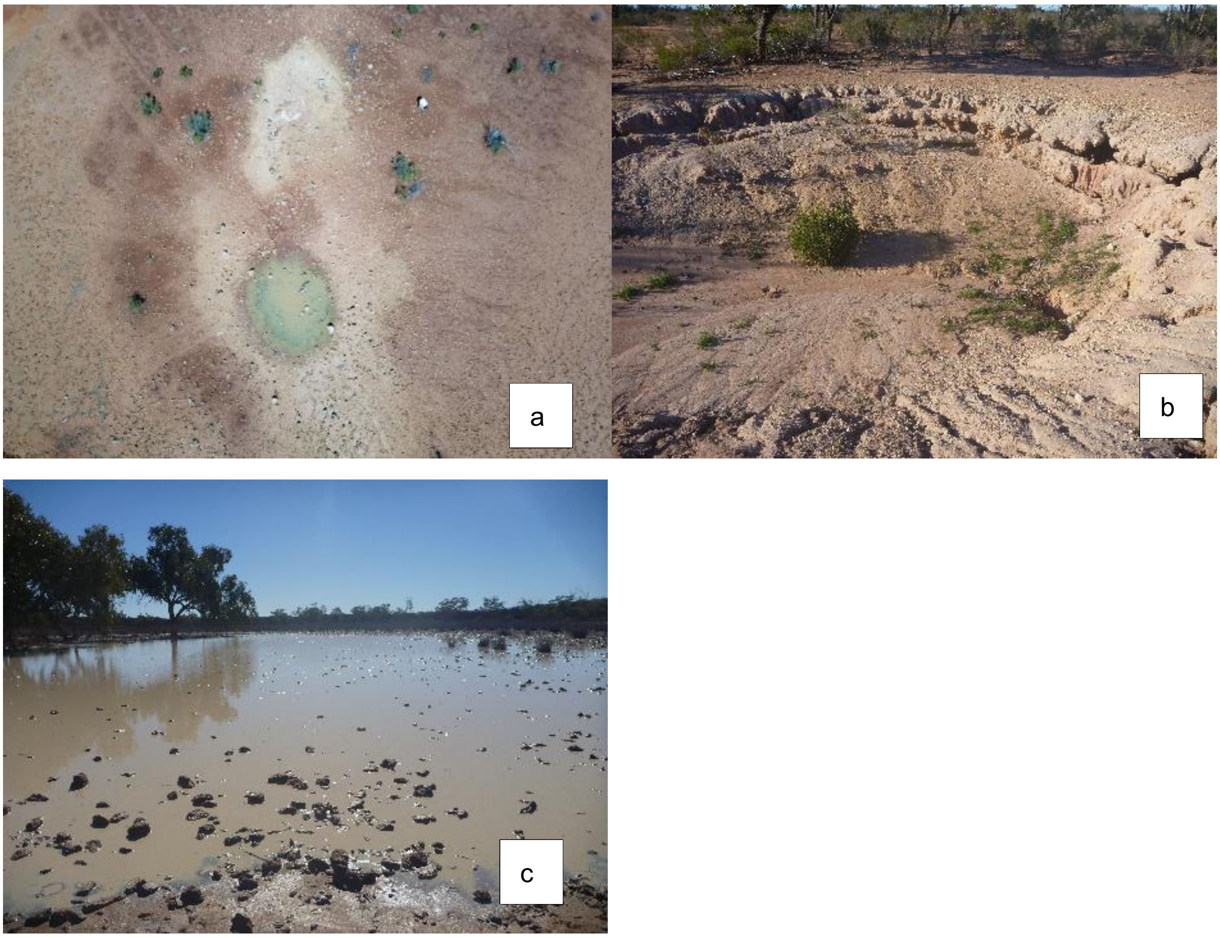

Figure 59: Aerial photo of Thooro Mud active vent 976.24 (a), Thooro Mud collapsed mud vent (b) and rainfall filled claypan at Thooro, no date (c) (DPIE, 2020b)

5.1.12.2 Ecology

Ecology surveys were completed by DPIE identifying minimal vegetation.

DPIE also indicate that abundant Aboriginal cultural material was encountered.

5.1.12.3 Geological and Hydrogeological setting

The surface geology in the area of Thooro Mud Spring is shown on the Yantabulla 1:250,000 geology map (Wallis & McEwen, 1962) included on Figure 60. The map shows Thooro Mud Spring Complex to be located on Quaternary sand plains and possibly clay pans. These deposits are underlain by the Rolling Downs Group which is the dominant GAB formation in the vicinity of this complex. The southern margin of the GAB is located 100 km south of Thooro Mud Spring.

The geological sections shown on the Yantabulla map sheet (Wallis & McEwen, 1962) suggests Hooray Sandstone is not present beneath the Thooro Mud spring complex. The sections conflict with the GABWRA 3D visualisation (Geoscience Australia, 2013) of the GAB which suggests the Hooray Sandstone is located beneath the springs with varying thickness and continuity, reflecting the morphology of the underlying shallow basement rocks.

IECS (Commonwealth of Australia, 2014) support the notion of the Hooray Sandstone being present beneath these springs but notes *that bores “GW011334, GW003669, GW011266, GW010070 and GW004773 are tapping Hooray Sandstone, along with other minor aquifers present in the Coreena and Doncaster members of the Wallumbilla Formation”.* IESC (Commonwealth of Australia, 2014) also notes the geological log for registered borehole GW804172, drilled about 47 km southeast of the spring complex, suggests the Hooray Sandstone was encountered in this borehole between depths of about 332 and 395 m.

In light of the above, the Hooray Sandstone (as well as overlying aquifers associated with the Coreena and Doncaster members of the Wallumbilla Formation) may be present at this spring complex.

Devonian granites almost outcrop along what may be a locally significant basement high near the spring, which could form a geological barrier to GAB groundwater flow. This basement high is also included in GABWRA’s 3D visualisation (Geoscience Australia, 2013) of the GAB.

An unnamed fault runs approximately 2.6 km east of the complex, potentially in the Palaezoic basement rocks and not the GAB sediments. This fault is oriented north-south whilst the regional groundwater flow direction in the Hooray Sandstone in this area is expected to be to the southwest. IESC (Commonwealth of Australia, 2014) also noted, based on their observations during an inspection of the complex, that several springs were present either side of this fault, whilst further to the north the Wapweelah bore is also located on the inferred alignment of this fault. The GABWRA 3D visualisation (Geoscience Australia, 2013) of the GAB also shows notable stratigraphic offsets between about 100 m and 200 m in the Hooray Sandstone and underlying Injune Creek Formation which are expected to represent faulting in the full thickness of GAB units in this area.

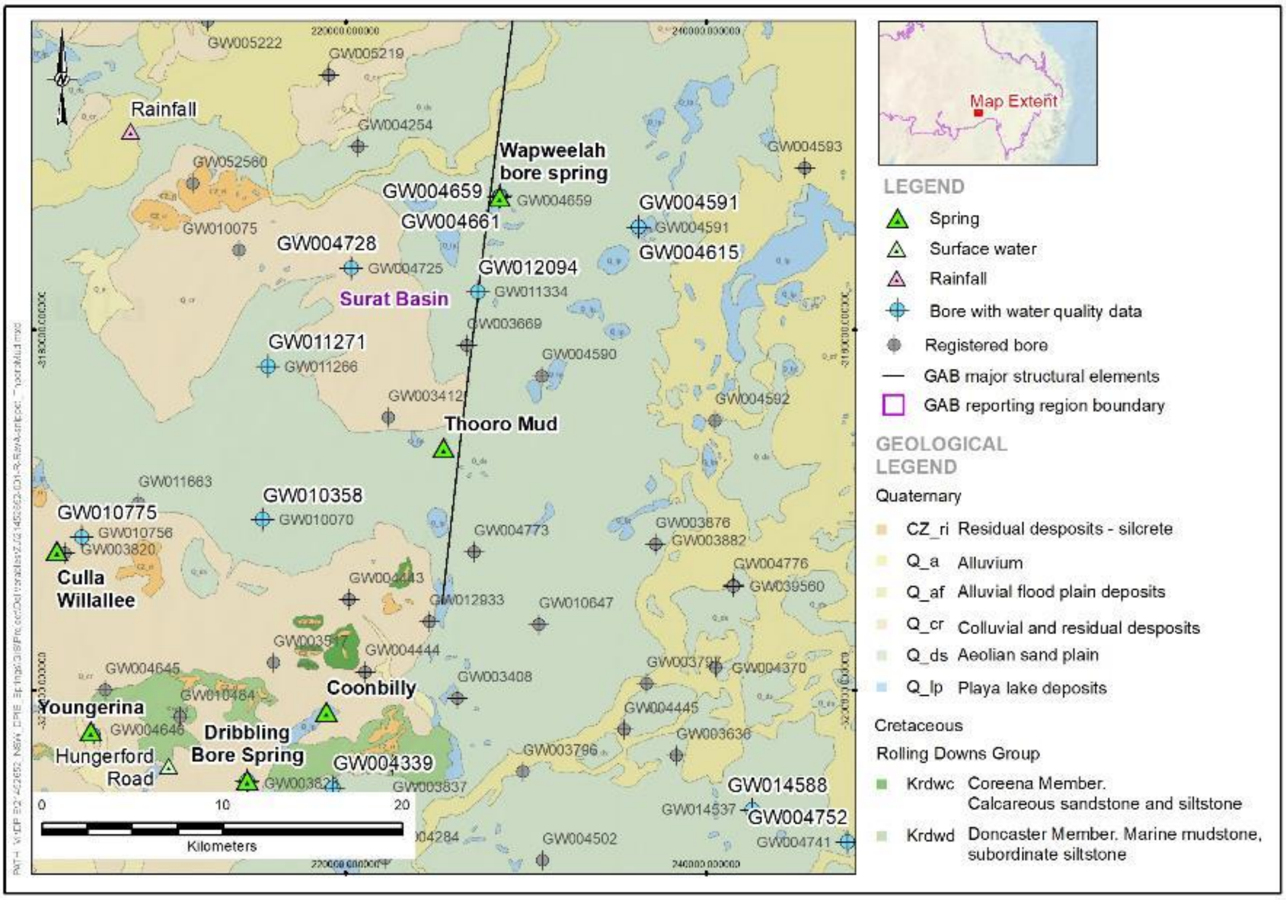

Figure 60: Thooro Mud Location Plan and Surface Geology (Wallis & McEwen, 1962)

5.1.12.4 GAB groundwater levels/artesian conditions

GW004591, GW004615, GW012097, GW004728, GW011271 and GW010358, are all located within 20 km of the spring (location on Figure 60). These were all artesian when they were installed between 1893 and 1955. Based on DPIE's records, only GW004591 and GW010358 were under artesian conditions in 2019.

5.1.12.5 Hydrogeochemistry

One water sample was collected from Thooro Mud in July 2019 and was analysed for major ions, metals and isotopes (^{2}H, ^{18}O, ^{36}Cl and ^{14}C).

5.1.12.5.1 Water quality

The water from Thooro Mud Spring is basic (pH of 9.2) with low salinity (550 mg/L). The water is of sodium, potassium-bicarbonate type, consistent with GAB water (see Piper plot on Figure 61).

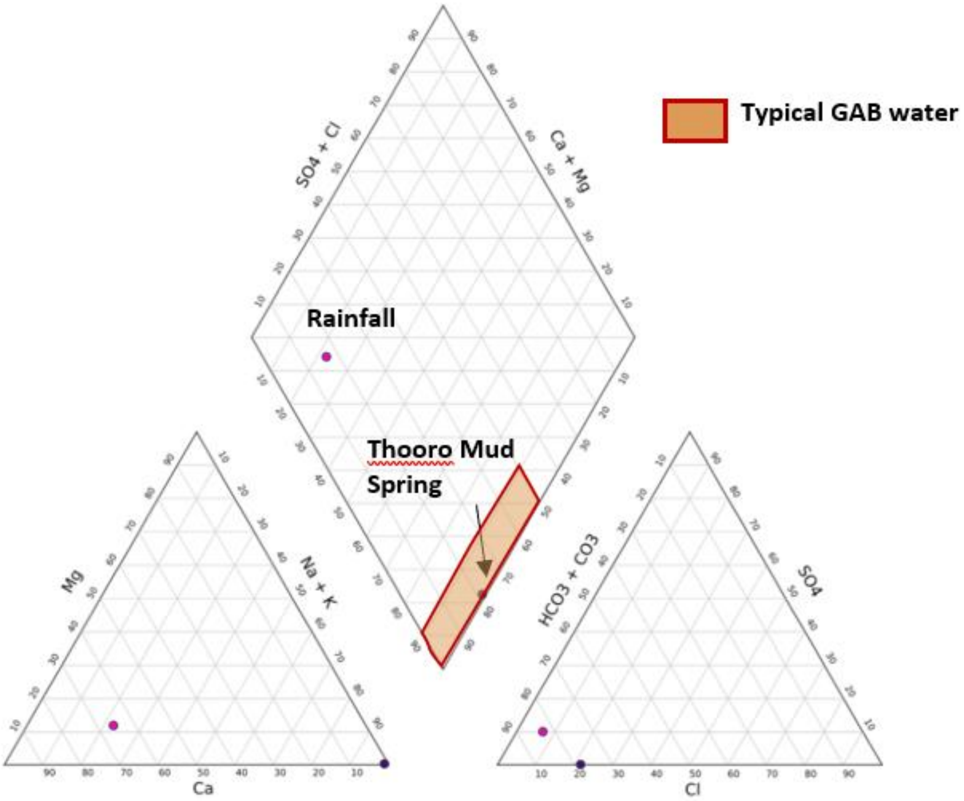

Figure 61: Piper plot Thooro Mud Spring

Most of the measured metals and metalloids are under or close to the detection except for :

- dissolved and total aluminium (concentration of 60 µg/L and 1100 µg/L respectively),
- dissolved iron (concentrations of 53 µg/L and 840 mg/L respectively);
- dissolved lithium (concentrations of 15 µg/L and 17 µg/L respectively) and
- dissolved strontium (with concentrations of 26 µg/L and 32 µg/L respectively).

5.1.12.5.2 Isotope information

Based on the isotope analysis presented in Section 4.5 the following main outcomes are relevant for the conceptualisation of this spring:

- The isotopic signature of ^{2}H and ^{18}O is similar to the groundwater bores.
- The pMC value of 14% suggests a relatively modern water or a sample that has mixed water source.
- The $^{36}Cl/Cl^{-}$ ratio is 47×10^{-15}. This is similar to the $^{36}Cl/Cl^{-}$ of GW004659 understood to be monitoring the Hooray Sandstone and located 14 km North of the spring. It is also similar to the $^{36}Cl/Cl^{-}$ ratio of the Hooray Sandstone in that area (Map 45 of Ransley et al, 2015).

5.1.12.6 Machine Learning outcome

The individual spring water quality is highly compatible with the local bores suggesting a high likelihood of connection between the aquifer tapped by those bores and that spring. Figure 62 shows its location in the PCA analysis.

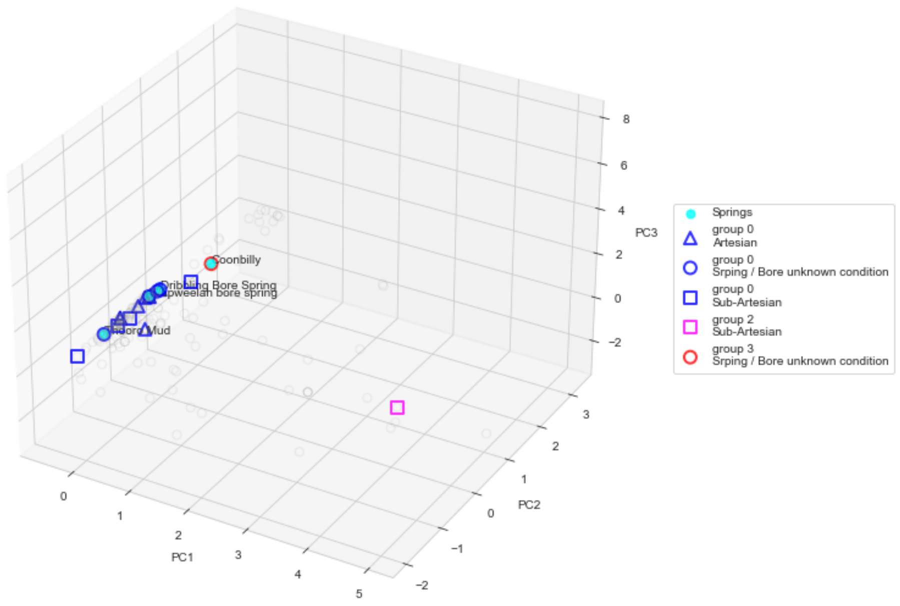

Figure 62:: Relative location of spring Thooro Mud Spring and closest bores in 3 dimensional PCA plot.

5.1.12.7 Conceptualisation and typology

The main components of the information reviewed to support the conceptualisation of Thooro Mud Spring are summarized below:

- DPIE describe Thooro mud complex, Thooro spring and Mascot ('Tanawanta') Spring as being a spring group. Only the Thoorro Mud Spring complex is described as being active with eight active vents and several collapsed inactive vents. One sample was collected from an active vent.
- The geological review indicates the spring is located within Quaternary sediments, but is underlain by the Rolling Downs Group and the Hooray Sandstone. The spring is located close to a basement fault, it is not clear, however, if this fault is also present in the GAB formations.
- The composition in major ions is magnesium-bicarbonate type, similar to GAB water. The pH is basic (unlike the GAB) with low salinity (similar to the GAB).
- The isotopic signature is consistent with shallow groundwater or a mix of shallow groundwater and GAB water. In particular, the ^{36}Cl/Cl- signature is consistent with GAB water, while the ^{14}C signature, expressed as pMC is consistent with a mixed source that could include the GAB and modern water.
- The machine learning outcome indicates there is a high likelihood of connection with the spring and the aquifer tapped by the surrounding bores.

The water source of this spring seems likely to be the GAB, supported by the major ions compositions and ^{36}Cl/Cl^{-} signature, with mixing from meteoric water, shallow groundwater or both (supported by the ^{14}C signature).

5.1.13 Thully Spring

5.1.13.1 General setting and summary of field observations

Thully Spring complex is located 25 km north of Bourke.

DPIE describe Thully Spring complex as consisting of active and inactive mud springs close to a dam and a defunct windmill (DPIE, 2020b). Eight vents are identified in total including Vents 961.1 and 961.4. DPIE described the vents as being either dry mud vents or filled with water, which they hypothesis as being surface water. DPIE also refers to them as “collapsed mud mound springs”.

Vent 961.1_ was sampled in October 2018 and both Vents 961.1 and 961.4 were sampled in July 2019.

DPIE does not provide photographs in their field report, nor do they describe any active flow (i.e “bubbling”)

5.1.13.2 Ecology

DPIE observe a sporadic covering of heavily grazed Glinus lotoides and many heavily grazed sedge clumps at the main vent (understood to be 961.1). No groundwater dependent vegetation was noted around the springs. Below a coolabah tree near the spring was less than 1% nardoo (Marsilea drummondii), a common widespread fern occurring in inland regions after flooding.

DPIE also observed encrusting algae around the edge of the spring.

DPIE did not assign an ecological value to the spring.

5.1.13.3 Geological and Hydrogeological setting

Thully Spring complex occurs amongst Quaternary sand plains and clay pans surrounded by larger plains of aeolian sand and silts as shown on the Enngonia 1:250,000 scale geological map sheet (Johnson & Menzies, 1965) included on Figure 63. These near-surface deposits are underlain by the Rolling Downs Group which is the dominant GAB formation in the vicinity of this complex. The southern margin of the GAB is located 25 km south of Thully Spring.

The geological description provided on the borehole summary for the closest registered borehole to Thully Spring (GW004674) suggests the Rolling Downs Group in this area largely comprises shale and is more than 190 m thick. GABWRA’s 3D visualisation of the GAB suggests it is also underlain by the Hooray Sandstone which rises with distance to the south, outcropping along the southern margin of the GAB between Bourke and Wilcannia. The Hooray Sandstone may not be laterally continuous from east to west across the Cunnamulla Shelf with unconformities across a number of basement highs in the vicinity of these springs.

Two (unnamed) faults run in the underlying basement rocks 8 km north and 12 km southeast of the Thully spring complex. The fault to the north intersects another fault in the basement rocks further west and northwest. A number of springs are located on either side of these faults including Native Dog, Lila, Colless and Old Gerara. It is noted this fault is oriented generally perpendicular to the indicated groundwater flow direction in the Hooray Sandstone (Ransley et al, 2015).

Whilst it is not known whether the above-mentioned faults are present in the GAB sediments, Rade (1954) suggests spring complexes at and in the vicinity of Thully may occur due to the interaction of regional groundwater flow with these structures.

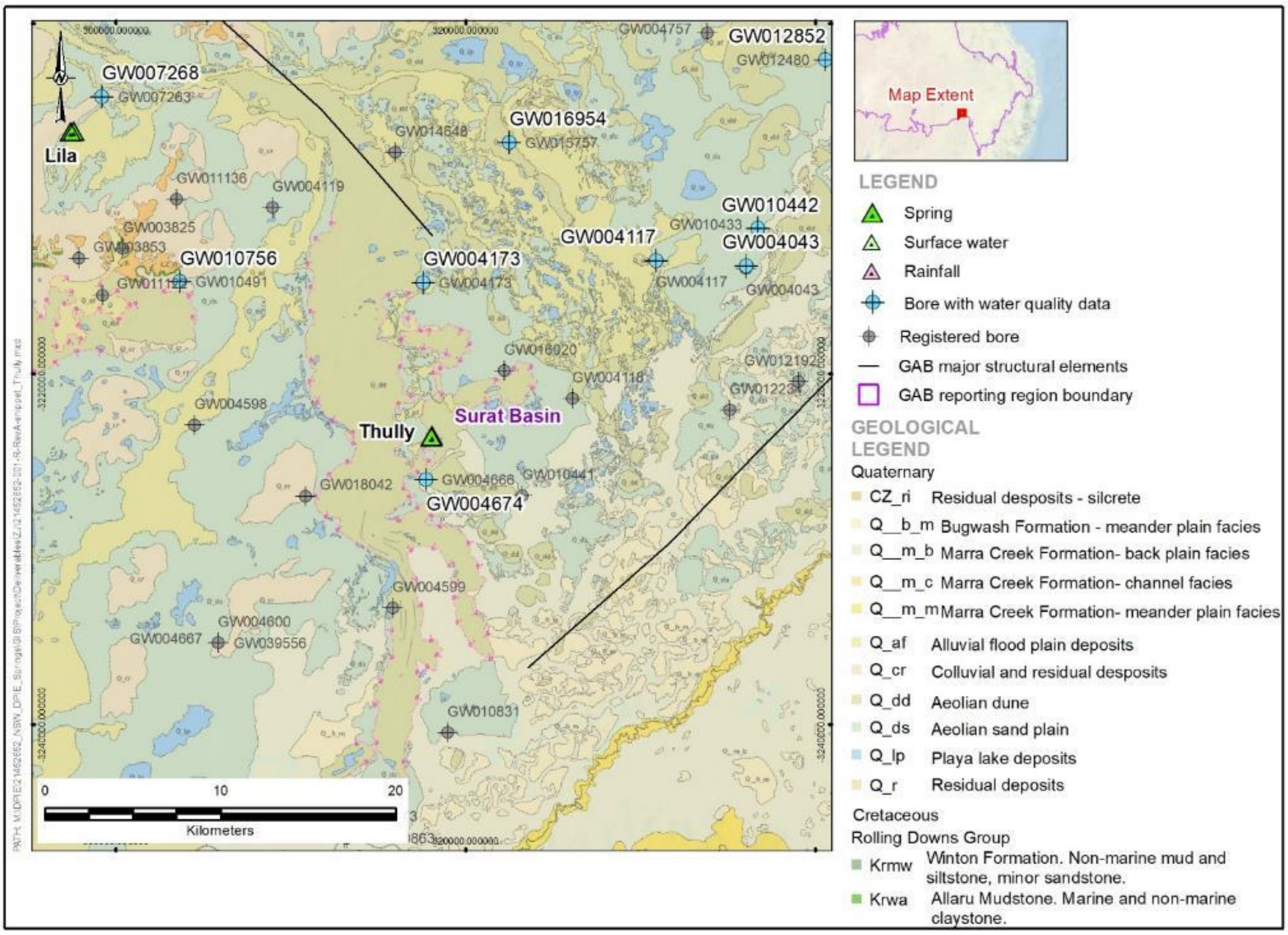

Figure 63: Thully location plan and 1:250,000 surface geology extracted from Johnson & Menzies, (1965)

5.1.13.4 GAB groundwater levels/artesian conditions

GW004674, GW004713, GW004117, GW004043 and GW010442, are all located within 20 km of the spring (location on Figure 63). These were all artesian when they were installed between 1895 and 1944. Based on DPIE's records, only GW004043, GW004117 and GW004674 were under artesian conditions in 2019.

5.1.13.5 Hydrogeochemistry

A total of three water samples were collected from Thully, one in October 2018 (from vent 961.1.1) and two in July 2019 (from vent 961.1 and 961.4). All three samples were analysed for major ions, metals and stable isotopes (^{2}H, ^{18}O and ^{87}Sr). The October 2018 sample collected from Vent 961.1 was also analysed for radioactive isotopes (^{36}Cl, ^{14}C and ^{3}H).

5.1.13.5.1 Water quality

Water from this vent is characterized by neutral pH (7.6-7.9). The salinity of vent 1961.1_1 is low (155 mg/L) while the salinity of Vent 961.4_1 is more saline (1300 mg/L).

The composition in major ion shown graphically on the Piper plot on Figure 64 indicates Vent 961.1 is sodium-bicarbonate type while Vent 961.4_1 is sodium-chloride. Different sources for at least some of the water in these two vents is an obvious inference.

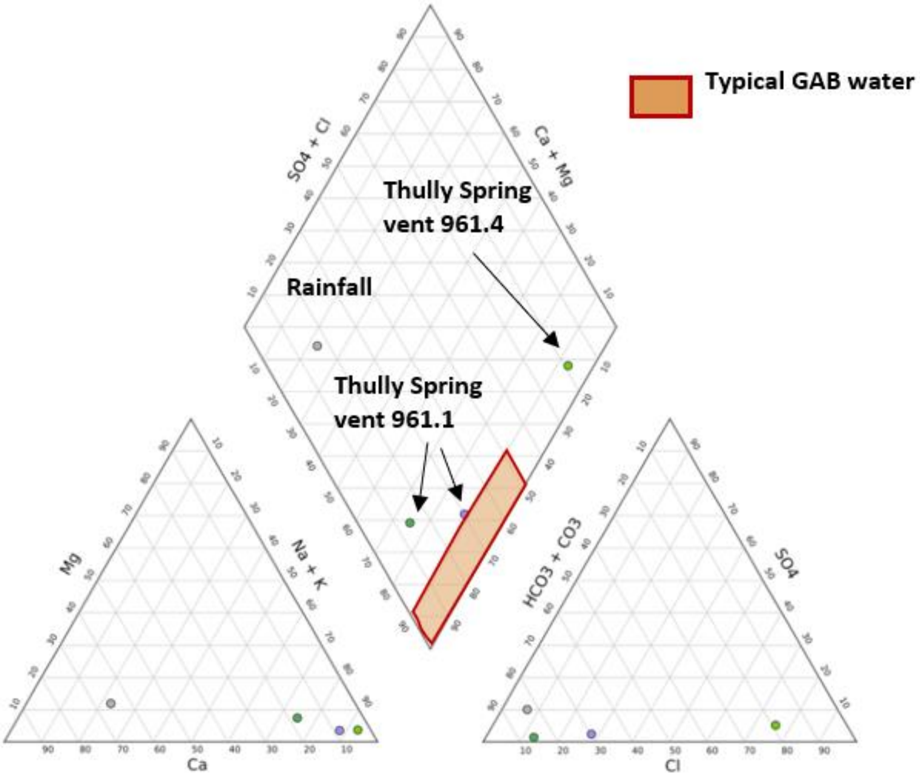

Figure 64: Piper plot Thully Spring

5.1.13.5.2 Isotope information

Based on the isotope analysis presented in Section 4.5 the following main outcomes are relevant for the conceptualisation of this spring:

- The two isotopic signature of the ratios of ^{2}H and ^{18}O for vent 961.1 collected in March 2018 and July 2019 plot close together and slightly lower than the Cobar LMWL. The sample collected from vent 961.4 in July 2019 is enriched in ^{2}H and ^{18}O compared to the sample collected from 961.1. This may suggest that water source for 961.1 and 961.4 are different, at least in part. Neither of the two springs group close to the groundwater bores (see Figure 6, Figure 7 and Figure 8).
- The October 2018 sample from vent 961.1 showed a tritium activity of 3.38. This is similar to the tritium activity in rainfall and suggests that the water is modern possibly of meteoric origin.
- the pMC value is 99% at vent 961.1 and 102% at vent 961.4, suggesting that the water is modern.
- The ^{36}Cl/Cl$^-$ ratio is 154x10^{-15} at vent 961.1. This is ten times higher than the groundwater bores in the area and over three times higher than the ^{36}Cl/Cl$^-$ ratios of the Hooray Sandstone in that area (Map 45 of Ransley et al. 2015), suggesting modern water.

5.1.13.6 Machine Learning outcomes

According to the PCA analysis this spring is in a transitional location. It has a low to moderate likelihood of some connection between the aquifer and that spring. Figure 65 shows its location in the PCA analysis.

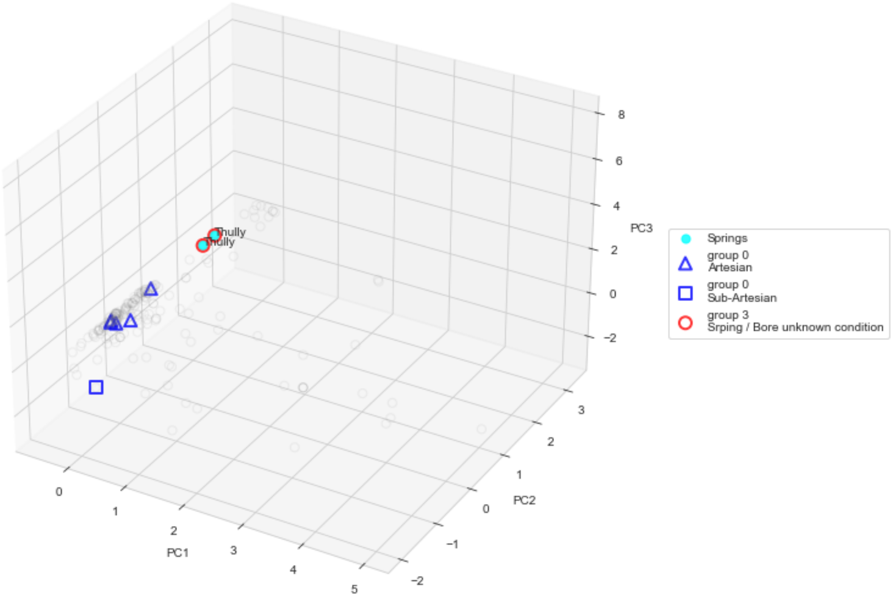

Figure 65:: Relative location of spring Thully and closest bores in 3 dimensional PCA plot

5.1.13.7 Conceptualisation and typology

The main components of the information reviewed to support the conceptualisation of the spring at Thully are summarized below:

- DPIE describes Thully Spring complex as consisting of active and inactive mud springs close to a dam and a defunct windmill (DPIE, 2020b). There is no evidence of active flow (“bubbling”).
- The geological review of the area indicates that at 190 m depth there is no evidence of Hooray Sandstone, although artesian flows are clearly present. There are no knowns faults close to Thully Spring.
- The two vents sampled show different composition in major ion composition, although broadly similar to GAB bores (i.e. sodium+potassium-bicarbonate/chloride type). The pH of both vents is similar to GAB, while salinity differs.
- The isotopic signature from vent 961.1 suggests the water source for this vent is modern, in particular the tritium activity would suggest the water source to be surface water.

Water from the two vents at Thully Spring cannot be regarded with any confidence as being derived purely from the GAB on the basis of the information provided.

Although the two vents do not have the same suites of isotopic analyses, the ^{3}H isotopic signature from vent 961.1 is consistent with a meteoric water source. Isotopic analyses common to both vents indicate modern water, perhaps. associated with Quaternary sediments and maybe a subtle topographic low zone.

In parallel with the chemical and isotopic data, the site is inferred to have been a reliable source of water with multiple vents in a low relief, arid area. That aspect alone argues for a GAB source element.

We suggest that the GAB is a small but persistent source of water for Thully Spring, with variable connectivity up to the individual vents and providing the persistence of wet conditions with minimal discharge rates. In this instance, the chemistry of Vent 961.1 suggests a greater GAB input, and a low salinity due to dilution with meteoric water and the other vent (961.4) owes its existence to a GAB source but the chemistry is presumably dominated by evaporation of shallow groundwater to give a chloride signature.

5.1.14 Youltoo Spring

5.1.14.1 General setting and summary of field observations

Youltoo Spring is located 270km west of Bourke.

DPIE describe Youltoo Spring as an active mud spring with water expression and expected rainfall influence. The spring is wide at the head and narrows to a long narrow channel at the tail, with turbid water at the time of sampling (see Figure 66). It is located in a low-lying clay pan. DPIE indicate some ruins and a dam are located nearby.

One sample was collected from the Spring in July 2019 and given the Vent number 1001.

Figure 66: Youltoo Spring July 2019 (DPIE, 2020b)

5.1.14.2 Ecology

Ecology survey found no fish, some aquatic plants and macrophytes and macroinvertebrates in abundance in the tail (DPIE, 2020b). DPIE did not assign an ecological value for the spring.

5.1.14.3 Geological and Hydrogeological setting

The 1:250,000 scale surface geology extracted from the White Cliffs 1:250 000 Geological Sheet (Rose et al, 1964) is presented on Figure 67. The Rolling Downs Group occurs at Youltoo Spring and is variably covered by colluvial deposits of angular, poorly sorted sands and gravels. Occurrences of Quaternary fluvial sands, silts and clays also occur along local waterways.

The GABWRA 3D visualisation (Geoscience Australia, 2013) of the GAB suggests the Rolling Downs Group in this area is typically less than 30 m thick and overlies the Hooray Sandstone which is the dominant GAB formation. The Hooray Sandstone gently rises from northeast to southwest as the underlying basement rocks become shallower. The southern margin of the GAB is located approximately 32 km south of Youltoo Spring. There are no known faults or basement highs in the vicinity of this spring. The nearest known fault is about 25 km northeast of the spring and oriented north – south, somewhat parallel to the groundwater flow direction in the Hooray Sandstone in this area (Ransley et al, 2015). The fault is also mapped in both the basement rocks beneath the GAB and within the Rolling Downs Group with the White Cliffs geological map sheet suggesting that it may continue further to the south, passing within 15 km of this spring.

A second fault is located about 40 km to the northeast of this spring (Ransley et al, 2015) and oriented northwest – southeast. It is not known whether it is present in the basement rocks only or continues into the GAB formations.

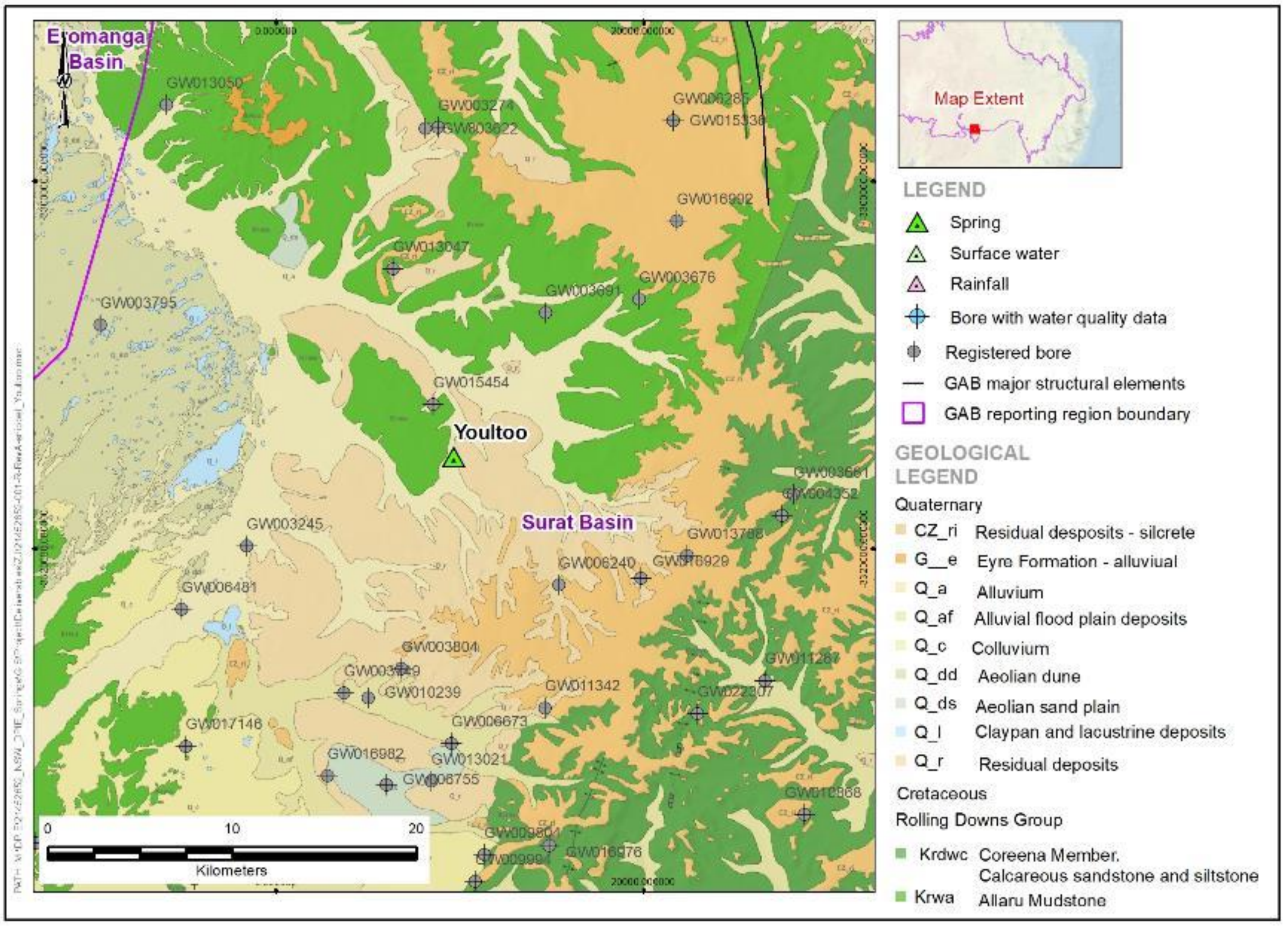

Figure 67: Youltoo location plan and surface geology (Rose et al, 1964)

5.1.14.4 GAB groundwater levels/artesian conditions

Based on the information provided by DPIE and available on the online portal by Water NSW, there are no bores within 20 km with recent water level or pressure information or indication about whether they are artesian.

5.1.14.5 Hydrogeochemistry

One sample was collected from Youltoo in July 2019 and analysed for major ions, metals and isotopes (^{2}H, ^{18}O, ^{87}Sr, ^{36}Cl, ^{14}C and ^{3}H).

5.1.14.5.1 Water quality

- Water from this vent is caracterized by neutral pH (7.6-7.9). There is a discrepancy between the field measurement of pH of 9.8 and the laboratory measurement of 6.8.
- The salinity of the sample is low (450 mg/L).
- The composition in major ions is shown graphically on the Piper plot on Figure 68. The sample from vent 1001 can be seen to sodium-bicarbonate type with significant chloride.

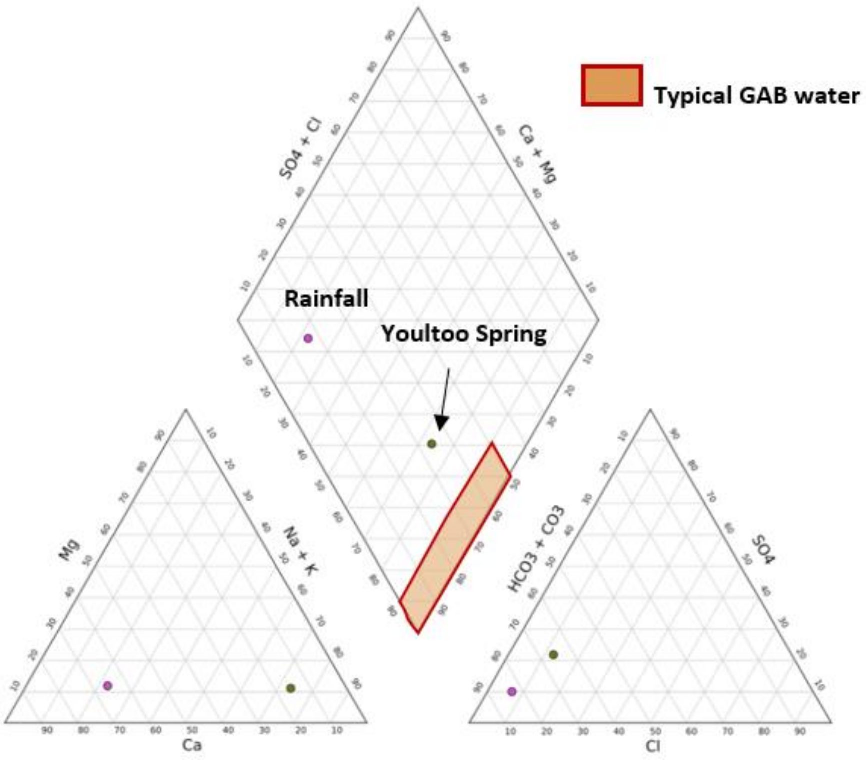

Figure 68: Piper plot of Youltoo Spring

5.1.14.5.2 Isotope information

Based on the isotope analysis presented in Section 4.5 the following main outcomes are relevant for the conceptualisation of this spring:

- the isotopic signature of ^{2}H and ^{18}O is slightly lower than the Cobar LMWL. The sample from Youltoo does not plot close to the groundwater bores.
- The sample presents a high tritium activity of 2.27, suggesting modern water.
- The pMC value was measured at 93%, suggesting that the water is modern.
- The ^{36}Cl/Cl^{-} ratio of 126x10^{-15} is similar to the ^{36}Cl/Cl^{-} ratio of GW040866, which is understood to be monitoring the Rolling Downs Group (based on GABWRA 3D model and from which other artesian supplies have been obtained) and located 38 km to the southeast. The spring ratio is 3 times higher than the ^{36}Cl/Cl^{-} ratios of the Hooray Sandstone in that area (Map 45 of Ransley et al., 2015).

5.1.14.6 Machine Learning outcomes

The spring shows no water quality compatibility with the local bores. This suggests the spring is sourced from aquifers or surface water that is not being sampled by the local bores. Figure 69 shows its location in the PCA analysis.

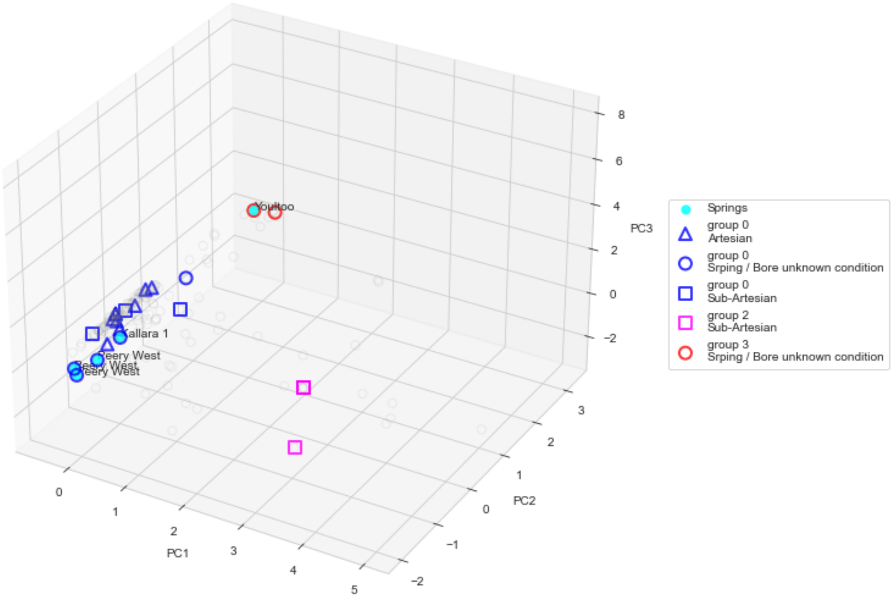

Figure 69:: Relative location of Youltoo Spring and closest bores in 3 dimensional PCA plot

5.1.14.7 Conceptualisation and typology of Youltoo Spring

The main components of the information reviewed to support the conceptualisation of the spring at Youltoo are summarized below:

- DPIE indicate a possible mud spring that may have been covered with rainwater and local runoff perhaps. DPIE does not indicate evidence of low (i.e “bubbling”) nor do they report other remnant mounds.
- The area is underlain the Rolling Downs Group with a thickness of approximately 30 m. The are no known faults or basement highs close to the spring.
- The water signature of general parameters, major ion composition and salinity is similar to GAB water (although slightly higher in chloride).
- Radioactive isotope results indicate that the water source as sampled cannot be from the GAB solely since there are clear indications of meteoric water or shallow modern groundwater.

It is not possible to confidently decide a water source for this spring, based on the single collected sample and the possibility of the surface water body there being derived from rainfall before sampling. On balance, it judged most likely to be a GAB spring with a low flow, possibly derived from the Rolling Downs Group rather than the Hooray Sandstone, and with mixing from both meteoric water and shallow, modern groundwater.

5.1.15 Youngerina Spring

5.1.15.1 General setting and summary of field observations

Youngerina Spring is located 100 km northwest of Bourke.

DPIE (2020b) describes Youngerina Spring, Vent number 973, as being a long-inactive spring site. A tank with water is observed nearby as well as numerous inactive, crescent shaped, mound spring vents consisting of consolidated calcareous silt in red sandy soils.

No photographs were included in DPIE's field report. One sample was collected but it is unclear where it was collected. It is assumed it was collected from the water tank.

5.1.15.2 Ecology

An ecology survey was not made available for Youngerina Spring.

5.1.15.3 Geological and Hydrogeological setting

The surface geology in the area of Youngerina Spring is shown on the Yantabulla 1:250,000 geology map (Wallis & McEwen, 1962) included on Figure 70. The Rolling Downs Group occurs at Youngerina Spring and is variably covered by Quaternary wind-blown sand dunes and clay pans.

GABWRA's 3D visualisation of the GAB suggests the Hooray Sandstone is present beneath the Rolling Downs Group at typically 50 m thick or less. This visualisation also suggests the thickness of both the Injune Creek Formation and Hooray Sandstone vary significantly in the area, and the latter may locally be absent.

Devonian granitic basement rocks outcrop less than 10 km west of this spring complex. This basement high point is expected to form a geological barrier to groundwater flow in the Hooray Sandstone.

Two (unnamed) faults run 7 km to the west and 20 km to the northeast of Youngerina Spring, in the underlying basement rocks. The fault to the northeast has an inferred length of about 40 km with both the Thooro Mud and Wapweelah Bore spring complexes being located close to its alignment. There is no evidence these faults are present in the GAB sediments, however. Rade (1954) suggests spring complexes at and in the vicinity of Youngerina may occur due to the interaction of regional groundwater flow, which is expected to be from northeast to southwest, with these structures. IESC (Commonwealth of Australia, 2014) also notes that the springs in the Yantabulla area occur along the eastern margin of a granitic basement horst, with small faults connecting Kullyna – Native Dog and Coonbilly–Youngerina springs

Nearby duricrust formations associated with near-surface weathered zones of the Rolling Downs Group may indicate vertical migration of pressurised groundwater from the Hooray Sandstone via regional fault sets through the Rolling Downs aquitard (Ransley et al, 2015).

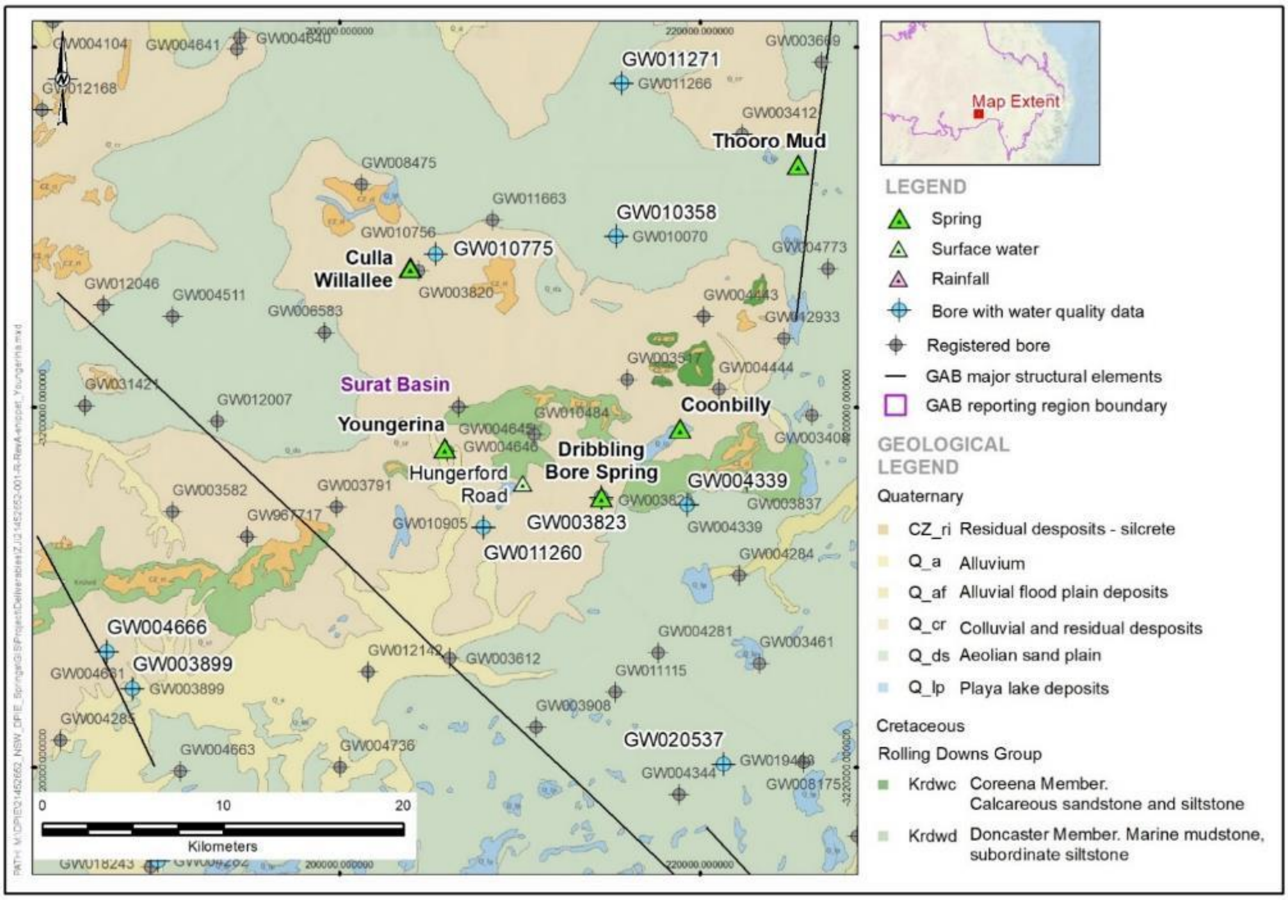

Figure 70: Youngerina location plan and surface geology (Wallis & McEwen, 1962)

5.1.15.4 GAB groundwater levels/artesian conditions

Based on the information provided by DPIE, information about artesian condition in 2019 are available for four bores within 20 km of Culla Willallee Spring (see location on Figure 29). All bores except GW004339, GW010775 and GW011271 were artesian in 2019.

5.1.15.5 Hydrogeochemistry

One sample was collected from Youngerina Spring in July 2019 and analysed for major ions, metals and isotopes (^{2}H, ^{18}O, ^{87}Sr, ^{36}Cl, ^{14}C and ^{3}H), although it is unclear what was sampled as the spring was described by DPIE as being inactive.

5.1.15.5.1 Water quality

The water sample is slightly basic (pH of 8.4) while the salinity is low (450 mg/L).

The composition in major ion shown graphically on the Piper plot on Figure 71 indicates the sample from Youngerina is magnesium-bicarbonate type and plots closer to the rainfall sample.

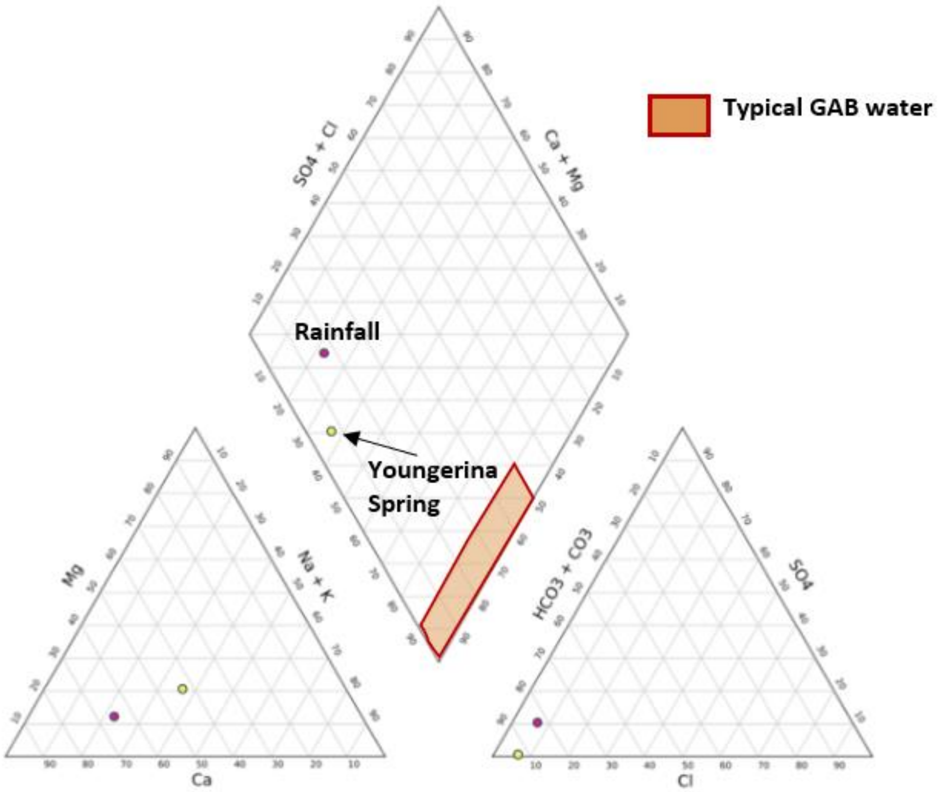

Figure 71: Piper plot Youngerina Spring

The sample collected from Youngering presents the following concentrations in dissolved metals:

- 620 µg/L of dissolved aluminium
- 310 µg/L of dissolved iron
- 11 µg/L of dissolved iron
- 61 µg/L of dissolved manganese
- 60 µg/L of dissolved nickel
- µg/L of dissolved zinc and
- 1100 µg/L of dissolved strontium.

The concentrations of other dissolved metals were below the detection limit or only slightly above.

5.1.15.5.2 Isotope information

Based on the isotope analysis presented in Section 4.5 the following main outcomes are relevant for the conceptualisation of this spring:

- the isotopic signature of ^{2}H and ^{18}O is slightly lower than the Cobar LMWL and is highly enriched (both in ^{2}H and ^{18}O) compared to the GAB groundwater bores.
- The sample showed a high tritium activity of 1.95 TU. This is slightly lower than the tritium ratio in rainfall and suggests that the water is relatively modern.
- the pMC value of 103% suggests that the water is modern.

- ^{36}Cl/Cl^{-} ratio of 141x10$^{-15.}$ This is three times higher than the ^{36}Cl/Cl^{-} of GW003823 and GW004339 understood to be monitoring the Hooray Sandstone and located 38 km southeast and 3 times higher than the ^{36}Cl/Cl^{-} ratios of the Hooray Sandstone in that area (Map 45 of Ransley et al., 2015).

5.1.15.6 Machine Learning outcomes

The individual spring water quality is highly compatible with the local bores suggesting a high likelihood of connection between the aquifer tapped by those bores and that spring. Figure 72 shows its location in the PCA analysis.

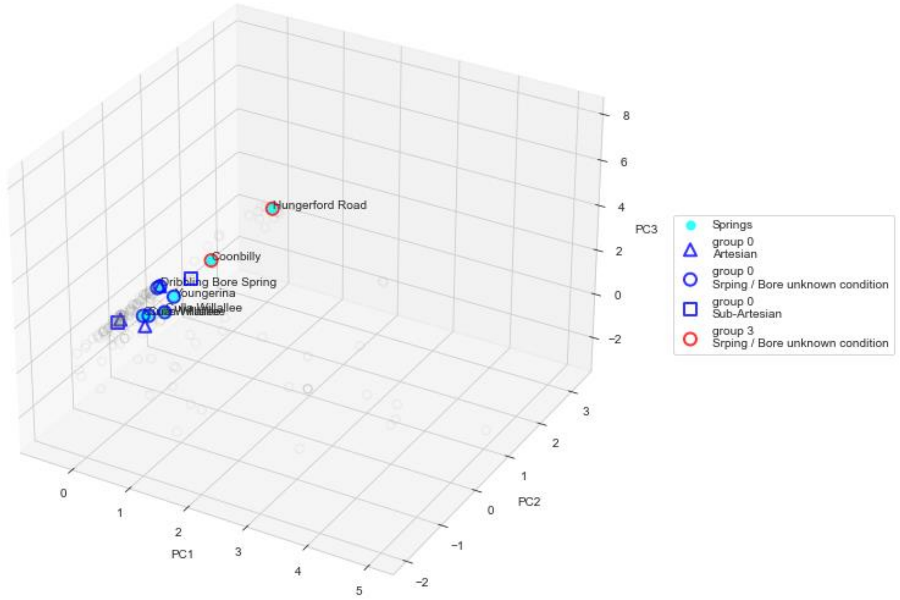

Figure 72: Relative location of Youngerina Spring and closest bores in 3 dimensional PCA plot

5.1.15.7 Conceptualisation and Typology of Youngerina Spring

The main components of the information reviewed to support the conceptualisation of the spring at Youngerina are summarized below:

- DPIE describe Youngerina Spring as being an inactive spring site. In addition, numerous remnant mound spring vents are reported nearby. Mound Springs alone provide strong evidence for GAB water emerging at the site.
- One water sample was collected but it is unclear where it was collected if the springs are dry.
- The geological review indicates the Rolling Downs Group occur at the spring to a depth of approximately 50 m and that it is underlain by the Hooray Sandstone.
- The composition in major ions is magnesium-bicarbonate type, different from any of the groundwater bores sampled and different from the typical major ion composition of the GAB. The pH is slightly basic (unlike the GAB) with low salinity (similar to the GAB).
- The isotopic signature is not consistent with the GAB but more consistent with meteoric water, runoff from recent rainfall or shallow groundwater.

The water source of the water sampled at Youngerina Spring is unlikely to come from the GAB. We have not seen evidence that there is a spring at this site.

5.2 Bogan River Supergroup

5.2.1 Coolabah Spring

5.2.1.1 General setting and summary of field observations

Coolabah spring is located 125 km southeast of Bourke.

DPIE describe Coolabah Spring as being a mud spring with water expression, and potentially additional vents, spaced approximately 20 to 50 m apart in the low-lying areas of the floodplain. DPIE describe the surrounding as showing “evidence of past GAB springs”.

The spring is used for livestock, and feral pigs wallow in the water. DPIE also describe evidence of shrinkage in the wetted area of the spring and that it may be affected from surface water runoff from the floodplain.

In the March 2018 survey, the landholder advised that 17 mm of rainfall was recorded at the property the day before sampling (DPIE 2020). One sample was collected during the March 2018 survey.

Figure 73: Coolabah (DPIE 2020)

5.2.1.2 Ecology

DPIE identify the groundwater dependent flora Coolabah spring to include Alternanthera angustifolia, Cynodon dactylon, Cyperacea spp.(unidentified), Marsilea drummondii and Muehlenbeckia cunninghamii. No commonwealth (EPBC Act 1999) or state (BC Act 2016) listed threatened plant species were present (DPIE, 2020b). Grazing disturbance was low and animal digging (soil disturbance) was high at the time of sampling.

DPIE describe the groundwater dependent fauna at the site to be restricted to macroinvertebrates and amphibians. One frog species was recorded directly adjacent to the aquatic zone of the spring: Crinia deserticola. In total, eleven different macroinvertebrate taxa were recorded. The most abundant were from the micro crustacean family Cyclopidae (DPIE, 2020b).

Compared to other springs sampled, Coolabah had low diversity (21% of all taxa sampled) and abundance. No commonwealth (EPBC Act 1999) or state (BC Act 2016 & Fisheries Management Act 1994) listed threatened species were present.

DPIE described this spring as having low ecological value.

5.2.1.3 Geological and hydrogeological setting

According to available stratigraphy and the mapped extent of the GAB by Habermehl and Lau (1997) Coolabah Spring lies within the outer margins of the GAB boundary. The GABWRA 3D Visualisation (Geoscience Australia, 2013) contradicts this boundary, showing the spring location approximately 5 km outside the interpreted extent of the GAB, in the metamorphic rocks of the Lachlan Fold Belt.

Figure 74 shows the 1:250,00 scale surface geology at the Spring extracted from Brunker (1971). The spring lies within residual deposits and alluvial soils.

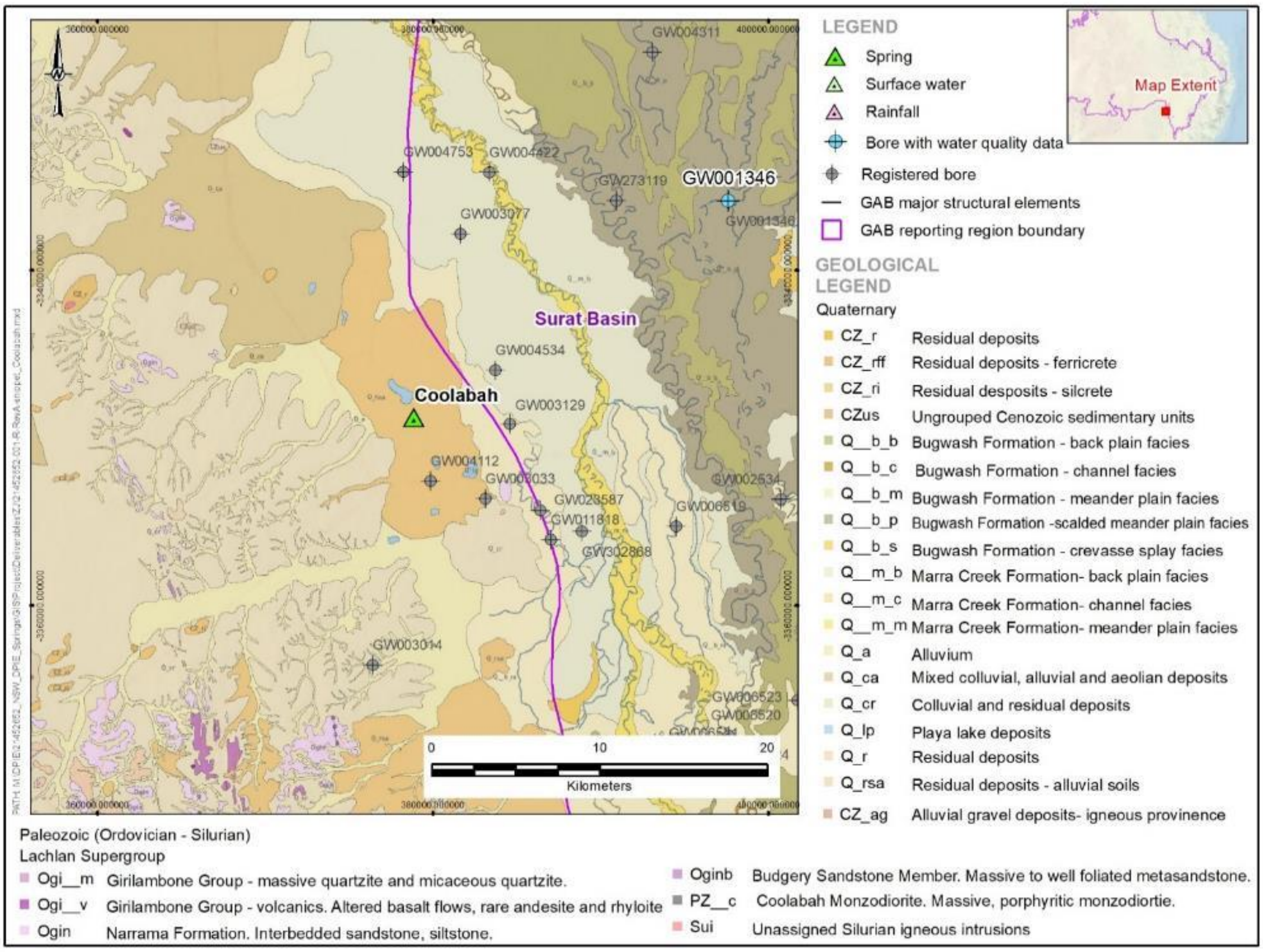

Figure 74: Coolabah location and surface geology

5.2.1.4 Hydrogeochemistry

One sample was collected from Coolabah in March 2018 and analysed for major ions, metals and isotopes (^{2}H, ^{18}O, ^{87}Sr, ^{36}Cl, ^{14}C and ^{3}H). The sample was collected the day after a rainfall event.

5.2.1.4.1 Water quality

Water from this vent is slightly acidic pH (6.4) and with low salinity (120 mg/L, derived from electrical conductivity measurement). The water is of sodium, potassium-bicarbonate type, broadly similar to GAB water although of higher salinity that is typical deep in the basin (see Piper plot on Figure 75).

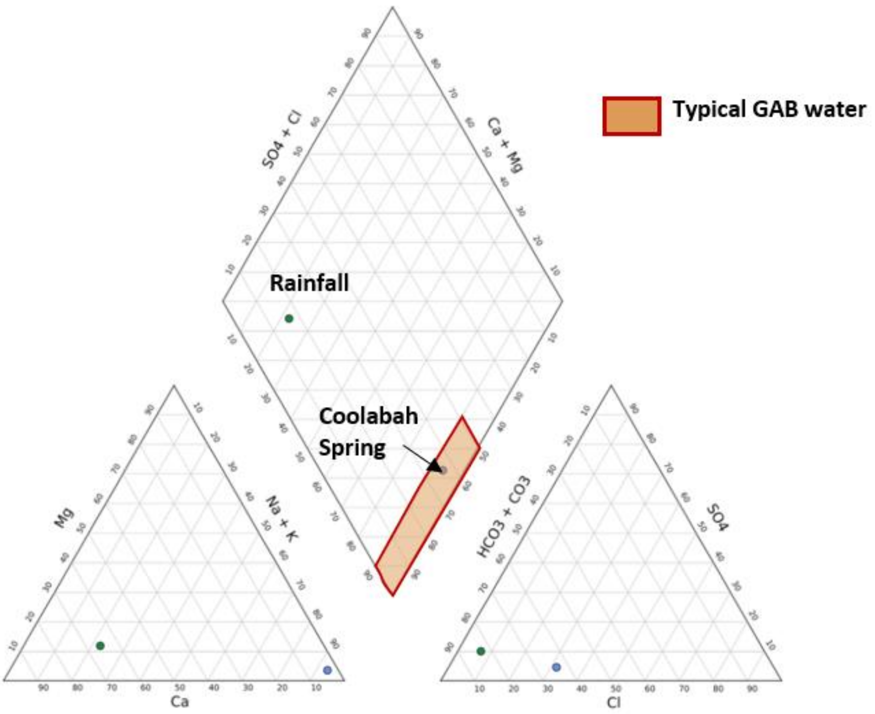

Figure 75: Piper plot Coolabah Spring

Several concentrations in dissolved metals are significantly higher than the detection limit including aluminium (1000 µg/L), iron (490 µg/L), manganese (38 µg/L) and strontium (11 µg/L). Concentration in dissolved arsenic, copper, lithium and nickel were slightly above the detection limit.

Similarly, several concentrations in total metals are significantly higher thant the detection limit including aluminium (23000 µg/L), iron (28000 mg/L), lithium (13 µg/L) manganese (470 µg/L), nickel (18 µg/L) strontium (50 µg/L) and zinc (54 µg/L). Concentration in total arsenic and lead were slightly above the detection limit.

5.2.1.4.2 Isotope information

Based on the isotope analysis presented in Section 4.5 the following main outcomes are relevant for the conceptualisation of this spring:

- The isotopic signature of ^{2}H and ^{18}O shows the sample from Coolabah depleted in ^{2}H and ^{18}O compared to the LMWL at Cobar. The isotopic signature is different to that of groundwater bores (i.e. does not plot close to the groundwater bores on Figure 6).
- The tritium activity was measured at 1.95 TU, suggesting modern water.
- The pMC is 92%, suggesting modern water.
- The ^{36}Cl/Cl^{-} ratio us 221x10^{-15}. This five times higher than the ^{36}Cl/Cl^{-} ratios of the Hooray Sandstone in that area (Map 45 of Ransley et al., 2015).

5.2.1.5 Machine Learning outcome

The spring shows no water quality compatibility with the local bores. This suggests the spring is sourced from aquifers or surface water that is not being sampled by the local bores. Figure 76 shows its location in the PCA analysis.

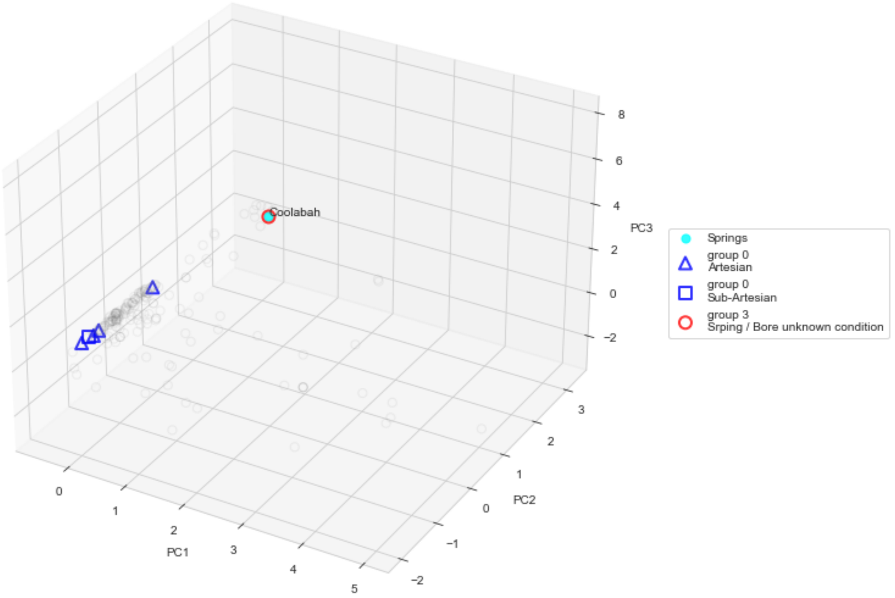

Figure 76: Relative position of Coolabah Spring and closest bores in 3 dimensional PCA plot

5.2.1.6 Conceptualisation and typology of Coolabah Spring

The main components of the information reviewed to support the conceptualisation of the spring at Coolabah are summarized below:

- DPIE describe Coolabah Spring as being as being a mud spring with water expression, and potentially additional vents. One sample was collected during the March 2018 survey after a rainfall event.
- The geological review indicates that Coolabah Spring lies just outside the extent of the GAB boundary.
- The composition in major ions is sodium+potassium-bicarbonate type, somewhat similar to the major ion composition of the GAB. The pH is slightly acidic (unlike the GAB) with higher salinity than deep in the GAB.
- The isotopic signature is not consistent with the GAB but more consistent with meteoric water, runoff from recent rainfall or shallow groundwater.

The water source of the water sampled at Coolabah Spring is likely not from the GAB, although a GAB source cannot be ruled out. It is not clear whether the spring flow can be sustained by meteoric water, surface runoff or non-GAB water in the Tertiary sediments. Being close to the generalised margin of the GAB, it is conceivable that it is a basement (Lachlan Fold Belt rocks) discharge mixed with meteoric water and local modern shallow groundwater. Note that the sample was collected soon after rainfall.

5.2.2 Cumborah Spring

5.2.2.1 Summary of field observations

Cumborah Spring is located about 500 metres north-west of the village of Cumborah in northern New South Wales (180 km northeast of Bourke).

DPIE describe the spring as consisting of four inactive vents, some of which likely containing rainwater. The main active vent (Vent 992) is described as having bubbling conduits (shown on photograph b on Figure 77). The area around the main vent was waterlogged. DPIE also describe a second active vent (Vent 992.3) which is actually a 2 m excavation equipped with a pump providing water for local use. Water samples were collected from the two main vents (992 and 992.3).

Cumborah is listed in Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources (2008) and Queensland Herbarium (2015), it also holds significant cultural heritage values to the local Aboriginal people.

Figure 77: a) drone photo of the main spring vent, b) main vent 992 and c) excavated vent with pump vent 992.3 (DPIE, 2020b)

5.2.2.2 Ecology

Cumborah Spring holds significant cultural heritage values to the local Aboriginal people. The site is tied to the dreaming stories of the ‘Rainbow serpent’.

DPIE ecological surveys were carried out and identified that groundwater dependent flora are present however an ecological value was not determined for this spring.

5.2.2.3 Geological and hydrogeological setting

Cumborah Spring is located in the Surat Basin on an outcrop of the Griman Creek Formation (Commonwealth of Australia, 2014) of the Rolling Downs Group as shown on the surface geology map on Figure 78, extracted from the Angledool 1:250 000 Geological Map (Burton, 2011). The Griman Creek Formation consists of thinly bedded medium to fine sandstone, siltstone and mudstone with sporadic coal seams, and in the vicinity of the Cumborah spring complex is unconformably overlain by Tertiary sediments, most notably conglomerate and pebbly fine to coarse-grained quartz-rich sands.

GABWRA 3D visualisation of the GAB indicates the Hooray Sandstone is present beneath these springs and is the dominant GAB unit with thicknesses up to 600 m. The Hutton Sandstone may also be present beneath the Hooray Sandstone, separated by the Injune Creek Formation. Close to Cumborah spring complex the thickness of the Rolling Downs Group is up to 300 m thick.

IESC (Commonwealth of Australia, 2014) notes several geological faults or other structures have been mapped to the north and north-west of the Cumborah spring complex. The depth of faulting is not known, however IESC (Commonwealth of Australia, 2014) note they appear to be associated with the Tertiary sediments and suggest the Cumborah springs may be sourced from the near-surface shallow Tertiary aquifers as opposed to much deeper GAB aquifers.

No water chemistry data are available for water bores within a 10-kilometre radius of the spring complex.

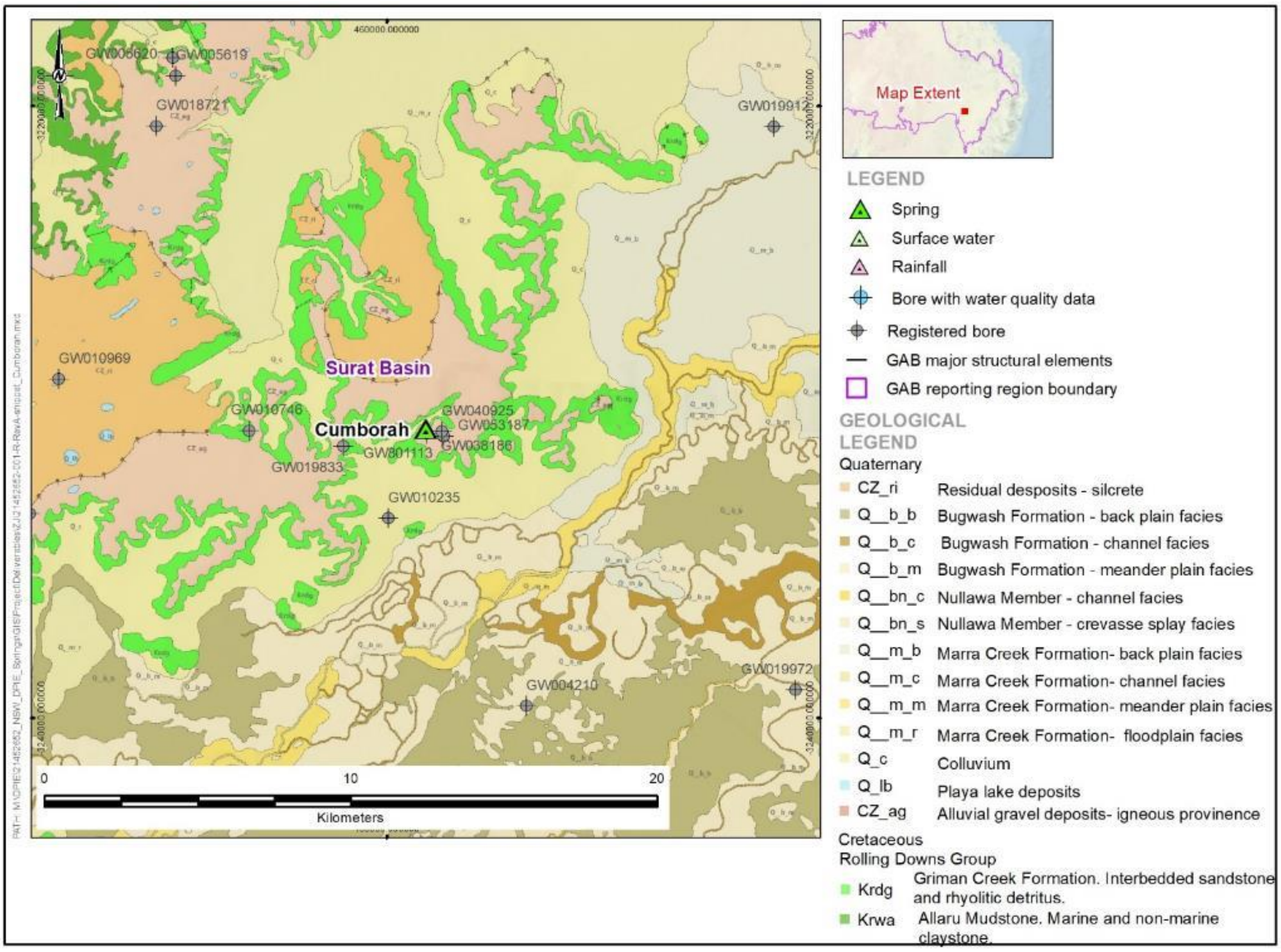

Figure 78: Cumborah location and surface geology

5.2.2.4 Hydrogeochemistry

Two samples were collected from Cumborah in March 2018 from vent 992 and 992.3 and analysed for major ions, metals and isotopes (^{2}H, ^{18}O, ^{87}Sr, ^{36}Cl, ^{14}C and ^{3}H).

5.2.2.4.1 Water quality

Water from both samples is neutral pH (7.2-7.3) with low salinity (410-430 mg/L). The water is of sodium, potassium-chloride type, unlike the GAB which is generally sodium-bicarbonate dominant (see Piper plot on Figure 79).

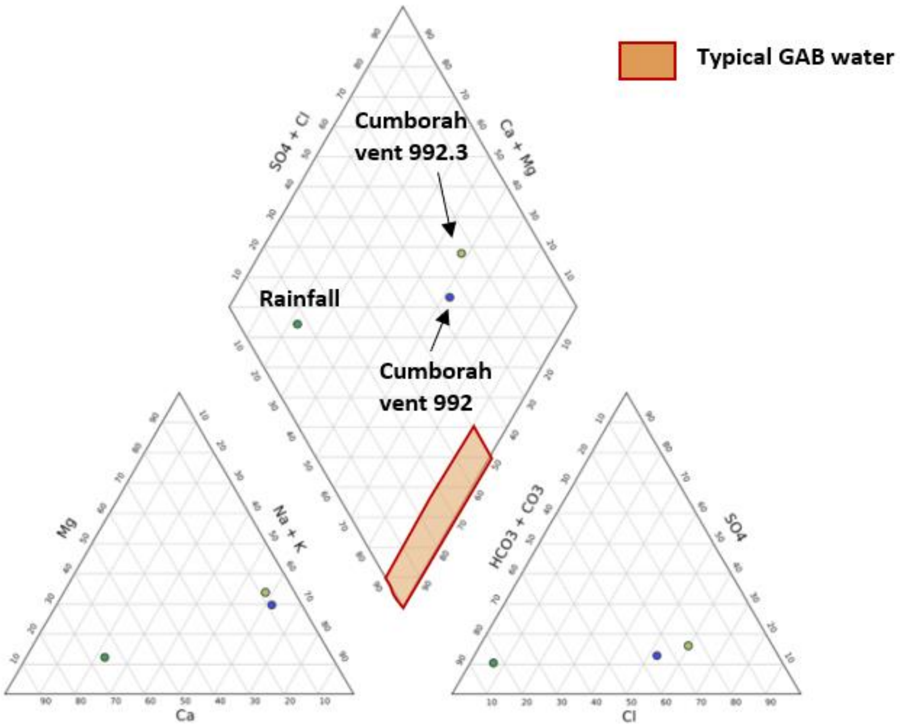

Figure 79: Piper plot Cumborah Spring

The concentration in metals and metalloids is different between the two samples. Generally, more metals are observed in vent 992.1 than 992.3. Concentration of several dissolved metals (iron, manganese, aluminium, cadmium, chromium and copper) are observed in the sample taken from vent 992 but not in vent 992.3 (although concentration in dissolved copper is observed in vent 992.3 but not 992).

In addition, concentration in several total metals (alumiun, iron, lead, maganese, nickel and zinc) are between 7 and 230 times higher in the sample from vent 992 compared to the sample from vent 992.3.

5.2.2.4.2 Isotope information

Based on the isotope analysis presented in Section 4.5 the following main outcomes are relevant for the conceptualisation of this spring:

- The isotopic signature of the ratios ^{2}H and ^{18}O of both samples is similar, LMWL for COBAR and GWML and is slightly enriched in both ^{2}H and ^{18}O compared to the GAB groundwater bores.
- The tritium activity of both samples is similar (1.1 and 1.21 TU) and suggests modern water.
- The pMC of both samples is similar (103% and 102%) and suggests that the water is modern.
- the ^{36}Cl/Cl^{-} ratio of both samples is similar, 378×10^{-15} for vent 992 and 400×10^{-15} for vent 992.3. This 10 times higher than the ^{36}Cl/Cl^{-} ratios of the Hooray Sandstone in that area (Map 45 of Ransley et al., 2015).

5.2.2.5 Machine Learning outcome

The spring does not have bores in the vicinity to evaluate the water quality compatibility. However, the global PCA analysis suggests the spring is sourced from aquifers or surface water that has not been sampled.

5.2.2.6 Conceptualisation and typology

The main components of the information reviewed to support the conceptualisation of the spring at Cumborah are summarized below:

- Cumborah Spring includes one main vent (vent 992), a second vent consisting of a 2-meter excavation equipped with a pump (vent 992.3) and other smaller vents. Two water samples were collected from Vents 992 and 992.3.
- The geological review indicates that Cumborah Spring lies in the Surat Basin on an outcrop of the Griman Creek Formation.
- The pH of this spring is neutral with low salinity (similar to GAB water). The composition in major ions is sodium+potassium-chloride type, unlike GAB water.
- The isotopic signature is not consistent with the GAB but more consistent with meteoric water, runoff from recent rainfall or shallow groundwater.

The water source of the water sampled at Coolabah Spring is likely not from the GAB. However, it is unclear whether its flow can be sustained by meteoric water, surface runoff or non-GAB water in the Tertiary sediments.

5.3 SPRING GROUPS AND TYPOLOGY SUMMARY

Table 5 summarises the spring grouping and typology determined from the work completed in this assessment. The definitions of the groups used to classify the springs are summarised below in

Table 4. In addition, Table 5 includes a qualitative description of the confidence level of the conceptualisation of each spring, described as low, moderate and high.

The structural conceptual model types are described in Appendix A while the classification of the machine learning outcome is described in Section 4.6.

Table 4: Definitions of groups used in spring classification

Model Type	Classification Name	Definition
Structure	Conceptual Model 1b	Basin margin, structure (fault zone)
Structure	Conceptual Model 1c	Mid-basin, structure (fault zone)
Structure	Conceptual Model 2	Basin margin, sediment thinning
Structure	Conceptual Model 3	Basin margin, structure / sediment thinning
Structure	Conceptual Model 4	Astrobleme
Machine Learning outcome	Group 0	Highly compatible with GAB bores
Machine Learning outcome	Group 1	Anomalous
Machine Learning outcome	Group 2	Transitional composition
Machine Learning outcome	Group 3	Low compatibility with GAB bores
Wetland type	1a	Permanent regional and local groundwater systems

Model Type	Classification Name	Definition
Wetland type	1b	Permanent regional and local groundwater systems with surface water influence
Wetland type	2	Semi-permanent, diffuse flow from likely sub-artesian source
Wetland type	3	Intermittent flow from regional and local groundwater system sources
Wetland type	4b	Semi-permanent, fresh spring, connected to local groundwater and surface water

Table 5: Spring group and typology summary

Spring	Spring Group	Wetland Type	Structural Setting	Machine Learning Grouping	Water Source	Ecological Rating	Confidence level
Bingewilpa	Bourke	1a	not applicable, free flowing bore	Group 2	GAB but wetland fed from adjacent bore	-	High
Colless	Bourke	2	1c - Mid-basin, structure (fault zone)	Group 3	GAB with some modern water mixing	-	Moderate
Coonbilly	Bourke	2	1c - Mid-basin, structure (fault zone)	Group 3	GAB with abundant modern water mixing	Low	Moderate
Culla Willallee	Bourke	2	1c - Mid-basin, structure (fault zone)	Group 0	Possibly low GAB source flow with mixing	Low	High
Gooroomero	Bourke	2	Undetermined	Group 3	Low potential to be GAB, has a modern signature	-	High
Lila	Bourke	1a	1c - Mid-basin, structure (fault zone)	Group 3	Low potential to be GAB, has a modern signature	-	Low
Mulyeo	Bourke	2	not applicable, free flowing bore	Group 0	GAB but wetland fed from adjacent bores	Low	High
Native Dog	Bourke	2	1c - Mid-basin, structure (fault zone)	Group 3	Likely evaporatively-concentrated local runoff	Low	High

Spring	Spring Group	Wetland Type	Structural Setting	Machine Learning Grouping	Water Source	Ecological Rating	Confidence level
Old Gerara	Bourke	1b	1c - Mid-basin, structure (fault zone)	Group 3	Chemistry not consistent with GAB but strong flow	Low	Moderate
Peery West	Bourke	1b	2 - Basin margin, sediment thinning	Group 0	GAB	High	High
Tharnowanni	Bourke	-	1c - Mid-basin, structure (fault zone)	Group 3	Not GAB	-	High
Thooro Mud	Bourke	1b	1c - Mid-basin, structure (fault zone)	Group 0	Likely GAB with mixing	Low	Moderate
Thully	Bourke	1b	1c - Mid-basin, structure (fault zone)	Group 3	Likely low GAB source flow with mixing	Low	Low
Youltoo	Bourke	1b	2 - Basin margin, sediment thinning	Group 3	Ambiguous, maybe GAB aquitard	-	Moderate
Youngerina	Bourke	1b	1c - Mid-basin, structure (fault zone)	Group 0	Maybe GAB with mixing	-	Low
Coolabah	Bogan River	1b	2 - Basin margin, sediment thinning	Group 3	Ambiguous	Low	Moderate
Cumborah	Bogan River	3	Undetermined	Group 3	Ambiguous with modern signature and ionic composition which suggests not a GAB source	-	High

6.0 KNOWLEDGE AND INFORMATION GAPS

Throughout the assessment and conceptualisation of the springs, gaps in the overall knowledge and the information available were identified. This knowledge and information gaps relate to the following areas:

- Conflicting and limited understanding of the depth and thickness of the GAB geological formations.
- Bore lithology and construction details are in some cases limited.

- There is some variability in the sampling of the springs (different vents were sampled, some springs were sampled after rainfall events).
- There is some variability in the description of each spring and photos were not always available.
- Data gaps and anomalies in analytical and location data from spring survey.

A detailed description of the knowledge and information gaps is presented in the table in Appendix D.

7.0 RECOMMENDATIONS FOR ADDITIONAL INVESTIGATIONS

DPIE has requested recommendations be provided for further investigation to improve the confidence of the conceptualisation of the spring, inform spring management and guide decisions for future GAB springs surveys. An addendum to this report is proposed which will outline a process for ranking spring value to guide future management decisions.

7.1 General comments on future actions

Should DPIE seek to better understand the mechanisms and confirm any reliance on GAB, the following should be considered:

1) ***Monitoring:*** simply extending existing monitoring, repeating sampling and analysis work from time to time or on a regular basis may not provide value unless the sampling is linked to wet and dry periods (regarding precipitation). Such monitoring will add data, but not necessarily useful data. This would maintain familiarity with springs' locations, surface conditions and appearance and provide information on changes to flow. Fixed photo points may be a useful adjunct to future assessment.
2) ***Mixed waters***: the vast majority of the springs exhibit characteristics of mixed sources of water, most with strong indications of a GAB source with additional "modern" water from rainfall and local runoff near the spring or shallow groundwater of modern origin.
    a. More specialist interpretation of the isotopic data might resolve, at least semi-quantitatively, the relative proportions of GAB water and modern water.
    b. More sampling will be useful, with consistent parameter selection.
3) ***Prioritisation***: some springs may be more important than others for ecological or other reasons. Some may not merit any more study other than occasional visits to verify their condition. For the springs judged high priority for which further clarification of their classification or behaviour is required, designing a study program would be a valuable approach.
    a. Study programs would be site-specific.
    b. Seasonal variations are likely to affect recharge and evaporation of surface water and shallow groundwater. A regular schedule of visits may, or may not, be worthwhile, depending upon the specific objectives, spring by spring.
    c. Rainfall in these areas can be event-based rather than seasonal. A set of data during a dry period, perhaps six months or more after the last rainfall, might be a way of minimising the effects of precipitation and surface water that has accumulated near or over a particular vent. This approach might reduce the ambiguity where water of GAB characteristics chemically had isotopic evidence of modern waters.
    d. Other environmental aspects may be important for particular springs, this judgement is beyond the scope of this study.

4) ***Parameters***:

a. the addition of nitrate (NO_3) to the suite of analytes, may provide a possible indicator of shallow groundwater, as it is absent from the GAB water but not uncommon in arid zone shallow aquifers.

b. It is debatable whether the metal analyses should be continued, at least for the purpose of characterising the springs. There may be other reasons for measuring metal concentrations.

c. It is debatable whether the ^{87}Sr analyses should be continued, at least for the purpose of characterising the springs.

7.2 Specific Recommendations

Table 6 provides a simple list of what would be the next actions for each individual spring. Most interpreted water origins indicate a mix of modern signatures from the isotopic analyses and strong hints of the basic sodium bicarbonate signature of typical GAB water. Springs predominantly had low flow rates, therefore with greater opportunity for mixing close to the surface with modern, shallow groundwater or local runoff that had accumulated near or submerging the vents. To reduce ambiguity, sampling during a known drought period would be a practical approach.

Table 6: Opportunities for further study

Spring	Source of water	Comments	Opportunities/Recommendations
Bourke Supergroup			
Bingewilpa	GAB but wetland fed from adjacent bore	Vent(s) likely submerged within dam	None. No spring to sample
Colless	GAB with modern water mixing	Vents inactive, no description of where sample was taken	Confirm nature of spring and presence of vent to sample confidently before extending
Coonbilly	GAB with abundant modern water mixing	Multiple small vents which are heavily grazed	Sample again after prolonged dry period to assess whether modern water signatures are still present
Culla Willallee	Maybe GAB with mixing	No description of spring or where sample was taken	Confirm nature of spring and presence of vent to sample confidently before extending
Gooroomero	Not confident is GAB and has modern signature	No description of spring or sample vent	Confirm nature of spring and presence of vent to sample confidently before extending
Lila	Not confident is GAB and has modern signature	Multiple vents without a clear description. Different vents sampled and intermittent flow, potential to halt completely and become hard to find	Confirm nature of spring and presence of vents, to sample confidently before extending. Select single vent for any future sampling.
Mulyeo	GAB but wetland fed from adjacent bores	Spring not found	None. No spring to sample
Native Dog	Probably evaporatively-concentrated local runoff	Multiple inactive vents, sample taken from one which had pooled water	Check and sample again after prolonged dry period to assess whether spring is active or inactive.

Spring	Source of water	Comments	Opportunities/Recommendations
Old Gerara	Chemistry not consistent with GAB but strong flow	Active 200 L/hour vent and adjacent bore, both sampled	Resample spring
Peery West	GAB	Multiple mounds with varying flow rates	Given it is a genuine “mound spring” and has ecological significance, this is a high priority for further monitoring.
Tharnowanni	Not GAB	Dam, no evidence of spring	None
Thooro Mud	GAB with modern water mixing	Mud spring with multiple active and inactive vents	Sample after prolonged dry period for representative water sample, without potential meteoric or surface water influence, with complete range of analytes.
Thully	Maybe GAB with mixing	Multiple mud spring vents, no evidence of active discharge	Check and sample again after prolonged dry period to assess whether spring is active or inactive.
Youltoo	Ambiguous, maybe GAB aquitard?	Mud spring with rainfall influence	Sample after prolonged dry period for representative water sample, without potential meteoric or surface water influence, with complete range of analytes.
Youngerina	Maybe GAB with mixing	Multiple inactive mounds with no description of sample source	Sample after prolonged dry period for representative water sample, without potential meteoric or surface water influence, with complete range of analytes.
Bogan River Supergroup			
Coolabah	Ambiguous	Mud spring with possible multiple vents, sampled soon after rain	Sample after prolonged dry period for representative water sample, without potential meteoric or surface water influence, with complete range of analytes.
Cumborah	Ambiguous but modern signature and ionic composition suggests not GAB water	Multiple vents, one active and one sample from a shallow dug well at the site	Potential for occasional monitoring of condition and flow rate, given its local value as a water supply this is a low priority for GAB investigation.

8.0 CONCLUSION

The objective of this desktop groundwater assessment was to:

- identify the typology of the selected GAB NSW springs;
- conceptualise the groundwater dependency of these springs; and
- potentially define their aquifer source.

These objectives have been met within the limitations of the information and data sets available at the time of this assessment.

Springs have predominantly been found to be of uncertain or mixed origin sources. Few springs can be confidently stated not to have a GAB source, and conversely only three locations can be said to have evidence that infers they are likely from the Hooray Sandstone, two of these with an additional shallow or meteoric source.

Analysis of the major ions and isotopes has provided the clearest lines of evidence, reinforced by the outcomes of the Machine Learning analysis. Metals did not add significant evidence to the assessment. Further understanding of the effects of seasonal changes and weather events on the spring chemistry would provide further clarity for conceptualisation of the source of these springs.

Springs have been classified by their hydrogeological, structural, ecological and chemical characteristics. This grouping by typology brings together the conceptualisation of the springs into groups which share similar characteristics and through these classifications infers the origin of the spring water.

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10.0 IMPORTANT INFORMATION RELATED TO THIS REPORT

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

Signature Page

Golder Associates Pty Ltd

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https://golderassociates.sharepoint.com/sites/140889/project files/6 deliverables/21452652-001-r gab springs conceptualisation/21452652-001-r-rev0 gab springs conceptualisation rev0.docx

APPENDIX A

Literature Review

1.0 GAB SUMMARY

Much work has been done in the Great Artesian Basin (GAB) by Queensland, South Australian and NSW state governments, CSIRO, Geoscience Australia and private petroleum industries. The purpose of this literature review is to identify work done that is relevant and provides value and methodology to this assessment.

1.1 GAB Background

The GAB is Australia's largest groundwater basin, containing an estimated 64,900 million megalitres of groundwater (Hillier et al, 2002). It is comprised of the Surat, Eromanga, Carpentaria and part of the Clarence-Moreton geological sub-basins and their overlying Cenozoic cover. Recharge zones predominantly occur in the high rainfall areas of the north and east of Queensland and Northern NSW and extend west and south-west into arid and semi-arid regions across Queensland, New South Wales, South Australia and the Northern Territory. The hydrogeology of the GAB is complex, containing multiple sedimentary layers with varying groundwater flow rates, connections with overlying and underlying basins, vertical connections between aquifers and the presence of faults that can either act as lateral barriers to flow or as conduits between aquifers (Ordens et al, 2020).

The GAB underlies 208,000 square kilometres of New South Wales and in this area includes a part of the larger Surat and Eromanga geological basins that were deposited in the Jurassic and Cretaceous periods (210 to 65 million years ago). These geological basins overlie older geological basins such as the Bowen and Gunnedah Basins and older basement rocks (DPIE, 2020a). Over 8,500 water supply bores have been drilled in the NSW portion of the GAB since the commencement of exploration for groundwater in the late 1870s. Approximately 8,200 water supply bores currently exist in the NSW GAB (DPIE, 2020a), amongst these, 7,512 are sub-artesian bores and 687 are artesian bores. These groundwater sources support towns and industries across the western regions of NSW including pastoral, opal mining and spa baths. The GAB aquifers also support the irrigation industry in some recharge areas.

The artesian conditions found in the NSW GAB area support a number of artesian springs. Historically, water supply from GAB springs and associated wetlands, some with unique flora and fauna, flowed constantly, some showing seasonal variation. The springs and associated wetlands were a source of sustenance for the Aboriginal nations of these lands, often serving as clan meeting places, and have an important place in the Dreaming.

To preserve or maintain artesian pressure, to conserve some important springs and the valuable GAB resource that is fundamental for many farming and pastoral enterprises, licensing and legislation has long been in place. Recently, the Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources (DPIE, 2020a) has been introduced. Free-flowing bores are progressively being capped and open "bore drains" replaced with pipes that reticulate the water to tanks and troughs.

1.2 Information Sources

The following information sources were important to this assessment.

Great Artesian Basin Springs Survey Site Selection Methodology DPIE initiated the GAB Springs Survey in 2017 to increase the understanding of the ecological and hydrogeological features of the NSW GAB springs. Sample collection and field survey work was conducted through 2018 and 2019 during three field events to ground-truth the site locations and start data collection. The site selection methodology for the survey documents the site selection methodology.

The Great Artesian Basin Water Resource Assessment (DPIE, 2020a) was a desktop study conducted to provide an analytical framework to assist water managers in the GAB to meet National Water Initiative (NWI) commitments. It outlined the current status of water resources in the GAB and the potential impacts of climate change and resource development on those water resources. The Assessment highlighted areas that require further investigation, including a gap analysis.

Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources 2008

DPIE is the custodian of the WSP. The springs are documented as a single coordinate in a table of the published WSP, Schedule 4. Schedule 4 was developed by NSW Government based on historical datasets. Historical information used includes outcomes reported by Pickard (1992) of Macquarie University, who surveyed artesian springs in the western division of NSW.

Hydrogeological Atlas of the Great Artesian Basin (Ransley et al, 2015)

The Hydrogeological Atlas of the Great Artesian Basin (the atlas) presents a compilation of maps documenting some of the key regional geological, hydrogeological and hydrochemical aspects of the GAB. It discusses the regional baseline information which can be used to assess future changes to the resource. It draws upon recent work undertaken by Geoscience Australia (GA) that has contributed to a number of projects, such as the CSIRO-led Great Artesian Basin Water Resource Assessment (GABWRA).

Great Artesian Basin Water Resource Assessment (GABWRA) (Geoscience Australia, 2013)

The GABWRA was a comprehensive basin-scale assessment of water resources and the potential impacts of climate change and groundwater development to 2070. The assessment sort to collate the hydrology and geology knowledge for the whole GAB in a consistent way, including three-dimensional (3D) visualisation of the GAB.

A 3D visualisation was produced as part of the GABWRA. Key datasets of the 3D visualisation include contact surfaces between major aquifers and aquitards, well lithostratigraphic and wire-line data and hydrogeochemistry produced by State and National Agencies. GOCAD® was used to develop the 3D visualisation and create tools for visualisation and conceptualisation of the GAB through the Geoscience Australia World Wind 3D data viewer. While not a model, it is these datasets, which have formed the basis of previous models, that have been used within this assessment to determine supplement the information provided by DPIE to determine formation membership, geological and structural understanding.

Queensland Spring Database (Queensland Herbarium, 2015)

The Queensland dataset is information that has emerged since the WSP was implemented in 2008. The documentation has GAB spring data from 1995 to 2015. The data has been checked, tested and compiled by the Queensland Herbarium. The data in the database comes from a range of people and agencies.

DPIE requested the GAB spring dataset relevant to NSW from the Queensland Herbarium. The dataset was provided as an excel spreadsheet. Supporting documents for the dataset were also provided from Queensland Herbarium.

Groundwater Dependant Ecosystems spatial database (Referred to as Commonwealth GDE dataset) (Bioregional Assessment Programme, 2016)

The Groundwater Dependant Ecosystems spatial dataset is a spatial layer available through DPIE's geospatial databases, extracted as an Excel table for the NSW GAB groundwater sources extent. The dataset includes a single spring complex name, coordinate and brief description on data source and justification for site selection.

Independent Expert Scientific Committee (IESC, 2014) on Coal Seam Gas and Large Coal Mines

This report describes the surveys of 848 springs in four GAB supergroups: 252 in Springsure, 436 in Eulo, 145 in Bourke and 7 in Bogan River. The surveys included all of the likely Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) listed springs.

1.2.1 Groundwater Modelling

Four basin-wide GAB groundwater models have been developed in recent years:

- GABSIM (CSIRO, 2012) conceptualising the hydrostratigraphy, hydrogeology and groundwater flow systems of the GAB.
- GABHYD was developed based on the GABSIM model and uses the same hydrogeological framework.
- GABFLOW (Welsh, 2000) was developed to study the steady state of the Cadna-owie – Hooray Aquifer using MODFLOW software and recharge areas from Habermehl and Lau (1997). It predicted that significant increases in artesian pressure heads were achievable if the water wastage at the time could be stopped.
- GABtran (Welsh, 2006) was a transient model of the GAB developed using a calibration period from 1965 to 1999, much longer than in previous modelling. Excluding anthropogenic discharge, this model is most sensitive to recharge and hydraulic conductivity.

1.3 Geological and Hydrogeological Setting

1.3.1 Geological setting

The GAB geology on a regional scale is represented by around 47 geological Formations and 20 Members that make up the Eromanga, Carpentaria, Laura, Surat and Clarence-Moreton geological basins of the GAB. The basins have been formed through similar depositional history and tectonic evolution with underlying structural differences, particularly in Eromanga and Surat basins, that have formed the hydrogeologic basins (Ransley et al, 2015).

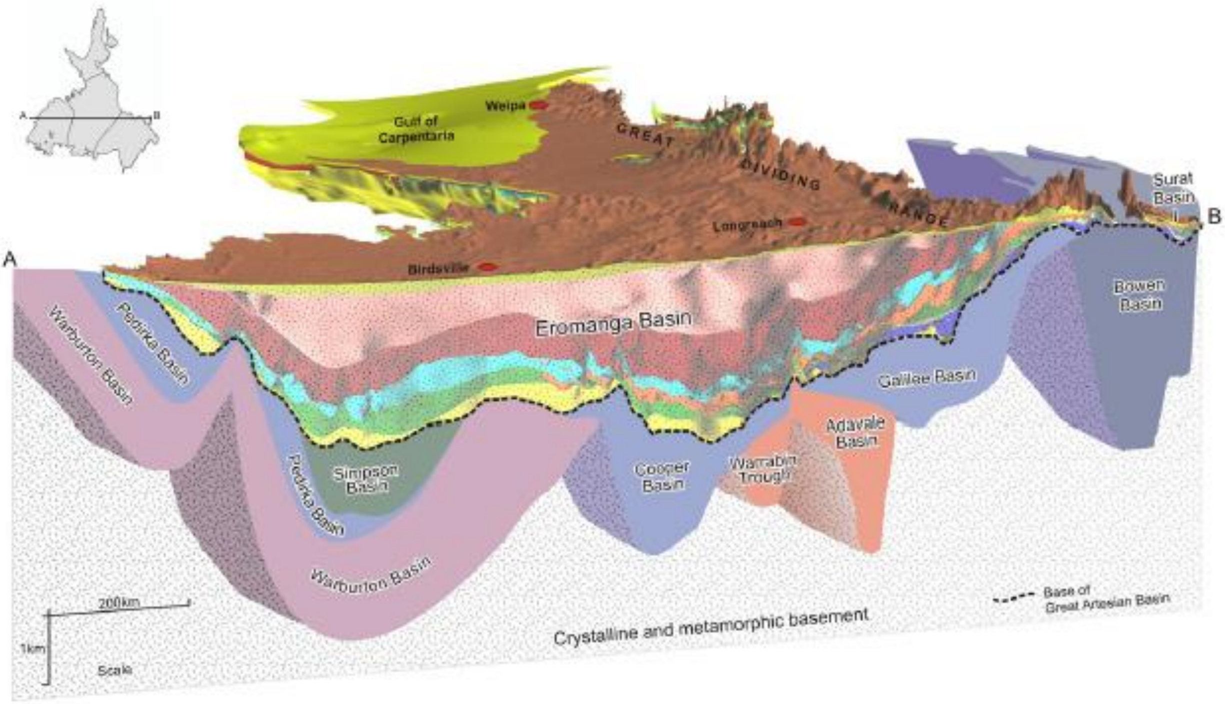


Figure 1: Three-dimensional illustration of a slice through the GAB (Smerdon et al, 2012)

The geology of the NSW GAB consists of five main surface geological sequences; Cenozoic unconsolidated sediments, Cenozoic extrusive volcanics, Mesozoic GAB sedimentary rocks, and Palaeozoic and Proterozoic fold belt rocks. These sequences are shown on the 3D section of the GAB presented on Figure 1 (Smerdon et al, 2012) and summarised in Table 1. The NSW GAB is part of the larger Surat and Eromanga geological basins that were deposited in the Jurassic and Cretaceous periods of Mesozoic era and overlie the older Bowen and Gunnedah Basins.

Table 1: Sequences of the NSW GAB

Geological Sequence	Description
Cenozioc Sediments	Unconsolidated sediments unconformably overlying the Rolling Downs Group and covers much of the NSW GAB (Ransley & Smerdon, 2012). The unconsolidated sediments are made up of clay, silt, sand, and gravels primarily deposited by the river systems of the Darling River drainage basin (Watkins & Meakin, 1996).
Cenozoic Extrusive Volcanics	The main peak near Coonabarabran and topographic high near Warialda in the WRP area are formed by Cenozoic extrusive volcanic rocks of basalts (DPIE, 2019).
Mesozoic GAB	The NSW GAB sedimentary rocks are part of the larger Surat and Eromanga geological basins consisting of sandstone, mudstone, siltstone, shale and coal. The Sedimentary Formations noted within the assessment area of the NSW GAB basin are presented in Figure 2 and Figure 3.
Surat Basin	The sediments of the Surat Basin inter-finger with sediments of the Eromanga Basin (Cresswell & Smerdon, 2012), both consisting of sandstone, mudstone, siltstones, shale and coal. The Surat Basin extends southwards from south-eastern Queensland into northern NSW where it is referred to as the Coonamble Embayment. This forms the central region of the NSW GAB. It unconformably overlies the Lachlan Fold Belt in the west and the New England Fold Belt in the east.
Coonamble Embayment	The GAB boundary on the north eastern side of the Coonamble Embayment is an erosional one, delineated by the limit of Pilliga Sandstone. In this area a groundwater divide demarcates the boundary between the GAB and the adjacent Oxley Basin. The western GAB margin is concealed beneath Cenozoic sediments where the GAB sediments abut deeply weathered schists and phyllites of the Ordovician Girilambone Group.
Palaeozoic and Proterozoic Fold Belt	The Palaeozoic Lachlan Fold Belt and New England Fold Belt, comprised of sedimentary rocks, metasediments and metavolcanics, make up some of the basement beneath the NSW GAB. They are significant to the GAB in areas where the basement becomes relatively shallow, resulting in thinning of the upper formations (DPIE 2020).

The geology of the assessment area is composed of various interlayed sandstones, mudstones, siltstones, shales and (to a lesser degree) coals. The Euromanga Basin, greater Surat Basin and the Coonamble Embayment (which forms the southern-most portion of the Surat Basin), all comprise the south-eastern portion of the GAB. The major hydrostratigraphic units in these areas including the Rolling Downs Group, Hooray Sandstone, Injune Creek Formation and Hutton Sandstone, are also shown in the conceptual cross sections shown in Figure 2 (which is oriented east – west across the northern portion of the GAB in NSW) and Figure 3 (oriented north – south in the Coonamble Embayment in the southern portion of the Surat Basin).

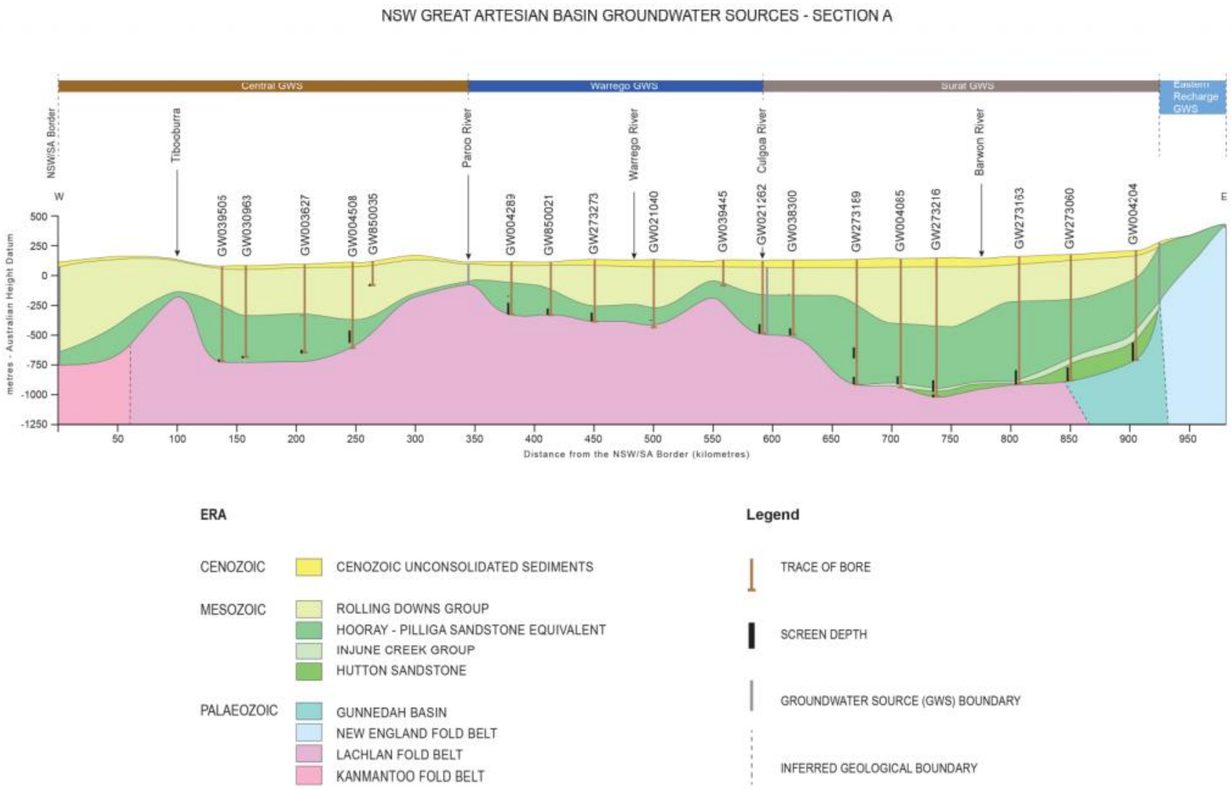


Figure 2: DPIE (2019) west-east geological cross section through the NSW GAB

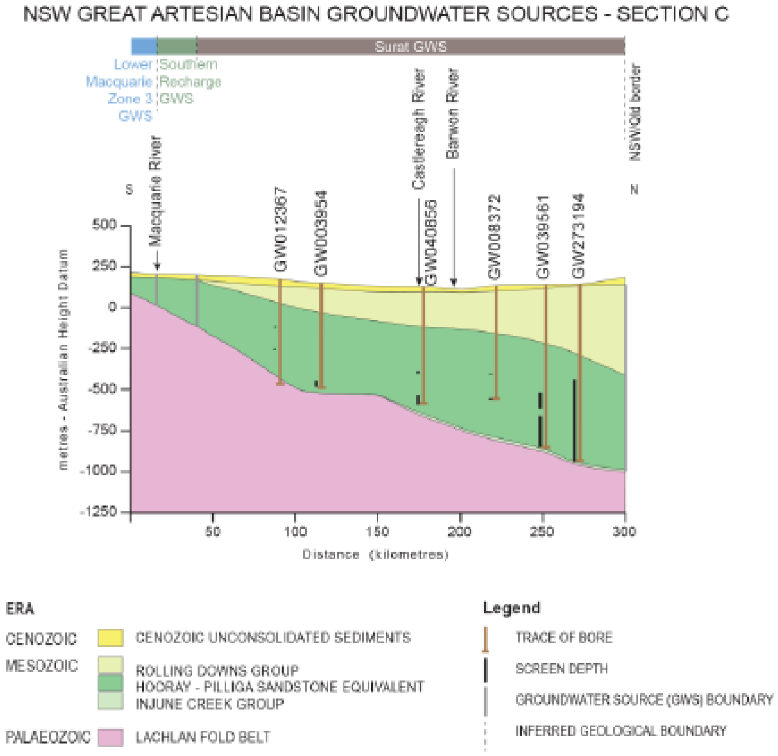


Figure 3: DPIE (2019) north-south geological cross section through the NSW GAB

1.3.2 Major Geological Structures

The NSW GAB sedimentary rocks are part of the larger Eromanga and Surat geological basins, the latter of which includes the Coonable Embayment and forms the central region of the NSW GAB (DPIE, 2019). Sediments of both basins are generally flat-lying and inter-finger (Cresswell & Smerdon, 2012), forming a series of stacked and mostly continuous aquifers and aquitards stretching east to west across much of the NSW portion of the GAB.

Beneath the Warrego Groundwater Source the Nebine Ridge separates the Eromanga and Surat sub-basins (Ransley et. al., 2015). Palaeozoic-aged rocks of the Cunnumulla and Lightning Ridge Shelf also create a regionally-significant basement high beneath much of the Warrego Groundwater Source (Ransley et. al., 2015). The Thargomindah Shelf also underlies the GAB formations in the northern portion of the Central Groundwater Source.

Information regarding faulting of the NSW GAB formations is scarce. Ransley et. al. (2015) indicates faulting is present in these units with apparent increasing frequency from east to west, particularly west of the Nebine Ridge. They are generally of one of three primary orientations, either northwest – southeast, northeast – southwest or north – south, however their displacements are not known. Major structural elements of the GAB that are known are shown in Figure 4.

Rade (1954) suggests spring complexes of the Bourke Supergroup between latitudes of about 145° and 149° may outcrop due to the interaction of regional groundwater flow paths with northwest – southeast oriented faulting in the GAB formations. IESC (2014) also notes springs in the Yantabulla area occur along the eastern margin of a granitic basement horst, with small faults connecting Kullyna – Native Dog and Coonbilly–Youngerina springs. The nearby Dribbling Bore and Hungerford Road spring complexes, both of which are located to the southwest of Coonbilly Spring, and the Culla Willallee and Youngerina spring complexes are all located in similar geological settings lending support to this mechanism.

Map 16 of Ransley et. al. (2015) also shows the Colless, Culla Willallee, Lila and Youngerina spring complex outcrops or is close to mapped duricrust formations associated with near-surface weathered zones of the Rolling Downs Group. These are hypothesised by GA to indicate the current and/or past upward migration of groundwater under pressure from the Hooray Sandstone via high angle, regionally pervasive and intra-formational polygonal fault sets in the Rolling Downs Group which, in conjunction with other geological structures and general rock fabric discontinuities such as jointing and bedding, provide vertical groundwater flow pathways through the Rolling Downs Group aquitard.

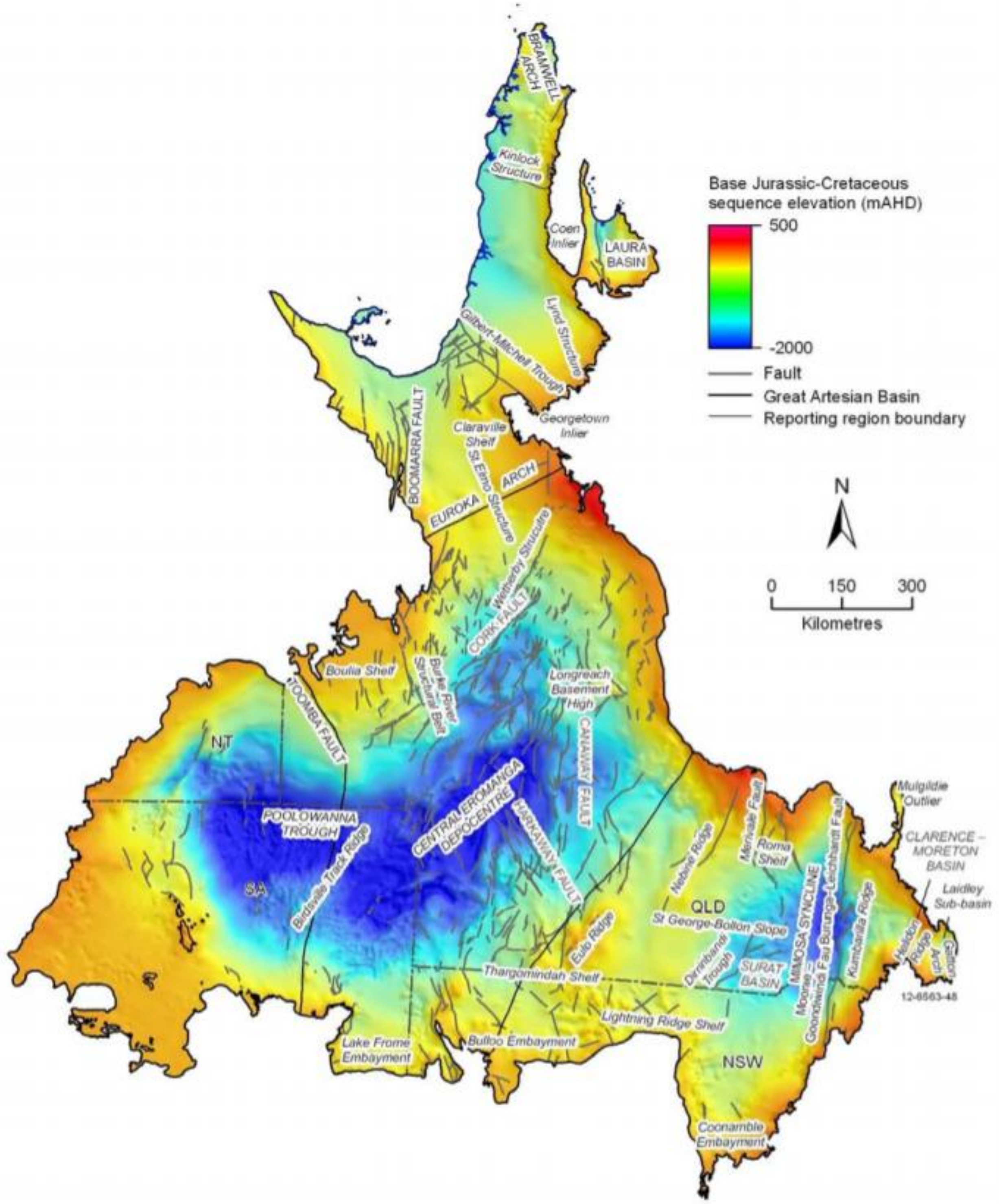


Figure 4: Major structural elements of the GAB (Ransley et al, 2012)

1.3.3 Hydrogeological setting

The GAB contains an extensive and complex groundwater system. The aquifers of the NSW GAB are composed predominantly of porous sandstones and confined by aquitards of both fluvial and marine mudstone and siltstone of Jurassic and Cretaceous age. Groundwater is stored within the permeable sandstone formations, and to a lesser extent fractures and faults, which are interbedded with siltstone and mudstone aquitards.

Groundwater flow is from the recharge areas on the western slopes of the Great Dividing Range (GDR) in New South Wales and Queensland, south westerly towards the Eyre (Ransley et al, 2015). The underlying basins are hydraulicly connected through overlap of aquifers and leaky aquitards above and below the GAB aquifers (Ransley et al, 2012).

1.3.3.1 NSW GAB Regions of this Assessment

The NSW Water Sharing Plan for the NSW GAB (WSP 2008, Draft WSP 2020) defined five NSW GAB groundwater sources for management purposes. Three of these areas, the Surat, Warrego and Central Groundwater Sources (as shown in Figure 5), fall within this area of study.

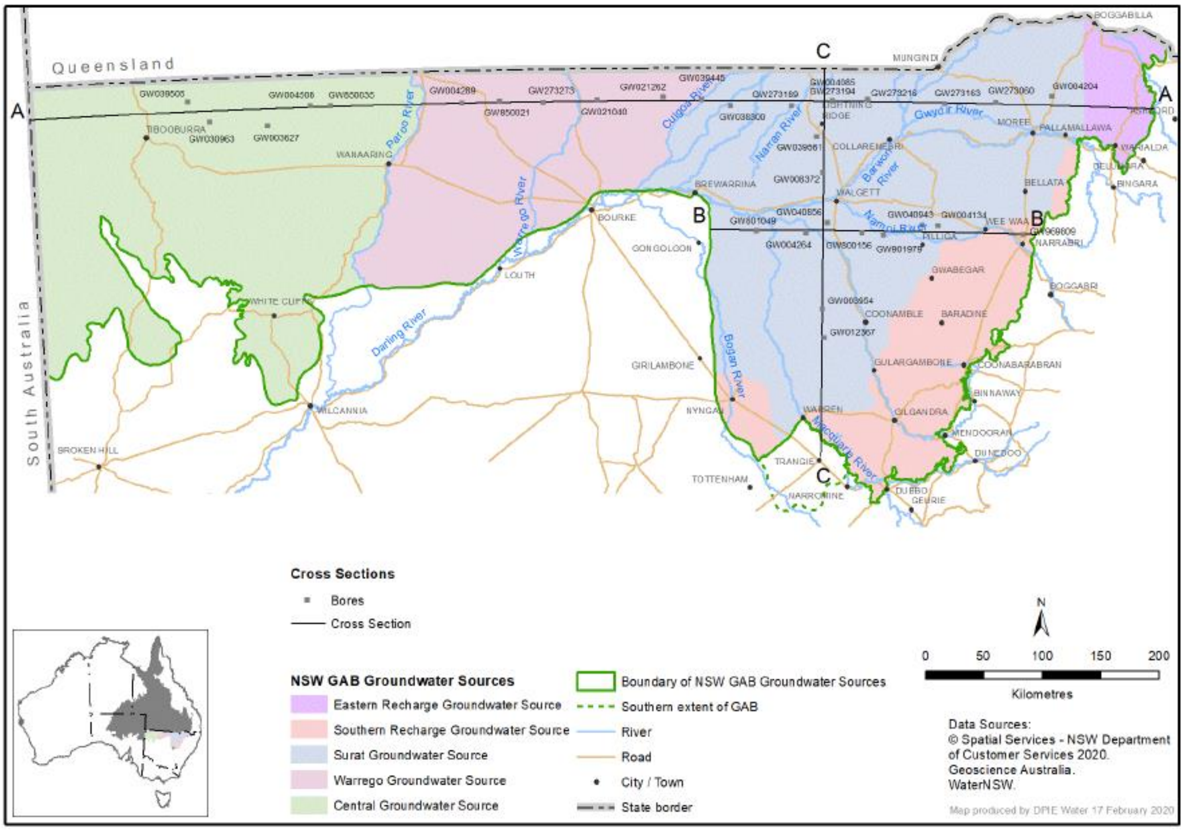


Figure 5: Location of DPIE (2019) geological cross sections and groundwater source areas

The aquifers within the NSW GAB groundwater sources are comprised of predominantly sandstones, confined by aquitards of both fluvial and marine siltstones, mudstones and shale. The Rolling Downs Group acts as confining layer over the deep aquifers and it is comprised of a very thick aquitards of mudstones, siltstones and shale. The upper part of the Rolling Downs Group has minor semi-confined aquifers (Cresswell & Smerdon, 2012).

Discharge from the GAB occurs as natural discharge in the form of concentrated spring outflow, vertical leakage towards the regional water table, subsurface outflow into the neighbouring basins,

The hydrogeological cross sections in Figure 3 and Figure 4 illustrate the major aquifer forming units, aquitards and the basement rocks across the NSW GAB. A detail hydrogeological summary of three groundwater sources is presented in

Table 2.

Table 2: Description of GAB Groundwater Sources in the assessment area (DPIE, 2020a).

Hydrogeological Description	Surat Groundwater Source	Warrego Groundwater Source	Central Groundwater Source
Predominant GAB aquifers	Pilliga and Mulga Sandstone	Hooray and Mooga Sandstones	Hooray and Mooga Sandstones
Distribution of artesian conditions and depth	Across most of the water source area Pilliga Sandstone: 400 - 1250 m Mooga Sandstone: 200 - 350 m	Across most of the water source area Hooray Sandstone: 400 – 750 m Mooga Sandstone: 200 – 350 m	Artesian conditions occur only in a few areas in the north, central, southeast and southwest part of this groundwater source. Hooray Sandstone: 400 – 900 m Mooga Sandstone: mostly subartesian
Groundwater flow direction(s)	Towards the west to southwest and north-west from the Eastern and Southern Recharge Groundwater Sources	Towards south from Queensland and converging with the south-westerly flow	Towards the south and southwest.
Artesian head (m above ground level in the predominant GAB aquifer)	Pilliga Sandstone: 10 – 52 Mooga Sandstone: up to 20	Hooray: 20 – 50 Mooga: Not available	Hooray: up to 30
Maximum flow rate in artesian bores	Pilliga Sandstone: 45 L/s Mooga Sandstone: 20 L/s	Hooray Sandstone: 55 L/s Mooga Sandstone: 15 L/s	Hooray Sandstone: 35 L/s Mooga Sandstone: mostly subartesian
Salinity (mg/L)	Pilliga Sandstone: 500 – 1300 Mooga Sandstone: 500 to 2000	Hooray Sandstone: 500 – 2000 Mooga Sandstone: 1000 – 3500	Hooray Sandstone: 900 – 2000 Mooga Sandstone: brackish
Temperature (°C)	Pilliga Sandstone: 35 – 58 Mooga Sandstone: 25 to 30	Hooray Sandstone: 35 – 48 Mooga Sandstone: 25 to 30	Hooray Sandstone: 58 – 74 Mooga Sandstone: 25 to 33

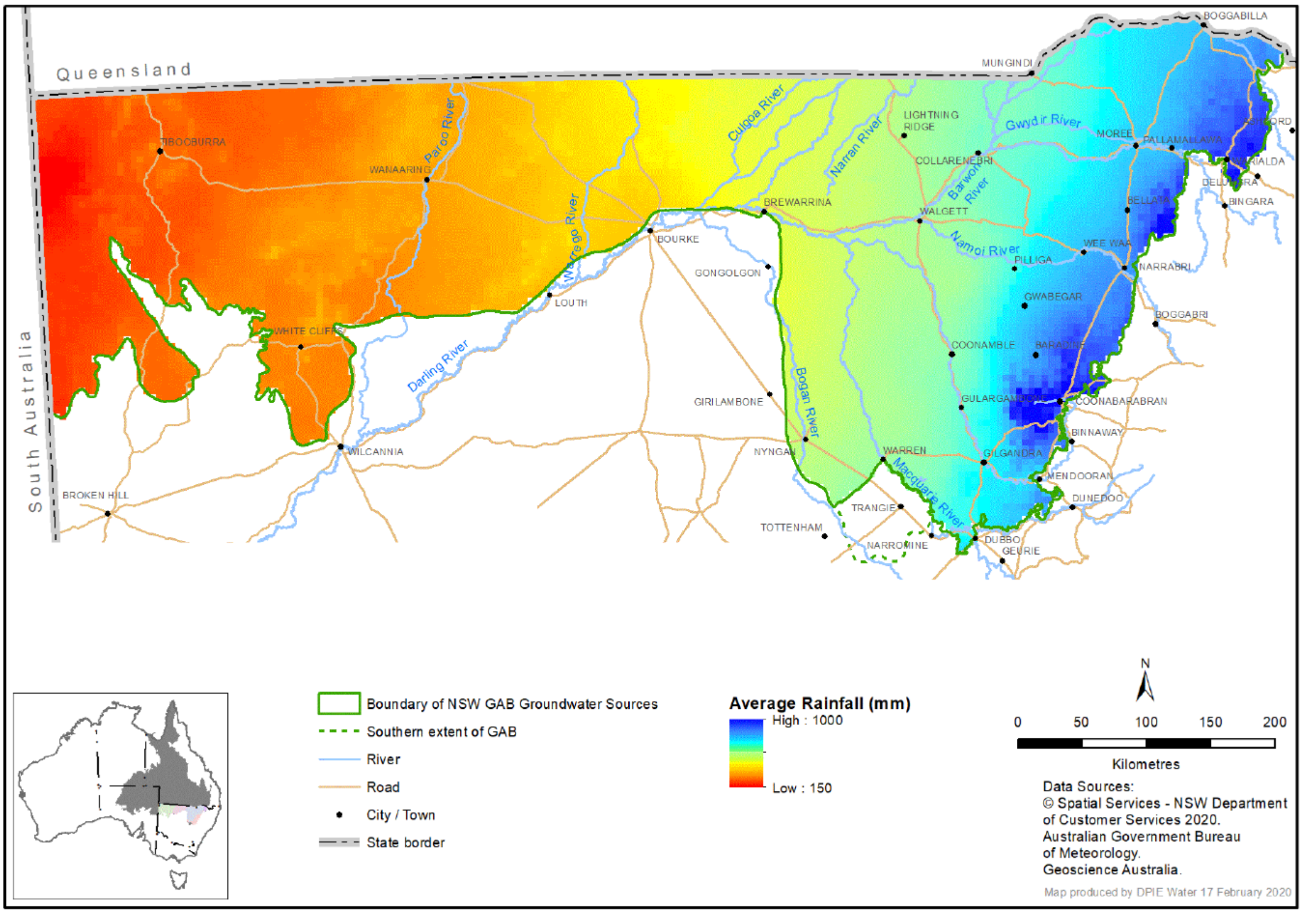
1.3.4 Capping and Piping Project

The National Partnership Agreement (NPA) on the Great Artesian Basin Sustainability Initiative (GABSI) between the Commonwealth of Australia and member states, South Australia (SA), New South Wales (NSW), Queensland (QLD) and the Northern Territory (NT), commenced in 2009 to fund the capping and piping of GAB wells legally operating in an uncontrolled manner. The NSW government implemented the Cap and Pipe the Bores Project. Approximately 400 free flowing bores have been controlled and 18,000 km of piping installed, saving an estimated 80,000 ML of groundwater annually (DPIE, 2021).

1.4 Climate and Hydrology

The NSW GAB project area experiences a semi-arid climate, characterised by hot summers and mild winters with seasonal evaporation. Temperatures in the north west range from a winter average minimum of approximately 7ºC and a summer average maximum of around 35ºC. The climate in the central and western part of the NSW GAB is influenced by its low-lying topography and distance from the coast. Rainfall is generally summer dominant, averaging approximately 750 mm at Coonabarabran in the south east and gradually decreasing to approximately 185 mm in the west at Tibooburra (Figure 6).

About 25% of the NSW GAB Groundwater Sources fall into the Lake Eyre catchment. All major rivers within the NSW GAB area are located within the Murray Darling Basin catchment. The NSW GAB area is also dominated by wide flood plains with elevation less than 200 m AHD and tributaries into Barwon-Darling River. These being the flood plains of the Barwon–Darling, Culgoa, Namoi, Gwydir, Macquarie, Bogan, Castlereagh, Warrego and Paroo River systems (DPIE, 2020).



Data Sources:
© Spatial Services - NSW Department of Customer Services 2020.
Australian Government Bureau of Meteorology.
Geoscience Australia.

Map produced by DPIE Water 17 February 2020

Figure 6: Average annual rainfall of the NSW GAB (DPIE, 2020a)

1.5 Ecology

Wetlands form around spring vents, ranging in size from puddles to large wetlands and streams. Flora and fauna rely on the spring water supply in semi-arid and arid areas, supporting plants and provide habitat for fauna including endemic crustaceans, fish and snails. Alternatively, mud springs are generally a drier, unvegetated surface with thick mud.

Some communities of native species dependent on artesian discharge of groundwater in GAB spring wetlands are listed as 'Endangered' under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBCAct).

1.5.1 Groundwater Dependent Ecosystems

Groundwater dependent ecosystems (GDE) are defined as 'ecosystems that require access to groundwater to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services' (DPI Water, 2016).

The artesian conditions found in the NSW GAB area support, in addition to GDEs expected to be found in the landscape, a number of artesian springs, which are a unique feature of the GAB. The following two types of GDES are found within the NSW GAB Area.

- High probability groundwater dependent (vegetation) ecosystems - NSW Department of Industry Water developed a method for the identification of high probability groundwater dependent vegetation ecosystems and associated ecological value. This process has identified many high probability vegetation GDE and their ecological values in the Southern and Eastern Recharge Groundwater Source (NSW DPIE, 2020) and does not fall within the area of spring assessment.
- High priority groundwater dependent (springs) ecosystems – Total 51 springs were identified in the NSW GAB (DPIE 2020). The GAB springs in NSW have watered megafauna dating back to 36-30,000 years, support endemic ecosystems and continue to sustain wetlands of international importance (Ramsar site) today. GAB springs are a matter of national and international environmental significance. They support endangered ecological communities protected under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).

Two high priority GDEs, Coolabah Spring west of the Surat Groundwater Source and Wee Wattah Spring southwest of Warrego Groundwater Source fall just outside the boundary of the NSW GAB groundwater sources. The location of these two springs needs further investigation regarding their source aquifer. Whilst they may be geographically outside the GAB, they may be fed by discharge form the GAB into the adjacent rock strata.

1.6 Spring Terminology

When classifying springs in the GAB they are classified by features such as size, geomorphology, location in the landscape, underlying structural geology and regional hydrogeological setting (for example, whether they are located in recharge areas or discharge areas). The emerging nomenclature that encompasses features traditionally referred to as springs is based on the concept of groundwater-dependent ecosystems. Specific terminology used to describe and group springs has evolved through work done understanding the Queensland GAB springs and has been adopted across the GAB to define springs. For the purpose of consistency with the emerging nomenclature, springs are identified as 'wetlands' regardless of where they occur in the landscape.

Table 3: GAB Springs nomenclature and definitions (Fensham & Fairfax, 2003) (Qld EPA, 2005)

Spring nomenclature	Definition
Vent	Groundwater conduit discharging to the surface.
Spring	A vent or vents where the discharge forms a single spring wetland.
Spring group	Multiple springs in a similar geomorphic setting.
Spring complex	A cluster of spring vents which share similar geomorphological characteristics and broad similarities in water chemistry.
Spring supergroup	Regional cluster of spring complexes.
Spring wetland	Springs and watercourse springs are identified as ‘wetlands’ regardless of where they occur in the landscape.
Mud spring	Springs which are typically unvegetated with a dried exterior from which thick mud occasionally oozes to the surface.
Mound spring	Artesian springs with a mound formation at the expression. Mounds can be vegetated or bare and vary in size from 0.2–6m in height.

1.7 Previous conceptualisation in NSW

Previous conceptualisation of the GAB in NSW is predominantly confined to basin-wide assessments which encompass the entire GAB. Two major assessments, the Hydrogeological Atlas of the Great Artesian Basin (Geoscience Australia, 2015) and the GAB Water Resource Assessment (Smerdon et al, 2012c), consolidated the geology and hydrogeology knowledge in a consistent way to be used as a baseline for further work.

The GAB Water Resource Assessment developed a comprehensive description of the GAB aquifers, including the geological history, structure of the rock layers, and 3D visualisation of aquifers and aquitards. It presented the relationship between geological features and their influence on groundwater movement in the GAB and identified hydrogeological connections between geological basins and the overlying alluvial aquifers. We also have a better understanding from the assessment on groundwater migration and the potential for groundwater to move vertically across geological formations.

Groundwater models were developed to assess the effects of climate and groundwater demand on GDEs and water levels across the Cadna-owie – Hooray Aquifer. The assessment conceptualizes the GAB resource from a basin-wide view and by region. The reports for the Surat and Central Eromanga regions specifically have been used in this assessment.

Independent Expert Scientific Committee (Commonwealth of Australia, 2014) on Coal Seam Gas and Large Coal Mines undertook hydrogeological survey of the GAB Springs including springs located in NSW. They have used information on spring complex, geology, hydrogeology, regional stratigraphy and underlying aquifers, artesian condition water chemistry comparisons of springs and water bores (where available) to identify the source aquifer and typology. However, a comprehensive hydrogeochemical data or isotope data from same time period for groundwater bores and springs were not available for these bores for the analysis and interpretation. This assessment has supplemented the field observations provided by DPIE with observations from this report.

1.8 Conceptualisation of GAB bores in South Australia and Queensland

Much work has been done to understand the GAB springs in South Australia and Queensland. The basin has been subject of scientific investigations and management programs since the early 1900s. CSG work in Queensland has provided more detailed understanding of the groundwater resource and the impact on springs. The last 10 years have seen a large increase in available data and a corresponding large investment in improving scientific understanding of the GAB's hydrogeology, including in areas that have undergone intensive monitoring and assessment prior to and during coal seam gas (CSG) extraction or mining (particularly in the Surat Basin region of the GAB).

Between 2012 and 2015 a study was completed on the springs in the Surat Cumulative Management Area (CMA) which expanded on the recharge and discharge classification of springs and identified six mechanisms by which springs occur:

- A change in geology
- A perched water table
- Geological structures
- Thinning of a confining layer
- A change in slope
- A window into the water table.

In addition to hydrogeological mechanisms spring classification was broadened to include surface characteristics such as their substrate and location within the surrounding area. These characteristics better relate to a springs function and the potential response from a change to hydrogeological conditions. This spring wetland typology classification is summarised in Section 1.9.

The Queensland Springs Database combines the previous government, private and commercial work done in the Queensland GAB And provides a comprehensive catalogue of springs. Information is available including location, grouping (e.g. complex and supergroup), associated regional ecosystem, source aquifer, conservation rankings, physical properties, general morphology, water chemistry (incomplete dataset), floristic composition, disturbance, faunal composition, survey effort, etc. The terminology and inputs into classification and typology assessment of this report are based on the structure and methodology of the Queensland Springs Database.

A Hydrogeological and Ecological Characterisation of Springs Near Lake Blanche, Lake Eyre Basin, South Australia (Keppel et al, 2016) was prepared by the South Australian Department of Environment, Water and Natural Resources (DEWNR). The report presents the hydrogeological and ecological characterisation of a number of spring complexes in the Lake Blanche region that were identified as most at risk to diminished flow or changes in water quality. A number of conceptual models describing the variations of underlying geological structural primarily responsible for spring expression were developed.

1.9 Conceptualising and classifying springs

The hydrogeological, structural and ecological understanding of the characteristics of GAB springs are incorporated into a framework for classifying springs. Springs can be classified according to 'type', effectively classifying them according to common physical attributes allowing managing bodies a way to assess the vulnerability to be applied to a spring type, rather than an individual spring. The attributes which are classified into types are summarised in

Table 4: Characteristics used for GAB spring classification

Classification Type	Definition
Spring group	The GAB springs located in NSW have been identified (NSW DPIE, Nov 2019) as belonging to the Bourke and Bogan River Supergroups
Wetland typology	Conceptual models of underlying spring expression types. These are summarised in Table 5. Table 4
Spring Structural Models	Classification of the underlying structural geology based on standardised conceptual models. These are summarised in Section 1.10.2.

1.10 Spring Typology

GAB springs are present around geological structures, often in groups, which allow groundwater to discharge to the surface such as faults, aquitards, thinning of the confining layer or topographic features such as a break of slope or a depression which intersects an aquifer (Habermehl, 2020). GAB springs are classed as either recharge or discharge springs based on their hydrogeology. Recharge springs form where aquifers outcrop at the surface, typically in the recharge zones on the eastern margins of the GAB. All other springs associated with GAB aquifers, known as discharge springs, occur where GAB aquifers or faults are exposed at the surface, tending to occur down gradient of recharge areas (Fensham and Fairfax, 2003).

1.10.1 Wetland typology

A wetland typology was developed by the Queensland Office of Groundwater Impact Assessment (OGIA) which groups wetlands based on the dominant hydrogeological and hydraulic processes that form the wetlands. Attributes for each type describe how the wetlands occur within the landscape and potential responses to changes in the underlying hydrogeology driving the wetland.

The attributes are:

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

Table 5 and Figure 7 below summarise the typology classifications and attributes (OGIA, 2016).

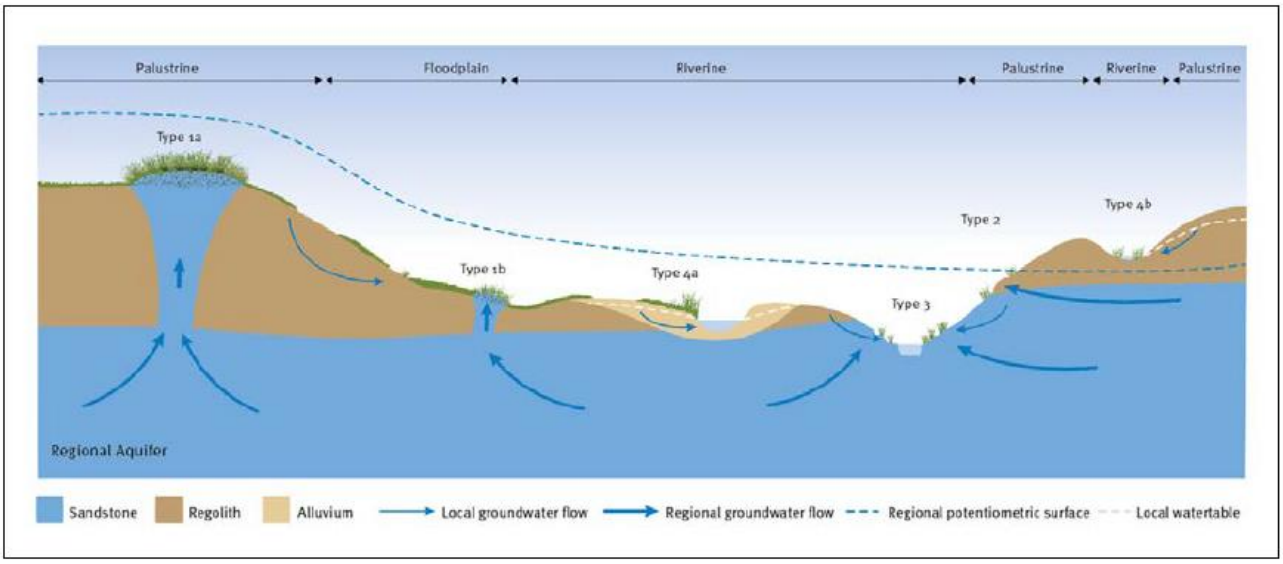


Figure 7: Wetland setting and dominant landscape process for each wetland type (OGIA, 2016)

Table 5: Wetland type summary (OGIA, 2016)

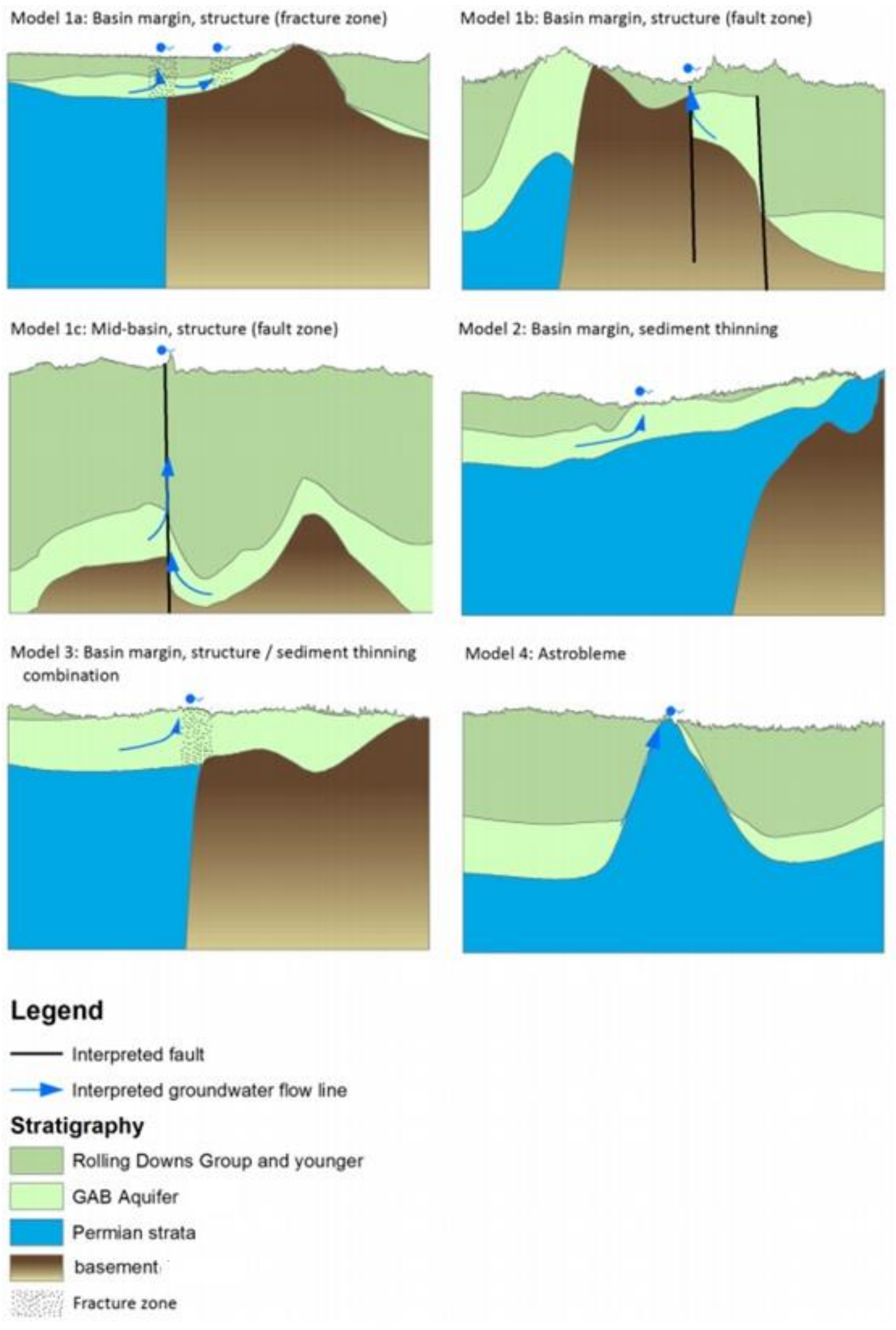
Wetland Type	Definition
Type 1a	Located along low-lying hill slopes or floodplains. Permanent discharge zones which may vary seasonally or with artesian pressure. Form wetlands with extensive regolith zones, providing habitat for wetland vegetation. Groundwater is from regional and local groundwater systems, discharge is generally diffuse.
Type 1b	Similar to Type 1a but occur adjacent to or in the interface between the floodplain and riverine settings. They may receive surface water during high stream-flow events and discharge rate and wetland is significantly influenced by surface flow events.
Type 2	Semi-permanent and dominated by diffuse discharge. May experience changes to seasonal or long-term climate variations. These wetlands are supported by low levels of artesian pressure, such that small changes in the groundwater system can cause the spring to stop flowing.
Type 3	Permanent to semi-permanent free-flowing springs, receiving flow from both regional and local groundwater flow systems. These spring wetlands occur within outcropping sandstone and are confined to watercourse areas. Changes in climate and/or groundwater pressure affect the discharge rate (reducing surface flow), rather than decreasing the area of the wetland.
Type 4a	Non-GAB Springs. Semi-permanent fresh riverine-to-palustrine wetlands with minor wetland soils and moderate vegetation cover. Mainly connected to local groundwater systems and located within riverine environments with deep, sandy, alluvial deposits.
Type 4b	GAB Springs. Semi-permanent fresh riverine-to-palustrine wetlands with minor wetland soils and moderate vegetation cover. Mainly connected to local groundwater systems and located within riverine-to-palustrine environments with shallow-to-nil consolidated material. These wetlands can form in areas of significant topography.

1.10.2 Spring Structural Models

The Hydrogeological and Ecological Characterisation of Springs Near Lake Blanche, Lake Eyre Basin, South Australia (Keppel et al, 2016) expanded on the previous five structural models defined to describe springs (Keppel et al, 2015):

- Conceptual model 1a: Basin margin, structure (fracture zone)
- Conceptual model 1b: Basin margin, structure (fault zone)
- Conceptual model 1c: Mid-basin, 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

Models 1a and 1b are related to either the form of deformation responsible for conduit formation or the scale of the fault structure. The data available on fault zones for this assessment is regional, any springs associated with regional fault zones have been classified as 1b. Where finer-scale data is available model 1a may be used to identify more localised scale faults. Schematic diagrams of these models are presented in Figure 8.
Figure 8: Schematic diagrams of various structural models (Keppel et al, 2016).



Source: Modified from Keppel et al. (2015b)

Figure 8: Schematic diagrams of various structural models (Keppel et al, 2016)

APPENDIX B

Spring Classification Attributes

GAB Springs Classification Attributes

SPRING	SPRING LOCATION AND GROUP DETAILS							GEOMORPHOLOGY						SPRING FLOW				ECOLOGY	WATER CHEMISTRY		
Spring Name	**Latitude**	**Longitude**	**Elevation (mAHD)**	**Site / Vent ID**	**No. Vents**	**Supergroup**	**Groundwater Source**	**General Morphology**	**Mound Dimensions**	**Erosional Landform Pattern**	**Surface composition**	**Water course**	**Adjacent Environment**	**Flowing at time of inspection**	**Flow Estimate at time of inspection**	**Saturation**	**Activity**	**Conservation Ranking**	**pH (pH units)**	**EC (µS/cm)**	**TDS (mg/L)**
Bingewilpa	-30.0275	142.6622	94	1270_1	2	Bourke	Central GWS	Engineered excavation & embankment	N/A (since modified)	Clay pan plus low sand dunes	Clay	1.0 km west of spring	ow-lying sand dunes and clay pans	Yes	Unknown	Unknown	Unknown	-	7.6	6000	3000
Colless	-29.4653	146.2819	119	969.2_1	2	Bourke	Warrego GWS	Mound + spring extension	1.5 m high; 40 m diameter	Low rolling hills	Rocky seep	No	Low rolling hills	No	Unknown	Intermittent	Intermittent	-	7.2	730	500
Coolabah	-30.8329	146.9495	143	994.1_1	4	Bogan River	Surat GWS	Mud spring in low lying area	15 m diameter	Gilgai plains	Clay	No	Gilgai plains	Yes	Unknown	Intermittent	Intermittent	Low	6.4	170	1200
Coonbilly	-29.5325	145.257	125	974.17_1	22	Bourke	Warrego GWS	Mud spring in low lying area	2 m diameter	Level floodplain	Clay	0.5 km west of spring	Floodplain	Yes	Unknown	Intermittent	Intermittent	Low	7	520	440
Culla Willallee	-29.454	145.1014	129	963_1	-	Bourke		Mud spring in low lying area	-	Clay pan	Clay	Runoff catchment	Red soil, flat, schlerophyl forest	Yes	Diffuse	Active	Permanently active	Low	7.7	1000	700
Cumborah	-29.7412	147.7644	155	992_1 / 992.3_1	1	Bogan River	Surat GWS	Flat	Unknown	Level plain	Gravel	No	Low rolling hills	Yes	10 ml / sec	Permanent	Permanent	-	7.2	560	410
Gooroomero	-29.0908	146.6492	148	967.2_1	-	Bourke	Warrego GWS	-		-	-	-	-	-	-	-	-	-	7.5	890	520
Lila	-29.5634	146.0687	124	006.3_1 / 1006.4_	-	Bourke	Warrego GWS	-	-	-	-	-	-	-	-	-	-	-	6.6	43	26
Mulyeo	-30.6318	144.4224	91	1005_1 / 1005_2	-	Bourke	Warrego GWS	-	-	-	-	-	-	-	-	-	-	Low	7.9	1600	960
Mulyeo (Kallara)	-30.63195	144.2221	88	NS	-	Bourke	Warrego GWS	-	-	-	-	-	-	-	-	-	-	Low	7.9	1600	920
Native Dog	-29.5244	145.8339	141	960.1_1	-	Bourke	Warrego GWS	-	-	-	-	-	-	-	-	-	-	Low	7.7	150	160
Old Gerara	-29.2679	146.3832	136	965_1	2	Bourke	-	Excavated vent and tail channel	Pond	-	-	No	Flat farm land	Yes	200 L/hr	Active	Permanently active	Low	6.8	480	490
Peery West	-30.7329	143.5751	80	1000.200_1	5	Bourke	Central GWS	Sandy clay pan	Sandy mound	Rocky terrain	Sandy clay	No		Yes				High	7.6	1700	1000
Tharnowanni	-29.9088	145.1357	110	-	-	Bourke	-	-	-	-	-	No	Arid red soil.	No	Not flowing	Inactive/Intermittent	Inactive/Intermittent	-	8.5	460	640
Thooro Mud	-29.3994	145.3216	138	-	-	Bourke	Warrego GWS	-	-	-	-	-	-	-	-	-	-	Low	9.2	1100	550
Thully				-	-	Bourke	Warrego GWS	-	-	-	-	-	-	-	-	-	-	Low	7.6	280	170
Youltoo	-30.5772	143.1008	147	1001_1	-	Bourke	Central GWS	-	-	-	-	-	-	-	-	-	-	-	6.8	120	450
Youngerina	-29.5442	145.1225	121	973_1	-	Bourke	Warrego GWS	-	-	-	-	-	-	-	-	-	-	-	8.4	660	360

APPENDIX C

DPIE Analytical Tables

Table 1: In situ water chemistry results for springs

Spring Name	Supergroup	Vent ID	Latitude	Longitude	Date sampled	Temp (oC)	pH (pH units)	EC as SPC (µS/cm)	Redox (mV)	Dissolved oxygen (mg/L)	Total alkalinity as CaCO3 (mg/L)
Bingewilpa	Bourke	1270	-30.0275	142.6622	07-12-19	29.3	7.38	7435	-128	0.7	685
Coolabah	Bogan River	994.1	-30.8329	146.9495	23/10/2018	23.2	6.37	172	112	7	-
Colless	Bourke	969.2	-29.4653	146.2819	23/10/2018	30.2	6.39	780	17	3.37	-
Culla Willallee	Bourke	963	-29.454	145.1014	03-06-18	21.3	8.02	903	85	1.76	-
Culla Willallee	Bourke	963	-29.454	145.1013	03-09-18	26.7	8.56	9800	145	6.39	-
Culla Willallee	Bourke	963	-29.454	145.1013	03-11-18	12.2	8.52	615	193	9.37	406
Coonbilly	Bourke	974.17	-29.5325	145.2569	03-09-18	26.5	7.81	586	70	5.51	-
Cumborah	Bogan River	992	-29.7412	147.7644	16/10/2018	21	7.32	1130	152	5.82	-
Cumborah	Bogan River	992.3	-29.7412	147.7646	17/07/2019	27	7.07	950	93	3.63	-
Gooroomero	Bourke	967.2	-29.0908	146.6493	15/10/2018	24.3	6.91	910	147	2.4	-
Lila	Bourke	1006.4	-29.5636	146.067	15/10/2018	12.5	5.6	33	220	6.84	-
Lila	Bourke	1006.3	-29.5634	146.0687	25/10/2018	24.5	7.08	48	130.7	5.11	-
Mulyeo1	Bourke	1005.2	-30.6318	144.4224	25/10/2018	23.6	8.08	2319	-149.5	17	1.42
Mulyeo1	Bourke	1005.1	-30.632	144.4222	24/07/2019	24.2	7.6	2318	-136.8	25.8	2.18
Native Dog	Bourke	960.1	-29.5244	145.8339	07-11-19	11.1	7.43	123	173	6.4	-
Old Gerara	Bourke	965	-29.2679	146.3832	07-11-19	25.5	7.84	535	84	0.27	-
Peery West	Bourke	1000.2	-30.7329	143.5751	23/07/2019	22	7.16	1783	16	0.66	-
Peery West	Bourke	1000.2	-30.7329	143.5751	03-12-18	17.6	8.6	1461	101	5.92	740
Peery West	Bourke	1000.2	-30.7329	143.5751	03-07-18	17.6	8.02	960	131	4.64	-
Tharnowanni	Bourke	-	-29.9088	145.1357	13/07/2019	21.7	8.55	484	145.9	-	7.8
Thooro Mud	Bourke	976.24	-29.3994	145.3216	10-12-18	16.7	8.08	2203	103	5.82	-
Thully	Bourke	961.1	-29.716	146.2843	10-10-18	22.1	7.4	208	157.6	54.1	5.38
Thully	Bourke	961.1	-29.7159	146.2843	16/07/2019	8.8	6.1	244	225	72	8.2
Thully	Bourke	961.4	-29.7165	146.2842	22/10/2018	8.7	7.2	1712	169	50	5.6
Youngerina1	Bourke	973	-29.5442	145.1225	25/07/2019	16	8.25	538	82.7	8.02	355
Youltoo	Bourke	1001	-30.5772	143.1008	25/07/2019	20.8	9.81	149	19	151.1	17
Rainfall			-29.2434	145.1397	16-10-18	23.1	8.12	146	123	6.13	-

Note:

Electrical conductivity is recorded as specific conductance, at 25 degrees Celsius.

Tharnowanni sample was collected from an excavated dam in a clay pan. There is very low confidence in the certainty of that the Tharnowanni spring has been identified.

There are also no known survey records of this spring and anecdotal information indicates there is no springs in the area.

Dash symbols indicate data was not available.

1 Indicates artesian bores are free flowing at the site identified as springs. Mulyeo is the site of two free flowing bores.

Table 2: Laboratory physical parameters and major ions water chemistry results for springs

		Bingewilpa	Colless	Coolabah	Coonbilly	Culla Willallee	Culla Willallee	Culla Willallee	Cumborah	Cumborah	Gooroomero	Lila	Lila	Mulyeo	Mulyeo	Native Dog	Old Gerara	Peery West	Peery West	Peery West	Tharnowanni	Thooro Mud	Thully	Thully	Thully	Youltoo	Youngerina	Rainfall
Date sampled		12-07-19	23-10-18	06-03-18	09-03-18	11-03-18	16-10-18	17-07-19	15-10-18	15-10-18	25-10-18	25-10-18	24-07-19	11-07-19	11-07-19	23-07-19	12-03-18	07-03-18	13-07-19	12-10-18	10-10-18	16-07-19	22-10-18	25-07-19	25-07-19	09-07-19	18-07-19	16-08-18
Vent ID		1270.000	969.200	994.100	974.170	963.000	963.000	963.000	992.000	992.300	967.200	1006.300	1006.400	1005.100	1005.200	960.100	965.000	1000.200	1000.200	1000.200	-	976.240	961.100	961.100	961.400	1001.000	973.000	Rainfall
Laboratory physical water chemistry																												
pH	pH units	7.6	7.2	6.4	7	7.7	8.3	8.7	7.2	7.3	7.5	6.6	6.6	7.9	7.9	7.7	6.8	7.6	8.2	8.3	8.5	9.2	7.6	7.8	7.9	6.8	8.4	7
EC	µS/cm	6000	730	170	520	1000	940	770	560	640	890	43	33	1600	1600	150	480	1700	1500	1500	460	1100	250	280	2100	120	660	89
TDS	mg/L	3000	500	1200	440	700	1000	760	410	430	520	26	21	960	920	160	490	1000	970	960	640	550	140	170	1300	450	360	61
Ionic Balance	%	-1	7	-6	-2	-8	-10	-11	4	6	4	-4	-14	1	2	-11	-4	-8	-2	13	9	-10	-3	-19	-1	-14	-4	7
Calcium	mg/L	24	3.8	1.1	20	7.5	5.4	18	8.9	9.8	4.3	0.6	0.9	8.1	8.3	7	1.5	7.5	7.5	8.3	13	2.5	4.5	8.1	14	2.6	61	12
Potassium	mg/L	16	10	7.6	5.2	13	7.5	12	9.6	15	14	5.7	3.6	4.3	4.4	2.5	12	6.8	5.3	6.4	7.4	4.4	3.5	4.1	10	5	7.4	2.9
Sodium	mg/L	1200	180	30	100	210	190	130	63	64	180	4.4	2.4	380	390	19	89	360	370	540	120	230	50	36	390	11	54	3
Magnesium	mg/L	11	5.5	0.7	5.1	5.3	3.2	6.1	17	22	2.1	<0.5	<0.5	1.9	1.9	1.1	1.2	2.2	1.4	1.9	4.9	<0.5	1.1	2	8.3	1.1	17	1.3
Total hardness	mg/L	110	32	6	70	41	27	71	92	110	19	<3	<3	28	29	22	9	28	24	29	52	6.3	16	28	70	11	220	35
Hydroxide Alkalinity	mg/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Bicarbonate Alkalinity	mg/L	730	280	60	270	480	440	410	83	61	170	15	14	560	560	77	94	720	720	720	180	410	99	140	210	36	350	32
Carbonate Alkalinity	mg/L	<5	<5	<5	<5	<5	<5	28	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	16	72	<5	<5	<5	<5	9	<5
Total alkalinity	mg/L	730	280	60	270	480	440	430	83	61	170	15	14	560	560	77	94	720	720	720	190	490	99	140	210	36	360	32
Sulfate	mg/L	<1	8	4	<1	<1	<1	1	26	36	1	<1	<1	<1	<1	<1	7	<1	<1	<1	25	<1	3	2	47	12	1	4
Chloride	mg/L	1400	66	20	20	92	82	25	80	100	150	3	1	200	200	3	95	170	110	150	32	88	25	13	500	5	15	2
Dissolved Inorganic Carbon	mg/L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fluoride	mg/L	2	0	0	0	0	0	0.4	0	0	0	0	<0.1	3	3	0.1	0	0	3.7	0	0	2.6	0	0.1	<0.1	<0.1	0.4	0
Bromide	mg/L	2.4	0	0	0	0	0	<0.5	0	0	0	0	<0.5	0.5	0.6	<0.5	0	0	<0.5	0	0	<0.5	0	<0.5	1.7	<0.5	<0.5	0

Table 3: Laboratory analysed dissolved and total metals results for springs

		Bingewilpa	Colless	Coolabah	Coonbilly	Culla Willallee	Culla Willallee	Culla Willallee	Cumborah	Cumborah	Gooroomero	Lila	Lila	Mulyeo	Mulyeo	Native Dog	Old Gerara	Peery West	Peery West	Peery West	Tharnowanni	Thooro Mud	Thully	Thully	Thully	Youltoo	Youngerina
Date sampled		12-07-19	23-10-18	06-03-18	09-03-18	11-03-18	16-10-18	17-07-19	15-10-18	15-10-18	25-10-18	25-10-18	24-07-19	11-07-19	11-07-19	23-07-19	12-03-18	07-03-18	13-07-19	12-10-18	10-10-18	16-07-19	22-10-18	25-07-19	25-07-19	09-07-19	18-07-19
Vent ID		1270	969.2	994.1	974.17	963	963	963	992	992.3	967.2	1006.3	1006.4	1005.1	1005.2	960.1	965	1000.200	1000.200	1000.200	-	976.24	961.1	961.1	961.4	1001	973
Laboratory metals																											
Aluminium	µg/L	<10	<10	1000	2000	50	20	40	<10	<10	20	<10	1200	<10	<10	5100	100	100	10	<10	<10	60	680	1500	20000	1800	620
Arsenic	mg/L	1	1	1	5	2	1	2	<1	<1	<1	1	<1	<1	<1	2	4	<1	<1	<1	14	<1	3	3	8	1	4
Cadmium	µg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Chromium	µg/L	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	6	<1	<1	<1	<1	<1	<1	<1	<1	35	<1	1
Copper	µg/L	<1	<1	8	3	<1	1	2	<1	1	<1	3	6	<1	<1	4	<1	<1	<1	2	5	<1	4	12	37	6	3
Iron	µg/L	170	240	490	1200	21	14	<10	22	<10	1200	120	540	180	300	3400	59	65	<10	29	<10	53	370	670	17000	810	310
Lithium	µg/L	360	7	3	6	10	10	15	3	3	9	2	2	28	29	6	3	78	69	65	1	15	2	3	28	2	11
Lead	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2	<1	<1	<1	<1	<1	<1	<1	<1	9	<1	<1
Manganese	µg/L	<5	9	38	130	12	7	<5	6	<5	83	8	5	<5	<5	30	<5	<5	<5	6	<5	<5	<5	8	250	8	61
Mercury	µg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Nickel	µg/L	<1	<1	4	3	<1	<1	27	2	2	<1	1	2	<1	<1	2	<1	<1	<1	<1	2	<1	2	3	23	<1	60
Silver	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Strontium	µg/L	2300	110	11	240	250	160	520	210	250	27	10	12	230	230	77	17	300	320	310	150	26	44	71	190	24	1000
Zinc	µg/L	1	<1	3	8	3	1	2	2	11	10	4	23	2	<1	9	2	3	2	2	<1	1	1	21	66	4	9
Total Aluminium	µg/L	<10	510	23000	9600	16000	62000	30000	4600	20	50	2400	1500	220	<10	9400	2800	510	240	3900	13000	1100	84000	150000	270000	15000	6900
Total Arsenic	µg/L	1	1	4	7	3	3	3	2	<1	<1	1	<1	<1	<1	2	6	<1	<1	<1	15	<1	7	11	23	4	5
Total Cadmium	µg/L	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.2	0.3	<0.1	<0.1
Total Chromium	mg/L	<1	1	31	9	13	44	26	7	<1	<1	3	<1	<1	<1	11	4	<1	<1	<1	12	<1	61	110	210	14	15
Total Copper	mg/L	<1	<1	30	8	9	29	14	11	<1	<1	4	2	7	<1	5	2	<1	<1	1	13	1	36	71	130	14	6
Total Iron	mg/L	200	500	28000	8000	9300	34000	13000	6800	31	2000	2700	680	370	320	6000	3200	410	250	2700	12000	840	54000	110000	220000	17000	5000
Total Lithium	µg/L	360	8	13	13	24	56	30	5	2	8	3	2	29	29	9	5	84	69	65	4	17	41	81	120	7	14
Total Lead	mg/L	<1	4	9	3	6	24	8	25	<1	4	3	<1	<1	<1	3	3	<1	<1	<1	3	<1	35	71	85	7	2
Total Manganese	µg/L	<5	9	470	320	240	920	210	130	<5	89	60	13	5	5	61	38	10	9	20	160	56	540	1800	2700	210	120
Total Mercury	µg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total Nickel	µg/L	<1	1	18	8	7	22	36	15	2	<1	4	<1	<1	<1	4	1	<1	<1	<1	10	<1	39	70	120	8	31
Total Silver	mg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Total Strontium	mg/L	2300	120	50	300	570	1400	840	290	250	30	20	19	230	230	85	25	440	340	410	180	32	300	470	590	74	1100
Total Zinc	mg/L	1	1	54	23	30	94	64	70	13	19	23	7	15	<1	13	19	3	3	2	24	6	110	210	340	45	53

Table 4: Strontium isotope ($^{87}Sr/^{86}Sr$) results for springs

	Bingewilpa	**Colless**	**Culla Willallee**	**Culla Willallee**	**Cumborah**	**Cumborah**	**Gooroomero**	**Lila**	**Mulyeo**	**Mulyeo**	**Native Dog**	**Peery West**	**Peery West**	**Tharnowanni**	**Thully**	**Thully**	**Youltoo**	**Youngerina**
Date sampled	07-12-19	23/10/18	16/10/18	17/07/19	15/10/18	15/10/18	25/10/18	25/10/18	07-11-19	07-11-19	23/07/19	13/07/19	10-12-18	10-10-18	22/10/18	25/07/19	07-09-19	18/07/19
Vent ID	1270	969.2	963	963	992	992.3	967.2	1006	1005	1005	960.1	1000	1000	-	961.1	961.4	1001	973
87Sr/86Sr	0.7075	0.7089	0.7078	0.7078	0.7081	0.7081	0.7082	0.7082	0.7084	0.7084	0.7081	0.7092	0.7093	0.708	0.7078	0.708	0.7101	0.7078

Table 5: Stable water isotope (δ ^{2}H and δ ^{18}O/^{16}O) results for springs

		Bingewilpa	**Colless**	**Coolabah**	**Coonbilly**	**Culla Willallee**	**Culla Willallee**	**Culla Willallee**	**Cumborah**	**Cumborah**	**Gooroomero**	**Lila**	**Lila**	**Mulyeo**	**Mulyeo**	**Native Dog**	**Old Gerara**	**Peery West**	**Peery West**	**Peery West**	**Tharnowanni**	**Thooro Mud**	**Thully**	**Thully**	**Youltoo**	**Youngerina**
Date sampled		07-12-19	23/10/18	03-06-18	03-09-18	03-11-18	16/10/18	17/07/19	15/10/18	15/10/18	25/10/18	25/10/18	24/07/19	07-11-19	07-11-19	23/07/19	03-12-18	03-07-18	13/07/19	10-12-18	10-10-18	16/07/19	22/10/18	25/07/19	07-09-19	18/07/19
Vent ID		1270	969.2	994.1	974.2	963	963	963	992	992.3	967.2	1006	1006	1005	1005	960.1	965	1000	1000	1000	-	976.2	961.1	961.4	1001	973
Stable water isotope																										
Hydrogen Isotope	δ ^{2}H VSMOW (‰)	-41.4	-37.7	-32.4	-22.2	-31.2	-35.7	23.5	-22.6	-22	-12.2	0	-4.1	-38.9	-39.2	4.5	-11.1	-40.4	-39.1	-37.8	59.1	-32.6	2.8	39	31	28.3
Hydrogen Isotope Uncertainty	δ ^{2}H VSMOW (‰)	1	1	0.3	0.3	0.3	1	1	1	1	1	1	1	1	1	1	0.3	0.3	1	1	1	1	1	1	1	1
Oxygen Isotope Result	δ ^{18}O/^{16}O VSMOW (‰)	-6.67	-5.95	-2.82	-1.14	-4.05	-5.25	5.86	-3.91	-4.06	-0.07	2.13	-1.32	-6.36	-6.46	0.12	0.67	-6.53	-6.39	-6.18	13.28	-4.74	1.47	8.27	5.99	7.33
Oxygen Isotope Uncertainty	δ ^{18}O/^{16}O VSMOW (‰)	0.15	0.15	0.3	0.3	0.3	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.3	0.3	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15

Table 6: Radiocarbon isotope ($^{13}C/^{14}C$-DIC) results for Great Artesian Basin spring water sampled from March 2018 to July 2019.

		Bingewilpa	Colless	Coolabah	Coonbilly	Culla Willallee	Culla Willallee	Culla Willallee	Cumborah	Cumborah	Gooroomero	Lila	Mulyeo	Mulyeo	Native Dog	Old Gerara	Peery West	Peery West	Peery West	Thooro Mud	Thully	Thully	Youltoo	Youngerina
Date sampled		07-12-19	23/10/18	03-06-18	03-09-18	03-11-18	16/10/18	17/07/19	15/10/18	15/10/18	25/10/18	25/10/18	07-11-19	07-11-19	23/07/19	03-12-18	03-07-18	13/07/19	10-12-18	16/07/19	22/10/18	25/07/19	07-09-19	18/07/19
Vent ID		1270	969	994	974	963	963	963	992	992	967	1006	1005	1005	960	965	1000	1000	1000	976	961	961	1001	973
Radiocarbon isotope results																								
DIC conc.	ppm	168	67	26.9	66.58	102.66	91	89	19	15	44	BLD	128	133	19	20.7	121.09	162	179	103	19	38	< 6	78
DIC conc.	Mmol /L	14	5.6	2.2	5.54	8.55	7.6	7.4	1.6	1.3	3.7	BLD	10.6	11.1	1.6	1.72	10.08	13.5	14.9	8.5	1.6	3.2	<0.5	6.5
$\delta^{13}C/^{12}CDIC(VPDB)$	‰	-2.4	-6.6	-14.3	-7.8	-6.3	-6.4	-3.5	-12.9	-10.7	-3.5	BLD	-4.7	-5	-14.5	-7.3	-3.1	-4	-3.3	-6.7	-9	-8.2	-8.3	-3
^{14}C DIC	pMC	0.27	25.17	92.34	102.25	35.08	15.89	93.51	103.04	102.85	102.43	99.34	0.21	0.26	100.33	103.05	2.57	4.2	2.51	14.02	99.79	102.3	93.48	103.1
Age Correction																								
Conventional Radiocarbon Age	Years	47500	11080	640	Mdn	8415	14770	540	Mdn	Mdn	Mdn	55	49700	47800	Mdn	Mdn	29430	25470	29620	15780	Mdn	Mdn	540	Mdn
Tamers	Years	43418	6564	0	0	3241	9559	0	0	0	0	0	45372	43854	0	0	24914	20438	24810	10582	0	0	0	0
Ingerson and Pearson	Years	29220	394	0	0	0	3942	0	0	0	0	0	37154	35900	0	0	13009	10978	13722	5291	0	0	0	0
Fontes and Garnier	Years	27577	25	0	0	0	3619	0	0	0	0	0	36580	35356	0	0	11886	10249	12746	4994	0	0	0	0
Revised F&G v2	Years	31425	1710	0	0	0	5024	0	0	0	0	0	38451	37110	0	0	14656	12491	15335	6407	0	0	0	0
$\delta^{13}C$ mixing formula	Years	33711	2586	0	0	0	6181	0	0	0	0	0	39938	38564	0	0	17000	14100	17304	7460	0	0	0	0
^{14}C Final age	Years	>30000	2000	Mdn	Mdn	Mdn	5000	Mdn	Mdn	Mdn	Mdn	Mdn	>30000	>30000	Mdn	Mdn	15000	12000	15000	6000	Mdn	Mdn	Mdn	Mdn

Note – “Mdn” refers to Modern carbon age.

Table 7: 36-Chloride isotope results for springs

	Bingewilpa	**Colless**	**Coolabah**	**Coonbilly**	**Culla Willallee**	**Culla Willallee**	**Culla Willallee**	**Cumborah**	**Cumborah**	**Gooroomero**	**Lila**	**Mulyeo**	**Mulyeo**	**Native Dog**	**Old Gerara**	**Peery West**	**Peery West**	**Peery West**	**Tharnowanni**	**Thooro Mud**	**Thully**	**Youltoo**	**Youngerina**
Date sampled	07-12-19	23/10/2018	03-06-18	03-09-18	03-11-18	16/10/2018	17/07/2019	15/10/2018	15/10/2018	25/10/2018	25/10/2018	07-11-19	07-11-19	23/07/2019	03-12-18	03-07-18	13/07/2019	10-12-18	10-10-18	16/07/2019	22/10/2018	07-09-19	18/07/2019
Vent ID	1270	969.2	994.1	974.2	963	963	963	992	992.3	967.2	1006	1005	1005	960.1	965	1000	1000	1000	-	976.2	961.1	1001	973
^{36}Cl/Cl$^-$ isotope results																							
Cor_CL36/CL	1.40E-14	1.12E-13	2.20E-13	1.30E-13	6.90E-14	6.50E-14	8.10E-14	3.80E-13	4.00E-13	1.90E-13	1.90E-13	2.00E-14	1.70E-14	1.90E-13	5.50E-13	2.80E-14	2.00E-14	2.50E-14	1.30E-13	4.70E-14	1.50E-13	1.30E-13	1.40E-13
Sigma	7.70E-16	4.51E-15	1.10E-14	5.90E-15	3.90E-15	2.80E-15	3.40E-15	1.60E-14	1.60E-14	7.50E-15	1.70E-14	1.00E-15	9.60E-16	7.50E-15	2.20E-14	5.90E-15	1.00E-15	1.30E-15	6.60E-15	2.00E-15	6.00E-15	6.70E-15	5.60E-15
Sigma[%]	5.4	4.03	5.16	4.46	5.68	4.25	4.2	4.32	3.97	3.99	8.89	5.1	5.7	4	4.07	21.5	5.2	5.16	5.06	4.1	3.88	5.3	4
Cor.F.[%]	2.4	0.7	3.2	2.5	4.2	1.4	1	0.3	0.4	1.3	21.2	2.1	2.7	0.3	1.7	21	2.3	3.8	0.8	0.9	0.3	2.4	0.4

Table 8: Tritium isotope results for springs

		Bingewilpa	**Colless**	**Culla Willallee**	**Culla Willallee**	**Cumborah**	**Cumborah**	**Gooroomero**	**Lila**	**Mulyeo**	**Mulyeo**	**Native Dog**	**Peery West**	**Peery West**	**Tharnowanni**	**Thully**	**Youltoo**	**Youngerina**
Date sampled		07-12-19	23/10/18	16/10/18	17/07/19	15/10/18	15/10/18	25/10/18	25/10/18	07-11-19	07-11-19	23/07/19	13/07/19	10-12-18	10-10-18	22/10/18	07-09-19	18/07/19
Vent ID		1270	969.2	963	963	992	992.3	967.2	1006.3	1005.1	1005.2	960.1	1000.200	1000.200	-	961.1	1001	973
Tritium isotope																		
Isotope activity	Bq/kg	0.004	0.017	0.028	0.214	0.144	0.131	0.093	0.556	0.003^	0.006	0.163	0.004^	0.01	0.383	0.402	0.27	0.232
Isotope uncertainty	Bq/kg	0.003	0.003	0.004	0.01	0.007	0.007	0.005	0.022	0.003	0.003	0.008	0.003	0.003	0.015	0.016	0.013	0.011
Isotope Lower Limit of Detection	TU	0.006	0.007	0.007	0.006	0.007	0.007	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006
Isotope Uncertainty	TU	0.03^	0.14	0.23	1.8	1.21	1.1	0.78	4.67	0.03^	0.05	1.37	0.03^	0.08	3.22	3.38	2.27	1.95
Isotope Lower limit of detection	TU	0.02	0.03	0.03	0.09	0.06	0.06	0.04	0.18	0.03	0.03	0.07	0.03	0.03	0.13	0.14	0.11	0.09
Tritium Isotope	TU	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.05	0.05

Table 9: In situ water chemistry results for bores

Bore Name	Latitude	Longitude	Date sampled	Temp (oC)	pH (pH units)	EC as SPC (µS/cm)	Redox (mV)	Dissolved oxygen (mg/L)	Total alkalinity as CaCO3 (mg/L)
GW040866	-30.7691	143.4201	03-07-18	7.2	25	1871	-51	3.6	-
GW004591	-30.3474	143.84	15/07/2019	36.3	8.18	1346	-136.9	not measured	416

Table 10: Physical chemical parameters and major ions chemistry results for bores

		GW004591	16783A	GW004259	GW004339	GW003823	GW040866	GW004705	GW008253	GW008253	GW004659	GW004659	GW012246	GW012246	GW001346	GW001648	GW001817	GW003436	GW003440	GW003564	GW003665	GW003695	GW003717	GW003734	GW003761	GW003785	GW003831	GW003843
Date sampled		15-07-19	15-03-18	13-03-18	11-03-18	12-03-18	07-03-18	21-03-18	21-03-18	27-03-18	22-03-18	20-03-18	23-03-18	26-03-18	09-03-18	25-02-18	19-06-19	05-04-18	29-05-19	16-05-19	23-05-19	02-05-18	01-06-19	05-04-18	03-03-18	14-06-19	02-06-19	16-05-19
Vent ID		Bore	991_1	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore
Laboratory physical water chemistry and major ions																												
pH	pH units	8.5	8.4	8.3	7.5	7.9	7.2	8.4	8	8.4	8.3	8.5	8	8.4	8.5	8.6	8.7	8.7	8.3	8.3	8.2	8	8.49	8.4	8.6	8.47	8.4	8.3
EC	µS/cm	970	880	940	1100	750	1700	910	1300	1000	730	730	780	790	1100	1100	1100	910	1700	2100	830	1400	1000	1000	1100	922	973	1900
TDS	mg/L	440	560	580	600	440	990	500	770	610	500	510	480	490	720	670	680	550	910	1100	520	830	616	610	730	574	602	1000
Ionic Balance	%	-9	-6	-7	-5	-6	-2	3	4	11	1	1	2	0	-3	1	1	10	5	2	-4	16	3.12	8	0	1.17	2.99	3
Calcium	mg/L	4.4	1.6	3.2	11	3.6	71	4.5	6	3.9	2.4	2.2	5	4.7	3.1	2.6	2.8	2.1	20	12	4.6	9.2	3	3.9	2.6	5	3	33
Potassium	mg/L	1.7	2.2	1.8	3.5	1.7	15	2.6	2.7	1.6	1.9	1.7	1.9	1.7	2.2	2.2	1.6	1.8	2	3	1.8	3.3	1	1.6	1.6	1	2	2.7
Sodium	mg/L	200	210	220	210	170	220	230	330	300	190	180	210	200	270	290	290	280	360	460	200	420	253	290	280	235	241	380
Magnesium	mg/L	<0.5	<0.5	<0.5	1.6	<0.5	45	2.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.7	<0.5	<0.5	<0.5	4.6	3.7	<0.5	3.9	<1	<0.5	<0.5	<1	<1	10
Total hardness	mg/L	11	4	8	34	9	360	21	15	10	6	5	12	12	10	7	7	5	70	46	12	39	7	10	7	12	7	120
Hydroxide Alkalinity	mg/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<1	<5	<5	<1	<1	<5
Bicarbonate Alkalinity	mg/L	430	390	450	290	330	270	300	370	320	330	310	360	350	530	570	520	390	380	450	380	460	421	470	510	415	381	390
Carbonate Alkalinity	mg/L	12	25	24	<5	<5	<5	33	<5	10	<5	25	<5	19	27	21	25	30	<5	<5	<5		20	11	31	28	11	<5
Total alkalinity	mg/L	440	420	480	290	330	270	340	370	330	330	330	360	370	560	590	550	420	380	450	380	460	441	480	540	444	392	390
Sulfate	mg/L	<1	<1	<1	<1	<1	140	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<15	<1
Chloride	mg/L	63	67	57	190	66	330	110	220	140	59	53	63	58	62	23	47	62	270	390	79	170	60	55	61	49	68	360
Dissolved Inorganic Carbon	mg/L	0	0	0	0	0	0	110	120		110		120															
Fluoride	mg/L	0.6	0	0	0	0	0	0	0		0		0				1.4		0.6	0.7	0.9		0.7			0.5	0.8	0.5
Bromide	mg/L	<0.5	0	0	0	0	0	0	0		0		0				1		0.6	0.6	<0.5		0.205			0.13	0.225	0.9

Table 10: Physical che

		GW003843-DUPLICATE	GW003855	GW003862	GW003899	GW004008	GW004014	GW004035	GW004043	GW004046	GW004047	GW004048	GW004049	GW004081	GW004117	GW004145	GW004146	GW004149	GW004159	GW004173	GW004214	GW004219	GW004282	GW004295	GW004300	GW004337	GW004417	GW004512
Date sampled		16-05-19	03-06-19	17-05-19	16-05-19	15-05-19	28-04-18	08-03-18	20-04-18	27-03-18	22-03-18	23-03-18	26-03-18	30-05-19	27-02-18	14-05-19	14-05-19	03-06-19	03-06-19	27-02-18	18-04-18	18-05-19	17-05-19	23-03-18	02-03-18	24-05-19	06-06-19	30-05-19
Vent ID		Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore
Laboratory physical wat																												
pH	pH units	8.3	8.44	8.4	8.4	8	8.1	8.5	8.2	8.3	8.5	8.3	8.3	7.9	8.5	8.4	8.1	7.7	7.9	8.6	8.3	8.5	8.4	8.3	8.7	8.4	8.1	8
EC	µS/cm	1800	977	850	970	3900	740	1100	1100	780	890	830	1100	1700	1000	1700	3200	3900	2800	980	1000	1100	840	970	960	720	3450	3200
TDS	mg/L	1000	617	520	540	1800	420	660	660	600	660	510	660	1000	680	960	1700	2000	1300	680	600	680	490	740	670	460	1910	1700
Ionic Balance	%	2	2.38	0	3	0	12	2	4	2	0	-1	1	3	1	2	1	1	3	1	5	1	2	0	1	-2	1	8
Calcium	mg/L	33	4	3.8	3.8	38	2.7	2.5	5	4	2.4	4.5	6.2	8.7	4.6	8.6	26	25	17	5.2	3.7	3.8	3.1	4.1	4	3.1	20	47
Potassium	mg/L	2.6	3	1.5	1.9	4.8	1.6	1.6	1.9	1.9	1.7	1.8	2	3.8	2	3.4	4.8	6.4	5.5	1.6	1.7	1.6	1.5	1.9	1.5	1.2	7	4.8
Sodium	mg/L	380	237	200	240	800	220	290	320	230	210	210	260	420	260	390	660	810	620	250	310	270	210	260	250	180	777	690
Magnesium	mg/L	10	2	<0.5	<0.5	2	<0.5	<0.5	0.7	0.6	0.7	<0.5	2.5	2.3	1	0.5	4.7	6.9	4.1	0.7	<0.5	<0.5	<0.5	0.5	<0.5	<0.5	<16	1.8
Total hardness	mg/L	120	18	9.4	9.6	100	7	6	15	13	9	11	26	31	16	23	85	92	58	16	9	9.4	7.7	12	10	7.8	116	120
Hydroxide Alkalinity	mg/L	<5	<1	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<1	<5
Bicarbonate Alkalinity	mg/L	390	376	330	440	270	310	500	490	390	320	390	360	580	460	510	360	530	580	440	470	480	340	500	430	330	564	240
Carbonate Alkalinity	mg/L	<5	16	<5	5	<5		28			30			<5	22	7	<5	<5	<5	24		18	7		33	10	1	<5
Total alkalinity	mg/L	390	393	340	440	270	310	530	490	390	350	390	360	580	480	520	360	530	580	460	470	500	350	500	460	340	564	240
Sulfate	mg/L	<1	<1	<1	<1	<1	<1	<1	1	<1	<1	<1	3	<1	<1	<1	<1	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	<1
Chloride	mg/L	370	85	81	50	1100	59	58	130	69	87	59	150	220	67	230	810	910	530	66	100	65	70	53	60	61	913	810
Dissolved Inorganic Carbon	mg/L																											
Fluoride	mg/L	0.5	0.4	1.7	0.4	0.7								3		2.9	1.5	2.8	3.2			0.6	0.8			0.6	3.1	3.8
Bromide	mg/L	0.8	0.295	<0.5	<0.5	2.1								<0.5		0.6	1.6	2.6	<0.5			<0.5	<0.5			<0.5	1.22	1.6

Table 10: Physical che

		GW004519	GW004523	GW004541	GW004559	GW004563	GW004567	GW004581	GW004581	GW004591	GW004591	GW004615	GW004641	GW004661	GW004666	GW004674	GW004675	GW004678	GW004690	GW004694	GW004699	GW004699-DUPLICATE	GW004709	GW004725	GW004725-DUPLICATE	GW004728	GW004733	GW004733
Date sampled		06-04-18	22-05-19	08-05-18	14-05-19	22-05-19	13-05-19	30-05-19	30-05-19	09-04-18	15-07-19	16-05-19	18-05-19	16-05-19	01-08-18	17-05-19	22-04-18	18-05-19	28-03-18	01-05-19	03-06-19	03-06-19	04-06-19	20-05-19	20-05-19	25-05-19	13-05-19	27-02-18
Vent ID		Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore
Laboratory physical wat																												
pH	pH units	8.5	8.6	8.2	8.5	8	8.4	7.5	7.5	7.9	8.5	8.5	8.2	8.2	8.3	8.4	8.1	8.6	8.3	8.3	7.7	7.8	8.61	8.4	8.4	7.4	7.7	8.8
EC	µS/cm	740	770	910	920	1800	960	7400	7400	950	970	1200	750	960	1000	1400	1200	900	720	1200	11000	11000	1060	930	930	10000	3700	1100
TDS	mg/L	440	470	530	560	1000	630	3800	3800	520	440	760	420	670	620	840	670	490	460	800	5800	6000	644	520	560	5900	2100	680
Ionic Balance	%	11	-3	13	-5	3	1	5	5	8	-9	-5	-3	-2	9	2	-1	-2	8	9	2	2	1.04	-3	-3	4	3	2
Calcium	mg/L	2.9	2.8	2.7	3.2	9.3	4.6	82	82	4.5	4.4	2.9	6.2	7.3	5.4	7.3	10	2.5	5.8	8.4	100	100	3	3.6	3.6	130	24	2.7
Potassium	mg/L	1.4	1.5	1.9	2.3	3.4	2.2	15	15	1.6	1.7	2.1	2.7	2.4	2.7	2.5	2.3	1.5	1.2	2.7	17	17	1	1.5	1.5	16	9	1.3
Sodium	mg/L	220	180	300	200	400	250	1500	1500	280	200	290	160	240	300	350	350	230	210	350	2000	2000	255	220	220	1800	850	290
Magnesium	mg/L	<0.5	1	<0.5	2.2	2.6	1.7	17	17	<0.5	<0.5	0.7	2.1	0.9	1.8	4.2	1.3	<0.5	<0.5	1	75	73	<1	<0.5	<0.5	22	14	<0.5
Total hardness	mg/L	7	11	7	17	34	19	270	270	11	11	10	24	22	21	35	31	6.3	14	25	560	550	7	8.9	8.9	410	120	7
Hydroxide Alkalinity	mg/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<1	<5	<5	<5	<5	<5
Bicarbonate Alkalinity	mg/L	290	330	440	360	430	400	320	320	430	430	620	320	450	480	420	430	420	300	490	240	250	343	430	440	150	560	480
Carbonate Alkalinity	mg/L	14	18		20	<5	12	<5	<5		12	29	<5	<5		17		31		<5	<5	<5	30	15	17	<5	<5	42
Total alkalinity	mg/L	310	340	440	380	430	410	320	320	430	440	650	320	450	480	440	430	460	300	490	240	250	373	450	450	150	560	520
Sulfate	mg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	4	<1	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	6	<1
Chloride	mg/L	60	61	53	94	300	110	2000	2000	63	63	45	59	75	63	230	260	50	65	130	3300	3300	127	50	50	2800	910	64
Dissolved Inorganic Carbon	mg/L																											
Fluoride	mg/L		4.8		0.9	1.2	0.7	1.4	1.4		0.6	1.7	0.6	0.9		0.8		0.6		0.9	0.9	0.9	0.7	0.7	0.7	1.1	2.6	
Bromide	mg/L		<0.5		<0.5	0.6	<0.5	3.7	3.7		<0.5	<0.5	<0.5	<0.5		<0.5		<0.5		<0.5	5	5	0.375	<0.5	<0.5	<0.5	<0.5	

Table 10: Physical che

		GW004735	GW004741	GW004752	GW004759	GW007181	GW007251	GW007263	GW007268	GW007456	GW008175	GW008317	GW008449	GW008622	GW008853	GW010038	GW010070	GW010358	GW010371	GW010433	GW010442	GW010491	GW010491_DUPLICATE	GW010756	GW010775	GW010785	GW010786	GW010905
Date sampled		24-05-19	02-05-18	01-05-19	13-05-19	22-04-18	13-03-18	13-07-19	14-05-19	03-06-19	29-05-19	20-05-19	19-03-18	23-05-19	23-06-19	28-05-19	28-03-18	25-05-19	13-07-19	27-02-18	25-05-19	22-03-18	22-03-18	29-03-18	28-05-19	01-05-19	01-08-18	26-04-18
Vent ID		Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore
Laboratory physical wat																												
pH	pH units	8.2	8.2	8.4	7.8	8.3	7	8.82	7.5	8.49	8.4	8.5	8.5	7.7	8.6	7.8	8.4	8.2	8.78	8.6	8.3	8.4	8.4	8.3	8.4	8.6	8.3	8
EC	µS/cm	2500	870	920	4400	1400	7000	1040	8300	997	730	870	820	6300	1400	6200	900	1800	1070	1000	1400	980	980	730	1100	1100	970	2000
TDS	mg/L	1300	520	630	2400	770	3900	621	4900	628	480	560	620	3500	800	3400	580	1100	621	690	670	600	640	460	660	720	600	1000
Ionic Balance	%	5	14	5	-6	-2	-1	0.16	-2	1.92	-1	-8	1	1	3	1	9	1	2.55	0	-2	0	0	9	-2	4	7	15
Calcium	mg/L	16	5.5	6.4	18	7.2	95	4	120	3	2.3	2.7	2.9	76	4.5	29	5.3	11	5	4.6	6.9	5.3	5.3	6.7	5.3	5.2	4	45
Potassium	mg/L	3.9	1.5	1.9	10	2	12	2	14	2	1.3	1.3	1.5	10	2.2	11	1.5	2.5	2	1.9	2	1.6	1.7	1.6	1.6	1.9	1.9	3.7
Sodium	mg/L	500	270	270	860	400	1300	261	1700	241	180	210	210	1300	340	1200	270	410	261	260	320	260	260	210	250	320	280	450
Magnesium	mg/L	10	1.4	0.5	10	1.1	31	2	13	2	<0.5	<0.5	<0.5	4.9	1.9	20	<0.5	0.7	<1	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1.2	15
Total hardness	mg/L	80	19	18	86	23	360	18	350	16	5.7	6.8	7	210	19	150	13	30	12	14	17	13	13	17	13	13	15	180
Hydroxide Alkalinity	mg/L	<5	<5	<5	<5	<5	<5	<1	<5	<1	<5	<5	<5	<5	<5	<5	<5	<5	<1	<5	<5	<5	<5	<5	<5	<5	<5	<5
Bicarbonate Alkalinity	mg/L	320	350	470	590	480	150	444	170	390	310	450	360	170	450	580	400	430	456	470	420	470	470	300	470	480	460	280
Carbonate Alkalinity	mg/L	<5		11	<5	14		64	<5	20	<5	19	29	<5	19	<5	12	<5	66	25	<5	25	26		5	27		
Total alkalinity	mg/L	320	350	480	590	490	150	509	170	411	310	470	390	170	460	580	420	430	522	490	420	500	490	310	470	510	460	280
Sulfate	mg/L	9	<1	<1	<1	5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2	3
Chloride	mg/L	520	80	55	1200	310	2300	58	2800	79	59	61	53	1900	170	1500	64	340	65	66	230	57	57	67	83	110	59	400
Dissolved Inorganic Carbon	mg/L																											
Fluoride	mg/L	1.1		0.8	2.8			0.6	0.8	0.5	0.6	0.6		0.9	1.2	2.4		0.6	1.4		0.6				0.6	0.8		
Bromide	mg/L	1.2		<0.5	<0.5			0.175	4.8	0.275	<0.5	<0.5		4.2	1.3	2.6		0.8	0.185		<0.5				<0.5	<0.5		

Table 10: Physical che

		GW011260	GW011265	GW011265-DUPLICATE	GW011266	GW011271	GW011334	GW012094	GW012120	GW012121	GW012197	GW012197-DUPLICATE	GW012285	GW012419	GW012428	GW012480	GW012852	GW013049	GW013140	GW014317	GW014524	GW014537	GW014588	GW014672	GW014675	GW014760	GW014764
Date sampled		01-08-18	23-05-19	23-05-19	20-03-18	27-04-18	20-03-18	28-04-18	17-05-19	19-03-18	21-05-19	21-05-19	09-04-18	14-07-19	31-05-19	15-06-19	01-05-18	09-06-19	27-04-18	31-05-19	15-06-19	04-05-18	20-04-18	02-03-18	24-04-18	21-05-19	01-05-18
Vent ID		Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore
Laboratory physical wat																											
pH	pH units	8.4	8.1	8.1	8.5	8.3	8.5	8.3	7.8	8.6	8.1	8.4	7.5	8.78	8.23	8.48	8.3	8.16	8.1	8.27	7.46	8.1	8.2	8.4	8.4	7.8	8.4
EC	µS/cm	980	1300	1300	890	820	820	760	6700	1200	1900	1900	820	1300	1080	1080	1100	2800	750	1040	10900	2400	960	960	930	3400	1000
TDS	mg/L	580	850	840	540	460	500	460	3800	860	1100	1100	500	760	685	645	670	1560	430	645	6840	1300	580	640	530	1900	650
Ionic Balance	%	8	-3	-2	1	9	1	10	-4	-2	1	0	7	3.01	5.24	0.54	13	2.06	10	2.89	0.65	20	3	-2	12	-1	13
Calcium	mg/L	4.8	6.4	6.5	3.9	3	3.7	1.7	67	2.5	15	14	3.9	9	4	4	4.1	18	3.3	3	333	26	4	5.6	3.2	25	3.5
Potassium	mg/L	1.8	3.5	3.5	1.5	1.7	1.5	1.9	15	1.6	4	3.9	1.5	1	2	1	1.5	7	1.5	2	15	3.9	1.7	1.7	1.4	7.5	1.3
Sodium	mg/L	290	320	330	230	250	210	220	1300	300	430	410	240	303	280	274	340	637	220	264	1820	670	280	230	280	700	320
Magnesium	mg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	50	<0.5	5.6	5.4	<0.5	<1	<1	<1	<0.5	8	<0.5	<1	<142	9	<0.5	0.6	<0.5	14	<0.5
Total hardness	mg/L	12	16	16	10	7	9	4	370	6	60	58	10	26	10	10	10	78	8	7	1420	100	10	16	8	120	9
Hydroxide Alkalinity	mg/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<1	<1	<1	<5	<1	<5	<1	<1	<5	<5	<5	<5	<5	<5
Bicarbonate Alkalinity	mg/L	450	560	570	400	380	360	330	390	570	410	400	370	470	474	478	470	529	320	470	182	310	430	430	400	430	430
Carbonate Alkalinity	mg/L	7	<5	<5	30		29		<5	38	<5	8		71	1	30		1		1	1			17	12	<5	13
Total alkalinity	mg/L	460	560	570	430	380	390	330	390	600	410	410	370	541	474	508	470	529	320	470	182	310	430	450	410	430	450
Sulfate	mg/L	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	20	3	2	<1	<1	<1	<1
Chloride	mg/L	56	140	140	52	56	53	53	2100	58	400	400	56	134	61	66	78	713	56	58	3630	510	110	64	53	890	68
Dissolved Inorganic Carbon	mg/L																										
Fluoride	mg/L		3	3					1.3		1.4	1.3		0.8	0.8	0.7		3.2		0.8	0.4					2.2	
Bromide	mg/L		<0.5	<0.5					<0.5		0.5	0.5		0.386	0.22	0.18		1.24		0.2	7.65					1	

Table 10: Physical che

		GW014796	GW014870	GW014998	GW015748	GW015748-DUPLICATE	GW015749	GW015757	GW016954	GW017678	GW018041	GW018053	GW018888	GW019483	GW020537	GW021144	GW021148	GW021190	GW021352	GW021483	GW022754	GW025066	GW025423	GW027500	GW027500	GW029101
Date sampled		16-05-19	25-05-19	27-03-18	29-05-19	29-05-19	29-05-19	18-04-18	09-06-19	04-06-19	22-04-18	21-03-18	29-05-19	25-03-18	20-05-19	21-04-18	20-05-19	21-04-18	29-05-19	01-06-19	24-04-18	20-03-18	02-06-19	02-03-18	30-05-19	03-05-18
Vent ID		Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore
Laboratory physical wat																										
pH	pH units	7.4	8.43	8.4	7.7	7.7	7.7	8.2	8.19	8	8.3	8.4	7.9	8.4	8.4	8.2	8.3	8.2	8.07	8.44	8.2	8.5	8.52	8.4	8.37	8
EC	µS/cm	11000	820	940	10000	10000	9500	1100	2630	1700	1100	770	4200	700	740	970	690	1000	4930	1060	1000	1100	1030	1000	1050	1500
TDS	mg/L	7000	476	580	6100	6000	5400	600	1490	880	710	540	2400	450	480	580	430	660	2720	668	590	850	613	680	696	930
Ionic Balance	%	-4	0.42	11	8	8	7	4	1.88	-2	4	2	8	-3	-5	3	-9	4	4.37	3.89	10	-1	3.05	1	3.67	16
Calcium	mg/L	290	2	3.5	120	120	62	4.3	14	8.1	3.3	2.8	18	2.7	4	2.8	2	3.9	65	4	3.2	5.4	2	3.7	2	8.7
Potassium	mg/L	13	1	1.7	15	15	16	1.6	7	3.4	1.7	1.7	8.3	1.8	1.1	1.9	1.4	1.6	6	2	2	1.5	1	1.8	2	3.5
Sodium	mg/L	1900	183	280	1900	2000	2000	310	621	370	340	190	960	170	170	290	160	310	860	264	310	260	257	280	275	460
Magnesium	mg/L	64	<1	<0.5	140	140	52	<0.5	7	0.8	<0.5	<0.5	15	<0.5	<0.5	<0.5	<0.5	<0.5	26	<1	<0.5	<0.5	<1	<0.5	<1	0.5
Total hardness	mg/L	990	5	9	860	880	370	11	64	23	8	7	110	7	10	7	5	10	269	14	8	13	5	9	5	24
Hydroxide Alkalinity	mg/L	<5	<1	<5	<5	<5	<5	<5	<1	<5	<5	<5	<5	<5	<5	<5	<5	<5	<1	<1	<5	<5	<1	<5	<1	<5
Bicarbonate Alkalinity	mg/L	110	306	320	520	520	500	480	721	590	540	320	650	300	320	450	340	470	228	427	480	460	426	500	468	520
Carbonate Alkalinity	mg/L	<5	16	9	<5	<5	<5		1	<5		23	<5	21	6		<5		1	17		29	24	20	12	
Total alkalinity	mg/L	110	322	330	520	520	500	480	721	590	540	340	650	320	330	450	350	470	228	444	480	490	449	520	480	520
Sulfate	mg/L	6	<1	<1	350	350	2	1	<1	<1	1	<1	<1	<1	<1	1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1
Chloride	mg/L	3900	61	120	2500	2500	2500	110	537	200	110	57	880	60	71	100	53	110	1500	73	49	81	59	58	59	160
Dissolved Inorganic Carbon	mg/L																									
Fluoride	mg/L	<0.1	0.6		2.2	2.2	2.1		4.3	3.3			3.3		2		0.6		1	1.2			0.7		0.8	
Bromide	mg/L	11	0.19		5.3	5.3	5.3		0.84	1.2			1.5		<0.5		<0.5		3.46	0.24			0.2		0.2	

Table 10: Physical che

		GW030684	GW030868	GW032500	GW039377	GW039445	GW039455	GW050527	GW273269
Date sampled		28-05-19	19-03-18	14-06-19	02-03-18	03-03-18	30-05-19	29-05-19	08-03-18
Vent ID		Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore
Laboratory physical wat									
pH	pH units	7.9	8.6	8.65	8.7	8.7	8.5	8.53	8.5
EC	µS/cm	5700	970	1020	900	810	1140	1060	1100
TDS	mg/L	2900	700	595	580	540	713	643	680
Ionic Balance	%	2	-3	2.44	-2	-2	4.24	1.12	4
Calcium	mg/L	30	3.4	4	2.7	3.8	2	3	2.2
Potassium	mg/L	11	1.5	2	1.6	1.5	1	1	1.6
Sodium	mg/L	1100	240	256	220	200	302	242	300
Magnesium	mg/L	20	<0.5	<1	<0.5	<0.5	<1	<1	<0.5
Total hardness	mg/L	160	9	10	7	9	5	7	6
Hydroxide Alkalinity	mg/L	<5	<5	<1	<5	<5	<1	<1	<5
Bicarbonate Alkalinity	mg/L	590	450	417	390	340	494	425	500
Carbonate Alkalinity	mg/L	<5	33	40	31	32	24	31	31
Total alkalinity	mg/L	590	480	458	420	370	518	456	530
Sulfate	mg/L	<1	<1	<1	<1	<1	<1	<1	<1
Chloride	mg/L	1400	56	60	61	59	65	65	57
Dissolved Inorganic Carbon	mg/L								
Fluoride	mg/L	2.8		0.6			1	0.7	
Bromide	mg/L	2.6		0.158			0.23	0.195	

Table 11: Dissolved metals chemistry results - bores

		GW004591	16783A	GW004259	GW004339	GW003823	GW040866	GW004705	GW008253	GW008253	GW004659	GW004659	GW012246	GW012246	GW001346	GW001648	GW001817	GW003436	GW003440	GW003564	GW003665	GW003695	GW003734	GW003761	GW003843
Date sampled		15-07-19	15-03-18	13-03-18	11-03-18	12-03-18	07-03-18	21-03-18	21-03-18	27-03-18	22-03-18	20-03-18	23-03-18	26-03-18	09-03-18	25-02-18	19-06-19	05-04-18	29-05-19	16-05-19	23-05-19	02-05-18	05-04-18	03-03-18	16-05-19
Vent ID		Bore	991_1	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore
Laboratory metals (dissolved)																									
Aluminium	mg/L	<0.01	0.02	<0.01	<0.01	0.02	0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Arsenic	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.001	<0.01	<0.01	<0.01	0.002	0.005	0.001	<0.01	<0.01	<0.01	<0.01	0.002	0.002	<0.01	<0.01
Cadmium	mg/L																								
Chromium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Iron	mg/L	0.097	0.016	0.22	0.13	0.081	9.5	0.061	0.53	0.47	0.22	0.076	0.078	0.079	0.077	0.051	0.16	0.17	0.11	0.045	0.21	0.21	0.048	0.05	0.049
Lithium	mg/L	0.015	0.013	0.014	0.019	0.01	0.004	0.006	0.01	0.008	0.005	0.005	0.008	0.009	0.015	0.011	0.017	0.009	0.019	0.038	0.004	0.03	0.017	0.021	0.022
Lead	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Manganese	mg/L	0.009	<0.005	0.012	0.057	0.006	0.32	0.014	0.011	0.008	<0.005	<0.005	0.006	0.006	<0.005	<0.005	<0.005	<0.005	0.022	0.012	0.005	0.009	0.006	<0.005	0.033
Mercury	mg/L																								
Nickel	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Silver	mg/L																								
Strontium	mg/L	0.081	0.041	0.079	0.15	0.039	0.81	0.077	0.11	0.069	0.047	0.049	0.098	0.1	0.15	0.15	0.088	0.065	0.42	0.21	0.067	0.3	0.076	0.069	0.65
Zinc	mg/L	<0.001	0.002	0.003	0.004	0.001	0.008	<0.001	0.003	0.001	0.002	<0.001	<0.001	<0.001	0.003	0.045	0.004	<0.001	0.004	0.002	0.006	0.013	<0.001	<0.001	0.002

mg/L	unit not indicated in information provided by DPIE, assumed to be in mg/L

Cadmium, Mercury and Silver <LOR

Table 11: Dissolved metals c

		GW003843-DUPLICATE	GW003862	GW003899	GW004008	GW004014	GW004035	GW004043	GW004046	GW004047	GW004048	GW004049	GW004081	GW004117	GW004145	GW004146	GW004149	GW004159	GW004173	GW004214	GW004219	GW004282	GW004295	GW004300	GW004337	GW004417
Date sampled		16-05-19	17-05-19	16-05-19	15-05-19	28-04-18	08-03-18	20-04-18	27-03-18	22-03-18	23-03-18	26-03-18	30-05-19	27-02-18	14-05-19	14-05-19	03-06-19	03-06-19	27-02-18	18-04-18	18-05-19	17-05-19	23-03-18	02-03-18	24-05-19	06-06-19
Vent ID		Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore
Laboratory metals (dissolved)																										
Aluminium	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Arsenic	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.002	<0.01	<0.01	0.002	<0.01	<0.01	<0.01	<0.01	<0.01	0.002	0.001	0.001	0.002	<0.01	<0.01	0.003	<0.01	<0.01	
Cadmium	mg/L																									
Chromium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Copper	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.008	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Iron	mg/L	0.061	0.043	0.074	0.27	0.043	0.026	0.17	0.08	0.031	0.081	0.15	0.041	0.064	0.018	0.16	0.2	0.26	0.095	0.096	0.033	0.044	0.086	0.031	0.26	
Lithium	mg/L	0.022	0.006	0.015	0.024	0.008	0.008	0.015	0.008	0.011	0.01	0.015	0.026	0.039	0.021	0.022	0.06	0.039	0.026	0.014	0.016	0.007	0.023	0.011	0.005	
Lead	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Manganese	mg/L	0.034	<0.005	0.005	0.024	0.01	<0.005	<0.005	0.007	<0.005	0.008	0.008	<0.005	0.008	<0.005	0.015	<0.005	0.005	0.006	<0.005	0.007	0.009	<0.005	0.006	0.008	
Mercury	mg/L																									
Nickel	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Silver	mg/L																									
Strontium	mg/L	0.67	0.053	0.097	0.48	0.074	0.11	0.088	0.095	0.056	0.1	0.18	0.19	0.11	0.19	0.66	0.76	0.58	0.087	0.066	0.11	0.066	0.12	0.094	0.052	
Zinc	mg/L	0.002	0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.007	0.002	0.001	0.002	<0.001	0.001	0.002	<0.001	<0.001	0.001	

🟨 mg/L	unit not indicated

Cadmium, Mercury and Silver

Table 11: Dissolved metals c

		GW004512	GW004519	GW004523	GW004541	GW004559	GW004563	GW004567	GW004581	GW004581	GW004591	GW004591	GW004615	GW004641	GW004661	GW004666	GW004674	GW004675	GW004678	GW004690	GW004694	GW004699	GW004699-DUPLICATE	GW004725	GW004725-DUPLICATE
Date sampled		30-05-19	06-04-18	22-05-19	08-05-18	14-05-19	22-05-19	13-05-19	30-05-19	30-05-19	09-04-18	15-07-19	16-05-19	18-05-19	16-05-19	01-08-18	17-05-19	22-04-18	18-05-19	28-03-18	01-05-19	03-06-19	03-06-19	20-05-19	20-05-19
Vent ID		Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore
Laboratory metals (dissolved)																									
Aluminium	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Arsenic	mg/L	<0.01	<0.01	<0.01	0.002	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.004	<0.01	0.001	<0.01	<0.01	0.003	<0.01	<0.01	0.002	<0.01	<0.01	<0.01	<0.01
Cadmium	mg/L																								
Chromium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Iron	mg/L	0.15	0.032	0.013	0.052	0.13	0.15	0.33	1.5	1.5	0.081	0.097	0.037	0.19	0.14	0.029	0.046	0.1	0.27	0.11	0.18	1.3	1.1	0.067	0.069
Lithium	mg/L	0.043	0.004	0.022	0.01	0.014	0.072	0.018	0.13	0.13	0.016	0.015	0.017	0.012	0.029	0.028	0.028	0.021	0.014	0.006	0.02	0.097	0.096	0.013	0.014
Lead	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Manganese	mg/L	0.05	<0.005	0.006	0.013	0.008	0.013	0.005	0.019	0.019	0.008	0.009	<0.005	0.012	0.015	<0.005	0.007	0.021	0.011	0.006	0.006	0.045	0.045	0.006	0.006
Mercury	mg/L																								
Nickel	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Silver	mg/L																								
Strontium	mg/L	0.67	0.041	0.049	0.089	0.068	0.23	0.095	2.8	2.8	0.1	0.081	0.14	0.16	0.16	0.15	0.22	0.27	0.077	0.044	0.2	3	3	0.099	0.1
Zinc	mg/L	0.002	<0.001	0.003	<0.001	0.004	0.008	0.004	0.002	0.002	<0.001	<0.001	0.001	0.003	0.005	0.002	<0.001	<0.001	0.006	<0.001	0.003	0.014	0.009	<0.001	<0.001

mg/L	unit not indicated

Cadmium, Mercury and Silver

Table 11: Dissolved metals c

		GW004728	GW004733	GW004733	GW004735	GW004741	GW004752	GW004759	GW007181	GW007251	GW007268	GW008175	GW008317	GW008449	GW008622	GW008853	GW010038	GW010070	GW010358	GW010371	GW010433	GW010442	GW010491	GW010491 DUPLICATE	GW010756
Date sampled		25-05-19	13-05-19	27-02-18	24-05-19	02-05-18	01-05-19	13-05-19	22-04-18	13-03-18	14-05-19	29-05-19	20-05-19	19-03-18	23-05-19	23-06-19	28-05-19	28-03-18	25-05-19	13-07-19	27-02-18	25-05-19	22-03-18	22-03-18	29-03-18
Vent ID		Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore
Laboratory metals (dissolved)																									
Aluminium	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Arsenic	mg/L	<0.01	0.001	<0.01	<0.01	<0.01	<0.01	0.001	0.004	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.000002	0.003	<0.01	0.011	0.011	<0.01
Cadmium	mg/L																								
Chromium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.000001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper	mg/L	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.000001	<0.001	<0.001	<0.001	<0.001	<0.001
Iron	mg/L	1.7	0.75	0.053	0.18	0.059	0.17	0.12	0.11	0.62	1.5	0.3	0.047	0.045	0.94	0.081	0.35	0.086	1.5	0.00007	0.061	0.71	0.13	0.13	0.24
Lithium	mg/L	0.17	0.042	0.009	0.032	0.009	0.019	0.064	0.017	0.2	0.083	0.002	0.014	0.013	0.069	0.025	0.11	0.014	0.019	0.000017	0.038	0.013	0.022	0.023	0.016
Lead	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.000001	<0.001	<0.001	<0.001	<0.001	<0.001
Manganese	mg/L	0.14	0.019	0.005	0.018	<0.005	0.005	<0.005	0.013	0.12	0.063	0.007	0.008	0.008	0.056	0.009	<0.005	0.01	0.019	0.000009	0.011	0.029	0.006	0.006	0.006
Mercury	mg/L																								
Nickel	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.000001	<0.001	<0.001	<0.001	<0.001	<0.001
Silver	mg/L																								
Strontium	mg/L	3.3	0.65	0.051	0.45	0.1	0.11	0.5	0.18	2.1	2.8	0.04	0.083	0.093	2.1	0.096	1.4	0.098	0.25	0.00011	0.084	0.14	0.08	0.081	0.12
Zinc	mg/L	0.09	<0.001	0.002	0.002	0.008	0.001	<0.001	0.001	0.024	0.009	<0.001	0.004	<0.001	0.006	0.028	0.003	<0.001	0.002	<0.000005	<0.001	0.006	0.003	<0.001	<0.001

mg/L unit not indicated

Cadmium, Mercury and Silver

Table 11: Dissolved metals c

		GW010775	GW010785	GW010786	GW010905	GW011260	GW011265	GW011265-DUPLICATE	GW011266	GW011271	GW011334	GW012094	GW012120	GW012121	GW012197	GW012197-DUPLICATE	GW012285	GW012852	GW013140	GW014537	GW014588	GW014672	GW014675	GW014760	GW014764
Date sampled		28-05-19	01-05-19	01-08-18	26-04-18	01-08-18	23-05-19	23-05-19	20-03-18	27-04-18	20-03-18	28-04-18	17-05-19	19-03-18	21-05-19	21-05-19	09-04-18	01-05-18	27-04-18	04-05-18	20-04-18	02-03-18	24-04-18	21-05-19	01-05-18
Vent ID		Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore
Laboratory metals (dissolved)																									
Aluminium	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.00001	<0.01	<0.01	<0.01
Arsenic	mg/L	<0.01	<0.01	0.002	<0.01	0.003	<0.01	<0.01	<0.01	<0.01	<0.01	0.002	<0.01	<0.01	<0.01	<0.01	0.002	0.001	0.001	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium	mg/L																								
Chromium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Iron	mg/L	0.44	0.17	0.12	0.21	0.037	0.055	0.055	0.089	0.046	0.23	0.13	0.48	0.05	0.051	0.055	0.069	0.06	0.049	0.46	<0.01	0.1	0.046	0.26	0.021
Lithium	mg/L	0.006	0.018	0.015	0.03	0.011	0.024	0.026	0.015	0.011	0.013	0.009	0.058	0.024	0.096	0.095	0.013	0.019	0.009	0.027	0.008	0.027	0.014	0.15	0.017
Lead	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Manganese	mg/L	0.007	0.007	0.008	0.036	0.006	<0.005	<0.005	0.007	0.007	0.012	0.01	0.03	<0.005	<0.005	<0.005	0.007	0.007	0.008	0.023	0.006	0.005	<0.005	0.008	<0.005
Mercury	mg/L																								
Nickel	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Silver	mg/L																								
Strontium	mg/L	0.097	0.032	0.11	1.2	0.079	0.15	0.16	0.095	0.07	0.1	0.049	1.7	0.075	0.37	0.43	0.13	0.11	0.081	0.52	0.086	0.077	0.069	0.68	0.087
Zinc	mg/L	0.002	0.016	<0.001	<0.001	0.016	0.002	0.001	0.001	0.001	0.005	<0.001	0.014	<0.001	0.004	0.004	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	0.008	<0.001

mg/L	unit not indicated

Cadmium, Mercury and Silver

Table 11: Dissolved metals c

		GW014796	GW014998	GW015748	GW015748-DUPLICATE	GW015749	GW015757	GW017678	GW018041	GW018053	GW018888	GW019483	GW020537	GW021144	GW021148	GW021190	GW022754	GW025066	GW027500	GW029101	GW030684	GW030868	GW039377	GW039445	GW273269
Date sampled		16-05-19	27-03-18	29-05-19	29-05-19	29-05-19	18-04-18	04-06-19	22-04-18	21-03-18	29-05-19	25-03-18	20-05-19	21-04-18	20-05-19	21-04-18	24-04-18	20-03-18	02-03-18	03-05-18	28-05-19	19-03-18	02-03-18	03-03-18	08-03-18
Vent ID		Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore
Laboratory metals (dissolved)																									
Aluminium	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Arsenic	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.001	<0.01	<0.01	<0.01	0.002	<0.01	<0.01	0.002	<0.01	0.002	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium	mg/L																								680
Chromium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Iron	mg/L	0.96	0.067	3.4	1.7	1.6	0.06	0.053	0.09	0.034	0.19	0.11	0.13	0.027	0.064	0.23	0.033	0.27	0.089	0.24	2.9	0.031	0.042	0.021	0.11
Lithium	mg/L	0.13	0.011	0.098	0.1	0.17	0.023	0.026	0.016	0.01	0.062	0.003	0.019	0.008	0.007	0.015	0.013	0.025	0.012	0.023	0.11	0.015	0.011	0.016	0.005
Lead	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Manganese	mg/L	0.24	0.006	0.15	0.15	0.023	<0.005	<0.005	0.006	0.005	<0.005	0.007	0.009	0.011	0.011	0.008	0.008	0.007	0.006	<0.005	0.035	0.006	0.005	0.007	0.005
Mercury	mg/L																								<5
Nickel	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Silver	mg/L																								31
Strontium	mg/L	5.4	0.091	3	2.9	4	0.079	0.19	0.099	0.072	0.63	0.05	0.1	0.083	0.048	0.1	0.09	0.13	0.071	0.2	1.6	0.078	0.065	0.054	0.088
Zinc	mg/L	0.034	<0.001	0.004	0.005	0.003	0.002	0.002	<0.001	0.001	0.014	<0.001	0.002	<0.001	0.003	0.001	0.011	0.001	0.002	0.003	0.003	<0.001	<0.001	<0.001	<0.001

mg/L	unit not indicated

Cadmium, Mercury and Silver

Table 12: Strontium isotope ($^{87}Sr/^{86}Sr$)chemistry results - bores

	GW004591
Date sampled	15-07-19
Vent ID	Bore
$^{87}Sr/^{86}Sr$	0.7049189

Table 13: Stable water isotope (δ 2H and δ 18/16O) results - bores

		GW004591	**16783A**	**GW004259**	**GW004339**	**GW003823**	**GW040866**	**GW004705**	**GW008253**	**GW008253**	**GW004659**	**GW004659**	**GW012246**
Date sampled		15-07-19	15-03-18	13-03-18	11-03-18	12-03-18	07-03-18	21-03-18	21-03-18	27-03-18	22-03-18	20-03-18	23-03-18
Location ID		Bore	991_1	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore	Bore
Stable water isotope													
Hydrogen Isotope	δ ^{2}H VSMOW (‰)	-38.9	-40.4	-39.8	-38.7	0	-36	-40.3	-39		-39.5		0
Hydrogen Isotope Uncertainty	δ ^{2}H VSMOW (‰)	1	0.3	0.3	0.3	0	0.3	0.3	0.3		0.3		0
Oxygen Isotope Result	δ $^{18/16}$O VSMOW (‰)	-6.32	-6.47	-6.26	-6.03	0	-5.05	-6.22	-6.07		-6.12		0
Oxygen Isotope Uncertainty	δ $^{18/16}$O VSMOW (‰)	0.15	0.3	0.3	0.3	0	0.3	0.3	0.3		0.3		0

Table 14: Radiocarbon isotope (^{13}C-^{14}C-DIC) results - bores

		GW004591	**16783A**	**GW004259**	**GW004339**	**GW040866**	**GW008253**	**GW004659**
Location ID		Bore	991_1	Bore	Bore	Bore	Bore	Bore
Date sampled		15-07-19	15-03-18	13-03-18	11-03-18	07-03-18	21-03-18	22-03-18
Radiocarbon isotope results								
DIC conc.	ppm	101	83.73	86.96	70.78	66.69	79.42	76.14
DIC conc.	Mmol /L	8.4	6.97	7.24	5.89	5.55	6.61	6.34
$\delta^{13/12}C_{DIC(VPDB)}$	‰	-6.4	-7.5	-3.7	-7.9	-12	-7.3	-7.5
^{14}C DIC	pMC	0.32	0.43	0.46	1.62	24.92	0.44	0.71
Age Correction								
Conventional Radiocarbon Age	Years	46200	43790	43310	33130	11165	43630	39790
Tamers	Years	41867	39382	38841	28831	6593	39285	35253
Ingerson and Pearson	Years	36225	35093	28695	24558	5419	34680	30947
Fontes and Garnier	Years	35899	34869	27868	24334	5369	34433	30721
Revised F&G v2	Years	37306	36085	30214	25483	6153	35680	31940
δ^{13}C mixing formula	Years	38465	37102	31996	26497	6899	36726	32956
^{14}C Final age	Years	>30000	>30000	>30000	26000	6000	>30000	>30000

Table 15: ^{36}Cl/Cl results - bores

Bore Name	Date sampled	Vent ID	Cor_CL36/CL	Sigma	Sigma[%]	Cor.F.[%]
GW004591	15-07-19	Bore	2.80E-14	1.35E-15	4.8	1.8
16783A	15-03-18	991_1	4.42E-14	1.90E-15	4.2897566	2
GW004259	13-03-18	Bore	1.28E-14	7.73E-16	6.0493344	9.3
GW004339	11-03-18	Bore	4.95E-14	2.64E-15	5.3275374	4.4
GW003823	12-03-18	Bore	4.42E-14	1.82E-15	4.1176471	1.6
GW040866	07-03-18	Bore	1.55E-13	8.25E-15	5.3193548	3.5
GW004705	21-03-18	Bore	3.34E-14	2.23E-15	6.671653	5.8
GW008253	21-03-18	Bore	1.55E-14	1.75E-15	11.301259	10.8
GW008253	27-03-18	Bore				
GW004659	22-03-18	Bore	5.18E-14	4.29E-15	8.2785935	7.1
GW004659	20-03-18	Bore				
GW012246	23-03-18	Bore	0	0	0	0
GW012246	26-03-18	Bore				

Table 16: Tritum results - bores

		GW004591
		Bore
		15-07-19
Tritium isotope		
Isotope activity	Bq/kg	0.003^
Isotope uncertainty	Bq/kg	0.003
Isotope Lower Limit of Detection	TU	0.006
Isotope Uncertainty	TU	0.02^
Isotope Lower limit of detection	TU	0.03
Tritium Isotope	TU	0.05

APPENDIX D

Knowledge and Information Gaps

Information Gaps and Recommendations

Information Gap	Recommendations
Conflicting and limited understanding of the depth and thickness of the GAB geological formations Generally the geological decsriptions on the Borehole Summary Worksheets provided are generic and do no include details of the GAB formation(s) encountered nor ultimately targetted for groundwater abstraction. As such identification of specific aquifers and aquitards is difficult and often not possible, thereby complicating assessments trying to link GAB formation groundwater quality profiles with the geochemistry of spring discharges.	An assessment by a suitably experienced person of the bore lithology in the GAB formations encountered in all registered boreholes up to 20 km of each spring.
Bore lithology and construction details are in some cases limited A discrepancy was identified between the GABWRA 3D model and the DPIE cross-section, based on registered bore logs and lithological understanding of the area. The base of the Hooray Formation, the predominant GAB aquifer in the assessment area, differs between the two separate studies, with inconsisten depths and shape of the base of the Hooray Formation. This inconsistency was considered in all spring source interpretations. This discrepancy has been noted also in the report Ecological and hydrogeological survey of the Great Artesian Basin springs - Springsure, Eulo, Bourke and Bogan River supergroups (Commonwealth of Australia, 2014).	As above, an assessment by a suitably experienced person of the bore lithology in the GAB formations encountered in all registered boreholes up to 20 km of each spring.
Connectivity between Cenozoic alluvium and underlying GAB. This connectivity is understood on a regional scale. Locally there is variability in the permeability of the alluvium and incision of deep leads into the GAB sandstones. These variations create a complexity to understanding the connectivity on a local level.	Further work would need to be carried out at a local level to map the alluvium relative to the GAB formations.
Impacts of water extraction The impact of water extraction and changes in groundwater elevation may have on groundwater flow relative to springs and the changes to water quality through mixing	Assess impact of water extraction in GAB on groundwater elevation trends.
Nomenclature Discrepancies were identified in data tables provided for the names of some springs. Some spring vents and complexes sharing the same locality had discrepancies in naming	Location details have been used to collate locations. A quality check and cross-checking on all spring data is recommended.
Units for metals in file "NSW DPIE Spring Survey 2018-19.xlsx" Arsenic is listed as "Arsenic" in NSW DPIE Spring Survey 2018-19.xlsx and is in mg/L. Arsenic is listed as "Arsenic-Total" in GAB Springs chemistry all rounds.xlsx which is in ug/L. Magnitude of results for these two sets are the same. The third set of results in GABS_MS50km_LABRESULTS_2018_2019.xlsx doesn't have units, Arsenic is listed as "Arsenic-Dissolved".	The magnitude of results has been used to make assumptions about the correct units. A quality check and cross-checking on all spring data is recommended.
Analyte units Data supplied in file GABS_MS50km_LABRESULTS_2018_2019 had no units for the analytes and the following locations showed results that appeared to be 4 orders of magnitude lower than the other locations. It is assumed from the file name that these results are collated from multiple laboratory reports and that there is a possibility that results were in both mg/L and ug/L. The following locations were omitted from machine learning to avoid errors: GW003717, GW003785, GW003831, GW003855, GW004417, GW004709, GW007263, GW007456, GW012419, GW012428, GW012480, GW013049, GW014317, GW014524, GW014870, GW016954, GW021352, GW021483, GW025423, GW027500, GW032500, GW039455, GW050527	A quality check and cross-checking on all spring data is recommended.
Discrepency between GAB Atlas and DPIE bore data The contour map of the base of the Hooray Sandstone in the GeoScience Australia GAB 3D model is inconsistent with the interpreted stratigraphy of the NSW GAB Resource report completed by Department of Primary Industries, Office of Water. Golder combined the two into a Leapfrog model for comparison (Figure) and interpolated formations based on this data	This has been noted in the areas of the report relying on this data.
Muleo and Kallara, multiple co-ordinates in field sheets and spreedsheets Muleo is described as being on the Kallara property. Field sheets detail nearby bores. Used Water NSW database to accurately locate springs. Kallara field sheet (vege survey) has a drawn figure of the springs tha matches the aerial photo from Muleo. Same sample date, and analytical data is duplicated. It is assumed from the diagram and the analytical data that they are the same locations. We've assume because the two registered bores co-ords match Water NSW that the report co-ords are accurate.	Confirmation on spring locations
Field observations not provided Dribbling Bore Spring does not have field sheet or ecological survey. It is unclear whether a separate spring is active here. They have been excluded from discussion in the report	Dribbling Bore Spring survey to determine activity, groundwater dependence and ecolological value.
Photos for some locations not provided Tully, Goomooroo, Wapeela. Photos provide valuable information on the surface geomorphology, wetland typology and spring activity.	Survey to provide photos and additional data.
Youngerina sampling location not provided Field sheet states no spring present, no evidence of a mound but a water tank was present	Confirmation on sampling location or additional survey and sampling to confirm.
Uncertainty in how Tritium results are reported Results are tabulated with what appears to be analytical results under the "Isotope Uncertainty" column.	A quality check and cross-checking on all this data against lab reports is recommended.
No information or field sheet for bore GW17283A	Confirmation of sampling method and location.
Lila Spring did not have field sheet Sampling methodology, climatic events and exact location are not provided	Lila Spring survey and confirmation of sampling method and location.
Variability in sampling across multiple events There is some variability in the sampling of the springs where different vents were sampled across multiple events and some springs were sampled after rainfall events and during dry periods at other times. Further understanding of the effects of seasonal changes and weather events on the spring chemistry would provide further clarity for conceptualisation of the source of these spring	Sampling and surveying of these locations at the same sampling point in dry conditions would allow comparison or spring sources without interference from meteoric or surface water.
Ecological assessments were not provided for all locations Ecological survey field sheets were provided for Bingawilipa, Lila, Muyleo, Native Dog, Peery West, Yooritoo; these do not provided an assessment of that data or concluded an ecological rating.	Ecological surveys for springs considered to be at risk and of ecological value.
Strontium only sampled in one location	Further sampling would need to be conducted to provide a data set for comparison.

APPENDIX E

Important Information Related to this Report

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