Nathan Dam

- Supplementary Groundwater Technical Report
- Final

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SUPPLEMENTARY GROUNDWATER TECHNICAL REPORT

- Final

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1. INTRODUCTION

In April 2012 SunWater released the Nathan Dam and Pipelines Environmental Impact Statement (EIS). Chapter 15 presented the results of a numerical groundwater model, predicted impacts to the groundwater system and associated springs, and nominated future management and monitoring actions.

Comments received from the Queensland Department of Natural Resources and Mines (DNRM) and the (then) Commonwealth Department of Sustainability, Environment, Water, Population and Communities (SEWPaC), now Department of the Environment (DoE) challenged the extent and utility of the data and information used to inform the conceptual and numerical groundwater models. The following underlying points were raised:

- the appropriate use of data from existing groundwater bores;
- a need for drilling and construction of new bores to supplement existing data;
- appropriate interpretation of new data based on the conceptual understanding of the groundwater system; and
- understanding the accuracy of the numerical modelling outputs, specifically in the key area of interest (i.e. around the springs), given the limitations of the input data and modelling approach.

To address the above concerns, SunWater commissioned Sinclair Knight Merz (SKM) to undertake additional desktop and field based hydrogeological assessments over the period from July 2012 to December 2013.

Details of these assessments are provided in this document. However, in summary, the results of the further work indicate the conceptual understanding presented in the EIS remains appropriate as does the numerical modelling which has provided a conservative estimate (over prediction, but within realistic bounds) of the likely impacts to the groundwater system.

For clarity, this document does not specifically address impacts to the EPBC listed “Community of native species dependant on discharge from the Great Artesian Basin”. That assessment is provided in Chapter 28 of the Supplement to the EIS and it takes into account this revised groundwater assessment as appropriate to the form of impact on that community of species.

1.1. Desktop assessment

The aims of the desktop assessment, undertaken in August 2012, were:

- to validate the data and assumptions input to the EIS numerical groundwater model;
- to identify any data gaps (if any) to inform the post-EIS groundwater field program; and
- to demonstrate that the approach taken within the EIS to assess potential impacts to GAB springs was in line with current industry practice and remains suitable for the Project's groundwater impact assessment.

1.2. Fieldwork

A detailed groundwater-specific field program was initially deemed unwarranted for the EIS due to the relatively high number of existing groundwater studies in the general vicinity of the Project (largely related to springs), readily available existing data (e.g. DNRM groundwater bore database (GWDB) and Queensland Springs database) and an existing conceptual model developed during a previous IAS for a dam near this site.

Following the desktop assessment, including review of the DNRM and SEWPaC comments, a post-EIS groundwater field program was deemed warranted.

The aims of the field program were to:

- supplement information gathered during the desktop assessment;
- fill the data gaps identified; and
- use the additional data to determine if the conceptual and numerical groundwater models developed during the EIS were, and remain valid.

This report does not present an update of the EIS models, as it was found from these post-EIS investigations that such an update was not necessary. Discussion is confined to how the new information differs from or supports the original EIS assessment.

A preliminary framework for a groundwater and springs monitoring program is presented as Appendix A. It is expected that this will be refined further should the Project be approved.

2. DESKTOP ASSESSMENT

As detailed in Chapter 15 of the EIS, there are three principal environmental receptors of groundwater that may be impacted by construction of the Project; (1) groundwater bores, (2) groundwater springs and (3) surface water baseflow.

Potential impacts include:

- Drawdown of groundwater potentiometric surface via dewatering for construction of the dam wall (Short term) – Potential impact: decreased discharge from bores and springs
- Inundation of the land surface and shallow groundwater systems within the area of the dam Full Supply Level (FSL) (Long term) – Potential impact: drowns bores or springs
- Increased groundwater pressure as a result of the weight of the dam water body (Long term) – Potential impact: increased discharge from bores, springs or to river baseflow
- Construction of the pipeline and associated infrastructure (Long term) – Potential impact: physical damage to springs.

Therefore, addressing the information and knowledge gaps as nominated by the agencies relates to addressing only points 1 and 3.

Three tasks were undertaken:

- review of available regional groundwater data;
- a comparative review of recent relevant literature to determine the appropriateness of the EIS conceptual groundwater model (described in Section 2.2); and
- review of other methods of groundwater assessments in the Project area including approaches to assessment of Great Artesian Basin springs (described in Section 2.3).

2.1. Data sources and literature reviewed

In the Project area, published groundwater studies undertaken post-EIS focus almost solely on the springs and their role as a key component of the local groundwater system. Due to the limited extent of new data from existing bores within the Project area (described below) the current desktop assessment has focussed on reviewing new springs information.

2.1.1. Groundwater Bore Database

There are a number of public and private groundwater bores in the Project area. Bores are required by law to be listed in the DNRM Ground Water Data Base (GWDB). However, based on previous work in similar rural areas, it is likely there are also a small number of unregistered bores. A bore survey, including to identify these unregistered bores will be undertaken by SunWater prior to commencement of construction.

According to the GWDB (at July, 2012) no bores have been registered in the Project area since the submission of the EIS. Monitoring data recorded in the database has been updated and includes water level data from 4 bores, general water quality data from 13 bores and laboratory analysis of water from 10 bores.

Given the lack of additional (new) bores in the GWDB and previously identified issues of data quality within the GWDB, no further work was carried out in assessing the GWDB as part of the desktop assessment.

2.1.2. Queensland Springs Database

The then Queensland Department of Environment and Resource Management (DERM) QLD Springs Database (Version 5) was consulted in 2010 when the EIS was initially developed and it identified 73 springs in the Project area. Field investigations undertaken by Chenoweth (2010) as part of the EIS identified an additional 17 springs. Of these 90 springs, 21 were identified as affected by temporary drawdown during dam construction and 52 were identified as affected by increased groundwater pressure and flow during operation.

The springs within the Project area are associated with nine (9) spring complexes; all in the Springsure supergroup.

At the commencement of the desktop assessment, in July 2012, the most up-to-date database was obtained from the Queensland Herbarium in July 2012 (J. Drimer, pers. comm. 2012). This version is referred to as the "current database" throughout this report. Although all survey data collected in recent years may not be incorporated into the database, this was assumed to be the most up-to-date record. The Herbarium was contacted in early 2014 and advised that this database remained current for the Project area (R. Fensham, pers. comm. 2014).

Since the EIS was published, there have been changes to the database with some additional springs added, the location of some springs refined, and further information included for some springs. Specifically, springs 26 and 28 of the Dawson River 7 complex have been incorporated into Dawson River 8 complex. Additional springs have been added in the Boggomoss, Newton and Dawson River 4, 6 and 9 complexes. However it is unclear whether these springs include the springs identified by Chenoweth (2010). It has been assumed for the purposes of this assessment that all springs identified by Chenoweth (2010) have been incorporated into the current database.

Appendix B identifies the EPBC status of each spring as listed in the current database. Appendix B also identifies which of these springs are impacted by the Project.

Table 1 includes a summary of the spring complexes and associated number of vents in the Project area, from the EIS and the current database. The springs are shown in Figure 1 as identified in the current database. Additional details on the springs from the current database are presented in Appendix B.

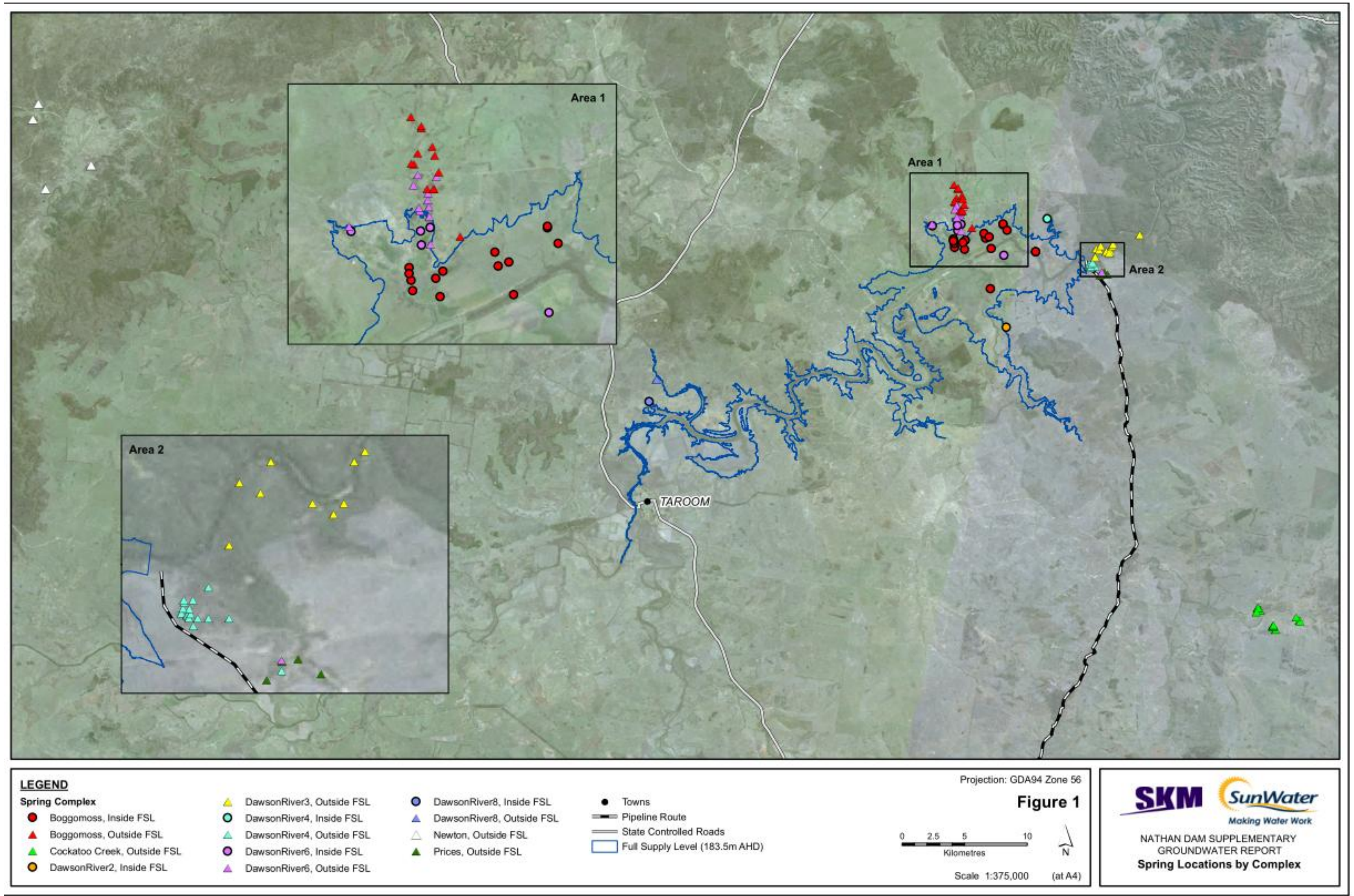
- Table 1 Springs identified in the Nathan Dam and Pipeline project area

Spring complex (complex ID (number))	Number of spring vents	
	QLD Springs Database V5 in 2010 (Recorded in EIS)	Current springs database (July 2012)
Boggomoss (5)	25	30
Dawson River 2 (2)	1	1
Dawson River 3 (3)	10	10
Dawson River 4 (4) ^	12	18
Prices (580) ^	N/A – incorporated into (4)	4
Dawson River 6 (6)	15	17
Dawson River 7 (7)	2	N/A – incorporated into (8)
Dawson River 8 (8)	1	3
Cockatoo Creek (9)	6	19
Newton (85)	1	4
Chenoweth spring vents	17*	0~
Total	90	106

^ Springs 40, 41, 52 and 67 were assigned to Dawson River 4 complex in the EIS, however the QLD Springs Database gives them as being in Prices complex. The Database assignment of Prices complex was retained in this study.

* Identified by Chenoweth as part of EIS field investigations and recorded in the EIS but not included in V 5 of the QLD Springs Database

~ Any new vents identified since V5 of the Database (see discussion below around identifying new vents) are included in the count by spring complex name.



- Figure 1 Spring Locations by Complex

2.1.3. *Data review process*

Matrix tables were developed to standardise the review process and analyse available spring information. The basic format of the matrix tables mirrors the table format of the DERM QLD Springs Database. Table 2 presents the sources used to collate background information on each spring. Springs are primarily referred to by Site Number throughout this report as well as preliminary Site Number, Site and Complex Name, where any confusion of identity might exist.

- Table 2 Background information included in the matrix table template

Background spring information			Source
Spring identifier hierarchy	Site Number		QLD Springs Database
	Preliminary Site Number		
	Site Name		
	Complex Name		
	Complex Number		
	Supergroup Name		
Spring ranking	Conservation Rank	Spring / vent	QLD Springs Database
		Complex	
Potential impact and risk	Relative position to proposed dam wall (upstream/ downstream)		Nathan Dam EIS
	Modelled potential impact	Within dewatering drawdown cone	
		Inundated at Full Supply Level (FSL)	
		Within area of increased groundwater pressure and flow	
EIS coverage	Vent / spring included in Nathan Dam EIS		Nathan Dam EIS

The literature was then assessed for information across 13 broad (19 specific) categories. The categories were compiled from a review of available literature and covered current standard assessment practice on springs (Section 2.5). The categories against which each spring was assessed are included in Table 3, along with an explanation of purpose.

- Table 3 Categories for assessment in the matrix table template

Aspect	Category		Purpose description
Spring properties *Purpose:* Description of spring attributes to allow spring value, potential impact, and similar springs to be identified	Location / elevation		Define site, local and regional aquifer properties
	Size (mound and soak)		Define site
	Discharge seasonality / pereniality		Determine water source
	Flow rate		Spring source aquifer
	Water chemistry (range of parameters)		Spring source aquifer, flow path residence time
	Water age		
	Ecology	Flora and fauna survey (terrestrial and aquatic)	Describes spring composition
		Ecological values	Describes spring composition
	Geomorphology and landscape position		Determine water source
	Condition (damage / fencing)		Baseline data for future impact assessment

Aspect	Category		Purpose description
	Photographs		Define site / spring ID, baseline data for future impact assessment
Hydrogeology *Purpose:* Identification of source aquifer and potential impact on system	Local bore/s	Lithology (bore log)	Describes local geology
		Water chemistry (range of parameters)	Link spring to source aquifer, flow path residence time
		Water age	
		Water level (temporal)	Link spring to source aquifer, local and regional aquifer properties
		Local bore aquifer characteristics (i.e. pump test)	Spring reaction to impacts
	Discharge / recharge assignment (EPBC)		Spring source aquifer
	Conceptualisation of flow path to spring	Regional (source aquifer)	Spring source aquifer
		Local (spring specific) - source aquifer and path	

The data review process was developed to allow the viewer to easily determine the extent of current knowledge on a particular spring or spring system aspect and facilitate a preliminary assessment of the need for any further work. The available data was reviewed and the data coverage for each spring was assessed for each category listed in Table 3. The data availability was visually represented by assigning a colour coding:

- Y – data is available under this category
- ~Y – most data is available under this category
- ~Y – data is available under this category for a spring site but it is unclear whether the available data relates to the spring site as a group or just the primary vent
- N – data is not available under this category

The completed matrix tables are presented in Table B.2 (Spring properties) and Table B.3 (Hydrogeology) in Appendix B.

The following points provide clarification of the assessment of data availability for springs:

- 16 springs were included as additions to the list of springs presented in the EIS, however it is unknown how many of these represent the springs identified as B1-17 in the EIS (Chenoweth 2010). It was assumed that the new vents identified in Chenoweth (2010) were included in the current (July 2012) version of the QLD Springs Database.
- There were a number of cases (springs 37, 47, 56, 64, 65, 68, 320 and 321) where a number of vents were present at the spring site. In many cases, studies did not make clear the vent surveyed or whether the data was valid for all vents at that site. It has been noted in the matrix tables where this has impacted the interpretation of data availability but as at least four of these eight springs will not be impacted by the Project, the quality of the data is less relevant.

- Groundwater bores were only assessed in relation to the springs where bore details were included in a reviewed study, i.e. no new assessment of groundwater bores was undertaken.
- Springs 67 (Prices12) and x346 (also known as nv346) may have been confused by Klohn Crippen Berger (KCB) (2012a). The site survey for springs 39, 40, 41, 52 and 67/nv346 in June 2011 notes that "there was some confusion at the visit to the locality of vent nv364 – this was assigned to vent 67" (KCB 2012a). The QLD Springs Database lists the springs as separate vents in different complexes; 67 as Prices 12 in Prices complex and xv346 as nv346 in Dawson River 6 complex. The separation of the springs as per the Database was retained in the matrix tables, and the assignment from KCB (2012a) was for spring 67.
- Springs 40, 41, 52 and 67 are listed in the Database as being in Prices complex, however they were listed in the EIS as being part of Dawson River 4 complex, as the latest update to the Database has revised the complex name for these springs. These springs are located spatially in a group with site names of Prices 7-3, 5 and 12, rather than Dawson River 4. However, these springs also exist spatially adjacent to spring 39 which is assigned in the Database to the Dawson River 4 complex. It appears therefore that there is some confusion in the Database as to which complex these springs belong. For this study, the naming hierarchy in the latest version of the Database was retained in the matrix table.

2.1.4. Data review outcomes

Table 4 summarises the general data availability across all springs of interest for the spring property categories described above. The data coverage has been qualitatively ranked, based primarily on the number of records containing each information category. For the eleven categories related to spring properties, the available literature is ranked as:

- Good for 4
- Fairly good for 5
- Medium for 1, and
- Very poor for 1 (water aging).

- Table 4 Summary of spring property data availability by category from the literature review

Category			Summary of data availability
Spring properties	Location / elevation		Good coverage although some spring vents lack individual elevation data.
	Size (mound and soak)		Fairly good coverage although it is unclear what area has been measured for some sites. Some springs have no data available.
	Discharge seasonality / pereniality		Fairly good coverage although it is unclear whether some data is for the spring site or for all vents at some sites, and some assessments are made from single observations and this is not sufficient to assign a temporal category. Some springs have no data available, including most of Newton complex.
	Flow rate		Fairly good coverage although some assessments are single visual estimates of flow (not measured) and may not be sufficient to assign a potentially temporal category. Some springs have no data available.
	Water chemistry (range of parameters)		Medium coverage although many sites have only been tested for in-field parameters and it is unclear whether some data is for the spring site or for all vents at some sites. Many springs have no data available, including all of Dawson River 3 and Newton complexes.
	Water age		Very poor coverage and much of the available raw water chemistry results have not been converted to an age. Most springs have no data available. The most work has been done for Cockatoo Creek complex.
	Ecology	Flora and fauna survey (terrestrial and aquatic)	Fairly good coverage although aquatic ecology is almost entirely missing and it is unclear whether some data is for the spring site or for all vents at some sites. Surveys generally cover flora species list, vascular plants, and some macro-invertebrate sampling, the presence/absence of fish and invasive species. Some springs have no data available. There is generally good coverage for Boggomoss and Dawson River 6 complexes and very poor coverage for Newton complex.
		Ecological values	Fairly good coverage although it is unclear whether some data is for the spring site or for all vents at some sites. Some springs have no data available.
	Geomorphology and landscape position		Good coverage for most complexes although data is missing for Newton and Dawson River 3 complexes. Some other springs have no data available.
	Condition (damage / fencing)		Good coverage for most complexes although it is unclear whether some data is for the spring site or for all vents at some sites. Some other springs have no data available.
	Photographs		Good coverage for most complexes although it is unclear whether some data is for the spring site or for all vents at some sites. Data is missing for Newton and Dawson River 3 complexes. Some other springs have no data available.

Table 5 summarises the general data availability across all springs of interest for the hydrogeology categories described above. The data coverage has been qualitatively ranked, based primarily on the number of records containing each information category.

For the eight hydrogeology categories the available literature is ranked as:

- Very good for 2
- Poor for 1
- Very poor for 4, and
- No data for 2.

Table 5 Summary of hydrogeology data availability by category from the literature review

Category			Summary of data availability
Hydrogeology	Local bore/s	Lithology (bore log)	Very poor coverage and for some sites the bores are not that close to springs or the proximity is unknown. Most springs have no data available.
		Water chemistry (range of parameters)	Very poor coverage and for some sites the bores are not that close to springs or the proximity is unknown. Many sites have also only been tested for in-field parameters. Most springs have no data available.
		Water age	No data available during desktop assessment.
		Water level (temporal)	Very poor coverage and for these sites only one reading has been taken which is not sufficient to assign a temporal category. Most springs have no data available.
		Local bore aquifer characteristics (i.e. pump test)	No data available during desktop assessment.
	Discharge / recharge assignment (EPBC)		Very good coverage. Where an assignment is not made it is due to the spring being listed as non-GAB or inactive on the Spring Database. Note: that no assessment of the appropriateness/accuracy of the assignment was made.
	Conceptualisation of flow path to spring	Regional (source aquifer)	Very good coverage. All springs covered by some form of general regional conceptualisation.
		Local (spring specific) - source aquifer and path	Poor coverage and the where conceptualisations exist, they assign a broad geological unit as a source aquifer based on site observation, some water chemistry results and minor desktop study. Better coverage for Cockatoo Creek, Dawson River 4 (and Prices) and Dawson River 8 complexes. No specific flow path is conceptualised. Many springs have no data available.

Based on the gap analysis described here, data and knowledge gaps identified included:

- the nature of any groundwater interactions between the local alluvial aquifer and the adjacent or underlying aquifers of the Surat Basin.
- groundwater levels and pressures in the Precipice Sandstone and other aquifers;
- information on the hydraulic properties of the Precipice Sandstone and other aquifers (e.g. transmissivity, specific yield);
- identification of possible paths for preferential aquifer recharge; and
- accurate data with which to calibrate the numerical model.

The identified gaps were then used to guide the development of the field program as described in Section 3.

2.2. Review of other conceptual models and comparisons with adopted approach

Work undertaken since the EIS completion has focused on the conceptual hydrogeology of the Project area and the hydrogeological aspects of the springs.

The following section summarises and compares the main conceptual models of relevance.

2.2.1. Nathan Dam EIS (SKM 2010)

The EIS conceptual model was based on information available at the time. A discussion of the base assumptions and uncertainty of the approach was included in Appendix 15E of the EIS.

The available information included regional geological mapping, existing information presented in previous reports and literature, and bore data (i.e. stratigraphic information based on lithology logs and groundwater levels and quality monitoring from the DERM GWDB). The bore data was used to develop and/or calibrate modelled surfaces of depth to groundwater, groundwater potentiometric levels, and geological stratigraphic surfaces, which informed conceptualisation of the groundwater environment, groundwater flow patterns and recharge/discharge areas in the Project area. The raw data available meant that it was possible to infer groundwater interactions between aquifers through accepted hydrogeological principles/logic at a regional scale, but not at a sub-regional scale.

The springs conceptualisation within the Project area was limited by lack of hydrogeological data in the area of interest as previous surveys of the springs were overwhelmingly biased towards collection of physical and ecological data. The recovery plan for EPBC listed springs developed by Fensham, Ponder and Fairfax (2010) focused on GAB springs in general and acknowledged that while the connectivity of groundwater sources to spring vents is understood in general terms, the details of the hydrology at individual spring locations is poorly understood, and in some places the source aquifer to the spring is not known (Fensham et al. 2010).

The conceptual model was based on information available at the time on spring discharge patterns, previous reports, regional-scale discussions in the literature of the GAB springs and general hydrogeology, and assumptions based on fundamental principles, e.g. using spring positioning and above ground geology and landscape features to support the idea that the springs are likely to be fault controlled (DNR 1996). In addition to the bore data discussed above, the majority of this information was sourced from the previous review undertaken by DNR (1996) on the *Boggomoss* springs in the Dawson River area as part of an earlier Nathan (Dawson River Dam) impact assessment.

The DNR (1996) study included comparison of major ions in water samples from seven springs within the Project area with nearby artesian bores (a total of 13), which supported the conclusion that the springs assessed were sourced from underlying artesian aquifers; five from the Precipice Sandstone (including one vent within Dawson River 3 complex, one in Dawson River 4 complex, two in the Boggomoss complex, and one thought to be in Dawson River 2 complex). Two vents within Dawson River 8 complex were identified as being sourced from the Hutton Sandstone/Eurombah Formation.

The EIS assessment of available data concluded that the Precipice Sandstone is the dominant hydrogeological unit in the local groundwater system, with the groundwater system and associated springs being fault controlled. The majority of the springs appear to be controlled by the artesian pressure within the Precipice Sandstone and the thickness of the overlying aquitard (Evergreen Formation and/or low permeability units within the Precipice Sandstone).

2.2.2. QCLNG Project Water Management and Monitoring Plan (QGC 2012)

Coal Seam Gas (CSG) companies are required to develop water monitoring and management plans (WMMP) for their projects. At the time of the desktop assessment in late 2012, none had been published. However, QGC granted access to their document for use in the desktop assessment.

Within its WMMP, QGC presented its pre-survey understanding (preliminary conceptual models) of the Cockatoo Creek Complex and Dawson River 8 springs and local groundwater system that drives them. Importantly, apart from its own internal geological and hydrogeological models, QGC did not rely on information or data sources not already assessed in the Nathan Dam EIS or Section 2.3.

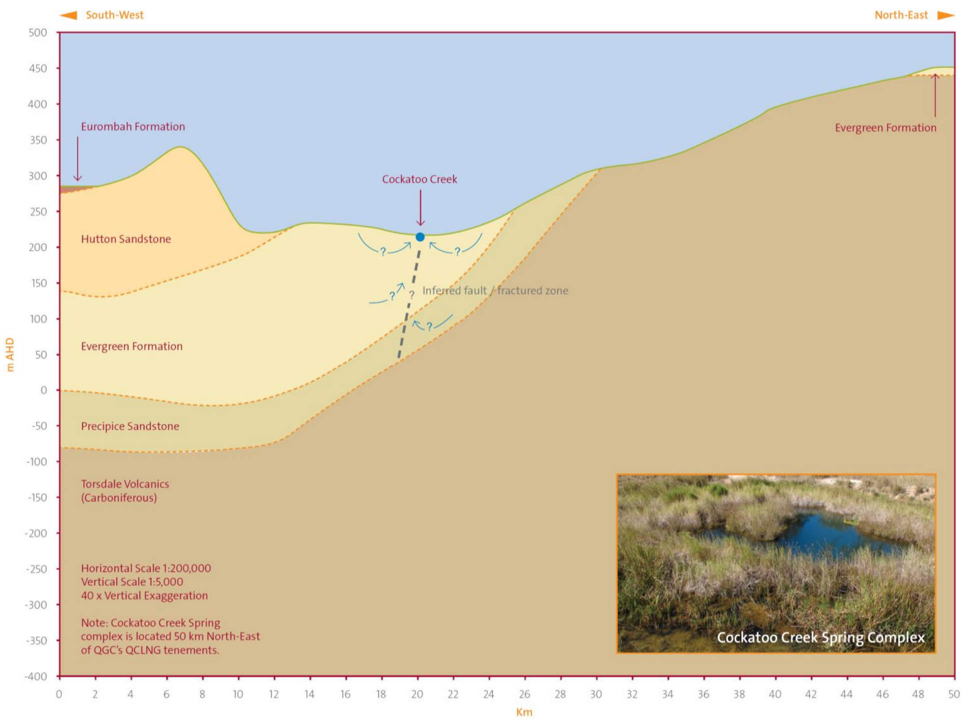
QGC reports that there was still limited information to support the general consensus in the literature that fracturing and faulting are considered to play a large role in controlling the local groundwater system and were potential conduits for groundwater to spring vents.

The conceptual models presented are based on QGC's most recent internal geological model and hydrogeological assessment of the region, and the GEN2 groundwater numerical modelling undertaken in the area (Golder 2011, in QGC 2012).

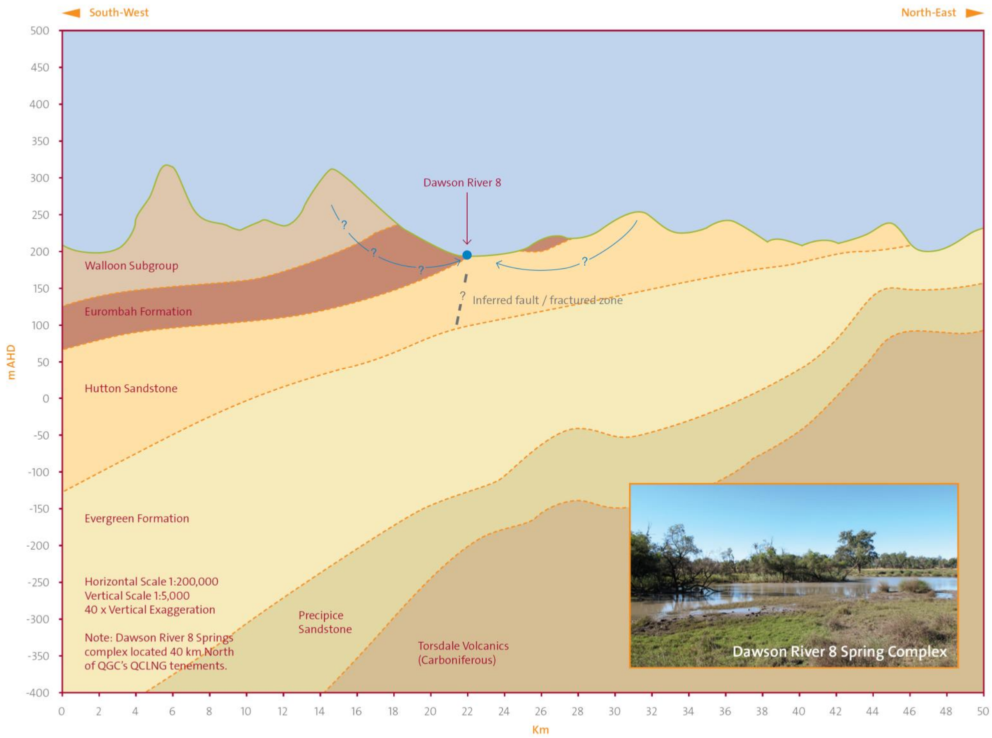
It is generally assumed that the primary source aquifer for springs is that which underlies the springs with topography being used to infer likely flow paths where significant, e.g. local flow paths from 'up slope' or nearby elevated areas that flank the Cockatoo Creek complex that is located in a topographic depression. All three complexes are considered to be potential outlets of fault and fracture conduits, with some evidence for this found in local linear features present near Cockatoo Creek (source of information assumed to be from literature review). An accompanying diagram illustrates the key ideas presented in the text and highlights the uncertainty in the groundwater flow processes and structural influence on springs presented or assumed (Figure 2 and Figure 3).

Confirmation of intermediate flow paths by isotopic age dating is suggested to be underway for Cockatoo Creek.

In summary, this report emulates the conceptualisation approach adopted in the EIS, producing a similar conceptual model.



- Figure 2 Conceptual diagram of Cockatoo Creek spring complex (taken from QGC, 2012)



- Figure 3 Conceptual diagram of Dawson River 8 spring complex (taken from QGC 2012)

2.2.3. QWC Underground Water Impact Assessment (QWC 2012b)

QWC (now part of the Department of Energy and Water Supply (DEWS)) instigated works toward delivering an Underground Water Impact Assessment (UWIR) for the Surat Cumulative Management Area (CMA), comprising the Surat and southern Bowen Basins (QWC 2012b). In relation to the Nathan Dam Project area, the Springs Impact Management Strategy (SIMS) set out to identify all springs potentially affected (by CSG extraction), confirm their locations, their values and assess the spring's connectivity to underlying aquifers.

Two field survey programs were undertaken as part of the QWC work: collection of a suite of hydrogeological attributes (KCB 2012a) and collection of ecological and botanical information (Fensham et al. 2012). Following field investigations, a desktop analysis of source aquifers was undertaken for some spring complexes (KCB 2012b). These individual studies, and the links between them are summarised below.

- Hydrogeological attribute surveys (KCB 2012a)

A hydrogeological field survey was undertaken to gather spring vent specific information.

A total of 23 spring complexes including 86 vents and nine adjoining bores were surveyed. Sixty water quality samples were analysed with a subset of 24 samples used for radio carbon analysis. The surveys included 34 vents relevant to the Nathan Dam project area; at least one within all nine associated complexes except Newton and Dawson River 3.

Of the vents surveyed in the Nathan Dam area, a general water quality sample was taken at 12 vents, with 10 also analysed for stable isotopes and five for 14C.

Water samples were collected from each vent visited, with some results being used in the source aquifer investigations that followed (discussed below; KCB 2012b), however, as part of the field surveys an in-field source aquifer assessment (conceptualisation) was also undertaken. This was based on background information collated preceding the surveys to identify geology and bore water levels close to the springs combined with visual observation of surface geology on site. The most likely source aquifer suggested for all the Nathan Dam vents visited was Precipice Sandstone except vent 38 (part of Dawson River 8 complex), which was thought to be sourced from the younger Hutton Sandstone or Birkhead Formation.

The report summarises spring types based on a basic conceptualisation derived from the information collected. These are described in Table 6 and Table 7. The analysis of field data suggested a trend in source aquifer, spring flow and spring type, with Hutton Sandstone outcrop springs generally having lower flow rates, minor sediment based mounds and no peat development (KCB 2012a). In contrast, those associated with Precipice Sandstone were observed to *'have higher flow rates and were more commonly associated with peat mounds where they were located in a confining layer'*. It was also highlighted that numerous vents were located 'near or at geological boundaries or structures', again suggesting geological structure plays an important role on controlling the local groundwater system.

- Table 6 Springs located over confined aquifers (reproduced from KCB 2012a)
  Note: percentages relate to *all* springs visited; only 34 of which are of interest to the Nathan Dam Project

Spring Type	Description
Springs with peat mounds	30% of the vents visited consisted of peat substrate mounds (Boggomosses) over confined aquifer conditions. The source aquifer to these springs is predominantly the Precipice Sandstone aquifer capped with the Evergreen Formation (22 vents), although the Hutton Sandstone aquifer capped with the Birkhead Formation (4 vents) was also identified. Examples included the Boggomosses and the Scott's Creek Complexes.
Springs with sediment mounds	3% of vents visited have notable sediment mounds with little or no peat development. These included two Hutton Sandstone aquifer sites capped with Birkhead Formation and one Precipice Sandstone aquifer site capped with Evergreen Formation.
Springs with no mounding present	3% of vents were surface seeps with no definable mound structures were present verifying the confined aquifer. Example included Lucky Last (vent 285B) and Cockatoo Creek (vent 320).
Direct discharge to creeks (spring fed creeks)	7% of vents visited appeared to direct discharge through confining-layer "caps" to creeks. Source aquifers for these were Precipice sandstone aquifers capped with Evergreen Formation and Hutton Sandstone aquifers capped with Birkhead Formation. Examples included Scott's Creek and vents Yebna (vent 534).

- Table 7 Springs located within unconfined aquifers (reproduced from KCB 2012a)
  Note: percentages relate to all springs visited; only 34 of which are of interest to the Nathan Dam Project

Spring Type	Description
Springs with peat mounds	7% of the vents visited consisted of peat mounds (Boggomoss) over source aquifers at outcrop (Precipice Sandstone (5 vents), Clematis Sandstone (1 vent)). Examples included vent 408.1 and Price Creek (vents 47 and 51).
Springs expression high in landscape	9% of vents visited appeared to be seeps from source aquifer at outcrop. Seven vents were located in the Gubberamunda Sandstone with spring flows / levels linked to climatic patterns. One vent of this style was also observed in the Hutton Sandstone at outcrop. These vents are notably mid to upper slope in the landscape. Examples included Six Mile spring complex.
Seepage from recent alluvium	One vent visited was significantly different from others and appeared to be sourced from younger groundwater within young alluvial material, indicating a water table window (vent OR1).
Direct discharge to creeks (spring fed creeks)	26% of the vents visited appeared to be sourced from direct discharge from the formation at the outcrop to creeks. These vents were from Precipice Sandstone (13 vents), the Boxvale Sandstone Member of the Evergreen Formation (5 vents), Hutton Sandstone (2 vents) and Clematis Sandstone (2 vents). Examples included the Springwater and Yebna spring complexes. Evidence of upwelling in some creek beds suggests that these springs may not be solely water table windows. It is inferred that some degree of confinement within the aquifers at outcrop occurs; and / or that the water may be also sourced from deeper confined aquifers.

Desktop assessment of source aquifers (KCB 2012b)

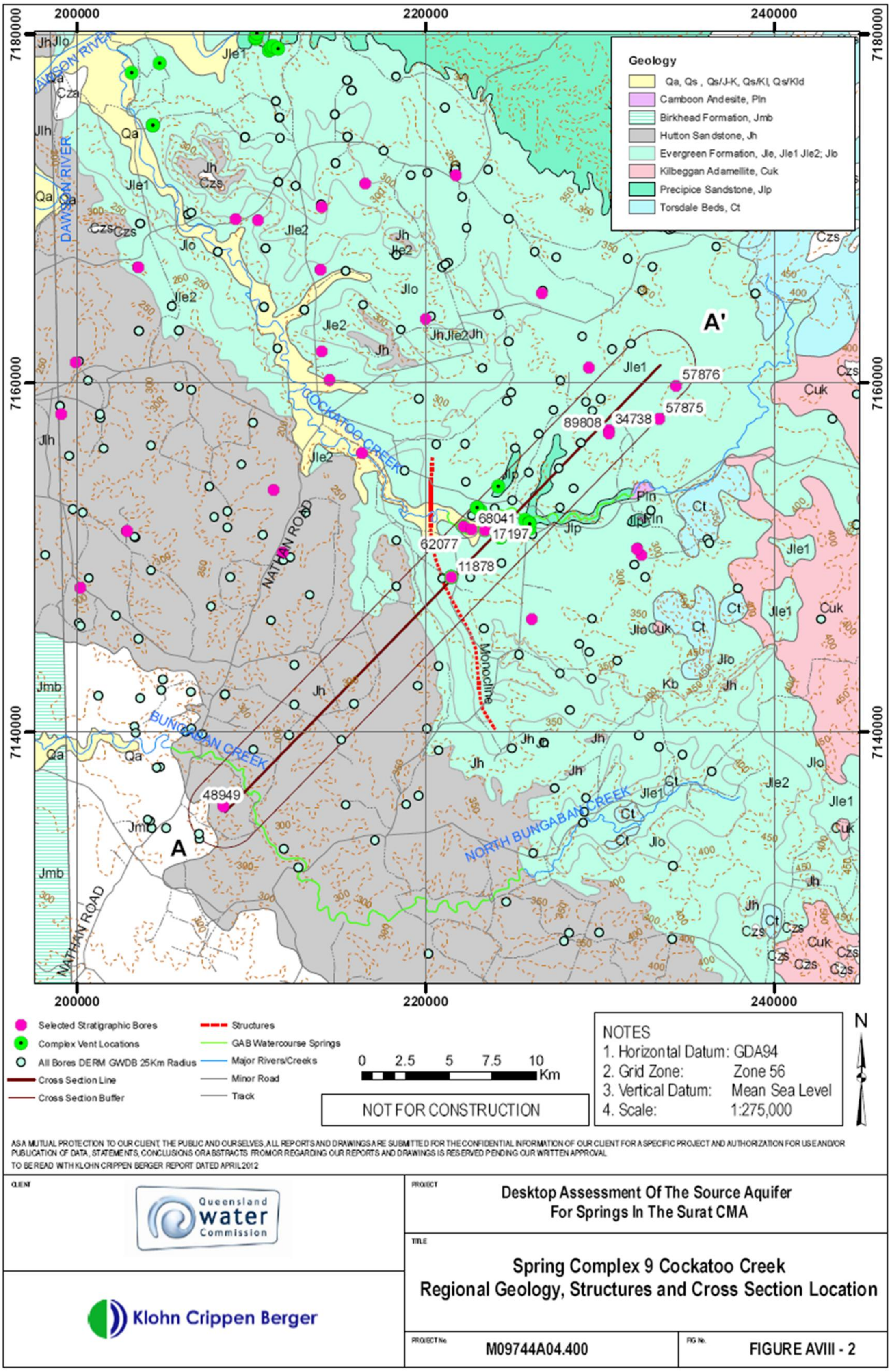
Following the field surveys, a desktop or conceptual assessment was undertaken to identify source aquifers for certain springs in the Surat CMA (KCB 2012b). The springs were chosen by the QWC based on three criteria, including *areas where water levels in aquifers are likely to be most affected* (by CSG activities). Of the springs of interest in the Nathan Dam Project area this only included the Cockatoo Creek Complex; the other complexes relevant to the Nathan Dam Project were outside of the modelled predictions of groundwater drawdown due to currently approved CSG activities, though this may change in the future.

The study used the outcomes of KCB 2012a survey data as a basis on which to build the assessment. Additional information included assignment of source aquifer to all DERM bore and data tables from the GWDB, data from CSG proponents within 20 km of springs collected by QWC (including groundwater quality, piezometric head and borehole geology), isotope and water quality compiled by DERM Healthy Headwaters Project Activity 1.2, and information collated from literature review of key references with water isotope data for the Surat Basin aquifers.

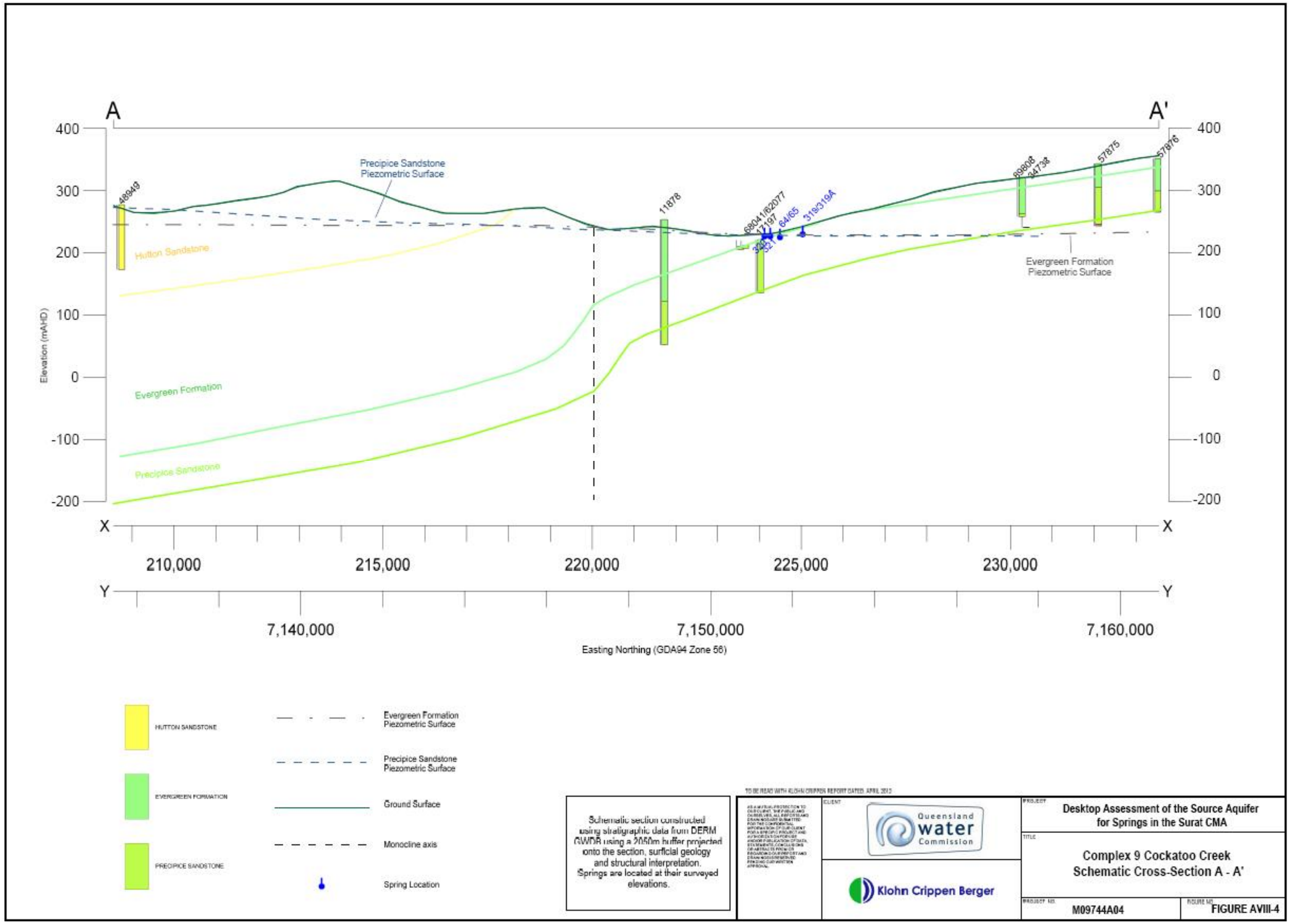
Hydrogeological cross sections were developed based on stratigraphic logs from the GWDB (Figure 4 and Figure 5) and water quality results from five spring vents and four nearby bores were analysed (locations shown in Figure 6) and compared with field observations from KCB (2012a). Stable isotope and radiocarbon results, including historical data if available, were also analysed to assess the likely source aquifer. The report details the data collected and any analysis undertaken for each spring complex in the Appendices; providing maps of key data points and the cross section developed.

A brief summary of spring types and conceptual flow regimes is provided in the report. For the Cockatoo Creek complex, the report concludes that the most likely source aquifer is the Precipice Sandstone and that there is potential influence from the Evergreen Formation and near-surface soil water before discharge to the surface. KCB (2012b) also suggest an important component of the local groundwater system may be direct groundwater discharge to creeks where the Precipice Sandstone is at outcrop or through a thin veneer of capping Evergreen Formation.

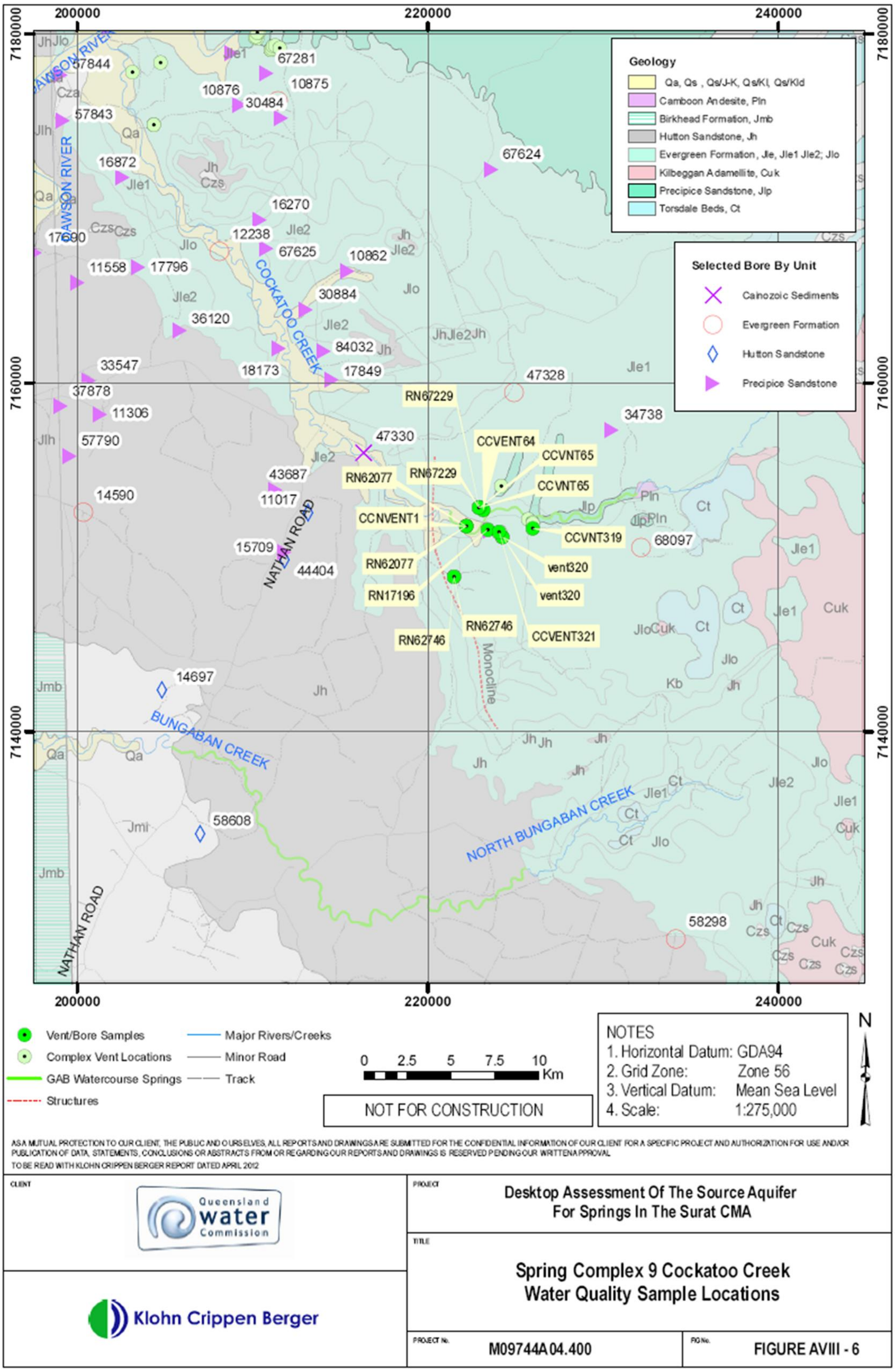
The KCB (2012b) approach to conceptualisation relied heavily on hydrochemistry data collected during their field work in combination with the same information used in the EIS. Regardless of the approach, the outcomes of the conceptualisation remain similar to those detailed in the EIS.



- Figure 4 Structural geology and stratigraphic bores selected for cross section (KCB 2012b)



- Figure 5 Schematic hydrogeological cross section near Cockatoo Creek spring complex (KCB 2012b)



- Figure 6 Water quality sample locations and nearby DERM registered bores (KCB 2012b)

2.2.4. *Water Resource Assessment (CSIRO 2012)*

The assessment aimed to provide *'an analytical framework to assist water managers in the Great Artesian Basin (GAB) to meet National Water Initiative commitments'* and in doing so, reconceptualised the GAB groundwater system on a regional to basin scale through comprehensive compilation of the latest information on hydrogeology and flow systems.

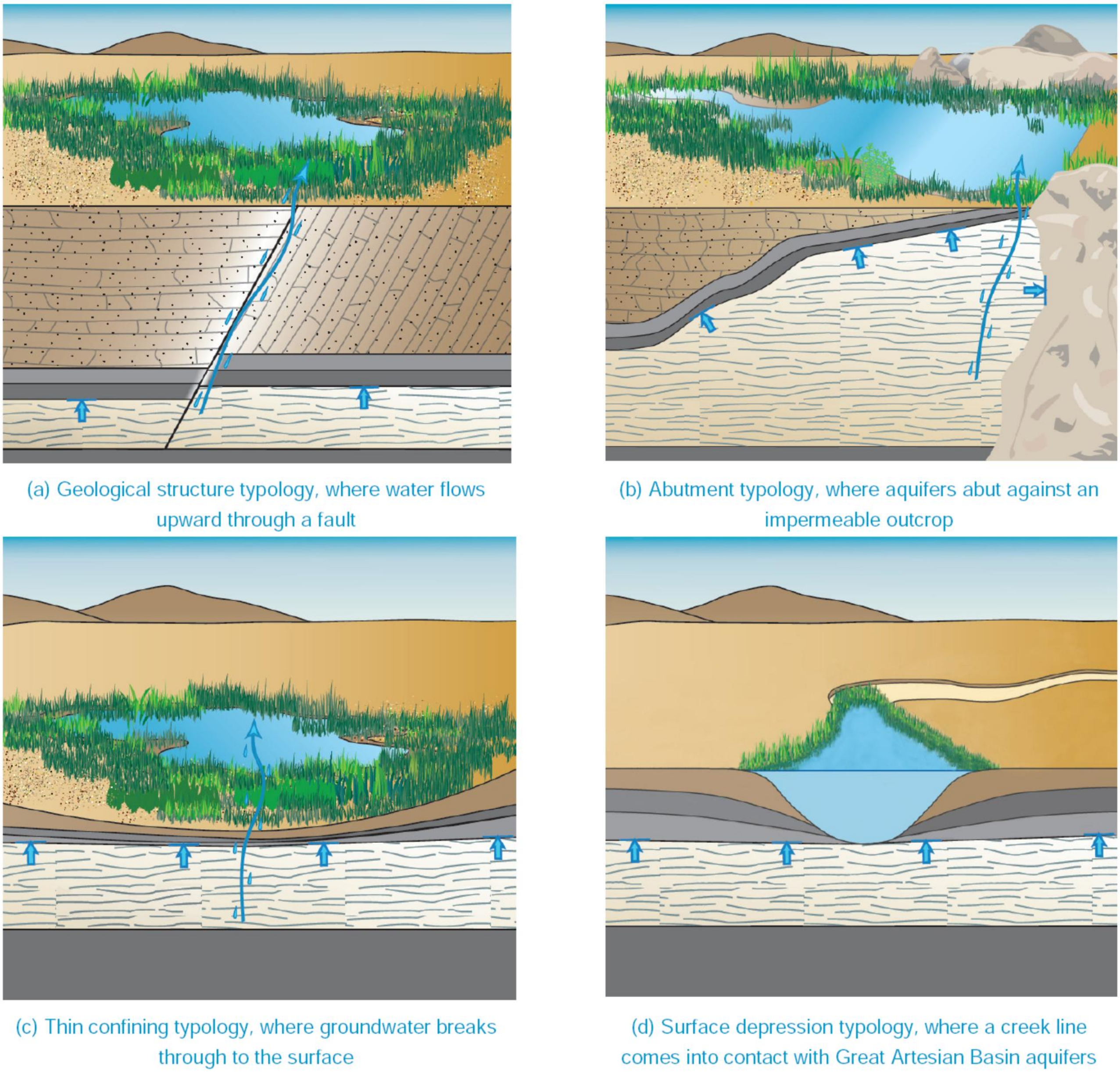
The report draws on the conceptualisation of the GAB by Habermehl in 1980 and reconceptualises the basin based on studies undertaken and reports published since that time. The impact assessment looked at springs at the complex scale (but reported findings at the supergroup scale in the regional reports). A companion technical report (not available at the time of writing) contains greater detail. The report states that *'ecological and hydrological (including water quality) data are not uniformly available across the GAB'* and that these data are required to *'undertake a more comprehensive assessment [and at a smaller (spring) scale] of the vulnerability of springs to drawdown'.*

The report highlights the importance of firstly identifying the hydrogeological and hydrological processes driving formation and maintenance of the GAB springs in order to understand the impact to springs from changes in the groundwater system.

The potential types of groundwater-dependent ecosystems (including springs) were identified drawing on the Habermehl (1980) conceptualisation and classified in line with the Australian National Aquatic Ecosystems (ANAE) framework (Auricht 2011) and the further tiers of classification (the structural linkage tier) developed by Green, White, Scholz and Gotch (2012). The structural linkage tier allows knowledge of the geological and hydrological environment of an area or site (i.e. conceptualisation) to help identify the type(s) of spring(s) occurring and hence the likely physical processes that form and maintain them. The four typologies are illustrated in Figure 7.

Classification of GAB springs into these typologies was not undertaken by CSIRO but following literature review of the area, typologies (a), (c) and (d) are listed to occur within the Springsure supergroup; the *Dominant structural linkage type* being (d) Surface depression (creek-line) and the *Dominant hydraulic environment* as *Non-artesian*. The majority of the Surat Basin springs are thought to be associated with geological faults; those in recharge areas occurring '*as a result of 'overflow' or 'rejection' of recharge into aquifers',* or in topographic lows where aquifers are intersected (CSIRO 2012).

The overall usefulness of the Assessment in relation to the Nathan Dam Project is limited, as the Assessment aims to present a high level regional to basin scale overview of groundwater system conceptualisation types adjacent to GAB springs, but does not provide a detailed assessment of the local groundwater system in the Nathan Dam Project area. Moreover, the conceptualisation developed as part of the EIS fits within the general framework described by CSIRO, in particular spring type (a) depicted in Figure 7.



- Figure 7 Conceptualisation of structural linkage processes that form springs in the GAB ((a) to (c) developed by Queensland DERM (2011) and (d) adapted from DERM (2011)) (CSIRO 2012)

2.2.5. Conceptual model comparisons

All 'new' conceptual models summarised above support the two main assumptions presented in the Nathan Dam EIS:

1. that the springs are fault controlled or occur due to aquitard thinning; and
2. all spring complexes in the Nathan Dam area are likely to be primarily sourced from the Precipice Sandstone aquifer, except Dawson River 8 where the Hutton Sandstone aquifer is thought to be the main water source.

Significant amounts of new data are available on some individual spring vents following recent surveys. This includes more surface based hydrogeological attribute data with subsurface data consisting solely of water sample analyses. None of the new data has contradicted the conceptual model developed as part of the EIS.

There has been no new (available) data to help characterise aquifer properties in the Nathan Dam Project area since the EIS. The exception to this is the work undertaken by KCB (2012a) with respect to the Cockatoo Creek complex. The conclusion, as stated above, supports the conceptual model presented in the Nathan Dam EIS.

2.3. Review of other groundwater assessment approaches and comparisons with adopted approach

Major projects undertaken in Queensland have been historically required to prepare a groundwater impact assessment (GWIA) where there is a potential that the project may affect the local or regional groundwater systems. These assessments have taken similar approaches to that adopted in the EIS, presenting their assessments of site setting, impact assessment, risks and management of impacts, where appropriate.

There currently exists no specific standard accepted practice for groundwater impact assessment related to GAB springs. Assessments and frameworks published following the EIS have been reviewed and compared to that used in the EIS.

2.3.1. QWC Underground Water Impact Report (UWIR, QWC, 2012)

The development of the UWIR included:

- a summary of the legislative framework and requirements for the assessment
- an overview of the project
- compiling a current understanding of the geology and hydrogeology of the area;
- developing a regional cumulative groundwater flow model (the regional model);
- analysing uncertainty in model predictions;
- undertaking a comprehensive survey of the relevant springs in the Surat CMA for their hydrogeological and ecological attributes; and
- compiling an inventory of all existing and proposed monitoring bores and activities in the Surat CMA.

The UWIR for the Surat CMA includes:

- a prediction of impacts on water levels;
- a water monitoring program;
- a spring impact management strategy; and
- assignment of responsibilities to individual petroleum tenure holders to undertake water management activities in the area.

The report provides a logical and definitive method for compiling the necessary background data, the methodology used to carry out impact prediction and describing the management of impacts.

It is this 'standard' that provides a basis for comparing the groundwater impact assessment undertaken for the Nathan Dam EIS. The EIS approach followed a very similar methodology including overview of legislation, geology and hydrogeology of the area, development of a numerical groundwater model, prediction of impacts on groundwater levels and development of monitoring and management plans. The EIS assessment did not include a field survey of existing bores however SunWater has committed to do so prior to construction. Nor did it include site survey relating to the hydrogeology of the springs, although ecological survey was undertaken.

2.3.2. Spring Impact Management Strategy (QWC 2012b)

As part of the Surat UWIR, QWC developed the *Spring Impact Management Strategy* (SIMS) to identify springs and assess the risk resulting from water extraction. At the time of writing, this became the currently accepted framework for spring risk assessment and management related to drawdown resulting from CSG industry activities.

Components of the SIMS include the identification of springs, the connectivity of spring to underlying aquifers, risks to springs, a spring monitoring program, and spring impact mitigation strategy.

QWC defined a spring as potentially affected if it overlies a GAB aquifer where the long-term predicted impact on water levels at the location of the spring resulting from the extraction of water by petroleum tenure holders exceeds 0.2 m. As well as the springs identified using the regional groundwater flow model, the QWC included high value springs that are located up to 10 km beyond the 0.2 m limit, to allow for the limitations associated with modelling very small changes in water level (QWC 2012b).

The risk assessment method scores each spring vent against criteria for both likelihood and consequence. The likelihood assessment considers the likelihood of a reduction in flow to a spring and was based on the magnitude of predicted impact on aquifers underlying the spring (maximum drawdown from the regional groundwater model). It also considers proximity of the spring to a CSG production tenure as well as proximity of the spring's source aquifer to a target CSG/petroleum formation.

Consequence of impact criteria included: the spring's conservation ranking (based on Fensham *et al*. 2010) and distance of the spring from the recharge area for the spring's source aquifer (this was used as a surrogate measure of ecosystem resilience to changes in flow, i.e. the further away from the recharge site, the less resilient the system is to variation in flow).

The SIMS included development of a spring monitoring program. The monitoring program was aimed at identifying changes in the volume and chemistry of groundwater flowing to a spring (i.e. monitoring the local groundwater system) and any change in the character of the spring itself. Monitoring sites were selected based on outcomes of the risk assessment described above.

The assessment of spring impacts in the EIS follows a similar process with impacted springs identified based on modelled impacts to groundwater pressure, level and flow. The consequence of impacts to springs was then assessed based on the magnitude of the impact and the ecological values of the springs. In general terms this is a similar approach; however, the EIS risk assessment did not individually assess all the specific criteria included in the QWC SIMS risk assessment. There are major differences in the types of impacts assessed by QWC and that related to the Nathan Dam project and both impact assessments and monitoring programs should not be seen as directly relevant. For example the drawdown impact related to dewatering of dam foundations is short term only and water levels will return to normal rapidly once dewatering ceases. Similarly the impact of water in the full dam is to increase groundwater levels in local aquifers, rather than to potentially decrease them as CSG-related drawdown does.

The monitoring program proposed as part of the EIS included monitoring of groundwater and impacted springs in each spring complex affected with a range of the parameters identified in the SIMS, although not all, to be included in the Nathan Groundwater Monitoring Plan.

2.3.3. South Australian Risk Assessment Framework (Green et al. 2012)

The National Water Commission (NWC), in conjunction with the South Australian Government, released a *South Australian Risk Assessment Framework* (Green *et al.* 2012). This is a technical framework rather than a policy framework and it solely focuses on the risks of drawdown to discharge springs in the arid zone (i.e. western margins of the GAB) (Gotch, pers. comm., 2012).

The Framework identifies that accurate measurements of spring elevation and the pressure surface of the source aquifer are essential to include in a risk assessment tool (Green *et al.* 2012).

The spring classification incorporated geomorphic, hydrogeochemical, spatial and ecological criteria.

2.3.4. Water Resource Assessment (CSIRO 2012)

CSIRO (2012) considered the following aspects of springs in their conceptualisation: spring type (based on Green *et al.* 2012), water source, the hydraulic environment (i.e. recharge or discharge spring/ artesian or non-artesian), structural linkage (geological and hydrological processes that form springs) and surface morphology (types described in Green *et al.* (2012). Ecological value was also assessed (EPBC listed sites and spring complex conservation rankings based on Fensham *et al* (2010)).

Risk was determined using conservation value and drawdown predictions. CSIRO stated that the whole-of-GAB spring dataset (from Fensham *et al.* 2010) has a limited range of fields that are desirable in assessing the impacts of drawdown on springs. For example, it does not contain water quality information or information about the spring typologies (structural linkages and surface morphology) at a suitable scale for assessment. This has been improved somewhat for the Surat region by recent surveys (Fensham *et al.* 2012 and KCB 2012a).

2.3.5. *General Groundwater Dependent Ecosystems approaches (Serov et al. 2012)*

As well as strict spring risk assessment approaches, there are recent risk assessment guidelines and protocols for broader Groundwater Dependent Ecosystems (GDEs). The New South Wales' Office of Water developed risk assessment guidelines for GDEs (Serov, Kuginis and Williams 2012) which involve the consideration of "assets" such as water quantity, water quality, aquifer integrity and biological integrity. In order to determine the magnitude of risk from an activity, Serov *et al.* (2012) state the following as minimum information requirements: spring type/habitats, area, condition, groundwater source and nature of dependency, natural watertable fluctuation and levels, water level requirement for habitats, groundwater depth, and species within the GDE community (including exotic).

2.3.6. *Review of assessment approaches*

In terms of a comparison with the EIS risk assessment process, the following can be concluded:

- All reviewed frameworks acknowledge the current limited availability of site specific hydrogeological data.
- Frameworks developed by CSIRO and Green et al. (2012) are broad scale with little practical guidance on assessment of project specific impacts. All frameworks focus on the risk of drawdown on springs, with little guidance on the assessment of increased water levels, pressures and discharge. Furthermore, the frameworks provide no guidance on determining when groundwater level variation should be considered an impact or within the bounds of normal fluctuations.
- Currently the QWC's UWIR and SIMS present a good outline of current practice.
- The methodology of assessment adopted in the EIS generally follows the approach adopted in the UWIR (QWC, 2012) with SunWater already committing to overcome the identified shortfall of a bore survey, which in itself is not considered critical.

2.4. Summary of desktop assessment findings

The main conclusions of the desktop assessment are:

- The majority of data and information available for the groundwater system in the Project area relates to springs, with the exception of the DNRM GWDB.
- The majority of data and information available for springs in the Project area relates to physical and ecological surface characteristics, while in most cases water age and a large range of hydrogeological data is absent.
- A list of key data gaps to be targeted through field survey has been compiled.
- Studies undertaken since the EIS confirm the results of the EIS conceptual model of spring source aquifer and the fact that the majority of springs in the region are controlled by faults and aquitard thinning.
- None of the new data collected has contradicted the conceptual model developed as part of the EIS.
- All reviewed frameworks acknowledge the current limited availability of hydrogeological data for use in spring risk and composition assessments and request that more data on morphology, salinity and ecosystem connectivity is included in assessments, including site specific data.

- Currently the QWC's UWIR and SIMS present a good outline of current practice in terms of groundwater assessment including impact assessment, cumulative assessment and springs.
- The methodology of assessment adopted in the EIS generally follows the approach adopted in the UWIR, with the exception of site survey relating to the hydrogeology of the springs and survey of existing bores.

3. FIELD PROGRAM

3.1. Introduction

The desktop assessment found that the conceptualisation of groundwater flows and spring processes presented in the EIS agrees with other relevant studies in the Project area. It also identified that the validity of any assessment of spring impacts is enhanced by the availability of detailed spring and groundwater data.

To validate the spring impact assessment undertaken as part of the EIS, a field work program was developed and implemented.

This section details the:

- design (and peer review) of the field program (Section 3.2);
- implementation of the field program (Section 3.3); and
- analysis of the results of the field program (Section 3.4).

3.2. Field program design

The objectives of the field program were nominated above.

During the field program design an ancillary objective was identified; to position any new bores where they could be used in this assessment, as well as in an ongoing monitoring program.

Based on the gaps identified during the desktop assessment, the key information to be targeted by the field program was:

- field observations by a hydrogeologist;
- lithological information, specifically detailing the extent of any aquitards associated with the springs, and depth to the source aquifer;
- groundwater pressures and levels, and seasonal fluctuation associated with spring systems; and
- groundwater chemical information to confirm source aquifer to the springs.

From this information, it was expected to be able to:

- further the understanding of the nature of any groundwater interactions between the local alluvial aquifer and adjacent or underlying aquifers of the Surat Basin;
- identify possible paths for preferential aquifer recharge;
- identify the relative contribution of local and regional groundwater flow to spring complexes; and
- validate the numerical model based on more accurate data.

3.2.1. Stage 1 – Identification of general site investigation locations

The first stage in the field program design was the selection of suitable springs and landscape for the installation of monitoring bores and locations for spring water sampling. Co-location of bores and springs aimed to allow direct comparisons of data gathered from the bores and the adjacent springs, but without damaging the springs. The sites selected were required to:

- have suitable access for a drilling rig and future access for field staff to continue monitoring;
- be adjacent springs that are outside the FSL and within the predicted impact zone; and
- be representative of spring groups within the Springsure supergroup.

Four 'general site locations' were identified to represent the breadth of the area potentially impacted by increasing groundwater pressure (as defined by the EIS groundwater model). These were:

- downstream of the proposed dam within outcropping Precipice, where springs are modelled to have large increases in discharge volumes;
- directly north of the inundation area within the Boggomoss complex, where springs have some degree of confinement (aquitard) and are modelled to be impacted by the change in groundwater pressure;
- Cockatoo Creek, to the south of the inundation region, outside the area modelled to be impacted by changes in groundwater levels (to function as a control site); and
- at the tail of the inundation region, near the township of Taroom, representing springs in a marginal impacted zone and near the towns water supply bore.

During the field program design, the Coordinator General commissioned RPS Aquaterra to provide independent peer review of the proposed field program, results and analysis, on behalf of DoE and the Coordinator General. The peer reviewer was involved prior to the initial site visit, providing advice on the suitability of the proposed bore locations, concluding that the chosen locations were a '*sound design to build on previous investigations and understanding*'.

3.2.2. Stage 2 – Refinement of proposed bore locations

As not all proposed sites proved suitable, the sites were reviewed based upon a pragmatic approach to identify which bores could be postponed or removed from the program because either:

- an existing bore could be refurbished and initial data readings used, in place of drilling a new bore; or
- where a nested site was proposed, one of the bores could be removed without significant impact to the data capture.

The revised works program was discussed with and approved by the peer reviewer prior to commencement of the field program.

The final program included five new monitoring bores and refurbishment of two existing bores. A summary of the bore locations and purpose are provided in Table 8. Figure 8 presents a locality plan and cross-section at each bore.

- Table 8 Summary of new and refurbished monitoring bores

Bore ID	Aquifer Monitored	Purpose
Dawson River MB01	Hutton Sandstone	Observe groundwater pressure and quality in the vicinity of the Dawson River springs (short term) Monitor to the west of the inundation area and to observe any change in the Hutton Sandstone aquifer (long term)
Dawson River MB02	Hutton Sandstone	As above
Boggomoss (north) MB02	Precipice Sandstone	Observe groundwater pressure and quality in the vicinity of the Boggomoss springs (short term) Monitor to the north of the inundation area and to observe any changes in the Precipice Sandstone aquifer associated with Boggomoss springs (long term)
Boggomoss (south) MB03	Precipice Sandstone	As above
Boggomoss (south) MB04	Precipice Sandstone	As above
Cockatoo Creek RN67229*	Precipice Sandstone	Observe groundwater pressure and quality in the vicinity of the Cockatoo Creek springs (short term) Monitor to the far southeast of the inundation area as a control site and to observe any changes in the Precipice Sandstone aquifer associated with Cockatoo Creek springs (long term)
Spring Creek PB01*	Precipice Sandstone	Observe groundwater pressure and quality in the vicinity of the Dam Wall location (short term)

*Refurbished existing bores

Aside from this program, two bores (Spring Creek MB01 and PB02) had been installed by SunWater near the proposed dam wall during preliminary dam design and data loggers were installed but not retrieved till the post-EIS field program. Water level data for both bores is available from July 2010 to July 2011.

3.3. Description of the field program

The field program described above was implemented over the period from October 2012 to August 2013. The program comprised the following four tasks:

- Site visit by a hydrogeologist to a representative sample of springs;
- Sampling of water from springs;
- Installation of new groundwater monitoring bores; and
- Groundwater level and quality sampling from newly installed and refurbished monitoring bores.

This section details the execution and timing of these four tasks.

3.3.1. Initial springs site visit

The initial spring site visit was undertaken by SKM and SunWater hydrogeologists between 29 October – 1 November 2012.

General hydrogeological and geological observations were recorded and water samples were taken from the springs (Table 9).

- Table 9 Location of springs visited

Site ID	Complex	Vent	Easting	Northing	Zone
Spring Creek_3	Dawson River (3)	36	210999	7181395	MGA Zone 56
South Boggo_27	Dawson River (6)	27	200803	7183848	MGA Zone 56
North Boggo_8	Boggomoss (5)	8	200590	7185714	MGA Zone 56
Mount Rose_33	Boggomoss (5)	33	201196	7180879	MGA Zone 56
Cockatoo_64	Cockatoo Creek (9)	64	223154	7152685	MGA Zone 56
Dawson_28	Dawson River (8)	28	782056	7170899	MGA Zone 55
Dawson_38	Dawson River (8)	38	781516	7169127	MGA Zone 55

3.3.2. Springs water sampling

Results of in-situ water quality testing are provided in Table 10. Lab analysis of metals was undertaken by ALS, while stable isotopes analysis for oxygen, deuterium and Carbon-13 was completed by CSIRO. Results of these analyses are presented in Appendix C.

- Table 10 In-situ water quality testing for initial spring site visit

Site ID	Date	pH	Temp °C	EC (us/cm)	DO (% sat)
Spring Creek_3	1/11/2012	7.0	23.0	141	6.6
South Boggo_27	31/10/2012	6.6	19.2	890	9.1
North Boggo_8	31/10/2012	3.6	19.4	194	9.0
Mount Rose_33	30/10/2012	6.1	24.0	300	33.0
Cockatoo_64	30/10/2012	-	-	-	-
Dawson_28	29/10/2012	7.3	20.0	893	1.9
Dawson_38	29/10/2012	8.3	21.8	1047	22.7

A second round of water samples was taken from these springs between 31 July and 1 August 2013. Results of in-situ water quality testing of physico-chemical parameters are provided in Table 11. Lab analysis of major cations and anions was undertaken by ALS. Results of these analyses are presented in Appendix D.

- Table 11 In-situ water quality testing for second spring site visit

Site ID	Date	pH	Temp °C	EC (us/cm)	DO (% sat)	Turbidity (NTU)
Spring Creek_3	1/08/2013	7.1	22.3	148	87.9	17.6
South Boggo_27	1/08/2013	6.5	18.0	463	28.7	36.1
North Boggo_8	1/08/2013	3.5	16.2	9	32.5	1.7
Mount Rose_33	1/08/2013	6.3	12.0	318	52.0	18.5
Cockatoo_64	31/07/2013	7.6	21.8	313	39.3	0
Dawson_28	31/07/2013	7.4	18.8	1008	79.0	308.1

3.3.3. Bore installation and refurbishment

The installation of new bores and refurbishment of existing bores was completed between 17 May and 7 July 2013 in accordance with standard procedures.

Detail regarding the bore design construction, estimated groundwater flow rates during drilling and geochemical analyses for bores and adjacent springs was reported in the *Nathan Dam & Pipelines SEIS Groundwater Monitoring Network Expansion Project Field Report* (SunWater, 2013), provided as Appendix E.

3.3.4. Groundwater level and quality sampling from bores

During and immediately following completion of bore installation and refurbishment, groundwater levels and pressures were measured for each bore. This is described in full in Appendix D. Water samples were collected between 7 and 8 July 2013. The results are provided in Appendix E.

Groundwater levels and pressures were again measured after the bores had time to settle on 31 July – 1 August 2013, presented in Table 12. Physico-chemical parameters were also measured for Boggomoss MB02 at this time (Table 13).

- Table 12 Groundwater levels/pressures recorded

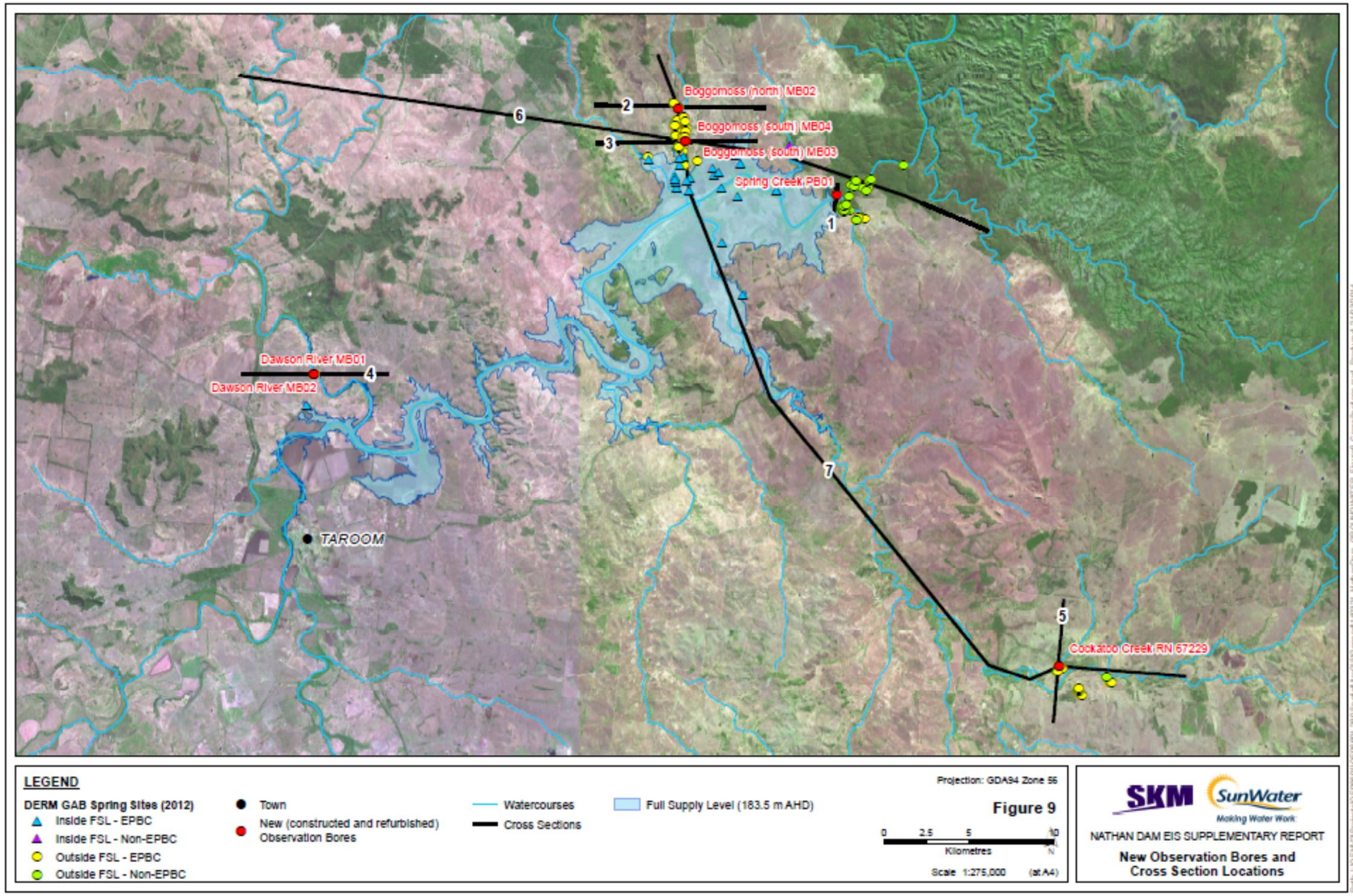
		Sub-artesian Bores		Artesian Bores	
Site ID	Date & Time	SWL (m bTOC)	Stickup (m)	Pressure (psi)	Equivalent mH_20
Cockatoo Creek	1/08/2013	-	-	5	3.50
Boggomoss MB02	1/08/2013	-	-	18	12.65
Boggomoss MB03	1/08/2013	-	-	19	13.35
Boggomoss MB04	1/08/2013	-	-	35	24.60
Dawson MB01	1/08/2013	4.2	0.88	-	-
Dawson BM02	1/08/2013	3.9	0.88	-	-

- Table 13 In-situ water quality testing for Boggomoss MB02

Site ID	Date & Time	pH	Temp °C	EC (us/cm)	DO (% sat)	Turbidity (NTU)
Boggomoss MB02	1/08/2013 11:32	6.7	24.4	1	442	44.0

SINCLAIR KNIGHT MERZ SKM

SunWater Making Water Work



- Figure 8 Location of groundwater bores with cross-sections

3.4. Analysis of field program results

This section details the analysis of the results of the field program.

3.4.1. Field observations by a hydrogeologist

During the initial spring site visit the following key observations were made regarding spring hydrogeology and spring function:

- Landholders of springs (Boggomoss and Dawson River) described the impact to individual springs during the recent floods, post 2009. In all cases the spring discharge zone returned to its pre-flood extent after each event. This indicates that the springs are generally stable and respond slowly to changes in recharge.
- Landholders reflected the springs appeared not to change in size or rate of discharge in line with short term climate variation (<5 year). In general it is believed that the occurrence of the springs is very stable. The exception being an isolated Boggomoss spring that collapsed, leaving a hole filled with water, rather than a vegetated mound. The reason for this was not identified but may suggest that a response to changing groundwater pressures will be in the degree of spring mounding supporting vegetation. This supports the slow acting nature of the hydrogeological systems hosting the springs (as above).
- A proportion of the proposed inundation area is covered in black, flood plain soils derived from alluvium of the Dawson River and its tributaries. The soils contain swelling clays that crack when dry and expand when wet. During the site visit it was apparent that several billabongs or oxbow wetlands alongside creeks contained water while the drainage lines were dry. This suggests that the induced recharge from inundation through the soils into the groundwater system may be less than estimated during the EIS.
- Dawson River springs occupy a locally elevated position compared to the nearest drainage line. Springs 26 and 28 (within Dawson River 8) were discharging while the adjacent creek was dry (4 metres lower in the landscape). This observation implies that a specific subsurface hydrogeological regime (stratigraphic or structural) drives the groundwater flow to the spring zone, rather than topographic controls where water flows to the locally lowest position.
- Boggomoss springs, Cockatoo Creek springs, and the water course springs within Cockatoo Creek are aligned with the regional Leichardt Fault structure and are documented to be all sourced from the Precipice Sandstone aquifer. The significant difference between the spring types is that the Boggomoss springs are expressed as vegetated mounds, some with significant elevation, while the Cockatoo Creek springs are relatively flat features. The different spring forms are influenced by the geomorphological process as well as the geological structure and groundwater system driving the water source. Cockatoo Creek is a more dissected landscape with outcropping sandstone exposed in drainage lines with distinct free flowing springs, while the Boggomoss springs occur in a broader valley with significantly thicker preserved regolith and no outcropping sandstone. It is proposed that the thickness of the regolith and geomorphological evolution process (dissection and deposition) have significant control over the vegetation type and discharge form of springs, as well as sub-surface geological processes.

In summary, these field observations suggest that the hydrogeological constraints affecting spring flow and their persistence are reflective of a generally stable hydrogeological flow regime, a slow response to recharge, based on low permeability of the formations and the tightness of structure in the geology hosting the springs. These features are generally consistent with those adopted in the impact modelling undertaken for the EIS.

3.4.2. Stratigraphy

Drilling to different depths within each bore was planned with the aim of intersecting and logging different hydrogeological units to provide information on:

- the extent of aquitards associated with the springs;
- the depth to the source aquifer; and
- interactions between the local alluvial aquifer and underlying aquifers.

Differentiation of the shallow geology intersected at the drilling locations, based on lithological logs, is difficult. The lithology comprised an alternation between siltstone, claystone, shale, arenite and conglomerate that could not be attributed to specific aquifer or aquitard 'layers'. Because the study area is located at the edge of the Surat Basin (with some units outcropping to the east of the site) the units have thinned and weathered and are therefore very difficult to differentiate. At the three sites within the Boggomoss complex, the Evergreen formation could not be differentiated during drilling.

Drill site selection to avoid the springs, waterways and areas of sensitive vegetation meant that the local alluvial aquifer was not encountered at any of the drilling sites.

It was found that groundwater was encountered within discrete thin permeable layers within the stratigraphic sequence, as evidenced by records of inflow rates during drilling (Table 14). When these thin layers were intersected during drilling, the flow rate was found to be relatively high but also found to slow rather quickly as they became depressurised, reflecting their relatively low permeability. This is in contrast to general regional conceptualisation that suggests GAB aquifers are relatively thick and homogenous units. This supports the concept that the traditional understanding of aquifers and aquitards does not apply here and instead the outcropping/subcropping geological units are comprised of low permeability consolidated sediments, with thin zones of higher permeability material (interbeds or lenses), bedding plane conduits and cross cutting structural conduit planes.

- Table 14 Flow rates during drilling

Bore ID	Aquifer Monitored	Depth Interval (mBGL)	Flow Rate (L/s)
Dawson River MB01	Hutton Sandstone	0 - 10 0 - 13 20 - 21 20 - 32 20 - 38 20 - 44	0.33 0.84 0.61 0.80 4.45 17.5
Dawson River MB02	Hutton Sandstone	20 - 23	1.01
Boggomoss (north) MB02	Precipice Sandstone	8 - 13 8 - 19 20 - 26 20 - 38	1.84 2.25 3.61 3.43
Boggomoss (south) MB03	Precipice Sandstone	26 - 30 26 - 48	0.84 Too high to measure
Boggomoss (south) MB04	Precipice Sandstone	20 - 28 20 - 38 20 - 44 20 - 50 20 - 52.5	1.25 1.01 1.01 1.25 0.46

3.4.3. Groundwater Levels and Pressures

The EIS numerical groundwater model was calibrated against an *inferred* potentiometric surface and spring flow volumes. The observation bores installed during this phase of investigation have allowed collection of site-specific potentiometric head data.

A schematic cross-section has been developed for each bore presenting the general landscape formation, the modelled or *inferred* potentiometric surface, the bore location and depth, and the observed potentiometric head. The location of the cross-sections with reference to the bore locations is presented in Figure 8. Figure 9 to Figure 15 present the cross-sections at each bore-location with the modelled and observed potentiometric head. When compared to the elevation of the land surface and the inferred geology, the difference between the modelled and observed potentiometric surfaces is small, especially on the large spatial scale of the area modelled and it compares well with the Surat CMA UWIR (QWC, 2012) modelled outcomes.

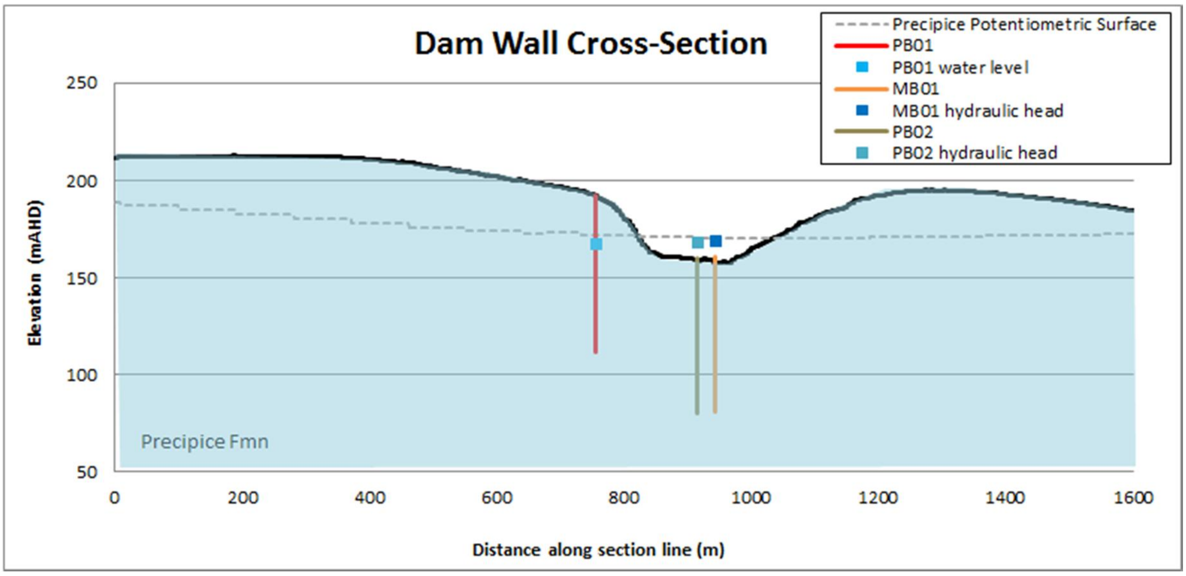
The comparison between the EIS modelled potentiometric head values and the latest observed values is also presented in Table 15, as well as the results of groundwater level monitoring from two bores near the proposed dam wall that were destroyed prior to the current field program.

This comparison indicates that in general the EIS numerical model overestimates artesian pressures with some underestimation around Boggomoss MB04. The average difference in the groundwater levels is 2.6 m, with a median value of -1 m, and six of the nine points within ±2 m of observed values.

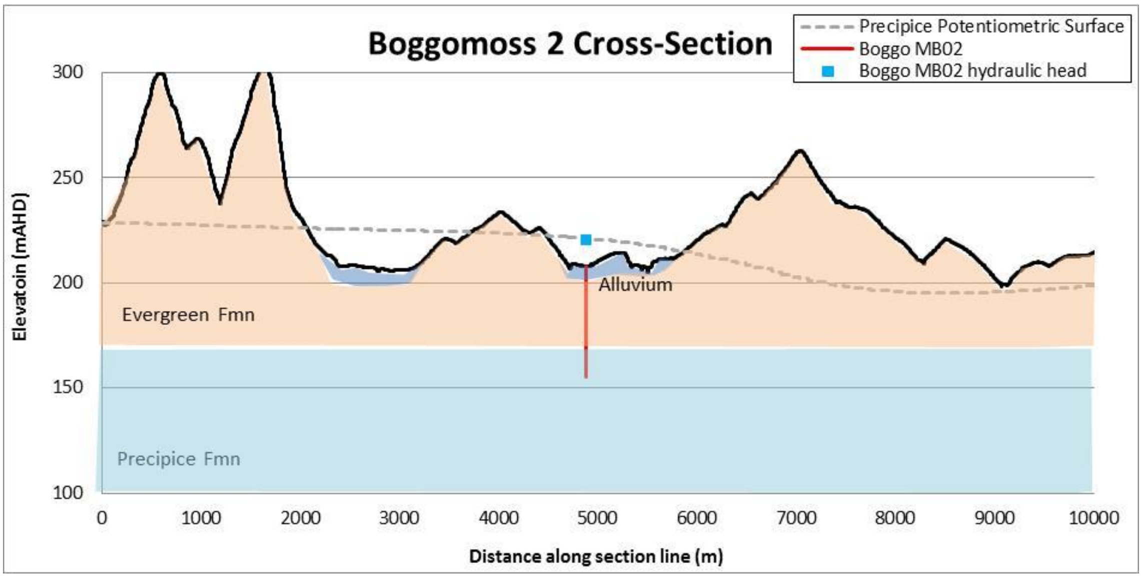
▪ Table 15 Comparison of groundwater elevations/pressures

Bore Id	Aquifer	Bore Comment	Model Potentiometric Surface (mAHD)	Observed Potentiometric Head (mAHD)	Pressure Difference (m)
Spring Creek PB01	Precipice Sandstone	Located near dam wall, sub artesian	172	168	-4
Spring Creek MB01	Precipice Sandstone	Located near dam wall, artesian, destroyed November 2011	170	169 *	-1
Spring Creek PB02	Precipice Sandstone		170	168 *	-2
Boggomoss (north) MB02	Precipice Sandstone	Artesian	221	221	0
Boggomoss (south) MB03	Precipice Sandstone	Artesian	216	206	-10
Boggomoss (south) MB04	Precipice Sandstone	Artesian	216	217	+1
Dawson River MB01	Hutton Sandstone	Sub artesian, constructed in Hutton Sandstone aquifer.	188	187	-1
Dawson River MB02			188	188	0
Cockatoo Creek RN 67229	Precipice Sandstone	Artesian	227	221	-6
				Average	-2.6

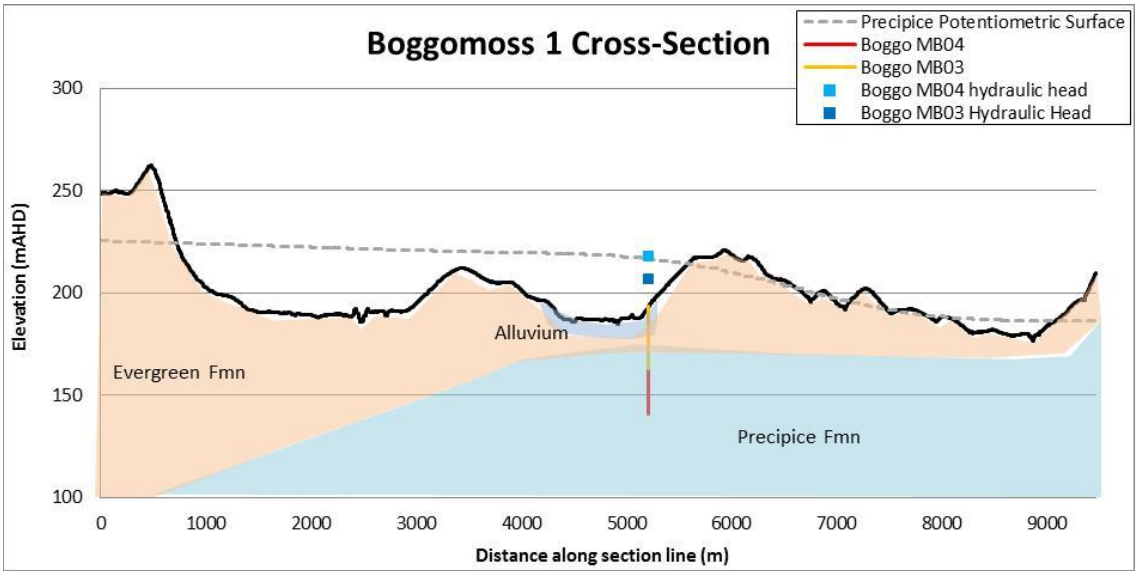
* data recorded prior to current field program



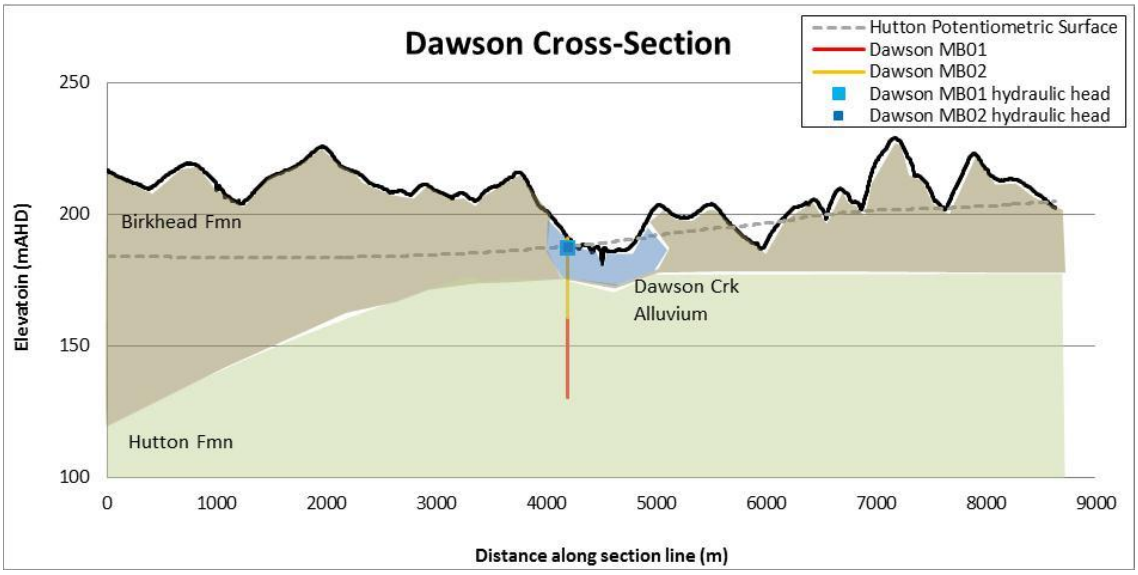
▪ Figure 9 Schematic cross section #1 through the dam wall with modelled and observed potentiometric head



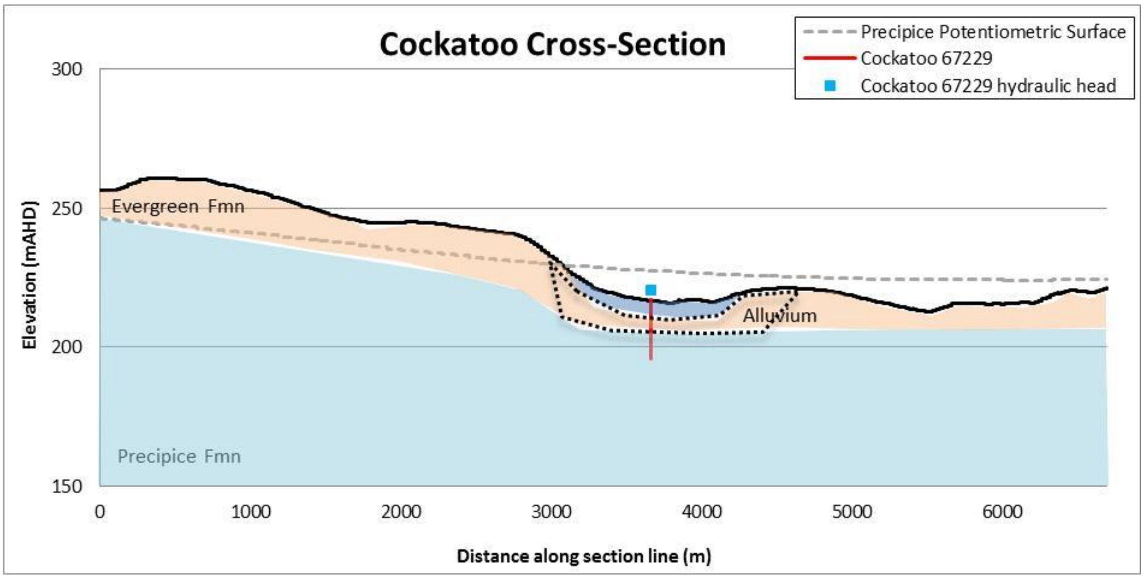
- Figure 10 Schematic cross section #2 through Boggomoss MB03, and MB04 with modelled and observed potentiometric head



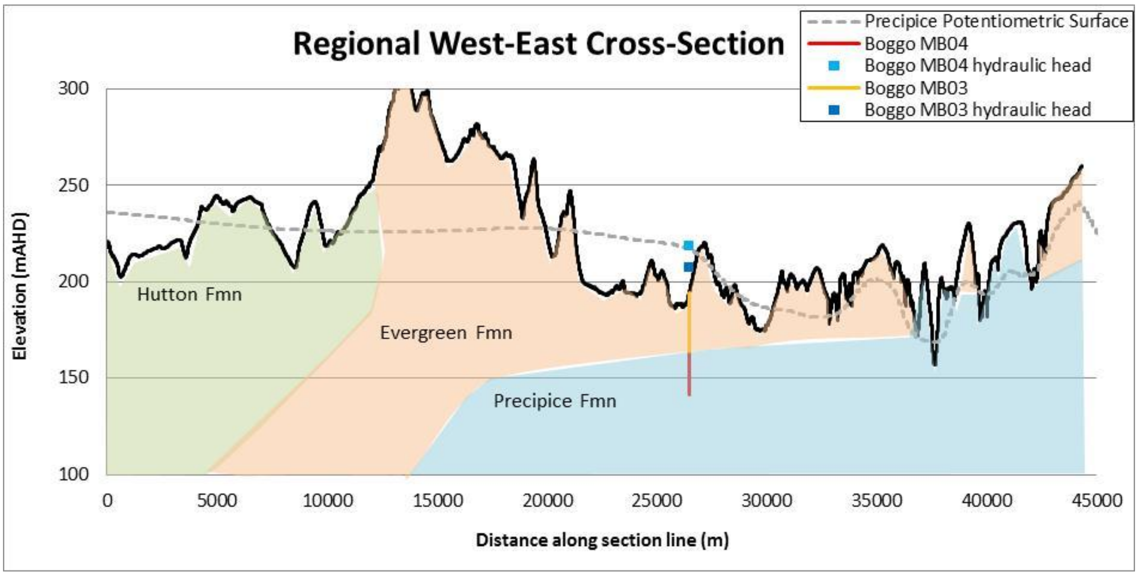
- Figure 11 Schematic cross section #3 through Boggomoss MB02 with modelled and observed potentiometric head



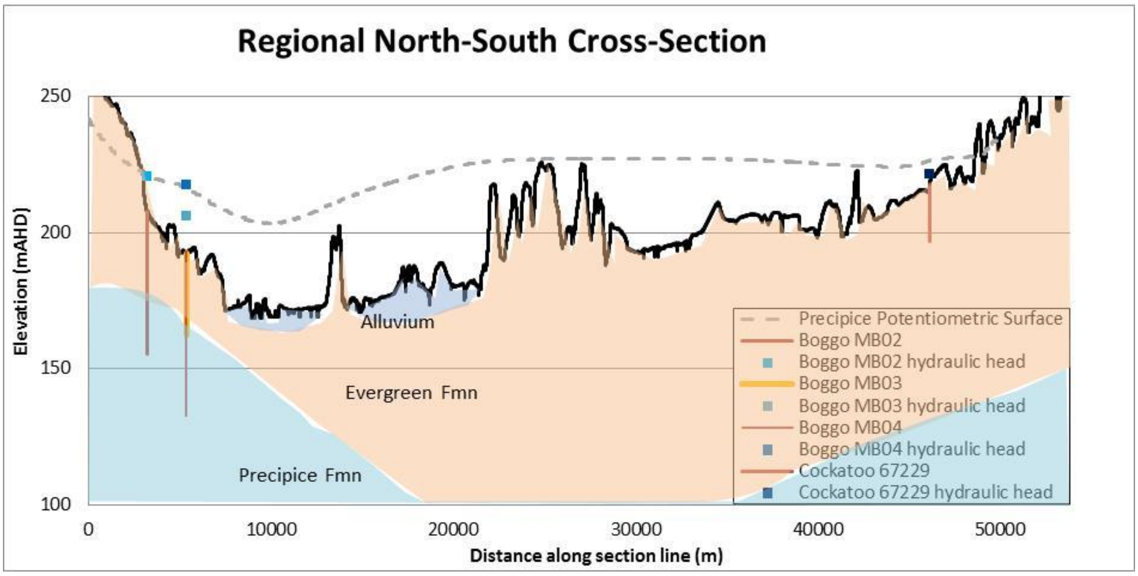
- Figure 12 Schematic cross section#4 through Dawson MB01 and MB02 with modelled and observed potentiometric head



- Figure 13 Schematic cross section #5 through Cockatoo RN67229 with modelled and observed potentiometric head



- Figure 14 Schematic cross section #6 through the spring sites with modelled and observed potentiometric head

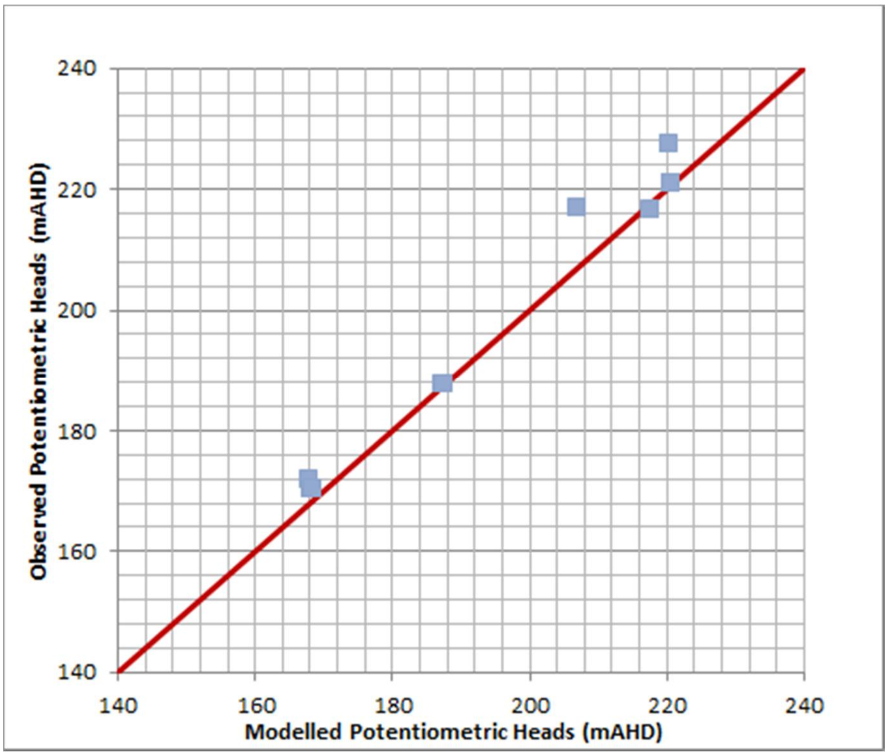


- Figure 15 Schematic cross section #7 through the spring sites with modelled and observed potentiometric head

Figure 16 provides a plot of the potentiometric heads observed through this field program with those modelled as part of the EIS. The clustering of points around the red 1:1 line demonstrates the fit of the model to observed data.

Based on this comparison, the scaled Root Mean Square (RMS) error of the calibrated model is 7.6%. Considering the assumption of the modelling, regional scale of the model and the data density, this is a satisfactory outcome when considered in the light of the Australian Groundwater Modelling Guidelines (NWC, 2012). As such, this is in line with accepted industry standards. As an example, the reported scaled RMS errors for the regional steady state groundwater model used by QWC as the basis for its SIMS range from 4.6 – 9.3%

for the aquifers relevant to this project (Precipice, Hutton, Evergreen). As such, upon reviewing the latest acquired groundwater bore level data, it is considered that the EIS groundwater model remains appropriate.



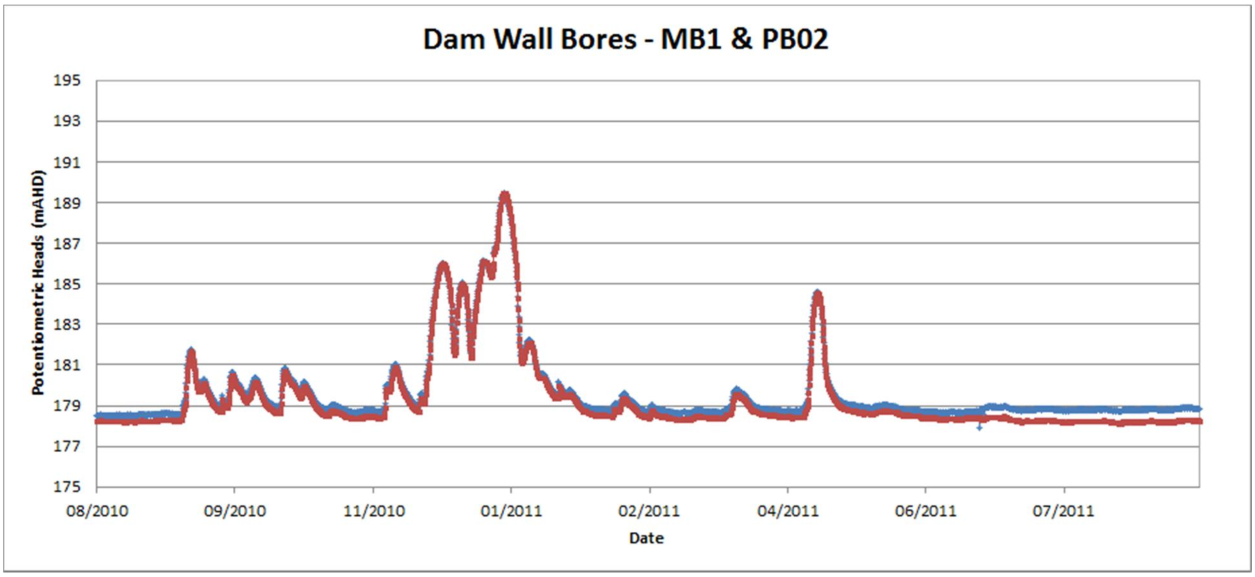
- Figure 16 Comparison of modelled and observed potentiometric heads

Prior to being decommissioned, groundwater bores Spring Creek MB01 and PB02 (located at the Dam Wall site) were fitted with data loggers in 2010 and captured continuous groundwater level data for over one year to November 2011 (Figure 17). This temporal data was not available at the time of EIS model calibration.

Importantly, these bores capture the impact of the December 2010 – January 2011 rainfall events and associated large floods, with the data showing an increase in groundwater elevation up to 10 m, likely driven by the resulting recharge pulse during the flood event.

The 2010/2011 flood event included wide-spread inundation of the Dawson River floodplain, including many springs, over a period of up to 13 weeks. Significantly, the groundwater levels quickly return to pre-flood equilibrium pressures, suggesting that the local groundwater systems behave in a typical manner, with aquifer storage taking up the available water in a predictable fashion. There is little cumulative effect on groundwater pressures from the recharge event and flooding.

In the EIS, a conservative estimate (over prediction, but within realistic bounds) of potential impacts was provided based on a steady-state model with the dam at Full Supply Level. Water resource modelling indicates that the proposed dam is likely to be at or above Full Supply Level approximately 10% of the time, generally with the level at or above full supply for periods of around 6 months. The observed groundwater behaviour during and following the 2010-2011 floods suggest that during periods where the dam is at lower levels, groundwater levels will also lower and may return to pre-inundation levels. This further suggests that the potential impacts to springs presented in the EIS are likely to be over-estimated.



- Figure 17 Groundwater levels for decommissioned monitoring bores at the Dam Wall site

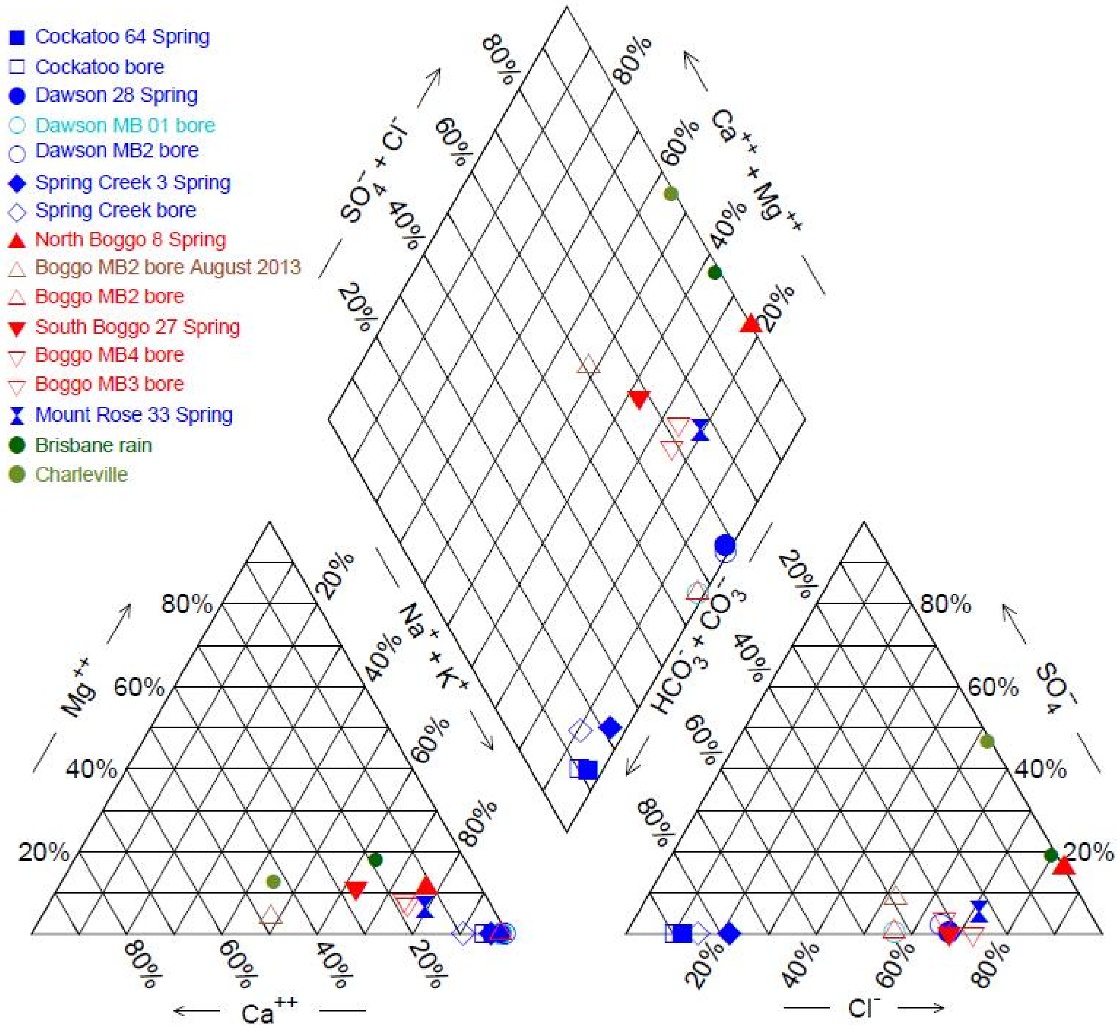
3.4.4. Hydrochemistry

Analysis of the major cation and anion information has been undertaken to suggest the source aquifer for each spring. It should be noted that the conclusions drawn are based upon only one round of chemical results.

The groundwater and spring samples were plotted on a Piper diagram (Figure 18), expanded Durov plot (Figure 19) and as a series of extended Schoeller plots (Figure 20 and Figure 21).

Average concentrations for rainfall recorded for Brisbane and Charleville (CSIRO, 2012) have also been plotted. These are indicative of the rainfall chemistry that might contribute to local groundwater recharge.

The Piper plot indicates that adjacent bores and springs have very similar chemistry; the Cockatoo Creek and Spring Creek bores/springs have similar source water chemistry (sodium-bicarbonate type), as do the Mount Rose and Boggomoss springs/bores (sodium-(calcium)-chloride-(bicarbonate) type). The distinct differences in the source water type for the Cockatoo/Spring Creek relative to Boggomoss/Mount Rose sites indicates different source aquifers and supports the conceptualisation presented in the EIS – that the springs are predominantly driven by discharge from the underlying GAB aquifers at each spring site with limited mixing with locally infiltrating rainfall or runoff.

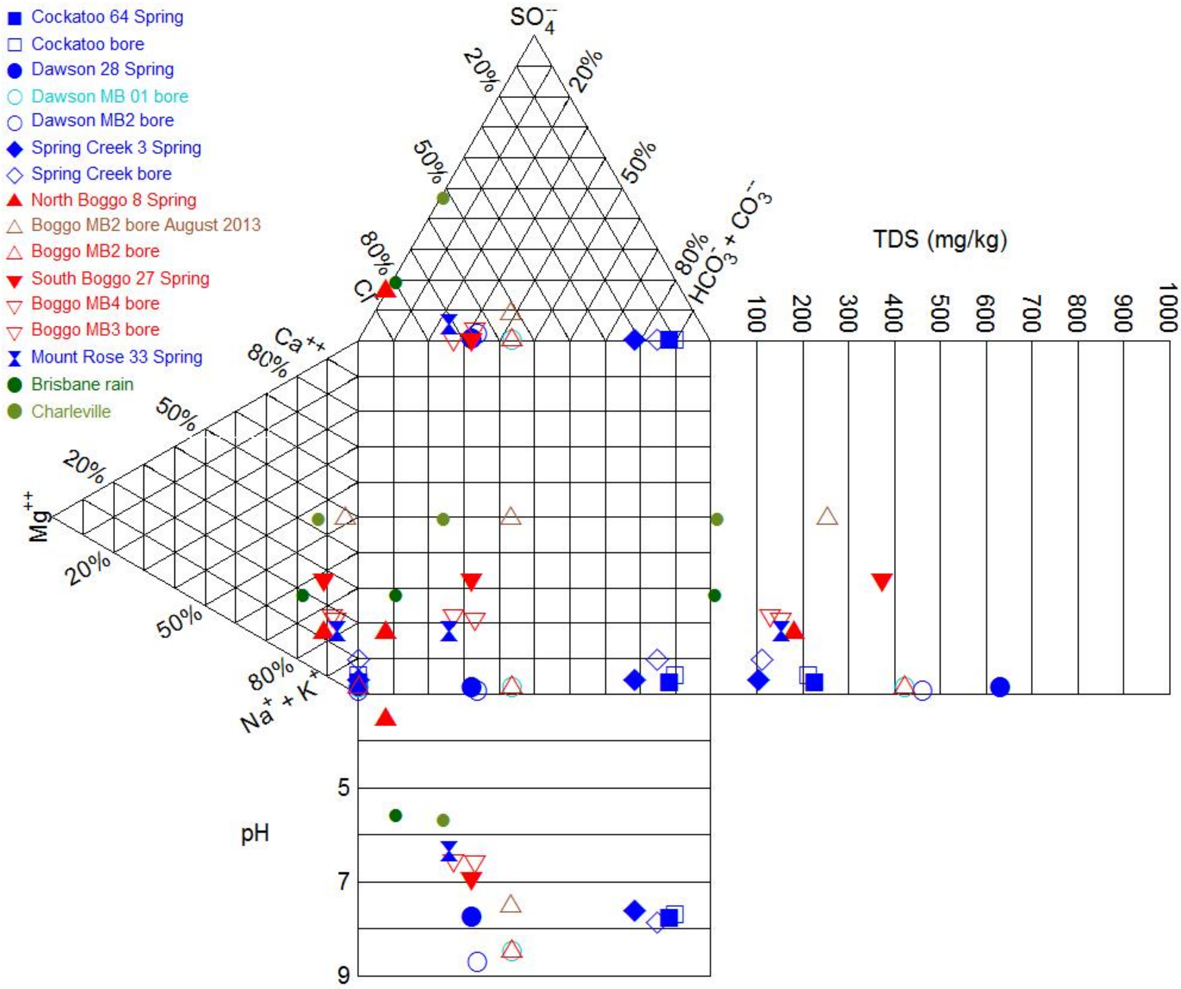


■ Figure 18 Piper diagram for groundwater and spring samples

The Durov plot incorporates pH and salinity into the chemistry plots. In Figure 19, samples of similar origin are superimposed, whilst mixing and evolutionary pathways plot as trends, particularly in the TDS (total dissolved solids) and pH squares.

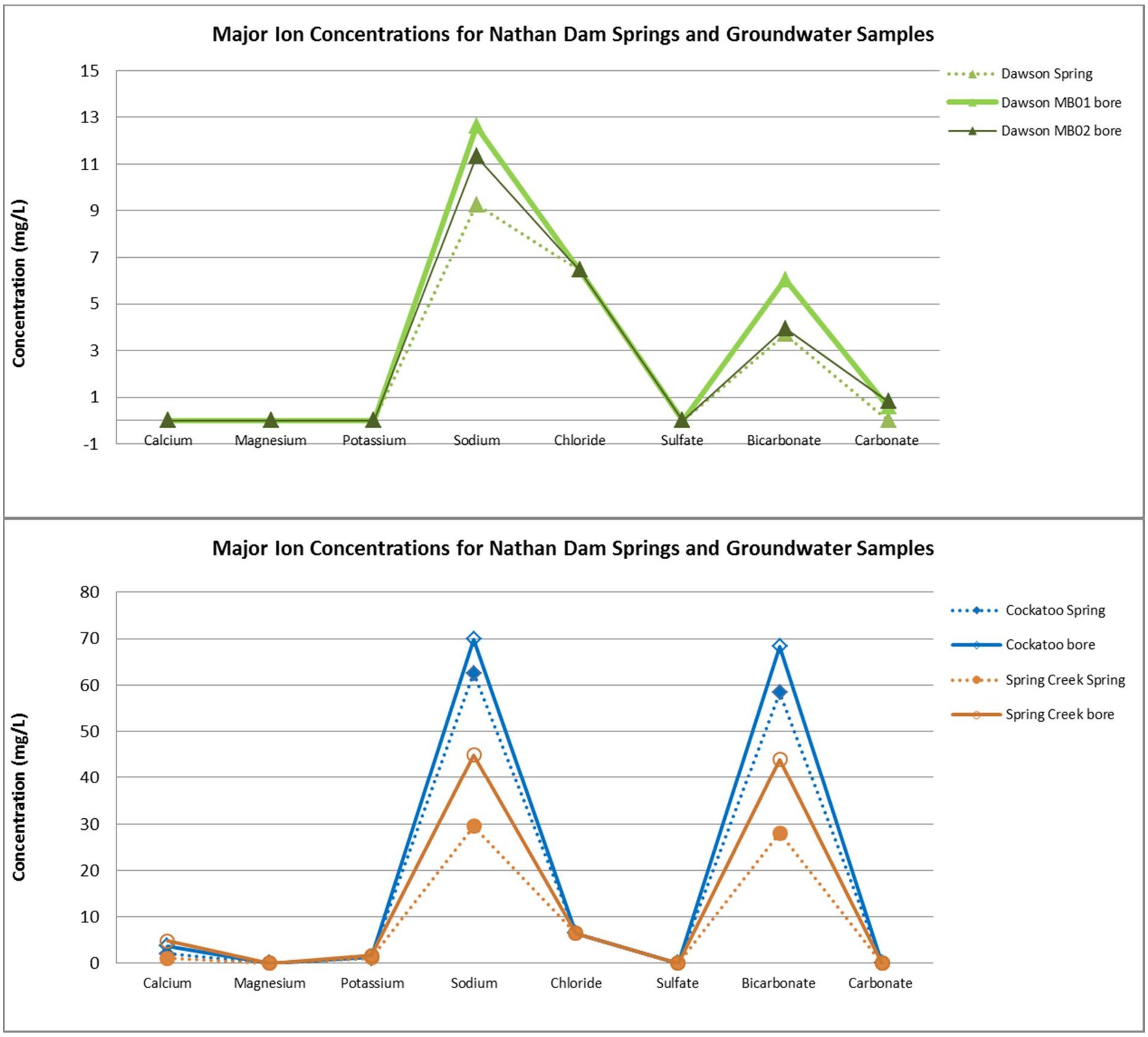
Figure 19 shows that there is a potential mixing trend between the rainfall and groundwaters around the Dawson site to generate the spring waters, but in general, the spring waters appear to have a greater and more obvious proportion of groundwater input.

The North Boggomoss Spring sample has anomalously low pH, reflected in the absence of bicarbonate.

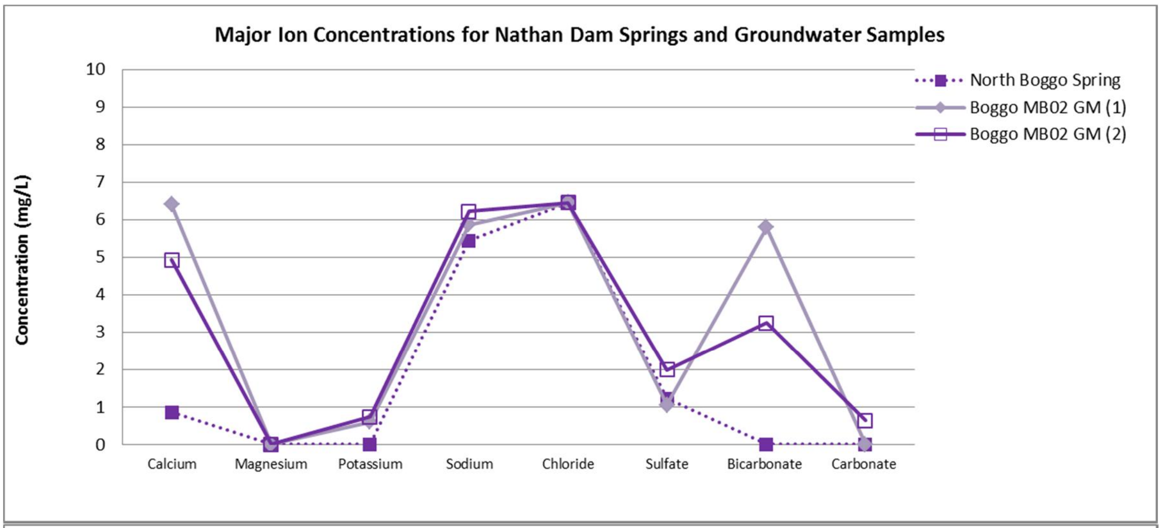


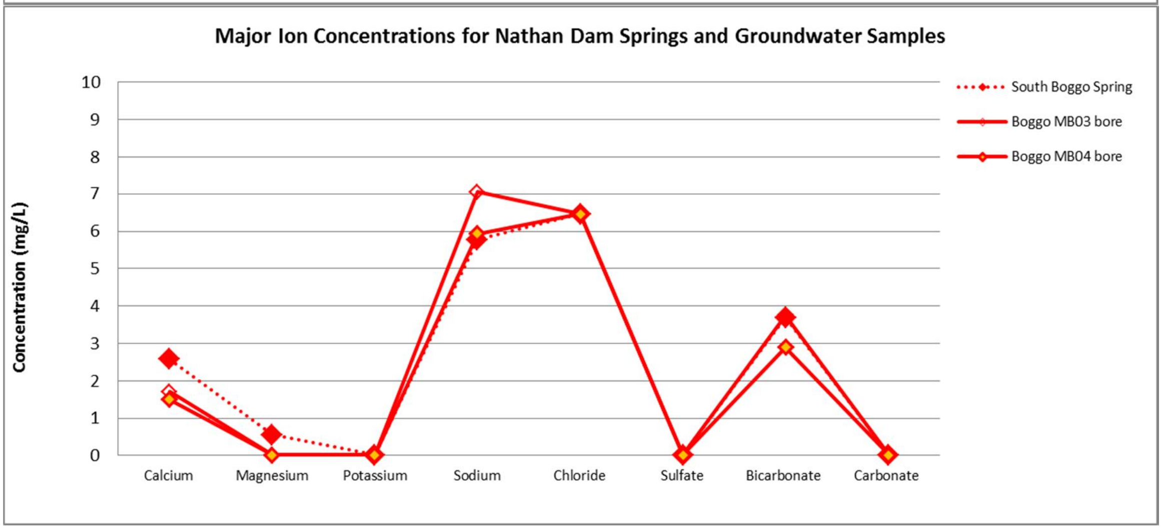
- Figure 19 Durov plot of groundwater and spring samples

Major ion chemistry at the different sites is compared in Figure 20 and Figure 21. The relative associations accentuate the relationships shown in the Piper and Durov plots. Thus, most springs exhibit ion concentrations comparable to the underlying geological formation with a depletion of phases that might be expected due to exsolution and precipitation when the spring waters discharge. Thus, Dawson, Cockatoo and Spring Creek Springs all show a depletion in sodium and bicarbonate in the spring samples, from carbonate precipitation at these sites, while Boggomoss shows a greater loss of calcium, relative to sodium, and bicarbonate and a slightly reduced sulphate in the spring waters, suggesting additional precipitation of gypsum at this spring site.



- Figure 20 Major Ion Concentrations for spring / groundwater Pairs – Dawson and Cockatoo Springs





- Figure 21 Major ion concentrations for spring/groundwater pairs – Boggomoss Springs

Spring waters have been sampled for stable isotopes of water and carbon as has long term data for rainfall at Brisbane airport. A more recent study by CSIRO (2012) has established that long-term averages for Australia can be reasonably estimated and do not vary greatly geographically, although seasonal effects can be extreme.

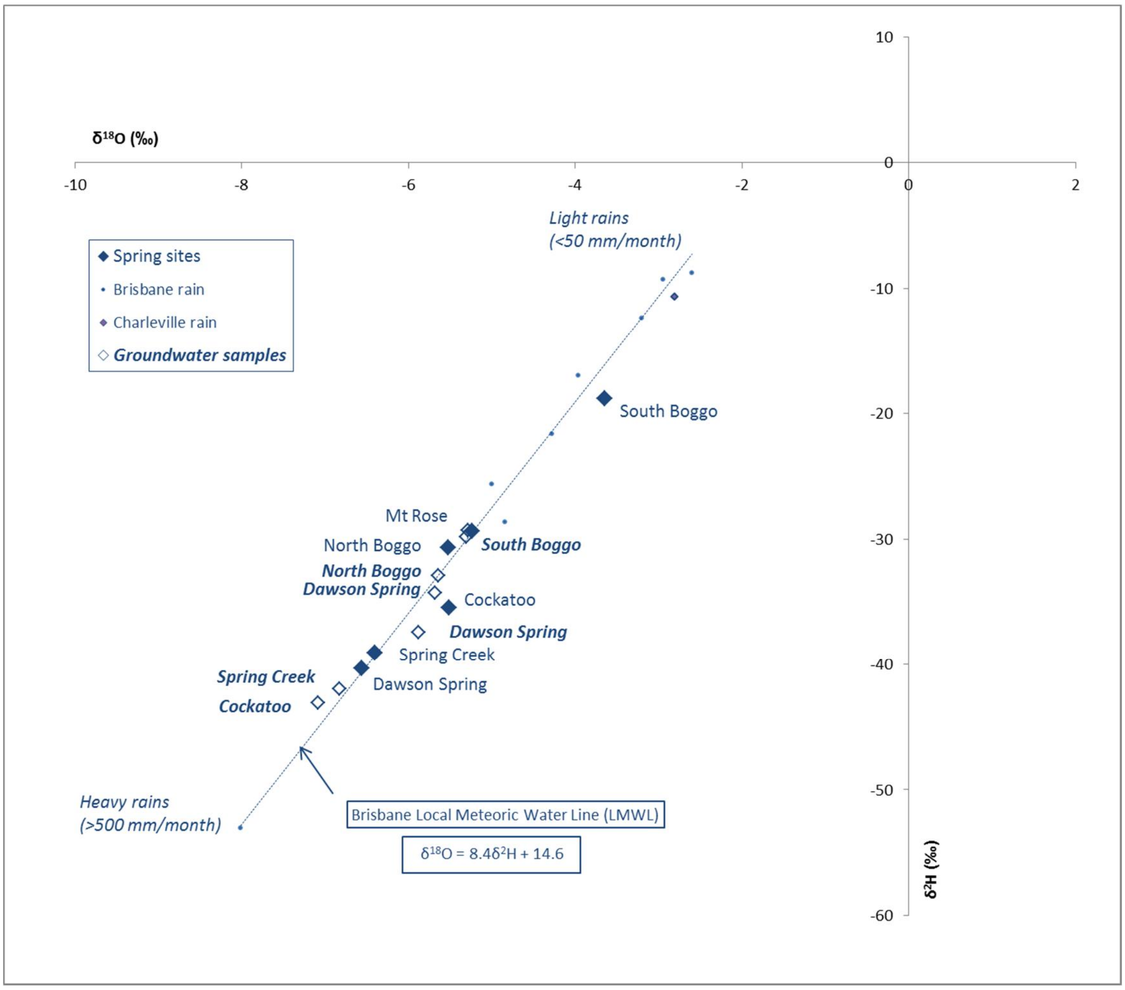
Oxygen and hydrogen isotopic data for the spring samples plot close to the local meteoric water line for Brisbane rainfall (Figure 22), indicating a primary source from precipitation, but many groundwaters also plot with similar values which may represent rapidly recharged groundwaters that have undergone minimal alteration as the rain infiltrates to the aquifers.

Based on the Brisbane rainfall data collated by the IAEA, high rainfall events typically generate highly depleted isotopic waters, while light events tend to exhibit enriched isotopic signatures. Most of the spring samples exhibit isotope ratios close to ratios of heavy rainfall events, although waters from South Boggomoss exhibit an enriched isotopic signature more typical of light rainfall. Groundwaters generally also exhibit depleted ratios, suggesting that most recharge occurs following heavy rainfall events.

The waters of the sampled groundwaters and the water in the springs, therefore, appear to originate from heavy rainfall events. These are the rainfall events that are more likely to infiltrate and hence recharge the GAB aquifers in this region. There is no evidence for a lighter rainfall input to most of the springs, though Boggomoss and Mount Rose exhibit enriched isotopic signatures compared to the paired groundwaters and this may indicate incorporation of direct precipitation or runoff from lighter rainfall events contributing to water at these sites.

The isotopic data, therefore generally supports a common source for groundwaters and springs and supports the origin of spring waters from the underlying groundwaters of the GAB aquifers, with the exception of Boggomoss, where there is a suggestion of an additional, non-aquifer, source of water.

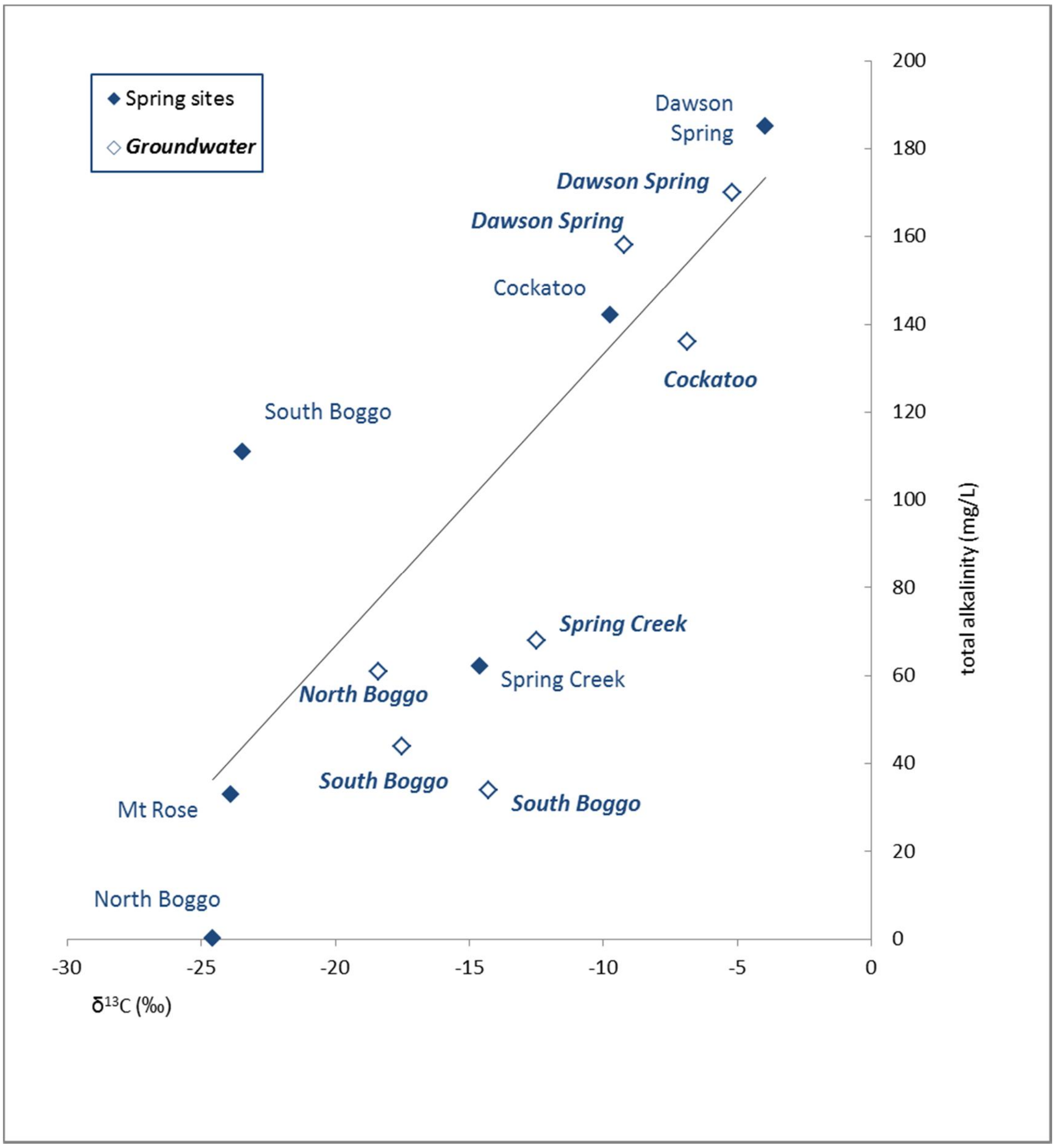
The slight separation of isotope signatures for each spring-groundwater pair suggests that there may be an additional spatial or temporal distinction between the waters sampled at each location that imposes a second order effect on the isotope ratios. Such an effect might include: varying proportions of a second water source (such as from an additional groundwater source, from groundwater in the regolith or surface flows); seasonal effects or changes in the dynamics of the spring.



- Figure 22 Stable isotope plot for spring samples – water isotopes

The carbon isotope data is plotted in Figure 23. . Carbon isotopes become enriched as the alkalinity of spring samples increases. This trend is indicative of precipitation of carbonates, with greater precipitation at Dawson Spring than in North Boggomoss. Indeed, the isotopic ratios for Boggomoss (North and South) and Mt Rose are indicative of values observed in shallow recharged groundwaters and reflect depletion of atmospheric CO_2 during photosynthesis. This process is suggestive of groundwaters rich in bicarbonate reaching the surface, oxidising and depositing carbonates at the surface.

There is a close association between the carbon isotope signatures of the springs with those from underlying groundwaters, supporting the idea of a common source, particularly as there is good separation between the different spring groups. The exception is Boggomoss North, although the anomalously low pH is suspicious for this sample.



- Figure 23 Carbon stable isotope plot for spring samples

In summary:

- The Cockatoo Creek and Spring Creek samples are sodium-carbonate type waters, while the Boggomoss samples and the Dawson Creek samples are sodium-chloride (with minor calcium-bicarbonate) type waters.
- Groundwater and spring water samples for the Cockatoo Creek and Spring Creek site are similar, suggesting the Precipice Sandstone is the primary source aquifer for those springs.
- Groundwater and spring water samples for the Dawson River site are similar, suggesting the Hutton Sandstone is the primary source aquifer for those springs.
- Groundwater and spring water samples for Boggomoss (south) are similar, suggesting the Precipice Sandstone is the primary source aquifer for those springs.
- Boggomoss (north) groundwater and spring water samples are different. The spring sample is driven to the far right side of the Piper plot due to low carbonate concentrations and has anomalous isotopic characteristics. The difference in the chemistry of the groundwater and spring discharge may be due to chemical processes occurring in the root zone and regolith hosting the spring mound, rather than an actual difference in source aquifer or a significant component of rainwater at the spring site at the time of sampling.
- The isotope data collected shows there is a close association between carbon isotope signatures of springs with those from groundwaters at associated bores. This provides strong evidence of a common source between the spring and the associated groundwater, particularly as there is good separation between the carbon signatures of springs from different spring complexes. The exception is Boggomoss North, although the anomalously low pH is suspicious for this sample.

3.5. Summary of findings from the field program

The field work program was developed to fill data gaps identified following the EIS, increase understanding of the local groundwater system subsequent to the EIS, and confirm some of the assumptions of the EIS. A summary of the key findings is provided below:

1) Anecdotal information collected during field visits suggest that springs do not move or cease to flow after periods of inundation, most notably after the recent floods during 2010-11. Specifically Boggomoss and Dawson River springs were inundated for up to several weeks; however their size or form were not altered. These field observations suggest that the hydrogeological constraints affecting spring flow and their persistence are reflective of a generally stable hydrogeological flow regime and a slow response to recharge. This is consistent with the conceptualisation adopted in the EIS.

2) Water quality samples have been taken for springs and the associated bores installed as part of this field program. The hydrochemistry and stable isotope analysis of these samples has been used to suggest the source aquifer for each spring complex. This further supports the groundwater conceptualisation developed for the EIS and used as a basis for the numerical modelling undertaken for the EIS.

3) The Nathan Dam groundwater model was developed based on a traditional conceptualisation of well-defined macroscopic-scale aquifer and aquitard layers typically associated with the GAB. Distinction between regional-scale aquifer and aquitard units and local scale aquifer and aquitard units could not be reconciled from recent drilling investigations. Where high groundwater pressures and flows were encountered, they were not necessarily associated with a transition from aquitard to aquifer by the conventional regional-scale definitions. Instead, they were associated with thin and discrete higher permeability zones within an essentially consistent lithological sequence of low permeability sediments. This contrasts with the macroscopic scale conceptualisation presented in previous groundwater studies and the EIS. However, the discretisation in models is generally unable to resolve at a high resolution the heterogeneity of the mesoscopic scale lithological features which appear to govern spring flow and pressures. However, the groundwater model provides a reasonable representation of the system (particularly when compared with the QWC UWIR), and is a satisfactory tool for prediction of the effects the Nathan Dam will have on springs and existing users.

4) Layer 1 of the EIS groundwater model comprised the alluvial aquifer with hydraulic parameters typical of the sand, silt and clay lithology conceptualised for alluvial material (i.e. a horizontal and vertical hydraulic conductivity of 5 m/day and 0.5 m/day, respectively). Qualitative analysis of the alluvial material during the field program identified the presence of vertosols. The impact of the vertosols not being included in the groundwater model is the potential overestimate of induced recharge from inundation through the soils into the groundwater system; i.e. the numerical groundwater model may overestimate the impacts to the groundwater system. This is nonetheless a conservative assumption.

5) Comparison between the potentiometric surface from the EIS model and the observed measurements from the new bores installed in the areas of key interest (i.e. around the springs), indicates that the model has provided a reasonable estimate of hydraulic head, with a scaled RMS error of 7.6% for the calibrated model in the areas of key interest. This is consistent with the Australian Groundwater Modelling Guidelines (NWC, 2012) and accepted industry standards. As such the existing model is considered to be appropriate for its intended use of assessing likely impacts on springs and existing users.

Following compilation of the field program results, the independent peer reviewer reviewed a draft of this report And stated that the '*investigation and spring assessment undertaken in the EIS and SEIS*[1] *generally followed the assessment approach outlined in the Queensland Water Commission Underground Water Impact Report (QWC UWIR 2012) Spring Impact Management Strategy (SIMS).*'

[1] Now AEIS

4. SUMMARY AND CONCLUSIONS

The Nathan Dam project EIS was released in April 2012. Review comments received from DNRM and SEWPaC related to groundwater focused on the validity of the conclusions drawn on the likely impact of the dam inundation to the groundwater system and associated springs. In essence, the extent and utility of the data and information used to inform the conceptual and numerical models was challenged. Specifically, the following underlying points were raised:

1) the appropriate use of existing data from existing groundwater bores;

2) a need for drilling and construction of new bores to supplement and confirm existing data;

3) appropriate interpretation of new data based on the conceptual understanding of the groundwater system; and

4) understanding the accuracy of the numerical modelling outputs, specifically in the key area of interest (i.e. around the springs), given the limitations of the input data and modelling approach.

To address the above concerns and provide further confidence in the groundwater impact assessment, SunWater commissioned Sinclair Knight Merz (SKM) to undertake additional desktop and field based hydrogeological assessments. These assessments were undertaken over the period from July 2012 to December 2013.

The key results of the desktop assessment are:

1) The majority of previous groundwater data relevant to the Project area is focussed on characterising groundwater springs. The majority of data relates to physical and ecological surface characteristics of springs, while in most cases water age and a large range of hydrogeological data is absent.

2) All available data from existing groundwater bores was accessed and reviewed for use in the EIS. A survey of existing bores was not considered necessary but SunWater has committed to undertake such a survey prior to commencement of construction.

3) All new data available for individual spring vents post-EIS was reviewed. There is now more hydrogeological attribute data available. This is mainly surface based information, with subsurface data consisting solely of water sample analyses. Based on this review, the need for further drilling was confirmed and a field program developed to fill specific identified data gaps.

4) A review of conceptualisations of the local Project area groundwater system following the EIS was completed. All studies undertaken since the EIS confirm the results of the EIS conceptual model of spring source aquifer and that the majority of springs in the region are predominantly controlled by faults and aquitard thinning.

   None of the new data collected for springs post-EIS has contradicted the conceptual model developed as part of the EIS.

5) The Nathan EIS impact assessment was generally consistent with the form and level of assessment completed as part of QWC's Underground Water Impact Report, with the exception of the inclusion of a survey of the hydrogeological characteristics of impacted springs. The field program was designed to include such survey.

A field program was undertaken following the desktop assessment to fill the data gaps identified. Key results of the field program are:

1) Temporal data for two existing bores near the proposed dam wall was identified and reviewed. Based on review of the DNRM GWDB, no more groundwater bore data has become available since the EIS (other than that generated by this study).

2) The field program was designed such that co-location of monitoring bores and monitored springs allowed direct comparisons of data gathered from the bores and the adjacent springs. Five new bores have been installed and two existing bores have been refurbished as part of this investigation. Stratigraphic, water level and pressure and water quality data have been gathered from these bores.

3) Water quality analyses suggest that the Precipice Sandstone is the primary source aquifer for the Cockatoo Creek, Spring Creek and Boggomoss (south) springs, while the Hutton Sandstone is the primary source aquifer for the Dawson River spring. There is some uncertainty around the water samples and results for the Boggomoss (north) spring. This confirms the groundwater conceptualisation developed for the EIS and used as a basis for the numerical modelling undertaken for the EIS.

4) The EIS groundwater model was calibrated to an inferred potentiometric surface due to a lack of observation bore data and issues with the available bore data quality derived from the GWDB. Comparison between the potentiometric surface from the model and the groundwater level observations in the vicinity of the springs collected as part of this field program show good agreement, consistent with the Australian Groundwater Modelling Guidelines (NWC, 2012).

The model was developed based on the traditional conceptualisation of well-defined aquifer and aquitard layers typically associated with the GAB. However, during the drilling program, distinction between regional-scale aquifer and aquitard units could not be made and high groundwater pressures and flows appeared to be associated with thin and discrete higher permeability zones within an essentially consistent lithological sequence of low permeable sediments. This means that the potential impact on the groundwater system from the dam is likely less than that presented in the EIS.

Vertosols were identified in alluvial material during the field program. These soils are often referred to as 'black soils' and characteristically crack open when dry and have very large water holding *capacity* when wet. These were not included in the EIS groundwater model. This means that the model may overestimate the induced recharge from inundation through the soils into the groundwater system. This means that the potential impact on the groundwater system from the dam is likely less than that presented in the EIS.

Field observations, anecdotal data and temporal groundwater level data were reviewed for the 2010-2011 floods. These field observations suggest that the hydrogeological constraints affecting spring flow and their persistence are reflective of a generally stable hydrogeological flow regime and a slow response to recharge, based on low permeability of the formations and the tightness of structure in the geology hosting the springs. This is consistent with the conceptualisation adopted in the EIS. It is also consistent with the relatively permeable modelled aquifer parameters of the Precipice Sandstone adopted in the EIS.

The numerical groundwater model was based on the best available data at the time of the EIS. The model shows good agreement with observed groundwater levels. Based on the hydrogeological observations from this field survey, the model is considered to provide a conservative estimate of the potential groundwater impacts of the dam. As such the existing model is considered to be appropriate for its intended use of assessing likely impacts on springs and existing users.

The above conclusions represent a refinement of the EIS hydrogeological conceptual model, not a revision of it. Overall, the results of this study confirm that the fundamental assumptions and conceptualisation presented in the EIS remain appropriate for assessing the impacts to the groundwater system from the Nathan Dam Project. The data collected as part of this study confirm the conceptualisation developed as part of the EIS. Furthermore, the results of this assessment indicate the initial numerical modelling undertaken during the EIS is likely to provide a conservative estimate (over prediction, but within realistic bounds) of groundwater impacts and remains suitable.

The field program design, results, analysis and conclusions presented here were reviewed by an independent peer reviewer on behalf of the Coordinator General and DoE. The scope of this review was to assess the adequacy and appropriateness of the data gathered, the hydrogeological conceptualisation and the impact assessment conclusions with regard to the Great Artesian Basin Springsure Group springs. This review concluded that the EIS and SEIS (now known as the AEIS) presented '*sufficient data to adequately evaluate risks to groundwater in the Nathan Dam study area*'.