

Water resource management plan

Joint industry plan for an early warning system for the monitoring and protection of EPBC springs

AE-B

Enter ▶

Go back to contents ▶

Joint Industry Plan for an Early
Warning System
for the Monitoring and
Protection of EPBC Springs
30 September 2013

Executive Summary

The CSG operators in the southern Bowen and Surat Basins, Santos, Origin Energy and Origin Energy on behalf of APLNG (hereafter referred to as Origin) and the Queensland Gas Company (QGC) (from here on jointly referred to as the Proponents) have developed a Joint Industry Plan (JIP) for a groundwater monitoring and management system to ensure springs protected by the Environment Protection and Biodiversity Conservation Act, 1999 (EPBC Act) are not impacted by coal seam gas (CSG) production. This is a requirement of the Proponent's project approvals under the EPBC Act which require the CSG activities to have "no adverse impacts" to Matters of National Environmental Significance (MNES), which for groundwater relates to discharge from the Great Artesian Basin via springs (EPBC springs). Arrow Energy has been consulted in the preparation of this plan.

The plan has been developed in accordance with comments received from Geoscience Australia (GA, 2011, 2012), the Commonwealth Department of the Environment and the Expert Panel for Major Coal Seam Gas Projects (Expert Panel). The plan is also intended to align with spring monitoring and mitigation requirements obligated by the Surat Cumulative Management Area (Surat CMA) Underground Water Impact Report (UWIR)

The fundamental concepts and primary principles of the JIP are:

- To ensure consistency in the approach to springs monitoring and management between the proponents
- To measure groundwater drawdown at locations and times such that meaningful responses can be undertaken before there is any impact on MNES springs;
- An early warning approach based on modelling and monitoring to manage increasing levels of risk;
- The use of the Surat CMA cumulative impact model (CIM) to assess risks to the springs;
- A clearly defined network of monitoring bores allocated to each of the proponents;
- Single proponent responsibility for each EPBC spring aligning with Surat CMA UWIR Springs Strategy;
- Differences in approaches to limit/trigger setting at monitoring bores for on-tenements and off-tenements springs; and
- Alignment on exceedance response process and timing.

The UWIR identifies 33 spring vents amongst ten spring complexes and five watercourse springs that are at a higher risk of being affected by CSG activities. The principal risk criterion cited in the UWIR is the prediction of potential to experience more than 0.2 m drawdown in the source aquifer(s) at the spring location at any time. Not all of these higher risk springs are classified as EPBC springs and only five EPBC spring complexes were considered to be in the higher risk category. Drawdown greater than 0.2m is not predicted to occur at any spring until 2017 or later and none of the higher risk watercourse springs contain MNES.

The UWIR assigns responsibility to petroleum tenure holders for specific monitoring and mitigation actions at higher risk springs. Under the JIP, responsibility for the management and mitigation of potential impacts to springs will be in accordance with the responsible tenure holder assignments of the UWIR. On-tenement springs are the responsibility of the tenure holder and off-tenure springs are generally the responsibility of the closest tenure holder. Springs at which the Surat CMA UWIR cumulative Impact Model (CIM) does not predict drawdown (e.g. Cockatoo Creek, Boggomoss, Prices, Dawson River 2, Dawson River 6 and Dawson River 8) do not have a responsible tenure holder identified. Should future iterations of the CIM show an increased level of risk at those springs or should an investigation trigger for those springs be exceeded, responsibility will be assigned in accordance with the UWIR, using the same principle of closest producing tenure holder. Responsibility for each of the springs is identified in the next table.

Spring Complex Name	Location of Spring	UWIR – Selected Spring for monitoring	UWIR – Selected Spring for mitigation	MNES Present	Responsible Proponent
Scotts Creek	On APLNG tenement	✓	✓	✓	Origin
Yebna 2	On Santos tenement	✓	✓	✓	Santos
Lucky Last	On Santos tenement	✓	✓	✓	Santos
Elgin 2	Off-tenure	✗	✗	✓	Santos
Abyss	On Santos tenement	✓	✗	✓	Santos
Barton	On APLNG tenement	✓	✓	✗	Origin
Spring Rock Creek	On Santos tenement	✓	✓	✗	Santos
Abyss	On and off Santos tenements	✓	✗	✗	Santos
Yebna 2	On Santos tenement	✓	✓	✗	Santos
Ponies	On Santos tenement	✓	✗	✗	Santos
Wambo	On QGC tenement	✓	✗	✗	QGC
Carnarvon Gorge	Off-tenure	✗	✗	✓	ND
Cockatoo Creek	Off-tenure	✓	✗	✓	ND
Dawson River 2	Off-tenure	✗	✗	✓	ND
Boggomoss	Off-tenure	✗	✗	✓	ND
Dawson River 6	Off-tenure	✗	✗	✓	ND
Prices	Off-tenure	✗	✗	✓	ND
Dawson River 8	Off-tenure	✓	✗	✓	ND
W39	On Origin tenement	✓	✗	✗	Origin
W40	On Santos tenement	✓	✗	✗	Santos
W80	On Santos tenement	✓	✗	✗	Santos
W81	On Santos tenement	✓	✗	✗	Santos
W82	On Santos tenement	✓	✗	✗	Santos

ND = not defined, spring responsibility will be allocated to the responsible tenure holder if future iterations of the Surat CMA CIM indicate potential drawdown at a spring complex in the source aquifer or if an investigation trigger for of the spring complex is exceeded, whichever the earliest. EWS monitoring bore responsibilities are assigned.

An early warning system (EWS) has been developed to provide adequate time for assessment and implementation of management measures prior to potential negative effects on MNES. The EWS is built on the following key elements:

- The use of groundwater levels variations as an early warning proxy for impact to the ecosystem supported by the spring. This is conservative as a decrease in pressure does not necessarily result in an impact to MNES;
- A groundwater monitoring network that focuses on the primary source aquifers of EPBC springs (primarily Hutton and Precipice Sandstones). Intervening aquitards will not be monitored because drawdown must first propagate through either of the primary aquifers;
- The use of the regional cumulative impact model (CIM) developed for the Surat CMA UWIR to set action trigger, primarily using the 95th percentile prediction (P95) of drawdown. This corresponds to a drawdown that represents a statistical value from the 200 model runs for which 95% of the model runs have a smaller predicted drawdown. In other words, there is only 5% likelihood that this value be exceeded. Use of the P95 is conservative and therefore aligns with the Precautionary Principle.
- The development of drawdown trigger response processes that respond to increasing levels of risk to MNES.
- The ability to use the entire network of monitoring bores to support the assessment of regional scale responses to better understand the source of actual CSG-induced drawdown, and the associated potential risks to MNES.

The development of the Early Warning System monitoring network takes into account the mechanisms by which drawdown is propagated from the source (CSG production area) to the receptor (spring).

Two primary mechanisms exist for the transmittal of drawdown from CSG production to springs:

Hutton Sandstone sourced springs - Vertical propagation of pressure reduction from CSG production in the *Walloon Coal Measures* through the siltstones underlying the coal seams (including the Eurombah Formation aquitard) and into the Hutton Sandstone. The only spring sourced from the Hutton Sandstone that the Surat UWIR considered to be at high risk is Scotts Creek.

Precipice Sandstone sourced springs - Lateral propagation of depressurisation from potential CSG production from the *Bandanna Formation* at Spring Gully and Fairview, resulting in underdrainage of the Precipice Sandstone where the Bandanna Formation subcrops to the west of Fairview/Spring Gully (Santos refers to this area as the Contact Zone). The underdrainage would in turn propagate a cone of depression laterally through the Precipice Sandstone to the springs, such as the Lucky Last spring complex.

For the Walloon Coal Measures, the first potential source aquifer that can be impacted is the Hutton Sandstone; for the impact propagating from the Bandanna Formation, it is the Precipice Sandstone.

The JIP specifies a groundwater monitoring bore network that will be used to provide early warning of potential impact to a spring or spring complex (Figure 1). It comprises fourteen (14) Hutton Sandstone monitoring locations, sixteen (16) Precipice Sandstone monitoring locations and one Clematis Sandstone¹ monitoring location. These monitoring bores are a subset of the Proponent's combined groundwater monitoring bore network. Approximately 30% of the EWS monitoring bores are already in place and the remainder are planned to be installed by the end of 2016. Prioritisation of the EWS monitoring bore installation is scheduled to enable the early commencement of data collection at locations close to early CSG development areas. The bores will be constructed to allow the collection of both water pressure and water quality data.

The network comprises two types of installations:

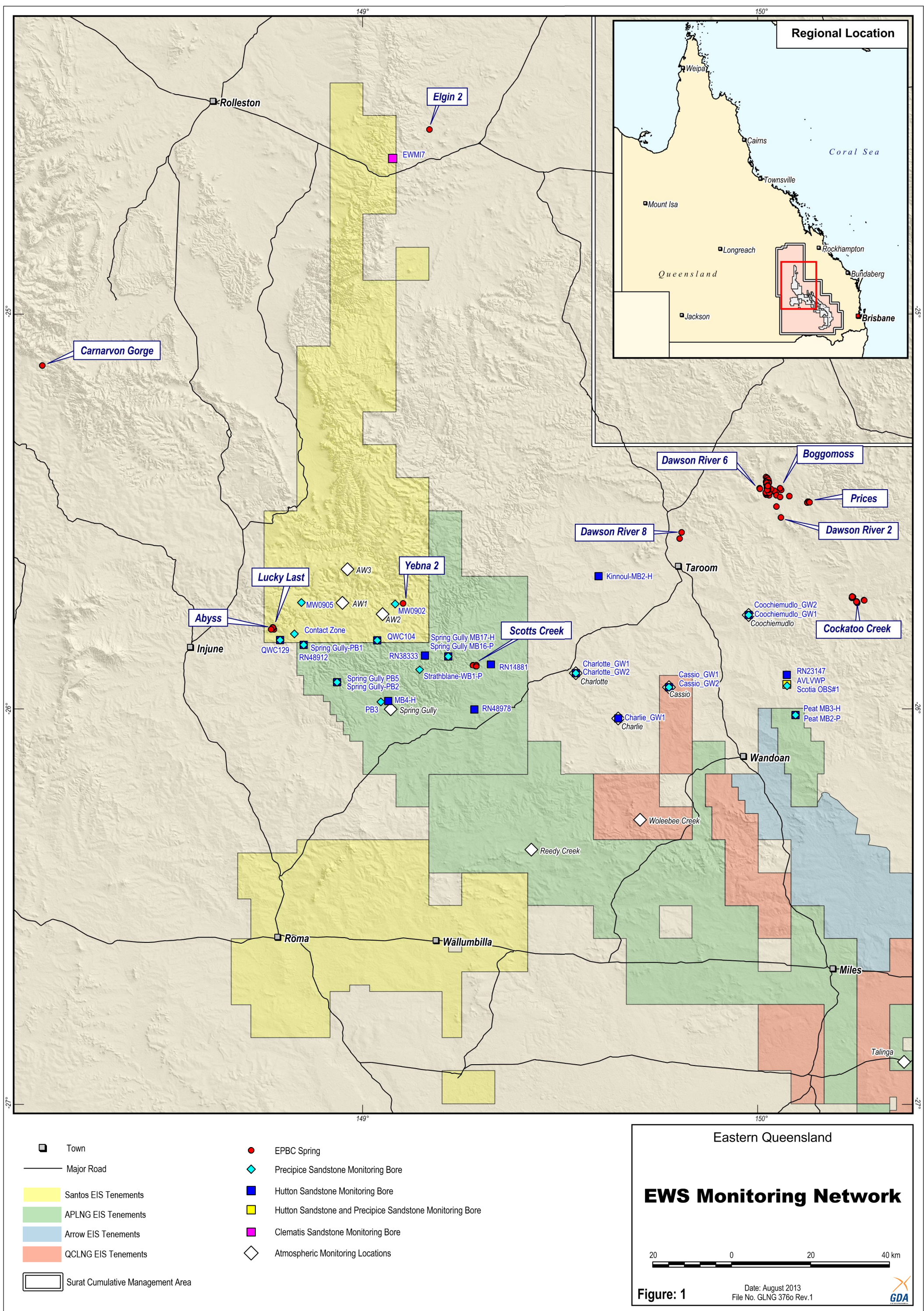
- An *Early Warning Monitoring Installation* (EWMI) will typically be on-tenure and close to the area of CSG water extraction or, between the extraction areas and the spring. These early warning bores are located to provide initial drawdown data, and secondary data in support of interpretation of observations made closer to springs. At these locations groundwater drawdowns are expected to be more pronounced due to their proximity to the source of drawdown.
- A *Trigger Monitoring Point* (TMP) located closer to the spring i.e. further away from the CSG production area. For on-tenure springs, the TMPs have been selected within close proximity of the springs.

In addition to the above EWS network, the Proponents will also be monitoring the CSG reservoirs (Walloon Coal Measures and the Bandanna Formation) to understand the timing and magnitude of drawdown at its source.

Two drawdown triggers have been developed that instigate actions commensurate with increasing levels of risk to MNES. Drawdown limits have been set, which if exceeded constitute a breach in approval conditions. These are defined in the following table.

Term	Approval Condition Terminology	Applies to Water Level	Applies to Water Quality
Investigation Trigger	A nominated value that triggers an action such as data review, model review, increased monitoring frequency, increased monitoring parameters. This is equivalent to 'early warning indicator' in the EPBC approval conditions.	✓	✓
Management / Mitigation Trigger	A nominated value at a TMP that triggers some action to be taken to prevent an impact occurring at an EPBC spring. For groundwater pressure, this is equivalent to 'drawdown threshold' in the EPBC approval conditions.	✓	✗
Drawdown Limit	A nominated value at a TMP that, if exceeded, would result in a breach of the Proponents' Approval Conditions.	✓	✗

¹ The Clematis Sandstone is no longer classified under the GAP ROP as a GAB aquifer. SEWPaC has yet to advise if the approval conditions apply to springs sourced from the Clematis Sandstone and meeting the criteria of community of native species dependant on GAB.

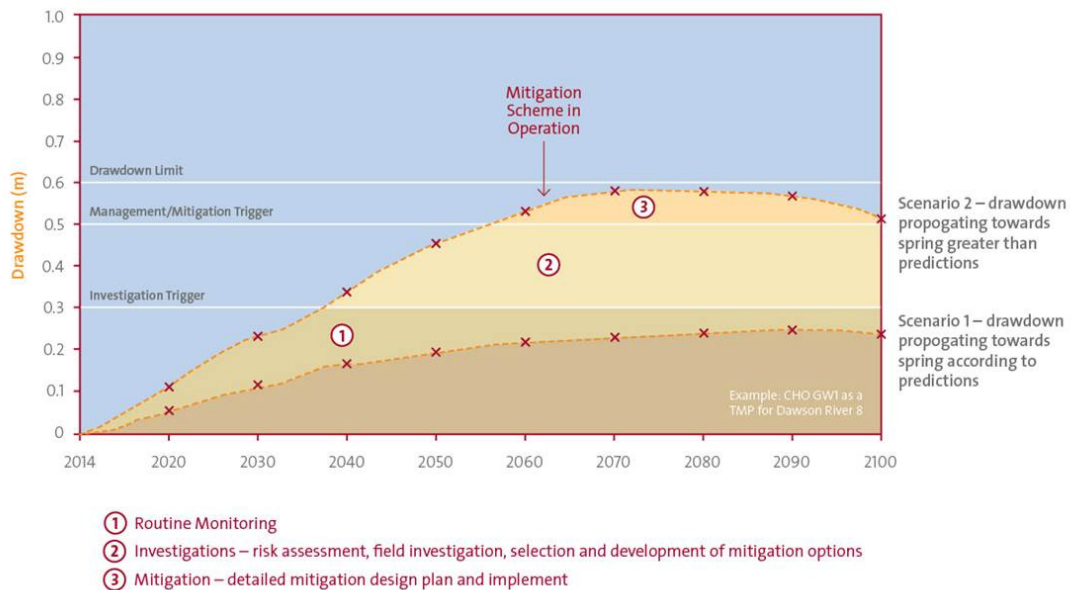


The JIP identifies investigation triggers, management triggers and drawdown limits for every bore in the EWS network, as appropriate.

For **off-tenure springs** located at a large distance from CSG production areas:

Case 1: General case

- The drawdown limit is set as the P95 drawdown in an EWS monitoring bore corresponding to the last time period in the model corresponding to zero metres drawdown at the spring. It is defined for TMPs only.
- The investigation trigger value is set at 50% of the drawdown limit for that EWS bore; and
- The management/mitigation trigger is set at 80% of the drawdown limit for that EWS bore.



Case 2: No drawdown predicted at spring

Where no drawdown is predicted at the spring by the CIM, the maximum P95 drawdown value at an EWS monitoring bore is used:

- The investigation trigger value is set at 50% of the maximum P95 drawdown value ;
- The management/mitigation trigger value is set at 80% of the maximum P95 drawdown value ; and
- The drawdown limit is set at the maximum P95 drawdown value.

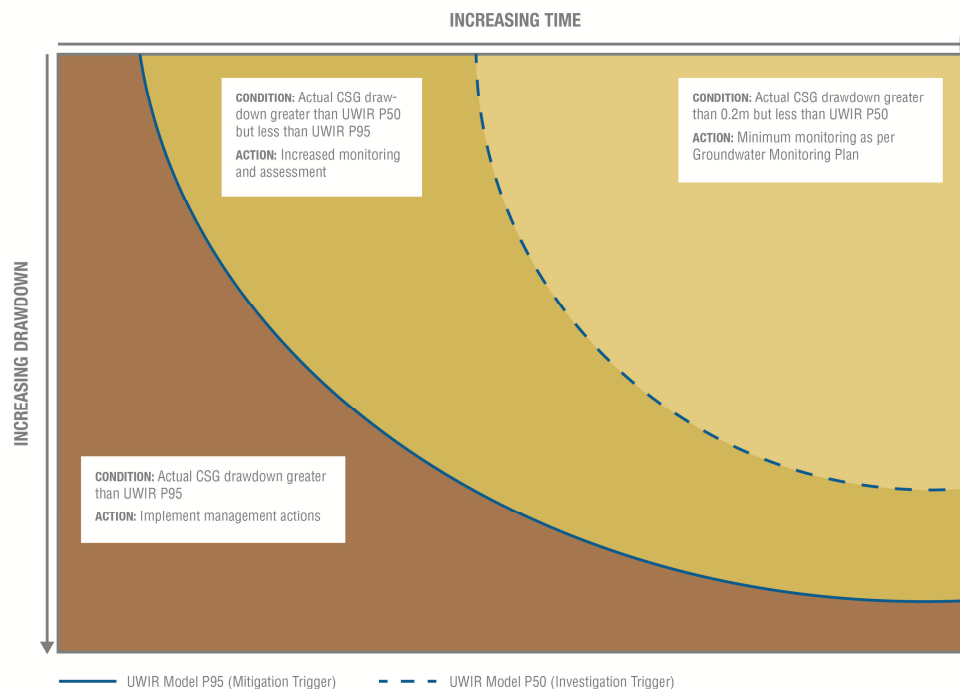
Case 3: No drawdown predicted at spring and at the TMP

Where no drawdown is predicted at the spring and no measurable drawdown is predicted at a TMP, the drawdown limit is set at 0.2 m, investigation triggers and management /mitigation triggers are set as the percentile of the drawdown limit:

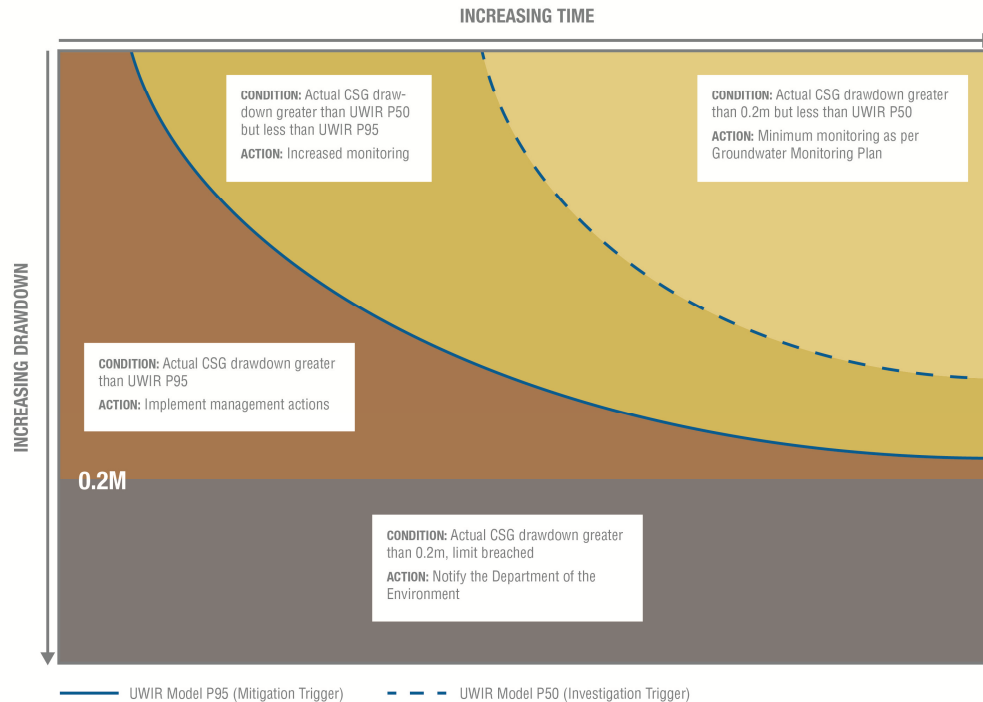
- The investigation trigger value is set at 50% of the drawdown limit, i.e. at 0.1 m;
- The management/mitigation trigger is set at 80% of drawdown limit, i.e. at 0.16 m; and
- The drawdown limit is set at 0.2 m

For **on-tenure springs**, or springs close to production areas:

- Investigations and mitigation triggers are defined at EWMI as the modelled P50 and P95 drawdown predictions, respectively. Exceedance of the P50 drawdown will trigger investigation and exceedance of the P95 will trigger management actions.



- For on-tenure springs TMPs are located close to the springs (typically less than 5 km) and act as a measurable proxy to assessing the monitoring of the source aquifer pressure at the spring. The Drawdown Limit is defined as 0.2 m CSG-induced drawdown at the TMP, 0.2 m being a measurable proxy for zero impact to MNES.

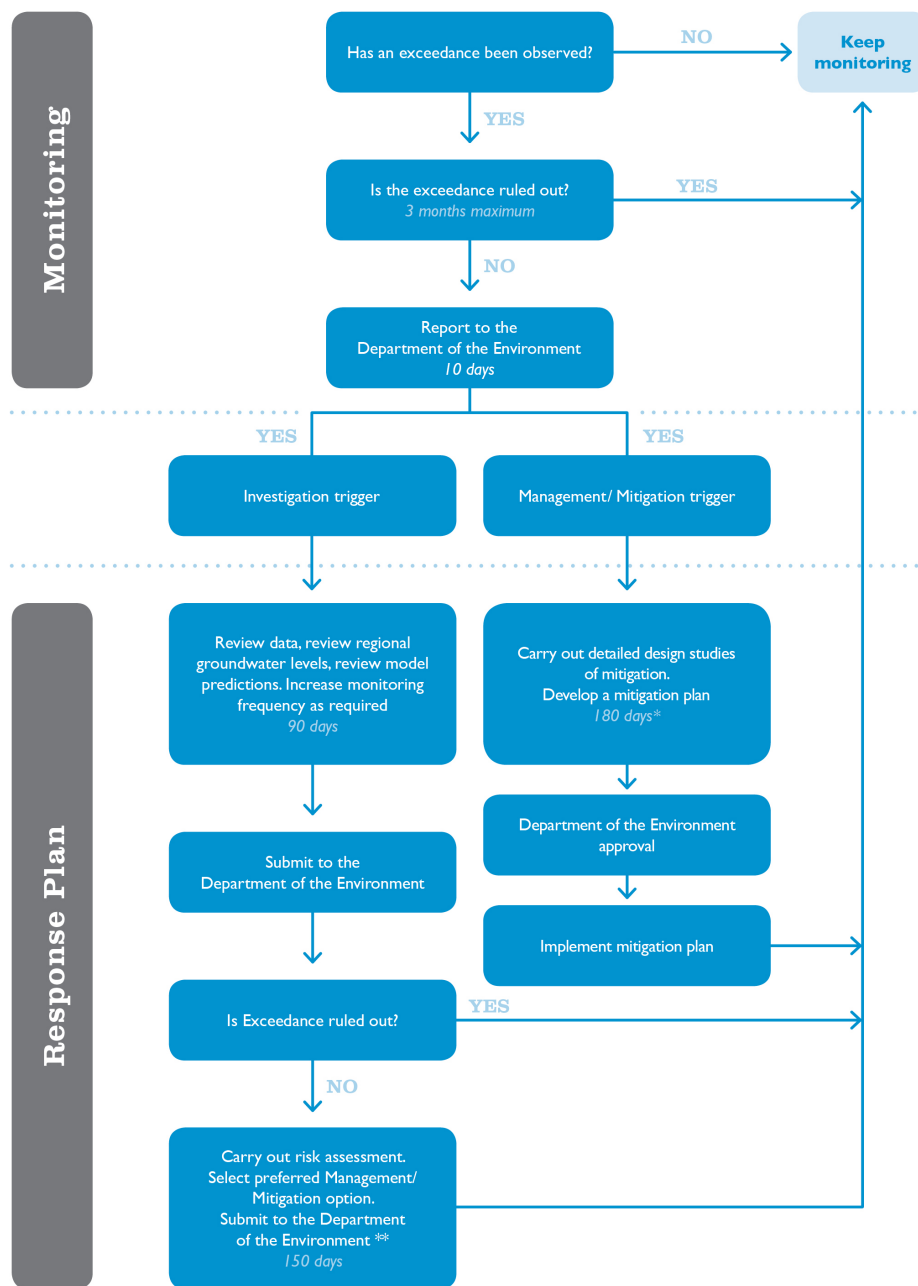


Investigation triggers for groundwater quality will be set following the collection of a baseline data set.

Water level data will be collected in each monitoring bore on a daily frequency. The data will be corrected to remove non-CSG related effects that may include barometric pressure fluctuations, the effects of earth tides, and the effects of groundwater extraction from the spring source aquifers. The corrected data will be used to calculate the CSG induced drawdown. If the corrected drawdown exceeds a trigger, the response process will apply (see following figure):

- 1) When an Investigation Trigger value is exceeded (at an EWMI or TMP), the responsible Proponent will
 - Verify the exceedance by:
 - Assessing observation data with historical data for the bore, this may include the use of a statistical trend procedure to remove natural variations;;
 - Assessing water level data in neighbouring bores monitoring the same aquifer;
 - Reviewing the model predictions and assess with observed water levels;
 - Identifying the potential causes that may have contributed to the exceedance; and
 - Increasing monitoring if necessary; then,
 - Notify The Department of the Environment within 10 days of confirmation of the exceedance

- Where an observed exceedance cannot be ruled out, the responsible Proponent will undertake a risk assessment and other studies resulting in nomination of a concept mitigation approach. This will include field investigations to assess site specific features, an assessment of the vulnerability of the spring to the level of predicted drawdown and a review of the hydrogeological conceptual model to understand the actual level of risk of impact to the EPBC springs. A methodology is proposed for the selection of potential impact management/mitigation solutions. One key element is the multi-criteria analysis which ensures that a range of criteria are taken into consideration in the selection process and in particular:
 - The timing available for implementation of the management/mitigation option;
 - The timing of the Proponent CSG activities; and
 - Other criteria such as technical success rate of the solution, environmental footprint, stakeholder and regulatory acceptability.
- 2) When a Management/Mitigation trigger is exceeded, the responsible Proponent will:
- Move to carry out detailed mitigation design and develop a mitigation plan. To this end, the previously selected impact management/mitigation concept(s) will be developed in detail. This will involve:
 - Confirmation of the concept options;
 - Additional field investigations;
 - Hydrogeological modelling;
 - Detailed engineering design studies.
 - Develop a mitigation plan. The mitigation plan will identify the potential of time before impact, the timing of mitigation and will potentially be redefining the value used as a “zero impact proxy”.
 - Submit the mitigation plan to The Department of the Environment; then
 - Implement the mitigation plan.
- 3) When a drawdown limit is exceeded and the exceedance cannot be ruled out, the responsible Proponent will report to The Department of the Environment within 10 days of confirmation of exceedance.



* Available time before impact taken into consideration in concept design choice. Time frames are consistent with impact propagation timing.
 ** Risk assessment and selection of preferred management /mitigation option is already done for Lucky Last, Yebna 2 and Scotts Creek.

The EWS is based on the underlying assumption that MNES with respect to GAB springs are dependent on spring flow. The sensitivity of the spring flow to drawdown in the source aquifer is dependent on the hydrogeological environment in which the spring exists, particularly the groundwater pressure in the source aquifer at the spring and the flow path for the water reaching the surface.

The time delay between an exceedance of the monitoring trigger and an exceedance of the management/mitigation trigger is estimated to be a minimum of three years for off tenements springs. While initial site-specific conceptual hydrogeological models have been developed and will be provided to The Department of the Environment by 1st November 2013 for the springs which the UWIR indicates are at a greater risk of potential drawdown (Lucky last, Yebna2, Scotts Creek spring complexes), conceptual hydrogeological models for springs that are more distant from CSG production or not predicted to be at risk will be developed for at the completion of the spring baseline monitoring.

Springs monitoring will be undertaken quarterly to match the frequency requested in the UWIR.

The first year of quarterly monitoring will constitute the baseline period. In addition to those items above, the baseline monitoring will include assessment of fauna, flora and macro-invertebrates, and collection of groundwater samples for isotope analysis. There are a range of weather stations across the area and others will be installed in close proximity to spring complexes, where required. The Proponents intend to use a common field team to undertake the spring baseline monitoring to ensure consistency between the companies.

Groundwater samples will be collected from the EWS monitoring bore network every six months. Statistical evaluation indicates that seven samples will be required to establish a baseline with a 95% confidence.

A *Quality Plan* for EWS monitoring has been developed by the Proponents which standardises:

- Field procedures for springs and groundwater sampling;
- Field quality assurance, quality control (QA/QC) procedures;
- Data management processes; and
- Data control processes.

Collection of monitoring data will be the responsibility of the proponent responsible for installation of each of the EWMI and TMPs. The Proponents can share the monitored data with each other through a range of existing data sharing agreements, and via provision of the data to the Office of Groundwater Impact Assessment. Reports will be prepared by the Proponents in accordance with their individual CSG WMMPs but will include a minimum of:

- Simple reporting of data every year (data and plots of data against trigger as appropriate, trend analysis after collection of baseline);
- A consolidated report every 3 years.

The following table summarises the commitments made in this JIP for the monitoring and management of EPBC springs.

Commitment	Due date
Define reference values for groundwater level and groundwater chemistry	Reference values will be defined for each groundwater bore of the EWS network, within six month of completion of baseline at the bore. This being a minimum of one year of groundwater levels and 7 six-monthly sampling events for groundwater quality. Values will be provided in the proponents' respective CWMMP for bores they are responsible for.
Review of the JIP	6 month following the release of updates of the Surat UWIR, if necessary.
Spring hydrogeological conceptual models: EPBC spring hydrogeological models as developed by the Proponents for the purpose of the EPMORs (Lucky Last, Yebna2, Abyss, Scotts Creek) and complementary hydrogeological cross sections as developed by KCB (KCB, 2012)	1 November 2013
Spring baseline report inclusive of the result of 4 three-monthly spring baseline monitoring and development of hydrogeological conceptual models for each spring complex	April 2015
Review of the EPBC conceptual model for those springs potentially fed by the Birkhead Formation, assessment of the requirement for Birkhead Formation monitoring bores in the EWS.	Following completion of proposed EWS monitoring bores network implementation. The matter will be discussed in the next update of the JIP.
Data model predicted drawdown	To be included in the Proponents' CWMMPs

Table of Contents

1	Introduction	19
1.1	Objectives of this Document.....	19
1.2	Scope of Industry Collaboration	22
1.3	Updates of the JIP	22
2	Spring Impact Management and Monitoring Requirements.....	22
2.1	Department of the Environment Spring Impact Management Requirements.....	22
2.2	Department of the Environment Monitoring Requirements.....	22
2.3	Surat UWIR Groundwater and Spring Monitoring Requirements	23
2.4	Surat UWIR Spring Mitigation Studies	27
3	Identified EPBC Springs and Surat UWIR Mitigation Springs for Monitoring	28
3.1	Definition of an EPBC Spring	28
3.2	Current Understanding for this JIP.....	29
3.3	EPBC Spring Responsibility.....	30
4	Baseline Spring Assessments & Spring Hydrogeological Conceptual Models Preparation	33
5	Conceptual Models for Drawdown Impact Propagation to EPBC Springs.....	36
6	Proposed EPBC Spring Early Warning System.....	42
6.1	Key Elements of the EWS	42
6.1.1	Use of groundwater level variations to inform on impact to springs.....	42
6.1.2	Use of the regional cumulative impact model.....	43
6.1.3	Definition of exceedance levels	45
6.2	Monitored Aquifers.....	45
6.3	EWS Monitoring Strategy Outline	47
7	EWS Groundwater Monitoring Network Implementation	50
7.1	Monitoring Locations and Responsibilities Finalisation.....	50
7.2	Monitoring Bore Types	51
7.2.1	Standard single aquifer monitoring bores	51
7.2.2	P&G Act Monitoring Bores.....	51
7.2.3	Private Bores or Water Act Bores	52
7.3	Installation Timing & Baseline Collection	53
7.4	Groundwater Monitoring.....	57
7.4.1	Groundwater Level Monitoring	57
7.4.2	Atmospheric Pressure Monitoring.....	57

7.4.3	Groundwater Quality Monitoring	58
8	EWS Levels of Exceedances Levels for Groundwater Monitoring	61
8.1	Definitions	61
8.2	Groundwater level drawdown exceedance criteria –Off-tenement Springs.....	62
8.3	Groundwater Level Drawdown Exceedance Criteria–On-tenement Springs	66
8.4	Updates of Trigger LevelValues.....	70
8.5	Groundwater Quality Investigation Trigger Values	70
8.6	Definition of Reference Values	70
9	Exceedance Response Measures	71
9.1	Available response time	71
9.2	Exceedance response process	74
9.3	Change to Spring Attributes.....	77
9.4	Potential mitigation options	78
9.5	Data review procedures and reporting.....	81
9.6	Groundwater level trend analysis to differentiate CSG-induced impact from natural variations.....	81
10	References	83

Table of Figures

Figure 2-1: Precipice Sandstone Monitoring Sites (Surat UWIR – QWC 2012).....	25
Figure 2-2:Hutton Sandstone Monitoring Sites (Surat UWIR – QWC 2012)	26
Figure 3-1: Classification of current EPBC Springs(QLD Herbarium, 2011).....	28
Figure 3-2: Location of EPBC Springs and Surat UWIR Selected Springs	32
Figure 5-1: Location of Springs in relation to source of Impact.....	39
Figure 5-2: Conceptual Model of Impact Propagation – Surat Basin.....	40
Figure 5-3: Conceptual Model of Impact Propagation – Bowen Basin	41
Figure 6-1: Concept of Proposed Early Warning Groundwater Monitoring Scheme for EPBC Springs	49
Figure 7-1: Standard single aquifer monitoring bores	51
Figure 7-2: P&G Act Monitoring Bores	52
Figure 7-3: Private Bores Equipped with Telemetry	53
Figure 8-1: Schematic of Groundwater Pressure Exceedance Response for off-Tenement Springs....	62
Figure 8-2: Schematic of Groundwater Pressure Exceedance Response for on-Tenements Springs...	67
Figure 9-1: Early Warning System Monitoring Exceedance and Response Process for EPBC Springs..	76

Tables

Table 1-1: Approval Conditions addressed by the JIP	20
Table 3-1: Summary of Spring Complexes Nominated for Monitoring	29
Table 3-2: Watercourse Springs for Monitoring	30
Table 3-3: Spring Responsibility Assignment	31
Table 4-1: Spring Baseline Water Quality	35
Table 5-1: Impact propagation pathways for EPBC springs	38
Table 6-1: Estimated P95 (CIM v1.2) Drawdowns at the Most at Risk Spring Complexes	44
Table 6-2: Predicted drawdown levels at EPBC springs	44
Table 6-3: Definition of Exceedance Criteria	45
Table 6-4: Monitored Aquifers	47
Table 7-1: JIP EWS Timing of Installation and Length of Baseline Collection	55
Table 7-2: Atmospheric Pressure Monitoring Locations	58
Table 7-3: Groundwater Baseline Water Quality	59
Table 8-1: Definition of Exceedance Criteria	61
Table 8-2: Applicable triggers and drawdown limits for off-tenement springs	64
Table 8-3: Applicable triggers and drawdown limits for on-tenement springs	68
Table 9-1: Response time available for springs management and mitigation	72
Table 9-2: Possible Mitigation Options	78
Table 9-3: Work program for spring mitigation option selection	79

Appendices

APPENDIX A – JIP EWS Groundwater Monitoring Network
APPENDIX B – QUALITY PLAN
APPENDIX C – Notes to Table 8.2 and Table 8.3
APPENDIX D – Methodology for Trend and Statistical Analysis

Glossary

Aquifer	A saturated, permeable geological unit that is permeable enough to yield economic quantities of water to boreholes.
Aquitard	A saturated geological unit with a relatively low permeability that retards and restricts the movement of water, but does not prevent the movement of water; while it may not readily yield water to boreholes and springs, it may act as a storage unit.
Artesian aquifer	A confined aquifer under hydrostatic pressure.
Autocorrelation	(a). Correlation between the elements of a series and others from the same series separated from them by a given interval. (b). A calculation of such correlation
Baseline Data	A data set for each nominated EWMI and TMP that is made up of data that is used to derive the reference value, i.e. the value of the parameter prior to impact by CSG activities.
Basin	A depression of large size in which sediments have accumulated.
Confined aquifer	An aquifer overlain by a confining layer of significantly lower hydraulic conductivity in which groundwater is under greater pressure than that of the atmosphere; the aquifer is bounded above and below by an aquitard.
Drawdown	Change in hydraulic head relative to a background condition, indicating the difference in head which has occurred at a given location relative to an initial time at the same location.
Drawdown Limit	A nominated value at a TMP that, if exceeded, would result in a breach of the Commonwealth Approval Conditions should drawdown exceed this value (see Condition 49 a). This value corresponds to greater than 0 +/-0.2 m modelled impact at an EPBC Spring.
Earth tides	Earth tide or body tide is the small (typically <1 metre) motion of the Earth's surface at periods of about 12 hours and longer. The motion is caused by the gravity of the Moon and Sun. The largest body tide constituents are semi-diurnal, but there are also significant diurnal, semi-annual, and fortnightly contributions. Though the gravitational forcing causing earth tides and ocean tides is the same, the responses are quite different.
Ecosystem	A community of plants, animals and bacteria and the physical and chemical environment they inhabit.
EPBC Spring	A spring complex where the presence of <i>The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin</i> , or threatened species listed under the EPBC Act that are reliant on springs has been confirmed – further discussion is available in Section 3.1.
EWMI	Early Warning Monitoring Installation
EWS	Early Warning System
Formation	(a) A unit in stratigraphy defining a succession of rocks of the same type. (b) A body of rock strata that consists of a certain lithology or combination of lithologies.
Groundwater Dependent Ecosystems	Terrestrial or aquatic ecosystems whose ecological function and biodiversity are partially or entirely dependent on groundwater.

Groundwater model	A simplified conceptual or mathematical image of a groundwater system, describing the features essential to the purpose for which the model was developed and including various assumptions pertinent to the system. Mathematical groundwater models can include numerical and analytical models.
Investigation Trigger (Early Warning Trigger Value)	A nominated value at an EWMI and TMP that triggers some action such as data review, model review, increased monitoring frequency, increased monitoring parameters. For groundwater pressure, this is equivalent to 'early warning indicator' referred to in Condition 49)d.
Management / mitigation Trigger (Exceedance Threshold)	A nominated value at a TMP that triggers some action to be taken to prevent an impact occurring at an EPBC spring (i.e. a mitigation activity). For groundwater pressure, this is equivalent to 'drawdown threshold' referred to in Condition 49)d
MNES	Matters of National Environmental Significance as defined under part 3 of the EPBCAct, 1999
Outcrop	(a) The part of a rock formation that appears at the surface of the ground. (b) A term used in connection with a vein or lode as an essential part of the definition of apex. It does not necessarily imply the visible presentation of the mineral on the surface of the earth, but includes those deposits that are so near to the surface as to be found easily by digging. (c) The part of a geologic formation or structure that appears at the surface of the earth; also, bedrock that is covered only by surficial deposits such as alluvium. (d) To appear exposed and visible at the earth's surface; to crop out.
Permeability	A measure of the capacity of rock or stratum to allow water or other fluids such as oil to pass through it (i.e. the relative ease with which a porous medium can transmit a fluid).
Piezometric surface	A surface of hydraulic heads or potentials, typically depicted by a map of equipotential contours such as a map of water-table elevations. See potentiometric surface.
Porosity	The volume of the voids divided by the total volume of porous medium (the percentage of a rock or soil that is represented by open voids or spaces): effective - the interconnected porosity which contributes to groundwater flow. Often used synonymously with specific yield although the two terms are not synonymous. fracture - the porosity of the fractures; intergranular - the porosity between the grains of a sediment or sedimentary rock; primary - intergranular porosity formed during the deposition of the sediment or from vesicles in igneous rocks; secondary - porosity formed after the rock is lithified by either dissolution or fracturing.
Potentiometric surface	In groundwater, an imaginary surface that defines the level to which water in a confined aquifer would rise were it completely pierced with wells
Proponents	Queensland Gas Company, Origin Energy on behalf of Australia Pacific LNG, Santos referred together as a collective
Reference value	Value defined using baseline data and thereafter used as a

	reference point for comparison with more recent data to assess the presence or absence of impact.
Spring complex	A cluster of spring vents where no adjacent pair of springs are more than 6km apart and all springs within the complex are located in a similar geomorphic setting
Spring vent	A spring
Subcrop	An occurrence of strata beneath the subsurface of an inclusive stratigraphic unit that succeeds an unconformity on which there is marked overstep
TMP	Trigger Monitoring Point
Transmissivity (T)	The rate of horizontal groundwater flow through the full saturated thickness (b) of an aquifer across a unit width (i.e. an area of $b \times 1$) (i.e. Through a 1 metre wide slice across the entire depth of an aquifer) under a unit hydraulic gradient (i.e. $\delta h / \delta l = 1$). Transmissivity may be quoted as $m^3/day/m$ [$L^3/T/L$], but is more commonly expressed as m^2/day [L^2/T]. It provides a better comparison of the possible yield of an aquifer than saturated hydraulic conductivity because it takes into account the saturated thickness of an aquifer. Transmissivity is related to the hydraulic conductivity of the aquifer by the equation $T=Kb$.
Unconfined aquifer	An aquifer with no confining layer between the water table and the ground surface where the water table is free to fluctuate.
Water table	Potentiometric surface of the upper most aquifer.

1 Introduction

1.1 Objectives of this Document

The CSG operators in the southern Bowen and Surat Basins, Santos, Origin Energy and Origin Energy on behalf of APLNG (hereafter referred to as Origin), Queensland Gas Company (QGC) (from here on referred to as the Proponents) have developed this collaborative Joint Industry Plan (JIP) which aims at harmonising the approach of monitoring and management of impact of EPBC springs by:

- Developing one common approach for the monitoring and impact management of EPBC springs which will prevent overlap between the Proponents;
- Ensure that early warning systems, monitoring points and values for exceedance triggers and drawdown levels are set in a same way; and
- Provide one single approach to spring monitoring and more specifically spring baseline acquisition through the use of a single consultancy.

It is noted that Arrow Energy also represent a CSG operator in the Surat CMA, Arrow Energy do not currently have project approval and associated conditions set under the EPBC Act. Arrow Energy has been consulted in the development of the JIP.

This document intends to:

- Summarise the sum of monitoring requirements that have been requested of the Proponents in the Surat UWIR and in the Proponents' approval conditions by the Department of the Environment in relation to EPBC springs;
- Propose an early warning system monitoring network and escalating levels of triggers to protect EPBC springs from any effect from CSG water extraction;
- Demonstrate that the Proponent will endeavour to identify potential impact early and adequately respond to prevent any adverse impact to EPBC springs; and
- Identify which proponent is responsible for management actions for each potentially impacted EPBC springs;
- Demonstrate the Proponents' commitments to meet the requirements of the EPBC approval.

The JIP addresses the risk of groundwater drawdown propagating from CSG production areas toward those springs hosting ecological communities that are listed as Matters of National Environmental Significance (MNES) under the Environment Protection and Biodiversity Conservation Act, 1999 (EPBC Act). An Early Warning System (EWS) scheme defines a spring monitoring network and a risk management and response program as required by The Department of the Environment. In developing this plan, the Proponents have taken into consideration the findings of the Surat UWIR (QWC, 2012).

By means of this JIP, Proponents seek to satisfy the conditions relating to the development of a monitoring program, establishment of triggers and implementation of response actions and mitigation strategies. Table 1-1 provides an overview of the conditions addressed in this proposal. Conditions not covered in the JIP are either covered in other joint industry projects independent of this JIP (Section 1.2), or covered in individual CSG WMMPs.

Table 1-1: Approval Conditions addressed by the JIP

Condition Number			Approval conditions committed to in the JIP	Additional approval conditions referred to in the JIP
Santos	QGC	Origin		
49.a	49.a	50.a	✓	NA
49.b	49.b (53Ba)	50.b	✗	✗
49.c	49.c	50.c	✗	✗
49.d	49.d	50.d	✓	NA
49.e	49.e	50.e	✗	✗
49.f	49.f (53Bb)	50.f	✗	✗
49.g.i	49.g.i	50.g.i	✗	✗
49.g.ii	49.g.ii	50.g.ii	✗	✗
49.g.iii	49.g.iii	50.g.11	✗	✗
49.g.iv	49.g.iv	50.g.iv	✓	✗
49.g.v	49.g.v	50.g.v	✓	NA
49.g.vi	49.g.vi	50.g.vi	✗	✗
49.g.vii	49.g.vii	50.g.vii	✗	✗
49.g.viii	49.g.viii	50.g.viii	✗	✗
49.g.ix	49.g.ix	50.g.ix	✗	✗
49.g.x	49.g.x	50.g.x	✗	✗
49.g.xi	49.g.xi	50.g.xi	✗	✗
49.g.xii	49.g.xii	50.g.xii	✓	NA
49.h. 1	49.h. 1	50.h. 1	✓	NA
49.h. 2	49.h. 2 (53Bc)	50.h. 2	✗	✗
49.i	49.i	50.i	✗	✗
53.a	523.a	53.a	✗	✗
53.b	52.b	53.b	✗	✗
53.c.i	52.c.i	53.c.i	✗	✗
53.c.ii	52.c.ii	53.c.ii	✗	✗
53.c.iii	52.c.iii	53.c.iii	✗	✗
53.c.iv	52.c.iv (53Bdi)	53.c.iv	✗	✗
53.c.v	52.c.v (53Bdii)	53.c.v	✗	✗
53.c.vi	52.c.vi	53.c.vi	✓	NA
53.c.vii	52.c.vii (53Bdiii)	53.c.vii	✗	✗
53.c.viii	52.c.viii	53.c.viii	✗	✗
53.c.ix	52.c.ix	53.c.ix	✗	✗
53.d.i.1	52.d.i.1	53.d.i.1	✗	✗
53.d.i.2	52.d.i.2 (53Beil)	53.d.i.2	✓	NA
53.d.i.3	52.d.i.3 (53BeII)	53.d.i.3	✗	✗
53.d.i.4	52.d.i.4 (53BeIII)	53.d.i.4	✗	✗
53.d.ii	52.d.ii (53Beii)	53.d.ii	✗	✗
68	68	70	✗	✓
69. a	69. a	71. a	✗	✓
69.b i	69.b i	71.b i	✓	NA

Condition Number			Approval conditions committed to in the JIP	Additional approval conditions referred to in the JIP
Santos	QGC	Origin		
69.b ii	69.b ii	71.b ii	✗	✓
69.b iii	69.b iii	71.b iii	✗	✓
69.b iv	69.b iv	71.b iv	✓	NA
69.b v.	69.b v.	71.b v	✓	NA
69.b vi.I	69.b vi.I	71.b vi.I	✓	NA
69.b vi.II	69.b vi.II	71.b vi.II	✓	NA
69.b vi.III	69.b vi.III	71.b vi.III	✗	✗
69.b vi.IV	69.b vi.IV	71.b vi.IV	✗	✗
69.b vii.	69.b vii.	71.b vii	✗	✓
69.b viii.	69.b viii.	71.b viii	✗	✓

Notes: NA – Not Applicable

The proposed approach has been progressed in accordance with comments received from Geoscience Australia (GA, 2011, 2012), the Commonwealth Department the Environment and the Expert Panel for Major CSG Projects.

1.2 Scope of Industry Collaboration

The industry is collaborating to undertake jointly the following studies and develop management tools in relation to springs:

- The Joint Industry Plan
- The undertaking of the spring baseline monitoring at the identified EPBC springs; and
- A spring mapping exercise for the areas within 100 km of the maximum predicted drawdown extent (Surat UWIR, QWC, 2012) and not covered by QWC spring survey (as required under Approval Conditions 68 for Santos or QGC and Condition 70 for Origin).

1.3 Updates of the JIP

Updates of the JIP will be made by the Proponents:

- Within six months after the release of an update of the Surat UWIR, when necessary;
- If required, should a monitoring investigation highlight the need to update the EWS methodologies or locations.

Any update would take into consideration any variation to the implementation of the JIP made through consultation with The Department of the Environment between the two revisions.

2 Spring Impact Management and Monitoring Requirements

2.1 Department of the Environment Spring Impact Management Requirements

The Proponents project approval conditions require the CSG activities to have “no adverse impacts” to MNES. To measure impact at a spring, a “zero drawdown” impact in the source aquifer at the spring has been used as a proxy at this time. This is a conservative approach as a decrease of pressure in the source aquifer may not necessarily result in an impact to MNES. The assessment of the vulnerability of a spring complex to a decrease in pressure in the source aquifer is site specific and requires ecological and hydrogeological assessments over a period of time, however the use of regional groundwater monitoring will provide early warning of potential impact and inform on potential impact at the springs.

2.2 Department of the Environment Monitoring Requirements

The monitoring of impact at EPBC spring is required through the monitoring of groundwater levels in source aquifers and the monitoring of spring conditions. In essence, the monitoring of EPBC springs needs to satisfy:

- The establishment of sufficient baseline data prior to the commencement of main production:
- Long-term monitoring programs for groundwater regimes, and for the condition and function of the EPBC Springs, should be implemented prior to CSG water extraction. A staged approach is acceptable with the primary focus for installation being in areas closer to impact as predicted by the Surat CIM.

- Collect data to establish how ecosystems function and baseline(pre-CSG development) spring conditions such that risk to EPBC springs from CSG production may be assessed and impact prevented or mitigated.
- Allow understanding of non-CSG production effects that may affect aquifer water level responses and spring behaviour.
- It is noted that changes to aspects such as ecosystem health (e.g. ecological diversity) and physio-chemical spring attributes (e.g. spring flow and spring water quality) are secondary impacts that would reflect changes to groundwater pressure and groundwater quality.
- The establishment of aquifer source monitoring infrastructure to enable early detection of potential impacts to EPBC springs.
- The establishment of drawdown threshold values and response actions which escalate with increasing levels of drawdown.

2.3 Surat UWIR Groundwater and Spring Monitoring Requirements

The Surat UWIR water monitoring program is summarised in Section 7 of the Surat UWIR (QWC, 2012), and is described in detail in Appendix G of that reference. The spring monitoring program is summarised in Section 8 of the Surat UWIR, and is described in detail in Appendix H of that document.

The required water monitoring program will establish a regional monitoring network of bores in the GAB aquifers and other hydrostratigraphic units as described in Table G-1 and as shown on the maps of Figures G-1 through G-9 of the Surat UWIR. Over 450 monitoring points at 142 locations are to be installed.

Maps showing locations of the required Precipice Sandstone and Hutton Sandstone monitoring bores under the Surat UWIR have been reproduced as Figure 2-1 and Figure 2-2. These maps have been reproduced as they relate to the main source aquifers for EPBC springs, the Hutton Sandstone and Precipice Sandstone.

The UWIR identifies 33 spring vents amongst ten spring complexes and five watercourse springs that are at a higher risk of being affected by CSG activities. Not all of these higher risk springs are classified as EPBC springs. Watercourse springs are sections of rivers where substantial baseflow is provided to the river. Those watercourse springs have not been observed to hold any EPBC listed species.

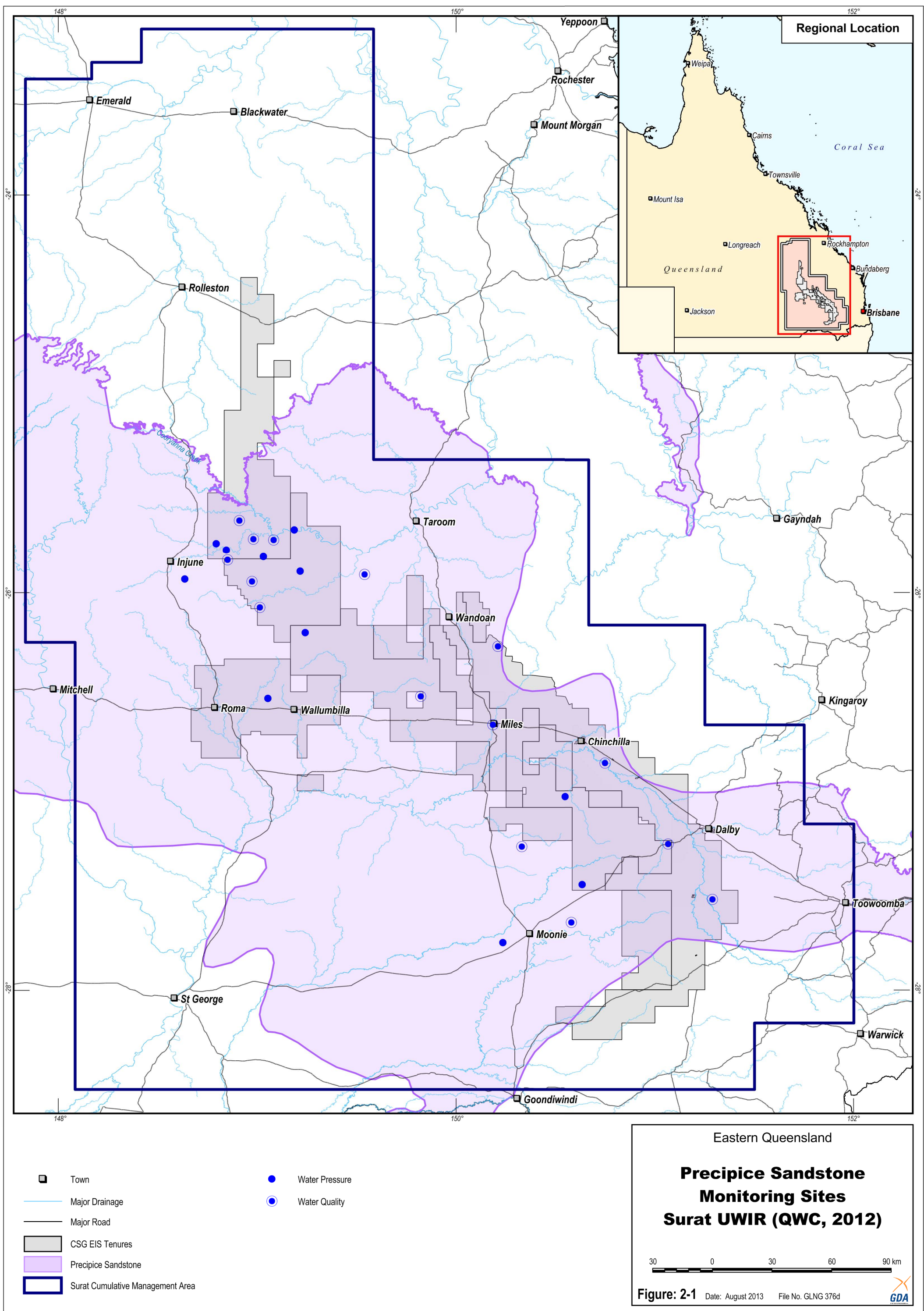
The Surat UWIR spring monitoring requirements include:

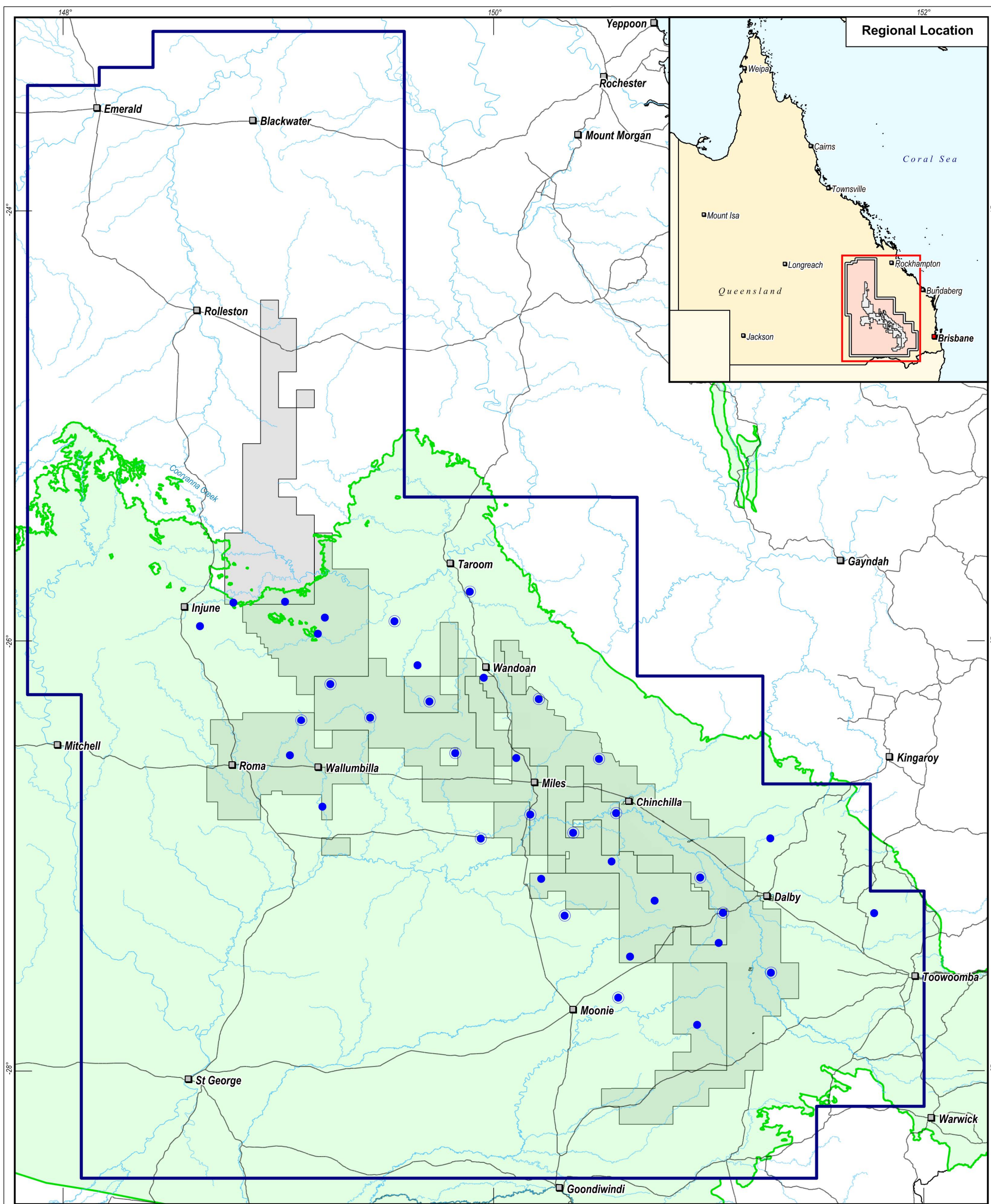
- Spring flow,
- Spring wetted area,
- Water chemistry, and
- Physical condition.

Methods for the required spring monitoring and water analytes are provided in Appendix H of the Surat UWIR. Monitoring is to be undertaken on a quarterly basis and results reported every six months.

The UWIR does not require the monitoring of fauna and flora, as the Office of Groundwater Impact Assessment (OGIA, formerly known as QWC) is of the view that “the identification of ecological assemblages is a matter for further research rather than regular monitoring” (section 8.4, UWIR). Accordingly, OGIA has identified a research project called “Ongoing knowledge about springs” (Appendix I of the Surat UWIR).

Accordingly, monitoring of the springs requested by the Surat UWIR has been incorporated with the monitoring of EPBC springs. The spring monitoring program addresses both the requirements of the Surat UWIR and the Commonwealth Projects approval conditions.





Eastern Queensland

**Hutton Sandstone
Monitoring Sites
Surat UWIR (QWC, 2012)**

30 0 30 60 90 km

Figure: 2-2 Date: August 2013 File No. GLNG 376e



2.4 Surat UWIR Spring Mitigation Studies

The Surat UWIR defines a spring impact mitigation strategy which is described in Section 8.5 and Table 8-4 (QWC, 2012). The principal criterion cited by OGIA for inclusion is the prediction of potential to experience more than 0.2 m drawdown in the source aquifer(s) at the spring location at any time. Five spring complexes (38 spring vents) were predicted to potentially experience drawdown of more than 0.2 m in the source aquifer. Drawdown greater than 0.2m is not predicted to occur at any spring until 2017 or later.

The UWIR assigns responsibility to petroleum tenure holders for specific monitoring and mitigation actions. The UWIR identifies the responsible tenure holder for each of the springs where greater than 0.2m of CSG-related drawdown is predicted at any time. Responsible tenure holders are required to develop and implement a spring mitigation strategy for each spring complex identified in the Surat UWIR for evaluation of spring impact mitigation options (Table 3-1 and Figure 3-2). A spring mitigation option assessment is due to be submitted to OGIA and DEHP on 1st September 2013 for those defined springs.

3 Identified EPBC Springs and Surat UWIR Mitigation Springs for Monitoring

3.1 Definition of an EPBC Spring

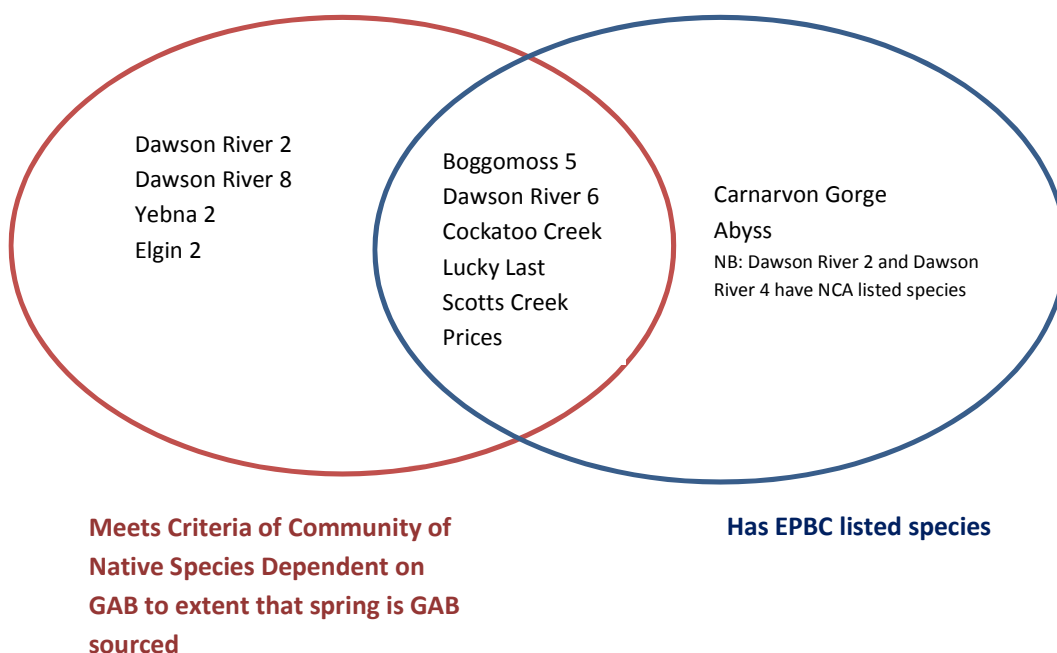
The Proponents projects approval conditions established under the EPBC Act relate to “*the community of native species dependant on the natural discharge of groundwater from the Great Artesian Basin*”.

The work done by the Queensland Herbarium (*Ecological and Botanical Survey of Springs in the Surat Cumulative Management Area, QLD Herbarium, 2011*) for the (then) Queensland Water Commission in support of the Surat Underground Water Impact Report has been used to identify EPBC springs in the Surat Basin. These springs have been included as they meet at least one of the below criteria:

- Meeting the criteria for the Community of Native Species Dependent on Groundwater Discharge from GAB i.e. the springs are defined as GAB artesian discharge springs. Dawson River 2 and 8, Cockatoo 2, Yebna 2 and Elgin 2 springs fall within this category, as their source is interpreted to be artesian GAB groundwater. These springs do not host EPBC or Queensland Nature Conservation Act (NC Act) listed species; and
- Hosting any EPBC or NC Act listed species.

The springs identified by the Queensland Herbarium can be classified according to the above criteria as displayed on the below diagram (Figure 3-1).

Figure 3-1: Classification of current EPBC Springs(QLD Herbarium, 2011)



The Carnarvon Gorge spring complex, located in the Carnarvon Gorge National Park, is supplied by groundwater from the outcropping Precipice Sandstone. The springs are not fed by GAB pressure discharge but rather by infiltration and rapid discharge of rainfall water (KCB, 2012). The rainfall water recharging the outcropping Precipice Sandstone is found emerging from the base of the Precipice Sandstone close to the unconformity with the underlying lower permeability siltstone of the Moolayember Formation. As such, the Carnarvon Gorge spring complex is not included in the scope of this JIP.

3.2 Current Understanding for this JIP

The Department of the Environment and the Surat UWIR monitoring requirements create a very comprehensive regionally distributed spring monitoring and protection network.

There are twelve spring complexes containing either EPBC listed species or EPBC communities within the Surat Cumulative Management Area (CMA). The locations of these EPBC Springs are shown on Figure 3-2. Summary information relating to each spring or spring complex is provided in Table 3-1.

The Surat UWIR requires spring monitoring at 33 spring vents within ten spring complexes and five watercourse springs (Table 3-2), it also requires the Proponents to implement a spring mitigation strategy at five spring complexes (Table 3-1).

Table 3-1: Summary of Spring Complexes Nominated for Monitoring

Spring Complex Name	Spring Complex Number	Number of EPBC-listed Vents in Complex ⁽¹⁾	Vent Number(s)	Location of Spring	UWIR – Selected Spring for monitoring	UWIR – Selected Spring for mitigation	EPBC Springs
Cockatoo Creek	9	19	319, 320, 320.1, 321, 321.2, 321.3, 321.4, 321.4, 321.5, 321.6, 321.7, 321.8, 64, 64.1, 65, 65.1, 65.2, 66, 684	Off-tenure	✓	✗	✓
Dawson River 2	2	1	42	Off-tenure	✗	✗	✓
Boggomoss	5	30	2, 3, 7-15, 29, 33, 37, 37v2, 44, 53-58, 61, 62, 63, 68, 68B, 29B, 44B	Off-tenure	✗	✗	✓
Dawson River 6	6	16	1, 4, 5, 6, 22, 23, 24, 25, 27, 30, 31, 32, 43, 59, 60, 25B	Off-tenure	✗	✗	✓
Prices	580	4	40,41,52,67	Off-tenure	✗	✗	✓
Dawson River 8	8	3	26,28,38	Off-tenure	✓	✗	✓
Scotts Creek	260	5	189-192, 192.1	On APLNG tenement	✓	✓	✓
Yebna 2	591	1	534	On Santos tenement	✓	✓	✓
Lucky Last	230	12	287,340, 686,687,687.1,687.2,687.3,687.4,687.5,687.6,688,689	On Santos tenement	✓	✓	✓
Elgin 2	594	1	540	Off-tenure	✗	✗	✓
Abyss	592	1	286 (EPBC), 716, 286.1, 286.2, 286.3	On and off Santos tenement	✓	✗	✓
Carnarvon Gorge	296	1	712	Off-tenure	✗	✗	✓
Barton	283	0	702, 703	On APLNG tenement	✓	✓	✗

Spring Complex Name	Spring Complex Number	Number of EPBC-listed Vents in Complex ⁽¹⁾	Vent Number(s)	Location of Spring	UWIR – Selected Spring for monitoring	UWIR – Selected Spring for mitigation	EPBC Springs
Spring Rock Creek	561	0	285	On Santos tenement	✓	✓	✗
311	311	0	535, 536, 693, 704, 499, 500, 500.1, 536.1, 536.2, 537, 692, 694-699	On Santos tenement	✓	✓	✓
Ponies	229	0	284	On Santos tenement	✓	✗	✗
Wambo	584	0	711, 711.1	On QGC tenement	✓	✗	✗

Notes:

- Spring names, complex numbers and vent numbers as per QLD Herbarium survey (QLD Herbarium, 2011).
- Abyss is partly on Santos tenements, EPBC spring vents are located on tenure, two non EPBC spring vents are located off-tenure.

Table 3-2: Watercourse Springs for Monitoring

Watercourse spring site number	Start Latitude	Start Longitude	Finish Latitude	Finish Longitude	Location of watercourse spring	UWIR – Selected Spring for monitoring
W39	-25.7256	149.3031	-25.6767	149.2351	On APLNG tenement	✓
W40	-25.6795	149.1373	-25.6848	149.0665	On Santos tenement	✓
W80	-25.7434	148.6857	-25.6977	148.4273	Off-tenure	✓
W81	-25.7127	149.0837	-25.7151	149.0283	On Santos tenement	✓
W82	-25.8038	148.7799	-25.8119	148.7327	On Santos tenement	✓

3.3 EPBC Spring Responsibility

The monitoring responsibility at the spring is defined in two folds:

- The baseline spring monitoring performed for all EPBC spring complexes is a joint industry program (refer to Section 4).
- Ongoing spring monitoring and spring mitigation responsibilities.

The proponents commit to assign responsibility of ongoing springs monitoring and spring mitigation to tenure holders. The practice mirrors the responsible tenure holder assignments of the UWIR. On tenements springs are the responsibility of the tenure holder. Off-tenure springs are generally the responsibility of the closest tenure holder.

For those spring at which the Surat UWIR cumulative Impact Model (CIM) does not predict drawdown (e.g. Cockatoo Creek, Boggomoss, Prices, Dawson River 2, Dawson River 6 and Dawson River 8), responsibility will be as summarised in Table 3-3:

- In accordance with the UWIR, should future iterations of the CIM show an increased level of risk at those springs.
- Assigned to the closer tenure holder should an investigation trigger for the considered spring complex be exceeded.

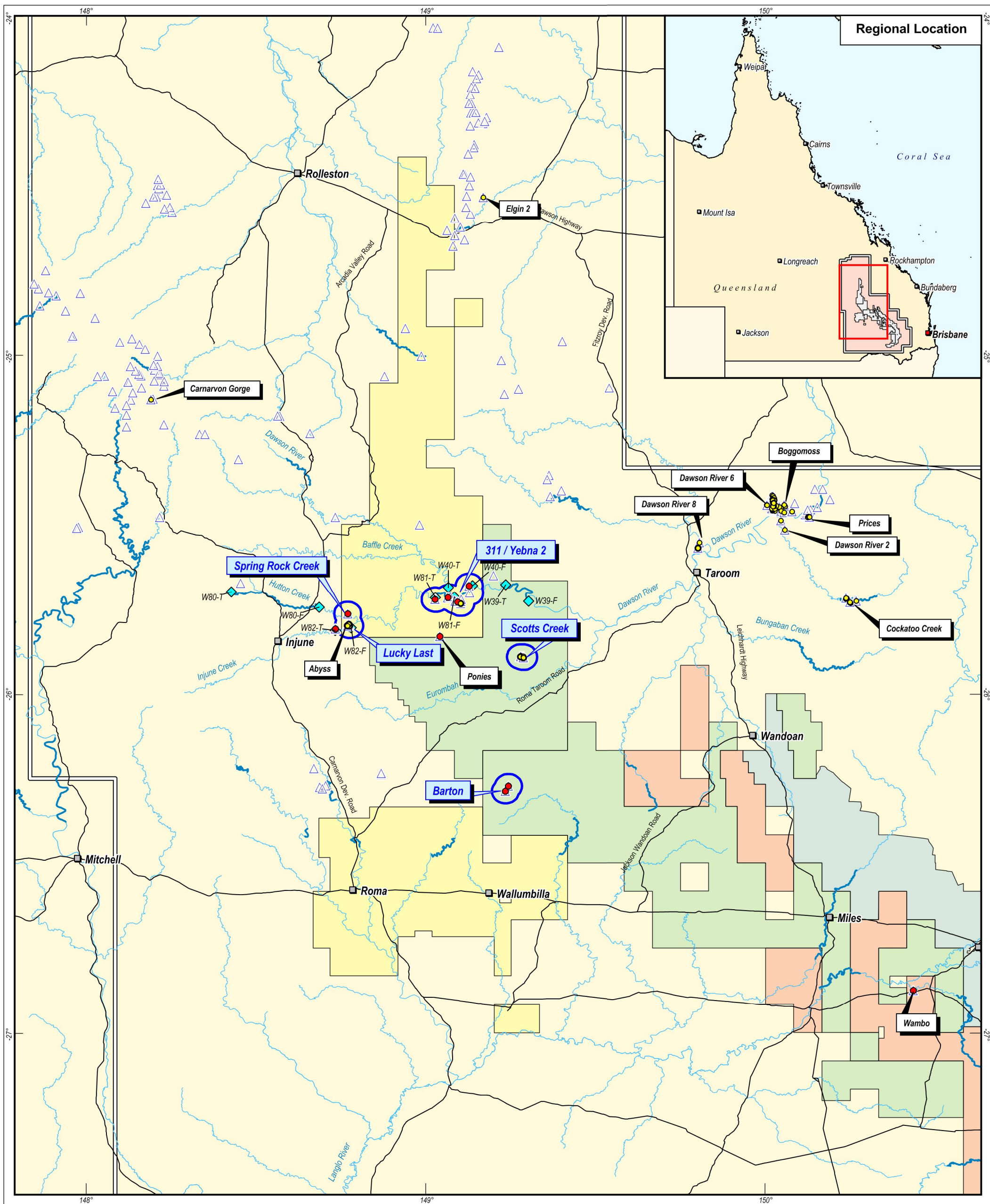
It should be noted that the groundwater monitoring bores from the EPBC spring EWS defined in latter sections of this JIP are all assigned and will be monitored by the tenure holder responsible for its installation.

Should additional EPBC springs be identified within the 100 km buffer area beyond the drawdown zone, the same assignation process will be followed.

Table 3-3: Spring Responsibility Assignment

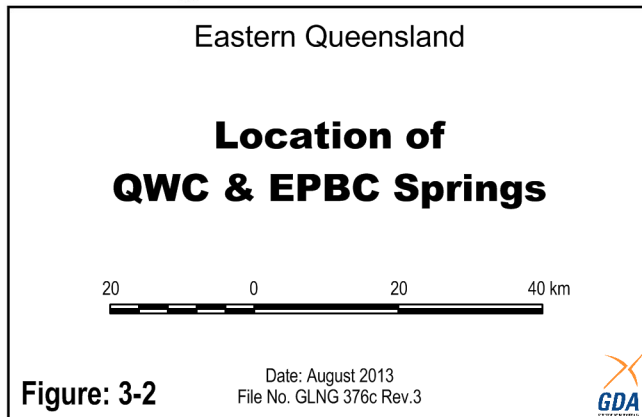
Spring Complex Name	Spring Complex Number	EPBC Status	Activities at spring	Location of Spring	Assigned responsible tenure holder
Cockatoo Creek	9	EPBC spring	Baseline	Off-tenure	To be advised under future revision of the Surat UWIR or when an investigation trigger is exceeded whichever the earliest.
Dawson River 2	2	EPBC spring	Baseline	Off-tenure	To be advised under future revision of the Surat UWIR or when an investigation trigger is exceeded whichever the earliest.
Boggomoss	5	EPBC spring	Baseline	Off-tenure	To be advised under future revision of the Surat UWIR or when an investigation trigger is exceeded whichever the earliest.
Dawson River 6	6	EPBC spring	Baseline	Off-tenure	To be advised under future revision of the Surat UWIR or when an investigation trigger is exceeded whichever the earliest.
Prices	580	EPBC spring	Baseline	Off-tenure	To be advised under future revision of the Surat UWIR or when an investigation trigger is exceeded whichever the earliest.
Dawson River 8	8	EPBC spring	Baseline & monitoring	Off-tenure	QGC (as assigned in the Surat UWIR)
Scotts Creek	260	EPBC spring	Baseline & monitoring	On APLNG tenement	APLNG
Yebna 2	591	EPBC spring	Baseline & monitoring	On Santos tenement	Santos
Lucky Last	230	EPBC spring	Baseline & monitoring	On Santos tenement	Santos
Elgin 2	594	EPBC spring	Baseline & monitoring	Off-tenure	Santos
Barton	283	Non - EPBC	Baseline & monitoring	On APLNG tenement	APLNG
Spring Rock Creek	561	Non - EPBC	Baseline & monitoring	On Santos tenement	Santos
Abyss	592	EPBC spring	Baseline & monitoring	On and off Santos tenements	Santos
311	311	Non EPBC	Baseline & monitoring	On Santos tenement	Santos
Ponies	229	Non EPBC	Baseline & monitoring	On Santos tenement	Santos
Wambo	584	Non EPBC	Baseline & monitoring	On QGC tenement	QGC
W39	^	Non EPBC	Baseline & monitoring	On APLNG tenement	APLNG
W40	^	Non EPBC	Baseline & monitoring	On Santos tenement	Santos
W80	^	Non EPBC	Baseline & monitoring	Off-tenure	Santos
W81	^	Non EPBC	Baseline & monitoring	On Santos tenement	Santos
W82	^	Non EPBC	Baseline & monitoring	On Santos tenement	Santos

Note: W39, W40, W80, W81 and W82 are watercourse springs (or sections of the creeks fed by groundwater baseflow). The baseline and monitoring program for those are different to others springs



- Town
- Major Drainage
- GAP ROP Spring Water Course
- Major Road
- Surat Cumulative Management Area
- Santos GLNG EIS Tenure
- APLNG EIS Tenure
- Arrow EIS Tenure
- QGC EIS Tenure
- EPBC Spring
- QWC Spring Vent Monitoring Location
- QWC Spring Water Course Monitoring Location
- QWC Surveyed Spring Vent
- Spring Impact Mitigation Sites (as selected in QWC UWIR)

Note:
EPBC Springs as identified by QWC Spring Survey January 2012



4 Baseline Spring Assessments & Spring Hydrogeological Conceptual Models Preparation

A joint Industry program has been initiated to undertake the spring baseline. It covers the EPBC springs and also other springs required for monitoring under the Surat UWIR. Baseline analyses to satisfy projects approval conditions and the requirements of the Surat UWIR over four three-monthly sampling events will comprise:

- Mapping of spring vent location and elevations, this will include the installation and survey of a permanent survey mark at each complex;
- Ground photography to record the appearance of springs and vegetation;
- Gauging of the following parameters, noting that some springs have such diffuse discharge that such quantification may not be possible or assessed reliably (in such cases a qualitative reliability score and photograph to accompany results are required):
- Discharge rates and inundation frequency: wetted area and/or visual flow observations;
- Groundwater temperature (where unaffected by surface temperatures)
- Physio-chemical field measurements (see Table 4-1);
- Ecological monitoring of fauna, flora and macro-invertebrates at relevant sites within each of the EPBC spring complexes; and
- Spring sampling for laboratory analyses of water chemistry as per Table 4-1.

The Proponents will be using a common field team to undertake the spring baseline monitoring to ensure consistency between the companies. The spring baseline program will follow the procedures and quality standards defined in the “Spring Quality Plan” provided as APPENDIX B of this JIP.

A joint industry spring baseline report will be submitted in April 2015 which will include:

- The results of the three- monthly sampling program over the four baseline events, and in particular:
 - Tabulation of water chemistry;
 - Preparation of tri-linear diagram plots of major ion chemistry;
 - Assessment of temperature and water chemistry correlations between springs and source aquifers;
 - Comparison against reliable water quality for local source aquifers;
 - Isotopic age dating; and
- A hydrogeological conceptual model for each of the EPBC spring complexes.

The development of the conceptual models will take into consideration other anthropogenic influences upon the source aquifers in the vicinity of each spring and more specifically:

- Location and rate of source aquifer extraction and entitlement from abstraction bores;
- Local land use and land management practices relevant to groundwater; and
- Any proposal for artificial groundwater recharge possibly affecting the spring.

Hydrogeological conceptual models have already been developed for those EPBC springs closest to CSG activities at which a risk of impact is predicted by the Surat CIM. This applies to the following spring complexes:

- Lucky Last;
- Yebna 2,
- Abyss; and
- Scotts Creek.

In addition to those, KCB had developed early hydrogeological cross sections for a number of spring complexes (KCB, 2012).

Santos will provide to The Department of the Environment on behalf of the Proponents for the 1st November 2013, a consolidated document which will contain the springs hydrogeological conceptual models for those EPBC spring complexes named above and any additional hydrogeological cross sections directly taken from KCB work.

As committed earlier, newly developed and/or updated conceptual models for each of the EPBC spring cluster will be included with the baseline results in the April 2015 submission.

Table 4-1:Spring Baseline Water Quality

Parameter	F/L ¹	Parameter	F/L ¹	Parameter	F/L ¹
Physio-chemical					
Dissolved oxygen	F	pH	F, L	Total dissolved solids	L
Electrical conductivity	F, L	Redox (Eh)	F	Total suspended solids	L
Free gas (4 gas meter incl CH ₄)	F	Temperature	F	Turbidity	F
Major ions					
Bicarbonate (as CaCO ₃)	L	Hydroxide (as CaCO ₃)	L	Sulphate	L
Calcium	L	Magnesium	L	Total Alkalinity (as CaCO ₃)	L
Carbonate (as CaCO ₃)	L	Potassium	L	Total Hardness (as CaCO ₃)	L
Chloride	L	Sodium	L		
Dissolved and total metals					
Aluminium	L	Copper	L	Selenium	L
Arsenic	L	Iron	L	Silica	L
Barium	L	Lead	L	Strontium	L
Beryllium	L	Lithium	L	Uranium	L
Boron	L	Manganese	L	Vanadium	L
Cadmium	L	Mercury	L	Zinc	L
Chromium	L	Molybdenum	L		
Cobalt	L	Nickel	L		
Nutrients					
Total Nitrogen as N (including NO _x & TKN)	L	Total Phosphorus as P	L	Nitrite	L
Dissolved sulphide	L	Nitrate	L	Total Kjeldahl Nitrogen	L
Minor elements					
Fluoride	L	Bromide	L	Iodide	L
Carbon					
Total Organic Carbon	L	Dissolved Inorganic Carbon	L	Dissolved Organic Carbon	L
Organics					
Total Petroleum Hydrocarbons	L	Polycyclic Aromatic Hydrocarbons	L	Volatile Organic Compounds	L
Benzene, Toluene, Ethylbenzene, Xylene	L	Phenols (standard LOR and suite)	L		
Dissolved Gases					
Free and total Carbon dioxide	L	C1-C4 (incl methane, ethylene and other gases)	L	Unionised Hydrogen sulphide	L
Isotopes(only in initial sampling)					
Deuterium H-2	L	Oxygen-18	L	Radiogenic Carbon-14	L
Strontium-87/Strontium-86	L	d-Carbon-13 (DIC)	L		

Notes: This suite is the same than the groundwater monitoring suite.

(1) F: Field-based measurements

L: Laboratory-based measurements

5 Conceptual Models for Drawdown Impact Propagation to EPBC Springs

Monitoring and management of impact to an EPBC springs must take cognisance of the mechanism(s) by which drawdown is likely to be propagated from the source (CSG production area) to the receptor (EPBC spring), as per the source-pathway-receptor model of assessing hydrogeological risk. The protection of all receptors requires a robust conceptual model to be developed. The vertical and areal distribution of the springs allows the development of fewer models, with the level of risk assessed to be proportional to the distance from the source of the potential drawdown. Therefore, focussing monitoring efforts on the gas fields in closest proximity to the springs, the formations through which the drawdown must propagate (Table 5-1), and the springs closest to the relevant development areas (Figure 5-1), will be the most effective approach to managing potential risks.

Based on groundwater pressures, Industry stratigraphy knowledge, outputs of the CIM, Santos has developed impact propagation conceptual models for the Surat and Bowen Basin CSG production fields.

Two primary mechanisms exist for the transmittal of drawdown to EPBC springs:

- 1) Vertical propagation of pressure reduction from CSG production in the Walloon Coal Measures through the siltstones underlying the coal seams (including the Eurombah Formation) and into the Hutton Sandstone and from there potentially to the Precipice Sandstone. This is illustrated on Figure 5-2.
 - The low vertical permeability of the siltstones will both attenuate and delay the magnitude of drawdown propagating to the Hutton Sandstone. Due to the relatively higher horizontal permeability of the Hutton Sandstone, the drawdown will then spread laterally from the areas of development outwards over time towards the springs.
 - Drawdown will first be realised at the springs closest in to the Walloon Coal Measure developments and closest to where development commences, e.g., . Scott's Creek and Dawson River 8 spring complexes. Scotts Creek spring complex lies approximately 40 km northwest of Origin's Combabula field and the QGC Woleebee Creek fields (QCLNG project) approximately 55 km to the southeast.
 - All other Hutton Sandstone sourced EPBC springs are at a greater distance from Walloon Coal Measures production. While the same mechanism for drawdown would apply, the magnitude of drawdown will be less and the time lag greater.
 - Drawdown to the Precipice Sandstone from this mechanism would need to transmit through the Evergreen Formation, which would significantly reduce the magnitude of drawdown in the source area.
- 2) Lateral propagation of depressurisation from potential CSG production from the Bandanna Formation at Spring Gully and Fairview, resulting in underdrainage of the Precipice Sandstone where the Bandanna Formation subcrops to the west of Fairview/Spring Gully (Santos refers to this area as the Contact Zone).
 - The underdrainage would propagate a cone of depression laterally through the Precipice Sandstone. This is illustrated on Figure 5-3.

- The EPBC springs most at risk from this mechanism are those at Lucky Last, located immediately northwest of the Spring Gully tenements (located on Santos tenement). Extremely high transmissivities observed in the Precipice Sandstone in the vicinity of Spring Gully (e.g. DRP-WI-1 and SG-PB3) suggest a low likelihood of propagating drawdowns of significant magnitude through the Precipice Sandstone. To impact the Hutton Sandstone, the drawdown from the Precipice Sandstone must propagate through the Evergreen Formation.

Analysis of time-series drawdown data from the UWIR model, confirms these mechanisms as the modelled sources of potential impacts to EPBC springs. The model does not appear to indicate any propagation of drawdown through intervening Evergreen Formation with the exception of an area between Miles and Dalby. This is of limited lateral extent and magnitude and, not in the vicinity of EPBC springs, therefore drawdown at an EPBC spring is more likely to be realised via the primary pathway.

Monitoring will therefore focus on the currently determined spring source aquifer. To provide an early warning of potential impacts to the EPBC springs, it is essential that the monitoring focuses on the source and the pathway to the spring, rather than in the immediate vicinity of the spring itself. Further, monitoring of the CSG reservoir formation will provide an indication of whether the timing of transmitted drawdown is likely to be greater or earlier than that modelled, and hence provide an indicator of the level of risk to the EPBC springs of concern.

Table 5-1: Impact propagation pathways for EPBC springs

Spring Complex Name	Interpreted Source Aquifer	Source of Interpretation of Source Aquifer	Impact Propagation Pathway
Cockatoo Creek	Precipice Sandstone, with possible influence of the Evergreen Formation	KCB, 2012	Vertically from the extraction in the WCMs, through the Hutton Sandstone then Evergreen Formation, and then laterally through the Precipice Sandstone. Potentially from underdrainage through contact between Permian Coals (Bandanna equivalent) and Precipice Sandstone at Scotia/Peat
Dawson River 2	Precipice Sandstone, with possible influence of the Evergreen Formation	KCB, 2012	
Boggomoss	Precipice Sandstone	KCB, 2012	
Dawson River 6	Precipice Sandstone, with possible influence of the Evergreen Formation	KCB, 2012	
Prices	Precipice Sandstone	KCB, 2012	
Dawson River 8	Hutton Sandstone, possibly lower Birkhead Formation	KCB, 2012	Vertically from the extraction in the WCMs and then laterally through the Hutton Sandstone to the spring
Scotts Creek	Hutton Sandstone	KCB, 2012	Vertically from the extraction in the WCMs and then laterally through the Hutton Sandstone to the spring
Yebna 2	Precipice Sandstone, Evergreen Formation	KCB, 2012; Santos, 2013	Underdrainage through contact between Bandanna Formation and Precipice Sandstone at Fairview/Spring Gully. Potentially underdrainage from the WCMs propagating to the Precipice Sandstone and then laterally to the spring.
Lucky Last	Precipice Sandstone	Santos	Underdrainage through contact between Bandanna Formation and Precipice Sandstone at Fairview/Spring Gully
Elgin 2	Clematis Sandstone	KCB, 2012	Vertically through the Rewan Formation from drawdown in the Bandanna Formation
Abyss	Hutton Sandstone	Santos, 2013	Vertically from the extraction in the WCMs and then laterally through the Hutton Sandstone to the spring. Potentially underdrainage from the WCMs propagating to the Hutton Sandstone and then laterally to the spring.

Notes:

1. Santos interpretation of the source aquifer is based on physico-chemical sampling started early in 2013 at the springs and work performed for the preparation of mitigation options selection reports (also referred as EPMOR) for the QLD government.
2. Both Evergreen Formation or Boxvale Sandstone (which is part of the Evergreen Formation) formation names are used in the literature to define spring aquifer sourced from the Boxvale Sandstone.

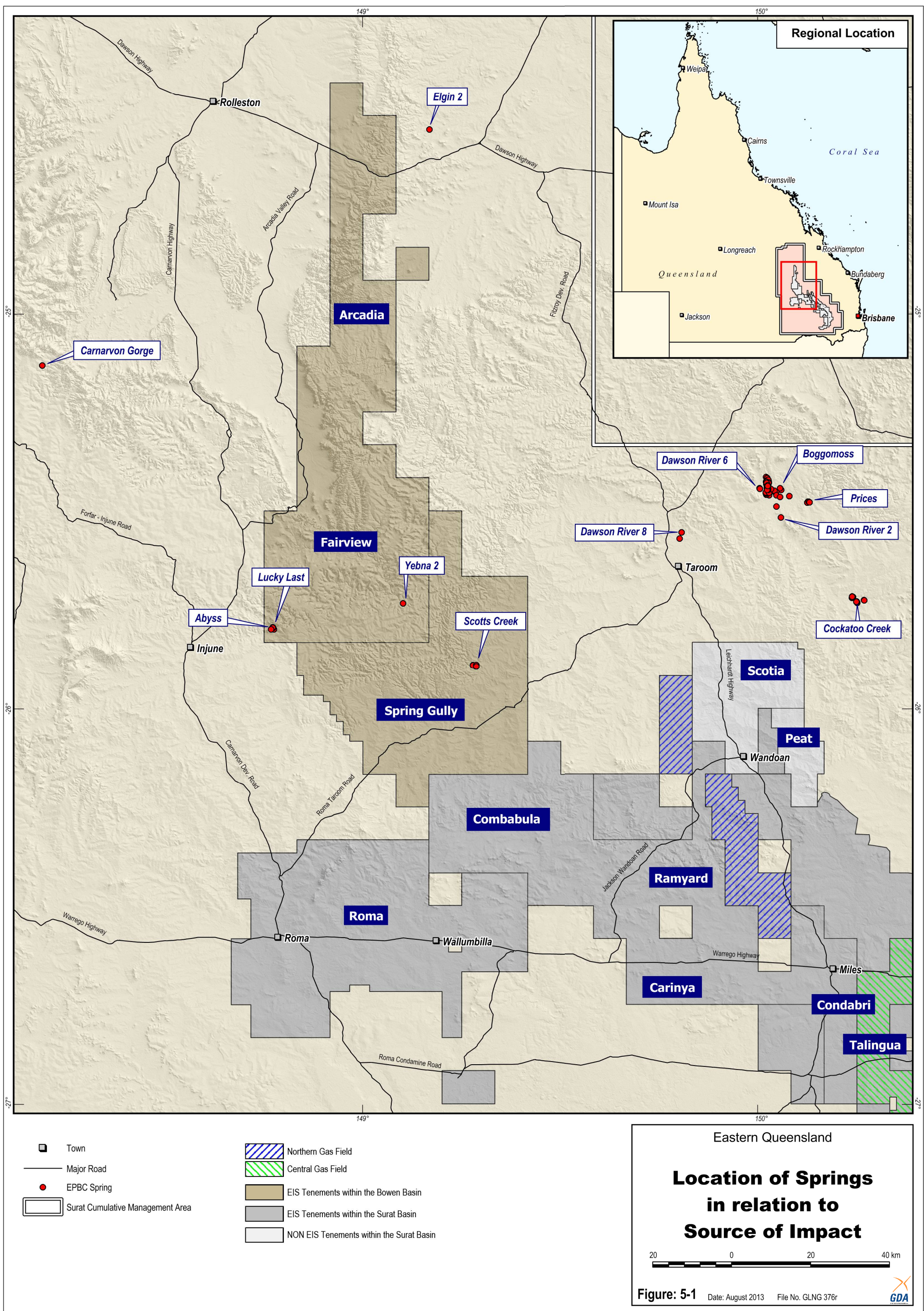


Figure 5-2: Conceptual Model of Impact Propagation – Surat Basin

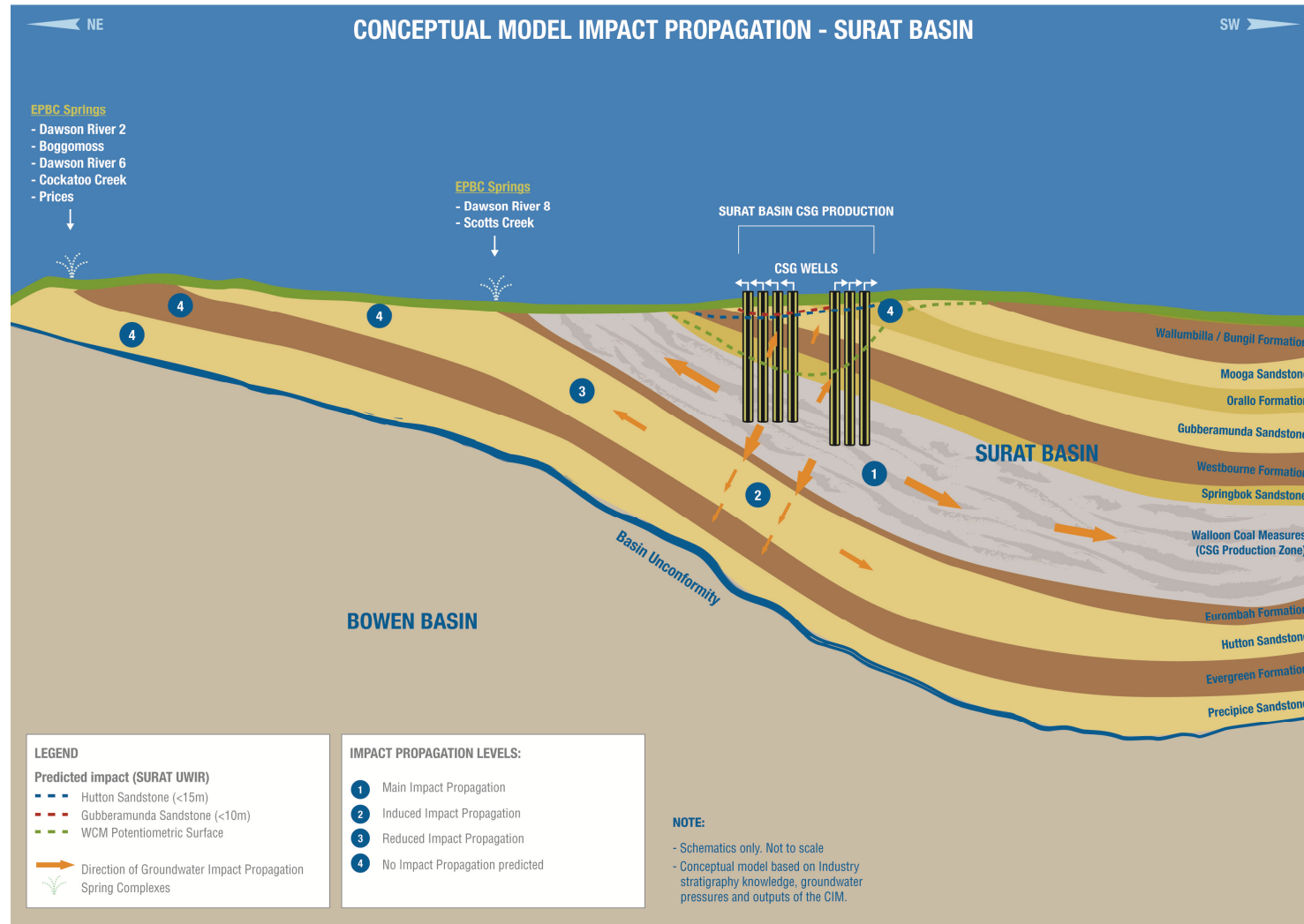
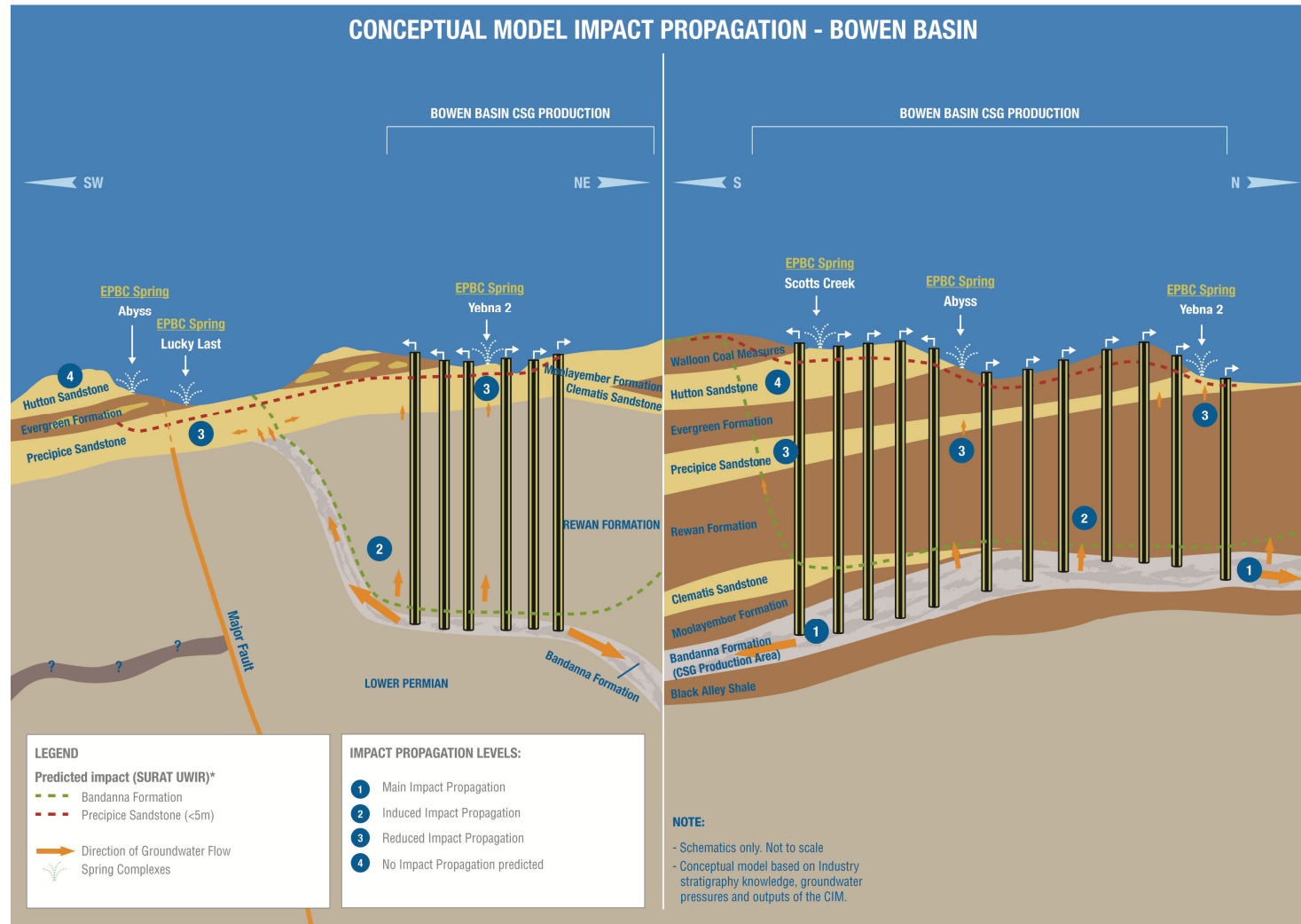


Figure 5-3: Conceptual Model of Impact Propagation – Bowen Basin



6 Proposed EPBC Spring Early Warning System

6.1 Key Elements of the EWS

This scheme will provide ‘early warning’ of pressure impacts propagating from CSG production areas toward springs, and will provide adequate time to develop and implement impact mitigation plans. The EWS is built on the following key elements:

- The use of groundwater levels variations as a proxy to impact to springs to provide early warning of potential impacts to EPBC springs;
- The focus of monitoring on the EPBC springs primary source aquifers (see Section 6.2);
- The use of the regional cumulative impact model (CIM) developed for the Surat CMA UWIR (QWC,2012); and
- The development of a drawdown trigger process that responds to increasing levels of risk to MNES allowing for sufficient assessment and implementation time before predicted potential impact.

All of the above key elements are defined in Section 6.1.1 through to Section 6.1.3. The trigger level development is discussed in Section 8; associated responses are discussed in Section 9.

6.1.1 Use of groundwater level variations to inform on impact to springs

Changes to measurable attributes at the springs such as discharge volumes, wetted area and vegetation response may not necessarily reflect regional changes to pressure head in the source aquifer due to CSG activities. For example, it is noted that some spring vents discharge water on an intermittent basis, independent of fluctuations in potentiometric surface in the source aquifer (NWC, 2013, Vol. III).

As a result, a “zero drawdown” impact in the source aquifer has been used as a proxy for the Projects Approval Conditions which require “no impact”. This is a conservative approach as a decrease of pressure in the source aquifer may not necessarily result in an impact at the springs. The assessment of the vulnerability of a spring complex to a decrease in pressure in the source aquifer is site specific and requires ecological and hydrogeological assessments over a period of time, however the use of regional groundwater monitoring will provide early warning of impact and inform the risk of potential impacts to MNES.

Reliable assessment of the potential influence of CSG water extraction on the springs must rely on regional scale groundwater level monitoring of the springs’ source aquifers. To understand the effects of CSG production on water level variations, external natural and anthropogenic must be removed from the water level response.

6.1.2 Use of the regional cumulative impact model

The EWS is developed using the Surat CIM findings which are the best available assessment of cumulative impacts of CSG production. The EWS uses the 95th percentile prediction of drawdown at selected locations. The percentile corresponds to the distribution of the predicted drawdowns for 200 model runs. A 95th percentile drawdown, also referred as Upper P95, is a statistical measure that indicates 95% of the model runs have a smaller predicted drawdown. In other words, there is only 5% likelihood that this value be exceeded. The P95 has been adopted to provide the assurance that sufficient time for assessment and implementation of mitigation would be available where necessary.

The model values presented in this JIP correspond to a recent re-run of the CIM, model version 1.2. The original UWIR model (v1.0) was updated to reduce water balance discrepancies via amended time-stepping (v1.1) and implement a more realistic abandonment pressure surface in a small number of leases (v1.2).

The Office of Groundwater and Impact Assessment (OGIA, formerly known as Queensland Water Commission, QWC) considers that these alterations have negligible effect on the 1 m and 5 m impact drawdown predicted for 2015 at the P95 statistical level. While there are minor differences in the 1m and 5m impact drawdown (P95) between v1.0 and v1.2 over longer time scales, OGIA does not consider them to be of material importance (pers. comm. M. Gallagher, OGIA, April 2013). The predictive resolution of a regional scale model such as the CIM is considered to be no less than 0.2m.

Predicted drawdown for each EPBC spring is summarised in Table 6-2. With the updates to the CIM discussed above, Lucky Last is the only spring predicted to experience greater than 0.2 m of CSG-related drawdown, with the first prediction of drawdown exceeding 0.1 m occurring in 2017 (see Table 6-1**Error! Reference source not found.**). The version of the CIM used for the UWIR (v1.0), predicted greater than 0.2 m of drawdown at Scott's Creek, however model v1.2 predicts less than 0.15m.

It should also be noted that timing wise, based on the cumulative groundwater modelling, the likelihood of observing a drawdown in a source aquifer before the end of 2017 is only 5%² (Table 6-1). This will potentially affect the Lucky Last EPBC springs (Lucky Last), and this is not predicted to occur before 2017. At the same spring complex, there is a likelihood of 50% that 0.1 m drawdown will occur by 2021, and that 0.2 m drawdown will occur by 2026 (Table 6-1). The estimated impact time-delay will provide sufficient time to establish baseline groundwater level (refer to Section 7.2).

Predicted drawdowns at EPBC springs in the source aquifer are provided in Table 6-2.

² This value is based on a predicted impact drawdown in the source aquifer at the spring of 0.2 m.

Table 6-1: Estimated P95 (CIM v1.2) Drawdowns at the Most at Risk Spring Complexes

Spring Complex Name	Scott's Creek	Lucky Last
Spring Complex Number	260	230
Interpreted Source Aquifer	Hutton Sandstone	Precipice Sandstone
P95 --maximum predicted drawdown (Year)	0.15m (in 2195)	1.34m (in 2059)
P50 --maximum predicted drawdown (Year)	0.06m (in 2165)	0.52m (in 2082)
Year when there will be 5% probability that the drawdown exceeds 0.1m (P95)	2071	2017
Year when there will be 50% probability that the drawdown exceeds 0.1m (P50)	NA	2021
Year when there will be 5% probability that the drawdown exceeds 0.2m (P95)	NA	2018

Table 6-2: Predicted drawdown levels at EPBC springs

Spring Complex Name	First Observed drawdown* Year – P95	First Observed drawdown* Year – P50	P95 maximum predicted drawdown (m)	Year of maximum predicted drawdown
Cockatoo Creek	2105	2145	0.02	2135
Dawson River 2	NA	NA	NA (0.006)	NA (2145)
Boggomoss	No drawdown predicted in the source aquifer at the spring location			
Dawson River 6	No drawdown predicted in the source aquifer(s) at the spring location			
Prices	No drawdown predicted in the source aquifer(s) at the spring location			
Dawson River 8	2027	2029	0.06	2054
Scotts Creek	2029	2038	0.15	2195
Yebna 2	2036	2061	0.04	2295
Lucky Last	2008	2015	1.3	2075
Elgin 2	No drawdown predicted in the source aquifer at the spring location			
Abyss	No drawdown predicted in the source aquifer at the spring location			

*based on a modelled drawdown of 0.01 m

6.1.3 Definition of exceedance levels

The EWS defines three levels of exceedance corresponding with escalating response to manage the risk to the EPBC spring and mitigate the impact where required. These exceedance levels are defined below in Table 6-3 and further defined in Section 8 for a selection of groundwater monitoring installations (Section 7.1). The network is further supported by the additional groundwater monitoring carried out by the Proponents. Exceedance levels have been defined separately for off-tenure and on-tenure springs.

Table 6-3: Definition of Exceedance Criteria

Adopted Terminology	Approval Conditions Terminology
Investigation Trigger	A nominated value at an EWMI and TMP that triggers some action such as data review, model review, increased monitoring frequency, increased monitoring parameters. For groundwater pressure, this is equivalent to 'early warning indicator' referred to in Condition 49)d.
Management / Mitigation Trigger	A nominated value at a TMP that triggers some action to be taken to prevent an impact occurring at an EPBC spring (i.e. a mitigation activity). For groundwater pressure, this is equivalent to 'drawdown threshold' referred to in Condition 49)d
Drawdown Limit	A nominated value at a TMP that, if exceeded, would result in a breach of the Commonwealth Approval Conditions should drawdown exceed this value (see Condition 49 a).

6.2 Monitored Aquifers

The currently understood primary source aquifers of the EPBC Springs are the Hutton Sandstone, Evergreen Formation and Precipice Sandstone, and the Clematis Sandstone aquifers of the Great Artesian Basin (GAB). The Proponents interpret the requirement for drawdown limits to apply to those aquifers which are primary source aquifers to EPBC listed springs (Table 6-4). As such, this removes the requirement to define spring- related default drawdown limits for the Mooga, Gubberamunda and Springbok Formations and the Walloon Coal Measures.

In addition, the choice of the monitored aquifers for each spring is intrinsically linked to the impact propagation pathways as defined in Section 5.

The Evergreen Formation is typically considered as an aquitard. The springs sourced from the Evergreen Formation are, most likely, sourced from the Boxvale Sandstone.

The Boxvale Sandstone is commonly recognised as discontinuous and occurring on relatively local scales (Green, 1997, Hoffmann, 2009). Monitoring within the Evergreen Formation would only be successful if the monitoring bore were installed in a part of the formation which was in direct hydraulic connection with the target spring. In addition, the scale of continuity of Boxvale Sandstone occurrences is so limited that such monitoring bores would probably not provide adequate early warning of impacts.

Considering that any potential impact on the Evergreen Formation from depressurisation of the WCM would have to propagate through the Hutton Sandstone, and through a preferential pathway in the intervening upper siltstone member of the Evergreen Formation, an observed drawdown in the Hutton Sandstone would therefore indicate a potential for impacts to the Boxvale Sandstone).

It should be noted that an impact observed in the Hutton Sandstone may not necessarily propagate to a “pocket” of Boxvale Sandstone.

Accordingly, linking investigation of potential Boxvale Sandstone impacts to monitoring observations in the Hutton Sandstone is considered to be a conservative approach. Similarly, the propagation of drawdown due to CSG production in the Bandanna Formation of the Bowen Basin, would need to transmit through the Precipice Sandstone before it could impact on a spring emanating from the Evergreen Formation.

The Birkhead Formation is a secondary potential source aquifer for Scotts Creek and Dawson River 8 springs. The Birkhead Formation is a lateral equivalent of the WCM, which however does not contain coal and can be considered to be an aquitard. Accordingly, impacts are considered to most likely propagate towards the springs through drawdown in the most transmissive formations i.e. the Hutton and Precipice Sandstones and not via direct propagation through the Birkhead/WCM. As such, the monitoring of the Precipice and Hutton Formations is considered to be appropriate for the springs considered, and will provide sufficient early warning of impact.

Nevertheless, lateral propagation of drawdown in the Birkhead Formation will be from tenures targeting the WCM. On-tenure monitoring of the WCM as required under the Surat UWIR, will provide adequate early warning of any horizontal propagation in the Birkhead Formation.

It is proposed that the conceptual model for spring impact will be reviewed at the end of the installation of the currently proposed monitoring program described in this report, and the requirement for dedicated Birkhead monitoring bores to be included in the EWS network will be assessed at that time.

The Clematis Sandstone is a primary source aquifer east of Arcadia Valley where it outcrops on the flanks of the Arcadia Valley.

All groundwater monitoring in relation to the EPBC Springs will therefore be focused on the major GAB source aquifers: the Hutton Sandstone, the Precipice Sandstone and Clematis Sandstone aquifers; unless subsequent assessment determines different source aquifers for the springs (Table 6-4).

Table 6-4: Monitored Aquifers

Basin of CSG Production	Potential Source Aquifer	Proposed Aquifer for Early Warning Monitoring
Bowen Basin CSG Production	Hutton Sandstone	✓
	Boxvale Sandstone (Evergreen Formation)	✗
	Precipice Sandstone	✓
	Clematis Sandstone	✓
Surat Basin CSG Production	Birkhead Formation	✗
	Hutton Sandstone	✓
	Boxvale Sandstone (Evergreen Formation)	✗
	Precipice Sandstone	✓

6.3 EWS Monitoring Strategy Outline

The Proponents has developed an EWS groundwater monitoring network which will provide:

- The tools for the monitoring, analysis and response mechanism to ensure a zero impact to EPBC springs;
- A framework for the application of exceedance levels; and
- The use of a representative periods for data monitoring to establish groundwater hydraulic head and water quality reference values and to normalise outliers.

A regional groundwater monitoring network will be used to provide early warning of potential impact to a spring or spring complex. Two sets of installations are proposed (Figure 6.1):

- An Early Warning Monitoring Installation (EWMI) which will provide an early warning of the impact occurring. These bores will typically be on-tenure and close to the area of CSG water extraction. These early warning bores are located to provide initial drawdown data, and eventually secondary data in support of interpretation of observations made closer to springs. At these locations groundwater level and groundwater quality effects are expected to be more pronounced in terms of the amplitude of the response to CSG water extraction as compared to Trigger Monitoring Points.
- A Trigger Monitoring Point (TMP) located closer to the spring i.e. further away from the CSG production area. For on-tenure springs, the TMPs have been selected within close proximity of the springs.

The network is designed around existing and purpose-built monitoring bores as follows:

- A selection of the monitoring bores required by the Surat UWIR: the installation of these bores has already commenced with ongoing construction being staged over a few years. Monitoring Network Implementation (MNI) reports were submitted to OGIA on 1st February 2013 (Reports on monitoring bore locations subsequently provided to The Department of the Environment);
- A selection of monitoring bores from the Proponents existing or planned monitoring networks;

- Additional purpose built monitoring bores to ensure adequate and appropriate spatial coverage to ensure early warning of potential impacts to EPBC springs.

Monitoring locations are discussed further in Section 7.1.

The benefits of the proposed strategy are that:

- It is a unified strategy among the Proponents that minimises the footprint in terms of intrusive drilling, monitoring bore visits and carbon footprint.
- It ensures that an adequate number of monitoring locations are established
- It makes use of the CIM findings in regard to the amount of drawdown that would result in management action. The CIM is deemed to be the most appropriate assessment of cumulative impacts of CSG production, and will be updated every three years as data from monitoring become available.
- The strategy recognises that it may be difficult to detect far-field drawdown responses which may potentially be very small, and that near-field responses provide an early warning of potential far-field effects.
- Observations made at several of the regional monitoring bores will come to support each other to allow the assessment of regional scale responses to better understand the source of actual drawdown measured in any bores in the monitoring network.

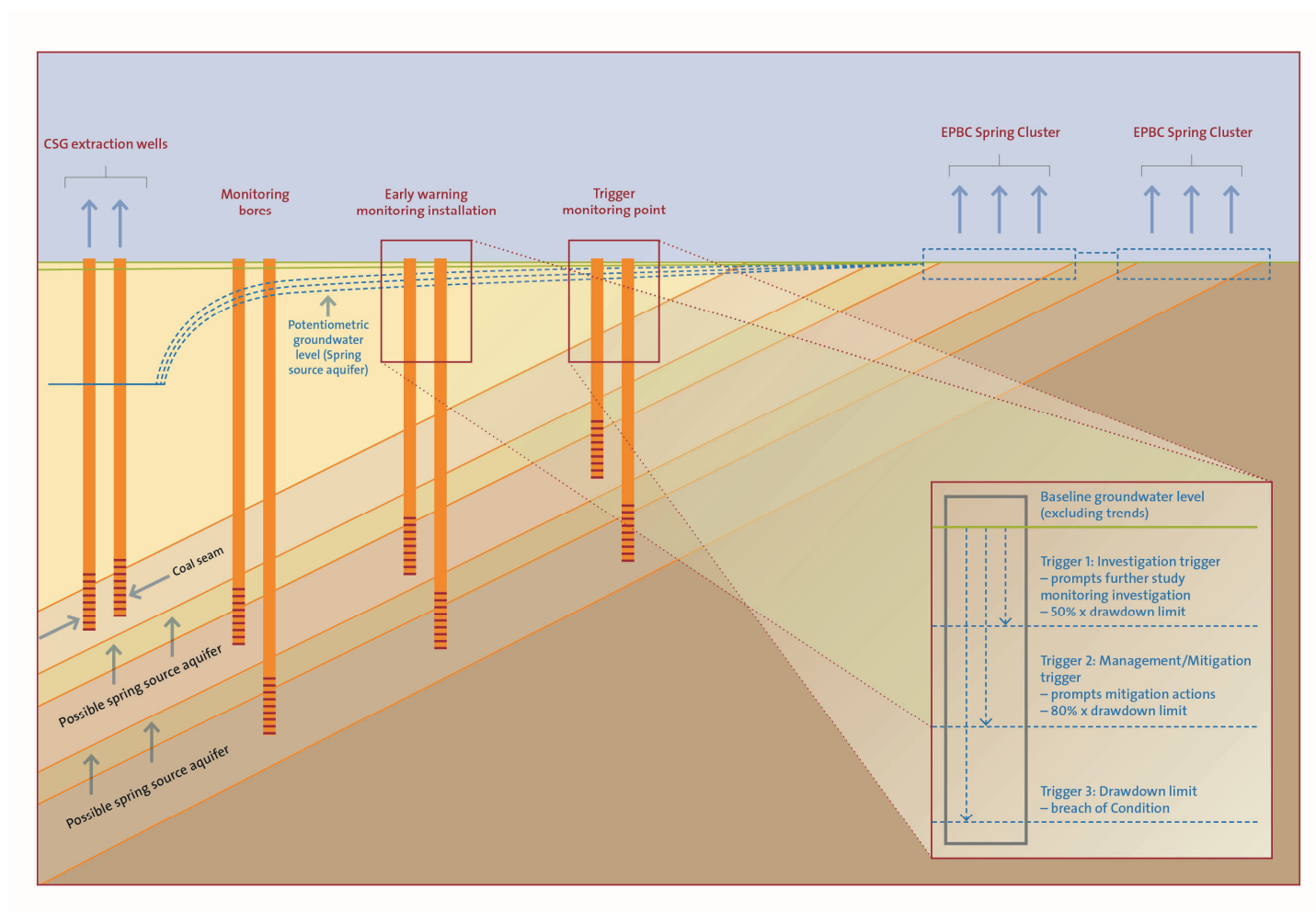


Figure 6-1: Concept of Proposed Early Warning Groundwater Monitoring Scheme for EPBC Springs

7 EWS Groundwater Monitoring Network Implementation

7.1 Monitoring Locations and Responsibilities Finalisation

The JIP EWS monitoring network is provided in APPENDIX A. It provides the location, installation timing and the responsible Proponent for installation and monitoring of the infrastructure. As discussed in Section 6.2, the monitoring network is designed to monitor the primary aquifer source and does not include the monitoring of the Boxxvale Sandstone, the Birkhead Formation or the Walloon Coal Measures. For each of the monitoring bores of the JIP EWS, exceedance levels and drawdown limits will be defined (Section 8).

Location maps are presented in APPENDIX A.

In addition to the above EWS network, the Proponents will also be monitoring the drawdown in the source coal beds, notably the WCMs and the Bandanna Formations. Those monitoring locations are also provided in Appendix A. No triggers will be applicable to the WCMs and to the Bandanna Formation. The Walloon Coal Measures has not been identified by the QWC as a primary connected source aquifer for MNES springs which lie outside the approved project areas (Surat UWIR, QWC, 2012). Accordingly, the Proponents do not propose to have a default drawdown limit or trigger for the Walloon Coal Measures aimed at the protection of MNES springs.

In line with Condition 48 and the fact that the WCM is not a primary source aquifer, the industry believes it is contrary to the EPBC Approvals to set a drawdown limit for the WCM to trigger response action for the protection of the EPBC listed springs.

However, the Proponents will monitor formation pressures in the Bandanna Formation and WCMs through the use of vibrating wire piezometers (VWP). These VWPs combined with the on tenement nested monitoring bores will provide accurate data to monitor the actual drawdown propagation and to calibrate (regional) modelling.

In addition to the WCMs and Bandanna Formations, the Proponents are also monitoring a much larger network of bores targeting the major aquifers and other formations across the southern Bowen Basin and the Surat Basin (APPENDIX A), with the objectives of:

- Acquiring a regional groundwater level and quality baseline,
- Monitoring the impact to aquifers resulting from CSG activities,
- Monitoring of changes of condition near groundwater users and environmental receptors (i.e. springs),
- Collecting data to improve and calibrate the groundwater flow models; and
- Collecting data to improve inter-aquifer connectivity knowledge.

7.2 Monitoring Bore Types

There are three primary well types/styles utilised within the Proponents CSG fields that are intended to deliver the required groundwater datasets to the relevant standards. These types and their application are defined further below.

Each of the bores selected by the Proponents are or will be constructed in accordance to the Australian standard *Minimum Construction requirements for Water Bores in Australia, 3rd Edition, 2012*. Where the monitoring bores are drilled through the petroleum reservoirs (Bandanna Formation or Walloon Coal Measures), then the standards defined in the *Petroleum and Gas (Production and Safety) Act 2004* are also applicable and will apply. These standards further increase the level of protections for bore integrity and protection of formations.

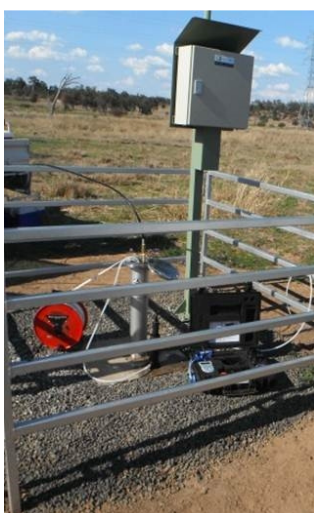
7.2.1 Standard single aquifer monitoring bores

There are a number of open standpipe bores across the Proponent's tenements. "Open standpipe" means the bore is screened across the target aquifer and is completed with some form of fitted cap (typically lockable) that is easily opened or lifted off by hand. No valves or forms of mechanical closure are fitted to the wellhead. Examples of open standpipe are presented in Figure 7-1. This is the standard single aquifer/formation monitoring bore completion in use throughout Australia.

Figure 7-1: Standard single aquifer monitoring bores



Condamine PS MW



Santos Monitoring bore



Boxgrove North BXGGWM02

These monitoring bores are drilled to access a single formation/aquifer, with formations above and below isolated from the target aquifer via annular grouting. This bore style is typically installed in formations above the WCMs (i.e. Gubberamunda Sandstone, Westbourne Formation, Springbok Sandstone) or the Bandanna Formation (i.e. Precipice Sandstone and Hutton Sandstone in the Bowen Basin). These bores may be constructed in a wide variety of diameters depending on use (50 mm to 150 mm), and typically utilise uPVC casing. For deeper bores or bores operating within aggressive environments mild or stainless steel casing is also commonly used.

7.2.2 P&G Act Monitoring Bores

Drilling of monitoring bores in proximity to the target reservoir or penetrating the gas reservoirs requires well control and well construction standards which differ from normal groundwater

bores. The P&G Act monitoring bores (or bores constructed using oilfield technology) completed to date have been drilled considering best practice in safety, with the use of blowout preventers, multiple casing strings, and a completion which ensures no fugitive gas emissions.

In particular, the bores are designed to comply with the “two barrier” industry standard, where the first barrier to gas migration is the cemented casing and the second barrier is the wellhead. Accordingly, as these monitoring bores have been drilled under the P&G Act, the construction and completion is somewhat different to the open standpipe format (standard monitoring bore format). Examples of P&G Act completions at wellhead are presented in Figure 7-2.

Figure 7-2: P&G Act Monitoring Bores



As with the standard “open standpipe” style these wells are wells drilled to access a single formation/aquifer, with formations above and below isolated from the target aquifer.

7.2.3 Private Bores or Water Act Bores

A number of private bores are equipped with water level sensors and telemetry. Some of these bores will be used as part of the EWS. The bores are selected for their location and the aquifer they are targeting. The bores included in the EWS network are confirmed to be in the selected aquifer through assessment methods ranging from confirmation of the bore construction from the drilling and installation records, from water quality analysis or to confirmation through downhole bore survey.

The bores are in most cases only intermittently active, allowing for full recovery and significant period of representative ‘static’ water levels. The recorded information provides not only water level data (after recovery for active bores) but also information on the aquifer response to stress and recovery in active bores.

Data from these bores will be filtered before analysis to retain the representative data.

Figure 7-3: Private Bores Equipped with Telemetry



7.3 Installation Timing & Baseline Collection

The proposed groundwater monitoring network is already partly in place. The proponents commit to complete the remaining monitoring bores installations by end of 2016 as per the schedule provided in APPENDIX A and reproduced in Table 7-1. This commitment is assuming land access agreements do not impede the installation schedule. Should land access prevent the timely installation of the EWS monitoring bores, alternative locations or timing will be discussed with The Department of the Environment.

The proposed strategy recognises that impact to springs is not expected to be observed for a number of years after the start of production (Section 6.1). Table 7-1 provides the length of time for baseline data acquisition between the planned installation date of a bore and time where impacts from CSG extraction activities are predicted to affect the aquifer at the bore.

The Proponents monitoring network installation is currently being implemented. Ongoing installations will be prioritised starting with bores closer to the source of potential drawdown with the target of having all bores installed by end of 2016.

The maximum likelihood of observing a drawdown in a source aquifer before the end of 2017 is 5% (Table 6-1). This will potentially affect the Lucky Last EPBC springs (Lucky Last), and this is not predicted to occur before 2017. For the Lucky Last spring complex, a number of monitoring bores are already in operation, most of the network will be in place by end of 2013 (Table 7-1) with the final monitoring network in place by end of 2015.

A number of monitoring bores are currently in place on the Proponents' tenements and will support the data collected in new bores.

Also, it should be noted that during the early stages of CSG development (from the present to approximately 2020), the producing well fields will not occupy the full extent of the production tenements.

Drilling and installation of the regional monitoring network has already commenced. Prioritisation of these bores and dedicated EWS monitoring bore installation are scheduled to enable the early acquisition of baseline data at locations closer to early CSG development zones. It should be noted however, that for some monitoring bores, the recommended date of completion of installation required by the UWIR may not be achievable for the following reasons:

- The bores to be completed are on average 500 to 600 m deeper than the production wells targeting the CSG reservoirs, Drilling at those depths requires very specific equipment which most petroleum rigs typically do not offer, thus significantly limiting the number of drilling rigs with the appropriate depth capacity;
- In order to limit land disturbance, the drilling program will use a planned or existing CSG well drilling pad wherever possible; and
- Land access processes require approximately 40 weeks for new on-tenure locations. Access to off-tenure land is significantly more complex and is likely to take significantly longer. This may render difficult the installation of off-tenure monitoring bores. The Proponents are seeking an arrangement with the Queensland government to install off-tenure bores on their behalf.

As a result, the Proponents will install the monitoring network in stages. In the first stage, the monitoring bores located on-tenements and nearest to the impact zone will be installed, in the next stages the other monitoring bores will be installed.

Table 7-1: JIP EWS Timing of Installation and Length of Baseline Collection

JIP bore ID	Monitoring Target	EPBC Spring Objective	Installation Year	Year of first predicted P95 drawdown (0.01 m)	Length of time for baseline acquisition
Spring Gully PB5	Precipice	Abyss & Lucky Last	2015	2008	None, some data available from June 2007 to April 2009 for PB2 (Precipice) before decommissioning.
Spring Gully --PB2	Hutton	Abyss	2015	2041	26 years
Spring Gully --PB1	Precipice	Abyss, Lucky Last	In place	2003	Monitoring commenced in 2007. Data to date shows increase in water level
RN48912	Hutton	Abyss	2013	2061	48 years
Contact Zone	Precipice	Abyss & Lucky Last	2014	2002	Located a few kilometres south of VWP0902 (also in the Contact Zone) for which records are available since December 2009
QWC129	Hutton	Abyss	2014	2105	92 years
QWC129	Precipice	Abyss & Lucky Last	2014	2005	None at this location. Monitoring has started in early 2013 in a Precipice private bore (OK station) nearby to this location
MW0905	Precipice	Abyss & Lucky Last	2015	NA	Location recently selected, Model output data not available for this location, however VW0903-P2 located nearby is monitored since 2009 and does not display any WL changes.
Cassio_GW1	Hutton	Dawson River 8, Boggomoss, Dawson River 2, Dawson River 6 & Prices	2013	2019	6 years
Cassio_GW2	Precipice	Boggomoss, Dawson River 2, Dawson River 6 & Prices	2013	2155	100+ years
Coochiemudlo_GW1	Hutton	Dawson River 8, Boggomoss, Dawson River 2, Dawson River 6 & Prices	2013	2024	11 years
Coochiemudlo_GW2	Precipice	Boggomoss, Dawson River 2, Dawson River 6 & Prices	2013	2275	200+ years
Peat MB2-P	Precipice	Cockatoo Creek	2014	2009	The model does not predict any impact greater than 0.1 m for that location
Peat MB3-H	Hutton	Cockatoo Creek	2014	2007	None, impact of 0.1 m not predicted to occur prior to 2037
Scotia OBS#1	Precipice	Cockatoo Creek	In place	NA	Water quality bore only, WL at AVLWVP
RN23147	Hutton	Cockatoo Creek	In place	NA	Water quality bore only, WL at AVLWVP
AVLVWP	Hutton and Precipice (WL)	Cockatoo Creek	In place (2012)	2007 2016	none, impact of 0.1 m not predicted to occur prior to 2040 4 years

JIP bore ID	Monitoring Target	EPBC Spring Objective	Installation Year	Year of first predicted P95 drawdown (0.01 m)	Length of time for baseline acquisition
Charlotte_GW1	Hutton	Dawson River 8, Dawson River 2, Dawson River 6, Prices, Boggomoss	2013	2019	6 years
Charlotte_GW2	Precipice	Dawson River 2, Dawson River 6, Prices, Boggomoss	2013	2040	27 years
Kinnoul-MB2-H	Hutton	Dawson River 8	2015	2024	9 years
EWM17	Clematis	Elgin 2	2015	NA	No drawdown predicted
RN38333	Hutton	Scotts Creek	In place	2017	4 years
WB1-P	Precipice	Scotts Creek	In place	2017	4 years
RN14881	Hutton	Scotts Creek	In place	2022	9 years
MB4-H	Hutton	Scotts Creek	2013	2037	24 years
RN48978	Hutton	Scotts Creek	In place	2022	9 years
QWC104	Hutton	Yebna 2	2014	2032	19 years
QWC104	Precipice	Yebna 2	2013	2013	NA, however 23 years of data before potential impact to the spring
MW0902	Precipice	Yebna 2	In place	2021	Over 8 years
Charlie_GW1	Hutton	Dawson River 8, Scott's Creek	2013	2018	5 years

At this stage there are no immediate plans to drill monitoring bores for the purpose of the EWS groundwater monitoring bore network into the Birkhead Formation (see Section 6.2). The need for installation of bores within the Birkhead Formation will be reassessed in the light of hydrogeological information collected from the earlier bores, and should future iterations of the CIM indicate an increased risk to the springs and need for further monitoring of the Birkhead Formation. The need for further monitoring bores to be installed at Elgin 2 will be further assessed following the acquisition of baseline monitoring data of the springs and the development of the conceptual hydrogeological models.

The Proponents aim to complete all installations by the end of 2016. The proposed timing is assuming no delay in the establishment of land access agreements, environmental constraints and the suitability of land access. Where the location of a new bore is likely to change from locations provided in this JIP significantly (more than 5 km for bores for off-tenure springs bores and more than 1 km for bores for on-tenure springs) or when the installation of a bore cannot be completed by the dates provided in Table 7-1, the responsible proponent would seek The Department of the Environment approval for the proposed changes.

As noted above, several locations may not be accessible to Proponents within the required timeframe due to landowner access constraints, but may be accessible to a government agency. If accessible to an agency, Proponents will enter negotiations with that agency to fund construction of the monitoring bore and monitoring costs.

7.4 Groundwater Monitoring

7.4.1 Groundwater Level Monitoring

Groundwater level monitoring will be automated in the monitoring bores. Telemetry is to be used on all bores to provide the data to the Proponents, where telemetry cannot be used, the water level loggers will be downloaded every three months as a minimum. The loggers installed will record a daily value, however data may be presented as a weekly average value for ease of data handling.

To ensure the accuracy in data collected by the water pressure loggers, wherever possible at a minimum every six month simultaneously with water bore sampling, groundwater level will be dipped regularly (typically just before a groundwater sampling event) to validate the logged data. Where an equipment drift is observed in the data, data will be corrected with a linear adjustment. Calibration of the instrumentation will be in accordance with manufacturer's recommendations.

7.4.2 Atmospheric Pressure Monitoring

Groundwater pressure readings need to be corrected for atmospheric pressure variations. The proponents already have in place, or plan to install a number of barometric pressure sensors across the extent of the gas fields (Table 7-2). In addition, the Proponents will install barometric pressure sensors at or in close proximity to each spring complex or cluster of spring complexes (for e.g. Lucky Last/Abyss and Boggomoss, Prices and the Dawson River springs). These installations will be augmented with data from Bureau of Meteorology weather stations.

Current installation and scheduled barometric pressure installations are reported in Table 7-2 and illustrated in APPENDIX A.

Table 7-2: Atmospheric Pressure Monitoring Locations

Station Name	Longitude	Latitude	Installation date	Responsible Proponent
Spring Gully	149.0713	-26.00044	In place	Origin
Reedy Creek	149.4267	-26.35629	In place	Origin
Talinga	150.3703	-26.89299	In place	Origin
Woleebee Creek	149.7024	-26.2809	In place	QGC
Charlie	149.6470	-26.0240	Jul-13	QGC
Cassio	149.7754	-25.9454	Oct-13	QGC
Coochiemudlo	149.9770	-25.7630	Jul-13	QGC
Charlotte	149.5400	-25.9100	Sep-13	QGC
AW1	148.9492	-25.7314	In place	Santos
AW2	149.0503	-25.7601	In place	Santos
AW3	148.9621	-25.6469	In place	Santos

7.4.3 Groundwater Quality Monitoring

Long term groundwater quality sampling will be undertaken in all bores constituting the EWS on a six-monthly basis

The range of parameters for establishing groundwater baseline is summarised in Table 7-3. The baseline period is defined as 3.5 years. This is based on a statistical evaluation of monitoring data (Santos, 2012) which recommends that seven samples taken every six month over 3.5 years are necessary to meet a 95% confidence and establish a baseline threshold value.

Following the baseline, long term monitoring will consist of a reduced suite of indicator parameters, to be determined following the baseline sampling campaign, but will include as a minimum physio-chemical parameters, dissolved metals and major ions.

Table 7-3: Groundwater Baseline Water Quality

Parameter	F/L ¹	Parameter	F/L ¹	Parameter	F/L ¹
Physio-chemical					
Dissolved oxygen	F	pH	F, L	Total dissolved solids	L
Electrical conductivity	F, L	Redox (Eh)	F	Total suspended solids	L
Free gas (4 gas meter incl CH ₄)	F	Temperature	F	Turbidity	F
Major ions					
Bicarbonate (as CaCO ₃)	L	Hydroxide (as CaCO ₃)	L	Sulphate	L
Calcium	L	Magnesium	L	Total Alkalinity (as CaCO ₃)	L
Carbonate (as CaCO ₃)	L	Potassium	L	Total Hardness (as CaCO ₃)	L
Chloride	L	Sodium	L		
Dissolved and total metals					
Aluminium	L	Copper	L	Selenium	L
Arsenic	L	Iron	L	Silica	L
Barium	L	Lead	L	Strontium	L
Beryllium	L	Lithium	L	Uranium	L
Boron	L	Manganese	L	Vanadium	L
Cadmium	L	Mercury	L	Zinc	L
Chromium	L	Molybdenum	L		
Cobalt	L	Nickel	L		
Nutrients					
Total Nitrogen as N (including NO _x & TKN)	L	Total Phosphorus as P	L	Nitrite	L
Dissolved sulphide	L	Nitrate	L	Total Kjeldahl Nitrogen	L
Minor elements					
Fluoride	L	Bromide	L	Iodide	L
Carbon					
Total Organic Carbon	L	Dissolved Inorganic Carbon	L	Dissolved Organic Carbon	L
Organics					
Total Petroleum Hydrocarbons	L	Polycyclic Aromatic Hydrocarbons	L	Volatile Organic Compounds	L
Benzene, Toluene, Ethylbenzene, Xylene	L	Phenols (standard LOR and suite)	L		
Dissolved Gases					
Free and total Carbon dioxide	L	C1-C4 (incl methane, ethylene and other gases)	L	Unionised Hydrogen sulphide	L
Isotopes(only in initial sampling)					
Deuterium H-2	L	Oxygen-18	L	Radiogenic Carbon-14	L
Strontium-87/Strontium-86	L	d-Carbon-13 (DIC)	L		

Notes: The minimum suite of analytes for ongoing monitoring is outlined. This suite is the same as the spring baseline suite.

F: Field-based measurements. L: Laboratory-based measurements

Long-term monitoring of water quality will establish the baseline groundwater quality against which changes or deviations can be compared.

To ensure consistency of groundwater monitoring through this EWS, the Proponents have developed a *Quality Plan*(APPENDIX B) which contains:

- The field procedures for groundwater sampling;
- The field quality assurance, quality control (QA/QC) requirements;
- Data management processes; and
- Data control processes.

All groundwater quality samples will be collected in accordance with the Quality Plan.

8 EWS Levels of Exceedances Levels for Groundwater Monitoring

8.1 Definitions

The Proponents individual approval conditions require the definition of three levels of exceedances: an *Early Warning Trigger Value*, an *Exceedance Threshold*; and a *Drawdown Limit*. A more intuitive terminology, as discussed with The Department of the Environment in Canberra on 22 March and as already provided in Section 6.1.3, is proposed below (see Table 8-1) and is used throughout the JIP.

Table 8-1: Definition of Exceedance Criteria

Adopted Terminology	Approval Condition Terminology
Investigation Trigger	A nominated value at an EWMI and TMP that triggers some action such as data review, model review, increased monitoring frequency, increased monitoring parameters. For groundwater pressure, this is equivalent to ‘early warning indicator’ referred to in Condition 49)d.
Management / Mitigation Trigger	A nominated value at a TMP that triggers some action to be taken to prevent an impact occurring at an EPBC spring (i.e. a mitigation activity). For groundwater pressure, this is equivalent to ‘drawdown threshold’ referred to in Condition 49)d
Drawdown Limit	A nominated value at a TMP that, if exceeded, would result in a breach of the Commonwealth Approval Conditions should drawdown exceed this value (see Condition 49 a). This value corresponds to greater than 0.2 m modelled impact at an EPBC Spring.

The criteria apply to either groundwater pressure alone or groundwater pressure and groundwater quality:

- Investigation trigger – applying to groundwater pressure and water quality
- Management / mitigation trigger – applying to groundwater pressure
- Drawdown Limit – applying to groundwater pressure.

The regional groundwater model developed for the Surat UWIR to examine the cumulative impact of CSG water extraction represents the most areally extensive impact assessment in terms of regional groundwater impact, and the only existing model that considers the cumulative impact of CSG extraction by all the Proponents. Accordingly, the groundwater level drawdown predicted by the CIM will be used to determine a prediction of the drawdown at each of the EWS regional monitoring bores.

A differentiation in approach is necessary between EPBC springs located off-tenements and on-tenements, as the approach for the off-tenements springs and initially agreed to by the Proponents relied on a percentile of the P95 drawdown. This resulted in predicted drawdowns for the on-tenement EPBC springs and associated EWS network being in the order of millimetres which is within measurement error for all monitoring instrumentation. Accordingly, separate groundwater pressure exceedance levels have been defined for both on and off tenement springs in the following sections.

Note that timing provided by this approach to develop and implement any necessary mitigation is provided in Section 9.

8.2 Groundwater level drawdown exceedance criteria –Off-tenement Springs

The time-drawdown data used will initially be the P95 predictions from the current CIM outputs, however this may be modified based on the revised predictions of future iterations of the Surat Basin model (as defined in Section 1). The JIP currently uses the outputs of model version 1.2 (refer to Section 0).

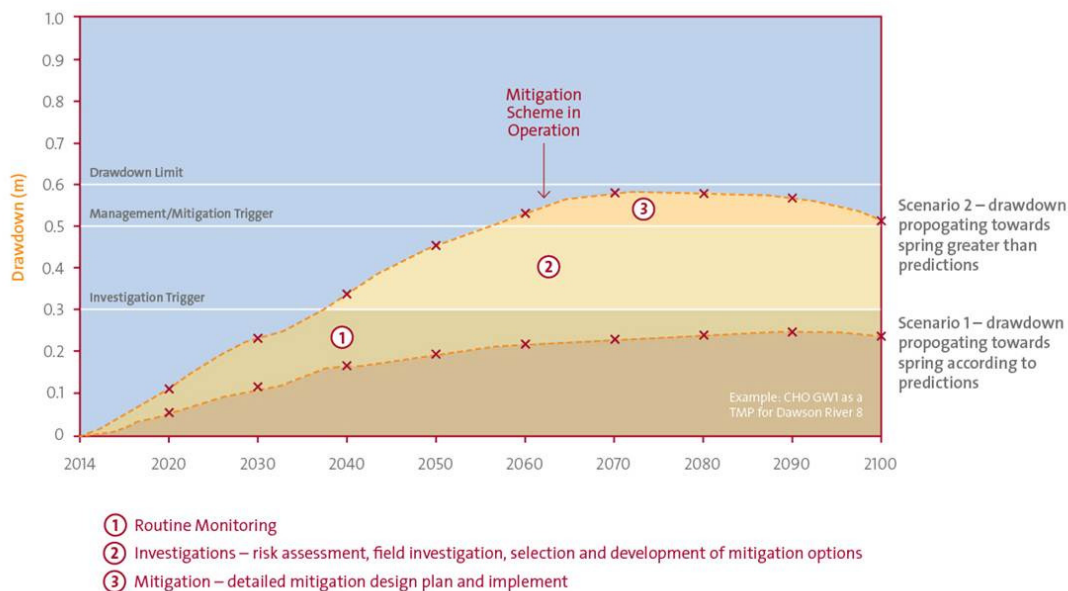
To assess the potential impact of CSG activities, estimated natural and anthropogenic (non-CSG) effects will be removed from the measured monitoring data. If a trigger or threshold is exceeded for a period exceeding three months, a response will be initiated.

The Proponent's approach is as follows:

Case 1: General case (Figure 8-1)

- The drawdown limit is set as the P95 drawdown in an EWS monitoring bore corresponding to the last time period in the model corresponding to zero metres drawdown at the spring. It is defined for TMPs only.
- The investigation trigger value is set at 50% of the drawdown limit for that EWS bore; and
- The management/mitigation trigger is set at 80% of the drawdown limit for that EWS bore.

Figure 8-1: Schematic of Groundwater Pressure Exceedance Response for off-Tenement Springs



Case 2: No drawdown predicted at spring

Where no drawdown is predicted at the spring by the CIM, the maximum P95 drawdown value at an EWS monitoring bore is used:

- The investigation trigger value is set at 50% of the maximum P95 drawdown value ;
- The management/mitigation trigger value is set at 80% of the maximum P95 drawdown value ; and
- The drawdown limit is set at the maximum P95 drawdown value .

Case 3: No drawdown predicted at spring and at the TMP

Where no drawdown is predicted at the spring by the CIM and no measurable drawdown is predicted at a TMP, the drawdown limit is set at 0.2 m, investigation triggers and management /mitigation triggers are set as the percentile of the drawdown limit:

- The investigation trigger value is set at 50% of the drawdown limit, i.e. at 0.1 m;
- The management/mitigation trigger is set at 80% of drawdown limit, i.e. at 0.16 m; and
- The drawdown limit is set at 0.2 m

Off-tenement springs triggers and drawdown limits values are provided in Table 8-2. Further notes and examples of plots of predicted drawdown are available in APPENDIX C. Data model predicted drawdown can be found in the Proponents individual CWMMP for those bores assigned to them.

Table 8-2: Applicable triggers and drawdown limits for off-tenement springs

Spring Complex	Interpreted source aquifer	Impact Propagation Pathway	Type of bore	EWS nominated monitoring bores – Target Aquifer	Investigation Trigger	Mitigation/ management Trigger	Drawdown Limit
Dawson River 8	Hutton Sandstone	Impact from CSG production in WCM propagating to the Hutton Sandstone, lateral propagation to springs. No impact propagating through the Precipice Sandstone	EWMI	Cassio GW1 –Hutton	0.5 m	0.8 m	NA
			EWMI	Charlie GW1 – Hutton	0.5 m	0.8 m	NA
			EWMI	Charlotte GW1 –Hutton	1.0 m	1.6 m	NA
			TMP	Kinnoul-MB2-H – Hutton (GA005)	0.40 m	0.64 m	0.80 m
			TMP	Coochiemudlo GW1 (CHAR)-Hutton	0.3 m	0.5 m	0.6 m
Cockatoo Creek	Precipice Sandstone	Impact from WCM propagating through the Hutton Sandstone and Evergreen Formation and lateral propagation to springs and potential gas production in Permian Coal propagating through the Precipice Sandstone.	EWMI	Peat-MB2-P (QWC128) – Precipice	0.2m	0.2 m	NA
			EWMI	Peat-MB3-H (QWC128) – Hutton	0.4 m	0.64 m	NA
			TMP	AVLVWP (GA004) –Hutton	0.25 m	0.4 m	0.5 m
			TMP	AVLVWP (GA004) –Precipice	0.10 m	0.16 m	0.20 m
Dawson River 6, Dawson River 2, Boggomoss, Prices	Precipice Sandstone	Impact from WCM propagating through the Hutton Sandstone and Evergreen Formation and lateral propagation to springs and potential gas production in Permian Coal propagating through the Precipice Sandstone.	EWMI	Cassio GW1 - Hutton	0.5 m	0.8 m	NA
			EWMI	Cassio GW2 (CAS)-Precipice ⁽¹⁾	0.5 m	0.8 m	NA
			EWMI	Charlotte GW2 (CHR)-Precipice	0.1 m	0.16 m	NA
			TMP	Coochiemudlo GW1 (CHAR) – Hutton	0.3 m	0.5 m	0.6 m
			EWMI	Charlotte GW1 (CHR)-Hutton	1.0 m	1.6 m	NA
			TMP	Coochiemudlo GW2 (CHAR)-Precipice	0.10 m	0.16 m	0.20 m

Spring Complex	Interpreted source aquifer	Impact Propagation Pathway	Type of bore	EWS nominated monitoring bores – Target Aquifer	Investigation Trigger	Mitigation/management Trigger	Drawdown Limit
Elgin 2 ⁽²⁾	Clematis Sandstone	Impact from propagation of drawdown in the Bandanna Formation through the Rewan Formation	EWMI	EWMI7 –Clematis	0.10 m	0.16 m	NA

Notes:

Dates at which triggers are expected to be reached are provided and discussed in Section 9.

(1) Default values – number to be updated following results of UWIR modelling

(2) For the Elgin 2 spring complex, only one EWMI has been defined for the monitoring of the Clematis Sandstone. The risk of impact to the Clematis Sandstone near Elgin 2 spring complex is very low, in addition the springs are sourced from the Clematis Sandstone which are separated from the Bandanna Formation coal seam by the Rewan Formation which in the Arcadia Valley region is very thick and has a very low vertical conductivity.

8.3 Groundwater Level Drawdown Exceedance Criteria–On-tenement Springs

The approach proposed above for monitoring off-tenement springs is not applicable for on-tenements springs and associated EWMIs and TMPs for the following reasons:

- The springs being located on-tenements are therefore much closer to the source of drawdown. Using the percentile of the P95 predicted drawdown at a TMP or EWMI would result in a zero drawdown at a spring, would result in assigning exceedance values in the order of millimetres. This is technically not possible to monitor.
- The model predictions indicate that impacts to the TMPs and EWMIs monitoring bores and impact to the spring complex are observed with a much shorter time delay (based on P95 drawdown predictions) than for off-tenement springs, thus the system does not allow for a simplified early warning system of the same nature as for off-tenure early warning.
- The ‘zero drawdown’ approach should be recognised as a proxy for zero impact to the end receptor, being the ecology supported by the EPBC springs. Accordingly, where the above conditions occur, an approach that is more focussed on the true risk to the EPBC species seems appropriate.

Investigations and mitigation triggers are defined at EWMIs and TMPs. The EWMIs and TMPs are located between the source of impact and the spring. As opposed to the approach for off-tenements springs, the trigger levels are based on the model P50 and P95 drawdown predictions.

The proposed approach defines exceedance levels and response for EWMIs and TMPs for on-tenement springs as follows:

At an EWMI for on-tenement springs:

At an EWMI, the P50 drawdown will be the Investigation Trigger, whereas, the P95 trigger will be the Mitigation/Management Trigger. The triggers will be implemented as shown on Figure 8-2.

At a TMP for on-tenement springs:

Drawdown limits are defined at TMPs only. TMP locations are nominated monitoring bores for each on tenement EPBC spring complex informing on groundwater pressure in the spring primary source aquifer. They are located close to the springs (typically less than 5 km) and act as a proxy to assessing the monitoring of the source aquifer pressure at the spring. The Drawdown Limit is defined as a 0.2 m drawdown at the TMP (exclusive of natural and non-CSG anthropogenic effects) and an exceedance of the drawdown limit will correspond to a breach of the Proponent’s Project approval conditions. An early warning system similar to that used at EWMIs for on-tenement springs will be implemented as shown on Figure 8-2.

A few examples in APPENDIX C illustrate the use of this approach at selected bores of the EWS monitoring network. Data model predicted drawdown can be found in the Proponents individual CWMMP for those bores assigned to them.

Figure 8-2: Schematic of Groundwater Pressure Exceedance Response for on-Tenements Springs

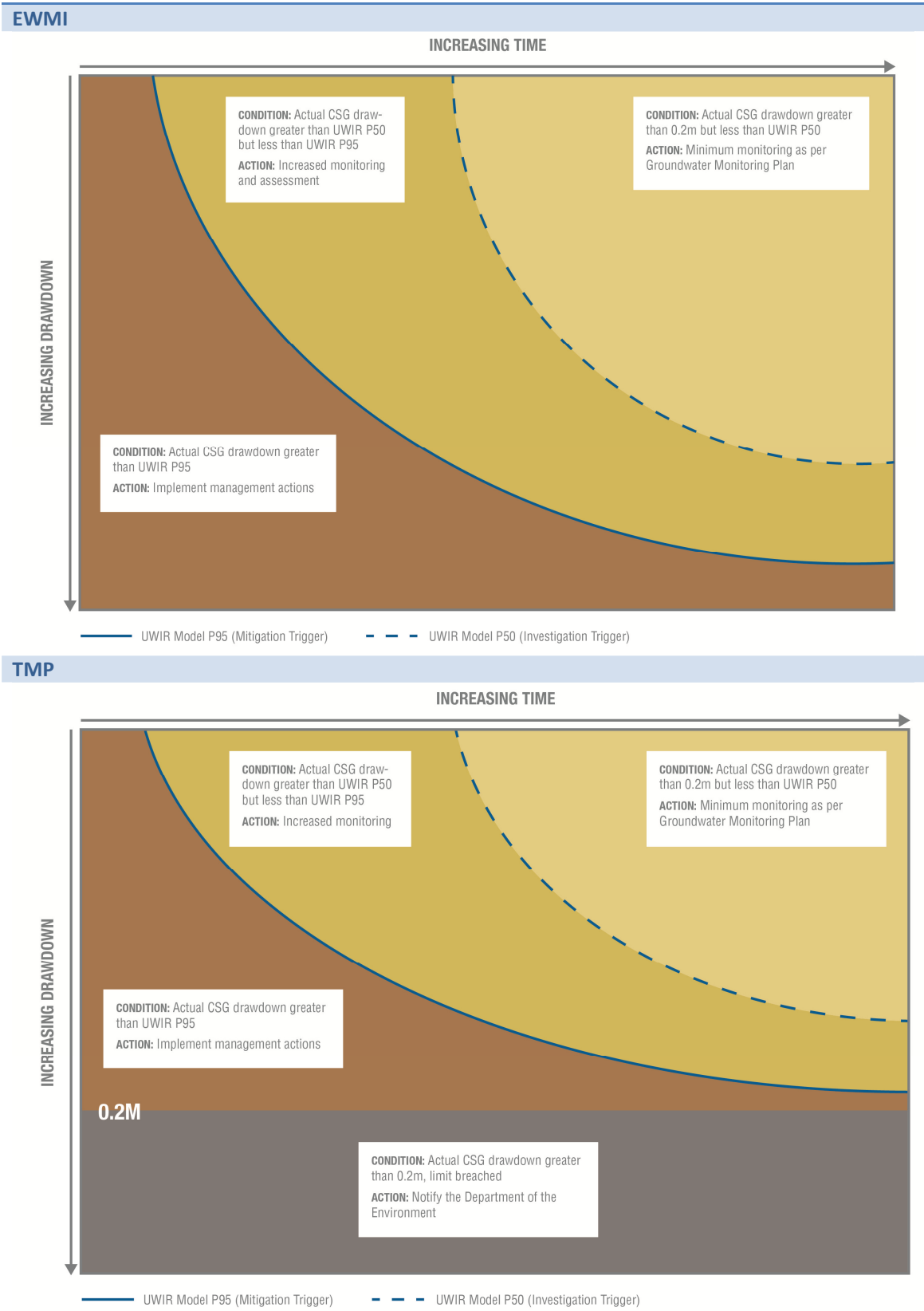


Table 8-3: Applicable triggers and drawdown limits for on-tenement springs

Spring Complex	Interpreted source aquifer	Impact Propagation Pathway	Type of bore	EWS nominated monitoring bores – Target Aquifer	Investigation Trigger	Mitigation/ management Trigger	Drawdown Limit
Scotts Creek	Hutton Sandstone	Impact from WCM to the South East propagating to the Hutton Sandstone	EWMI	Charlotte GW1 –Hutton	UWIR P50	UWIR P95	NA
		Impact from WCM to the South East propagating to the Hutton Sandstone	EWMI	Charlie GW1 –Hutton	UWIR P50	UWIR P95	NA
		Impact from WCM to the South East propagating to the Hutton Sandstone	EWMI	RN48978 (Lagoon Paddock)–Hutton	UWIR P50	UWIR P95	NA
		Impact from WCM to the South East propagating to the Hutton Sandstone	EWMI	Strathblance-WB1-P - Precipice	UWIR P50	UWIR P95	NA
			TMP	RN38333 – Hutton	UWIR P50	UWIR P95	0.2 m
		Impact from WCM to the South East propagating to the Hutton Sandstone	TMP	RN14881 – Hutton	UWIR P50	UWIR P95	0.2 m
			EWMI	Spring Gully MB16-P - Precipice	UWIR P50	UWIR P95	NA
			EWMI	Spring Gully MB17-H - Hutton	UWIR P50	UWIR P95	NA
			EWMI	Spring Gully PB3– Precipice	UWIR P50	UWIR P95	NA
			EWMI	MB4H - Hutton	UWIR P50	UWIR P95	NA
			EWMI	QWC104 –Hutton	UWIR P50	UWIR P95	NA
Yebna 2	Precipice Sandstone, Evergreen Formation	Impact from WCM to the South East propagating to the Hutton Sandstone and then to the Precipice Sandstone through the	EWMI	QWC104 –Precipice	UWIR P50	UWIR P95	NA
			EWMI	QWC104 –Precipice	UWIR P50	UWIR P95	NA

Spring Complex	Interpreted source aquifer	Impact Propagation Pathway	Type of bore	EWS nominated monitoring bores – Target Aquifer	Investigation Trigger	Mitigation/ management Trigger	Drawdown Limit
Abyss	Hutton Sandstone	Evergreen Formation					
		Impact from Bandanna Formation extractions propagating through the Precipice from the Spring Gully fields to the SW	TMP	MW0902 –Precipice	UWIR P50	UWIR P95	0.2 m
		Impact from WCM to the South East propagating to the Hutton Sandstone	EWMI	Spring Gully PB5 – Precipice	UWIR P50	UWIR P95	NA
			EWMI	Spring Gully PB2 – Hutton	UWIR P50	UWIR P95	NA
		Impact from Bandanna formation drawdown at Spring Gully propagating laterally through the Precipice Sandstone, vertical propagation from the Bandanna Formation CSG production at the Contact zone area	EWMI	Spring Gully PB1 – Precipice	UWIR P50	UWIR P95	NA
			EWMI	RN48912 (Spring Gully PB1) –Hutton	UWIR P50	UWIR P95	NA
			EWMI	Contact Zone –Precipice	UWIR P50	UWIR P95	NA
		Impact propagating vertically through the Contact Zone and laterally from the Fairview and Spring Gully fields	EWMI	MW0905 - Precipice	UWIR P50	UWIR P95	NA
			EWMI	QWC129 –Precipice	UWIR P50	UWIR P95	NA
			TMP	QWC129 –Hutton	UWIR P50NA	UWIR P95NA	0.2 m
		Impact propagating vertically through the Contact Zone and laterally from the Fairview and Spring Gully fields	EWMI	Contact Zone –Precipice	UWIR P50	UWIR P95	NA
			EWMIE WMI	MW0905 - Precipice	UWIR P50	UWIR P95	NA
			EWMI	Spring Gully PB5 – Precipice	UWIR P50	UWIR P95	NA
			TMP	QWC129 –Precipice	UWIR P50NA	UWIR P95NA	0.2 m

Notes:

Dates at which triggers are expected to be reached are provided and discussed in Section 9.

Further notes and example plots of predicted drawdown are available in APPENDIX C.

8.4 Updates of Trigger Level Values

The investigation trigger, management/mitigation trigger and drawdown limit are developed using the current CIM predictions. Those values may require updates to account for:

- The outcome of the update of the CIM as part of UWIR updates;
- The outcome of the interconnectivity studies;
- Mitigation options assessment work through the EPMORs required under the UWIR for the Lucky Last, Scotts Creek and Yebna 2 spring complexes; and
- Update to the Proponents' projects development plans and controls.

Reviews of the Surat CIM will possibly result in a review of the triggers and drawdown value as defined in Section 1. As a minimum, updates are expected to be required every three years to reflect the update of the CIM and Surat UWIR.

8.5 Groundwater Quality Investigation Trigger Values

Investigation trigger values for groundwater quality will be established after baseline is defined. No management/mitigation and drawdown limits will be defined. A groundwater quality baseline will be established over a minimum of seven sampling events on a six monthly basis (i.e. over a period of three and a half year).

An exceedance of a groundwater quality trigger values will trigger review and further evaluation to enable risk management such as confirmation of the exceedance and analysis of collected results jointly with groundwater pressure data. However, as any impact at the monitoring bore would be first observed in the pressure data, no management/mitigation triggers based on water quality is considered appropriate.

8.6 Definition of Reference Values

Reference values are necessary to enable a quantitative estimation of variation in water level or water quality value at a certain time.

Reference values will be calculated based on baseline data. The methodology for determining the reference value is given herein. Reference values for each bore of the EWS network will be defined within six month of completion of groundwater baseline. The values will be made available over time Proponents' individual CWMMP.

The baseline period for groundwater levels is defined as a minimum of one year of data. The baseline period for groundwater chemistry is defined as the collection of seven sampling events on a six-month basis, and will therefore last 3.5 years.

Reference values for water levels at EWS monitoring bores will be defined within the six months following the acquisition of a minimum one year of water level data. Reference values for groundwater quality will be defined within six months of the end of baseline.

The approach for identifying a baseline value or trend over the baseline period is:

- Collate water level pressure and hydrochemistry data over the baseline period;

- Collate all background information for the site data over the baseline period; of data. The baseline period data etc.,
- Collate DNRM and other CSG company data;
- Carry out a qualitative and quantitative assessment of the data including simple trends and seasonal variability; and
- Apply the trend analysis method if a baseline value is not readily apparent from simple averages or obvious trends. For water quality, baseline values will be defined for relevant analytes only and reference values will be set as a range of lower and upper confidence limit.

The methodology is further discussed in APPENDIX D.

9 Exceedance Response Measures

9.1 Available response time

The EWS is designed to provide sufficient warning time to enable response before impact on EPBC springs occurs. It is important to remind the reader that the EWS and associated timing of response relies on The CIM in its current state: the time between the exceedance of the Mitigation/management trigger and potential impacts at a spring is considered to be the minimum time over which such propagation could occur. Regardless, estimates based on the Surat CMI outputs (version 1.2) have been made of the time available between the investigation trigger, mitigation/management trigger and drawdown limit being reached. These are presented on Table 9-1.

The zero drawdown of groundwater pressure in the source aquifer is a proxy for zero impact at the springs. However, a drop of groundwater pressure at a spring may not necessarily result in any impact or any immediate impact to the spring ecosystem (included to EPBC listed species). The vulnerability of the spring to a decreased groundwater pressure will need to be assessed on a case by case basis (National Water Commission, 2013). This has the potential, on the basis of a site specific vulnerability assessment and in view of the collected monitoring data, to enable update to the “zero drawdown proxy” used. The risk assessment will identify potential updated triggers for management/mitigation.

For on tenements springs, Table 9-1 only provides the predicted year of impact, the approach does not allow to estimate in a similar manner to off-tenement springs the available time length. Mitigation studies have started with spring mitigation options assessment and selection currently being carried out for the Lucky Last, Scott’s Creek and Yebna 2 spring complexes. The studies outcomes have been reported to Queensland Department of Environment and Heritage Protection Early September 2013.

Table 9-1: Response time available for springs management and mitigation

Spring Complex	Main GAB aquifer interpreted to be source aquifer	Type of bore	EWS nominated monitoring bores – Target Aquifer	Investigation Trigger	Mitigation/ management Trigger	Drawdown Limit
Dawson River 8	Hutton Sandstone	EWMI	Charlotte GW1 --Hutton	2027	2030	NA
		TMP	Kinnoul-MB2-H – Hutton	2033	2039	2054
		EWMI	Charlie GW1 – Hutton	2047	2087	NA
Cockatoo Creek	Precipice Sandstone	EWMI	Peat-MB2-P (QWC128) --Precipice	2022	2034	NA
		EWMI	Peat-MB3-P (QWC128) --Hutton	2066	2105	NA
		EWMI	AVLVWP --Hutton	2066	2105	NA
		TMP	AVLVWP --Precipice	Not predicted	Not predicted	Not predicted
Dawson River 6, Dawson River 2, Boggomoss, Prices	Precipice Sandstone	EWMI	Cassio GW1 --Hutton	2037	2082	NA
		EWMI	Coochiemudlo GW1 (CHAR)- Hutton	2032	2041	NA
		EWMI	Charlotte GW1 (CHR)- Hutton	2027	2031	NA
		EWMI	Charlie GW2 --Precipice	2078	2093	NA
		EWMI	Cassio GW2 (CAS)- Precipice	Not predicted	Not predicted	NA
		EWMI	Charlotte GW2 (CHR)- Precipice	2105	2195	NA
		TMP	Coochiemudlo GW2 (CHAR)- Precipice	Not predicted	Not predicted	Not predicted
Elgin 2	Clematis Sandstone	EWMI	EWMI7 --Clematis	Not predicted	Not predicted	Not predicted
Scotts Creek	Hutton Sandstone	TMP	RN38333 --Hutton	Not predicted (EPMOR studies)	NA	Not predicted
		TMP	RN14881 --Hutton	Not predicted (EPMOR studies)	NA	2025
		EWMI	Charlie GW1 – Hutton	2047	2087	NA
Lucky Last	Precipice Sandstone	TMP	QWC129 --Precipice	EPMOR studies	NA	2016
Abyss	Hutton Sandstone	TMP	QWC129 --Hutton	Not predicted	Not predicted	Not predicted
Yebna 2	Precipice Sandstone	TMP	MW0902 -Precipice	EPMOR	NA	Not predicted

Spring Complex	Main GAB aquifer interpreted to be source aquifer	Type of bore	EWS nominated monitoring bores – Target Aquifer	Investigation Trigger	Mitigation/management Trigger	Drawdown Limit
studies						

Notes: “Not predicted” refers to a predicted drawdown values being lower than 0.2 m

NA – Not Applicable: providing a year for a trigger or drawdown limit may be not applicable in the case of the on-tenements springs EWS. Additionally, drawdown limits are only defined at TMPs (refer to Section 7 and 8).

Response time data taken from the output files of the Surat CMI model (version 1.2).

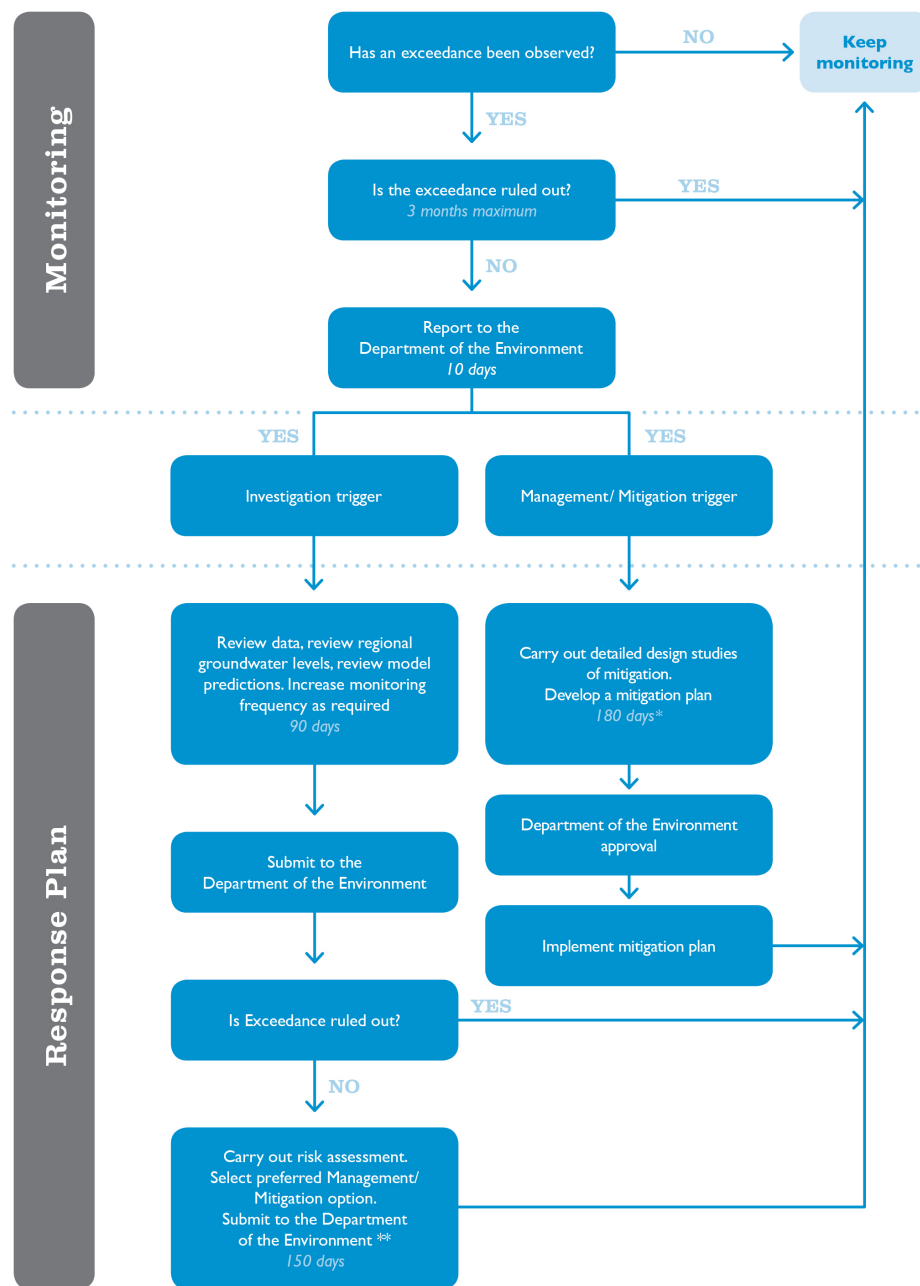
9.2 Exceedance response process

The flow chart diagram on Figure 9-1 provides a summary of the early warning system monitoring and response process.

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

- 1) When an Investigation Trigger value is exceeded (at an EWMI or TMP), the responsible Proponent will
 - verify the exceedance by:
 - Assessing observation data with historical data for the bore, this may include the use of a statistical trend procedure to remove natural variations;;
 - Assessing water level data in neighbouring bores monitoring the same aquifer;
 - Reviewing the model predictions and assess with observed water levels;
 - Identifying the potential causes that may have contributed to the exceedance; and
 - Increasing monitoring if necessary; then,
 - Notify The Department of the Environment within 10 days of confirmation of the exceedance
 - Where an observed exceedance cannot be ruled out, the responsible Proponent will:
 - Undertake a risk assessment and other studies resulting in nomination of a concept mitigation approach. This will include field investigations to assess site specific features, an assessment of the vulnerability of the spring to the level of predicted drawdown and a review of the hydrogeological conceptual model to understand the actual level of risk of impact to the EPBC springs (note: the hydrogeological conceptual models would have been developed earlier and provided to the Department at the end of spring baseline the latest). A methodology is proposed in Table 9-3 for the selection of potential impact management/mitigation solutions. One key element is the multi-criteria analysis which ensures that a range of criteria are taken into consideration in the selection process and in particular:
 - The timing available for implementation of the management/mitigation option;
 - The timing of the Proponent CSG activities; and
 - Other criteria such as technical success rate of the solution, environmental footprint, stakeholder and regulatory acceptability.
- 2) When a Management/Mitigation trigger is exceeded, the responsible Proponent will:
 - Move to carry out detailed mitigation design and develop a mitigation plan. To this end, the previously selected impact management/mitigation concept(s) will be developed in detail. This will involve:
 - Confirmation of the concept options;
 - Additional field investigations;

- Hydrogeological modelling;
 - Detailed engineering design studies.
 - Develop a mitigation plan. The mitigation plan will identify the potential of time before impact, the timing of mitigation and will potentially be redefining the value used as a “zero impact proxy”.
 - Submit the mitigation plan to The Department of the Environment; then,
 - Implement the mitigation plan.
- 3) When a drawdown limit is exceeded and the exceedance cannot be ruled out, the responsible Proponent will report to The Department of the Environment within 10 days of confirmation of exceedance.



* Available time before impact taken into consideration in concept design choice. Time frames are consistent with impact propagation timing.
 ** Risk assessment and selection of preferred management /mitigation option is already done for Lucky Last, Yebna 2 and Scotts Creek.

Figure 9-1: Early Warning System Monitoring Exceedance and Response Process for EPBC Springs

The response process diagram provides the length of time between elements of the response process. Time-lengths are set to allow only for assessment and communications from the Proponents to The Department of the Environment and site access where necessary.

9.3 Change to Spring Attributes

Changes to measurable attributes at the springs (e.g. discharge volumes, wetted area and vegetation response) occur on a regular basis and therefore future changes may not necessarily arise from regional changes to pressure head in the source aquifer due to CSG activities. Recent publications from the National Water Commission (National Water Commission, 2013) provide the results of an extensive study of springs in the western GAB. The reports identify the seasonal variability of spring ecology and the variability of flow to the spring. For example, it is noted that some spring vents discharge water on an intermittent basis, independent of fluctuations in potentiometric surface in the source aquifer, while other spring vents sometimes die out entirely with the creation of a new vent occurring nearby.

Measurable changes to the springs' attributes may therefore not necessarily be related to CSG water extraction. Changes to spring hydrology may instead be due in part or wholly to changes in:

- 1) Local landholder groundwater extraction processes (e.g. increased or decreased extraction rates);
- 2) Local meteorological conditions (e.g. short-term variations in air pressure, variable or sustained wet or dry periods);
- 3) Influences of earth tides;
- 4) Other natural indirect influences such as those relating to loading over aquifers after major wet seasons;
- 5) Natural physio-chemical, cyclic or non-cyclic succession of spring hydrology caused by the precipitation of material or ground slumping leading to clogging of spring flows and localised build-up of groundwater pressure:
 - This in turn results in local redirection of groundwater flow and the dissolution or erosion of originally precipitated or slumped material; and
 - The succession would be cyclic if the redirection of groundwater flow returned to the original vent location.
 - Climate Change

Spring hydrodynamics vary from spring to spring as a matter of groundwater pressure, pathway of water to surface, source aquifer hydro geochemistry and natural factors affecting a spring system. A detailed assessment for each spring would be carried out as a response to an exceedance of the investigation trigger. This work is already underway (as a requirement from the QLD Government, refer to Section 2.4) for the following EPBC springs:

- Lucky Last;
- 311/Yebna 2 complexes (Spring complex 311 is not EPBC classified but is located in the same area as the Spring Complex Yebna 2 with both having a potential impact exceeding 0.2 m, and thus are studied jointly); and
- Scotts Creek.

As mentioned in Section 4, conceptual hydrogeological models will be developed or refined, if already existing, for all EPBC springs at the end of the spring baseline program and a report submitted to The Department of the Environment by April 2015.

9.4 Potential mitigation options

If the monitoring data exhibits exceedance of an investigation trigger, the responsible Proponent will select possible mitigation solution(s). The list of mitigation options to be considered is extensive depending on the methodology used for implementation, however these options can be classified by the mitigation concept they are developed from. A list of possible mitigation options is presented in Table 9-2.

Table 9-2: Possible Mitigation Options

Potential Concepts of Spring Mitigation	Possible Mitigation Methods
Block impact with recharge	▪ Early recharge at the spring (head increase ahead of impact) ▪ Hydraulic barrier between propagation and spring (in source aquifer or source of impact)
Provide flow at springs	▪ Use water from a different source or from the same source tapped at a distance from the spring to supply spring flow at surface ▪ Remove invasive weeds
Use deeper artesian water for recharge	Recharge at spring with artesian water from another aquifer (this may necessitate water treatment)
Increase flow from aquifer source to surface	▪ Spring supply borehole
Spring impact offset through removal of impact from private usage	▪ Relocation ▪ Surrender ▪ Substitute

It should be noted that depending on the length of time for which mitigation is required, the selected mitigation may consist of several options which will be implemented successively.

The selection of the suitable spring mitigation option(s) will follow a work program similar to the one presented in Table 9-3. Initially, all mitigation options will be considered, through a high level multi-criteria analysis, unsuitable mitigation options will be set aside. The exercise will also be used to focus the studies on potentially viable mitigation options, it will ensure that sufficient time available for studies and implementation of the mitigation solution is taken into consideration and will also allow to identify any additional data requirements early in the mitigation selection process. When the vulnerability of the spring ecosystem to a decrease in water level in the source aquifer will be understood, the mitigation selection process will be refined and the mitigation option or combination of mitigation options will be selected.

Table 9-3: Work program for spring mitigation option selection

	Aspect	Scope of Work and Target
1. Mitigation Design	Mitigation options identifications	Identify all potential options for mitigation at the springs
	Mitigation options early assessment	Initial screening of mitigation options through a multicriteria analysis. Will also allow focusing work efforts in data which is effectively required.
2. Studies	Survey / topography	Survey spring vents elevation, topography at spring site, river bed elevation (if any), groundwater monitoring bore and private bore elevation nearby
		Prepare cross sections for hydrogeological conceptual models
	Surface water	Identify gauging stations near spring sites.
		Assess baseflow, identify source of baseflow, if same as spring source aquifer potential seasonal pattern, identify influence of dry/wet periods
		Identify relationship between groundwater level variations and river baseflow. What is the level of confidence in this assessment?
		Define if baseflow at a gauging station can be used as a trigger to impact to aquifer pressure?
	Hydrochemistry	Compare chemistry signatures for surface water, spring vents, and groundwater. Confirm/update previous results on aquifer source and GW/SW interactions on the basis of water quality.
	Ecology	Ecological survey, quarterly for one year to determine spring ecological values and seasonal variability. Select representative spring vents for ongoing monitoring
		How stable is the spring ecosystem, how can we identify an impact to the ecosystem (resulting from decreased water supply) on the flora?
		Assess the vulnerability of the spring ecology to a predicted drawdown in the source aquifer. Comment on resilience to dry periods, root zone extend, resilience to a lowered water level
		Define the point where impact to spring may be non-reversible for ecological species
	Spring History	Obtain all historical aerial photography and old remote sensing data for the spring area to document spring variability. Interview landholders/stakeholders for anecdotal knowledge.
	Groundwater	Gather available groundwater data for the area (incl. water levels, groundwater usage, groundwater chemistry). Assess reliability of the data. Discard low confidence data. Create maps.
		Carry out groundwater monitoring and spring monitoring events, possibly at the same time as the ecological monitoring.
		Define existing groundwater structures which could be used for monitoring
		Assess water level data, assess historical and seasonal variations
		Assess pressure heads in the source aquifer vs spring elevation
		Assess from the CIM the predicted level of impact at the spring and the timing of this impact and recovery.

	Aspect	Scope of Work and Target
3. Mitigation Assessment and selection	Geology	Assess geology at the site using published geological maps, and other sources such as seismic data or in-house geology to identify the presence of faults or geological features which can inform on spring behaviour. It may be necessary to carry out shallow seismic or resistivity imaging.
	CSG Production Areas	Establish impact propagation
	Hydrogeological conceptual model	Develop / refine hydrogeological conceptual models
		Assess the vulnerability of the spring flow to a decrease of water level in source aquifer. Refer to similar work by National Water Commission.
		develop the hydrogeological model and associated illustrations
	Vulnerability Assessment	Assess vulnerability of the EPBC springs in terms of predicted loss of pressure head in source aquifer, available pressure head, ecological vulnerability, interconnectivity between vents. The vulnerability assessment would follow the vulnerability assessment methodology developed for GAB springs of the Western GAB (National Water Commission, 2013, Vol VI)
	Mitigation	Using the initial high level MCA outcome and current understanding of vulnerability of EPBC spring , refine the MCA and select mitigation option(s)
		Define an early schedule for preparation of a mitigation plan.
		Identify data/studies requirements for the option(s) selected
	Review of spring drawdown limit	Review adequacy of the drawdown limit set in the JIP for the specific site
		If trigger is not adequate, propose to The Department of the Environment a new drawdown limit using either ecology, baseflow or aquifer pressure as an indicator. Define time available for implementation.

9.5 Data review procedures and reporting

Collection of groundwater monitoring data will be the responsibility of the proponent responsible for installation of the EWMIs and TMPs. It should be noted that although all EPBC springs responsibilities are not yet assigned (Section 3.3), the responsibility of installation and monitoring of all of the bores from the EWS network are assigned. The Proponents will then share the monitored data (once all data collection QA/QC has been performed) with the other Proponents through a range of existing data sharing agreements, and via provision of the data to OGIA. The Proponents have their respective data review and management policies (as explained within each of the CSG WMMPs).

It is proposed that reports will be prepared by the Proponents in accordance with their CSGWMMPs. This will include the following as a minimum:

- Simple reporting of data every year (data and plots of raw and corrected data against trigger as appropriate, trend analysis after collection of baseline);
- A consolidated report every 3 years.

The annual reports will include:

- Updated to the EWS monitoring network from the previous report (for example, new monitoring bores coming online);
- Graphic presentation of water level at each monitoring location;
- Groundwater level and water quality monitoring results;
- A description of methods used to correct measured water level data to remove non-CSG effects (barometric, earth tide, non-CSG groundwater extraction, seismic events, hydrostatic loading, etc.);
- Graphic comparison of the water level at EWMIs and TMPs (natural variations and anthropogenic effects (non CSG) removed) with investigation and mitigation/management triggers and drawdown limit; and
- Hydrogeological conceptual model for each of the EPBC spring (only in one report at the end of the spring baseline program).

The consolidated report will be prepared every 3 years and will include any updates to the conceptual hydrogeological models of the springs.

9.6 Groundwater level trend analysis to differentiate CSG-induced impact from natural variations

It is recognised that there are a broad range of processes that could cause groundwater level fluctuations and trends. These operate at various spatial and temporal scales and include level fluctuations due to changes in air pressure, rainfall, loading and unloading due to soil moisture and water level changes in unconfined aquifers, land use change and groundwater pumping. Groundwater level and water quality data trends will be observed and analysed.

There are basic issues in the raw level data that need to be addressed, such as private bore pumping, autocorrelation, earth tides and barometric effects. External influences (natural and non-CSG anthropogenic effects) will be removed from the measured water levels to understand the CSG-related trends by methods which will include:

- Appropriate models will be used to correct for earth tides and barometric effects;
- Autoregressive integrated moving average (ARIMA) models will be used to correct for autocorrelation effects in the water level time series; and
- Private bore pumping will be filtered out from reports of historical usage.

Trend analysis will be performed to remove natural variations to the monitored groundwater levels data.

QGC has developed a methodology for trend and statistical analysis (APPENDIX D), this methodology will be applied to the collected data.

In view of the baseline data, the methodology for trend and statistical analysis may need to be updated. In such case, methods used for the definition of reference values and data analysis will be provided with the reference values. Where the method for trend and statistical analysis provided in APPENDIX D remains adequate, this will be confirmed in the relevant report to the Department of the Environment.

10 References

DERM, Guideline Underground Water Impact Reports and Final Reports

Geoscience Australia, 2009, Groundwater Sampling and Analysis – A Field Guide

Geoscience Australia, November 2012, Guidance for the Combined Proponent Approach to Monitoring Potential Groundwater Impacts from Coal Seam Gas Activities to EPBC Springs in the Surat Basin

Green P.M et al., 1997, The Surat and Bowen basins South East Queensland, geological Survey of Queensland, Brisbane.

Hoffmann K.L et al., 2009, Sequence stratigraphy of Jurassic strata in the lower Surat Basin succession, Queensland. Australia Journal of Earth Sciences, 56(3): 461-476.

Klohn Crippen Berger, January 2012. Hydrogeological attributes associated with Springs in the Surat Cumulative Management Area. 315 pp. QWC, Brisbane.

Klohn Crippen Berger, May 2012. Desktop Assessment of the Source Aquifer for Springs in the Surat Cumulative Management Area. 179 pp. QWC, Brisbane.

National Water Commission, 2011, Australian Groundwater Dependent Ecosystems Toolbox

National Water Commission, 2013, Groundwater Discharge of the Western Great Artesian Basin, Allocating Water and Maintaining Springs in the Great Artesian Basin Vol III

National Water Commission, 2013, Groundwater Recharge, Hydrodynamics and Hydrochemistry of the Western Great Artesian Basin, Allocating Water and Maintaining Springs in the Great Artesian Basin Vol II

National Water Commission, 2013, Groundwater-dependent Ecosystems of the Western Great Artesian Basin, Allocating Water and Maintaining Springs in the Great Artesian Basin Vol V

National Water Commission, 2013, Hydrogeological Framework of the Western Great Artesian Basin, Allocating Water and Maintaining Springs in the Great Artesian Basin Vol I

National Water Commission, 2013, Risk Assessment Process for Evaluating Water use Impacts on Great Artesian Basin Springs, Allocating Water and Maintaining Springs in the Great Artesian Basin Vol VI

National Water Commission, 2013, Spatial Survey and Remote Sensing of Artesian Springs of the Western Great Artesian Basin, Allocating Water and Maintaining Springs in the Great Artesian Basin Vol IV

National Water Commission, 2013, Summary of Findings for Natural Resource Management of the Western Great Artesian Basin, Allocating Water and Maintaining Springs in the Great Artesian Basin Vol VII

Queensland Water Commission, July 2012. Underground Water Impact Report, Surat Cumulative Management Area. 218 pp. QWC, Brisbane.

RJ Fensham, C Pennay, J Drimer, Queensland Herbarium, January 2012. Ecological and Botanical survey of springs in the Surat Cumulative Management Area. 99 pp plus auxiliary database files. QWC, Brisbane.

Santos, 2012, Santos GLNG Statistical Rationale for Monitoring Programme Design

Sundance Environmental and Energy Specialists Ltd, July 2012, Statistical Validation of Existing Santos' Water Monitoring Programmes for Eastern Australia Coal Seam Gasification (CSG) Area, unpublished.

WaterMark Numerical Computing, May 2012. Predictive Uncertainty of the Regional-Scale Groundwater Flow Model for the Surat Cumulative Management Area. 311 pp. QWC, Brisbane.

APPENDIX A – JIP EWS Groundwater Monitoring Network

This Appendix comprises of the following:

Table A 1: EWS Monitoring Network 3

Table A 2: Regional Walloon Coal Measures and Bandanna Formation Monitoring 8

Table A 3: Regional Aggregated Industry Monitoring Network..... 9

Figure A 1: EWS Monitoring Network Map..... 16

Figure A 2: Regional Walloon Coal Measures and Bandanna Formation Monitoring Map..... 16

Figure A 3: Regional Aggregated Industry Monitoring Network Map 16

Figure A 3: Regional Atmospheric Monitoring Locations 16

Table A 1: EWS Monitoring Network

JIP EWS bore ID	Latitude	Longitude	Target Aquifer	Monitoring Frequency - Water Pressure	Monitoring Frequency - Water Quality	Monitoring Purpose: EWMI/TMP	MNES Monitoring Objective	Installation Timing	Responsible Proponent	Rationale / Comments
Spring Gully PB5	-25.9325	148.9355	Precipice Sandstone	daily	Six-monthly	EWMI	Abyss, Lucky Last	2015	Origin	
Spring Gully-PB2	-25.9325	148.9355	Hutton Sandstone	daily	Six-monthly	EWMI	Abyss	2015	Origin	
Spring Gully-PB1	-25.8375	148.8510	Precipice Sandstone	daily	Six-monthly	EWMI	Abyss, Lucky Last	In place	Origin	
RN48912	-25.8375	148.8511	Hutton Sandstone	daily	Six-monthly	EWMI	Abyss	2013	Origin	Only 38 m of Hutton Sandstone present at Spring Gully PB1 site but GWDB data for RN48912 (2.885 km ENE) suggests that at site there may be some saturation of the Hutton Sandstone..
Contact Zone	-25.8098	148.8276	Precipice Sandstone	daily	Six-monthly	EWMI	Abyss, Lucky Last	2013	Santos	Moved slightly within contact zone area to minimise land disturbance
QWC129	-25.8250	148.7916	Hutton Sandstone	daily	Six-monthly	TMP	Abyss	2014	Santos	
QWC129	-25.8250	148.7916	Precipice Sandstone	daily	Six-monthly	TMP	Lucky Last	2013	Santos	
MW0905	-25.7309	148.8456	Precipice Sandstone	daily	Six-monthly	EWMI	Abyss, Lucky Last	2014	Santos	
Cassio_GW1	-25.9454	149.7754	Hutton Sandstone	daily	Six-monthly	EWMI	Dawson River 8, Boggomoss, Dawson River 2, Dawson River 6 & Prices	2013	QGC	
Cassio_GW2	-25.9454	149.7754	Precipice Sandstone	daily	Six-monthly	EWMI	Boggomoss, Dawson River 2, Dawson River 6 & Prices	2013	QGC	
Coochiemudlo_GW1	-25.7630	149.9770	Hutton Sandstone	daily	Six-monthly	TMP	Dawson River 8, Boggomoss, Dawson River 2, Dawson River 6 & Prices	2013	QGC	

JIP EWS bore ID	Latitude	Longitude	Target Aquifer	Monitoring Frequency - Water Pressure	Monitoring Frequency - Water Quality	Monitoring Purpose: EWMI/TMP	MNES Monitoring Objective	Installation Timing	Responsible Proponent	Rationale / Comments
Coochiemudlo_GW2	-25.7630	149.9770	Precipice Sandstone	daily	Six-monthly	TMP	Boggomoss, Dawson River 2, Dawson River 6 & Prices	2013	QGC	
Peat MB2-P	-26.0152	150.0958	Precipice Sandstone	daily	Six-monthly	EWMI	Cockatoo Creek	2014	Origin	
Peat MB3-H	-26.0152	150.0958	Hutton Sandstone	daily	Six-monthly	EWMI	Cockatoo Creek	2014	Origin	
Scotia OBS#1	-25.9419	150.0742	Precipice Sandstone	daily	Six-monthly	EWMI (WQ)	Cockatoo Creek	In place	Santos	existing installations include one Precipice Sandstone monitoring bore, one Hutton Sandstone farm bore equipped with telemetry, one multilevel VWP Precipice and Hutton Sandstone included for WL.
RN23147	-25.9141	150.0736	Hutton Sandstone	daily	Six-monthly	EWMI (WQ)	Cockatoo Creek	In place	Santos	As above
AVLVWP	-25.9379	150.0739	Hutton Sandstone , Precipice Sandstone	daily	NA	TMP	Cockatoo Creek	In place	Santos	As above
Charlotte_GW1	-25.9100	149.5400	Hutton Sandstone	daily	Six-monthly	EWMI	Dawson River 8, Dawson River 2, Dawson River 6, Prices & Boggomos, Scotts Creek	2013	QGC	
Charlotte_GW2	-25.9100	149.5400	Precipice Sandstone	daily	Six-monthly	EWMI	Dawson River 2, Dawson River 6, Prices & Boggomos	2013	QGC	
Kinnoul-MB2-H	-25.6648	149.5973	Hutton Sandstone	daily	Six-monthly	TMP	Dawson River 8	2015	Origin	
EWMI7	-24.6074	149.0761	Clematis Sandstone	daily	Six-monthly	EWMI	Elgin 2	2015	Santos	The other possible options, is a private bores a few km to the south which is proposed to be equipped, subject to landholder negotiations
RN14881	-25.8872	149.3247	Hutton Sandstone	daily	Six-monthly	TMP	Scotts Creek	In place	Origin	

JIP EWS bore ID	Latitude	Longitude	Target Aquifer	Monitoring Frequency - Water Pressure	Monitoring Frequency - Water Quality	Monitoring Purpose: EWMI/TMP	MNES Monitoring Objective	Installation Timing	Responsible Proponent	Rationale / Comments
Spring Gully MB4-H	-25.9801	149.0652	Hutton Sandstone	daily	Six-monthly	EWMI	Scotts Creek	In place	Origin	Location of PB3 and MB4-H are on the Bandanna-Precipice subcrop and will therefore provide an earlier warning from Bandanna extraction potential effects.
PB3	-25.9818	149.0465	Precipice Sandstone	daily	Six-monthly	EWMI	Scotts Creek	2015	Origin	PB3 and MB4-H are at the same location
RN48978	-26.0014	149.2826	Hutton Sandstone	daily	Six-monthly	EWMI	Scotts Creek	In place	Origin	
QWC104	-25.8263	149.0370	Hutton Sandstone	daily	Six-monthly	EWMI	Yebna 2	2014	Santos	
QWC104	-25.8263	149.0370	Precipice Sandstone	daily	Six-monthly	EWMI	Yebna 2	2014	Santos	
MW0902	-25.7347	149.0829	Precipice Sandstone	daily	Six-monthly	TMP	Yebna 2	In place	Santos	
Charlie_GW1	-26.0240	149.6470	Hutton Sandstone	daily	Six-monthly	EWMI	Dawson River 8, Scotts Creek	2013	QGC	
Spring Gully MB16-P	-25.8666	149.2168	Precipice Sandstone	daily	Six-monthly	EWMI	Scotts Creek	2014	Origin	
Spring Gully MB17-H	-25.8665	149.2168	Hutton Sandstone	daily	Six-monthly	EWMI	Scotts Creek	2014	Origin	
RN38333	-25.8645	149.1580	Hutton Sandstone	daily	Six-monthly	TMP	Scotts Creek	In place	Origin	Existing instrumented private water bore Scott's Creek Bore (RN38333) 6.7 km to the WNW. Existing water bore — currently instrumented to observe groundwater levels
Strathblane-WB1-P	-25.9002	149.1444	Precipice Sandstone	daily	Six-monthly	EWMI	Scotts Creek	In place	Origin	Existing Strathblane WB1-P located 7.26 km to the west. No bores will be installed in the Clematis as available data shows no Clematis Sandstone within 8 km therefore this bore will not be installed.

Notes:

- Bore locations presented in this table are subject to land access agreements and sites conditions, the final locations may vary slightly.
- Where a significant change in bore location is required (more than 5 km for bores for off-tenure springs bores and more than 1 km for bores for on-tenure springs), the responsible proponent would notify the of the proposed changes.
- Proposed installation timing may vary due to land access and weather conditions. Should land access prevent the timely installation of the EWS monitoring bores, alternative locations or timing will be discussed with The Department of the Environment.
- Bore names will be adapted to reflect the Proponents bore nomenclature when not currently provided

Table A 2: Regional Walloon Coal Measures and Bandanna Formation Monitoring

Industry Bore ID	Latitude	Longitude	Target Aquifer	Monitoring Frequency - Water Pressure	Monitoring Frequency - Water Quality	Monitoring Purpose: EWMI/TMP	Monitoring Objective (see notes)	Installation Timing	Responsible Proponent	Comments
Thackery 6M	-26.0620	149.4530	Springbok & WCM	daily	-	EWMI	MNES, 2	2013	QGC	Thackery 6M will be equipped with a gauge in the Springbok.
Cassio 6M	-25.9460	149.7760	WCM (3 levels)	daily	-	EWMI	MNES, 2,5,6	2016	QGC	Cassio 6M is combined with the two Cassio aquifer monitoring holes targeting pressure and quality in the Hutton and Precipice.
QWC103	-25.9099	149.5404	WCM	daily	-	EWMI	MNES, 2,5,6	2016	QGC	Planned near Charlotte for 2016
Meeleebee MB3-W	-26.2423	149.1952	WCM (3 levels)	daily	-	EWMI	MNES, 2,5,6	2013	Origin	Replace with site of proposed monitoring bore Meeleebee MB3-W which is to be produced by workover of existing corehole Meeleebee 5 - 6.55 km to SW. 3 levels of monitoring in WCM.
Durham Ranch 23	-25.9765	149.1042	Bandanna Formation	daily	-	EWMI	MNES, 1,2	2013	Origin	Existing & instrumented monitoring well Durham Ranch 23. Existing monitoring bore - currently instrumented to observe groundwater levels.
Belington Hut State Forest	-25.3492	149.0188	Bandanna Formation, Clematis Sandstone	daily	-	EWMI	MNES, 2,5,6	2013	Santos	
Peat MB1-B	-26.0022	150.0841	Bandanna Formation (actually equivalent Baralaba Coal Measures)	daily	-	EWMI	MNES,1,2,4	2013	Origin	Proposed work over of existing gas well. Proposed workover of Peat 29 gas well to produce groundwater monitoring bore Peat MB1-B
Pony Hills	-25.8258	149.0376	Bandanna Formation	daily	-	EWMI	MNES, 2,4,5,6	2013	Santos	
QWC132	-25.9507	148.9734	Bandanna Formation	daily	-	EWMI	MNES,2	2013	Origin	Replace with proposed Spring Gully MB1-B location 0.61 km to south. New monitoring bore.
Polaris 22M	-26.1570	149.7990	WCM (3 levels)	daily	-	EWMI	2	2013	QGC	If Springbok is present a gauge will be installed in that formation also.
Lawnton 9M	-26.3060	149.9100	Springbok Sandstone & WCM (4 levels)	daily	-	EWMI	2,5,6	2013	QGC	The Lawnton 9M will be equipped with an additional gauge to measure Springbok pressure in addition to the WCM.
Philip 5M	-26.0870	149.6310	Springbok Sandstone & WCM (3 levels)	daily	-	EWMI	2,5,6 and 4 (Hutton Sdst only)	2013	QGC	Philip 5m is a core hole and will have pressure gauges in the Springbok and WCM.

Notes:

Objectives:

- 1 - Establish baseline
- 2 - Monitor impact to aquifer resulting from CSG activities
- 3 - Monitor changes of condition near groundwater users
- 4 - Monitor changes of condition near environmental values (springs)
- 5 - Data collection to improve and calibrate the groundwater flow models
- 6 - Data collection to improve inter-aquifer connectivity knowledge

Bore locations presented in this table are subject to land access agreements and sites conditions, the final locations may vary slightly.

Proposed installation timing may vary due to land access and weather conditions.

Bore names will be adapted to reflect the Proponents bore nomenclature when not currently provided.

Table A 3: Regional Aggregated Industry Monitoring Network

Bore Name	Planned construction date	Monitoring bore: Existing / Proposed	Target Monitoring Formations	latitude	longitude	Responsible Proponent
3	2016	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-27.6600	150.5800	QGC
	2016	Proposed	Springbok Sandstone	-27.6600	150.5800	QGC
	2016	Proposed	Hutton Sandstone	-27.6600	150.5800	QGC
	2016	Proposed	Precipice Sandstone	-27.6600	150.5800	QGC
11	2013	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-27.4701	150.6350	QGC
	2013	Proposed	Gubberamunda Sandstone	-27.4701	150.6350	QGC
	2013	Proposed	Springbok Sandstone	-27.4701	150.6350	QGC
	2013	Proposed	Hutton Sandstone	-27.4701	150.6350	QGC
	2013	Proposed	Precipice Sandstone	-27.4701	150.6350	QGC
12	2013	Proposed	Gubberamunda Sandstone	-27.3660	151.0300	QGC
	2013	Proposed	Westbourne Formation	-27.3660	151.0300	QGC
	2013	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-27.3660	151.0300	QGC
	2013	Proposed	Springbok Sandstone	-27.3660	151.0300	QGC
	2013	Proposed	Hutton Sandstone	-27.3660	151.0300	QGC
	2013	Proposed	Precipice Sandstone	-27.3660	151.0300	QGC
16	2013	Proposed	Gubberamunda Sandstone	-27.3100	150.8500	QGC
	2013	Proposed	Springbok Sandstone	-27.3100	150.8500	QGC
	2013	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-27.3100	150.8500	QGC
20	2013	Proposed	Gubberamunda Sandstone	-27.2900	150.6300	QGC
	2013	Proposed	Springbok Sandstone	-27.2900	150.6300	QGC
	2013	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-27.2900	150.6300	QGC
21	2013	Proposed	Condamine Alluvium	-27.2720	151.0710	QGC
	2013	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-27.2720	151.0710	QGC
	2013	Proposed	Springbok Sandstone	-27.2720	151.0710	QGC
	2013	Proposed	Hutton Sandstone	-27.2720	151.0710	QGC
	2013	Proposed	Precipice Sandstone	-27.2720	151.0710	QGC
	2013	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-27.2720	151.0710	QGC
24	2013	Proposed	Gubberamunda Sandstone	-27.2600	150.9300	QGC
	2013	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-27.2600	150.9300	QGC
	2013	Proposed	Springbok Sandstone	-27.2600	150.9300	QGC
26	2013	Proposed	Gubberamunda Sandstone	-27.2100	150.7500	QGC
	2013	Proposed	Springbok Sandstone	-27.2100	150.7500	QGC
	2013	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-27.2100	150.7500	QGC
31	2013	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-27.1713	150.7825	QGC
	2013	Proposed	Gubberamunda Sandstone	-27.1713	150.7825	QGC
39	2013	Proposed	Upper Juandah CMs, Lower Juandah CMs , Taroom Coals	-27.0286	150.5485	QGC
	2013	Proposed	Springbok Sandstone	-27.0286	150.5485	QGC
	2013	Proposed	Precipice Sandstone	-27.0286	150.5485	QGC
	2013	Proposed	Gubberamunda Sandstone	-27.0286	150.5485	QGC
	2013	Proposed	Hutton Sandstone	-27.0286	150.5485	QGC
43	2013	Proposed	Springbok Sandstone	-26.9490	150.4440	QGC
	2013	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-26.9490	150.4440	QGC
49	2013	Proposed	Springbok Sandstone	-26.8470	150.3001	QGC
57	2013	Proposed	Gubberamunda Sandstone	-26.6892	150.2555	QGC
	2013	Proposed	Springbok Sandstone	-26.6892	150.2555	QGC
	2013	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-26.6892	150.2555	QGC
67	2016	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-26.5500	150.4900	QGC
	2016	Proposed	Hutton Sandstone	-26.5500	150.4900	QGC
72	2016	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-26.5230	149.8220	QGC
	2016	Proposed	Precipice Sandstone	-26.5230	149.8220	QGC
	2016	Proposed	Hutton Sandstone	-26.5230	149.8220	QGC
	2016	Proposed	Springbok Sandstone	-26.5230	149.8220	QGC
	2016	Proposed	Gubberamunda Sandstone	-26.5230	149.8220	QGC
	2016	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-26.5230	149.8220	QGC
81	2013	Proposed	Gubberamunda Sandstone	-26.405	149.9790	QGC
	2013	Proposed	Springbok Sandstone	-26.405	149.9790	QGC
81	2015	Proposed	Springbok Sandstone	-26.3660	149.9790	QGC
	2015	Proposed	Upper Juandah CMs, Lower Juandah CMs , Taroom Coals	-26.3660	149.9790	QGC
89	2013	Proposed	Upper Juandah , Juanda SST, Lower Juandah , Tangalooma Coals, Taroom Coals , Lower Aquitard of the WCM (Eurombah Fmtn)	-26.2820	149.7140	QGC
	2013	Proposed	Gubberamunda Sandstone	-26.2820	149.7140	QGC

Bore Name	Planned construction date	Monitoring bore: Existing / Proposed	Target Monitoring Formations	latitude	longitude	Responsible Proponent
	2013	Proposed	Springbok Sandstone	-26.2820	149.7140	QGC
	2013	Proposed	Hutton Sandstone	-26.2820	149.7140	QGC
90	2014	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-26.3060	149.9100	QGC
	2014	Proposed	Springbok Sandstone	-26.3060	149.9100	QGC
96	2014	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-26.0527	149.4342	QGC
97	2014	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-26.087	149.631	QGC
	2014	Proposed	Springbok Sandstone	-26.087	149.631	QGC
	2013	Proposed	Hutton Sandstone	-26.0240	149.6470	QGC
100	2013	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-25.9450	149.6470	QGC
101	2016	Proposed	Birkhead Formation	-25.9490	149.3514	QGC
103	2013	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-25.9099	149.5404	QGC
	2013	Proposed	Hutton Sandstone	-25.9099	149.5404	QGC
	2013	Proposed	Precipice Sandstone	-25.9099	149.5404	QGC
107	2013	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-25.7630	149.9770	QGC
	2013	Proposed	Hutton Sandstone	-25.7630	149.9770	QGC
111	2016	Proposed	Birkhead Formation	-25.6187	149.7682	QGC
121	2016	Proposed	Springbok Sandstone	-27.2389	149.9842	QGC
	2016	Proposed	Upper Juandah CMs	-27.2389	149.9842	QGC
140	2016	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-26.1500	149.7690	QGC
River Road-4	Completed	Existing	Juandah CMs	-27.6390	151.1676	Arrow
RN 42230088	Completed	Existing	Condamine Alluvium	-27.5898	151.2341	Arrow
Pampas-5	2016	Proposed	Taroom CMs	-27.5889	151.2423	Arrow
Meenawarra-5	Completed	Existing	Juandah CMs, Taroom CMs	-27.5779	151.1338	Arrow
Meenawarra-21	2016	Proposed	Upper Juandah CMs, Lower Juandah CMs, Taroom Coals	-27.5778	151.1336	Arrow
RN 42231463	Completed	Existing	Condamine Alluvium	-27.5488	151.3130	Arrow
Carn Brea-17	2013	Proposed	Springbok Sandstone	-27.5488	151.3130	Arrow
Carn Brea-18	2013	Proposed	Upper Juandah CMs, Lower Juandah CMs, Taroom Coals	-27.5488	151.3130	Arrow
Carn Brea-19	2013	Proposed	Hutton Sandstone	-27.5488	151.3130	Arrow
Carn Brea-20	2013	Proposed	Evergreen Formation	-27.5488	151.3130	Arrow
Carn Brea-20	2013	Proposed	Precipice Sandstone	-27.5488	151.3130	Arrow
RN 42231339	Completed	Existing	Condamine Alluvium	-27.5306	151.5037	Arrow
RN 42231340	Completed	Existing	Walloon Coal Measures	-27.5318	151.5148	Arrow
RN 42231370	Completed	Existing	Condamine Alluvium	-27.4915	151.3932	Arrow
QWC Site 10	2016	Proposed	Condamine Alluvium - Walloon transition layer / Springbok	-27.4915	151.3932	Arrow
	2016	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-27.4915	151.3932	Arrow
Tipton West Pilot-1	Completed	Existing	Walloon Coal Measures	-27.4074	151.1404	Arrow
Tipton-157	2013	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-27.3981	151.0889	Arrow
RN 42231294	Completed	Existing	Condamine Alluvium	-27.3993	151.5484	Arrow
RN 42231295	Completed	Existing	Walloon Coal Measures	-27.3975	151.5619	Arrow
Plainview-1	Completed	Existing	Juandah CMs	-27.3858	151.2165	Arrow
Long Swamp-1	Completed	Existing	Juandah CMs	-27.3431	151.1242	Arrow
Tipton-195	2013	Proposed	Condamine Alluvium	-27.3206	151.2050	Arrow
Tipton-196	2013	Proposed	Condamine Alluvium - Walloon transition layer	-27.3206	151.2049	Arrow
Tipton West-4	Completed	Existing	Walloon Coal Measures	-27.3134	151.1986	Arrow
Tipton-196	2013	Proposed	Upper Juandah CMS	-27.3206	151.2049	Arrow
Tipton-197	2013	Proposed	Lower Juandah CMs, Taroom CMs	-27.3206	151.2049	Arrow
Mount Maria-20	2013	Proposed	Condamine Alluvium	-27.2885	151.3631	Arrow
	2013	Proposed	Condamine Alluvium - Walloon transition layer	-27.2885	151.3631	Arrow
Mount Maria-20	2013	Proposed	Upper Juandah CMs	-27.2885	151.3631	Arrow
RN 42230153	Completed	Existing	Condamine Alluvium	-27.2698	151.2381	Arrow
Plainview-25	2013	Proposed	Springbok Sandstone	-27.2731	151.2234	Arrow
	2013	Proposed	Upper Juandah CMs	-27.2731	151.2234	Arrow
QWC Site 27	2016	Proposed	Condamine Alluvium	-27.1952	151.3179	Arrow

Bore Name	Planned construction date	Monitoring bore: Existing / Proposed	Target Monitoring Formations	latitude	longitude	Responsible Proponent
	2016	Proposed	Condamine alluvium - Walloon transition layer	-27.1952	151.3179	Arrow
	2016	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-27.1952	151.3179	Arrow
QWC Site 28	2016	Proposed	Springbok Sandstone	-27.1793	151.1249	Arrow
	2016	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-27.1793	151.1249	Arrow
Stratheden-3	Completed	Existing	Juandah CMs	-27.1795	151.0439	Arrow
RN 42230159	Completed	Existing	Condamine Alluvium	-27.1656	151.2151	Arrow
QWC Site 30	2013	Proposed	Condamine Alluvium - Walloon transition layer	-27.1656	151.2151	Arrow
	2013	Proposed	Upper Juandah CMS	-27.1656	151.2151	Arrow
Daandine-124	Completed	Existing	Westbourne Formation / Springbok Sandstone	-27.1440	150.9481	Arrow
Daandine-123	Completed	Existing	Upper Juandah CMS	-27.1440	150.9481	Arrow
Daandine-134	2013	Proposed	sandstone or siltstone or mudstone of the Juandah Coal Measures	-27.1441	150.9480	Arrow
	2013	Proposed	Lower Juandah CMs	-27.1441	150.9480	Arrow
	2013	Proposed	Tangalooma Sandstone	-27.1441	150.9480	Arrow
	2013	Proposed	Taroom CMs	-27.1441	150.9480	Arrow
	2013	Proposed	lower aquitard of the Walloon Coal Measures	-27.1441	150.9480	Arrow
RN 42231548	Completed	Existing	Walloon Coal Measures	-27.1153	151.4978	Arrow
Daandine-162	2013	Proposed	Condamine Alluvium	-27.1199	151.0758	Arrow
Daandine-163	2013	Proposed	Condamine Alluvium - Walloon transition layer	-27.1200	151.0759	Arrow
Daandine-24	Completed	Existing	Juandah CMs, Taroom CMs	-27.1093	151.0539	Arrow
Daandine-2	Completed	Existing	Juandah CMs, Taroom CMs	-27.1024	150.9614	Arrow
Daandine-121	Completed	Existing	Hutton Sandstone	-27.1004	150.9557	Arrow
UWIR Site 41	2016	Proposed	Condamine Alluvium	-27.0100	151.1140	Arrow
	2016	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-27.0100	151.1140	Arrow
Kogan North-79	2013	Proposed	Condamine Alluvium	-27.0092	150.9003	Arrow
	2013	Proposed	Condamine Alluvium - Walloon transition layer	-27.0092	150.9003	Arrow
Kogan North-56	Completed	Existing	Juandah CMs, Taroom CMs	-27.0093	150.9003	Arrow
RN 42230203	Completed	Existing	Condamine Alluvium	-26.8989	150.9792	Arrow
UWIR Site 47	2016	Proposed	Upper Juandah CMS	-26.8989	150.9792	Arrow
Wyalla-16	2013	Proposed	Condamine Alluvium	-26.8597	150.7500	Arrow
	2013	Proposed	Springbok Sandstone	-26.8597	150.7500	Arrow
Wyalla-17	2013	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-26.8597	150.7500	Arrow
Wyalla-17	2013	Proposed	Precipice Sandstone	-26.8597	150.7500	Arrow
RN 42230209	Completed	Existing	Condamine Alluvium	-26.7422	150.6799	Arrow
Dundee-20	2013	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-26.7423	150.6795	Arrow
Castledean-18	2013	Proposed	Springbok Sandstone	-26.5529	150.2223	Arrow
	2013	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-26.5529	150.2223	Arrow
Burunga Lane-176	Completed	Existing	Upper Juandah , Lower Juandah , Taroom Coals	-26.2427	150.0502	Arrow
	Completed	Existing	Hutton Sandstone	-26.2427	150.0502	Arrow
Burunga Lane-174	Completed	Existing	Precipice Sandstone	-26.2427	150.0500	Arrow
UWIR Site 94	2016	Proposed	Upper Juandah , Lower Juandah , Taroom Coals	-26.1711	149.9542	Arrow
	2016	Proposed	Hutton Sandstone	-26.1711	149.9542	Arrow
RN 41620043	Completed	Existing	Springbok Sandstone	-27.9222	151.1214	Arrow
UWIR Site 124	2016	Proposed	Upper Juandah CMS	-27.9222	151.1214	Arrow
RN 42231591	Completed	Existing	Main Range Volcanics	-27.5913	151.8467	Arrow
UWIR Site 133	2016	Proposed	Upper Juandah CMS	-27.5913	151.8467	Arrow
RN 42231597	Completed	Existing	Main Range Volcanics	-27.7309	151.7628	Arrow
UWIR Site 134	2013	Proposed	Upper Juandah CMS	-27.7309	151.7628	Arrow
RN 42231411	Completed	Existing	Condamine Alluvium	-27.8251	151.4764	Arrow
UWIR Site 135	2016	Proposed	Upper Juandah CMS	-27.8251	151.4764	Arrow
UWIR Site 136	2013	Proposed	Main Range Volcanics	-26.9214	151.2871	Arrow
RN 42231553	Completed	Existing	Hutton Sandstone	-26.9214	151.2871	Arrow
	Completed	Existing	Main Range Volcanics	-27.2681	151.7701	Arrow
RN 42231524	Completed	Existing	Walloon Coal Measures	-27.2681	151.7701	Arrow
RN 42231590	Completed	Existing	Hutton Sandstone	-27.2681	151.7701	Arrow
UWIR Site 138	2016	Proposed	Bandanna Formation	-23.4558	148.9483	Arrow

Bore Name	Planned construction date	Monitoring bore: Existing / Proposed	Target Monitoring Formations	latitude	longitude	Responsible Proponent
Hopeland-17	2013	Proposed	Upper Juandah CMs, Lower Juandah CMs, Taroom Coals	-26.9729	150.6118	Arrow
Hopeland-17	2013	Proposed	Springbok Sandstone	-26.9729	150.6118	Arrow
Hollyrood 5	Completed	Existing	Lower Juandah CMs, Taroom CMs	-26.7922	148.7417	Santos
	Completed	Existing	Gubberamunda Sandstone	-26.7922	148.7417	Santos
WBLGWG06	2013	Proposed	Gubberamunda Sandstone	-26.7825	149.1969	Santos
54	2013	Proposed	Springbok Sandstone	-26.7825	149.1969	Santos
	2013	Proposed	Hutton Sandstone	-26.7825	149.1969	Santos
	2016	Proposed	Juandah CMs, Taroom CMs	-26.7875	149.2012	Santos
Coonardoo 2	Completed	Existing	Mooga Sandstone	-26.6833	148.9923	Santos
	Completed	Existing	Gubberamunda Sandstone	-26.6833	148.9923	Santos
	Completed	Existing	Juandah CMs, Taroom CMs	-26.6833	148.9923	Santos
RIC25	Completed	Existing	Juandah CMs, Taroom CMs	-26.6737	148.8464	Santos
Latemore South 2	Completed	Existing	Juandah CMs, Taroom CMs	-26.6366	149.1119	Santos
	Completed	Existing	Gubberamunda Sandstone	-26.6366	149.1119	Santos
	Completed	Existing	Springbok Sandstone	-26.6366	149.1119	Santos
BXGGWM02	Completed	Existing	Mooga Sandstone	-26.6033	149.3735	Santos
BXGGWG04	Completed	Existing	Gubberamunda Sandstone	-26.6033	149.3735	Santos
65	2016	Proposed	Juandah CMs	-26.6033	149.3932	Santos
Damper Creek 4a	2013	Completed	Juandah CMs	-26.5826	148.8511	Santos
	2013	Completed	Hutton Sandstone	-26.5826	148.8511	Santos
	2013	Completed	Gubberamunda Sandstone	-26.5826	148.8511	Santos
66	2013	Proposed	Springbok Sandstone	-26.5826	148.8511	Santos
Damper Creek 4a	2013	Completed	Mooga Sandstone	-26.5826	148.8511	Santos
Wingnut 3 (WNT3)	2013	Completed	Juandah CMs, Taroom CMs	-26.5331	149.0543	Santos
	2013	Completed	Gubberamunda Sandstone	-26.5331	149.0543	Santos
70	2013	Proposed	Springbok Sandstone	-26.5331	149.0543	Santos
70	2013	Proposed	Hutton Sandstone	-26.5331	149.0543	Santos
Latemore 2	2013	Proposed	Precipice Sandstone	-26.5855	149.0775	Santos
Stakeyard East 1	Completed	Existing	Juandah CMs	-26.5268	149.2130	Santos
	Completed	Existing	Gubberamunda Sandstone	-26.5268	149.2130	Santos
	Completed	Existing	Springbok Sandstone	-26.5268	149.2130	Santos
	Completed	Existing	Hutton Sandstone	-26.5268	149.2130	Santos
	Completed	Existing	Mooga Sandstone	-26.5268	149.2130	Santos
72	2013	Proposed	Gubberamunda Sandstone	-26.5310	149.8271	Santos
	2013	Proposed	Juandah CMs, Taroom CMs	-26.5310	149.8271	Santos
	2013	Proposed	Precipice Sandstone	-26.5310	149.8271	Santos
	2013	Proposed	Hutton Sandstone	-26.5310	149.8271	Santos
	2013	Proposed	Springbok Sandstone	-26.5310	149.8271	Santos
Bendemere 1	Completed	Existing	Juandah CMs, Taroom CMs	-26.4948	149.2130	Santos
	Completed	Existing	Gubberamunda Sandstone	-26.4948	149.2130	Santos
	Completed	Existing	Westbourne Formation	-26.4948	149.2130	Santos
	Completed	Existing	Springbok Sandstone	-26.4948	149.2130	Santos
TBD_VWP	Completed	Existing	Orallo Formation	-26.4652	149.0144	Santos
	Completed	Existing	Westbourne Formation	-26.4652	149.0144	Santos
76	2013	Proposed	Springbok Sandstone	-26.4392	148.9152	Santos
	2016	Proposed	Juandah CMs, Taroom CMs	-26.4392	148.9152	Santos
Montana 1 (MTA1)	Completed	Existing	Gubberamunda Sandstone	-26.4391	148.8004	Santos
Montana 1 (MTA1)	Completed	Existing	Juandah CMs, Taroom CMs	-26.4391	148.8004	Santos
ARMGWG13	2013	Proposed	Gubberamunda Sandstone	-26.3872	149.1257	Santos
ARMGWS03	2013	Proposed	Springbok Sandstone	-26.3872	149.1257	Santos
ARMGWH01	2013	Proposed	Hutton Sandstone	-26.3872	149.1257	Santos
BBWGW001	Completed	Existing	Orallo Formation	-26.4302	149.3388	Santos
BBWVWP	Completed	Existing	Mooga Sandstone	-26.4302	149.3388	Santos
82	2015	Proposed	Juandah CMs, Tangalooma Sst, Taroom CMs, Lower Walloon aquitard	-26.3872	149.1257	Santos
BLBGWM01	Completed	Existing	Mooga Sandstone	-26.3788	-26.3788	Santos
BLBGWG01	Completed	Existing	Gubberamunda Sandstone	-26.3788	-26.3788	Santos
Navarra 1	Completed	Existing	Gubberamunda Sandstone	-26.3365	148.8381	Santos
	Completed	Existing	Juandah CMs	-26.3365	148.8381	Santos
Mt. Eden 1 (MED1)	Completed	Existing	Juandah CMs	-26.2952	148.6330	Santos
104	2013	Proposed	Hutton Sandstone	-25.8258	149.0376	Santos
	2013	Proposed	Precipice Sandstone	-25.8258	149.0376	Santos
	2015	Proposed	Bandanna Formation	-25.8258	149.0376	Santos

Bore Name	Planned construction date	Monitoring bore: Existing / Proposed	Target Monitoring Formations	latitude	longitude	Responsible Proponent
FVW0902	Completed	Existing	Precipice Sandstone	-25.7863	148.8459	Santos
106	2014	Proposed	Boxvale Sandstone	-25.7863	148.8459	Santos
	2015	Proposed	Bandanna Formation	-25.7865	148.8467	Santos
FVW0903	Completed	Existing	Precipice Sandstone	-25.7538	148.7948	Santos
FVMW0902	Completed	Existing	Precipice Sandstone	-25.7347	149.0829	Santos
Dawson Bend 3 (WQ monitoring)	2015	Proposed	Bandanna Formation	-25.7353	149.0825	Santos
FVMW0903	Completed	Existing	Precipice Sandstone	-25.7310	148.9810	Santos
Fairview 182 (WQ monitoring)	2015	Proposed	Bandanna Formation	-25.7410	148.9777	Santos
112	2013	Proposed	Clematis Sandstone	-25.6446	149.1655	Santos
	2015	Proposed	Bandanna Formation	-25.6446	149.1655	Santos
113	2013	Proposed	Clematis Sandstone	-25.5317	148.7694	Santos
	2015	Proposed	Bandanna Formation	-25.5317	148.7694	Santos
114	2015	Proposed	Bandanna Formation	-25.4100	148.9052	Santos
115	2013	Proposed	Clematis Sandstone	-25.3492	149.0188	Santos
	2014	Proposed	Bandanna Formation	-25.3492	149.0188	Santos
116	2013	Proposed	Clematis Sandstone	-25.2420	148.9269	Santos
	2016	Proposed	Bandanna Formation	-25.2420	148.9269	Santos
117	2014	Proposed	Clematis Sandstone	-25.1784	148.8487	Santos
	2015	Proposed	Bandanna Formation	-25.1784	148.8487	Santos
118	2013	Proposed	Clematis Sandstone	-24.9198	149.0980	Santos
119	2013	Proposed	Clematis Sandstone	-24.7348	149.1400	Santos
122	2016	Proposed	Springbok Sandstone	-26.9346	149.6603	Santos
	2016	Proposed	Juandah CMs	-26.9346	149.6603	Santos
123	2013	Proposed	Hutton Sandstone	-25.9266	148.6361	Santos
	2013	Proposed	Precipice Sandstone	-25.9266	148.6361	Santos
	2016	Proposed	Walloon CMs; Bandanna Fm	-25.9266	148.6361	Santos
126	2014	Proposed	Precipice Sandstone	-27.7623	150.2355	Santos
127	2015	Proposed	Bandanna Formation	-25.8580	150.0812	Santos
129	2014	Proposed	Hutton Sandstone	-25.8246	148.7914	Santos
130	2013	Proposed	Precipice Sandstone	-25.6386	148.9103	Santos
	2015	Proposed	Bandanna Formation	-25.6386	148.9103	Santos
139	2016	Proposed	Bandanna Formation	-25.3170	148.6629	Santos
1	2016	Proposed	Gubberamunda Sandstone	-27.9667	150.9196	APLNG
	2016	Proposed	Springbok Sandstone	-27.9681	150.9203	APLNG
	2016	Proposed	Upper Juandah CMS	-27.9651	150.9236	APLNG
	2016	Proposed	Lower Juandah CMs	-27.9651	150.9236	APLNG
	2016	Proposed	Taroom CMs	-27.9650	150.9232	APLNG
2	2013	Proposed	Springbok Sandstone	-27.7895	150.9465	APLNG
	2013	Proposed	Upper Juandah CMS	-27.7942	150.9460	APLNG
	2013	Proposed	Lower Juandah CMs	-27.7942	150.9460	APLNG
	2013	Proposed	Taroom CMs	-27.7942	150.9460	APLNG
	2013	Proposed	Hutton Sandstone	-27.7895	150.9465	APLNG
6	2013	Proposed	Gubberamunda Sandstone	-27.5987	150.8990	APLNG
	2013	Proposed	Springbok Sandstone	-27.5987	150.8990	APLNG
	2013	Proposed	Upper Juandah CMS	-27.5983	150.8988	APLNG
	2013	Proposed	Lower Juandah CMs	-27.5983	150.8988	APLNG
	2013	Proposed	Taroom CMs	-27.5983	150.8988	APLNG
22	2013	Proposed	Springbok Sandstone	-27.2464	150.3367	APLNG
	2013	Proposed	Upper Juandah CMS	-27.2475	150.3366	APLNG
	2013	Proposed	Lower Juandah CMs	-27.2475	150.3366	APLNG
	2013	Proposed	Taroom CMs	-27.2475	150.3366	APLNG
	2013	Proposed	Hutton Sandstone	-27.2479	150.3365	APLNG
25	2016	Proposed	Gubberamunda Sandstone	-27.2455	150.4577	APLNG
	2016	Proposed	Springbok Sandstone	-27.2454	150.4577	APLNG
	2016	Proposed	Upper Juandah CMS	-27.2454	150.4573	APLNG
	2016	Proposed	Lower Juandah CMs	-27.2454	150.4573	APLNG
	2016	Proposed	Taroom CMs	-27.2454	150.4573	APLNG
35	2013	Proposed	Gubberamunda Sandstone	-27.1083	150.3942	APLNG
	2013	Proposed	Springbok Sandstone	-27.1083	150.3942	APLNG
	2013	Proposed	Upper Juandah CMS	-27.1111	150.3901	APLNG
	2013	Proposed	Lower Juandah CMs	-27.1111	150.3901	APLNG
	2013	Proposed	Taroom CMs	-27.1111	150.3901	APLNG
36	2016	Proposed	Springbok Sandstone	-27.1083	150.2213	APLNG
	2016	Proposed	Upper Juandah CMS	TBA	TBA	APLNG
	2016	Proposed	Lower Juandah CMs	TBA	TBA	APLNG

Bore Name	Planned construction date	Monitoring bore: Existing / Proposed	Target Monitoring Formations	latitude	longitude	Responsible Proponent
38	2016	Proposed	Taroom CMs	TBA	TBA	APLNG
	2016	Proposed	Hutton Sandstone	TBA	TBA	APLNG
	2013	Proposed	Springbok Sandstone	-27.0401	150.7790	APLNG
	2013	Proposed	Upper Juandah CMS	-27.0401	150.7790	APLNG
	2013	Proposed	Lower Juandah CMs	-27.0401	150.7790	APLNG
	2013	Proposed	Taroom CMs	-27.0401	150.7790	APLNG
40	2013	Proposed	Springbok Sandstone	-27.0224	150.3171	APLNG
44	2012	Existing	Gubberamunda Sandstone	-26.9417	150.2119	APLNG
	2012	Existing	Springbok Sandstone	-26.9417	150.2119	APLNG
	2013	Proposed	Upper Juandah CMS	-26.9315	150.2294	APLNG
	2013	Proposed	Lower Juandah CMs	-26.9315	150.2294	APLNG
	2013	Proposed	Taroom CMs	-26.9315	150.2294	APLNG
45	2016	Proposed	Springbok Sandstone	-26.8749	150.0195	APLNG
	2016	Proposed	Upper Juandah CMS	-26.8749	150.0195	APLNG
	2016	Proposed	Lower Juandah CMs	-26.8749	150.0195	APLNG
	2016	Proposed	Taroom CMs	-26.8749	150.0195	APLNG
	2016	Proposed	Hutton Sandstone	-26.8749	150.0195	APLNG
46	2012	Existing	Gubberamunda Sandstone	-26.8930	150.3703	APLNG
	2012	Existing	Westbourne Formation	-26.8932	150.3713	APLNG
	2012	Existing	Springbok Sandstone	-26.8930	150.3703	APLNG
	2013	Proposed	Upper Juandah CMS	-26.8937	150.3683	APLNG
	2013	Proposed	sandstone or siltstone or mudstone of the Juandah Coal Measures	-26.8937	150.3683	APLNG
	2013	Proposed	Lower Juandah CMs	-26.8937	150.3683	APLNG
	2013	Proposed	Tangalooma Sandstone	-26.8937	150.3683	APLNG
	2013	Proposed	Taroom CMs	-26.8937	150.3683	APLNG
	2013	Proposed	lower aquitard of the Walloon Coal Measures	-26.8937	150.3683	APLNG
	2013	Existing	Hutton Sandstone	-26.8924	150.3689	APLNG
	2012	Existing	Gubberamunda Sandstone	-26.8086	150.1710	APLNG
	2012	Existing	Springbok Sandstone	-26.8085	150.1710	APLNG
	2013	Proposed	Upper Juandah CMS	-26.7887	150.2176	APLNG
50	2013	Proposed	Lower Juandah CMs	-26.7887	150.2176	APLNG
	2013	Proposed	Taroom CMs	-26.7887	150.2176	APLNG
	2013	Existing	Hutton Sandstone	-26.8079	150.1708	APLNG
51	2013	Proposed	Hutton Sandstone	-26.8215	150.5541	APLNG
53	2012	Existing	Springbok Sandstone	-26.7578	150.3603	APLNG
	2016	Existing	Upper Juandah CMS	-26.8231	150.3492	APLNG
56	2013	Existing	Springbok Sandstone	-26.7311	150.4939	APLNG
	2013	Proposed	Upper Juandah CMS	-26.7314	150.4930	APLNG
	2013	Proposed	Lower Juandah CMs	-26.7314	150.4930	APLNG
	2013	Proposed	Taroom CMs	-26.7314	150.4930	APLNG
59	2016	Proposed	Gubberamunda Sandstone	-26.7142	150.0000	APLNG
	2016	Proposed	Springbok Sandstone	-26.7141	150.0000	APLNG
61	2016	Proposed	Springbok Sandstone	-26.6339	149.6881	APLNG
62	2013	Existing	Springbok Sandstone	-26.6295	150.1455	APLNG
	2013	Proposed	Upper Juandah CMS	-26.6840	150.2274	APLNG
	2013	Proposed	Lower Juandah CMs	-26.6840	150.2274	APLNG
	2013	Proposed	Taroom CMs	-26.6840	150.2274	APLNG
	2012	Existing	Precipice Sandstone	-26.6840	150.2262	APLNG
63	2016	Proposed	Upper Juandah CMS	-26.6417	149.8352	APLNG
	2016	Proposed	Lower Juandah CMs	-26.6417	149.8352	APLNG
	2016	Proposed	Taroom CMs	-26.6417	149.8352	APLNG
68	2013	Existing	Springbok Sandstone	-26.5536	150.1040	APLNG
	2013	Proposed	Upper Juandah CMS	-26.5630	150.0997	APLNG
	2013	Proposed	Lower Juandah CMs	-26.5630	150.0997	APLNG
	2013	Proposed	Taroom CMs	-26.5630	150.0997	APLNG
	2013	Proposed	Hutton Sandstone	-26.5634	150.0996	APLNG
69	2012	Existing	Mooga Sandstone	-26.5398	149.9595	APLNG
79	2013	Existing	Springbok Sandstone	-26.4819	149.7866	APLNG
	2013	Proposed	Upper Juandah CMS	-26.4005	149.7002	APLNG
	2013	Proposed	Lower Juandah CMs	-26.4005	149.7002	APLNG
	2013	Proposed	Taroom CMs	-26.4005	149.7002	APLNG
80	2013	Proposed	Gubberamunda Sandstone	-26.3994	149.5828	APLNG
	2013	Proposed	Springbok Sandstone	-26.3995	149.5828	APLNG
	2013	Proposed	Upper Juandah CMS	-26.4024	149.5772	APLNG
	2013	Proposed	Lower Juandah CMs	-26.4024	149.5772	APLNG
	2013	Proposed	Taroom CMs	-26.4024	149.5772	APLNG
84	2013	Existing	Springbok Sandstone	-26.3855	149.8473	APLNG

Bore Name	Planned construction date	Monitoring bore: Existing / Proposed	Target Monitoring Formations	latitude	longitude	Responsible Proponent
	2013	Proposed	Upper Juandah CMS	-26.3850	149.8478	APLNG
	2013	Proposed	Lower Juandah CMs	-26.3850	149.8478	APLNG
	2013	Proposed	Taroom CMs	-26.3850	149.8478	APLNG
85	2013	Existing	Springbok Sandstone	-26.3563	149.4267	APLNG
	2013	Existing	Upper Juandah CMS	-26.3566	149.4269	APLNG
85	2013	Existing	Lower Juandah CMs	-26.3566	149.4269	APLNG
	2013	Existing	Taroom CMs	-26.3566	149.4269	APLNG
	2013	Existing	Hutton Sandstone	-26.3577	149.4266	APLNG
87	2013	Proposed	Gubberamunda Sandstone	-26.3202	149.2627	APLNG
	2013	Proposed	Springbok Sandstone	-26.3201	149.2627	APLNG
	2013	Proposed	Upper Juandah CMS	-26.3183	149.2637	APLNG
	2013	Proposed	Lower Juandah CMs	-26.3183	149.2637	APLNG
	2013	Proposed	Taroom CMs	-26.3183	149.2637	APLNG
92	2013	Proposed	Springbok Sandstone	-26.2310	149.5642	APLNG
	2013	Proposed	Upper Juandah CMS	-26.2306	149.5651	APLNG
	2013	Proposed	Lower Juandah CMs	-26.2306	149.5651	APLNG
	2013	Proposed	Taroom CMs	-26.2306	149.5651	APLNG
93	2013	Proposed	Springbok Sandstone	-26.2423	149.1952	APLNG
	2013	Proposed	Upper Juandah CMS	-26.2423	149.1952	APLNG
	2013	Proposed	Lower Juandah CMs	-26.2423	149.1952	APLNG
	2013	Proposed	Taroom CMs	-26.2423	149.1952	APLNG
	2013	Proposed	Hutton Sandstone	-26.2420	149.1963	APLNG
	2013	Proposed	Precipice Sandstone	-26.2419	149.1967	APLNG
95	2013	Proposed	Bandanna Formation	-26.0749	149.1572	APLNG
98	2013	Existing	Hutton Sandstone	-26.0132	149.1933	APLNG
99	2012	Existing	Bandanna Formation	-25.9765	149.1042	APLNG
101	2012	Existing	Birkhead Formation	-25.9490	149.3514	APLNG
102	2013	Existing	Hutton Sandstone	-25.8645	149.1578	APLNG
	2013	Existing	Precipice Sandstone	-25.9002	149.1444	APLNG
	2013	Proposed	Bandanna Formation	-25.9066	149.1974	APLNG
105	2012	Existing	Precipice Sandstone	-25.8375	148.8510	APLNG
120	2012	Proposed	Boxvale Sandstone	-25.6834	149.1760	APLNG
	2013	Proposed	Precipice Sandstone	-25.6834	149.1760	APLNG
	2013	Proposed	Bandanna Formation	-25.6837	149.1760	APLNG
125	2012	Existing	Mooga Sandstone	-26.3381	149.5033	APLNG
128	2013	Proposed	Bandanna Formation	-26.0152	150.0958	APLNG
131	2013	Existing	Precipice Sandstone	-26.0751	149.0138	APLNG
	2013	Proposed	Bandanna Formation	-26.0429	149.0531	APLNG
132	2013	Proposed	Precipice Sandstone	-25.9325	148.9355	APLNG
	2013	Proposed	Bandanna Formation	-25.9507	148.9734	APLNG
141	2013	Proposed	Springbok Sandstone	-26.2026	149.4239	APLNG
	2013	Proposed	Upper Juandah CMS	-26.2027	149.4239	APLNG
	2013	Proposed	Lower Juandah CMs	-26.2027	149.4239	APLNG
	2013	Proposed	Taroom CMs	-26.2027	149.4239	APLNG

Notes:

Bore location information as best known at 01/02/2013, inclusive of final locations and planned locations not yet finalised

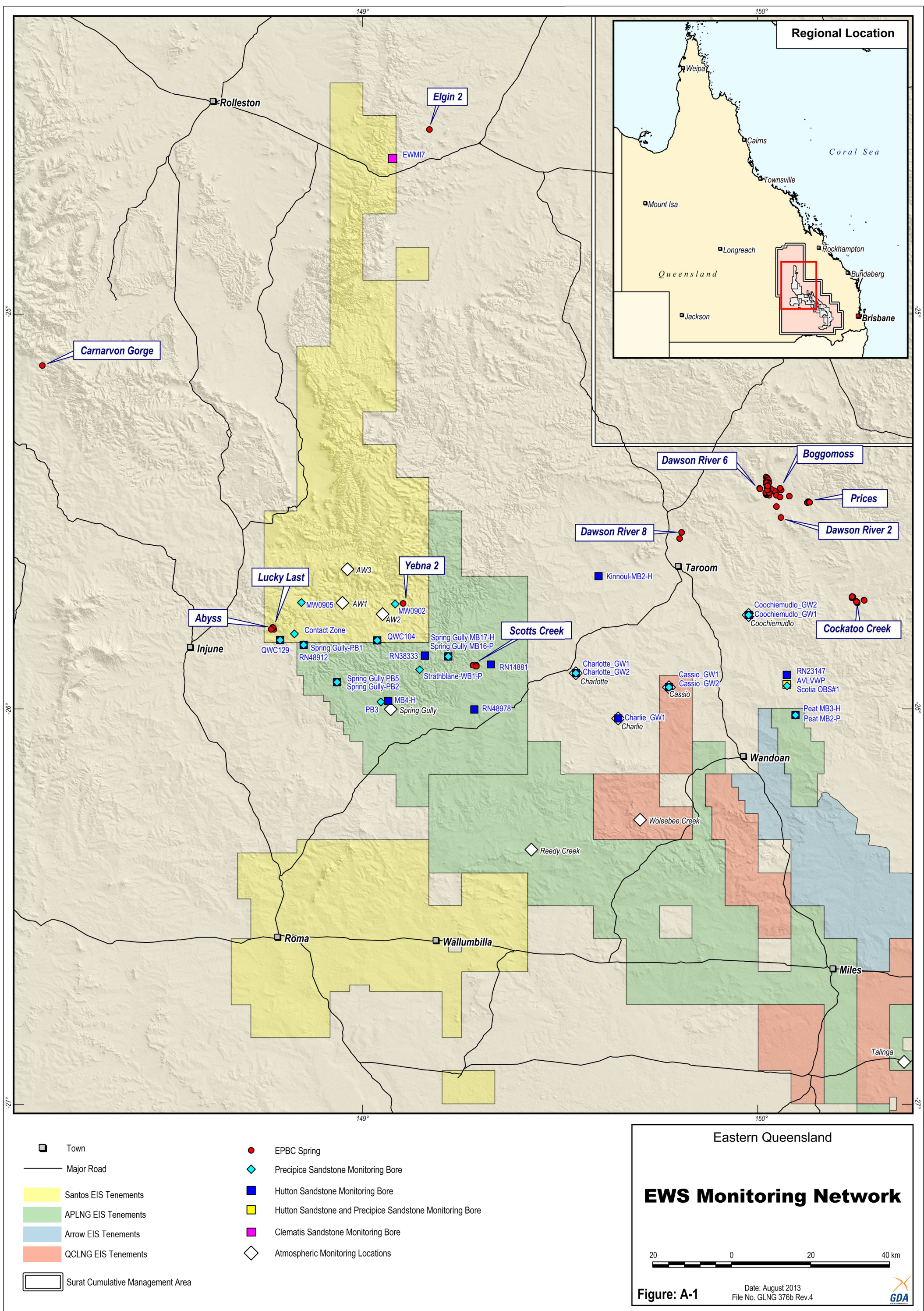
Monitoring objectives as per Surat UWIR, 2012

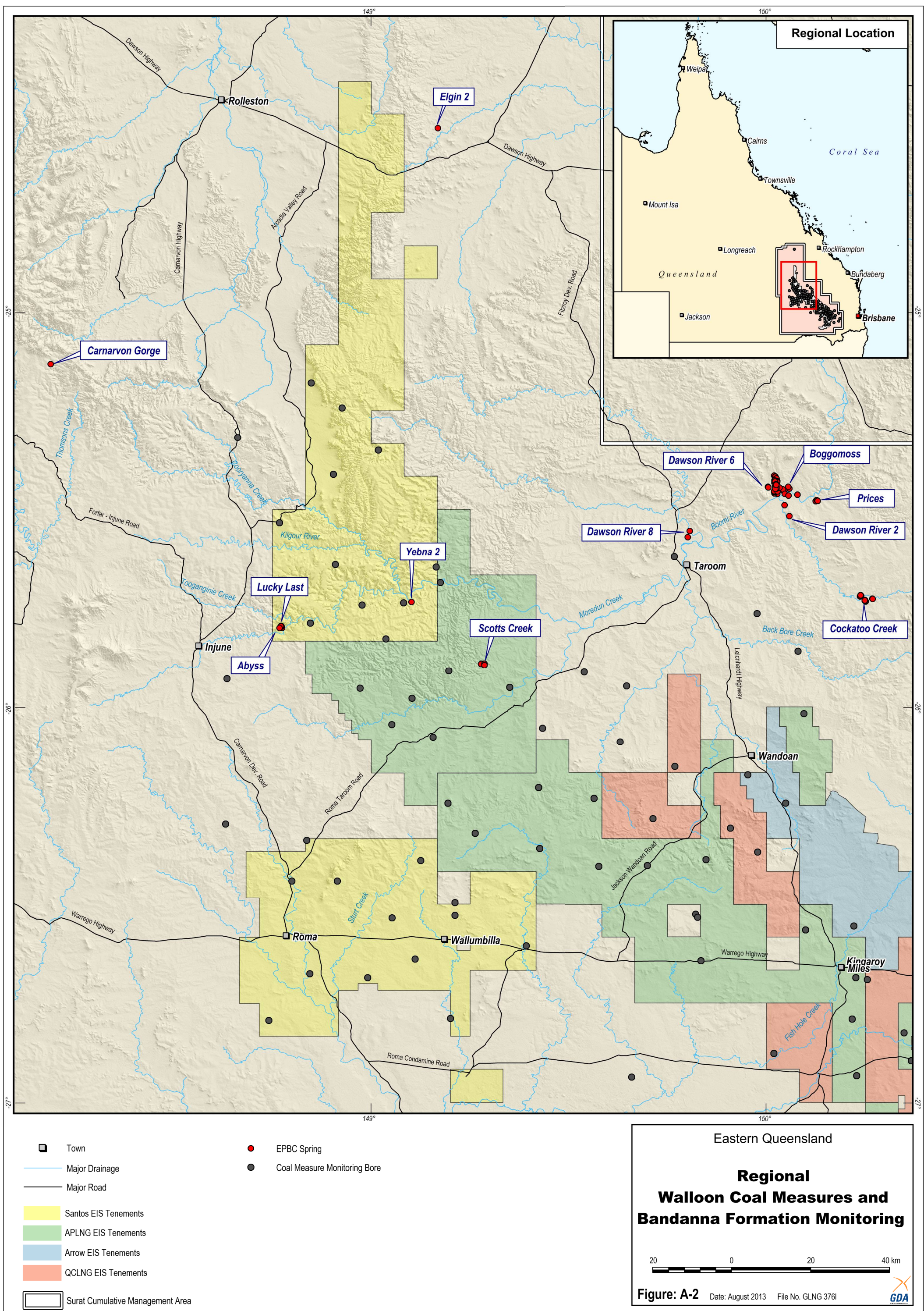
MNES Trigger values, exceedance thresholds or drawdown limit do not apply to these bores unless also selected in the EPBC springs monitoring network (Table 1)

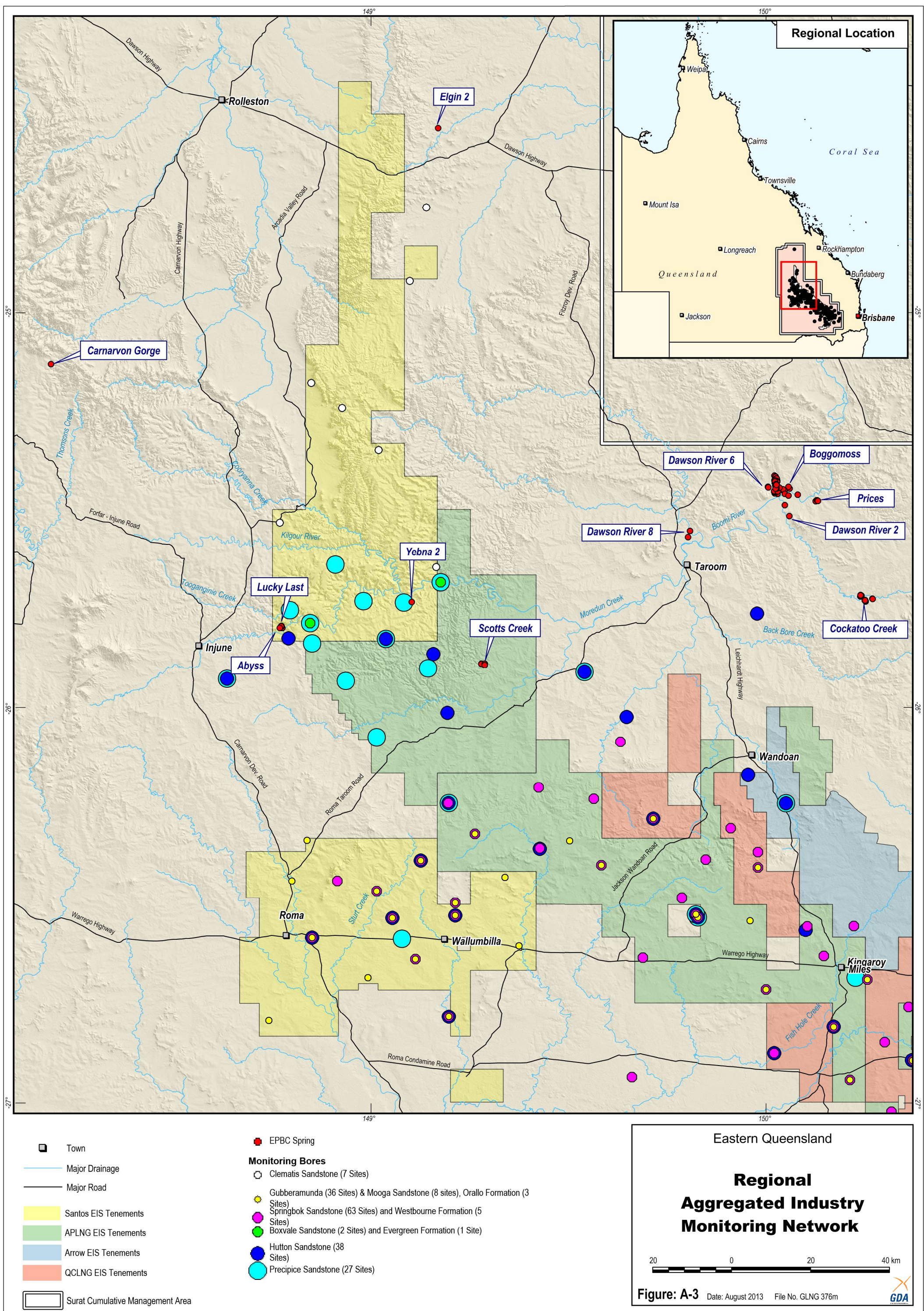
Installation dates are proposed, may vary due to weather and land access constraints

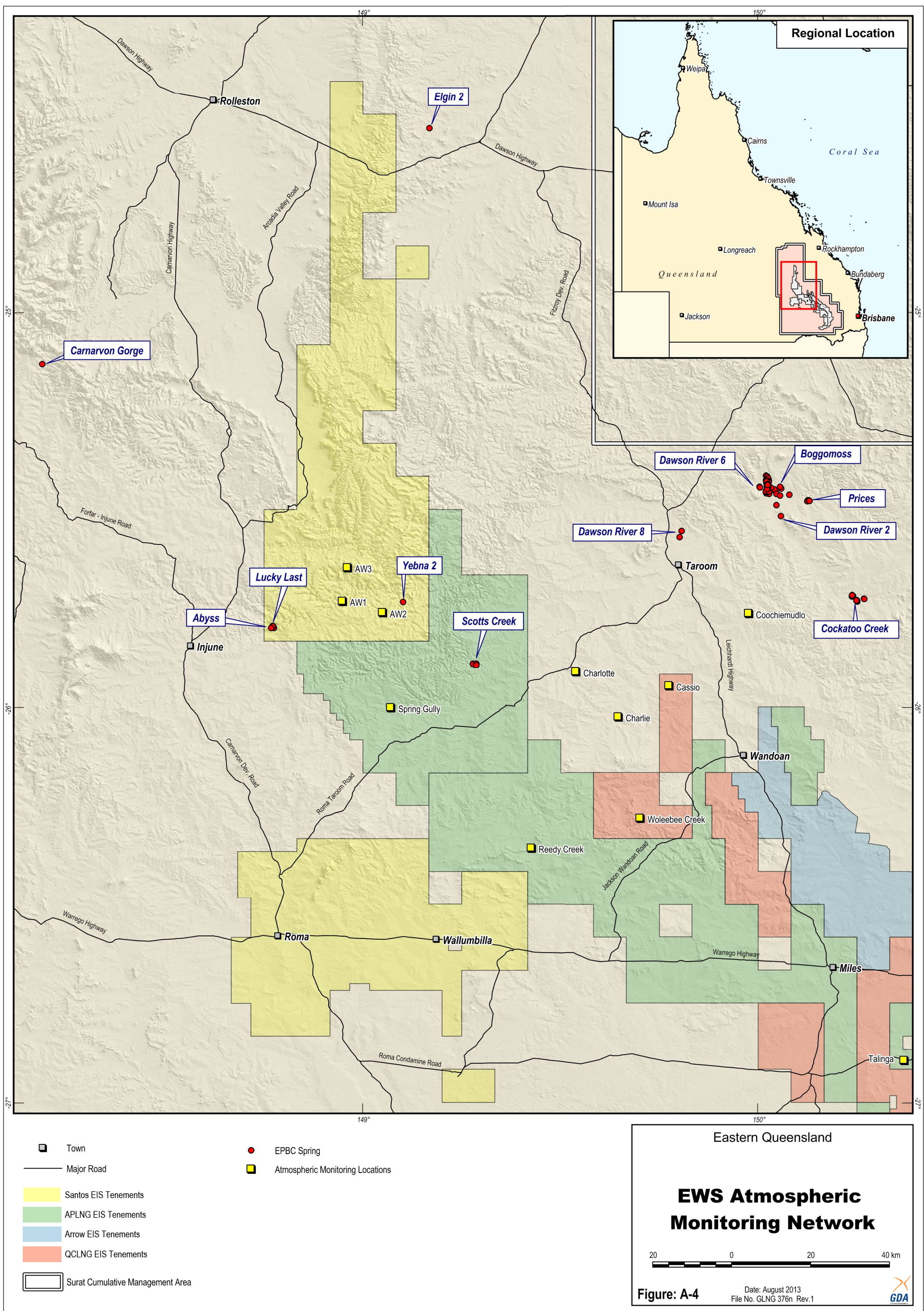
The bore name reflects the Proponent bore's name, or the site number provided in the Surat UWIR

"Proposed" bores include monitoring bores drilled but not yet finalised or ready for monitoring









APPENDIX B – QUALITY PLAN

Joint-Industry Early Warning System for Springs Quality Plan

Table of Contents:

1.	Introduction & Objectives of the Quality Plan	1
2.	Roles and Responsibilities	3
3.	Surat UWIR Conditions	4
4.	Spring Monitoring	5
	4.1.1. Location	5
	4.1.2. Spring Sampling Methodology.....	9
	4.1.3. Sampling Parameters	12
	4.1.4. Frequency	15
5.	Groundwater Water Monitoring Bores EWS Monitoring.....	16
	5.1. Location	16
	5.2. Groundwater Sampling Methodology	20
	5.3. Sampling Parameters	25
	5.4. Frequency.....	27
6.	Sampling QA/QC.....	28
	6.1. Duplicate samples	28
	6.2. Equipment Blank	29
	6.3. Field Blank.....	29
	6.4. Trip Blank.....	29
	6.5. Laboratory Blanks.....	29
7.	Sampling Handling and Dispatch.....	30
	7.1. Analytical Laboratories	30
	7.2. Sample Handling and Dispatch	30
8.	Data Management	31
9.	QA/QC Validation	33
	9.1. Precision	33
	9.2. Accuracy.....	33
	9.3. Completeness.....	34
	9.4. Representativeness.....	34
	9.5. Verification and Validation	35
10.	Definitions	36
11.	Abbreviations and Units	38
12.	References.....	40

List of Appendices:

APPENDIX A - Spring Monitoring Sites and Sites Label Names
 APPENDIX B – Groundwater Monitoring Sites and Sites Label Names
 APPENDIX C - Example Site ID Information Sheet
 APPENDIX D - Minimum Monitoring and Sampling Equipment
 APPENDIX E - Example Equipment Inspection Template
 APPENDIX F – Example of Calibration and Maintenance Requirements
 APPENDIX G - Sample Naming and Labelling Convention
 APPENDIX H - Chain of Custody Documents
 APPENDIX I - Example Springs Sample Information Sheet
 APPENDIX J - Example of Photograph Record Sheet
 APPENDIX K – Example of Groundwater Low Flow Purging and Sampling Monitoring Sheet
 APPENDIX L – Method for Spring Flow Monitoring as defined in the Surat UWIR (QWC, 2012)

List of Tables:

Table 4-1: Summary of Springs Nominated for Monitoring	6
Table 4-2: Watercourse Springs Nominated for monitoring	7
Table 4-3: Spring Sampling Procedures.....	9
Table 4-4: Springs Water Quality, Baseline and Ongoing (Outlined).....	14
Table 5-1: Groundwater Monitoring Bore Monitoring Network	17
Table 5-2: Low Flow Groundwater Sampling Procedure.....	21
Table 5-3: Groundwater Water Quality, Baseline and Ongoing (outlined)	26
Table 6-1: Summary of QA/QC Sampling Frequency	28
Table 9-1: Summary of Precision	33
Table 9-2: Summary of Accuracy	34
Table 9-3: Summary of Completeness	34
Table 9-4: Summary of Representativeness	35
Table 9-5: Verification and Validation	35

List of Figures

Figure 4-1: Spring Monitoring Locations	8
Figure 5-1: EWS Groundwater Monitoring Bores Location	19
Figure 8-1: Example of Monitoring and Data Management Workflow Diagram	32

1. Introduction & Objectives of the Quality Plan

The major coal seam gas (CSG) operators in the southern Bowen and Surat Basins (Santos GLNG, APLNG, QGC and Arrow Energy, from here on referenced to as the Proponents¹) have collaboratively developed this Quality Plan. The Quality Plan is a complementary document to the Joint-Industry Plan (JIP); it provides the quality requirements to ensure uniformity of approach and the quality and reliability of the results for monitoring data collected at the groundwater monitoring bores from the Early Warning System (EWS) monitoring network and at EPBC springs. The quality plan also applies to the monitoring work required in the Surat UWIR (QWC, 2012) Under the QLD Water Act.

This document serves to:

- Provide detailed monitoring methodologies for collection of representative spring water and groundwater samples;
- Define the requirement of the quality assurance / quality control program (QAQC); and
- Define the process for validation of the data.

The Quality Plan does not include the rationale for the establishment of the monitoring locations, monitoring bore installation methods, nor the reporting requirements for the data collected as part of this plan.

The Quality Plan is intended for use by the environmental field staff and those overseeing implementation of the monitoring programme. This Quality Plan has been prepared to facilitate consistent and scientifically robust implementation of the monitoring programme across the industry. The data collected from the activities defined in this plan will be utilised to assess changes to the monitored parameters. Changes identified during the monitoring program will be used to assess potential impacts to springs and provide early warning of any need for additional management or mitigation

This document, while addressing the Department of the Environment requirements also combines the spring monitoring requirements as set by the Surat UWIR (see Section 3.2).

The Quality Plan applies to the two types of monitoring performed in the context of spring monitoring:

- Monitoring at the spring vents; and
- Monitoring of the primary source aquifers at the monitoring bores forming the JIP EWS groundwater network.

The locations to which this plan applies to date are provided in the appendices, the list will evolve over time.

This Quality Plan was prepared in accordance with the following regulatory requirements:

- Department of the Environment monitoring requirements as specified within the EPBC Act 1999 Referrals; and
- Queensland Department of Environment and Heritage Protection (EHP) Environmental Authority (EA) Conditions.
- Section 378 of the Commonwealth Water Act (2000)

Additional consideration was given to the following reports:

- Surat Underground Water Impact Report (UWIR) Groundwater and Spring Monitoring Programs Requirements; and

¹ Note: Although Arrow does not yet have any project conditions set under the EPBC Act, Arrow has been consulted in the development of the Plan and supports this Quality Plan.

- Joint Industry Plan for Early Warning System for the Monitoring and Protection of (EPBC) Springs, (JIP).

2. Roles and Responsibilities

This Quality Plan is intended for use by suitably qualified and experienced personnel. A suitably qualified person is one who holds relevant qualifications, has demonstrated professional experience encompassing an appropriate range of competencies and has relevant inductions and training.

The monitoring can either be done in-house by the Proponents or contracted to appropriately qualified consultants. In the latter case, it will be the responsibility of the Proponent to ensure the quality requirements and procedures set out under this Plan are adhered to.

3. Surat UWIR Conditions

The Quality Plan was initially developed to ensure uniformity and reliability of data monitoring associated with the JIP. However, the Proponents are also required to undertake monitoring activities under the Surat Underground Water Impact Report (Surat UWIR, QWC, 2012), those requirements have been included in the Quality Plan. Section 8 of the UWIR describes the spring monitoring requirements. Responsible tenure holders must undertake quarterly monitoring and report results to the Commission every six months on a number of springs and spring watercourse areas.

In accordance with the Surat UWIR water monitoring program, monitoring requirements include:

- Spring flow,
- Spring wetted area,
- Water chemistry,
- Presence of EPBC listed flora and macro-invertebrates, and
- Physical conditions.

The Surat UWIR requirements will also be captured in this Quality Plan

4. Spring Monitoring

The Proponents have developed this Quality Plan for a collaborative approach to establish a monitoring program for EPBC springs and a regional EWS groundwater monitoring network. This program includes the monitoring of springs and of the monitoring bores forming the EWS. This section focusses on the monitoring at the springs.

Sampling Quality Assurance / Quality Control (QA/QC), sample handling and dispatch, and data management are discussed in Sub-sections 6 through 8, respectively.

An inventory of the EPBC springs within 100 km of the modelled maximum drawdown (defined by QWC, 2012) is currently underway. This inventory aims to identify all the springs within 100 km of zero drawdown extent and complete a ground truthing exercise to map the EPBC springs. The springs identified as GAB discharge springs and hosting EPBC listed species (i.e. EPBC Springs) will be added to this Quality Plan.

4.1.1. Location

To date, a total of 12 EPBC spring complexes consisting of 94 vents have been identified within the Surat Basin (QLD Herbarium for QWC, 2012). The Surat UWIR requires monitoring of 10 spring complexes consisting of 33 spring vents. In addition, a spring mitigation strategy is required at five of these complexes. Additional spring locations may be added overtime, similarly monitoring requirements may evolve overtime.

Spring complexes and spring watercourses required for monitoring and their associated vents are summarised in Table 4-1 and Table 4-2 and illustrated on Figure 4-1.

The site name and physical location of each of these springs is included in APPENDIX A. In the event that additional spring complexes are added or removed in the future, this Plan will be updated to incorporate the new spring complexes.

Table 4-1: Summary of Springs Nominated for Monitoring

Spring Complex Name	Spring Complex Number	Number of EPBC-listed Vents in Complex ⁽¹⁾	Vent Number(s)	Location of Spring	UWIR – Selected Spring for monitoring	UWIR – Selected Spring for mitigation	EPBC Springs
Abyss	592	1	286	On Santos tenement	✓	✗	✓
Abyss	592	0	716, 286.1, 286.2, 286.3	On and off Santos tenements	✓	✗	✗
Barton	283	0	702, 703	On APLNG tenement	✓	✓	✗
Boggomoss	5	30	2, 3, 7-15, 29, 33, 37, 37v2, 44, 53-58, 61, 62, 63, 68, 68B, 29B, 44B	Off-tenure	✗	✗	✓
Cockatoo Creek	9	19	319, 320, 320.1, 321, 321.2, 321.3, 321.4, 321.4, 321.5, 321.6, 321.7, 321.8, 64, 64.1, 65, 65.1, 65.2, 66, 684	Off-tenure	✓	✗	✓
Dawson River 2	2	1	42	Off-tenure	✗	✗	✓
Dawson River 6	6	16	1,6 ,22,27, 60, 43	Off-tenure	✗	✗	✓
Dawson River 8	8	3	26,28,38	Off-tenure	✓	✗	✓
Elgin 2	594	1	540	Off-tenure	✗	✗	✓
Lucky Last	230	12	287,340, 686,687,687.1,687.2,687.3,687.4,687.5,687.6,688,689	On Santos tenement	✓	✓	✓
Ponies	229	0	284	On Santos tenement	✓	✗	✗
Prices	580	4	40,41,52,67	Off-tenure	✗	✗	✓
Scotts Creek	260	5	189-192, 192.1	On APLNG tenement	✓	✓	✓
Spring Rock Creek	561	0	285	On Santos tenement	✓	✓	✗
Wambo	584	0	711, 711.1	On QGC tenement	✓	✗	✗
Yebna 2	591	1	534	On Santos tenement	✓	✓	✓
311	311	0	535, 536, 537, 704	On Santos tenement	✓	✓	✗

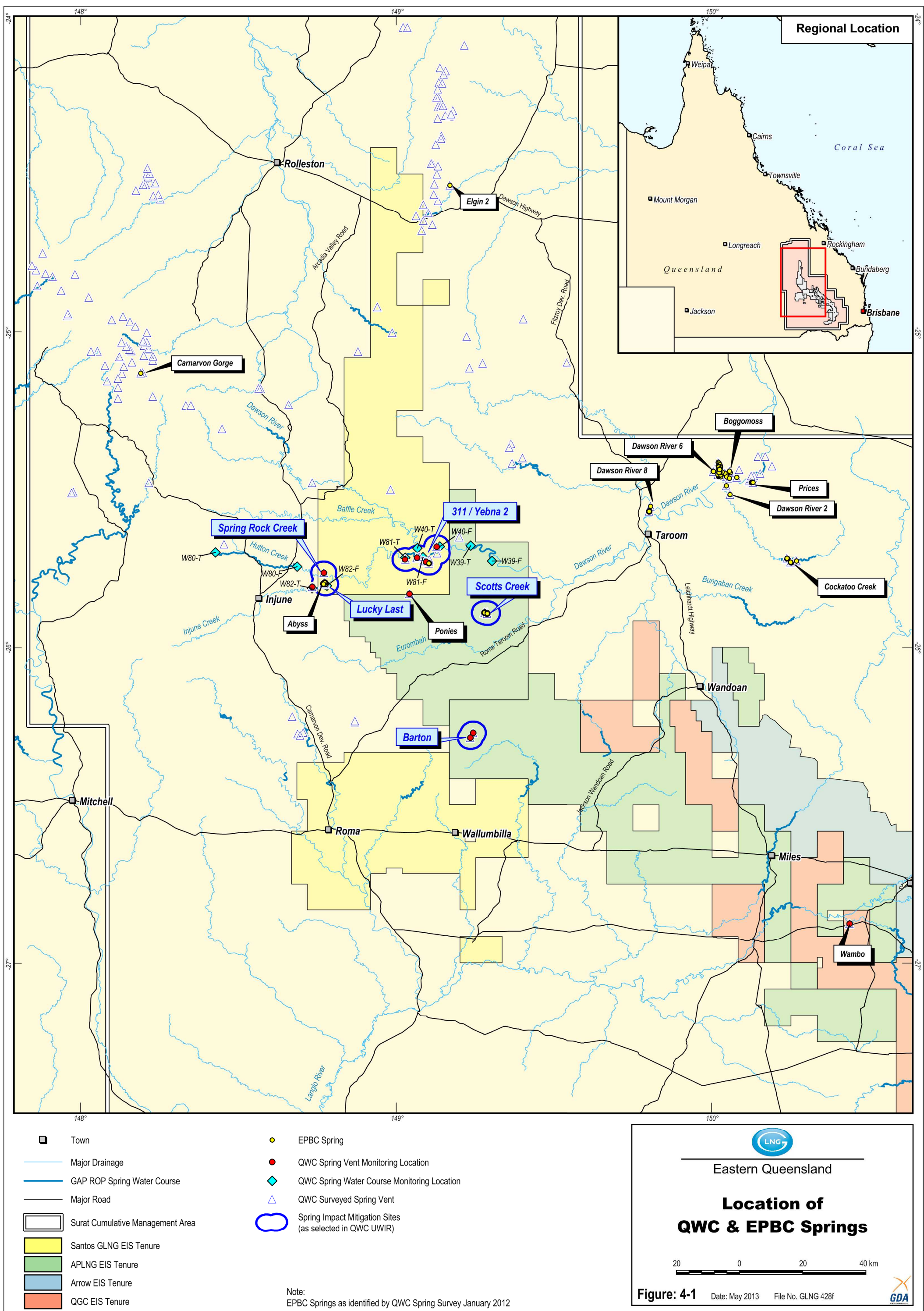
Notes:

- Spring names, complex numbers and vent numbers as per KCB studies for QWC.

(1) Two spring complexes are located over the same area and are generally referred to as one spring. Only Yebna 2 is EPBC listed

Table 4-2: Watercourse Springs Nominated for monitoring

Watercourse spring site number	Start Latitude	Start Longitude	Finish Latitude	Finish Longitude	Location of watercourse spring	UWIR – Selected Spring for monitoring
W39	-25.7256	149.3031	-25.6767	149.2351	On APLNG tenement	✓
W40	-25.6795	149.1373	-25.6848	149.0665	On Santos tenement	✓
W80	-25.7434	148.6857	-25.6977	148.4273	Off-tenure	✓
W81	-25.7127	149.0837	-25.7151	149.0283	On Santos tenement	✓
W82	-25.8038	148.7799	-25.8119	148.7327	On Santos tenement	✓



4.1.2. Spring Sampling Methodology

Table 4-2 below summarises the procedures for collecting spring samples. The spring monitoring procedure was developed in accordance with the methodology for spring monitoring presented in the UWIR (QWC, 2012).

Table 4-3: Spring Sampling Procedures

Step	Procedure
1. Prior to departure for site	- Conduct all pre-departure activities in compliance with company travel policies and procedures. - Ensure that permission has been granted for access to each site according to company policies and procedures. - Check site accessibility following wet weather - Ensure weed management procedures are followed. Vehicles must be cleaned and a weed hygiene declaration obtained. - Obtain the current Site ID Information Sheet and complete the form (initial visit) or review the form for site-specific information (refer APPENDIX B). - Ensure that all sampling equipment and supplies, PPE and decontamination equipment are transported to site. Refer to APPENDIX C for a list of monitoring equipment. - Ensure field equipment is calibrated prior to commencing the monitoring works r. Refer to APPENDIX D and APPENDIX E for the Equipment Inspection Template and Calibration Record Sheets, respectively.
2. Accessing sampling location	- Ensure access is safe (no flood, no fire hazard for example). The initial site visit will establish safe areas for parking the vehicle. This is not only important for safety but also critical at some sites to avoid damage to minor spring vents. - To avoid potential contamination do not disturb or modify the source pools or flow for the samples when accessing sampling locations or collecting samples - Park in designated areas and follow established tracks unless otherwise specified. - At mound springs, avoid walking on the spring structure, especially the smaller ones as those structures may not be solid enough to bear the weight of a person. - Access the previously sampled pool of water or find a suitable pool of water close to the vent. - Collect sample from as close to the actual physical monitoring point marked as possible. The use of a sampling pole may be necessary for some locations. Care should be taken while approaching mound springs. - Take care to minimise disturbance to the site. Do not leave any litter at the site. - Mound springs may not produce ponding water.
3. Field Observations	- Complete field observations section of Water COC (APPENDIX G). - Complete the Spring Sample Information Sheet (APPENDIX H).
4. Spring Flow Measurements	- During initial/ first visit to a spring: - Identify if the method required by the Surat UWIR is feasible (APPENDIX K). - Identify a suitable control point. - Use a standard low-flow hydrology method suitable for the site. - Record the method. Use the same control point and method each time the flow is measured. - Photograph the control points each time the flow is measured. - Record the photographs in accordance with the Photograph Record Sheet within APPENDIX I. - For watercourse springs, measure the flow at the start and finish locations. - For watercourse springs, comment on the extent of the flow beyond the end location.

Step	Procedure
	- Assign one of the following classifications of the spring. 1 = Wetland vegetation, spring pool, minor or major flow(s). 2 = Wetland vegetation, no spring pool, surface expression of free water, minor flow(s). 3 = Wetland vegetation, no spring pool, some surface expression of free water. 4 = Damp, wetland vegetation, no surface expression of free water. 5 = Dry, no wetland vegetation, no surface expression of free water, no evidence of salt scalding.
5. Spring Area and Flow	<u>SPRING VENTS:</u> - Measure spring area: - Record a referenced location using a differential GPS at the monitoring site, from which measurements are to be taken. Use a tape to measure length and width of the spring - Measurements will be taken along the perimeter or sides as traversing across the spring is not permitted. - For larger springs, use a differential GPS to establish the perimeter of the spring. The first visit to the spring will confirm the spring vent measure method to be used. - For the monitoring sites where there is flow away from the spring, the flow is to be measured. - If the flow is concentrated into a clearly defined channel where it can be measured, use a standard flow gauging technique. <i>Use the same control point and method each time the flow is measured.</i> - If the flow is not sufficiently concentrated there may be many small flows away from the spring with the result that direct measurement is impractical without potentially damaging spring values. In these situations, a visual estimate is required (QWC 2012). It is also required that one of the following classifications be assigned: 1: Wetland vegetation, spring pool, minor or major flows 2: Wetland vegetation, no spring pool, surface expression of free water, minor flows 3: Wetland, vegetation, no spring pool, some surface expression of free water 4: Damp, wetland vegetation, no surface expression of free water 5: Dry, no wetland vegetation, no surface expression of the water, no evidence of salt scalding. <u>WATERCOURSE SPRINGS:</u> - Estimation of spring area is not required.
6. Spring Physical Condition	<u>SPRING VENTS:</u> - Photograph the spring vent from all aspects using the defined "photography reference point", this will be set at the first site visit, as a minimum coordinates will be recorded, pegs may be present on site. - Photograph any significant disturbances noted at the spring. - For each photograph record the orientation and describe the features in the photograph. - Record the photographs in accordance with the example Photograph Record Sheet within APPENDIX I. - Assign one of the following classifications for spring disturbance. - No evidence of animal disturbance - Less than 10% of the total spring wetland area shows animal disturbance 10 to 50% of the total spring wetland area shows animal disturbance

Step	Procedure
	- More than 50% of the total spring wetland area shows animal disturbance <u>WATERCOURSE SPRINGS:</u> • A physical condition assessment is not required.
7. Labelling Sample Bottles	• Label sample containers in accordance with the established sample naming convention (refer APPENDIX F). • Select the appropriate sample bottles to correspond to the required list of analytes. • Nitrile (or latex) gloves must be worn when labelling the bottles. • Sample bottles are to be labelled as per the sample naming convention provided in APPENDIX F.
8. Field Water Quality Measurements	• The location of designated sampling areas must be recorded, ideally by differential GPS and if possible physically demarcated (e.g. using stakes/permanent markers if permitted) to ensure consistency of sampling locations between sampling events. • All monitoring equipment that is re-used on site must be thoroughly decontaminated prior to and following use at each location. Equipment should be decontaminated with clean water, Decon 90 and deionised water between samples. • Monitoring equipment used for the collection of physical field parameters (e.g., pH, DO, Eh) must be calibrated prior to use in the field; and calibrations records are to be kept. • Nitrile (or latex) gloves must be worn during field measurements and sample collection. When filling a container to measure field parameters, it should be placed below the surface and avoiding disturbance to the bottom strata and to avoiding collection of the surface film. • If flow is present then inlet should face into the flow in the main channel. Avoid turbid areas or back eddies. • Take all care to avoid contamination from the surrounding environment. • Where feasible, measurements should be taken in-situ. If so, the probe must not become covered in mud and must lie in the water. • If water field water quality parameters are measured in-situ they must be stable prior to recording. • Document which method is used to measure field parameters. • Field measurements are to be recorded on both the field sheet and a COC referencing the sample name, date and time; these measurements are also to be recorded within the site field sheet (as per example of Spring Sample Information Sheet in APPENDIX H).
9. Collection of Water Samples (non-isotopic analyses)	• All sampling equipment that is re-used on site must be thoroughly decontaminated prior to and following use at each location. Equipment should be decontaminated with clean water, Decon 90 and deionised water between sample sites. • Nitrile (or latex) gloves must be worn during sample collection. • Collect water samples for the parameters listed in Table 4-3. • Care must be taken when filling bottles with preservatives to avoid overfilling the container. In the event that sample bottles cannot be appropriately collected directly from the source, a clean, intermediate container, may be used. This should be a new non-preserved sample bottle, modified if necessary, and should not be reused between sample locations. Field Filtration: if required, it should occur using a 0.45 µm filter in either vacuum or pressure format. A new filter and storage container (e.g. syringe) must be used for each location sampled. • Collect QA/QC samples in accordance with Section 6. • Consider the following environmental factors when sampling:

Step	Procedure
	- Sampling equipment and containers must be kept away from sources of hydrocarbons; sampling personnel must ensure hands are washed following refuelling of vehicles or handling of equipment. - Samples must not be processed near to operating machinery as exhaust fumes contain a range of inorganic and organic contaminants and particulate material that can influence sample results. - Dust is a potential contaminant for all analyses; vehicles, storage areas and eskies must be cleaned regularly. - Rain can dilution spring source or make identification of previous monitoring site difficult. Unless sampling is urgent, (e.g. investigation) collection should be delayed until rain has ceased or a rain shield used.
10. Collection of Isotope samples • Deuterium H-2; • Oxygen-18; • d-Carbon-13 (DIC); and • Strontium-87/Strontium-86.	• Ensure appropriate sample bottles/vessels are used for individual analytes. • Label sample bottles with the sampling location and time and date of collection • Place the bottle into the spring upside down (if possible) keeping air inside the bottle. • Then fill the bottle by turning the right way up and keeping it submerged. • Ensure all air has been removed from the bottle • Place lid and tighten whilst still underwater. • Ensure no significant bubbles have developed in the sample, if so, re take sample.
11. Collection of Isotope samples • Radiogenic Carbon-14;	• Use laboratory-supplied and prepared containers. • Follow the sampling procedure required by the analytical laboratory • Ensure no or minimal exposure time the atmosphere occurs during sampling • Record the date and time of sampling.
12. Storage of Water Samples	• All water quality samples are to be stored in eskies in ice and remain on ice until received by the laboratory.
13. Shipment of Water Samples	• A complete and accurate COC sheet must accompany the samples for shipment. • The COC should be in resealable/zip locked bag, in the esky. • COC is to match the contents of each esky and there should be a separate COC for each esky. • The COC must be completed as specified in APPENDIX G (example COC form), including field observations, water quality measurements, types and quantities of bottles filled. • An electronic copy of the COC must also be submitted (see APPENDIX G). • Samples to be placed in eskies in double-bagged zip locked/resealable bags. Several bottles can be grouped together in these bags. • Each esky is to be filled with fresh ice prior to shipment. • Each esky is to be secured shut with adequate packing tape holding the lid in place. • The laboratory delivery address and security seals should then be put in place on the lid and over the separation between lid and body of the esky. • Ship to appropriate laboratory within the NATA accredited laboratory recommended holding times.

Note 1: A spring pool is defined as a body of water with a depth of more than 10 cm

4.1.3. Sampling Parameters

As per the UWIR document (QWC, 2012), the baseline and ongoing monitoring analytical program for the springs and groundwater sampling have been combined for the sake of simplicity. The spring baseline analytical list is provided in Table 4-3.

Isotopes sampling is to be performed only during one of the spring baseline monitoring events.

Once the baseline monitoring is completed, nutrients, carbon and organics will no longer form part of the analytical suite.

Table 4-4: Springs Water Quality, Baseline and Ongoing (Outlined)

Parameter	F/L ¹	Basis ²	Parameter	F/L ¹	Basis ²	Parameter	F/L ¹	Basis ²
Physio-chemical								
Dissolved oxygen	F	O	pH	F, L	Q, EPBC	Total dissolved solids	L	Q, EPBC
Electrical conductivity	F, L	Q, EPBC	Redox (Eh)	F	EPBC	Total suspended solids	L	EPBC
Free gas (O2, CO, H2S, CH4)	F	Q, EPBC	Temperature	F	Q, EPBC	Turbidity	F	O
Major ions								
Bicarbonate (as CaCO ₃)	L	Q, EPBC	Hydroxide (as CaCO ₃)	L	Q, EPBC	Sulphate (SO ₄ by ICPAES)	L	Q, EPBC
Calcium	L	Q, EPBC	Magnesium	L	Q, EPBC	Total Alkalinity (as CaCO ₃)	L	Q, EPBC
Carbonate (as CaCO ₃)	L	Q, EPBC	Potassium	L	Q, EPBC	Total Hardness (as CaCO ₃)	L	Q
Chloride	L	Q, EPBC	Sodium	L	Q, EPBC			
Dissolved and total metals								
Aluminium (by ICP/MS)	L	Q, EPBC	Copper	L	Q, EPBC	Selenium (by ICP/MS)	L	Q, EPBC
Arsenic	L	Q, EPBC	Iron (by ICP/MS)	L	Q, EPBC	Silica	L	EPBC
Barium	L	Q, EPBC	Lead	L	Q, EPBC	Strontium (by ICP/MS)	L	EPBC
Beryllium	L	Q, EPBC	Lithium (by ICP/MS)	L	EPBC	Uranium (by ICP/MS)	L	Q, EPBC
Boron (by ICP/MS)	L	Q, EPBC	Manganese	L	Q, EPBC	Vanadium	L	Q, EPBC
Cadmium	L	Q, EPBC	Mercury	L	Q, EPBC	Zinc	L	Q, EPBC
Chromium	L	Q, EPBC	Molybdenum (by ICP/MS)	L	Q, EPBC			
Cobalt	L	Q, EPBC	Nickel	L	Q, EPBC			
Nutrients								
Total Nitrogen as N (including NO _x & TKN)	L	EPBC	Total Phosphorus as P	L	EPBC	Nitrite	L	EPBC
Dissolved sulphide	L	EPBC	Nitrate	L	EPBC	TKN	L	EPBC
Minor elements								
Fluoride	L	Q, EPBC	Bromide	L	EPBC	Iodide	L	EPBC
Carbon								
TOC	L	EPBC	DIC	L	EPBC	DOC	L	EPBC
Organics								
TPH	L	EPBC	PAH	L	EPBC			
Benzene, Toluene, Ethylbenzene, Xylene	L	EPBC	Phenols (standard LOR and suite)	L	EPBC			
Dissolved Gases								
Free and total Carbon dioxide	L	Q	C1-C4 (incl methane, ethylene and other gases)	L	Q, EPBC	Unionised Hydrogen sulphide	L	Q
Isotopes (only in initial sampling)								
Deuterium H-2	L	EPBC	Oxygen-18	L	EPBC	Radiogenic Carbon-14	L	EPBC
Strontium-87/Strontium-86	L	EPBC	d-Carbon-13 (DIC)	L	EPBC			

- (1) F: Field-based measurements
L: Laboratory-based measurements
- (2) Q: QWC UWIR derived monitoring requirement
EPBC: EPBC matters derived monitoring requirement from Joint Industry Plan
O: Other, these parameters will be collected to confirm stabilisation of the of the water column.

4.1.4. Frequency

The Proponents will complete four EPBC springs baseline sampling events on a quarterly basis beginning in the Q4, 2013. Following the completion of these baseline sampling events, routine spring sampling will continue on a quarterly basis for those springs where a potential impact is predicted by the CIM.

5. Groundwater Water Monitoring Bores EWS Monitoring

This program includes the monitoring of the groundwater monitoring bores forming the EWS monitoring network and monitoring bores installed adjacent to springs. The groundwater monitoring network consists of monitoring bores on-tenure and off-tenure, bores being generally located between an EPBC Spring and a CSG production area. A number of these bores are in place, with the remaining bores scheduled to be installed before the end of 2016.

Sampling Quality Assurance / Quality Control (QA/QC), sample handling and dispatch, and data management are discussed in Section 6 through to Section 9.

5.1. Location

The installation of the EWMI and TMPs is currently underway. In general, the EWMI will be installed first, followed by the installation of the TMPs. Once the location of the bore network is determined, this plan will be updated to include the location of all EWMI and TMPs.

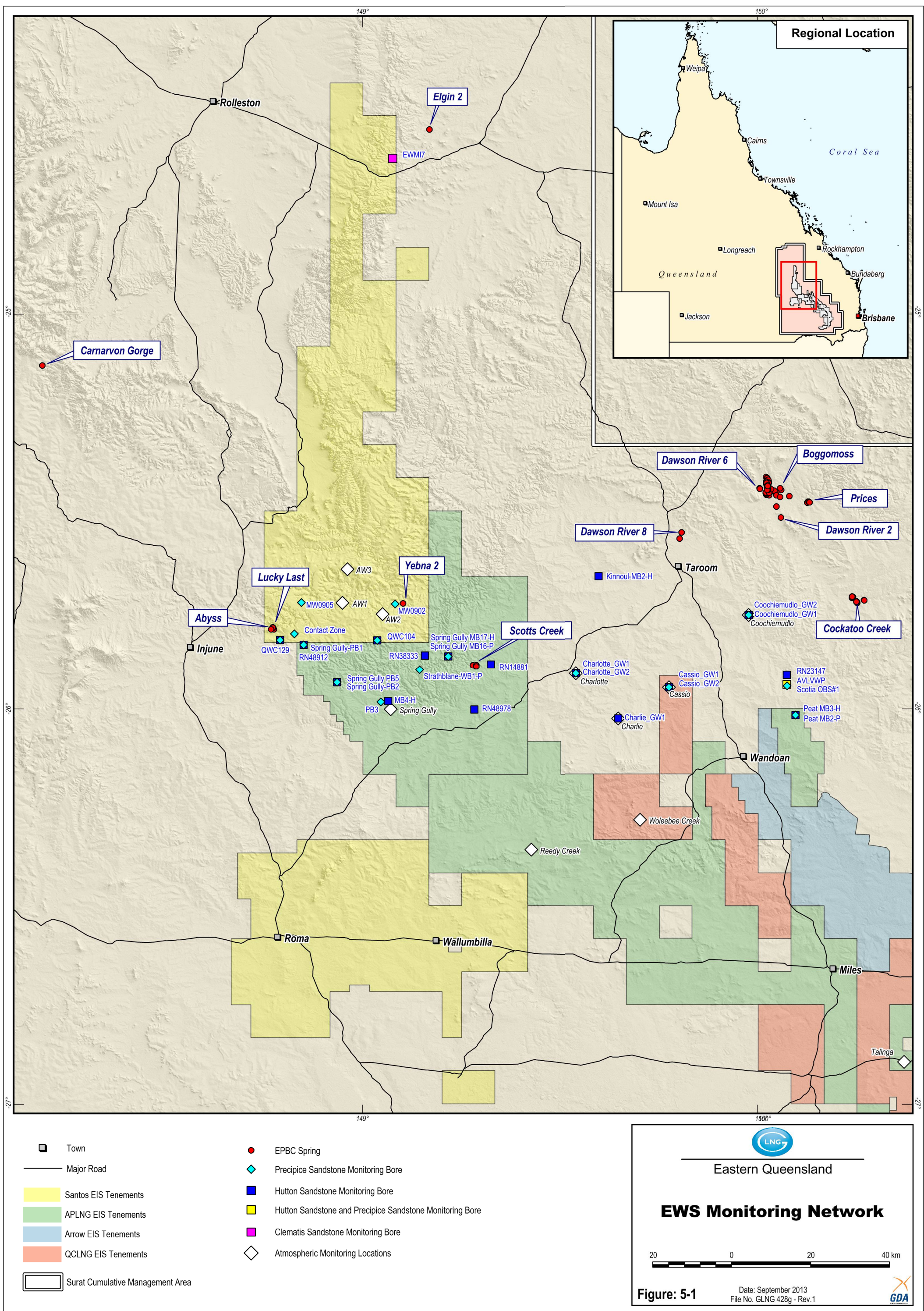
Refer to Table 4-6 and Figure 5-1 for details related to the EWS monitoring network.

Table 5-1: Groundwater Monitoring Bore Monitoring Network

JIP EWS bore ID	Latitude	Longitude	Target Aquifer	Monitoring Frequency - Water Pressure	Monitoring Frequency - Water Quality	Installation Timing	Responsible Proponent
Spring Gully PB5	-25.9325	148.9355	Precipice Sandstone	daily	Six-monthly	2015	Origin
Spring Gully-PB2	-25.9325	148.9355	Hutton Sandstone	daily	Six-monthly	2015	Origin
Spring Gully-PB1	-25.8375	148.8510	Precipice Sandstone	daily	Six-monthly	In place	Origin
RN48912	-25.8375	148.8511	Hutton Sandstone	daily	Six-monthly	2013	Origin
Contact Zone	-25.8098	148.8276	Precipice Sandstone	daily	Six-monthly	2013	Santos
QWC129	-25.8250	148.7916	Hutton Sandstone	daily	Six-monthly	2013	Santos
QWC129	-25.8250	148.7916	Precipice Sandstone	daily	Six-monthly	2013	Santos
MW0905	-25.7309	148.8456	Precipice Sandstone	daily	Six-monthly	2014	Santos
Cassio_GW1	-25.9454	149.7754	Hutton Sandstone	daily	Six-monthly	2013	QGC
Cassio_GW2	-25.9454	149.7754	Precipice Sandstone	daily	Six-monthly	2013	QGC
Coochiemudlo_GW1	-25.7630	149.9770	Hutton Sandstone	daily	Six-monthly	2013	QGC
Coochiemudlo_GW2	-25.7630	149.9770	Precipice Sandstone	daily	Six-monthly	2013	QGC
Peat MB2-P	-26.0152	150.0958	Precipice Sandstone	daily	Six-monthly	2014	Origin
Peat MB3-H	-26.0152	150.0958	Hutton Sandstone	daily	Six-monthly	2014	Origin
Scotia OBS#1	-25.9419	150.0742	Precipice Sandstone	daily	Six-monthly	In place	Santos
RN23147	-25.9141	150.0736	Hutton Sandstone	daily	Six-monthly	In place	Santos
AVLVWP	-25.9379	150.0739	Hutton Sandstone , Precipice Sandstone	daily	NA	In place	Santos
Charlotte_GW1	-25.9100	149.5400	Hutton Sandstone	daily	Six-monthly	2013	QGC
Charlotte_GW2	-25.9100	149.5400	Precipice Sandstone	daily	Six-monthly	2013	QGC
Kinnoul-MB2-H	-25.6648	149.5973	Hutton Sandstone	daily	Six-monthly	2015	Origin
EWM17	-24.6074	149.0761	Clematis Sandstone	daily	Six-monthly	2015	Santos
RN14881	-25.8872	149.3247	Hutton Sandstone	daily	Six-monthly	In place	Origin
Spring Gully MB4-H	-25.9801	149.0652	Hutton Sandstone	daily	Six-monthly	In place	Origin
PB3	-25.9818	149.0465	Precipice Sandstone	daily	Six-monthly	2015	Origin
RN48978	-26.0014	149.2826	Hutton Sandstone	daily	Six-monthly	In place	Origin
QWC104	-25.8263	149.0370	Hutton Sandstone	daily	Six-monthly	2013	Santos
QWC104	-25.8263	149.0370	Precipice Sandstone	daily	Six-monthly	2013	Santos
MW0902	-25.7347	149.0829	Precipice Sandstone	daily	Six-monthly	In place	Santos
Charlie_GW1	-26.0240	149.6470	Hutton Sandstone	daily	Six-monthly	2013	QGC
Spring Gully MB16-P	-25.8666	149.2168	Precipice Sandstone	daily	Six-monthly	2014	Origin

JIP EWS bore ID	Latitude	Longitude	Target Aquifer	Monitoring Frequency - Water Pressure	Monitoring Frequency - Water Quality	Installation Timing	Responsible Proponent
Spring Gully MB17-H	-25.8665	149.2168	Hutton Sandstone	daily	Six-monthly	2014	Origin
RN38333	-25.8645	149.1580	Hutton Sandstone	daily	Six-monthly	In place	Origin
Strathblane-WB1-P	-25.9002	149.1444	Precipice Sandstone	daily	Six-monthly	In place	Origin

Notes: New locations subject to landholder negotiations and agreements
Locations for new bores proposed from initial scouting, may be moved slightly



5.2. Groundwater Sampling Methodology

To obtain sample consistency, the groundwater sampling methodology has been developed in accordance with the following documents:

- DERM 'Monitoring and Sampling Manual 2009: Environmental Protection (Water) Policy 2009, Version 1 September 2009' guidelines;
- Australian Standard, 'AS/NZS 5667.11:1998 Water quality- Sampling, Part 11: Guidance on sampling of groundwaters'; and
- ASTM International standard 'D6771-02 Standard Practice for Low-Flow Purging and Sampling for Wells and Devices used for Ground-Water Quality Investigations.'
- Geoscience Australia, 2009, *Groundwater Sampling and Analysis – A Field Guide*

The procedure to collect low-flow groundwater samples is provided in Table 4-5. Note that this procedure is based on the assumption that all groundwater samples are to be collected by low-flow sampling techniques. In some cases this may not be practical nor the best method for the collection of representative groundwater samples. In some cases, such as for those bores already equipped with submersible or mono pumps, conventional methods may be applied. This would include purging of a minimum of three bore volumes, then collection of a water quality sample after confirming stabilisation of water quality parameters. The following steps should be used in lieu of steps 7 to 12 in the sampling procedure below in Table 4-5.

- Calculation of bore volume (L):
- $one\ bore\ volume = \pi \left(\frac{d}{2}\right)^2 h$
- With:
 - o d: diameter of piezometer (m)
 - o h: water height (m) in the bore. h=bore depth - SWL
 - o $\pi=3.14$
- Start pumping.
- If the owner/operator has pumped out at least 2x casing volumes in the past 24 hours then a further casing volume should be pumped out and continue pumping if necessary until EC & pH are stable before sampling.
- If the pump has not been operating in the past 24 hours, pump out 3x casing volumes of groundwater then ensure that pumping continues if necessary until EC & pH are stable before sampling. If the pumping time for 3x casing volumes exceeds 1.0 hrs, continue pumping until greater than 1x casing volume has been pumped out and until EC & pH are stable before sampling.
- Measure the pumping rate with the bucket and stop watch to calculate the purged volume. Take field water quality measurements (see water quality monitoring section in table 4-5 below).
- If it is not possible to pump 3 bore volumes, ensure a minimum of 1 x casing volume and EC & pH are stable, then collect water samples. Document the method of sample collection and total volume extracted,

Table 5-2: Low Flow Groundwater Sampling Procedure

Step	Procedure
1. Prior to departure for site	- Conduct all pre-departure activities in compliance with company travel policies and procedures. - Ensure that permission has been granted for access to each site according to company policies and procedures. - Ensure that all sampling equipment and supplies, PPE and decontamination equipment are prepared for transport to site. Refer to APPENDIX C for a list of monitoring equipment. - Ensure field equipment is calibrated prior to commencing monitoring works. Refer to APPENDIX D and APPENDIX E for the Equipment Inspection Template and Calibration Requirements, respectively. Records of the calibration must be kept.
2. Accessing sampling location	- Ensure access is safe. - Take care minimise disturbance to the site.
3. Measuring of gas in bore casing	- A multi-gas meter should be used (preferably the same model meter each trip) - Meter must be calibrated for methane detection. - Calibrate/bump test the meter as per manufacturer's instruction manuals. Document any calibration activities and record in the example Calibration sheet in APPENDIX E. - The gas measurement should be made immediately upon opening any valves or removing any well flange plates or coverings. Only partially remove the covering enough to insert meter wand or intake tubing. - Turn on the gas meter and wait for it to complete its start-up functions. Ensure it is measuring CH₄ in parts per million (ppm). Insert the "wand" or intake tubing of the gas meter approximately 1m into the bore casing. Wait for the CH₄ (ppm) reading to stabilise and document the reading including date and time. Record others gases if using a multi gas meter (eg CO₂, H₂S, etc). Remove the wand to fresh air, wait for it to read 0 ppm and then turn off/pack up the unit.
4. Cross Contamination	- Re-usable groundwater monitoring equipment (pumps, water quality meters, dip meters, etc.) must be thoroughly decontaminated prior to using and between sampling locations and events. This equipment should be decontaminated with clean water, Decon 90 and deionised water between samples. - Low flow tubing and bailers are not to be reused between bores. - Where possible, dedicated pumps should be installed and used for sample collection.
5. Determining standing head height of water in bore/well	- Measure the standing water level in the bore using an electronic water level sensor prior to sampling. Ensure the level is recorded from the same reference point during each monitoring event. This reference point should marked and documented during the first monitoring event. - If previous measurements are available, these should be reviewed to give indication of expected level. Data logger files should be downloaded from monitoring bores with pressure transducers installed. Do not delete the monitoring data recorded to data logger when downloading the data. The downloaded file name should be named to reflect the bore ID, the date and time of download and be consistent with previous downloaded files. - The sensor should be deployed with care to measure the water level: - When the sensor makes contact with water (the standing water level), the measurement on the tape or cable at the top of the casing (or appropriate reference point) should be noted. - This measurement should be recorded on the COC along with the sample ID, date and time of measurement. - To calculate the groundwater elevation (GW RL) in metres above height

Step	Procedure
	datum (mAHD), the SWL is subtracted from the surveyed height of the bore casing. - Also note the following observations of any liquid that may appear on the end of the water level sensor: - Clarity (slightly, moderately, highly turbid) - Colour (nil, black, brown, green, grey, orange, yellow) - Odour (no, sulphur, hydrocarbons).
6. Labelling of Sample Bottles	- Select the appropriate sample bottles for the required list of analytes. - Nitrile (or latex) gloves must be worn when labelling the bottles. - Sample bottles are to be labelled as per the sample naming convention provided in APPENDIX B. - Labelling should occur prior to the purging/sampling.
7. Installation of Low Flow Pump Intake	- Where a bore has no dedicated pump, lower low flow pump, with intake positioned to the required sample depth.. - Take care to minimise disturbance of water column. - Nitrile or latex gloves are to be worn when handling pump intakes or any groundwater tubing. - Following installation the water column within the bore should be allowed to stabilise prior to purging. - Calculate the volume of the sample tube and use as the minimum volume to be purged. - During purging, if high levels turbidity are encountered (>100NTU) reduce the pumping rate. If this does not lower readings, then stop the pumping and allow turbidity to settle (this length of time is dependent of the characteristic of each bore).² - The inlet of the pump should be placed at or near the mid-point of the screened area where the area screened is assumed to be homogenous material or the screened aquifer material is unknown or not documented. When the screened aquifer has heterogeneous material documented in bore logs, the pump intake should be positioned adjacent to the zone of highest hydraulic conductivities. - Do not place the intake of the pump too close to the top of the screen (potential intake of stagnant bore casing water) or the bottom of the screen (potential mobilisation and entrainment of settled solids).
8. Low Flow Purging, Determination of Pumping Rate	- Commence pumping rate at a low enough rate to minimise mobilisation and entrainment of particulate matter that is not naturally mobile. - Pumping rate must be determined on a bore-specific basis. This may be determined in advance using hydraulic testing results or previous sampling.. - If hydraulic parameters are not determined initial flow rate should be set low, generally 100mL/min or less. If the pump cannot achieve this rate, reduce rate as low as possible. - If the initial drawdown is rapid and continuous, decrease rate until level stabilises or recovers close to the static level.. - If drawdown is very low or imperceptible, raise rate slowly until the initiation of drawdown is observed, then reduce rate slightly and use this rate as documented sustainable pumping rate. - Once the optimum rate is established, it may be replicated for future monitoring events at that bore (providing well performance does not vary). - Maximum rate used for sampling should not exceed rate for purging.

² It is critical that the water level within the bore be maintained and not decrease measurably during low-flow sampling activities.

Step	Procedure
	The flow rate used should be recorded on a field monitoring sheet, such as the example included in APPENDIX J: Groundwater Low Flow Purging and Sampling Monitoring Sheet.
9. Low Flow Purging, Drawdown and Water Level Management	- The water level is to be measured throughout purging to ensure that minimal or no drawdown is induced and the water level quickly stabilises after pumping commences. This will indicate optimum flow rate. Adjust the pumping rate until this is achieved. - The aim is to stabilise the purging water level as quickly as possible. - The water level should be measured regularly to ensure there is no drawdown at any stage during purging.. - The goal is minimal drawdown (0.1m) during purging; however, the optimal drawdown will be based on site-specific conditions. - If purging is unable to be conducted without inducing continuous drawdown, traditional sampling techniques such as purging 3 bore volumes should be used to ensure a representative sample is collected. - The water level measurements are to be recorded on the Groundwater: Low Flow Purging and Sampling Monitoring Sheet in APPENDIX J.
10. Low Flow Purging; Measurement of Water Quality Indicator Parameters and Turbidity	- Water quality measurements are to occur continuously through a flow through cell and be recorded at 5 minute intervals during purging or at each litre of volume purged... - Parameters to be measured are pH, Electrical Conductivity, Temperature, Dissolved Oxygen and Redox. - Excessive or high variance in turbidity levels may indicate disturbance of the water column or excessive stress on the formation from over purging. - Water quality measurements are to be recorded until parameters have stabilised. - Water quality is considered stable when three consecutive readings over several minutes fall within the below ranges: - pH : ± 0.2 pH units (but may vary dependent upon the measuring accuracy of the device); - Electrical Conductivity : $\pm 10\%$ of reading; - Temperature: $\pm 10\%$ of reading - Dissolved Oxygen $\pm 10\%$ of reading; and - Redox: $\pm 10\%$ of reading. - The total purged volume should exceed that total volume of the pump tubing. - These are generally accepted guidelines. They may vary dependent upon the specific properties of each aquifer. - The water quality measurements are to be recorded on a field data collection sheet , such as the example in APPENDIX J: Groundwater Low Flow Purging and Sampling Monitoring Sheet..
11. Low Flow Sample Collection (non-isotopic samples)	- Sampling can commence once the equivalent of one tubing volume has been removed and the chemical indicator parameters have remained consistent for 3, 5 minute recordings - If an in-line, flow-through cell has been used to measure the water quality parameters it should be disconnected or bypassed during the sample collection. - The pumping rate during sample collection can remain at the established purging rate or adjusted downwards to minimise aeration, bubble formation or turbulent filling of sample bottles. - If high purge rates were sustainable during purging, reduce rate for sample collection. In most instances the sampling rate of less than 500mL/min is appropriate; however if sampling for VOC's (Volatile Organic Compounds) then a rate of less than 250mL/min should be adopted. - Fill the required sample bottles to the capacity specified for that bottle.

Step	Procedure
	- Nitrile or latex gloves shall be fitted when handling the sample bottles and sampling device that contains the sample. - If the sample bottle contains a preservative, care should be taken when filling not to overfill the sample. - Care must be taken to avoid the potential contamination of any parts of the tubing or pumps, particularly the outlets. - Field Filtration: Where field filtration is required (i.e. for dissolved metals) then filtration should occur using vacuum or pressure filtration equipment with a 0.45µm filter. A new filter/filter container should be used for each new sample location. - Collect QA/QC samples in accordance with Sub-section 4.3. - Consider the following environmental factors when sampling: - Sampling equipment and containers must be kept away from sources of hydrocarbons, including vehicle or machinery exhaust; sampling personnel must ensure hands are washed following refuelling of vehicles or handling of equipment. - Dust is a potential contaminant for all analyses; vehicles, storage areas and eskies must be cleaned regularly. Rain can cause dilution of samples; if raining, use a rain shield or delay collection until rain has ceased, if possible.
12. Collection of Isotope samples - Deuterium H-2; - Oxygen-18; - d-Carbon-13 (DIC); and - Strontium-87/Strontium-86.	- Ensure appropriate sample bottles/vessels are used for individual analytes. - Label sample bottles with the sampling location and time and date of collection - Then fill the bottle by turning the right way up and keeping it submerged. - Ensure all air has been removed from the bottle - Place lid and tighten whilst still underwater. - Ensure no significant bubbles have developed in the sample, if so, re take sample.
13. Collection of Isotope samples Radiogenic Carbon-14;	- Use laboratory-supplied and prepared containers. Avoid sample contamination by minimising contact with air as much as possible. - Follow sampling procedures as supplied by the laboratory. - Ensure no or minimal exposure time the atmosphere occurs during sampling - Record the date and time of sampling.
14. Storage of Water Sample	Collected water quality samples are to be stored in eskies on ice and chilled continually once collected until shipped to the laboratory (either in eskies with ice or refrigerator).
15. Shipment of Water Samples	- A complete and accurate COC sheet must accompany the samples for shipment. - The COC should be in resealable/zip locked bag, in the esky. - COC is to match the contents of each esky and there should be a separate COC for each esky. - The COC must be completed as specified in APPENDIX G (example COC form), including field observations, water quality measurements, types and quantities of bottles filled. - An electronic copy of the COC must also be submitted (see APPENDIX G). - Samples to be placed in eskies in double-bagged zip locked/resealable bags. Several bottles can be grouped together in these bags. - Each esky is to be filled with fresh ice prior to shipment. - Each esky is to be secured shut with adequate packing tape holding the lid in place. - The laboratory delivery address and security seals should then be put in place

Step	Procedure
	on the lid and over the separation between lid and body of the esky. • Ship to appropriate laboratory

5.3. Sampling Parameters

The suite of analytes addresses both the requirements defined in the Surat UWIR and the Joint Industry Plan, and is provided in Table 4-6. This list is the same as the spring monitoring list presented in Section 4.1.3.

Isotopes sampling is to be performed only during the first monitoring event.

Once the baseline monitoring is complete, nutrients, carbon and organics will no longer form part of the analytical suite.

Table 5-3: Groundwater Water Quality, Baseline and Ongoing (outlined)

Parameter	F/L ¹	Basis ²	Parameter	F/L ¹	Basis ²	Parameter	F/L ¹	Basis ²
Physio-chemical								
Dissolved oxygen	F	O	pH	F, L	Q, EPBC	Total dissolved solids	L	Q, EPBC
Electrical conductivity	F, L	Q, EPBC	Redox (Eh)	F	EPBC	Total suspended solids	L	EPBC
Free gas (O2, CO, H2S, CH4)	F	Q, EPBC	Temperature	F	Q, EPBC	Turbidity	F	O
Major ions								
Bicarbonate (as CaCO3)	L	Q, EPBC	Hydroxide (as CaCO3)	L	Q, EPBC	Sulphate (SO4 by ICPAES)	L	Q, EPBC
Calcium	L	Q, EPBC	Magnesium	L	Q, EPBC	Total Alkalinity (as CaCO3)	L	Q, EPBC
Carbonate (as CaCO3)	L	Q, EPBC	Potassium	L	Q, EPBC	Total Hardness (as CaCO3)	L	Q
Chloride	L	Q, EPBC	Sodium	L	Q, EPBC			
Dissolved and total metals								
Aluminium (by ICP/MS)	L	Q, EPBC	Copper	L	Q, EPBC	Selenium (by ICP/MS)	L	Q, EPBC
Arsenic	L	Q, EPBC	Iron (by ICP/MS)	L	Q, EPBC	Silica	L	EPBC
Barium	L	Q, EPBC	Lead	L	Q, EPBC	Strontium (by ICP/MS)	L	EPBC
Beryllium	L	Q, EPBC	Lithium (by ICP/MS)	L	EPBC	Uranium (by ICP/MS)	L	Q, EPBC
Boron (by ICP/MS)	L	Q, EPBC	Manganese	L	Q, EPBC	Vanadium	L	Q, EPBC
Cadmium	L	Q, EPBC	Mercury	L	Q, EPBC	Zinc	L	Q, EPBC
Chromium	L	Q, EPBC	Molybdenum (by ICP/MS)	L	Q, EPBC			
Cobalt	L	Q, EPBC	Nickel	L	Q, EPBC			
Nutrients								
Total Nitrogen as N (including NOx & TKN)	L	EPBC	Total Phosphorus as P	L	EPBC	Nitrite	L	EPBC
Dissolved sulphide	L	EPBC	Nitrate	L	EPBC	TKN	L	EPBC
Minor elements								
Fluoride	L	Q, EPBC	Bromide	L	EPBC	Iodide	L	EPBC
Carbon								
TOC	L	EPBC	DIC	L	EPBC	DOC	L	EPBC
Organics								
TPH	L	EPBC	PAH	L	EPBC	VOCs	L	EPBC
Benzene, Toluene, Ethylbenzene, Xylene	L	EPBC	Phenols (standard LOR and suite)	L	EPBC			
Dissolved Gases								
Free and total Carbon dioxide	L	D	C1-C4 (incl methane, ethylene and other gases)	L	D, EPBC	Unionised Hydrogen sulphide	L	D
Isotopes (only in initial sampling)								
Deuterium H-2	L	EPBC	Oxygen-18	L	EPBC	Radiogenic Carbon-14	L	EPBC
Strontium-87/Strontium-86	L	EPBC	d-Carbon-13 (DIC)	L	EPBC			

- (1) F: Field-based measurements
L: Laboratory-based measurements
- (2) Q: QWC UWIR derived monitoring requirement
EPBC: EPBC matters derived monitoring requirement from Joint Industry Plan
O: Other, these parameters will be collected to confirm stabilisation of the of the water column.

5.4. Frequency

Groundwater quality sampling and manual groundwater level measurements will be undertaken in all installations on a semi-annual basis, for both the baseline and routine long-term sampling programs. Where technically possible, continuous EC, temperature and water level readings will be monitored through the use of automated data logger in the monitoring bores.

Following completion of the baseline monitoring, long term monitoring will consist of a reduced suite of indicator parameters. This will be determined following the baseline sampling campaign, but will include as a minimum the physio-chemical parameters, dissolved metals and major ions.

For monitoring bores installed adjacent to the springs, the monitoring frequency will be as per the spring.

6. Sampling QA/QC

The following frequency will be used for QA/QC sampling (refer Table 4-7):

Table 6-1: Summary of QA/QC Sampling Frequency

QA/ QC Sampling	Frequency
Field-based	
Duplicate samples	1:10 One duplicate to be collected for every 10 samples collected.
Equipment Blank (or rinsate)	1/day or 1:20 One equipment blank per day per matrix, or one equipment blank for every 20 samples collected (per matrix), whichever is more frequent.
Field Blank	1:20 One field blank for each 20 samples (suite-specific)
Trip Blank	1/esky One trip blank to be collected for each esky being transported to a laboratory, only for sampling events involving potential BTEX and/or volatile hydrocarbons
Laboratory-based³	
Method Blank	1/batch One method blank is recommended to be prepared and analysed for each batch of samples analysed.
Instrument Blank	TBD The frequency is to be defined by the analytical method or at the analyst's discretion (e.g., after high concentration samples).
Method Spikes/ Method Spike Duplicates	TBD The laboratory conducts routine method spikes and duplicates to assess performance of analytical methods. For all analyses other than TPH/ PAH, the volume collected for a normal sample is sufficient. For TPH/ PAH samples additional volume of 3 by 500mL amber glass bottles is required. A note must be added to the COC to indicate QC samples are included in the batch.

6.1. Duplicate samples

Duplicate samples are collected from the same location in the same manner as the primary sample. Blind duplicates will be collected at a rate of one per ten primary samples to assess the precision (repeatability) of the sampling procedures and laboratory analyses. The duplicate results will be compared to the primary sample results to assess whether the data fall within an acceptable relative percent difference (RPD) range. Refer to Section 4.6 for additional details.

³ Note: Laboratory **must be** NATA accredited for the analyses performed. Note that laboratories performing the isotopes analysis in Australia are not systematically accredited, this include CSIRO laboratory.

6.2. Equipment Blank

Equipment blanks (also called rinsate samples) are collected to determine/verify proper decontamination of field and laboratory equipment. These samples help to assess the adequacy of the decontamination process and possible contamination from the total sampling, sample preparation and measurement process, when decontaminated sampling equipment is used to collect samples.

To collect an equipment blank (also referred to as a rinsate blank):

- 1) A sample of analyte free water poured over or through decontaminated field sampling equipment prior to the collection of environmental samples.
- 2) Recommended Frequency: one blank/day/matrix or one blank/20 samples/matrix, whichever is more frequent.

6.3. Field Blank

Field blanks are clean water sample taken in the field under identical conditions to samples. The field blank is used to verify that the sampling procedures are of a high standard and identify if contamination is occurring. The field blank water is provided by the laboratory in advance and will just need to be filled into the appropriate bottles on site.

6.4. Trip Blank

Clean water sample for analysis of volatile and semi volatile compounds, provided by the laboratory to test potential contamination during the transport of the samples. Trip blanks are to be subject to the same storage and transport conditions as empty sample bottles and samples. They should be submitted at sufficient frequency to detect influences from external sources on semi-volatile samples.

6.5. Laboratory Blanks

Laboratory blanks are prepared and used by the laboratories. The following summarises these blanks:

- **Method Blank:** A blank prepared to represent the matrix as closely as possible. The method blank is prepared/extracted/digested and analysed exactly like the field samples.
 - Purpose: Assess contamination introduced during sample preparation activities.
 - Frequency: one blank/batch (samples prepared at one time.)
- **Instrument Blank:** A blank analysed with field samples.
 - Purpose: Assess the presence or absence of instrument contamination.
 - Frequency: Defined by the analytical method or at the analyst's discretion (e.g., after high concentration samples).

7. Sampling Handling and Dispatch

7.1. Analytical Laboratories

Samples will be primarily sent to laboratories accredited under the National Association of Testing Authorities (NATA). The laboratory may subcontract specific analysis such as isotope analysis.

It should be noted most isotopes analysis are done by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Land and Water in South Australia which is not NATA accredited.

7.2. Sample Handling and Dispatch

All environmental samples are to be transported in approved laboratory bottles and suitably chilled ($\leq 4^{\circ}\text{C}$) for the duration of shipping. Samples must be accompanied by a fully completed COC (refer to APPENDIX G).

Where practicable, samples should be delivered to the laboratory by the sampling personnel to ensure correct handling and quality assurance purposes. In remote locations where delivery is not practicable, a pick-up location and collection time should be nominated by the transport company and sampling personnel to ensure timely collection of the samples.

Consignment notes must accompany all shipments to enable tracking and a copy of the note must be retained by the dispatcher. Transport companies that do not provide this information must not be engaged where other options exist.

Consignment note numbers must be entered onto the COC documentation prior to delivery to the lab or upon relinquishment of samples for tracking purposes.

Samples should be provided to the laboratory in the shortest practical delays as per the recommendations of the NATA accredited laboratory. In remote locations, the delays will inherently cause a breach of holding times for the shortest holding times. The analysis concerned would typically be:

- pH and dissolved oxygen - holding time of 6 hours; and potentially;
- Parts of the nutrients (Nitrite, nitrate, reactive phosphorus) – holding time of 2 days.

For the purpose of spring monitoring, those breaches are not expected to influence the outcome of the sampling results:

- The value of pH collected in the field is reliable, it can be used instead of the laboratory value or to support the laboratory value; and
- Nutrients concentrations are not key parameters for the characterisation and ongoing monitoring of springs.

8. Data Management

All environmental samples dispatched to the laboratory must be accompanied by a hard copy of the COC, whether delivered in person or by an approved transport service.

Following receipt of samples, a scanned copy of the COC will be sent by the laboratory. The laboratory analytical results will be sent by the laboratory in electronic formats compatible with the respective data management systems of the Proponents.

An example of data management process is provided in the schematic diagram shown in Figure 4-1. The process workflow has been broken down into five main sections:

- Document and Record Management;
- Sampling Plan;
- Sampling and Field Measurements;
- Data Entry Validation and Verification; and
- Reporting.

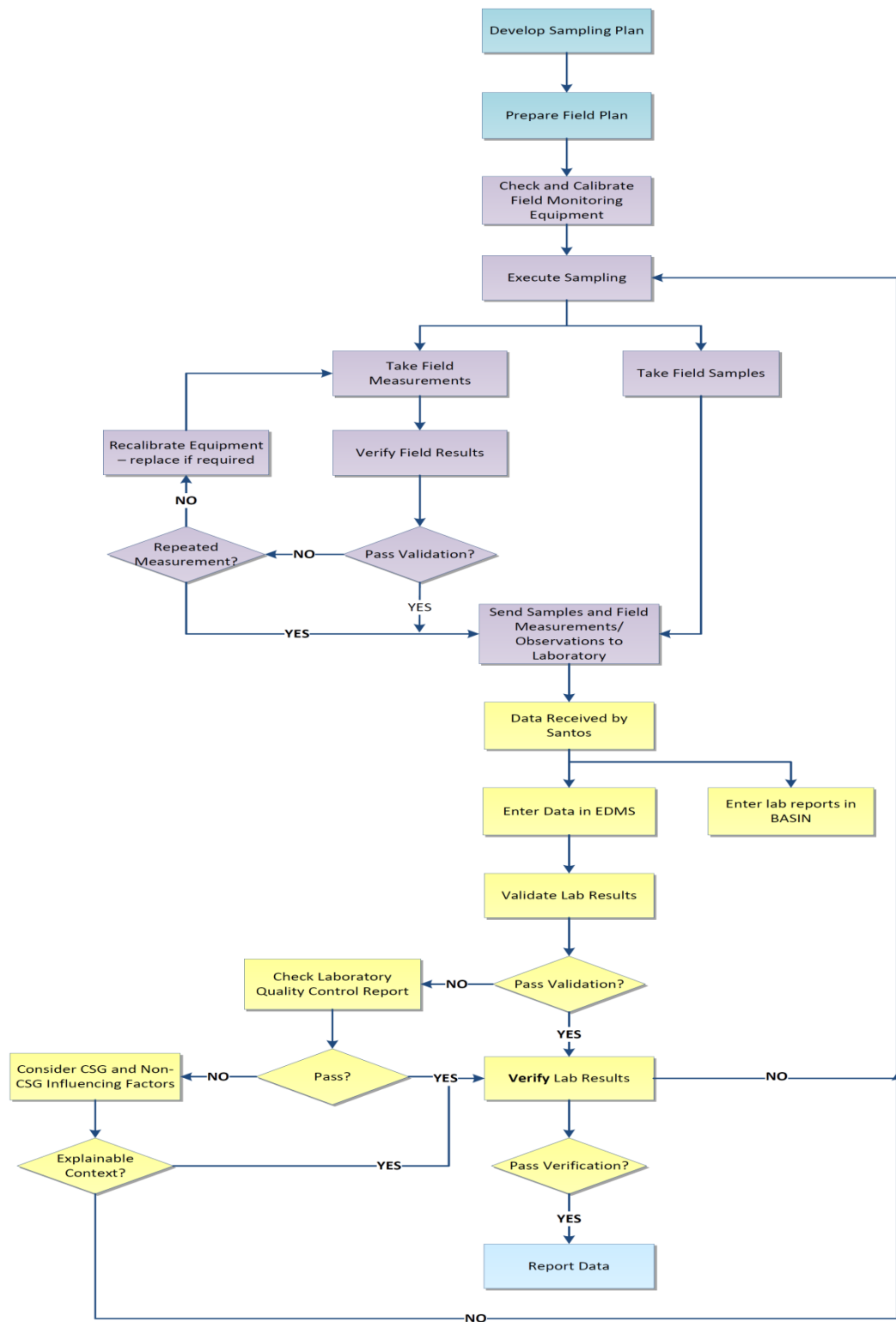


Figure 8-1: Example of Monitoring and Data Management Workflow Diagram

9. QA/QC Validation

QA/QC validation is required to be done as soon as the laboratory results are available to identify any outstanding results and failures in the field QA/QC. The errors observed should be reported and discussed with the laboratory. Field QA/QC failure will be reported and discussed with the field team to ensure they are not further reproduced.

9.1. Precision

Precision is the degree of agreement between repeated measurements of the same parameter under prescribed, similar conditions. Field and laboratory precision will be monitored using results from replicate/duplicate sample analyses. Precision can be expressed as the RPD of one result with another. The RPD is calculated as follows:

$$RPD = \left(\frac{(D_1 - D_2)}{\frac{(D_1 + D_2)}{2}} \right) = 100\%$$

Where:

RPD = Relative percent difference

D1 = first duplicate value

D2 = second duplicate value

The overall DQO for precision of analytical measurement is expressed as a per cent of the duplicate having RPDs within established control limits. Refer to Table 4-8 for a comparison of field-based and laboratory-based precision considerations.

Table 9-1: Summary of Precision

Precision	
<i>Field Precision</i>	The precision of field measurements will be evaluated through the analysis of replicate measurements. During groundwater sampling activities, multiple measurements of pH, specific conductance and temperature will be performed on different aliquots of water to ensure that adequate well purging has occurred prior to collecting the sample.
<i>Laboratory Precision</i>	Precision performance requirements for all chemical analyses performed by the analytical laboratory have been established. The analytical laboratory will assess precision by performing duplicate analyses on select samples at a frequency concurrent with methodology specifications.

9.2. Accuracy

Accuracy is the measure of the degree of agreement between an analysed value and the true or accepted value where it is known. Field and laboratory accuracy will be monitored using standards of known concentrations or values spiked into select samples. Accuracy can then be expressed as a percent recovery (%R), which is calculated as follows:

$$\%R = \frac{Q_d}{Q_a} \times 100\%$$

Where,

Qd = Spiked sample result minus the sample result

Qa = Spike amount

The over DQO for accuracy is the per cent of samples having a %R within prescribed control limits. Refer to Table 4-9 for a comparison of field-based and laboratory-based accuracy considerations.

Table 9-2: Summary of Accuracy

Accuracy	
<i>Field Accuracy</i>	The accuracy of data produced by field instruments will be maintained and documented by performing initial calibrations (refer APPENDIX E) followed by continuous calibration verifications and/or continuous calibrations with known standards in accordance with each Proponent's specified procedures or the manufacturers' procedures.
<i>Laboratory Accuracy</i>	Measures to be taken by the analytical laboratory to ensure accuracy include instrument tuning, instrument calibrations (initial and continuous), analyses of laboratory standards and analyses of independent QC samples.

9.3. Completeness

Completeness is a measure of the amount of valid data obtained from an analytical measurement system. It is expressed as a per cent of the overall data that were generated and is calculated as follows:

$$C = \frac{V}{T} \times 100\%$$

Where:

C = per cent completeness

V = number of measurements judged valid

T = total number of measurements

It is anticipated that 100 per cent of the proposed samples can be collected. It is expected that the laboratory will provide data meeting QC completeness criteria for a least 90 per cent of the samples analysed. Refer to Table 4-10 for a comparison of field-based and laboratory-based completeness considerations.

Table 9-3: Summary of Completeness

Completeness	
<i>Field Completeness</i>	Field measurements including pH, specific conductance and temperature will be taken where required. To ensure the completeness of the data generated from these measurements, calibration logs will be maintained for each instrument (refer APPENDIX E). In turn, these measurements will provide an indication of whether any measurements were made with instruments that were not calibrated or functioning properly.
<i>Laboratory Completeness</i>	Control limits for all chemical analyses performed within the analytical laboratory have been established. Analyses not meeting the specified control limits for a particular analysis will be flagged. It is expected that the laboratory will provide data meeting QC completeness criteria for at least 90 per cent of the samples analysed.

9.4. Representativeness

Representativeness is understood to be a sample or set of samples that provide a typical example of general groundwater or soil quality in a given area of concern. Refer to Table 4-13 for a comparison of field-based and laboratory-based representativeness considerations.

Table 9-4: Summary of Representativeness

Representativeness	
<i>Field Representativeness</i>	During any groundwater sampling activities, multiple readings of specified field parameters will be recorded during purging and sampling to facilitate, to the maximum extent possible, the collection of representative groundwater quality samples.
<i>Laboratory Representativeness</i>	The representativeness of laboratory-generated data will be maintained through careful sample preparation techniques and sample tracking procedures.

9.5. Verification and Validation

The data verification and validation methods to be followed are summarised below (refer Table 4-12):

Table 9-5: Verification and Validation

Verification and Validation	
<i>Field Data</i>	The field data package will be reviewed by the sampling personnel. To adequately assess the data package, the following items will be reviewed : • Field parameters/data contained in COC; • Field analysis and equipment calibration, and general condition of equipment; and • COCs for accuracy/completeness; • Comparison of the manual water level reading with the water level automated logger value.
<i>Laboratory Data</i>	After the field data package has been validated, the analytical data package will be validated. The analytical data package validation procedure may include the following: • Review of the sampling dates, sample extraction dates, and analysis dates to ensure samples were extracted and/or analysed within proper holding times. • Analytical methods and suggested detection limits are correct. • Review of field and laboratory blanks to evaluate possible contamination sources. • Review of field duplications to check the precision of chemical analyses and field sampling techniques. If available, field duplicates and laboratory duplicates for water matrices will be reviewed. • Review of surrogate spikes relative to allowable control limits specified for the particular method. • Review of matrix spike recoveries for organic analyses for evaluation of the presence of matrix influence that affect recovery of a particular analyte. Control limits will be reported when matrix spike data are reported. When matrix spike duplicates are performed/reported, the RPD will be calculated and RPD limits reported. • Review of matrix spike recoveries for inorganic analyses (considered definitive). If matrix spike recoveries are outside control limits, the data will be flagged as a quantitatively suspect or an estimated value.

10. Definitions

Term	Definition
Accuracy	The measure of the degree of agreement between an analysed value and the true or accepted value where it is known.
Aquifer Source Monitoring Infrastructure	Groundwater monitoring bores from the EWS network and monitoring EPBC springs primary source aquifers
Baseline Data ²	A data set for each nominated monitoring location that is preferably made up of data that is used to derive the reference value
Bore	Water observation bore or a water supply bore.
Coal seam gas water	Groundwater produced e in the process of coal seam gas exploration or production. Coal seam gas water typically contains significant concentrations of salts, has a high sodium adsorption ratio and may contain other contaminants that have the potential to cause environmental harm if released to land or waters through inappropriate management.
Completeness	A measure of the amount of valid data obtained from an analytical measurement system.
CWMMP	CSG Water Management and Monitoring Plan (Stage 2)
EPBC Act	Means the Commonwealth <i>Environment Protection and Biodiversity Conservation Act 1999</i>
EPBC Spring ²	A spring complex where the presence of <i>The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin</i> , or threatened species listed under the EPBC Act that are reliant on springs has been confirmed
Evaluation of Mitigation Options Report	A report evaluating the options for mitigating impacts on water pressures in the source aquifer for the identified spring`
Quality Plan	Joint-Industry Early Warning System for EPBC Springs Quality Plan – This document
Joint Industry Plan	The Joint Industry Plan for an Early Warning System for the Monitoring and Protection of EPBC Springs
Low Flow	Flow up to the one month average recurrence interval.
MNES ²	Matters of National Environmental Significance as defined by the EPBC Act, 1999
Precision	The degree of agreement between repeated measurements of the same parameter under prescribed, similar conditions.
Proponents ²	Queensland Gas Company, Australia Pacific LNG, Santos GLNG referred together as a collective
Representativeness	A sample or set of samples that provide a typical example of general groundwater or soil quality in a given area of concern.
Spring complex	A group of spring vents located in close proximity to each other. The spring vents are located in a similar geology and are fed by the same source aquifer. No adjacent pair of spring vents in the complex are more than 6 km apart.
Spring mitigation strategy	Mitigation strategy directed at only those springs where an impact of more than 0.2 m is predicted in the source aquifer of the springs
Spring vent	A single point in the landscape where groundwater is discharged at the surface. A spring vent can be mounded or flat and can also be represented by wetland vegetation, with no visible water at the location of the spring.
Springs	The land to which water rises naturally from below the ground and the land over which the water then flows. When used alone in this report, the term “springs” refers to spring

Term	Definition
	vents, spring complexes or watercourse springs.
Surat UWIR	Surat Underground Water Impact Report (QWC 2012)
Watercourse spring	A watercourse spring is a section of a watercourse where groundwater enters the stream from a GAB aquifer through the streambed. This type of spring is also referred to as a baseflow fed watercourse.
Waters	Includes all or any part of a creek, river, stream, lake, lagoon, swamp, wetland, spring, unconfined surface water, unconfined water in natural or artificial watercourses, bed and bank of any waters, non-tidal or tidal waters (including the sea), stormwater channel, stormwater drain, roadside gutter, stormwater run-off, and underground water.
Wetland	Defined under the Queensland Wetlands Program, this is any area of permanent or periodic / intermittent inundation, with water that is static or flowing fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six (6) metres. To be classified as a wetland, the area must have one or more of the following attributes: • at least periodically, the land supports plants or animals that are adapted to and dependent on living in wet conditions for at least part of their life cycle, or • the substratum is predominantly undrained soils that are saturated, flooded or ponded long enough to develop anaerobic conditions in the upper layers, or • the substratum is not soil and is saturated with water, or covered by water at some time. <i>Note: this definition does not include the EA-derived definition of wetlands.</i>

11. Abbreviations and Units

Acronym	Description
%R	Percent recovery
µm	Micrometre, which is one-thousandth of a millimetre (.001 mm)
¹⁴ C	Radiogenic Carbon-14
ALS	<i>ALS Laboratory Group</i>
APLNG	Australia Pacific LNG
AS / NZS	Australian Standard / New Zealand Standard
ASTM	American Society for Testing and Materials
BTEX	benzene, toluene, ethylbenzene, and xylenes
C	Per cent completeness
CIM	cumulative impact model
CMA	Cumulative Management Area
CO ₂	Carbon Dioxide
COC	Chain of Custody
CSG	Coal Seam Gas
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Cth	Commonwealth
CWMMP	CSG Water Management and Monitoring Plan
D1	First duplicate value in relation to calculating RPD
D2	Second duplicate value in relation to calculating RPD
DERM	Department of Environment and Resource Management
DIC	Dissolved inorganic carbon
DO	Dissolved oxygen
EC	Electrical Conductivity
EDMTP	Environmental Data Management Technical Procedure
EHP	Queensland Department of Environment and Heritage Protection
EPBC	Environment Protection and Biodiversity
EWMI	Early Warning Monitoring Installation
EWS	Early warning system
GA	Geoscience Australia
GIS	Geographic information system
GLNG	Gladstone Liquefied Natural Gas
GPS	Global Positioning System
ID	Identification
km	kilometre
L	Litre

Acronym	Description
m	metre
m ²	metre x metre
mg	milligram
min	minute
ml	millitre
NTU	Nephelometric Turbidity Units
OGIA	Office of Groundwater Impact Assessment
PAH	Polycyclic aromatic hydrocarbon
PPE	Personal protective equipment
Q2	Quarter 2 (April – June)
Qa	Spike amount used in calculating %R
QA/QC	Quality Assurance/Quality Control
Qd	Spiked sample results minus the sample result used in calculating %R
QGC	QGC Pty Limited (a Proponent), formerly Queensland Gas Company
QWC	Queensland Water Commission
RPD	Relative percent difference
T	Total number of measurements – used in calculating completeness
TKN	total Kjeldahl nitrogen
TMP	Trigger Monitoring Point
TOC	Total organic carbon
TOC	Top of casing
TPH	Total petroleum hydrocarbons
UWIR	Underground Water Impact Report
V	Number of measurements judged valid – used in calculating completeness
VOC	Volatile Organic Compounds
VWP	Vibrating wired piezometers

12. References

ASTM International standard 'D6771-02 Standard Practice for Low-Flow Purging and Sampling for Wells and Devices used for Ground-Water Quality Investigations.'

Australian Standard, 'AS/NZS 5667.11:1998 Water quality- Sampling, Part 11: Guidance on sampling of groundwaters'; and

Baskaran Sundaram, Andrew J. Feitz, Patrice de Caritat, Aleksandra Plazinska, Ross S. Brodie, Jane Coram and Tim Ransley for Geoscience Australia. 2009. Groundwater Sampling and Analysis – A Field Guide.

Department of Environment and Resource Management (DERM). September 2010. Monitoring and Sampling Manual 2009 Environmental Protection (Water) Policy 2009, Version 2.

DERM 'Monitoring and Sampling Manual 2009: Environmental Protection (Water) Policy 2009, Version 1 September 2009' guidelines;

DERM. Baseline Assessment Guidelines. May 2011.

DERM. Guideline Underground Water Impact Reports and Final Reports.

Geoscience Australia, 2009, Groundwater Sampling and Analysis – A Field Guide

Klohn Crippen Berger, January 2012. Hydrogeological attributes associated with Springs in the Surat Cumulative Management Area. 315 pp. QWC, Brisbane.

Klohn Crippen Berger, May 2012. Desktop Assessment of the Source Aquifer for Springs in the Surat Cumulative Management Area. 179 pp. QWC, Brisbane.

Puls, Robert W., and Michael J. Barcelona for US Environmental Protection Agency. 1996. Ground Water Issue: Low-Flow (minimal drawdown) groundwater sampling procedure. April 1996.

Queensland Herbarium, 2012, Ecological and Botanical survey of springs in the Surat Cumulative Management Area

Queensland Water Commission (QWC), 2012. Underground Water Impact Report for the Surat Cumulative Management Area.

RJ Fensham, C Pennay, J Drimer, Queensland Herbarium, January 2012. Ecological and Botanical survey of springs in the Surat Cumulative Management Area. 99 pp plus auxiliary database files. QWC, Brisbane.

Santos GLNG. October 2009. Eastern Queensland CSG Water and Soil Monitoring Strategy.

Santos, APLNG, QGC. 5 December 2012. Joint Industry Plan for Early Warning System for the Monitoring and Protection of EPBC Springs.

APPENDIX A - Spring Monitoring Sites and Sites Label Names

Table A1 – Spring vents monitoring sites

Table A2 – Watercourse Springs monitoring sites

Table A 1: Spring vents monitoring sites

Complex Name	Complex Number	Vent No	Latitude (decimal degrees)	Longitude (decimal degrees)	Spring complex name for labels	Site label name: Spring complex name_Vent No_SW_YYYYMMDD	Required flow measurement method	Tenure holder
Dawson River 2	2	42	-25.51502355	150.0586082	DR2	DR2_42_SW_YYYYMMDD		off-tenure
Boggomoss	5	2	-25.4576017	150.02148	Boggomoss	Boggomoss_2_SW_YYYYMMDD		off-tenure
Boggomoss	5	3	-25.45254651	150.0292412	Boggomoss	Boggomoss_3_SW_YYYYMMDD		off-tenure
Boggomoss	5	7	-25.42675664	150.0281648	Boggomoss	Boggomoss_7_SW_YYYYMMDD		off-tenure
Boggomoss	5	8	-25.41540657	150.0236539	Boggomoss	Boggomoss_8_SW_YYYYMMDD		off-tenure
Boggomoss	5	9	-25.41483661	150.023632	Boggomoss	Boggomoss_9_SW_YYYYMMDD		off-tenure
Boggomoss	5	10	-25.41246512	150.0209163	Boggomoss	Boggomoss_10_SW_YYYYMMDD		off-tenure
Boggomoss	5	11	-25.45118343	150.0435847	Boggomoss	Boggomoss_11_SW_YYYYMMDD		off-tenure
Boggomoss	5	12	-25.44135435	150.0563478	Boggomoss	Boggomoss_12_SW_YYYYMMDD		off-tenure
Boggomoss	5	13	-25.44085157	150.0563245	Boggomoss	Boggomoss_13_SW_YYYYMMDD		off-tenure
Boggomoss	5	14	-25.44762943	150.0427044	Boggomoss	Boggomoss_14_SW_YYYYMMDD		off-tenure
Boggomoss	5	15	-25.44349858	150.0337326	Boggomoss	Boggomoss_15_SW_YYYYMMDD		off-tenure
Boggomoss	5	29	-25.45161256	150.0204894	Boggomoss	Boggomoss_29_SW_YYYYMMDD		off-tenure
Boggomoss	5	33	-25.45913631	150.0285987	Boggomoss	Boggomoss_33_SW_YYYYMMDD		off-tenure
Boggomoss	5	37	-25.46079838	150.0796957	Boggomoss	Boggomoss_37_SW_YYYYMMDD		off-tenure
Boggomoss	5	37.1	-25.46083753	150.0798116	Boggomoss	Boggomoss_37.1_SW_YYYYMMDD		off-tenure
Boggomoss	5	44	-25.45863392	150.0475805	Boggomoss	Boggomoss_44_SW_YYYYMMDD		off-tenure
Boggomoss	5	53	-25.45486721	150.0210337	Boggomoss	Boggomoss_53_SW_YYYYMMDD		off-tenure
Boggomoss	5	54	-25.44534961	150.0591455	Boggomoss	Boggomoss_54_SW_YYYYMMDD		off-tenure
Boggomoss	5	55	-25.42186255	150.0227037	Boggomoss	Boggomoss_55_SW_YYYYMMDD		off-tenure
Boggomoss	5	56	-25.42472495	150.0217385	Boggomoss	Boggomoss_56_SW_YYYYMMDD		off-tenure
Boggomoss	5	56.1	-25.4245658	150.021045	Boggomoss	Boggomoss_56.1_SW_YYYYMMDD		off-tenure
Boggomoss	5	57	-25.42017349	150.0265028	Boggomoss	Boggomoss_57_SW_YYYYMMDD		off-tenure
Boggomoss	5	58	-25.42250065	150.0271392	Boggomoss	Boggomoss_58_SW_YYYYMMDD		off-tenure

Complex Name	Complex Number	Vent No	Latitude (decimal degrees)	Longitude (decimal degrees)	Spring complex name for labels	Site label name: Spring complex name_Vent No_SW_YYYYMMDD	Required flow measurement method	Tenure holder
Boggomoss	5	61	-25.45435894	150.0274468	Boggomoss	Boggomoss_61_SW_YYYYMMDD		off-tenure
Boggomoss	5	62	-25.43112764	150.0251739	Boggomoss	Boggomoss_62_SW_YYYYMMDD		off-tenure
Boggomoss	5	63	-25.45020088	150.0463916	Boggomoss	Boggomoss_63_SW_YYYYMMDD		off-tenure
Boggomoss	5	68	-25.4311504	150.0269657	Boggomoss	Boggomoss_68_SW_YYYYMMDD		off-tenure
Boggomoss	5	68.1	-25.43120943	150.0266768	Boggomoss	Boggomoss_68.1_SW_YYYYMMDD		off-tenure
Boggomoss	5	683	-25.45312751	150.0205662	Boggomoss	Boggomoss_683_SW_YYYYMMDD		off-tenure
Boggomoss	5	691	-25.48731898	150.0471372	Boggomoss	Boggomoss_691_SW_YYYYMMDD		off-tenure
Dawson River 6	6	1	-25.43409526	150.025268	DR6	DR6_1_SW_YYYYMMDD		off-tenure
Dawson River 6	6	4	-25.44578102	150.0236943	DR6	DR6_4_SW_YYYYMMDD		off-tenure
Dawson River 6	6	5	-25.44554528	150.0260319	DR6	DR6_5_SW_YYYYMMDD		off-tenure
Dawson River 6	6	6	-25.42748095	150.0227381	DR6	DR6_6_SW_YYYYMMDD		off-tenure
Dawson River 6	6	22	-25.4280454	150.0274794	DR6	DR6_22_SW_YYYYMMDD		off-tenure
Dawson River 6	6	23	-25.43585637	150.0256214	DR6	DR6_23_SW_YYYYMMDD		off-tenure
Dawson River 6	6	24	-25.43837566	150.0256315	DR6	DR6_24_SW_YYYYMMDD		off-tenure
Dawson River 6	6	25	-25.4368412	150.023329	DR6	DR6_25_SW_YYYYMMDD		off-tenure
Dawson River 6	6	27	-25.43227654	150.0253622	DR6	DR6_27_SW_YYYYMMDD		off-tenure
Dawson River 6	6	30	-25.44227155	150.0055029	DR6	DR6_30_SW_YYYYMMDD		off-tenure
Dawson River 6	6	31	-25.44085753	150.0048892	DR6	DR6_31_SW_YYYYMMDD		off-tenure
Dawson River 6	6	32	-25.44119617	150.0260088	DR6	DR6_32_SW_YYYYMMDD		off-tenure
Dawson River 6	6	43	-25.46326113	150.0567337	DR6	DR6_43_SW_YYYYMMDD		off-tenure
Dawson River 6	6	59	-25.44208309	150.0234976	DR6	DR6_59_SW_YYYYMMDD		off-tenure
Dawson River 6	6	60	-25.43021577	150.0215641	DR6	DR6_60_SW_YYYYMMDD		off-tenure
Dawson River 6	6	681	-25.43604964	150.0229777	DR6	DR6_681_SW_YYYYMMDD		off-tenure
Dawson River 8	8	26	-25.55242	149.807105	DR8	DR8_26_SW_YYYYMMDD		off-tenure (assigned to QGC)
Dawson River 8	8	28	-25.55242	149.807105	DR8	DR8_28_SW_YYYYMMDD		off-tenure (assigned to QGC)
Dawson River 8	8	38	-25.56850966	149.8021111	DR8	DR8_38_SW_YYYYMMDD	B	off-tenure (assigned to QGC)

Complex Name	Complex Number	Vent No	Latitude (decimal degrees)	Longitude (decimal degrees)	Spring complex name for labels	Site label name: Spring complex name_Vent No_SW_YYYYMMDD	Required flow measurement method	Tenure holder
Cockatoo Creek	9	64	-25.7176972	150.2409226	CcktooCk	CcktooCk_64_SW_YYYYMMDD		off-tenure
Cockatoo Creek	9	64.1	-25.71781297	150.2407025	CcktooCk	CcktooCk_64.1_SW_YYYYMMDD		off-tenure
Cockatoo Creek	9	65	-25.71645643	150.2390982	CcktooCk	CcktooCk_65_SW_YYYYMMDD		off-tenure
Cockatoo Creek	9	65.1	-25.71628444	150.2390233	CcktooCk	CcktooCk_65.1_SW_YYYYMMDD		off-tenure
Cockatoo Creek	9	65.2	-25.71621969	150.2391317	CcktooCk	CcktooCk_65.2_SW_YYYYMMDD		off-tenure
Cockatoo Creek	9	66	-25.719417	150.238101	CcktooCk	CcktooCk_66_SW_YYYYMMDD		off-tenure
Cockatoo Creek	9	319	-25.72546831	150.2688961	CcktooCk	CcktooCk_319_SW_YYYYMMDD		off-tenure
Cockatoo Creek	9	320	-25.73178874	150.2518877	CcktooCk	CcktooCk_320_SW_YYYYMMDD		off-tenure
Cockatoo Creek	9	320.1	-25.73194259	150.2519747	CcktooCk	CcktooCk_320.1_SW_YYYYMMDD		off-tenure
Cockatoo Creek	9	321	-25.72941864	150.2500176	CcktooCk	CcktooCk_321_SW_YYYYMMDD		off-tenure
Cockatoo Creek	9	321.1	-25.72965807	150.2498677	CcktooCk	CcktooCk_321.1_SW_YYYYMMDD		off-tenure
Cockatoo Creek	9	321.2	-25.72971516	150.2500017	CcktooCk	CcktooCk_321.2_SW_YYYYMMDD		off-tenure
Cockatoo Creek	9	321.3	-25.72976047	150.2501178	CcktooCk	CcktooCk_321.3_SW_YYYYMMDD		off-tenure
Cockatoo Creek	9	321.4	-25.72955732	150.2498508	CcktooCk	CcktooCk_321.4_SW_YYYYMMDD		off-tenure
Cockatoo Creek	9	321.5	-25.72944292	150.2498188	CcktooCk	CcktooCk_321.5_SW_YYYYMMDD		off-tenure
Cockatoo Creek	9	321.6	-25.7293432	150.2500551	CcktooCk	CcktooCk_321.6_SW_YYYYMMDD		off-tenure
Cockatoo Creek	9	321.7	-25.72893178	150.2501139	CcktooCk	CcktooCk_321.7_SW_YYYYMMDD		off-tenure
Cockatoo Creek	9	321.8	-25.72871228	150.2502401	CcktooCk	CcktooCk_321.8_SW_YYYYMMDD		off-tenure
Cockatoo Creek	9	684	-25.72583114	150.2694099	CcktooCk	CcktooCk_684_SW_YYYYMMDD		off-tenure
Ponies	229	284	-25.82954964	149.0413821	Ponies	Ponies_284_SW_YYYYMMDD	B	Santos
Lucky Last	230	287	-25.79806535	148.7755795	LuckyLast	LuckyLast_287_SW_YYYYMMDD	A	Santos
Lucky Last	230	340	-25.79399184	148.7731738	LuckyLast	LuckyLast_340_SW_YYYYMMDD	B	Santos
Lucky Last	230	686	-25.79477826	148.7734076	LuckyLast	LuckyLast_686_SW_YYYYMMDD	B	Santos
Lucky Last	230	687	-25.794811	148.7737796	LuckyLast	LuckyLast_687_SW_YYYYMMDD	B	Santos
Lucky Last	230	687.1	-25.79462441	148.773846	LuckyLast	LuckyLast_687.1_SW_YYYYMMDD	B	Santos
Lucky Last	230	687.2	-25.794561	148.7737828	LuckyLast	LuckyLast_687.2_SW_YYYYMMDD	B	Santos
Lucky Last	230	687.3	-25.79420224	148.7736134	LuckyLast	LuckyLast_687.3_SW_YYYYMMDD	B	Santos

Complex Name	Complex Number	Vent No	Latitude (decimal degrees)	Longitude (decimal degrees)	Spring complex name for labels	Site label name: Spring complex name_Vent No_SW_YYYYMMDD	Required flow measurement method	Tenure holder
Lucky Last	230	687.4	-25.79411808	148.7735415	LuckyLast	LuckyLast_687.4_SW_YYYYMMDD	B	Santos
Lucky Last	230	687.5	-25.79367953	148.7732965	LuckyLast	LuckyLast_687.5_SW_YYYYMMDD	B	Santos
Lucky Last	230	687.6	-25.79359458	148.7733188	LuckyLast	LuckyLast_687.6_SW_YYYYMMDD	B	Santos
Lucky Last	230	688	-25.79511407	148.7737482	LuckyLast	LuckyLast_688_SW_YYYYMMDD	B	Santos
Lucky Last	230	689	-25.79398988	148.7728387	LuckyLast	LuckyLast_689_SW_YYYYMMDD	B	Santos
Scotts Creek	260	189	-25.89150945	149.2859827	Scotts Ck	Scotts Ck_189_SW_YYYYMMDD	A	APLNG
Scotts Creek	260	190	-25.8884365	149.2874154	Scotts Ck	Scotts Ck_190_SW_YYYYMMDD		APLNG
Scotts Creek	260	191	-25.89175501	149.2874838	Scotts Ck	Scotts Ck_191_SW_YYYYMMDD	A	APLNG
Scotts Creek	260	192	-25.88895774	149.279041	Scotts Ck	Scotts Ck_192_SW_YYYYMMDD	A	APLNG
Scotts Creek	260	192.1	-25.88811432	149.2791888	Scotts Ck	Scotts Ck_192.1_SW_YYYYMMDD	B	APLNG
Barton	283	702	-26.27030324	149.2432849	Barton	Barton_702_SW_YYYYMMDD	A	APLNG
Barton	283	703	-26.28533269	149.234459	Barton	Barton_703_SW_YYYYMMDD	B	APLNG
311	311	535	-25.7202	149.0275078	311	311_535_SW_YYYYMMDD	A	Santos
311	311	536	-25.71449917	149.0654313	311	311_536_SW_YYYYMMDD	A	Santos
311	311	537	-25.72834046	149.0939031	311	311_537_SW_YYYYMMDD	A	Santos
311	311	704	-25.67971845	149.1272668	311	311_704_SW_YYYYMMDD	A	Santos
Spring Rock Creek	561	285	-25.76267665	148.769787	SpRckCk	SpRckCk_285_SW_YYYYMMDD	A	Santos
Prices	580	40	-25.47528611	150.1287009	Prices	Prices_40_SW_YYYYMMDD		off-tenure
Prices	580	41	-25.47671662	150.1309371	Prices	Prices_41_SW_YYYYMMDD		off-tenure
Prices	580	52	-25.4772879	150.1256939	Prices	Prices_52_SW_YYYYMMDD		off-tenure
Prices	580	67	-25.47553915	150.1272052	Prices	Prices_67_SW_YYYYMMDD		off-tenure
Wambo	584	711	-26.87419522	150.4371375	Wambo	Wambo_711_SW_YYYYMMDD	A	QGC
Yebna 2	591	534	-25.73264193	149.1027786	Yebna2	Yebna2_534_SW_YYYYMMDD	B	Santos
Abyss	592	286	-25.79817442	148.7691414	Abyss	Abyss_286_SW_YYYYMMDD	B	Santos
Abyss	592	286.1	-25.79815318	148.7702873	Abyss	Abyss_286.1_SW_YYYYMMDD	B	Santos
Abyss	592	286.2	-25.79795094	148.7701929	Abyss	Abyss_286.2_SW_YYYYMMDD	B	Santos
Abyss	592	286.3	-25.79762097	148.7687133	Abyss	Abyss_286.3_SW_YYYYMMDD	B	Santos
Abyss	592	682	-25.80809736	148.7341988	Abyss	Abyss_682_SW_YYYYMMDD	B	off-tenure (assigned to Santos)

Complex Name	Complex Number	Vent No	Latitude (decimal degrees)	Longitude (decimal degrees)	Spring complex name for labels	Site label name: Spring complex name_Vent No_SW_YYYYMMDD	Required flow measurement method	Tenure holder
Abyss	592	716	-25.80768618	148.7339995	Abyss	Abyss_716_SW_YYYYMMDD	B	off-tenure (assigned to Santos)
Elgin2	594	540	-24.53411959	149.1695497	Elgin2	Elgin2_540_SW_YYYYMMDD		off-tenure (assigned to Santos)

Table A 2 - Watercourse Springs Monitoring Sites

Watercourse spring site number	Start Latitude	Start Longitude	Finish Latitude	Finish Longitude	Location of watercourse spring	UWIR – Selected Spring for monitoring
W39	-25.7256	149.3031	-25.6767	149.2351	On APLNG tenement	✓
W40	-25.6795	149.1373	-25.6848	149.0665	On Santos tenement	✓
W80	-25.7434	148.6857	-25.6977	148.4273	Off-tenure	✓
W81	-25.7127	149.0837	-25.7151	149.0283	On Santos tenement	✓
W82	-25.8038	148.7799	-25.8119	148.7327	On Santos tenement	✓

APPENDIX B – Groundwater Monitoring Sites and Sites Label Names

JIP EWS bore ID	Latitude	Longitude	Target Aquifer	Site Label Name: GW ID_GW_YYYYM MDD – GW ID provided here	Responsible Proponent
Spring Gully PB5	-25.9325	148.9355	Precipice Sandstone	SG PB5	Origin
Spring Gully-PB2	-25.9325	148.9355	Hutton Sandstone	SG PB2	Origin
Spring Gully-PB1	-25.8375	148.8510	Precipice Sandstone	SG PB1	Origin
RN48912	-25.8375	148.8511	Hutton Sandstone	RN48912	Origin
Contact Zone	-25.8098	148.8276	Precipice Sandstone	TBA	Santos
QWC129	-25.8250	148.7916	Hutton Sandstone & Precipice Sandstone	QWC129	Santos
MW0905	-25.7309	148.8456	Precipice Sandstone	MW0905	Santos
Cassio_GW1	-25.9454	149.7754	Hutton Sandstone	CAS_GW1	QGC
Cassio_GW2	-25.9454	149.7754	Precipice Sandstone	CAS_GW2	QGC
Coochiemudlo_GW1	-25.7630	149.9770	Hutton Sandstone	Coochie_GW1	QGC
Coochiemudlo_GW2	-25.7630	149.9770	Precipice Sandstone	Coochie_GW2	QGC
Peat MB2-P	-26.0152	150.0958	Precipice Sandstone	Peat MB2-P	Origin
Peat MB3-H	-26.0152	150.0958	Hutton Sandstone	Peat MB3-H	Origin
Scotia OBS#1	-25.9419	150.0742	Precipice Sandstone	Scotia OBS#1	Santos
RN23147	-25.9141	150.0736	Hutton Sandstone	RN23147	Santos
AVLVWP	-25.9379	150.0739	Hutton Sandstone , Precipice Sandstone	AVLVWP	Santos
Charlotte_GW1	-25.9100	149.5400	Hutton Sandstone	Charlotte_GW1	QGC
Charlotte_GW2	-25.9100	149.5400	Precipice Sandstone	Charlotte_GW2	QGC
Kinnoul-MB2-H	-25.6648	149.5973	Hutton Sandstone	Kinnoul-MB2-H	Origin
EWMI7	-24.6074	149.0761	Clematis Sandstone	EWMI7	Santos
RN14881	-25.8872	149.3247	Hutton Sandstone	RN14881	Origin
Spring Gully MB4-H	-25.9801	149.0652	Hutton Sandstone	SG MB4-H	Origin
PB3	-25.9818	149.0465	Precipice Sandstone	SG PB3	Origin
RN48978	-26.0014	149.2826	Hutton Sandstone	RN48978	Origin
QWC104	-25.8263	149.0370	Hutton Sandstone, Precipice Sandstone	QWC104	Santos
MW0902	-25.7347	149.0829	Precipice Sandstone	MW0902	Santos
Charlie_GW1	-26.0240	149.6470	Hutton Sandstone	Charlie_GW1	QGC
Spring Gully MB16-P	-25.8666	149.2168	Precipice Sandstone	SG MB16-P	Origin
Spring Gully MB17-H	-25.8665	149.2168	Hutton Sandstone	SG MB17-H	Origin
RN38333	-25.8645	149.1580	Hutton Sandstone	RN38333	Origin
Strathblane-WB1-P	-25.9002	149.1444	Precipice Sandstone	Strathblane-WB1-P	Origin

APPENDIX C - Example Site ID Information Sheet

Site ID Information Sheet for _____ (Site ID)				
Date:		Field Staff		
Time:		Photo files		
Coordinates:		Site Type: (check one)		Spring
				Groundwater
Site Specific Access Conditions				
Site Specific Safety Hazards				
Previous Sampling Event Date and Notes				
General Comments				

[Attach site picture or map – include measurements of site layout]

APPENDIX D - Minimum Monitoring and Sampling Equipment

Surface water monitoring

The surface water monitoring/sampling equipment requirements are as listed below:

- Sampling Pole/Rod;
- Sample containers;
- Permanent Marker;
- Field Monitoring Sheet and Chain of Custody (COC) form;
- Photo record form;
- Site ID Information Sheet
- Spring Sample Information Sheet
- Calibrated water probe (pH, Temperature, Electrical Conductivity, Total Dissolved Solids (TDS), Dissolved Oxygen, Turbidity, Redox (optional));
- Level or flow meter;
- 50 metre tape measure (or use water level probe tape)
- Compass
- Multi-gas meter
- Clean Cooler/Esky (with ice);
- Distilled Water and spray/squirt bottle;
- Digital Camera;
- GPS;
- Disposable (Nitrile) gloves; and
- Maps or instructions on access to sites.

Groundwater monitoring

The groundwater monitoring/sampling requirements are listed below:

- Pressure filtration equipment (hand operated syringe; 0.45µM filters),
- Disposable gloves;GPS;
- Distilled water and spray/squirt bottle;
- Clean Cooler/Esky (with ice);
- Water level probe with appropriate tape/cable length
- Flow meter (
- Calibrated water quality probe (pH, Temperature, Electrical Conductivity, Total Dissolved Solids (TDS), Dissolved Oxygen, Turbidity, Redox (optional));
- Multi-gas meter
- Site ID Information Sheet
- Field Monitoring Sheet and Chain of Custody C(COC) form;
- Maps or instructions on access to sites
- Sample containers (as specified by the Monitoring Suites required);
- Permanent Marker; and
- Disposal water bailers (with appropriated length rope and reel) or appropriate Groundwater Pump (with adequate length of disposable tubing).

APPENDIX E - Example Equipment Inspection Template

Equipment Inspection Template

Item: _____

Make/Model: _____

Serial Number/Unique Identifier: _____

Date: _____

Time: _____

Date of Last Calibration: _____

Calibration Required: Yes / No

Calibration Completed Successfully: Yes / No

Comments on Calibration:

Item functionality checked: Yes / No

Item functioning correctly: Yes/No

Comments/Issues with functioning:

Comments on Wear and Tear (Please comment on any items needing replacement/servicing):

APPENDIX F – Example of Calibration and Maintenance Requirements

Equipment Requirements

A range of equipment is required so that the monitoring/sampling can occur to the correct standards. Equipment is defined as any instrument or consumable required to:

- Measure water level
- Measure flow rate
- Measure field water quality parameters
- Measure gas concentrations
- obtain the sample;
- handle/transfer or store the sample (i.e. the correct sample bottle/jar) for analysis; and
- equipment that the sample will be stored in.

Monitoring equipment should be consistent between sampling events to ensure potential variability in results due to the use of different equipment is minimised. A list of the required equipment for surface water, groundwater and soil monitoring/sampling can be found in APPENDIX C.

Calibration and maintenance requirements and procedures

Monitoring equipment to be used for field measurements must be calibrated when applicable or specified by standards or the manufacturer. Such monitoring equipment includes the water quality multi-parameter probe and sound level meter. Each piece/type of equipment that requires monitoring, along with the calibration requirements and schedule are described below. These are summarised below:

Table E1 Calibration requirements

Equipment Item	Calibration Type	Frequency
Water Quality Meter	Field calibration	Daily
	Full pH and independent Electrical Conductivity Calibration	Weekly
	Full Factory Calibration	Quarterly
Multi-parameter gas meter	Bump test	Weekly
	Factory Calibration	Minimum 6 monthly (depending on meter)
Groundwater Flow Controller	Factory flow rate check	Annually

Examples of a calibration templates to be completed following calibration are contained in APPENDIX E. The calibration requirements described include those to occur in the field prior to use and those that must be completed independently by laboratories or manufacturers.

Monitoring equipment (either portable or fixed) should be inspected and tested daily to ensure that it is operational prior to sampling. For portable equipment, this should occur each day prior to use, for fixed equipment this should occur on a regular basis as determined by the monitoring schedules. In the instance of surface water monitoring facilities, this would be on a monthly basis and a quarterly basis for fixed groundwater pumps. Records of these inspections and maintenance (including calibration) are required. Example templates for these are contained within APPENDIX E.

Portable Multi-Parameter Water Quality Probe Calibration

The portable multi-parameter water quality probe requires calibration to ensure the accuracy of the observations obtained in the field. Therefore calibration of the probe and the various sensors it contains should occur prior to each monitoring event, or more frequently during an extended use period when there is an expected shift in the style of sampling occurring (i.e. from streams to groundwater or an expected significant change in the levels of the parameters measured (i.e. acidic to basic solution, non-saline to highly saline water, etc.)) or where a potential contamination source has been encountered. At a minimum, the calibration should occur daily during an extended period.

This calibration should occur in a clean environment, following the procedures specified in the product manual. The calibrations should either be a multi-point calibration where applicable or to suit the expected measurements to be encountered.

It should be ensured that the solutions used for calibration are within their viable life and stored in the correct method. Care should be taken to avoid contamination of the calibration fluids during the calibration process. Documentation of the calibration is required. An example template calibration record sheet for the water quality meters are contained in APPENDIX E. Forms must be completed correctly for each calibration event for the equipment.

The completed form should be copied and saved into the applicable database for the proponent conducting the works. Copies of QAQC forms and results will be distributed and compiled as necessary. The following naming convention would apply:

- Date of Calibration (yymmdd)_CalibrationMachineName (CalibrationAQRAM-200/AP-800) _Date Range of Calibrations (i.e. 100211_CalibrationAQRAM-200/AP-800_10 07 23 - 10 07 30).

A hard copy of this form should also be kept on file.

Groundwater Pump Calibration

Correct measurement of volumes and rate of flow is important information, which is integral in correct groundwater sampling procedure. Therefore, it is important to ensure that the flow rate/volume readings on the pumps used for logging and sampling are accurate. To ensure that the measurements of pump rates or volumes on the machines are accurate, calibration should occur as per the manufacturer's standard or recommendation and no less than an annual basis. A record of the calibration documentation should be kept in to the applicable database for the proponent conducting the works. Copies of QAQC forms will be distributed to the other Proponents as necessary.

The naming convention of the calibrations documentation should be the following:

- Date of Calibration (yymmdd)_CalibrationMachineName_calibration_date range of calibrations (including name of company).

Multi-Parameter Gas Meter Calibration

Multi-gas meters should be calibrated as per the manufacturer's specifications. Daily bump testing should be conducted and a minimum of 6 monthly four-gas calibration. A greater frequency is required where very high gas concentrations are being measured or where bump testing fails.

Calibration of gas meters should be completed only in contamination free environments. Ensure the calibration is done using methane as the combustible gas.

The naming convention of the calibrations documentation should be the following:

- Date of Calibration (yymmdd)_CalibrationMachineName_calibration_date range of calibrations (including name of company).

Example Calibration Record Sheet

1.

Date / Time	
Equipment Type	
Equipment Make/Model	
Calibrated By	
Signature	

2.

Date / Time	
Equipment Type	
Equipment Make/Model	
Calibrated By	
Signature	

Parameter				
Calibration Standard				
Calibration Time				
Calibration Value				
Calibration Accuracy				

APPENDIX G - Sample Naming and Labelling Convention

1 Sample Naming

Within the current COC documents, refer APPENDIX G, there is a designated column for the naming of samples collected. This column is labelled 'Sample ID' (Figure E1). Within this column, the sample ID must be listed. This ID is to correspond with the established sample naming convention. This naming convention is described below. See Section 2 of this appendix for details related to sample labelling.

A convention exists for each type of field sample taken, including:

- Standard samples;
- Duplicate samples; and,
- Blank samples.

Table G1 - Sample Naming Convention

Sample Type	Naming Convention	Example
Standard	COMPLEX_VENT_SOURCE_DATE_TIME	FV_S2_SURF_W
Duplicate	DUP_COMPLEX_VENT_SOURCE_DATE_TIME	FV_D1_WELL_W
Blank	BK_COMPLEX_VENT_SOURCE_DATE_TIME	FV_SC4_BLANK

Where:

- COMPLEX – the Spring Complex Name as provided in APPENDIX A.
- VENT – the Spring Vent ID number
- SOURCE:
 - SW – Surface Water; or
 - GW – Groundwater
- DATE: YYMMDD

TIME: HH:MM

In addition to this, the sample date and time must be recorded on the sample bottle and chain of custody form. The columns on the COC where these are recorded are the 'Date' and 'Time' sections. It is important to complete these sections correctly, as the results provided by the laboratory will include the corresponding sample dates and times as part of the sample results dataset for entry in the database. The standard format for date and time is YYYYMMDD and HH:MM.

2 Sample Labelling

Complete the following standard practice when labelling sample containers/ bottles:

- Sample bottles to also be labelled with the sampler's name (first initial and surname), Sample ID, and date and time (24-hour format) of sample (to match COC).
- Sample bottles to be labelled as per sample naming convention (name to match ID on COC).
- Nitrile (or latex) gloves must be worn when labelling the bottles.
- Labelling should occur prior to the purging/sampling.

APPENDIX H - Chain of Custody Documents

The Chain of Custody (COC) document is a tool by which samples collected and their associated data is able to be submitted to the laboratory with the custody tracked through to its final delivery. This documentation also provides a legal component of the custody and tracking of the samples collected and submitted to laboratories for analysis. Therefore, the correct completion of this documentation is of high importance.

Example of Water COC

[illegible]

APPENDIX I - Example Springs Sample Information Sheet

Springs Sample Information Sheet				
Spring Complex Name			Date:	
Spring Complex No:			Time:	
Spring Vent No.:			Operator:	
Recent Weather Conditions:				
Seasonal Observations:				
Wet Area Data: (Circle one)				
Ponding water	YES	NO	N/A	
Water Flow	YES	NO	N/A	
Seeping (measure if flowing away from spring)	YES	NO	N/A	
Stagnant	YES	NO	N/A	
Flow Area: Length (dm) by Width (dm)				
Spring Classification (Check which applies)				
☐ 1: Wetland vegetation, spring pool, minor or major flows				
☐ 2: Wetland vegetation, no spring pool, surface expression of free water, minor flows				
☐ 3: Wetland, vegetation, no spring pool, some surface expression of free water				
☐ 4: Damp, wetland vegetation, no surface expression of free water				
☐ 5: Dry, no wetland vegetation, no surface expression of the water, no evidence of salt scalding				
Spring Vent Diagram:				
		- Measurements will be taken along the perimeter (traversing spring NOT permitted). - Use a tape to record area; - Use the same control point and method each time the flow is measured - Flow measurements - Measure when clearly defined channel - If impractical to take without potential damage to spring, use visual estimates and notate		
Field Parameters	Collected? (Value)		Sample Information	
TSS	Yes/No		Sampling Method:	
Electrical. Conductivity (µS/cm)	Yes/No		Time Sampled:	
pH	Yes/No		Sample ID:	
Eh (mV)	Yes/No		COC Reference No:	
DO (mg/L)	Yes/No		Duplicate taken? (Name if taken)	
Turb. (NTU)	Yes/No		General Comments:	
Temp (°C)	Yes/No			

APPENDIX J - Example of Photograph Record Sheet

This document is to track the photographs that are taken at monitoring locations throughout the field. The objective is to assist in recording the details of each photo so that they can be saved into the document storage system 'BASIN' appropriately and to record any observations associated with the photograph of importance.

Each photo is to be saved into to the applicable database for the proponent conducting the works. Results should be distributed and compiled as necessary under the following file name structure:

- YYMMDD_MonitoringLocation_Direction_Time (24hour) _Work Order Number, the year, month and date at the start is to be the date that the photo was taken.
- For example: 100817_ES6_Upstream_0915_EBP10010010).

Date	
Time (24HR)	
Monitoring Location (i.e. ES7)	
Aspect (i.e. upstream, downstream, sample site)	
Direction (degrees)	
Comments	

Date	
Time (24HR)	
Monitoring Location (i.e. ES7)	
Aspect (i.e. upstream, downstream, sample site)	
Direction (degrees)	
Comments	

APPENDIX K – Example of Groundwater Low Flow Purging and Sampling Monitoring Sheet

Location: _____ Bore _____

Date: _____

Time: _____

Device: _____ Elevation _____

Make/Model: _____

Serial Number: _____

Pressure: _____

Pump Rate: _____

Monument Height: _____

[illegible]

APPENDIX L – Method for Spring Flow Monitoring as defined in the Surat UWIR (QWC, 2012)

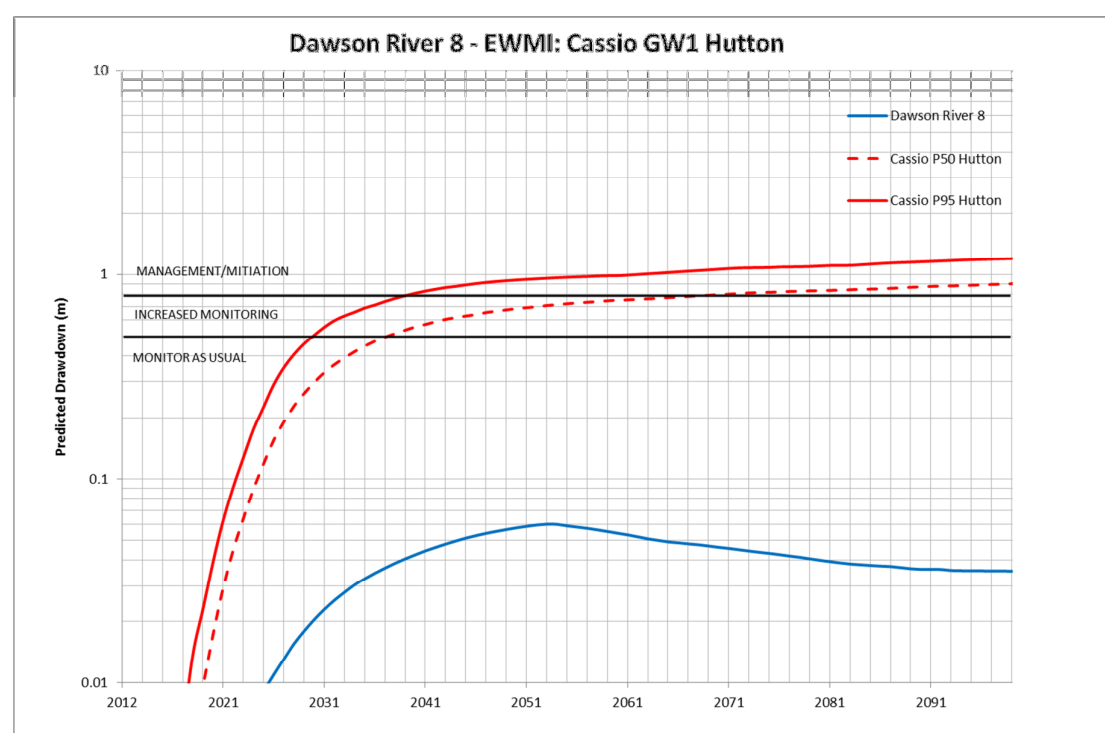
Spring attribute	Monitoring method	
Ambient conditions	Record the total rainfall for the 7-day period prior to monitoring. Use observations from the weather station closest to the monitoring site.	
Spring flow	Method A	Identify a suitable control point. Use a standard low flow hydrology method suitable for the site. Record the method. Use the same control point and method each time the flow is measured. Photograph the control points each time the flow is measured. For watercourse springs measure the flow at the start and finish locations as specified in Table H-5. For watercourse springs, comment on the extent of the flow beyond the end location as specified in Table H-5.
	Method B	Assign one of the following classifications to the spring.
		1 Wetland vegetation, spring pool ¹ , minor or major flow(s).
		2 Wetland vegetation, no spring pool, surface expression of free water, minor flow(s).
		3 Wetland vegetation, no spring pool, some surface expression of free water.
		4 Damp, wetland vegetation, no surface expression of free water.
		5 Dry, no wetland vegetation, no surface expression of free water, no evidence of salt scalding.
Spring area	Spring vents	Use the method described in Fensham & Fairfax 2009 For springs with an area greater than 1.5m ² , use a Differential Global Positioning System. For springs with a total area of less than 1.5m ² , estimate the total area. Using the area, estimate the spring flow using the method described by Fatchen (2001); $10^{(((\text{LOG}(\text{spring area in m}^2) - 3.692)/0.707))}$.
	Watercourse springs	Estimation of spring area is not required.

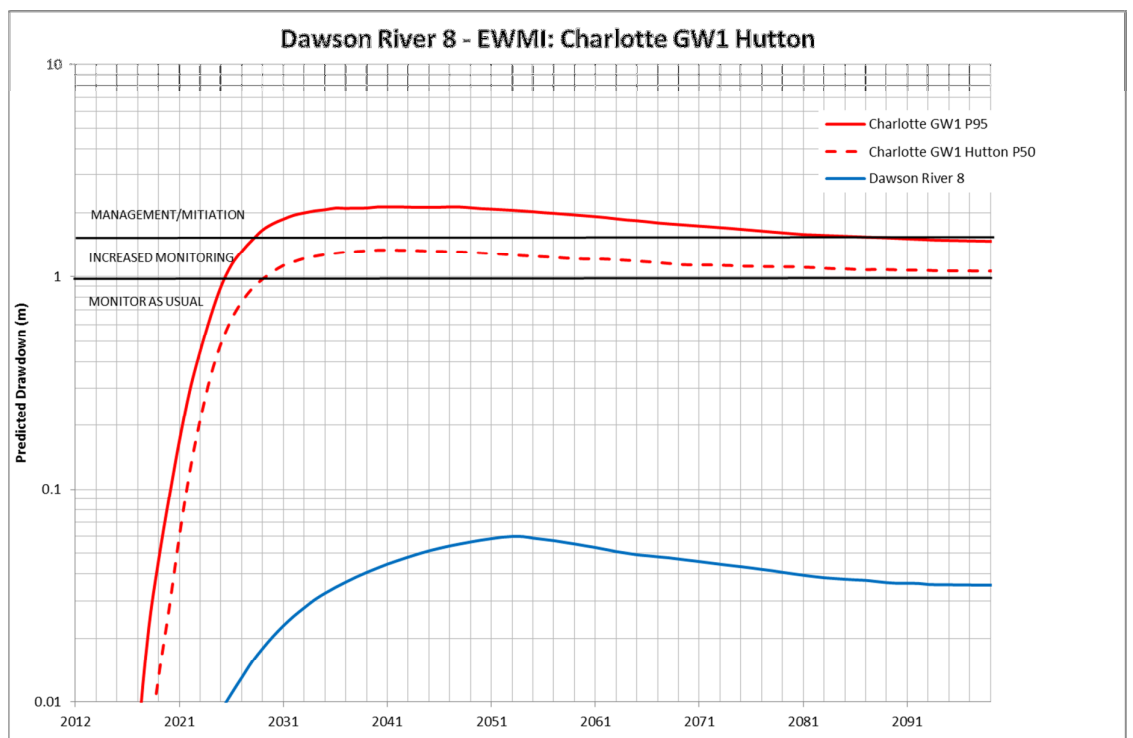
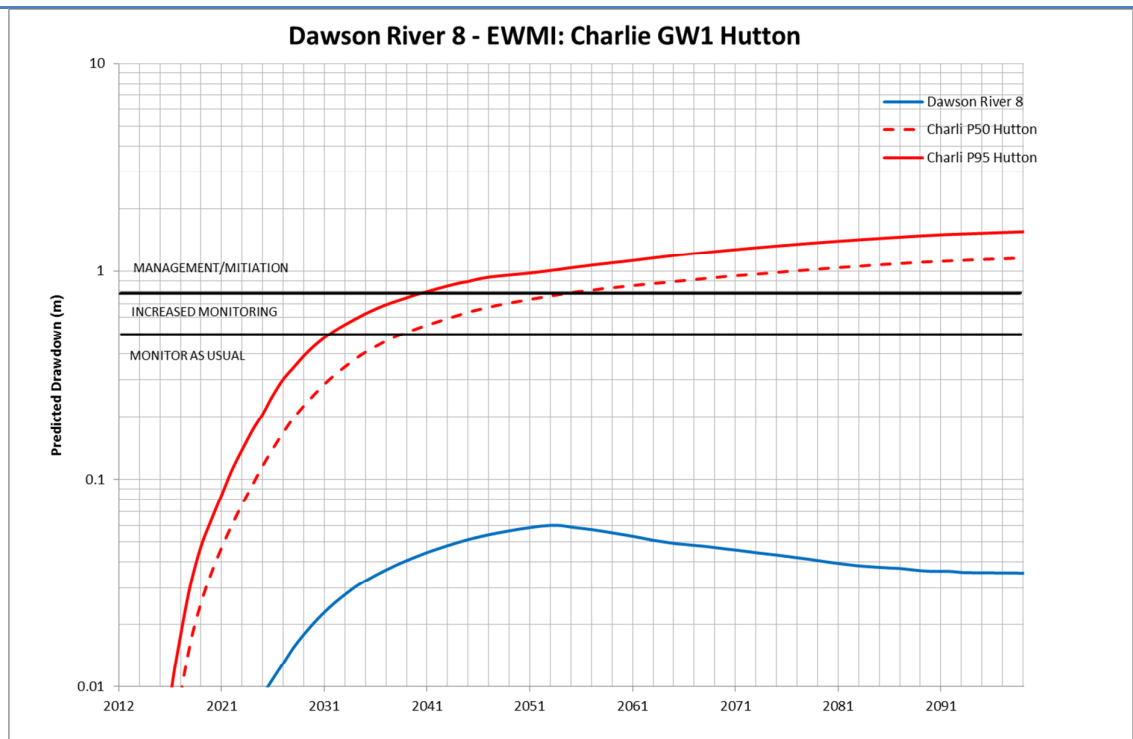
APPENDIX C – Notes to Table 8.2 and Table 8.3

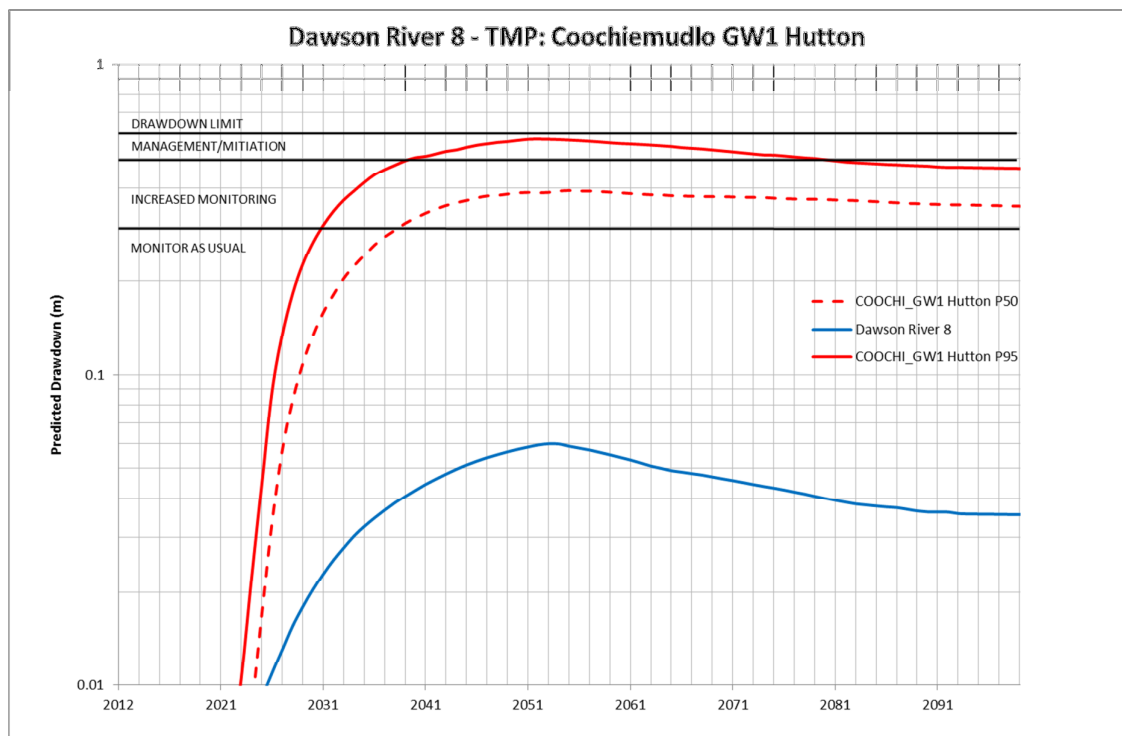
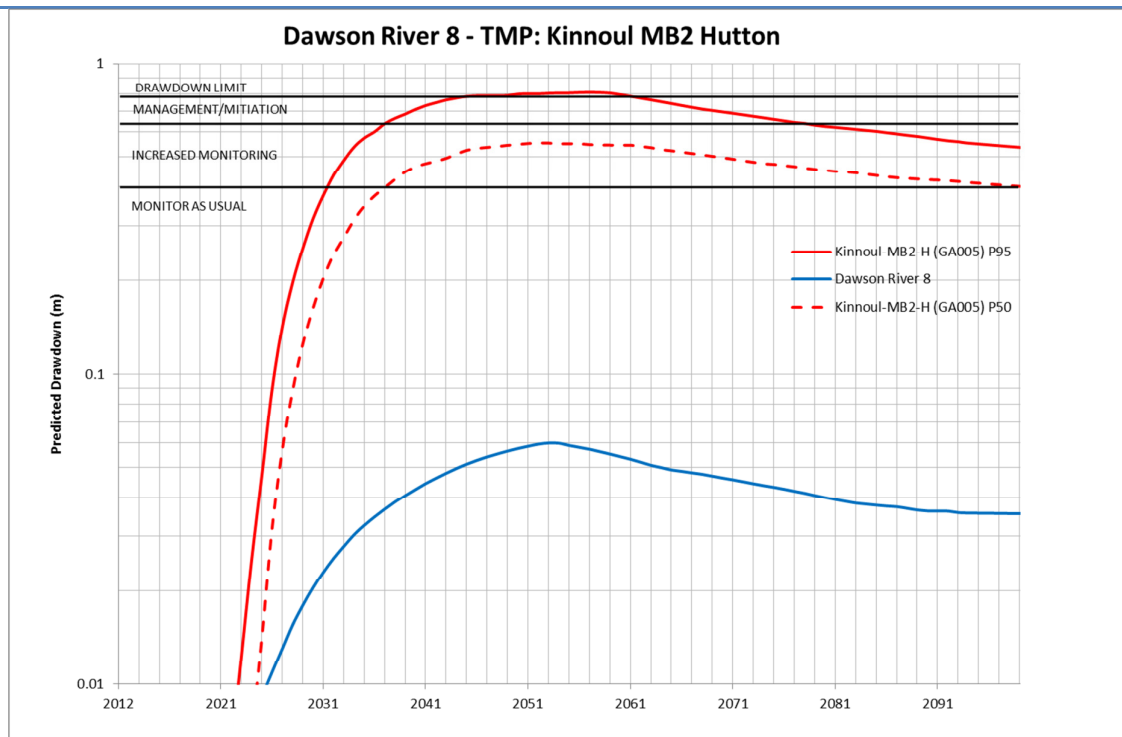
Notes to Table 8-2:

Dawson River 8:

- The propagation of the impact to this spring, if it were to occur would be from the WCMs to the Hutton Sandstone and then laterally through the Hutton Sandstone which is the primary source aquifer for the Dawson River 8 spring complex. As a consequence, monitoring of the Precipice Sandstone will not provide any further value with respect to the potential impacts to Dawson River 8 spring complex. All bores of the EWS for this spring complex will be Hutton Sandstone bores.

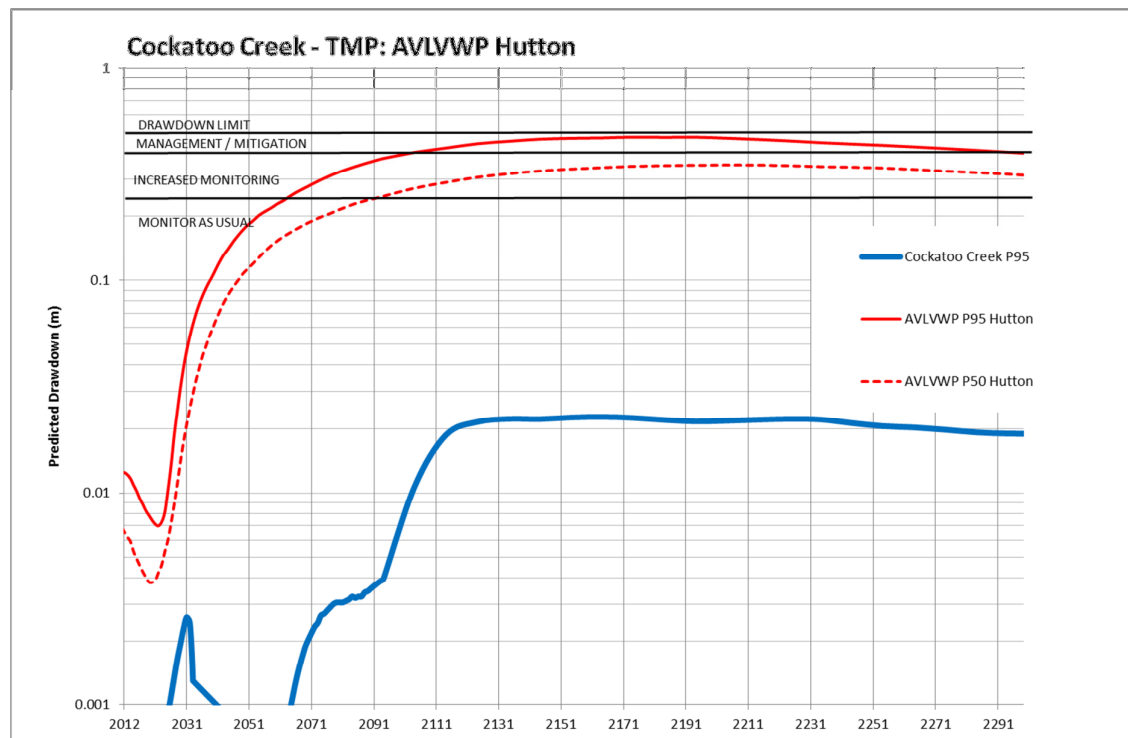


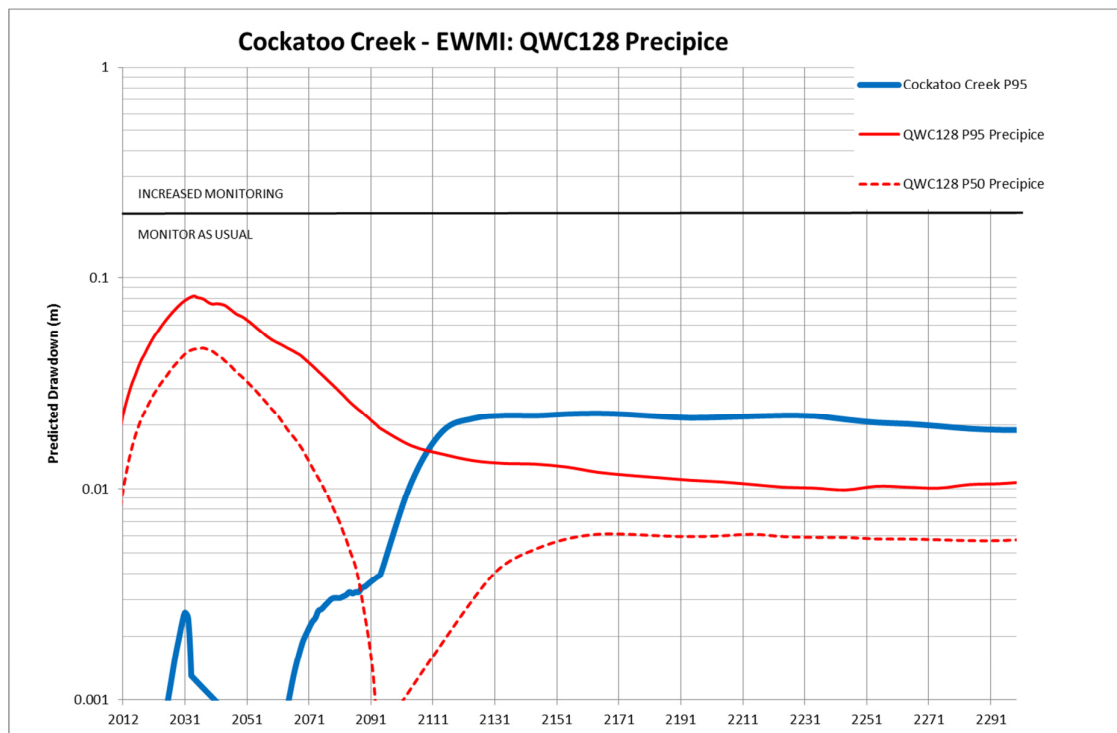
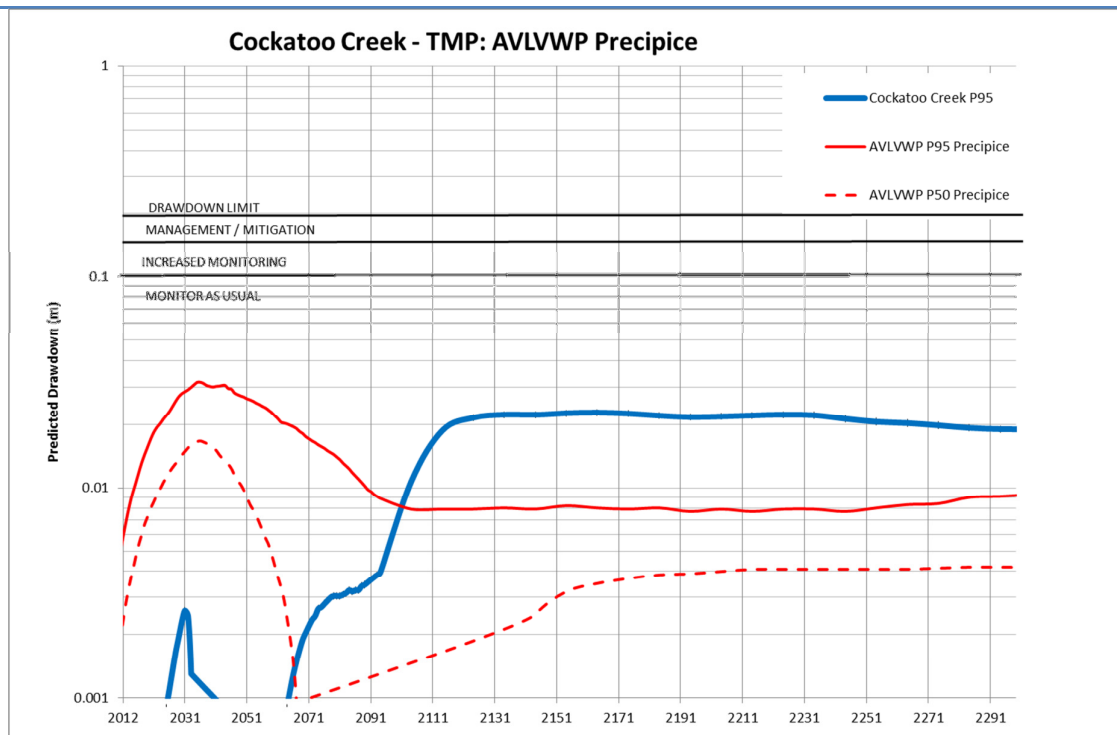


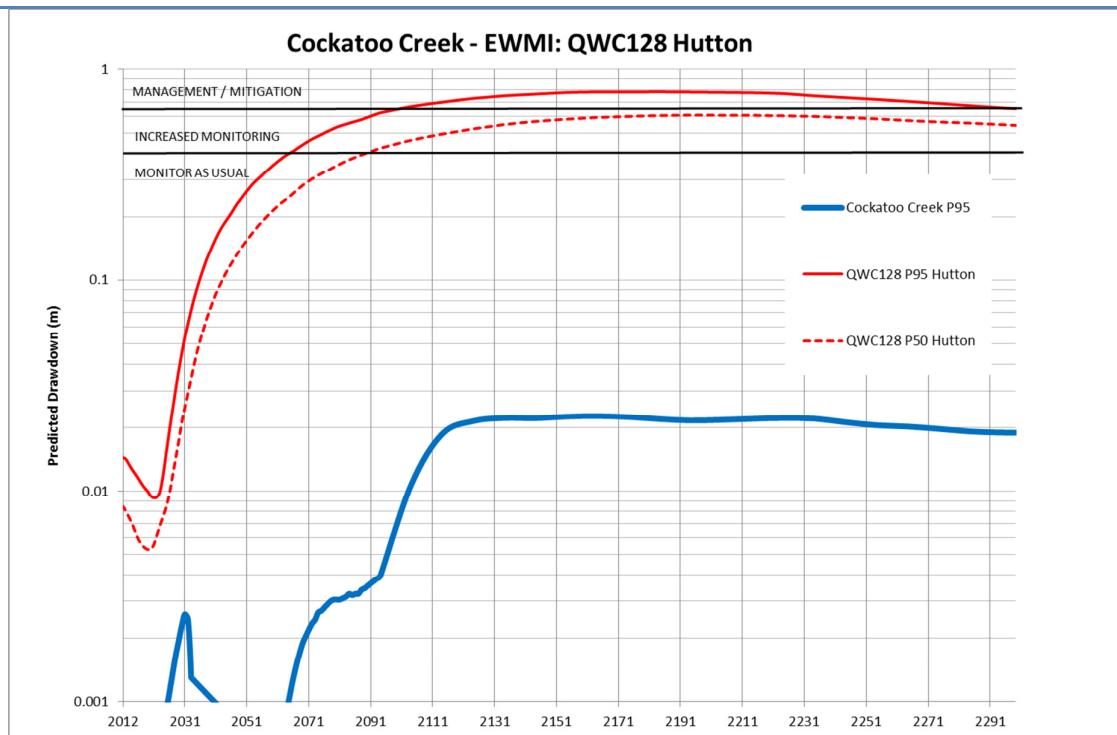


Cockatoo Creek:+

- The primary interpreted source aquifer is the Precipice Sandstone, there are potential contributions to the spring complex from the Evergreen Formation (KCB, 2012), as such EWMLs and TMPs are defined for both the Hutton Sandstone and Precipice Sandstone. The Hutton Sandstone is used as a proxy for the Evergreen Formation.
- The TMP is defined for the Precipice and Hutton aquifers at AVLWVP.

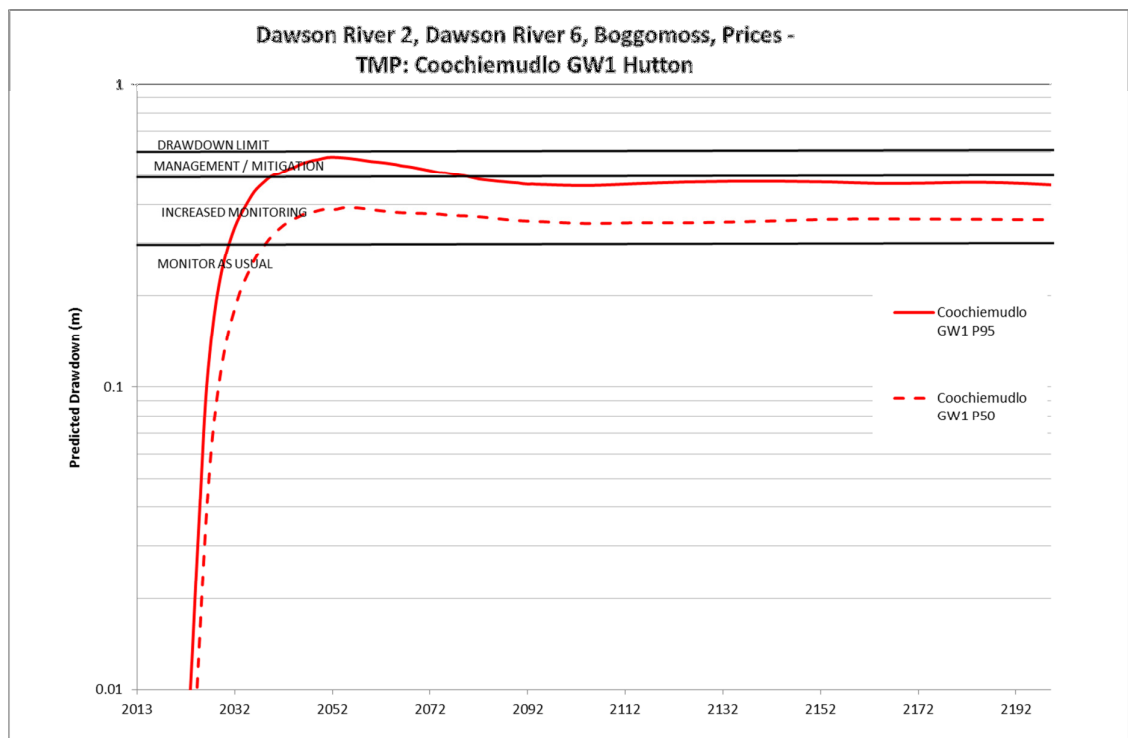
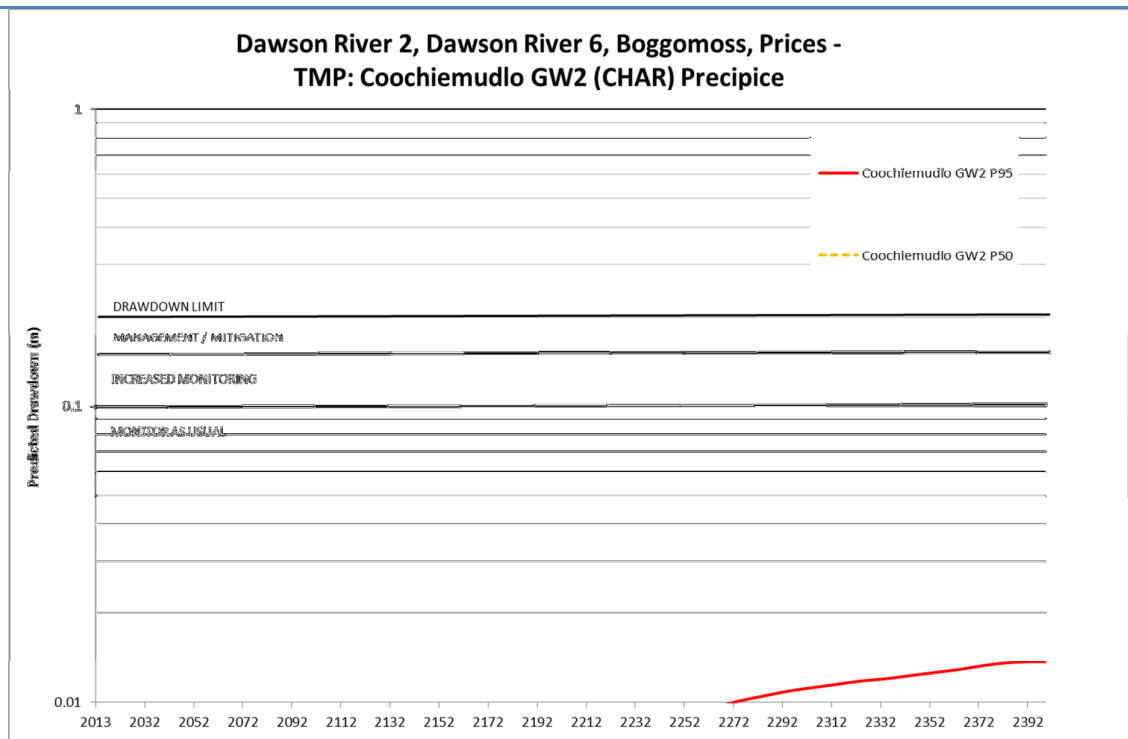


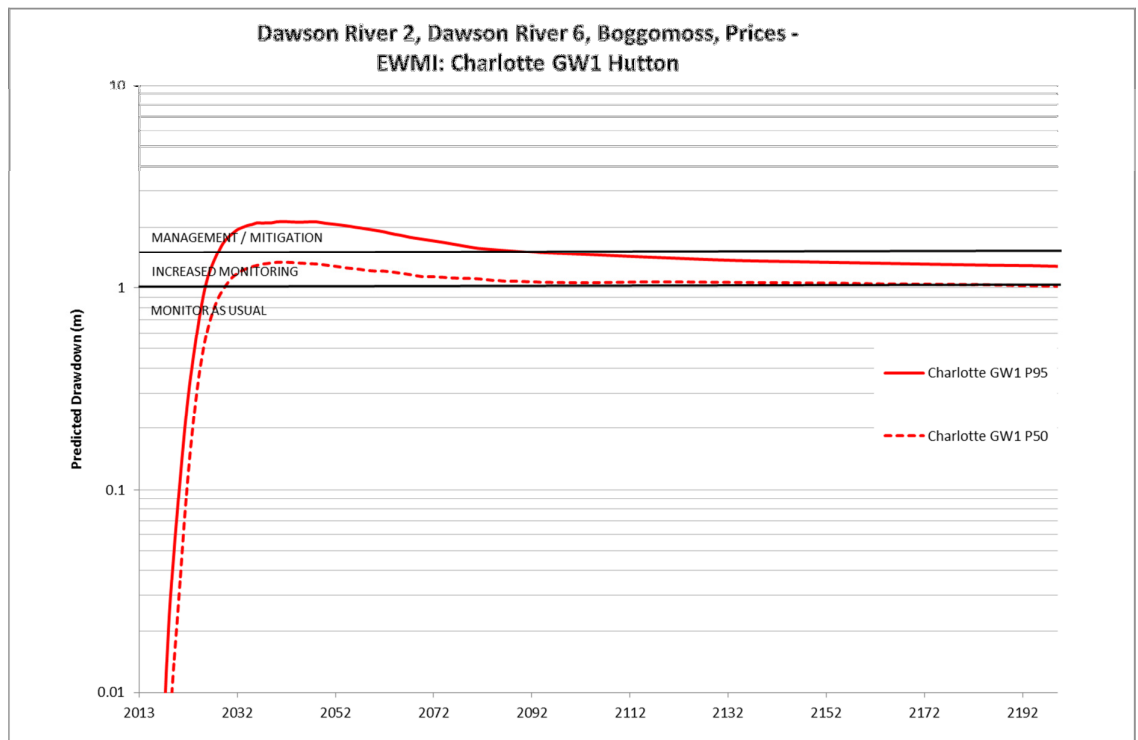
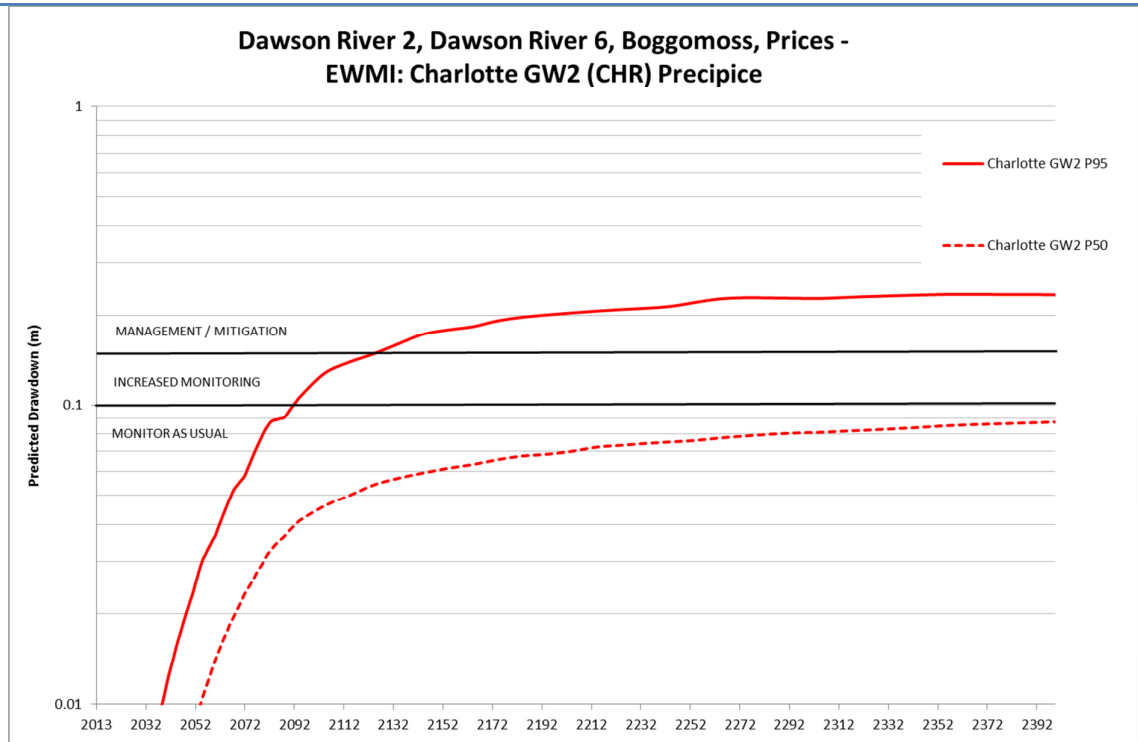


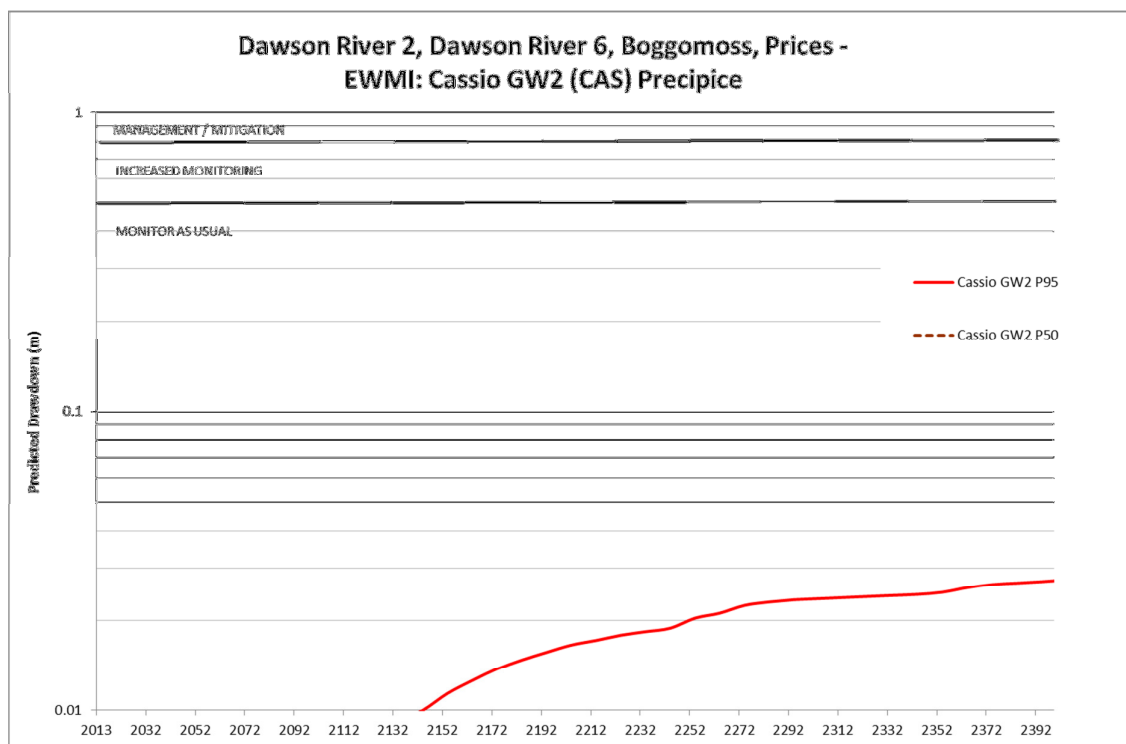
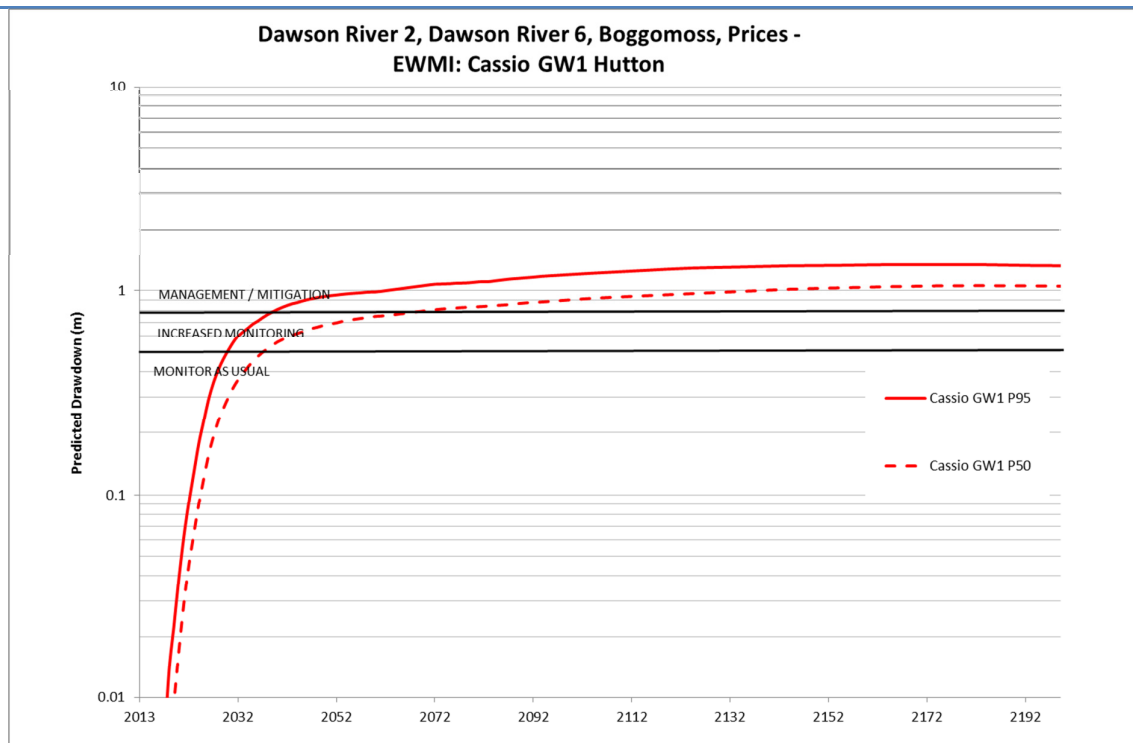


Dawson River 6, Dawson River 2, Boggomoss, Prices:

- The interpreted primary source aquifer is the Precipice Sandstone, potential contribution from the Evergreen Formation are identified in the KCB studies (KCB, 2012). As such both the Hutton Sandstone (used as a proxy for the Evergreen Formation) and the Precipice Sandstone will be monitored and exceedances and drawdown limits assigned to relevant bores of the EWS.
- No drawdown is predicted at the Dawson River 6, Dawson River 2, Boggomoss, Prices EPBC springs.
- EWMI and TMPs defined for Hutton and Precipice Sandstones
- The exceedance values are based on the P95 percentile corresponding to a zero drawdown at the spring.
- As, no measurable drawdown for Coochiemudlo GW2 (Precipice), the drawdown limit is set at 0.2 m, investigation trigger and management/mitigation trigger are set accordingly (0.1 m and 0.16 m respectively corresponding to 50% and 80% of 0.2 m).
- No measurable drawdown for Cassio GW2 (Precipice), the investigation trigger and management/mitigation triggers are set at 0.1 m and 0.16 m respectively (50% and 80% of 0.2 m).







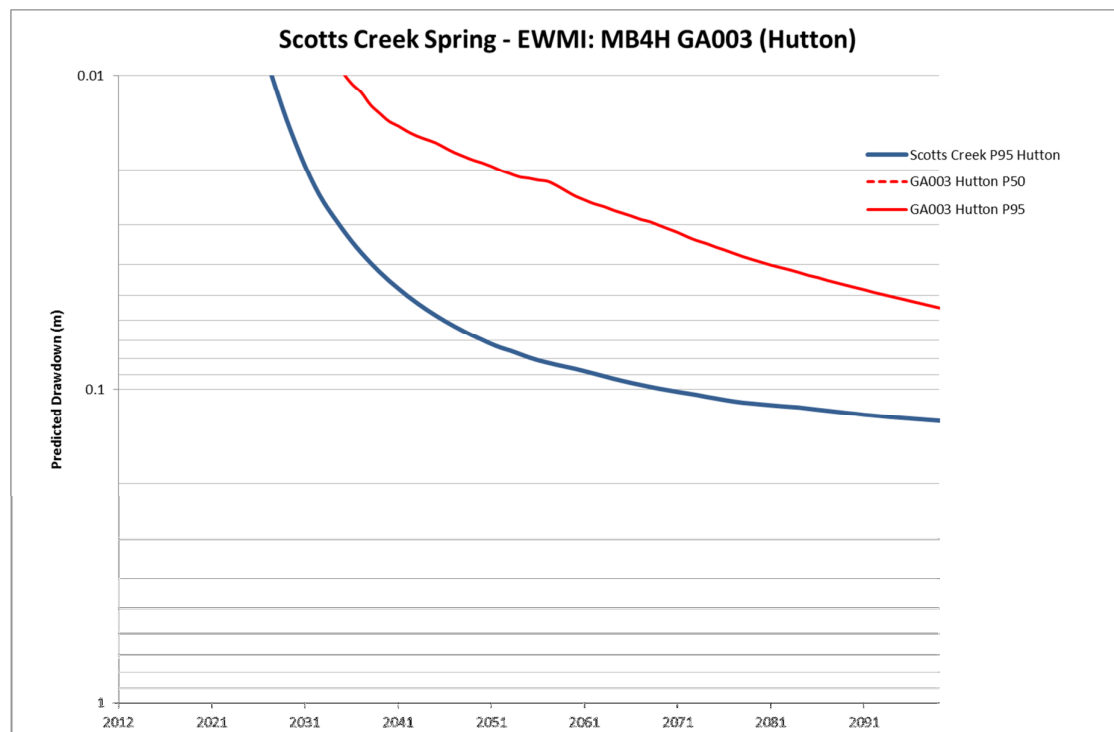
Elgin 2:

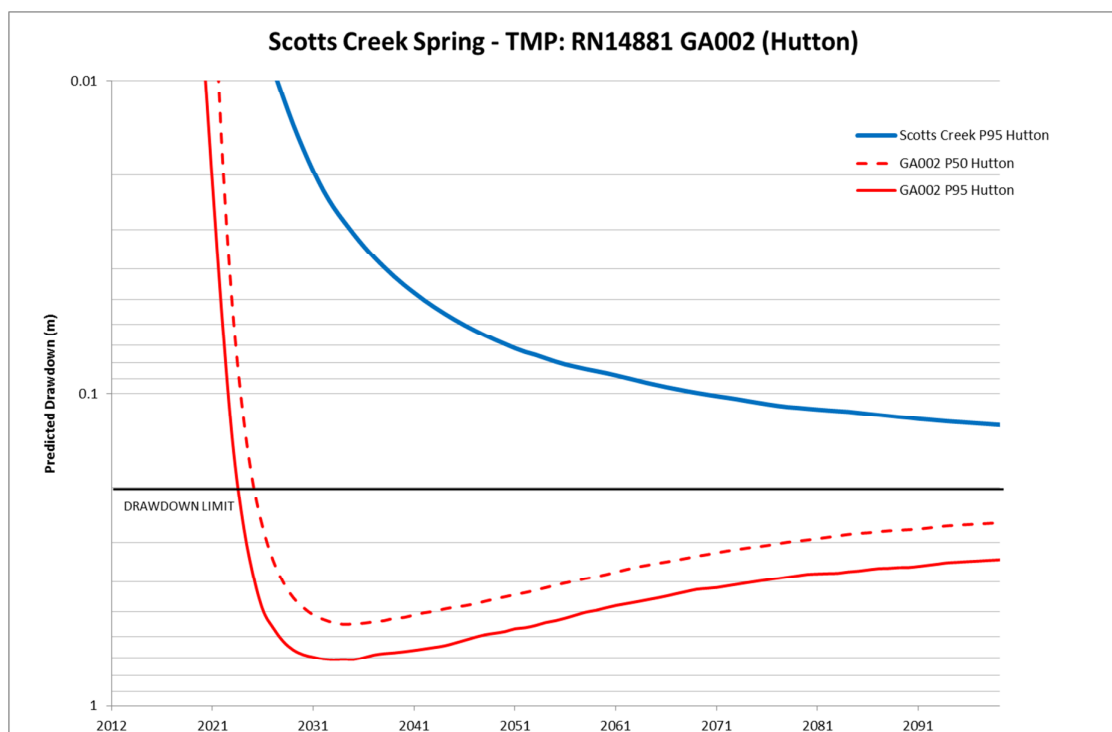
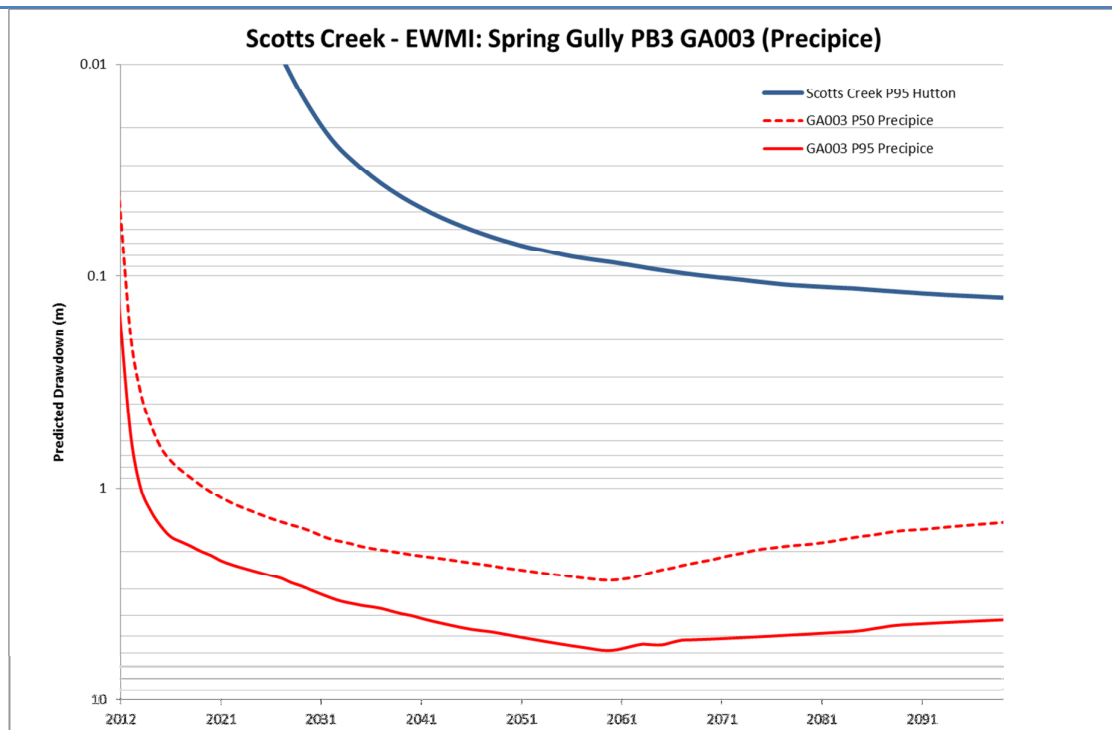
- No impact is predicted at Elgin 2
 - Only the EWMI is defined at this stage due to distance to the predicted zone of impact
 - Default values have been used for setting exceedances.
-

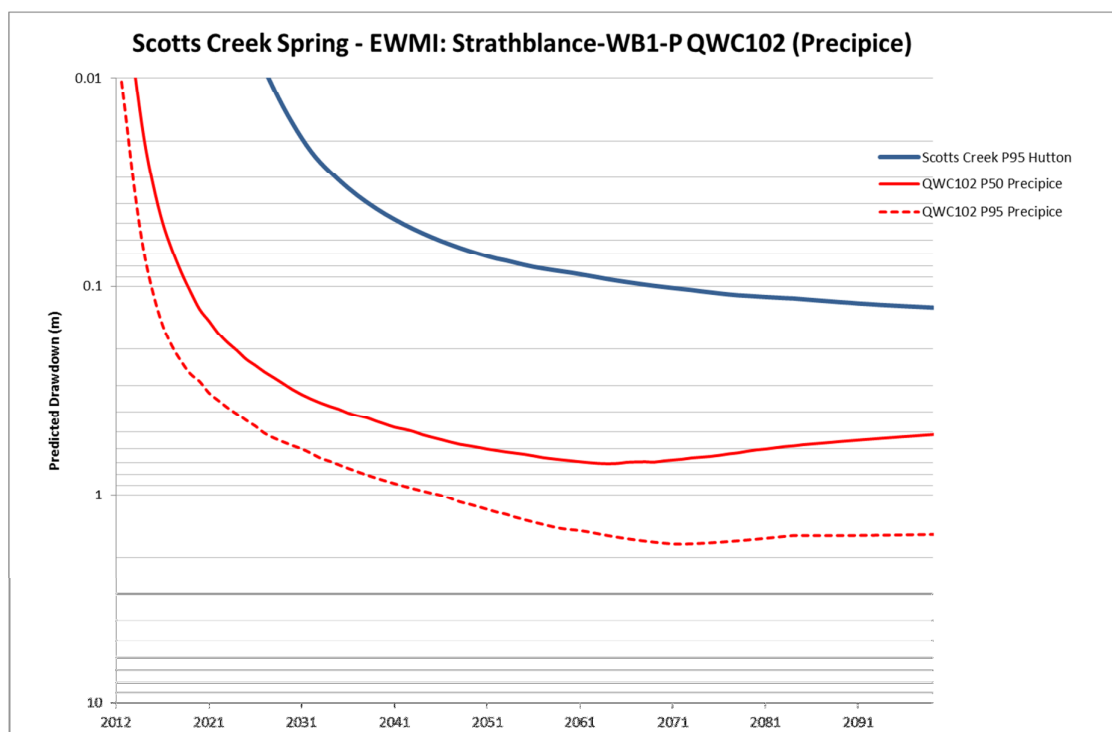
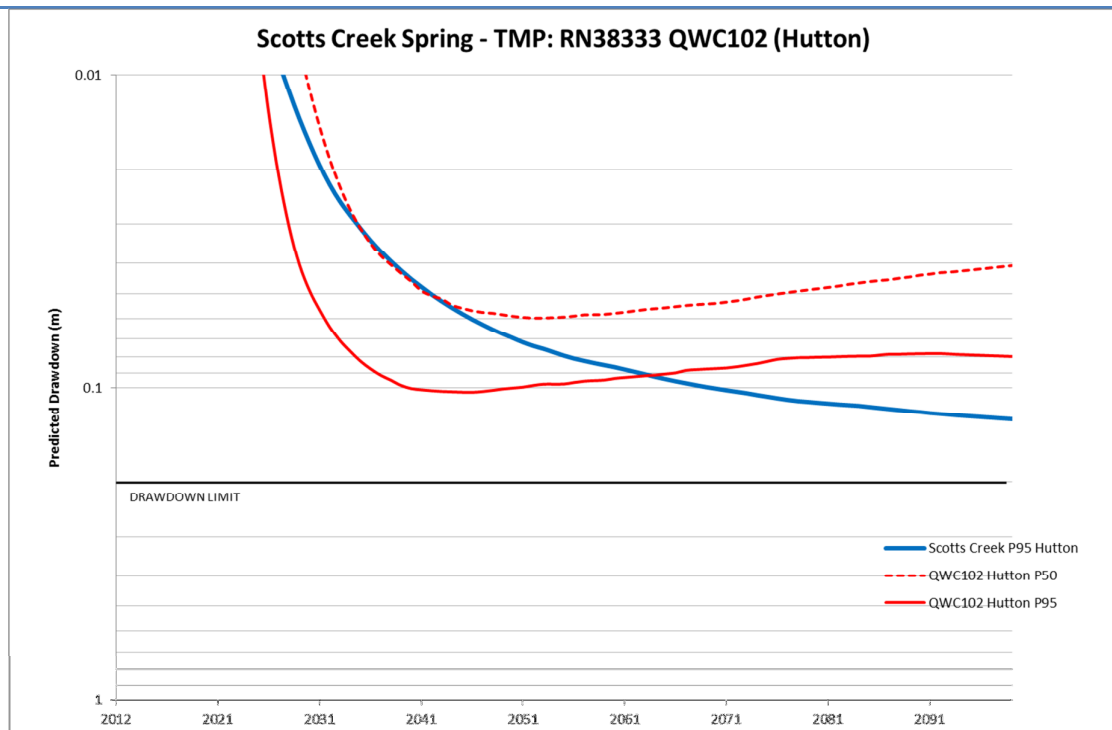
Notes to Table 8-3:

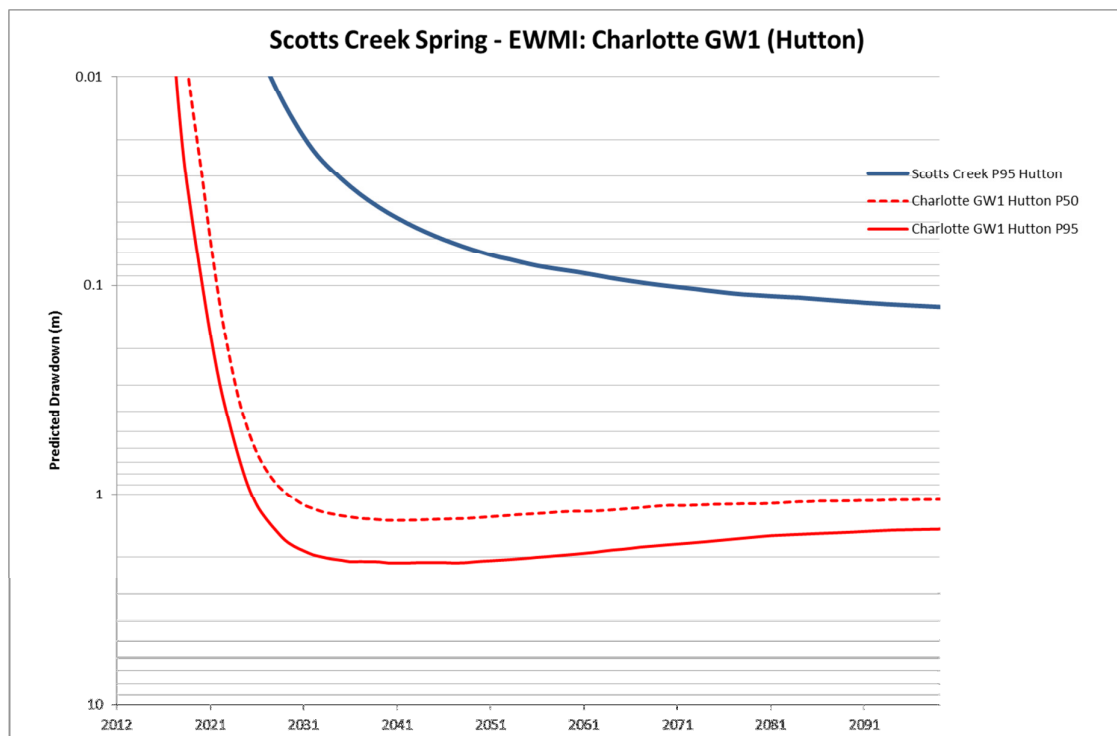
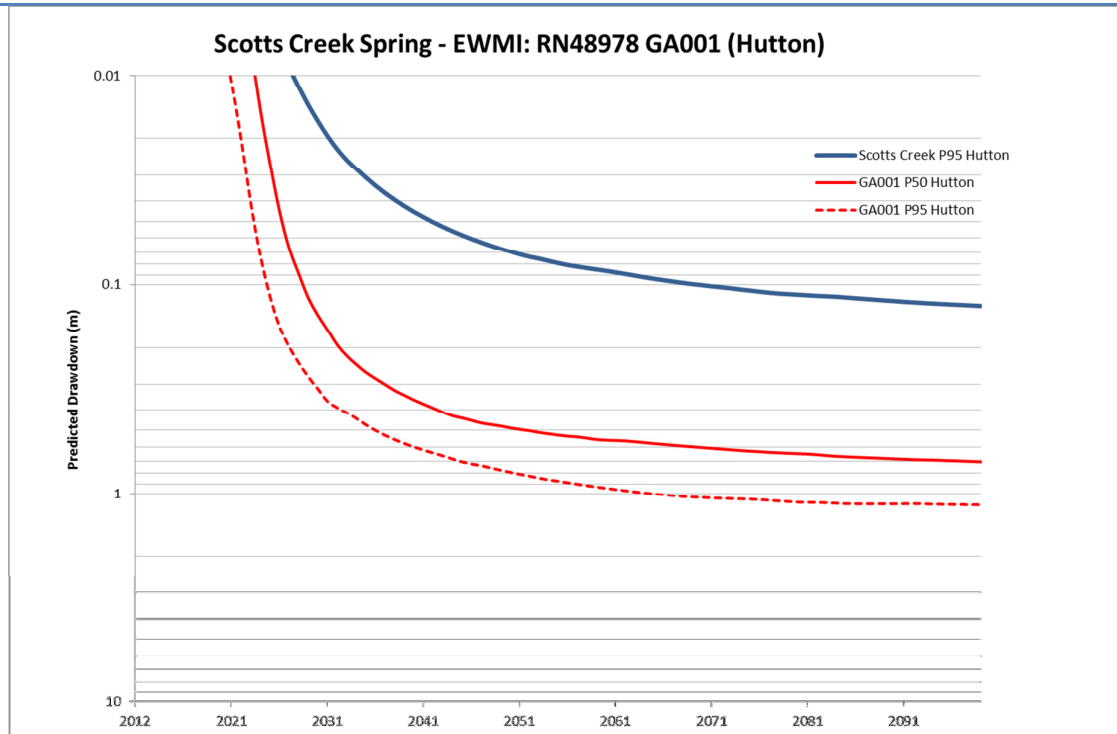
Scott's Creek:

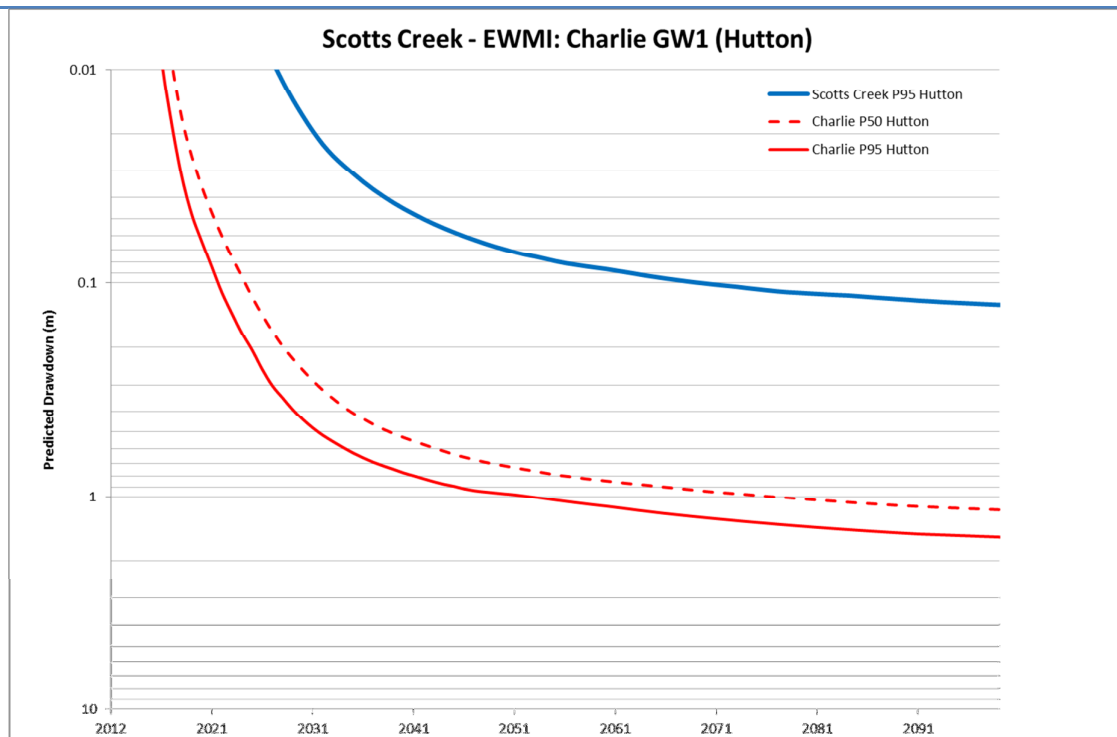
- Scott's Creek spring complex source aquifer is the Hutton Sandstone.
- Eight (8) EWMI's are defined for Scott's Creek, most of them being in the Hutton Sandstone, two of them being in the Precipice Sandstone.
- TMPs are defined for the Hutton Sandstone





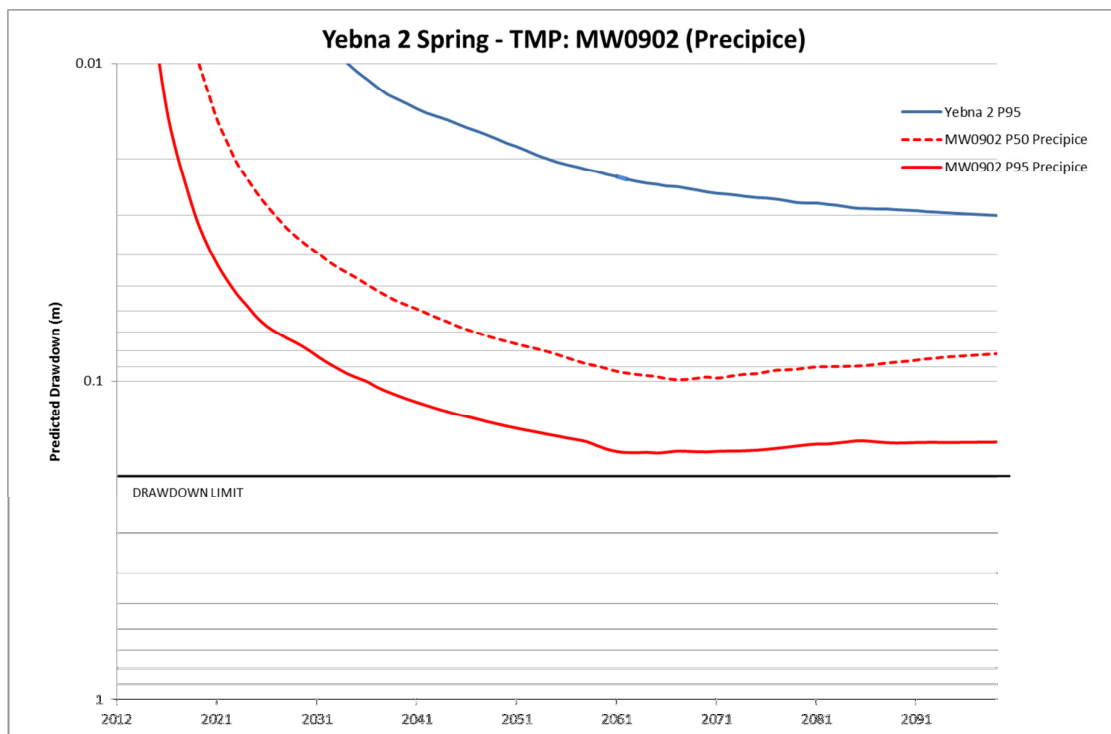


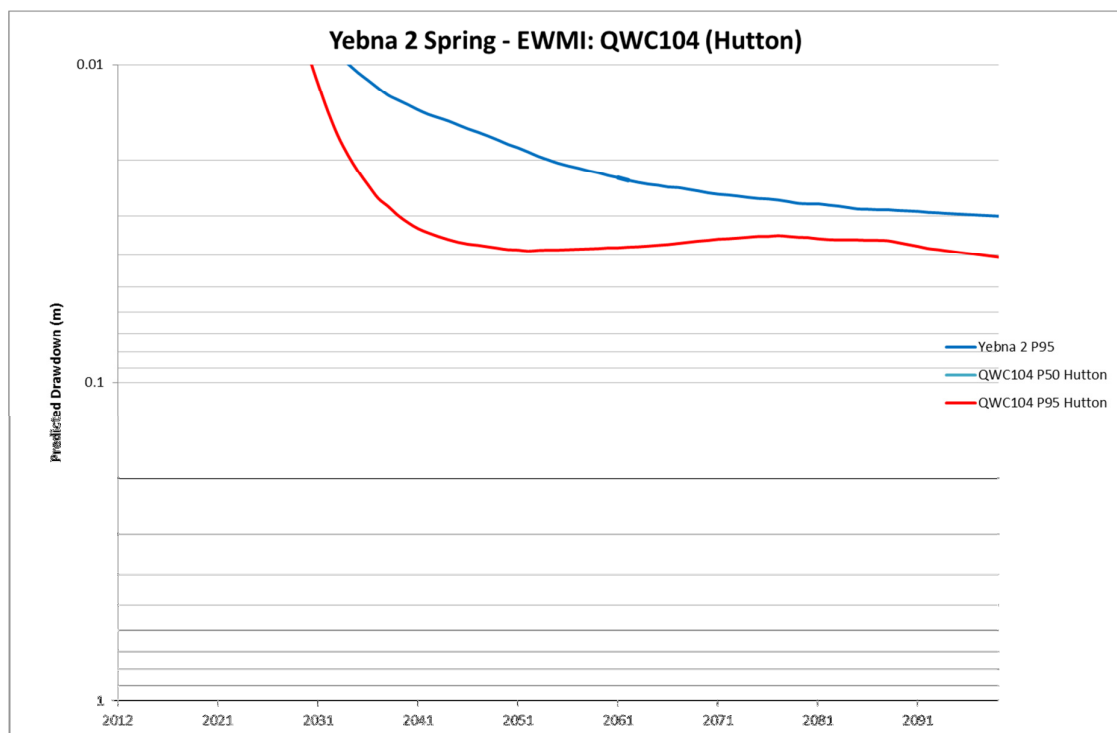
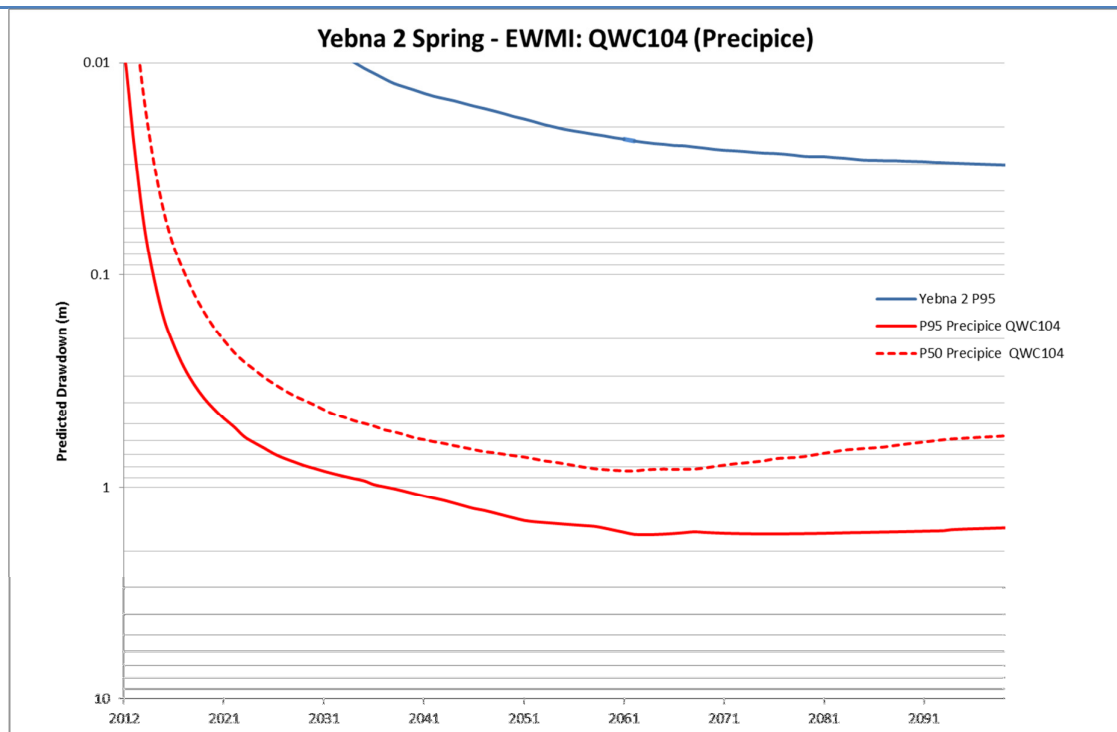




Yebna 2:

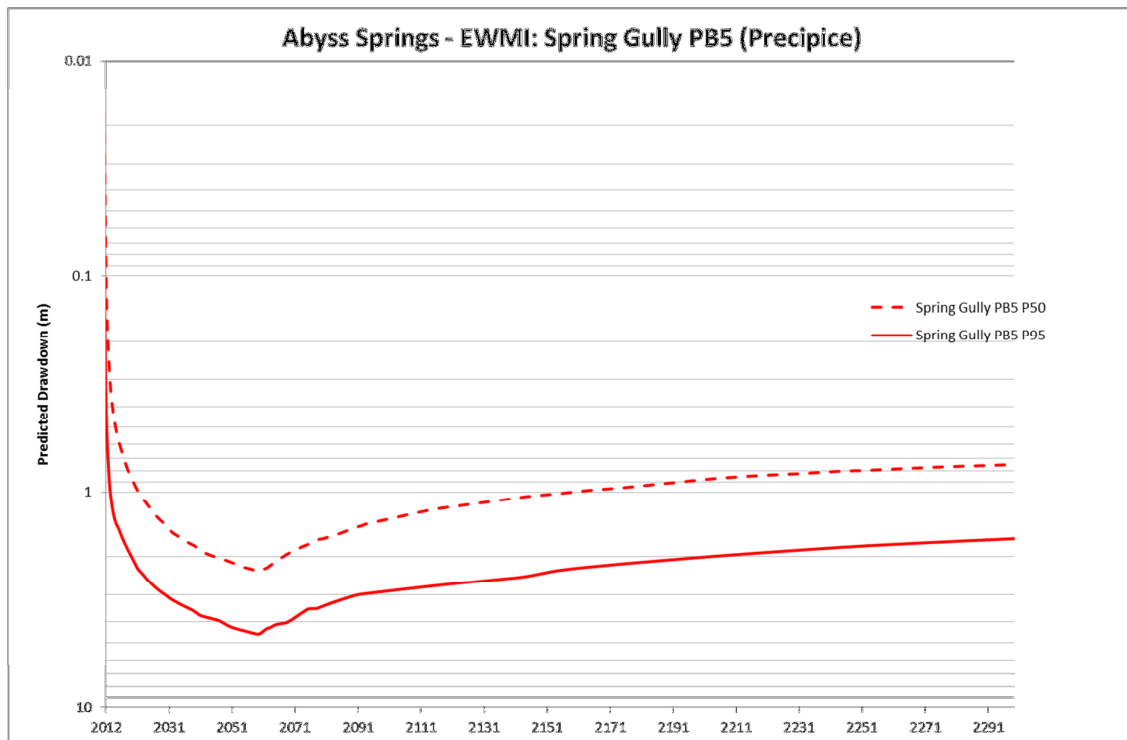
- QWC104 Hutton and QWC104 Precipice are located on the line of impact propagation to Yebna 2 and will be the two EWMIIs for Yebna 2. The Hutton Sandstone is not present at Yebna 2. The Boxvale Sandstone of the Evergreen Formation is an identified potential source aquifer for Yebna 2. Yebna 2 is located at the foothill of the Evergreen Formation outcrop. The source of the impact for Yebna 2 is impact through the Precipice Sandstone from the Bowen Basin CSG activities or impact propagating laterally through the Precipice Sandstone towards Yebna 2.
- The maximum P95 predicted drawdown at Yebna 2 is 0.04 m. The TMP used will be MW0902, an existing dedicated groundwater monitoring well in the Precipice Sandstone.

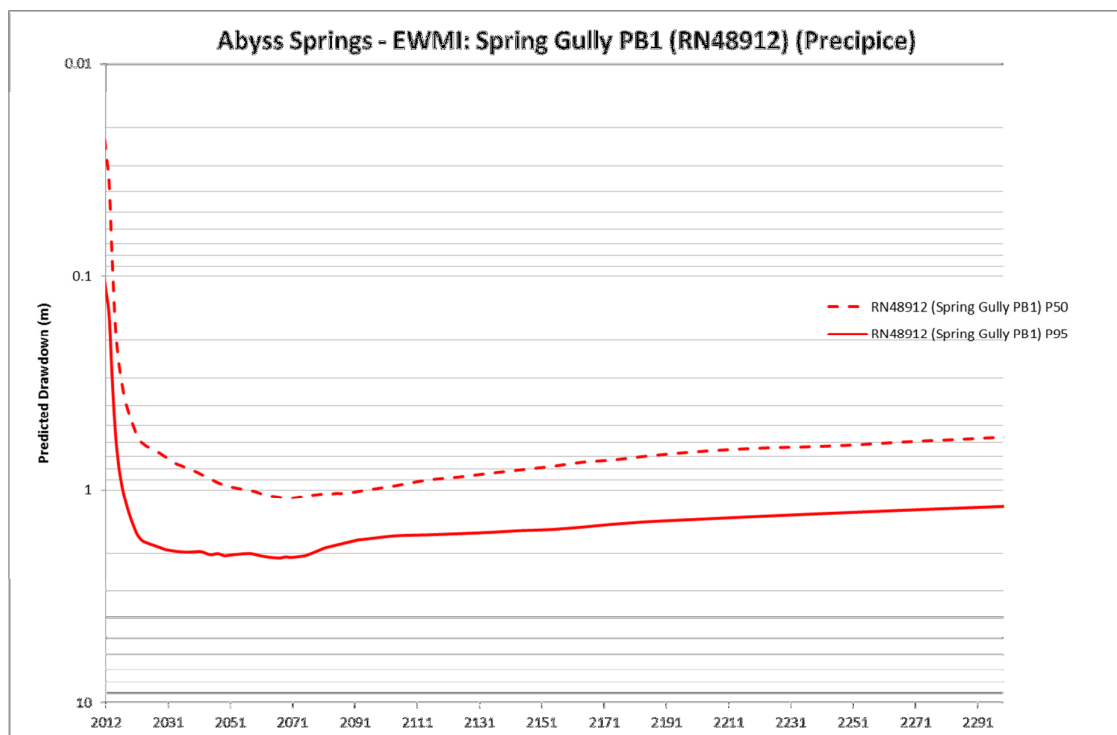
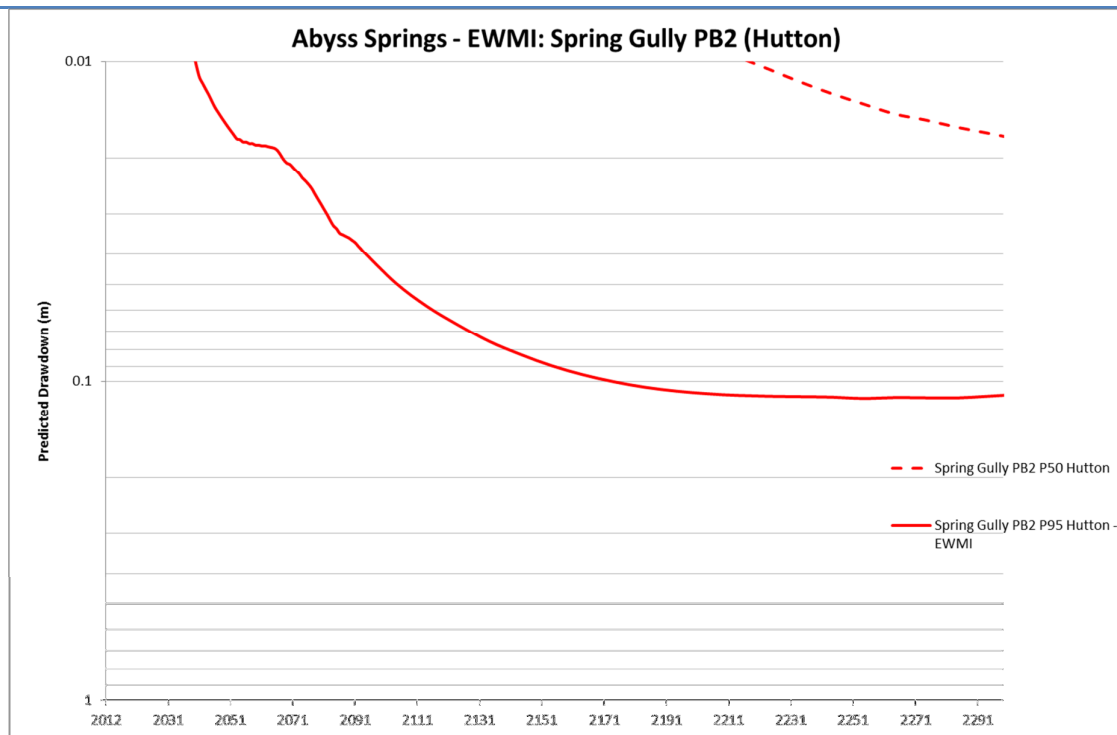


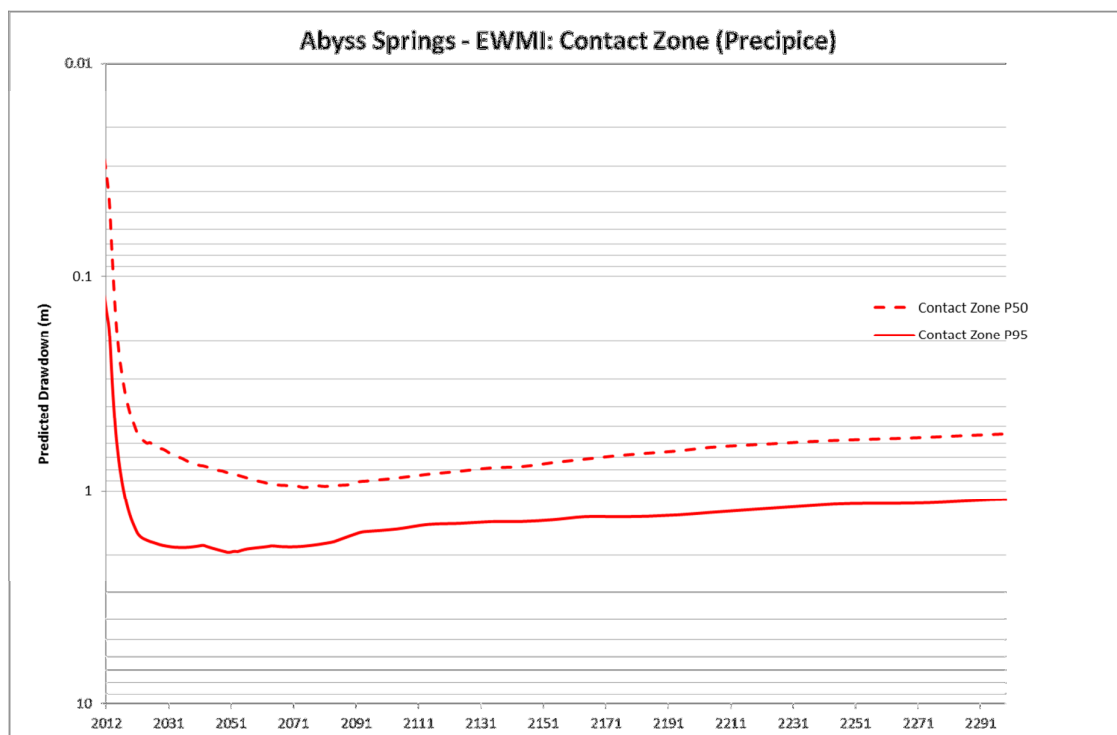
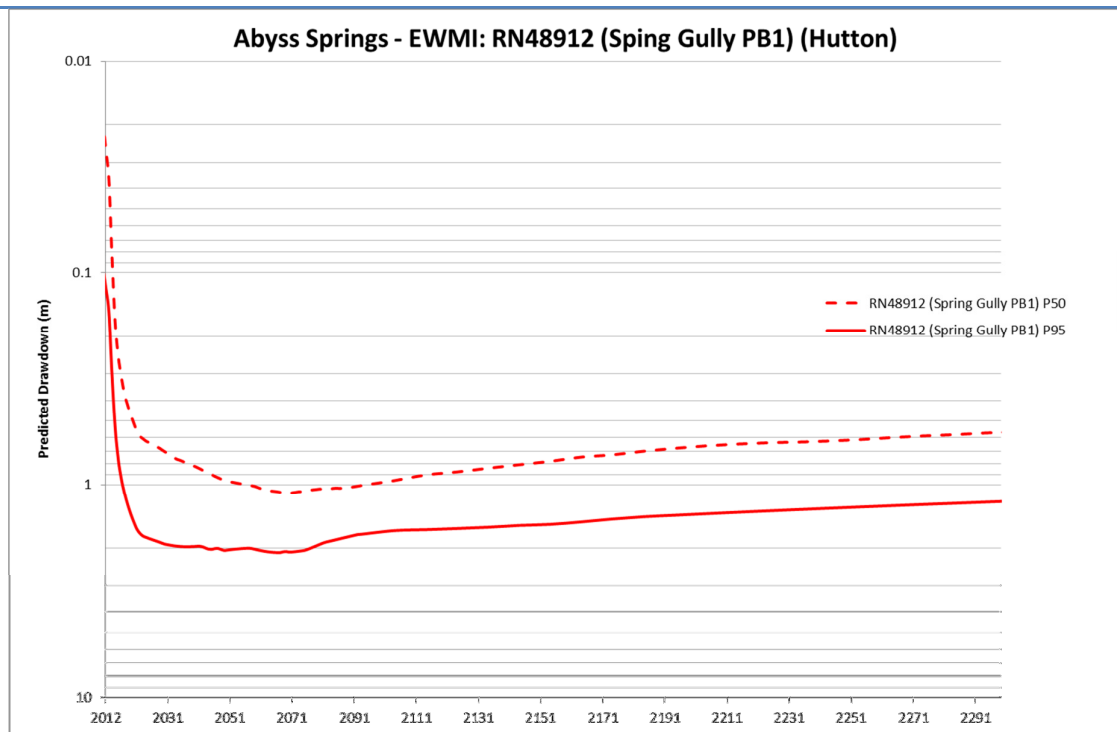


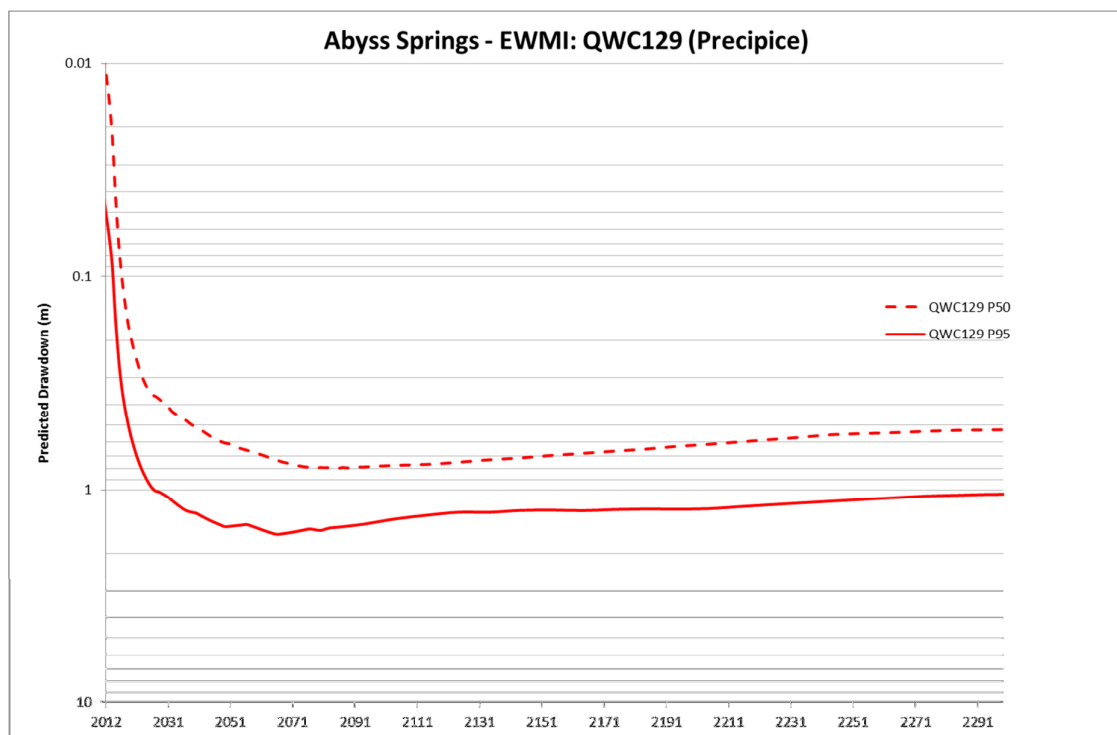
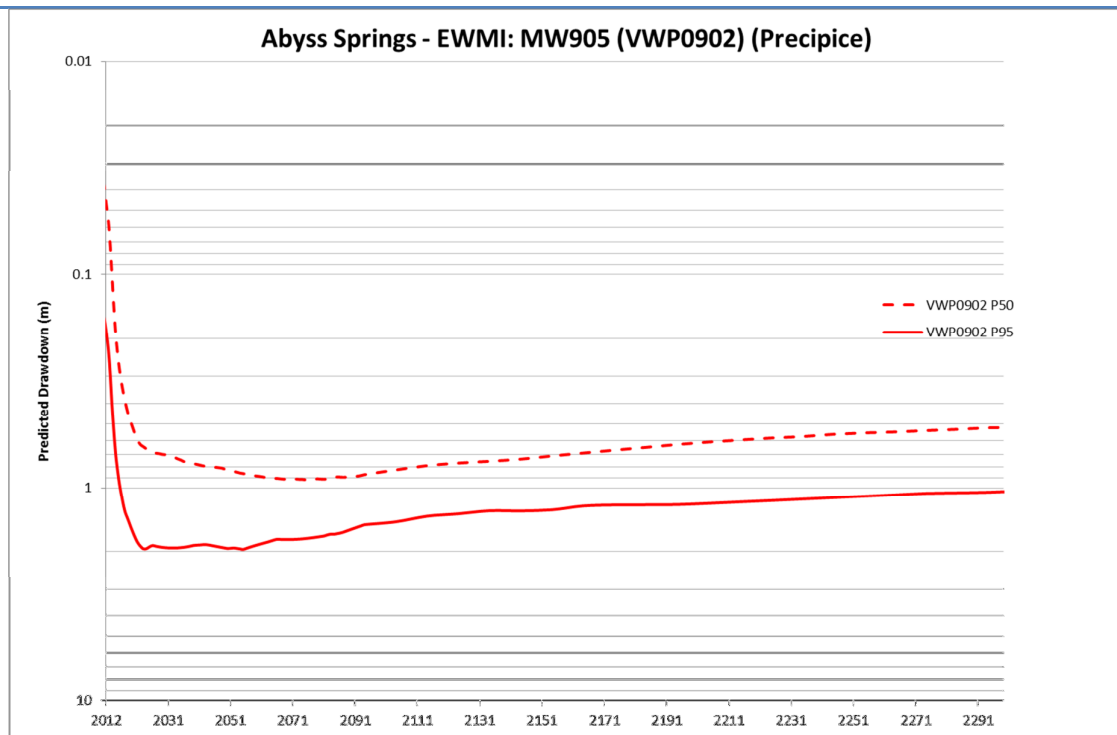
Abyss:

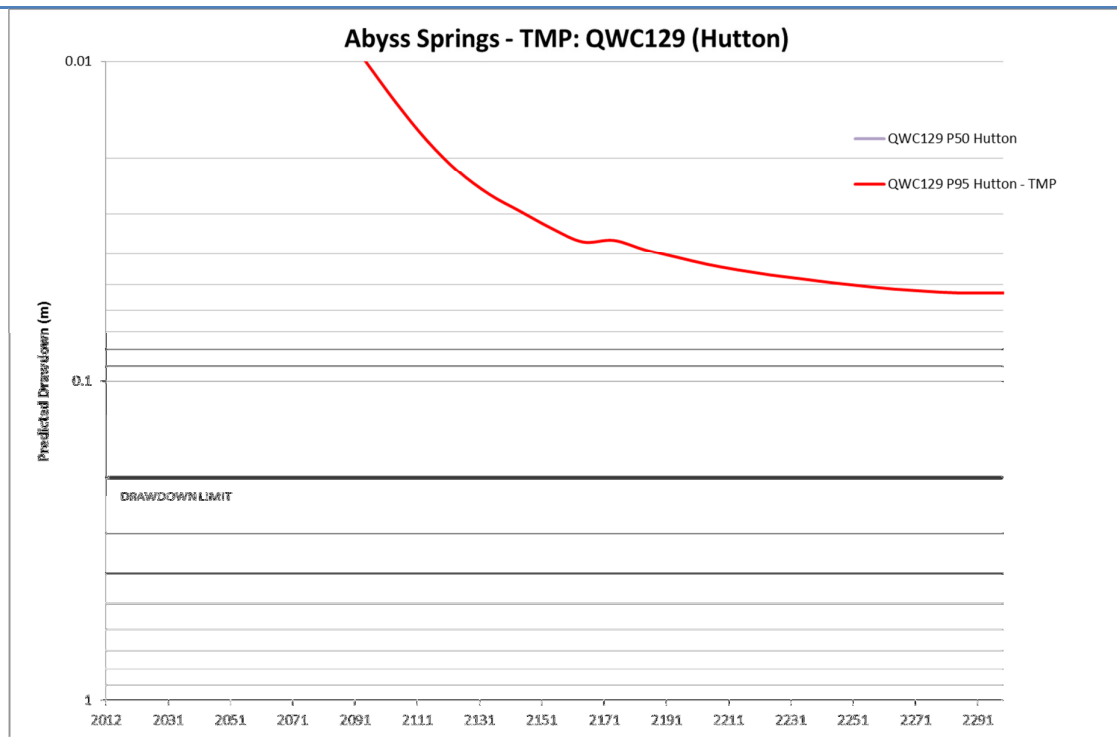
- .
- No impact is predicted by the CIM for the Abyss spring complex.
- The Hutton Sandstone is the interpreted source aquifer, it outcrops near the Abyss spring complex and is mostly present only to the south of the spring complex. Impact propagating from the east and north of the Abyss spring complex will be monitored through the use of Precipice EWMIs.
- A number of EWMIs in the Precipice Sandstone and Hutton Sandstone are defined. The TMP is set as being QWC129 – Hutton bore.
-





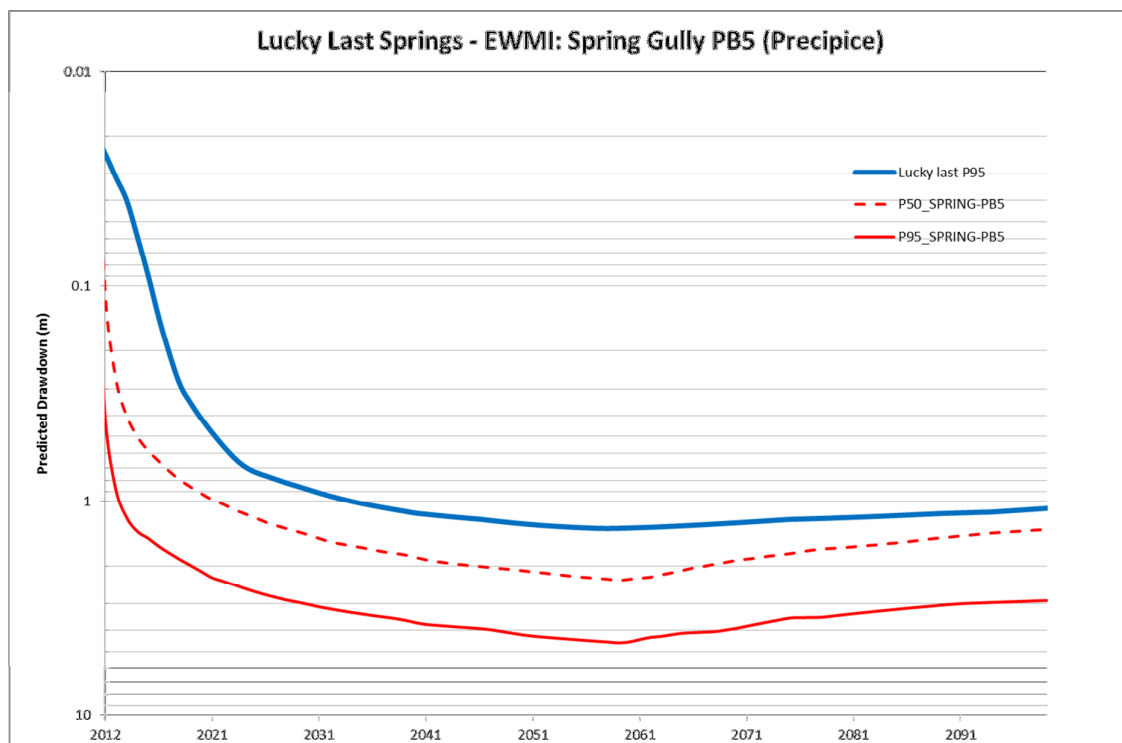


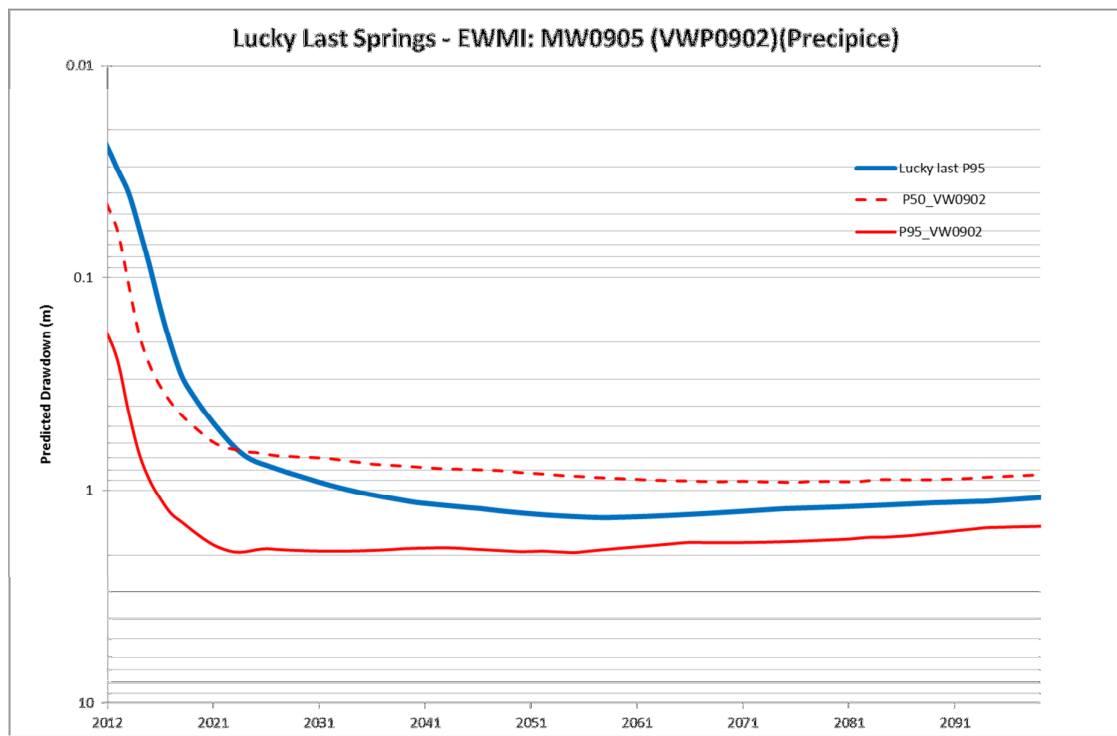
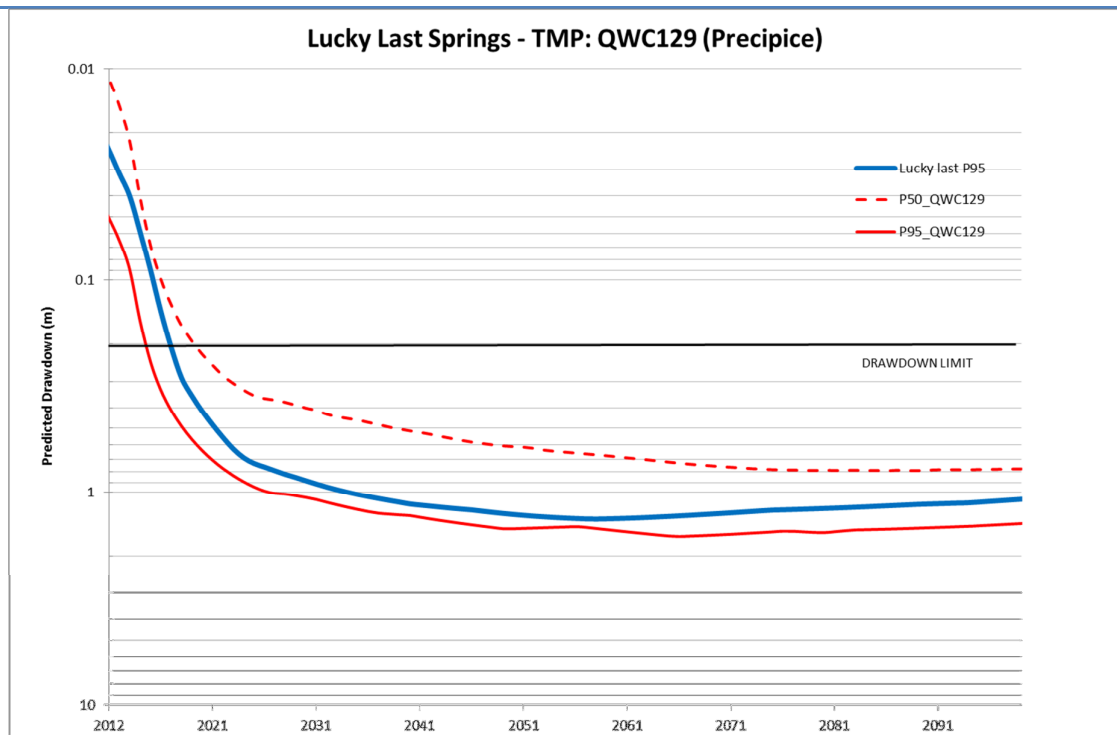


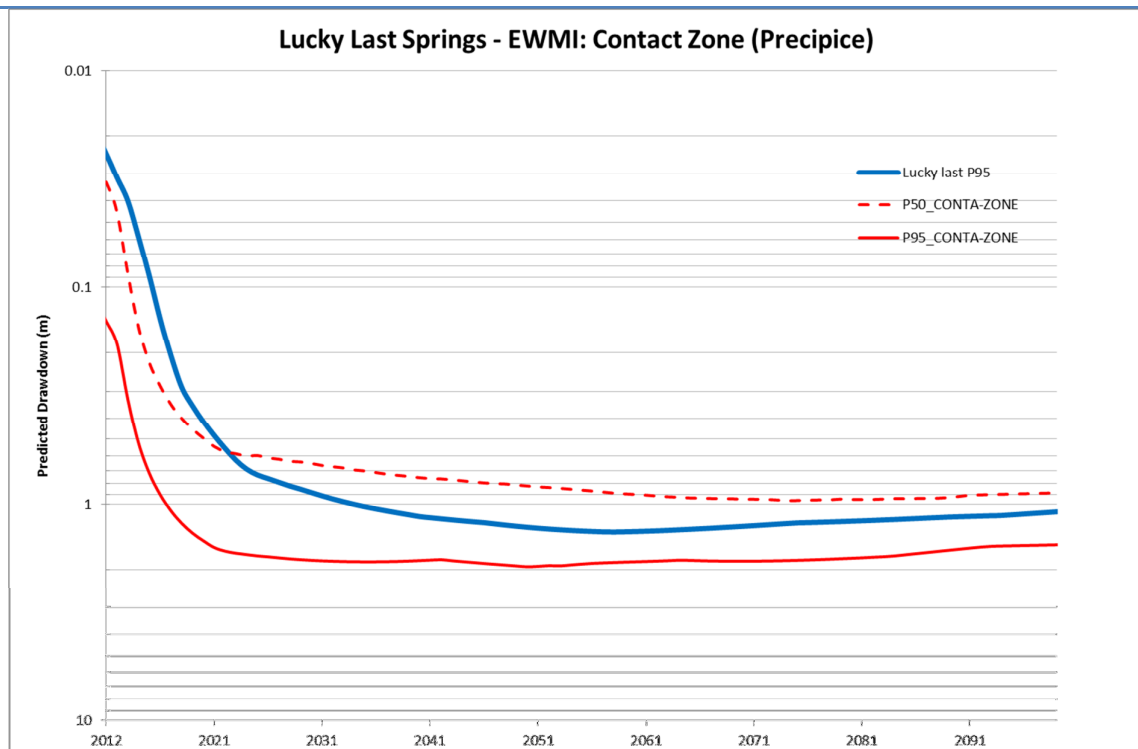


Lucky Last:

- Impact to Lucky Last is through the Precipice Sandstone, there is no propagation of impact to the Lucky Last spring complex through the Hutton Sandstone and as such, no EWMIIs are defined in the Hutton Sandstone.
- Contact Zone Precipice bore, Spring Gully PB5 and MW0905 are defined as EWMIIs and will provide early warning of propagation from areas to the south, west and north of the Lucky Last spring complex.
- QWC129 is within a few kilometres from the spring complex, the bore is in place. A 0.2 m impact in the Precipice Sandstone is predicted at QWC129 in 2016 (P95). Based on a 0.2 m drawdown impact (P95) in the aquifer source, impact at the Lucky Last springs is not predicted before 2018. QWC129 Precipice will be used as the TMP for Lucky Last.







APPENDIX D – Methodology for Trend and Statistical Analysis

**Methodology for Groundwater Level
and Quality Trend Analysis**

QCLNG-BE99-WAT-PRR-000001

Rev 1

April 2013



Commercial-in-Confidence – The contents of this report are highly confidential and of concern to QGC Pty Limited and its related bodies corporate for the purposes of the Right to Information Act 2009 (Qld) and the Freedom of Information Act 1982 (Cth). This report is provided on the condition that QGC Pty Limited will be consulted for the purposes of the Right to Information Act 2009 (Qld) and / or the Freedom of Information Act 1982 (Cth) if an access application is made.

Table of Contents

Executive Summary	10
Part 1	13
1. Background, Purpose and How to Use the Document	13
2. Hydrogeological conceptualisation	15
2.1 Introduction	15
2.2 Groundwater level impacts.....	15
2.3 Scale and Timeframe of Drawdown Issues.....	16
3. Groundwater level trend analysis	17
3.1 Guidance Documents	17
3.2 Introduction to key statistical trend analysis concepts	18
3.2.1 Objectives	18
3.2.2 Key Factors to Consider in Statistical Trend Analysis.....	18
3.3 Illustrative Case Study Locations for Method Demonstration.....	20
3.4 Influence of analysis period	20
3.5 Raw groundwater trends	25
3.6 Accounting for external influences on groundwater levels	27
3.6.1 Barometric pressure	28
3.6.2 Earth Tides	28
3.6.3 Loading and unloading.....	30
3.6.4 Regional groundwater influences	31
3.6.5 Local groundwater influences.....	36
3.6.6 Other groundwater influences	37
3.7 Frequency of monitoring required for trend analysis	37
3.7.1 Weighted mean drawdown over a representative period	37
3.7.2 Minimising autocorrelation using a ‘pre-whitening’ approach	38
3.7.3 Confirming serial correlation	39
3.7.4 Frequency of monitoring	40
3.8 Missing Data	40
4. Interpretation of groundwater level trend analysis	41
5. Hydrochemistry data trend analysis	43
5.1 Background	43
5.2 Limited data (< 5 years) available	43
5.3 Long term (> 5 years) record available	44
6. Selected Method of Trend Analysis	45
6.1 Hydrogeological conceptualisation	45
6.2 Groundwater level and pressure.....	45
6.3 Groundwater quality	46
6.4 Trend Analysis Interpretation and Reporting.....	47

Part 2.....	48
7. Test Application of the Selected Method.....	48
7.1 Introduction.....	48
7.2 Monitoring bore BWS-GW2	49
7.2.1 Step 1: Collate available data.....	49
7.2.2 Step 2: Account for barometric pressure and earth tides	51
7.2.3 Step 3: Period of analysis	53
7.2.4 Step 4: Develop and apply multiple regression model	53
7.2.5 Step 5: Weighted mean drawdown over a representative period	55
7.2.6 Step 6: Trend analysis	56
7.2.7 Summary of analysis	58
7.3 Monitoring bore RN 42230204.....	59
7.3.1 Step 1: Collate available data.....	59
7.3.2 Step 2: Account for barometric pressure and earth tides	61
7.3.3 Step 3: Period of analysis	63
7.3.4 Step 4: Develop and apply multiple regression model	64
7.3.5 Step 5: Weighted mean drawdown over a representative period	66
7.3.6 Step 6: Trend analysis	67
7.3.7 Summary of analysis	69
7.4 Monitoring bore RN 13030613.....	70
7.4.1 Step 1: Collate available data.....	70
7.4.2 Step 2: Account for barometric pressure and earth tides	72
7.4.3 Step 3: Period analysis	75
7.4.4 Step 4: Develop and apply multiple regression model	76
7.4.5 Step 5: Weighted mean drawdown over a representative period	80
7.4.6 Step 6: Trend analysis	80
7.4.7 Summary of analysis	83
7.5 Monitoring bore RN10925	84
7.5.1 Step 1: Collate available data.....	84
7.5.2 Step 2: Account for barometric pressure and earth tides	84
7.5.3 Step 3: Period of analysis	86
7.5.4 Step 4: Develop and apply multiple regression model	87
7.5.5 Step 5: Weighted mean drawdown over a representative period	92
7.5.6 Step 6: Trend analysis	93
7.5.7 Summary of analysis	94
7.6 Groundwater quality trend analysis application	95
7.6.1 Monitoring bore BEL-WH003.....	95
8. General observations and conclusions	97
References	100
Appendix A: Notes on statistical trend analysis techniques	103
Appendix B: Loading and unloading of confined aquifers	111

List of Figures

<i>Figure 3-1</i>	Combined monitoring bore network showing QGC and DNRM bores....	22
<i>Figure 3-2</i>	Groundwater level trends for site 42230204	23
<i>Figure 3-3</i>	Groundwater level time series and linear trend for Berwyndale South GW1	25
<i>Figure 3-4</i>	Groundwater level, daily rainfall and cumulative deviation from the mean daily rainfall for Berwyndale South GW1	27
<i>Figure 3-5</i>	Groundwater level accounting for air pressure and earth tides.....	29
<i>Figure 3-6</i>	Comparison of adjusted bore data and regional rainfall conditions.....	31
<i>Figure 3-7</i>	Groundwater level and trend at regional bore RN 13030613, corrected for barometric pressure and earth tides	33
<i>Figure 3-8</i>	Comparison of groundwater levels at example CSG monitoring bore (BWS-GW1) and regional bore (RN 13030613), both corrected for barometric pressure and earth tides	34
<i>Figure 3-9</i>	Regression relationship between example CSG monitoring bore and regional bore	35
<i>Figure 3-10</i>	Groundwater levels at CSG monitoring bore, showing variability explained by regional groundwater influences.....	35
<i>Figure 3-11</i>	Groundwater levels at CSG monitoring bore accounting for barometric pressure, earth tides, loading and regional groundwater influences.....	36
<i>Figure 7-1</i>	Raw groundwater levels at monitoring bore BWS-GW2	50
<i>Figure 7-2</i>	Comparison of groundwater levels at monitoring bore BWS-GW2 and barometric pressure observations from monitoring bore LAU-GW1	51
<i>Figure 7-3</i>	Synthetic earth tide for monitoring bore BWS-GW2	52
<i>Figure 7-4</i>	Groundwater levels at monitoring bore BWS-GW2, taking into account barometric pressure and earth tides	53
<i>Figure 7-5</i>	Groundwater level at BWS-GW2, daily rainfall and cumulative deviation from the mean daily rainfall at Harewood (042078)	54
<i>Figure 7-6</i>	Comparison of rainfall data at Harewood (042078) and groundwater levels at monitoring bore site BWS-GW2	55
<i>Figure 7-7</i>	Trend in groundwater levels at monitoring bore BWS-GW2 after accounting for barometric pressure, earth tide and climate.....	57
<i>Figure 7-8</i>	Check for Normality.....	57
<i>Figure 7-9</i>	Raw groundwater levels at monitoring bore RN 42230204.....	59
<i>Figure 7-10</i>	Groundwater levels at monitoring bore RN 42230204, with anomalous data removed.....	60
<i>Figure 7-11</i>	Barometric pressure recorded at Bureau of Meteorology sites 042023 (Miles Post Office) and 042112 (Miles Constance Street).....	61
<i>Figure 7-12</i>	Synthetic earth tide for monitoring bore site RN 42230204.....	62

<i>Figure 7-13</i> Groundwater levels at monitoring bore RN 42230204, taking into account barometric pressure and earth tides	63
<i>Figure 7-14</i> Groundwater level at monitoring bore RN 42230204, daily rainfall and cumulative deviation from the mean daily rainfall at Riverview Hopeland (041215)	65
<i>Figure 7-15</i> Comparison of rainfall data at Riverview Hopeland (041215) and groundwater levels at monitoring bore RN 42230204	66
<i>Figure 7-16</i> Trend in groundwater levels at monitoring bore site RN 42230204 after accounting for barometric pressure, earth tides and climate.....	68
<i>Figure 7-17</i> Check for Normality.....	68
<i>Figure 7-18</i> Groundwater levels at monitoring bore RN 13030613	71
<i>Figure 7-19</i> Barometric pressure recorded at Bureau of Meteorology sites 043015 (Injune) and 043091 (Roma).....	72
<i>Figure 7-20</i> Comparison of barometric pressure recorded at Bureau of Meteorology sites 043015 (Injune) and 043091 (Roma).....	73
<i>Figure 7-21</i> Recorded and extended barometric pressure at Bureau of Meteorology site 043015 (Injune).....	73
<i>Figure 7-22</i> Synthetic earth tide for monitoring bore RN 13030613.....	74
<i>Figure 7-23</i> Groundwater levels, taking into account barometric pressure and earth tides	75
<i>Figure 7-24</i> Weekly time series of groundwater levels that are independent of barometric pressure and, earth tides.	76
<i>Figure 7-25</i> Groundwater level at monitoring bore RN 13030613, daily rainfall and cumulative deviation from the mean daily rainfall at Injune (043015)	77
<i>Figure 7-26</i> Comparison of adjusted groundwater level at monitoring bore RN 13030613 and cumulative deviation from the mean daily rainfall at Injune (043015) ...	78
<i>Figure 7-27</i> Comparison of predicted and observed groundwater levels, accounting for rainfall influences.....	79
<i>Figure 7-28</i> Residual groundwater levels that are independent of barometric pressure, earth tides and rainfall influences.....	79
<i>Figure 7-29</i> Trend in groundwater residuals at monitoring bore RN 13030613 after accounting for barometric pressure, earth tide and climate.....	81
<i>Figure 7-30</i> Check for Normality (pre-2006).....	82
<i>Figure 7-31</i> Check for Normality (post-2009).....	82
<i>Figure 7-32</i> Raw groundwater levels at monitoring bore RN 10925.....	84
<i>Figure 7-33</i> Barometric pressure recorded at Bureau of Meteorology site 042112 (Miles Constance Street) and comparison with the groundwater level data at monitoring bore RN 10925.....	85
<i>Figure 7-34</i> Synthetic earth tide for bore site RN 10925.....	86
<i>Figure 7-35</i> Groundwater levels at RN 10925, taking into account barometric pressure and earth tides	86
<i>Figure 7-36</i> Groundwater level at monitoring bore RN 10925, daily rainfall and cumulative deviation from the mean daily rainfall at Harewood (042078).....	88

Figure 7-37	Comparison of raw rainfall data at Harewood (042078) and groundwater levels at monitoring bore site RN 10925, all data	89
Figure 7-38	Rainfall at Harewood (042078) lagged by two months and groundwater levels at monitoring bore site RN 10925, all data	89
Figure 7-39	Rainfall at Harewood (042078) lagged by two months and groundwater levels at monitoring bore site RN 10925, split into four periods	90
Figure 7-40	Rain corrected groundwater level	92
Figure 7-41	Trend in groundwater level at monitoring bore RN 10925 after removal of estimated influences of barometric pressure, earth tides and rainfall on groundwater levels	93
Figure 7-42	Check for Normality.....	93
Figure 7-43	Groundwater electrical conductivity at monitoring bore BEL-WH003....	95
Figure 7-44	Adjusted groundwater electrical conductivity at monitoring bore BEL-WH003	96
Figure Appendix A:1	Effect of serial correlation on the Type I error (likelihood of falsely identifying a trend) (Yue, 2002b).....	104
Figure Appendix A:2	Normal distribution relative to some example datasets that are not normally distributed	110

List of Tables

Table 2-1	Summary of processes affecting groundwater levels.....	16
Table 3-1	Assessment of statistical significance.....	19
Table 3-2	Summary of trend analysis results for bore 42230204 using three sample periods	24
Table 3-3	Summary of groundwater level trend analysis results, accounting for air pressure and earth tides	29
Table 3-4	Summary of serial correlation tests	38
Table 4-1	Summary contextual information for Berwyndale South GW1.....	41
Table 7-1	Monitoring bores used for trend analysis.....	48
Table 7-2	Summary statistics for monitoring bore BWS-GW2, with anomalous data removed	50
Table 7-3	Summary of trend analysis results for monitoring bore BWS-GW2.....	58
Table 7-4	Summary statistics for monitoring bore RN 42230204, with anomalous data removed.....	60
Table 7-5	Summary of trend analysis results for RN 42230204	69
Table 7-6	Summary statistics for monitoring bore RN 13030613	71
Table 7-7	Summary of trend analysis results for monitoring bore RN 13030613	83
Table 7-8	Summary statistics for monitoring bore RN 10925	84

Table 7-9 Summary of trend analysis results for monitoring bore RN 10925..... 94

Table 7-10 Summary statistics for monitoring bore BEL-WH003 96

Table Appendix A.1 Assessment of statistical significance 106

List of Appendices

Appendix A: Notes on statistical trend analysis techniques 103

Appendix B: Loading and unloading of confined aquifers 111

 Barometric efficiency 112

 Simplified approach in the absence of data 114

Executive Summary

This document provides the basis for carrying out an analysis of monitoring bore groundwater level and quality data trends. The document has been prepared to fulfil Commitment No.5 of the Stage 2 CSG WMMP, which is 'Completion of first groundwater level trend analysis assessment including mean drawdown weighting method for Hutton and Precipice Sandstones'. This document represents the first phase of developing a process and tools to effectively monitor potential groundwater changes resulting from CSG water extraction.

The document is aimed at interpreting trends in monitoring data that are collected principally from monitoring bores in and adjacent to the northern leases of the QCLNG project area and which are used as early warning monitoring installations and trigger monitoring bores for the protection of EPBC listed springs. The methodologies proposed are suitable for interpretation of groundwater level or quality responses in any of QGC's monitoring bores or groundwater pressure changes in Vibrating Wire Piezometers (VWP). It should be recognised that groundwater trends that could be due to CSG water extraction, particularly in off-site early warning and trigger monitoring bores, may take many years to be discernible.

The objective of the document is to provide a methodology to initially assess groundwater level and potential quality trends that may occur during the baseline data collection phase prior to and during the initial phase of production-scale CSG water extraction occurring in the QCLNG projects northern tenements. This is assumed to cover the period 2013 to 2014.

The overall objective of the monitoring program is to collect baseline groundwater level data in key monitoring bores over the period, from which subsequent drawdowns can be measured and trends deduced, and hence the performance of predictive groundwater models assessed and exceedance response plans actioned when and if necessary.

The methodologies outlined provide the basis for QGC management actions that are outlined in QGC's Exceedance Response Plan where threshold values (specified in the Stage 2 WMMP) for aquifer drawdown or groundwater contamination are exceeded.

Assessments of groundwater level and water quality data are required to inform QGC compliance against approval conditions and regulatory requirements. Importantly, if an observed trend cannot reliably be discerned from the background noise in the data, it cannot confidently be attributed to any potential causes, including Coal Seam Gas (CSG) operations. Queensland Government (DERM, 2012) and Geoscience Australia (GA 2012) guidelines recommend the use of formal statistical tests (such as linear regression and the Mann-Kendall test) to assess whether observed groundwater trends can reliably be discerned from the background noise in the data. Building on the recommended approaches, QGC has developed methods to analyse trends in groundwater levels and water quality over the life of QGC operations.

The groundwater level method recognises that there are a broad range of processes that could cause groundwater level fluctuations and trends which need to be separated from any potential impact from QGC activities. The key components of this method are:

- Hydrogeologic conceptualisation of the region to assist with data selection and data preparation;
- Examination of the data to exclude any data errors and anomalies;
- Removal of the influence of barometric pressure and earth tides from the groundwater level data where these are significant;
- Selection of a suitable period of analysis, including identification of break-points to separately analyse current versus long-term trends;
- Development of a regression model of groundwater level behaviour to isolate the effects of known quantifiable external influences, such as rainfall, local and regional groundwater activities, and hydraulic loading. Groundwater volumes pumped by all groundwater extractions (for example, water supply wells and CSG wells) will also be used in the analysis if available;
- Assessment of the serial correlation, and appropriate reprocessing of the data to generate a time series of the weighted mean drawdown over a representative period;
- Application of linear regression, Mann-Kendall and Seasonal Kendall statistical trend tests on both the raw data and the residual groundwater level data derived after taking into account known quantifiable external influences on the groundwater level;
- Complementary contextual information, including consideration of the hydrogeological setting, to support the interpretation of trend results; and
- A schedule of analysis (at least annually) and reporting consistent with compliance requirements.

The approach to consider groundwater quality trends is staged to reflect the limited data currently available through QGC's groundwater quality monitoring program. For the first five years of data collection (assuming six-monthly observations), raw data will be reviewed without undertaking formal statistical tests. Once at least five years of data has been collected, a statistical trend analysis procedure will be undertaken, consistent with the approach outlined for groundwater level data.

It is recognised that the data available will improve over time and QGC has developed this method such that it is adaptable to incorporate new data on groundwater behaviour at sites of interest.

The approach to assess trends in groundwater levels has been applied to four groundwater monitoring bores with varying lengths and types of groundwater level response from various geological formations across the Surat Basin. Various sources were used to obtain supporting information for the trend analysis, including Bureau of Meteorology (rainfall and barometric pressure), TSOFT (generation and synthetic earth tides), BETCO (accounting for barometric pressure and earth tides) and Water Quality Analyser (assessment of trends in groundwater data).

Application of the approach identified that the information available on the selected bores is highly variable. Some DNRM monitoring bores have been in operation for many decades and provide a long term record. However, these bores have generally been monitored on an infrequent basis particularly in the early years of operation, making it difficult to directly compare observations over time.

QGC trialled the method for assessment of weighted mean drawdown over a representative period on water level data from the Gubberamunda Sandstone bore Berwyndale South GW1. The assessment concluded that a weekly time series would be a representative period and that such a time period could be considered for other locations.

For bores in the northern gas fields that will monitor groundwater levels in the Hutton and Precipice Sandstones for EPBC springs early warning and threshold monitoring purposes, monitoring bore data is only available over a short period of time (in one instance, less than one year of records at the time of analysis). QGC will develop representative periods for estimating weighted mean water levels using the groundwater level trend analysis methodologies once twelve months of data has been collected in each of the bores. This work is expected to be completed Q1 2015.

An understanding of the local and regional hydrogeological conditions is necessary to interpret the outcomes from the statistical tests. QGC will develop background characteristics for each monitoring site which will describe the data that will be necessary for any meaningful trend analysis. For example, the location of nearby CSG wells or other abstractors, the nearest rainfall or barometric data or characteristics of well construction which may have any impact on data.

This assessment document has shown that trends and variations already exist in the data. This trend analysis is a robust framework while allows correction of that data to a level playing field against which CSG activities can be compared. Ultimately the trend analysis will be part of a toolkit of quantitative and qualitative methods to establish a baseline against which future conditions can be assessed. It is designed to be robust but flexible enough to incorporate new data as it becomes available.

The commitments arising out of this report include:

Commitment Number	Activity	Target Completion Date
4	Bore baseline assessments and data analysis	October 2013
4a	Background characteristics for each monitoring site	October 2013
4b	Development of an aquifer surveillance workflow	January 2014
4c	Development of methodology for establishing a baseline	April 2014
4d	Derivation of baseline for wells with sufficient record	July 2014

Part 1

1. Background, Purpose and How to Use the Document

This document provides the basis for carrying out an analysis of monitoring bore groundwater level and quality data trends. The document has been prepared to fulfil Commitment No.5 of the Stage 2 CSG WMMP, which is 'Completion of first groundwater level trend analysis assessment including mean drawdown weighting method for Hutton and Precipice Sandstones'. This document represents the first phase of developing a process and tools to effectively monitor potential groundwater changes resulting from CSG water extraction.

The document is aimed at interpreting trends in monitoring data that are collected principally from monitoring bores in and adjacent to the northern leases of the QCLNG project area and which are used as early warning monitoring installations and trigger monitoring bores for the protection of EPBC listed springs.

The purpose of the document is to provide a methodology to initially assess groundwater level and potential quality trends that may occur during the baseline data collection phase prior to and during the initial phase of production-scale CSG water extraction occurring in the QCLNG projects northern tenements. This is assumed to cover the period 2013 to 2014.

The principal objective is to develop baseline groundwater levels in key monitoring bores over the period, from which subsequent drawdowns can be measured and trends and the performance of predictive groundwater models assessed. This will be done by 'correcting' the data so that the signal represents the potential impacts of CSG abstraction only.

The methodologies proposed are suitable for interpretation of groundwater level or quality responses in any of QGC's monitoring bores or groundwater pressure changes in Vibrating Wire Piezometers (VWP). It should be recognised that groundwater trends that could be due to CSG water extraction, particularly in off-site early warning and trigger monitoring bores, may take many years to be discernible.

The methodologies outlined provide the basis for QGC management actions that are outlined in QGC's Exceedance Response Plan where threshold values (specified in the Stage 2 WMMP) for aquifer drawdown or groundwater contamination are exceeded.

The document is presented in two parts:

- **Part 1:** Sections 2 to 6 present the basis for using a statistical approach to groundwater trend analysis; and
- **Part 2:** Sections 7 to 10 describe the application of the techniques to data from four monitoring bores at various locations in the Surat Basin.

While the document focuses on statistical analyses techniques it emphasises the need for a parallel process of hydrogeological conceptualisation (**Sections 2 and 4**) to effectively

interpret trends, particularly where a trend might require short and medium-term management actions as outlined in the Exceedance Response Plan. **Sections 2.2 to 3.2** provide an outline of key analysis concepts using various historical data sources while **Sections 3.3 to 3.6** illustrate a range of techniques to assess various factors that can influence groundwater hydrographs.

A key assessment tool is the weighted mean drawdown. The basis for this management parameter is outlined in Section 3.7. Key factors influencing groundwater trends are summarised in Section 4. Section 5 considers the assessment of groundwater quality where limited and long term records are available.

The overall methods of trend analysis for groundwater level, pressure and quality to be used are presented in **Section 6**.

In Part 2, **Section 7** presents the application of the method to sample groundwater level and groundwater quality data. Changes in groundwater quality could also take many years to become evident.

Section 8 summarises the observations and conclusions reached from the application of the methodologies to four groundwater level and one groundwater quality data set.

Detailed information is provided in the appendices on a range of statistical trend analysis techniques, worked examples of specific analytical procedures methodology to assess loading and unloading of confined aquifers and the assessment of barometric efficiency.

2. Hydrogeological conceptualisation

2.1 Introduction

The method outlined in the following sections of this document provides a statistical approach to determining trends in groundwater level changes in monitoring bores and vibrating wire piezometers (VWP) over time. In parallel with this process, it is necessary to also undertake a hydrogeological conceptualisation of groundwater conditions at the site of interest to obtain information on:

- Local and regional hydrogeology at bore sites;
- Local patterns of groundwater use
- Climate stations of relevance to bore sites for incorporation in the statistical analysis;
- Guidance on additional data sets that may be relevant for collection and consideration in the statistical analysis; and
- Other relevant contextual information of relevance for the statistical analysis.

The hydrogeological conceptualisation will provide context for the interpretation of the data sets utilised in the statistical analysis methodology.

2.2 Groundwater level impacts

It is recognised that there are a broad range of processes that could cause groundwater level fluctuations and trends. These operate at various spatial and temporal scales, as summarised in **Table 2-1** and include groundwater level fluctuations due to changes in air pressure, rainfall, land use change and groundwater pumping by water users, including CSG activities.

Temporal scale	Processes
Short temporal scales	Air pressure fluctuations Earth tides, due to the sun and moon's gravitational effects
Medium temporal scales	Seasonal recharge events Local groundwater pumping Loading of confined aquifers due to recharge to overlying unconfined aquifers or from flooding (this can be medium or long term, depending on the nature of the influence)
Long temporal scales	Regional groundwater pumping for water supply purposes (including stock and domestic pumping and free flowing bores, irrigation use, other users – both registered and unregistered) Land use changes affecting recharge Loading of confined aquifers due to recharge to overlying unconfined aquifers or from flooding (this can be medium or long term, depending on the nature of the influence) Regional scale aquifer rehabilitation programs that restore groundwater pressures by capping and decommissioning old and free flowing bores Groundwater pumping causing impacts by other CSG companies Groundwater pumping causing impacts by QGC

Table 2-1 Summary of processes affecting groundwater levels

The groundwater monitoring program will provide groundwater data suitable for analysis to identify any changes in groundwater levels over time. This may include data on hydraulic head or drawdown. A rigorous method of trend analysis has been developed to help draw conclusions from the observed data collected from the QGC monitoring network. However, isolating the impacts of each physical process on groundwater level and/or pressure changes is only possible when sufficient and suitable data is available. Specifically identifying the impacts on groundwater that may be caused by QGC pumping requires detailed data for all other processes, including pumping data from other CSG companies. Without this level of detail, it is not possible to isolate the impacts of each potential influence.

2.3 Scale and Timeframe of Drawdown Issues

The use of trend analysis needs to be considered in the context of the magnitude of drawdowns and the timeframes over which they might occur. For instance drawdown predictions estimated by GA (GA,2012) based on the upper QWC model (95% percentile QWC, 2012) at the QGC Charlotte early warning monitoring bores, indicate that in the Hutton Sandstone a drawdown due to cumulative industry CSG groundwater extraction (below an arbitrary baseline level) of 0.1 m would not occur until 2020. Equally in the Precipice Sandstone such a drawdown is not predicted to occur until 2095.

3. Groundwater level trend analysis

3.1 Guidance Documents

Trend analysis guidance documents have been developed by the Queensland Department of Environment and Heritage Protection (DEHP) – formerly Department of Environment and Resource Management (DERM, 2012) and Geoscience Australia (GA 2012)

DERM has prepared a guideline which proposes the methods and inclusions for Underground Water Impact Reports and Final Reports. Included in this is guidance for the analysis of groundwater level trends in such reports. This includes:

- Preparation of underground water level (groundwater level) graphs using all data available (within the tenure, or as close to the tenure boundaries as possible);
- Presentation of underground water level trends along with rainfall (to display cumulative departure from the mean);
- Assessment of underground water level trends using data spanning pre- and post-commencement of CSG activities; and
- Assessment of underground water level trends using linear regressions of the time series data and non-parametric statistical tests, such as the Mann-Kendall test described in Yue *et al.* (2002a).

The first reporting element above requires a simple plot of the raw data. Similarly, presenting cumulative rainfall departure from mean rainfall conditions alongside the raw data is a simple technique that allows quick visual assessment of whether rainfall trends are strongly influencing groundwater level trends. Presenting trends in the data pre- and post-commencement of CSG activities is dependent on knowing when the CSG activities commenced and whether there is sufficient data either side of this change point.

The last recommendation in the State Government guidance is to undertake a statistical trend analysis using tests such as a Mann-Kendall test and linear regressions.

The GA guidelines, in particular:

- a) Emphasise the importance of assessing the independence of data sets by assessing serial correlation;
- b) Recommend the use of quantitative statistical tests for normality;
- c) Recommend the use of the non-parametric Seasonal Kendall Test in addition to the Mann-Kendall test to assess data sets with regular seasonal variability; and
- d) Recommend a number of methods for quantitative and qualitative analysis of modelled vs observed hydraulic head and drawdown.

The approach selected for use by QGC is documented in **Section 3.2**.

3.2 Introduction to key statistical trend analysis concepts

3.2.1 Objectives

The objective of the document is to provide a methodology to initially assess groundwater level and potential quality trends that may occur during the baseline data collection phase prior to and during the initial phase of production-scale CSG water extraction occurring in the QCLNG projects northern tenements. This is assumed to cover the period 2013 to 2014.

The principal objective is to develop baseline groundwater levels in key monitoring bores over the period, from which subsequent drawdowns can be measured and trends and the performance of predictive groundwater models assessed

Consequently the focus of this document is to develop and assess methodologies that consider the DERM guidelines and points a) to c) of the GA guidelines. Point d) will be evaluated once QGC has full access to the OGIA UWIR model or the in-house GEN3 model.

The document does not consider the use of control charts or the GA suggested methods for quantitative and qualitative analysis of modelled versus observed hydraulic head and drawdown at this time.

QGC will however assess these approaches as part of its ongoing groundwater monitoring and management activities. Future revisions of this document will include non-statistical methodologies to assess trends where appropriate.

3.2.2 Key Factors to Consider in Statistical Trend Analysis

While a simple line of best fit through the observed data can help to determine the magnitude of any trend in that data, this approach has a number of shortcomings including that (i) it is not known whether the trend is discernible from the background noise in the data, (ii) the influence of factors other than QGC operations cannot readily be identified within this trend, and (iii) the length of available data may influence the observations leading to false positive identification of a trend.

For these reasons, DERM (2012) and Geoscience Australia (2012) have recommended the use of formal statistical tests (such as linear regression and the Mann-Kendall test) to assess whether observed trends can reliably be discerned from the background noise in the data. In order to apply and interpret statistical trend tests a number of key concepts need to be understood.

A detailed discussion of statistical trend analysis techniques is provided in **Appendix A**. Key parameters of interest are described below.

The statistical significance of a trend is defined as the level of confidence that a detected trend is discernible from the underlying noise in the data. Statistical significance is typically interpreted as per **Table 3-1** (adapted from Chiew and Siriwardena, 2005). If the level of statistical significance is greater than 0.1, then a trend may be observed, but it is not possible to be confident that it is real. The trend could simply be due to random variation in the data. Importantly, if a trend is not statistically significant, it cannot confidently be attributed to any potential causes, including QGC operations.

Statistical significance is not the same as importance, and so while a change may be detected it may be such a small magnitude that it is not important. With any trend analysis,

the underlying drivers for a trend cannot be automatically inferred. Even where known influences are included in the analysis, correlation between those influences and the detected response does not automatically imply causality. It is necessary to undertake a complementary assessment to understand local context, physical processes and influencing factors, to understand drivers behind any observed statistically significant change.

Level of statistical significance (α)	Interpretation
$\alpha < 0.05$ (statistically significant at the 5% level of significance)	Strong evidence for trend
$\alpha < 0.1$ (statistically significant at the 10% level of significance)	Moderate evidence for trend
$\alpha > 0.1$ (not statistically significant at the 10% level of significance)	No clear evidence for trend

Table 3-1 Assessment of statistical significance

An example of testing for statistical significance is included in Appendix A.

Serial correlation is a measure of the similarity between observation points over time (i.e. the correlation between one data point and the next). Statistical analysis tests (such as trend analysis) are based on the assumption that data sets are not serially correlated, as serial correlation in time series data can adversely bias the trend analysis result. In particular, runs of consecutive data points above or below the mean of the dataset at the start or end of a time series can bias the trend analysis results. All statistical trend analyses require that data should not be serially correlated in order to be able to reliably quote the statistical significance of a trend. It is considered appropriate to aggregate the data to longer time steps where serial correlation is high. A number of tests are available to assess different data sets for serial correlation, including the Durbin-Watson test; Lag-1 autocorrelation coefficient and Spearman's Rank correlation coefficient (refer Appendix A). In practice, outputs from these tests should indicate a serial correlation less than 0.2 for validity with statistical assumptions. Further details on the importance of managing serial correlation are provided in **Section 3.7**. An example of testing for serial correlation is included in **Appendix A**.

Normality is described as the extent to which a data set follows a normal distribution. A number of quantitative tests are available to indicate the degree of departure from a normal distribution. However, there is no widely accepted objective test to classify data as normally or non-normally distributed. A subjective assessment with an element of judgement is therefore required to assess whether a data set is normally distributed. To support this, manual review of the data should be undertaken by plotting a histogram of the data for comparison against a standardised normal distribution. The data should demonstrate similar characteristics as the standardised distribution. Where a dataset is considered to not be normally distributed, parametric trend test assumptions will be invalidated. Transforms of the dataset (such as log transforms) can sometimes assist in reducing the skew in a dataset so that it better approximates a normal distribution. Non-parametric trend test results will be used in preference to the parametric trend test results where data is considered to not be normally distributed.

3.3 Illustrative Case Study Locations for Method Demonstration

The application of the method presented in this document is illustrated with an example data set from a representative bore. This case study shows how the trend analysis is conducted, including the process for accounting for external influences on bore hydrographs.

Groundwater data is available at various locations across the CSG tenements. This includes bores installed by Department of Natural Resources and Mines (DNRM), QGC and other CSG proponents. These bores monitor different constituents (for instance, groundwater levels, water quality parameters) and with different frequencies. For the purposes of demonstrating the method described in this document, a number of representative bores were selected. **Figure 3-1** shows the location of the case study bores for this analysis. The Berwyndale South GW1 data logger, located in the Gubberamunda Sandstone, was identified as a representative site for analysis. This bore is situated in QGC's Central Development Area, about 20 km east of Condamine in the direction of Chinchilla. This site has data available from late September 2011. At the time of preparing this method outline, about six weeks of hourly groundwater level data was available. The bore is located in an area where QGC has been pumping water and gas since 2005.

Sites RN 42230204 and RN 13030613 were identified as regional bores with long term periods of record of relevance for this analysis. Bore RN 42230204 is located about 50 km south east of Chinchilla in the direction of Dalby. This bore monitors the Walloon Coal Measures formation. Bore RN 13030613 is located approximately 110 km north-west of Roma. This bore monitors the Hutton Sandstone aquifer.

3.4 Influence of analysis period

The period of analysis can influence the trend analysis results, as illustrated by examining groundwater level behaviour in a long-term regional groundwater bore (42230204), shown in **Figure 3-1**.

The data record for the regional bore 42230204 was broken down into three discrete sample periods. As the focus of this illustration is on the influence of the data period, no pre-processing of the data has been undertaken. In practice, the raw data should be processed using the methods described in subsequent sections of this document to consider external influences on groundwater levels, serial correlation and the frequency of data observations. For this illustration, a linear trend was identified for each of these sample periods, with the period of data selected for the trend analysis heavily influencing the resulting trend estimate. It can be seen from **Figure 3-2** that there was an upwards trend from 1966 to the early 1990s, followed by a relatively steep increase in groundwater level to the mid-1990s. The most recent period displays a much flatter trend than both earlier periods. While there is variability in this most recent period of record, the magnitude of these fluctuations is much less than the apparent change in groundwater level in the 1990s. This example highlights the importance of the period of record over which a trend analysis is undertaken, as very different conclusions will be drawn about groundwater level behaviour based on examining the whole period of available data versus a shorter, more recent period. In addition, it also highlights the importance of being able to isolate trends from the inherent variability in groundwater levels.

Each of these three periods of data were analysed using the linear regression, Mann-Kendall and Seasonal Kendall tests. The results of this analysis are presented in **Table 3-2**. Using all three tests, a statistically significant trend at the 5% level of significance (strong evidence for trend) is observed for the first data period. During this time, groundwater levels were

trending upwards at a rate of 0.073 m/year. Analysis of the second period of data also indicates an increasing groundwater level, with both the linear regression and Mann-Kendall test indicating a trend that is significant at the 5% level of significance. There was insufficient seasonal data available to generate a result from the Seasonal Kendall test, as this test requires several data points per season and the monitoring frequency during this period was not adequate. Based on the linear trend analysis, the groundwater level was increasing at 0.77 m/year during this period. For the third period, it is unclear whether the observed trend is discernible from the noise in the data, with the linear regression indicating evidence for trend but the Mann-Kendall test indicating no evidence for trend over this 17-year period. There is insufficient seasonal data available in this period to generate a result from the Seasonal Kendall test, due to limited data across seasons. The available data over this most recent period indicates a slight increase in groundwater levels, but it is not clear whether this observation is simply a reflection of the groundwater level variability within the limited data set.

Figure 3-1 Combined monitoring bore network showing QGC and DNRM bores

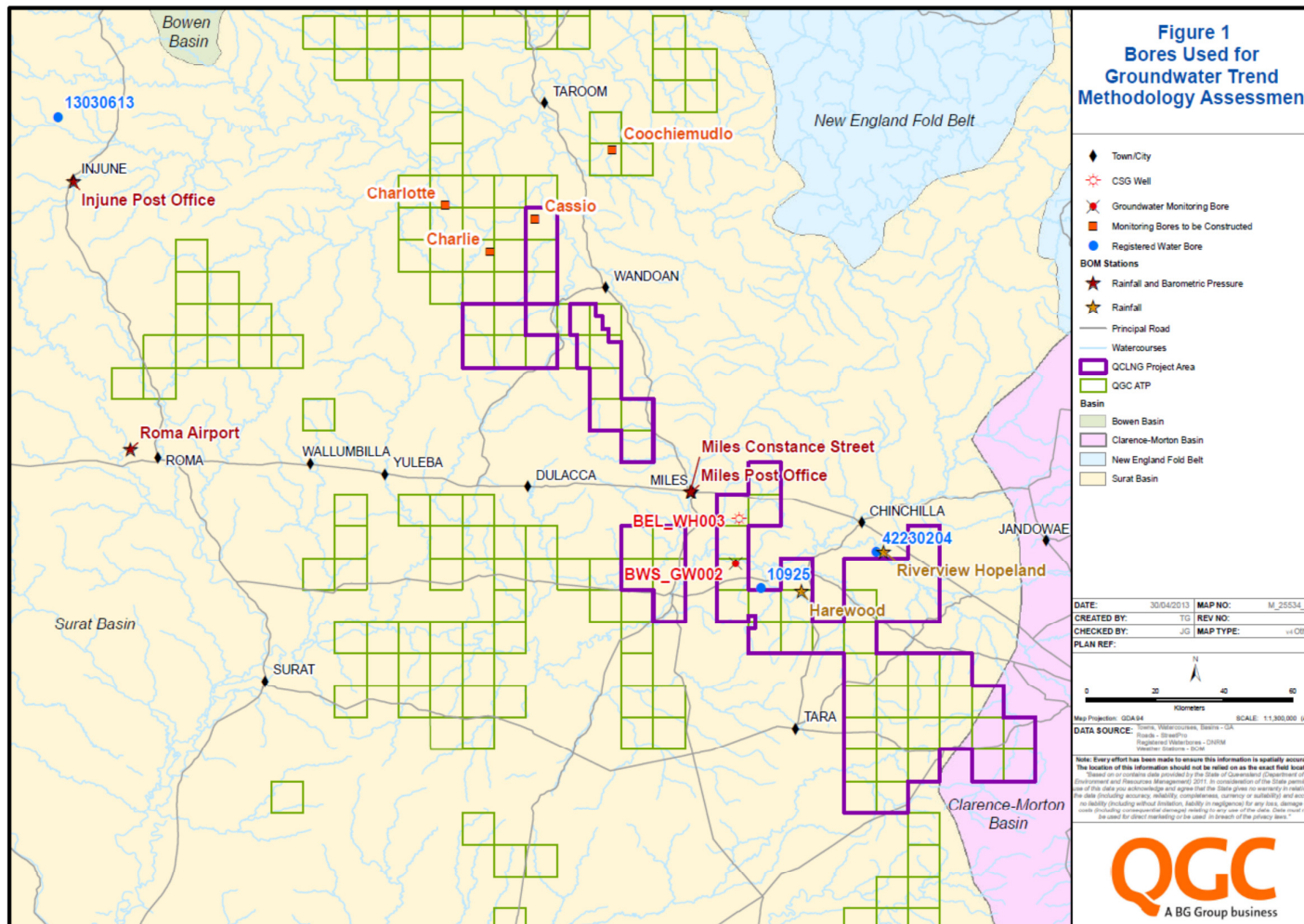
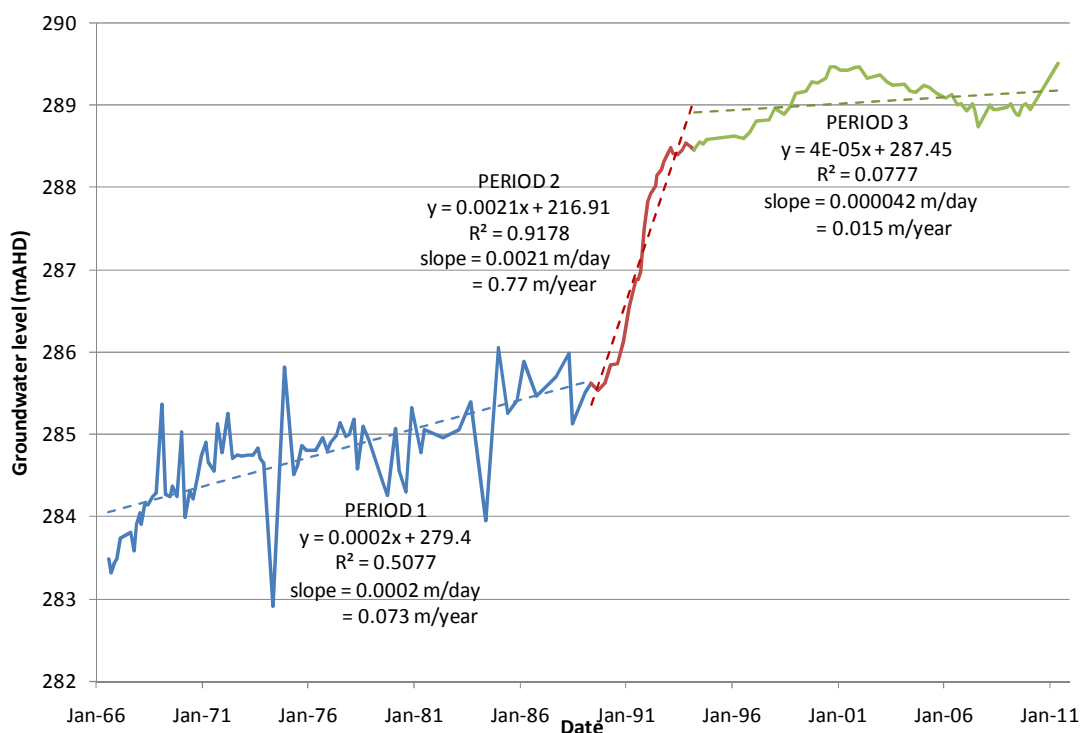


Figure 3-2 Groundwater level trends for site 42230204

In general, relatively short periods of record may be suitable to identify trends of large magnitude (for instance, the trend evident in the five years of data in the early 1990s at this site). In contrast, longer periods of record are required to confidently identify a trend in data when the magnitude of the trend is small and the variability of the data set is large.

The analysis at this site utilised data collected from 1966 until mid-2011. During this period, groundwater levels were recorded on an irregular basis with monitoring frequencies ranging from four days to almost one year. Since 2011, a data logger was installed at this location to monitor groundwater levels on a more regular (twice daily) basis. This recent period of record has been excluded from the analysis above as the change in monitoring frequency overly biases the trend outcomes without extensive resampling. This analysis provides an indication of the trends in groundwater prior to the installation of the data logger. In order to assess the trends in groundwater over the entire record (considering data before and after the data logger was installed), it is necessary to process the data logger records into a time step more compatible with the earlier part of the record. This will ensure that the large number of data points available more recently do not overly bias the analysis and generate a false trend outcome. Further consideration of the frequency of data monitoring is provided in **Section 3.7**.

Trend test	Period of analysis	Level of statistical significance	Trend magnitude
Regional groundwater bore 42230204 raw data – Period 1			
Linear Regression	1/8/1966-7/2/1989	5% (strong evidence for trend)	0.073 m/yr
Mann-Kendall		5% (strong evidence for trend)	N/A
Seasonal Kendall		5% (strong evidence for trend)	N/A
Regional groundwater bore 42230204 raw data – Period 2			
Linear Regression	25/5/1989-31/1/1994	5% (strong evidence for trend)	0.77 m/yr
Mann-Kendall		5% (strong evidence for trend)	N/A
Seasonal Kendall		N/A (inadequate seasonal data)	N/A
Regional groundwater bore 42230204 raw data – Period 3			
Linear Regression	6/4/1994-9/6/2011	10% (moderate evidence for trend)	0.015 m/yr
Mann-Kendall		Not statistically significant (no evidence for trend)	N/A
Seasonal Kendall		N/A (inadequate seasonal data)	N/A

Table 3-2 Summary of trend analysis results for bore 42230204 using three sample periods

The above analysis was undertaken by separating the data into three discrete periods by visual inspection, which is considered to be suitable in this case given the obvious changes in trend in the data. However, where data contains high variability, break points may not be easy to visually detect and further analysis may be required to help identify whether a break-point exists. If required, QGC will apply relevant tests such as the Distribution Free CUSUM test, Cumulative Deviation test and the Worsley Likelihood Ratio test, which are all readily available in statistical analysis software packages such as the e-water CRC's Water Quality Analyser package (available online: <http://www.ewater.com.au/products/ewater-toolkit/eco-tools/water-quality-analyser/>). Each of the above tests provides an indication of the timing of any break-point in the data, and notes whether this break-point is statistically significant. Whilst conceptually these tests perform similar analyses, the outcomes can differ. Visual inspection may still be required to confirm which test result is most appropriate for a given data set.

In the practical application of the break point tests, it is necessary to consider the objectives of the trend analysis to determine whether the data should be split into discrete periods. For instance, if the trend test is seeking information on the change in groundwater level conditions compared to representative background conditions, it may be relevant to isolate the period that reflects the baseline conditions. It is possible to re-apply the break point tests ad infinitum to continue to identify shorter periods for analysis. Some division of the data may be important if attempting to describe shifts in trends throughout various stages of the record. The segments of data must however remain of sufficient length to allow meaningful interpretation of the trend results. If the division of the data set does not add value to the interpretation of groundwater behaviour at a site, it should not be undertaken. In general, the time series data used for the trend analysis should not be shorter than one year (if a weekly

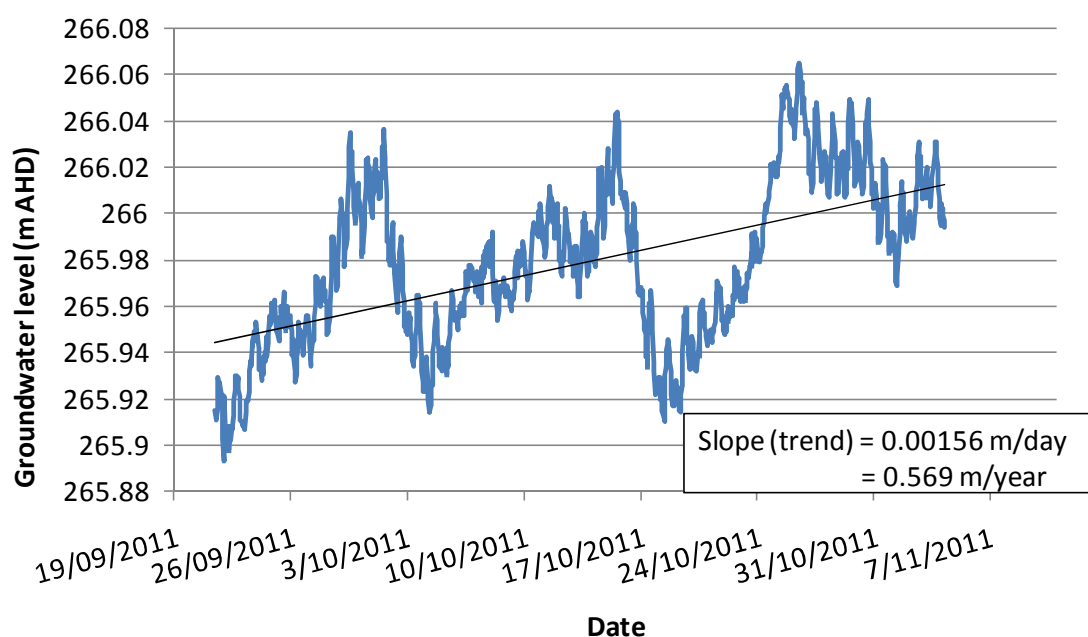
time step is applied), and not shorter than several years if the Seasonal Kendall test is to be applied.

3.5 Raw groundwater trends

To illustrate the application of the trend analysis methods, the raw groundwater level data over a 40-day period for Berwyndale South GW1 is analysed. The time series of raw data (which spanned six weeks at the time of the analysis) is presented in **Figure 3-3**. This bore is located in the Gubberamunda Sandstone aquifer, and is screened at a depth of approximately 100 m below the ground surface. A line of best fit is fitted to the data in **Figure 3-3**, which indicates a general increase in groundwater levels over time. The magnitude of this trend over the six-week period of available data was an increase of 0.57 m/year. Fluctuations in the data are evident on a number of temporal scales including hourly, daily and weekly. The linear regression does not attempt to replicate these fluctuations, but instead provides an overall indication of the magnitude of the change in groundwater levels over time.

Non-linear trend models, such as those that fit a spline curve to the data with a large number of degrees of freedom, could be used if further visual understanding of the non-linear variance of trends within a dataset is required (e.g. to illustrate the roughly fortnightly fluctuations in **Table 3-2**). However, these models typically report on only the linear component of a trend magnitude using a linear regression function, meaning that they provide little added value beyond which can be observed through visual representation and description of the data.

Figure 3-3 Groundwater level time series and linear trend for Berwyndale South GW1

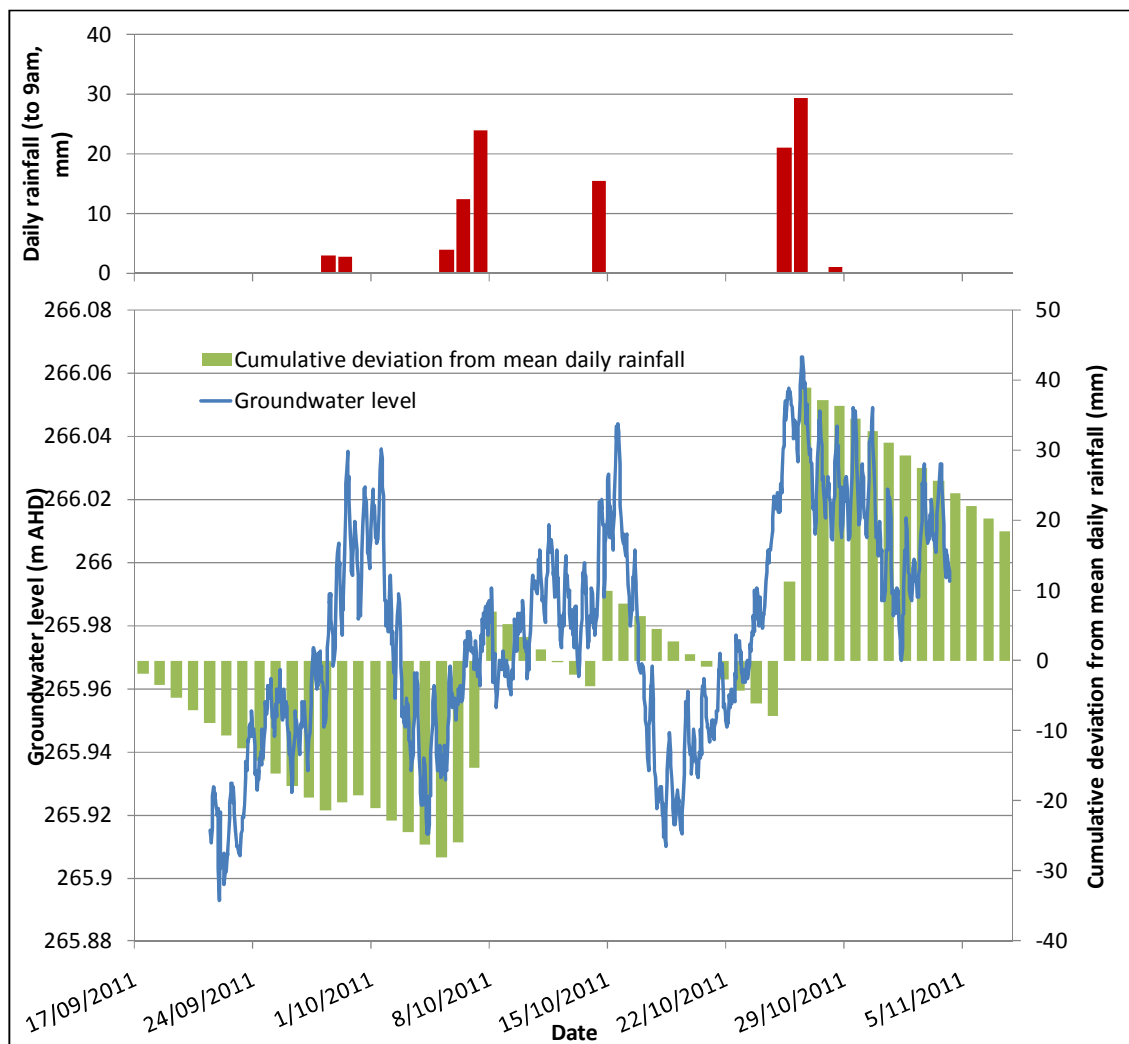


Rainfall has the potential to influence recharge, although this is not generally significant in the short term for bores located in confined aquifers or some distance from recharge sources. Rainfall effects may occur over longer time scales due to loading from flooding and groundwater level changes to overlying unconfined aquifers. In these situations, rainfall can drive seasonal changes in groundwater level, and rainfall trends can affect groundwater levels on a long term (annual to decadal) timescale. These impacts are considered further in the next section.

Figure 3-4 presents groundwater level data for the Berwyndale South bore and rainfall data from Harewood, about 20 km from the bore. This rainfall site was used in the analysis as it provided a period of data concurrent with the available bore data. The upper panel indicates the timing of rainfall events at this location, while the lower panel presents the cumulative deviation from the mean daily rainfall. For most of the six-week period of analysis, the rainfall is in deficit at this site. The groundwater level data is presented for comparison. Further analysis was undertaken by considering the possible relationship between rainfall and the cumulative difference from the average rainfall conditions with the groundwater bore level, including assessment at different time lags. No relationship was identified at this location. This is confirmed when reviewing the data in **Figure 3-4**, with groundwater level peaks occurring at different times to rainfall events.

In general, this assessment confirms that rainfall does not significantly influence trends in groundwater levels in this bore. Analysis of other local rainfall data indicated that the behaviour was generally consistent across the region.

Figure 3-4 Groundwater level, daily rainfall and cumulative deviation from the mean daily rainfall for Berwyndale South GW1



3.6 Accounting for external influences on groundwater levels

The identification of a trend in bore data does not provide information on any potential cause of that trend. Further details are required to better understand the influence of particular physical and anthropogenic processes on groundwater levels. This section provides an example investigation into the influence of air pressure, earth tides, regional and local groundwater behaviour and loading effects on groundwater levels. A number of other processes may also influence groundwater levels to varying degrees. The method outlined below provides a generalised approach that can be used to quantify the impact of external influences based on available data.

3.6.1 Barometric pressure

A data logger located close to the Berwyndale South GW1 site provides a time series of air pressure over a period concurrent with the Berwyndale South groundwater level data. In other locations, barometric pressure data may not be available over the full period of groundwater data. A regression between the pressure and bore level data should be established to infill short periods of missing data. Where barometric pressure data is unavailable over longer periods of time, atmospheric pressure information can be sourced from the Bureau of Meteorology. Manual analysis of this data can be undertaken to determine the link between groundwater level and barometric pressure. However specific software is also freely available. In this instance, the BETCO program developed at the University of Georgia was used to remove fluctuations due to barometric pressure and earth tides in aquifer water level measurements using a multiple regression technique. Further information on the software is available online at <http://www.hydrology.uga.edu/rasmussen/betco/>. As BETCO requests the use of groundwater level and barometric pressure data in consistent units, it may be necessary to pre-process the barometric pressure data prior to application. The most suitable approach will depend on the units of the available barometric pressure and bore data.

Applying this software with the Berwyndale South GW1 bore data and local barometric pressure data generates a time series that reflects adjusted groundwater levels to account for the pressure fluctuations. A trend analysis was undertaken using this modified time series, and the results are presented in **Table 3-3**. Both the linear regression and Mann-Kendall test identify a statistically significant trend at the 5% level of significance. The linear relationship indicates that groundwater levels are rising at a rate of 0.55 m/year independent of air pressure fluctuations. The Seasonal Kendall test has not been applied to this data set as it requires the data set to include multiple observations for each season.

There will be a network of barometric gauges across the QGC monitoring network to allow the removal of barometric effects.

3.6.2 Earth Tides

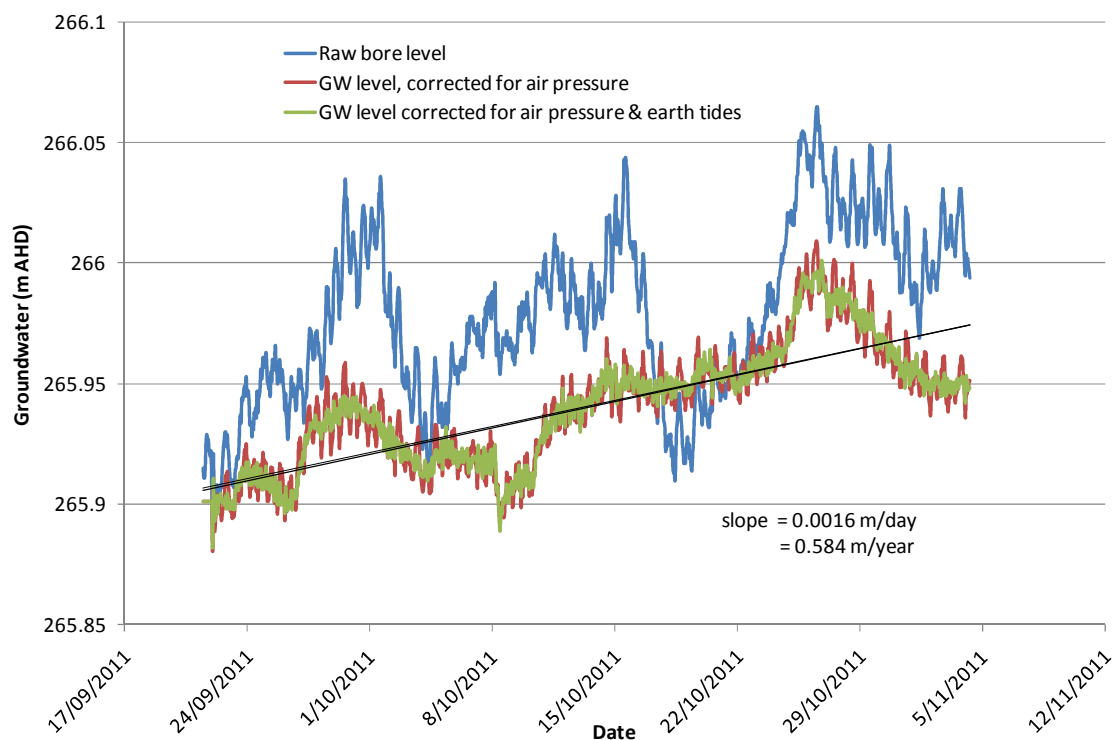
Water-level changes can occur due to aquifer deformation of which the main causes are earth tides. The tidal effects on groundwater, commonly called earth tides, have nothing to do with the oceans, but are related to the gravitational effects of the moon and sun. Change in gravitational attraction causes a slight dilation of some aquifers which, in turn, temporarily changes the aquifer porosity a slight amount. Wells showing tidal effects show two maximum and two minimum water levels per day, each of which are about six hours apart.

The effect of earth tides on groundwater level data can be considered using existing, readily downloadable software packages, including the BETCO tool. Time series data on earth tides are also available to be generated using various online software products. The TSOFIT product developed at the Royal Observatory of Belgium was utilised in this assessment (<http://seismologie.oma.be/TSOFIT/tsoft.html>). A synthetic time series of earth tides was obtained using TSOFIT, and applied in the BETCO software to generate a modified time series of groundwater levels that account for both barometric pressure and earth tides.

Figure 3-5 presents the adjusted time series data with the raw groundwater level data for comparison. A linear trend line has been fitted to the adjusted groundwater level data, which accounts for the influence of both air pressure and earth tides. The trendline for the air pressure adjusted data is also very similar to this line. These linear regression trendlines

provide a measure of the change in groundwater level over time. **Table 3-3** presents the outcomes from this trend analysis assessment. Both the linear regression and the Mann-Kendall test indicate strong evidence of an upwards trend in this adjusted data. A trend magnitude of 0.58 m/year is observed. The Seasonal Kendall test has not been applied to this data set as it requires the data set to include multiple observations for each season.

Figure 3-5 Groundwater level accounting for air pressure and earth tides



Trend test	Period of analysis	Level of statistical significance	Trend magnitude
Accounting for air pressure			
Linear Regression	21/9/2011-4/11/2011	5% (strong evidence for trend)	0.55 m/yr
Mann-Kendall		5% (strong evidence for trend)	N/A
Accounting for air pressure and earth tides			
Linear Regression	21/9/2011-4/11/2011	5% (strong evidence for trend)	0.58 m/yr
Mann-Kendall		5% (strong evidence for trend)	N/A

Table 3-3 Summary of groundwater level trend analysis results, accounting for air pressure and earth tides

3.6.3 Loading and unloading

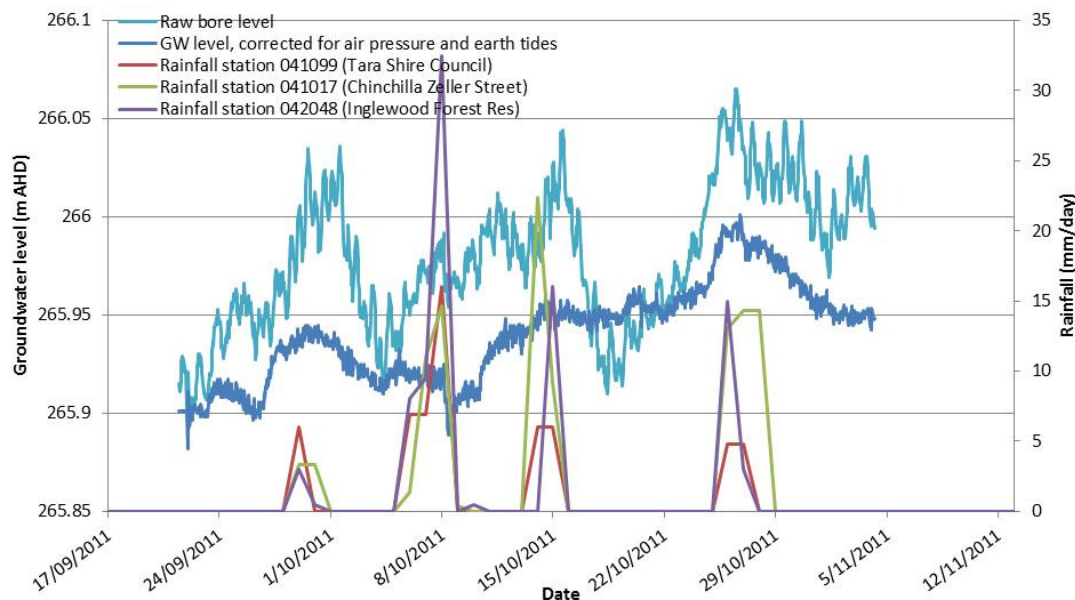
Trends in confined aquifer water levels are influenced by hydraulic loading and unloading caused by water table fluctuations in overlying unconfined aquifers and flooding of the land surface. A process is reported in the literature to determine the potentiometric level changes caused by overlying water table fluctuations, as outlined in **Appendix B**. However, this approach requires a suitable data set to be available for the groundwater levels in the overlying unconfined aquifer and a nearby barometric pressure record. In some instances this will be readily available; however in most locations this information is currently limited.

In the absence of a bore record in the overlying unconfined aquifer, rainfall data at the site of recharge of this overlying unconfined aquifer can be used as a surrogate. This assumes that recharge (and hence, groundwater levels in the unconfined aquifer) is driven by rainfall events. A regression relationship between this rainfall data and the groundwater levels at the bore of interest (confined aquifer bore) will be developed to isolate the influence of loading and unloading events. Time lags between rainfall events and any potential impact at the bore of interest will be considered by offsetting the time series data sets in the analysis.

The hydrogeological conceptualisation undertaken at the commencement of the study should identify the recharge zones for the relevant overlying unconfined aquifer. This process is necessary to identify the most appropriate monitoring bores or rainfall stations for analysis, to ensure the conditions assessed are representative of unconfined groundwater behaviour relevant to the confined monitoring bore site. In the absence of any relevant data to account for this influence, comment should be made in the reporting documentation that draws upon contextual information that may help to provide a qualitative assessment of loading/unloading impacts.

At present, a complete hydrogeological assessment at the Berwyndale South GW1 site has not been undertaken to identify the recharge zones of the overlying unconfined aquifer system and the best location to source data on this aquifer. In the absence of water level data for the overlying aquifer, the rainfall records across the region near the bore have been reviewed over the period of available groundwater data at the Berwyndale South GW1 site. Based on this review, the rainfall patterns across the region are observed to be reasonably consistent. In addition, the rainfall conditions are also consistent with the long term (based on the full data record) average rainfall conditions at each location.

Figure 3-6 shows the behaviour at a selection of regional rainfall stations over a time period concurrent with the Berwyndale South GW1 bore data. The cumulative deviation of rainfall from the mean was also calculated at each of these sites, and compared to the raw and corrected groundwater levels. There was no clear relationship between the bore data and rainfall data for these locations. This confirms that, based on the rainfall sites assessed, there is not likely to be an influence of loading or unloading in the overlying unconfined aquifer on the bore levels at the confined Berwyndale South GW1 bore site over the period of analysis.

Figure 3-6 Comparison of adjusted bore data and regional rainfall conditions

3.6.4 Regional groundwater influences

Regional groundwater pumping occurring within the Great Artesian Basin may also influence the groundwater levels observed in CSG monitoring bores. This includes extractions from farmers and artesian bore flows, which can date back to the early 1900s in some locations. More recently, regional activities within the Great Artesian Basin are restoring groundwater pressures due to capping of some free flowing bores. Raw data on pumped volumes and pressures restored over this time are difficult to obtain given the spatial and temporal nature of the activities, so it is recommended that this be taken into account by considering the bore levels at a long-term regional bore that is located outside the area of impact of CSG activities. The hydrogeological conceptualisation should confirm that suitable information is available, by considering the location of bores relative to regional groundwater influences and CSG activities. It may be relevant to consider the available data from several regional bores where available. It may also be relevant to consider other supporting information, such as groundwater models, where available. In the absence of relevant data to account for this influence, comment should be made in the reporting documentation on any relevant contextual information that may help to provide a qualitative assessment of regional impacts.

The trend analysis method outlined in this document (**Section 6**) should be applied at regional bores considered to be located outside the influence of CSG activities. The resulting trend outcomes at these sites should be visually compared to the trends observed at the CSG monitoring bore of interest. Comparison and regression analysis between these two data sets will be undertaken to account for any regional groundwater influences that may impact on the trends observed at the CSG monitoring bore of interest.

For the application to the case study analysis, a review of available groundwater level data confirms that there is no regional bore located in the Gubberamunda Sandstone aquifer that is directly relevant for assessment of regional trends that may be impacting on the Berwyndale South GW1 site. As such, it is not possible to incorporate regional trends in the

analysis of the Berwyndale South GW1 bore site. However, in order to provide a demonstration of the approach, bore RN 13030613, which is located approximately 60 km from the nearest CSG tenement boundary, is used to illustrate how regional groundwater behaviour may be considered in the assessment of impacts at the case study CSG bore being analysed. Monitoring bore RN 13030613 is located in the Hutton Sandstone aquifer, drilled to a depth of 123 m. As noted above, this bore does not provide data that is relevant for assessment of the regional influences at the Berwyndale South GW1 monitoring bore site. Instead, this bore data is being used as a sample regional data set for demonstration of the approach.

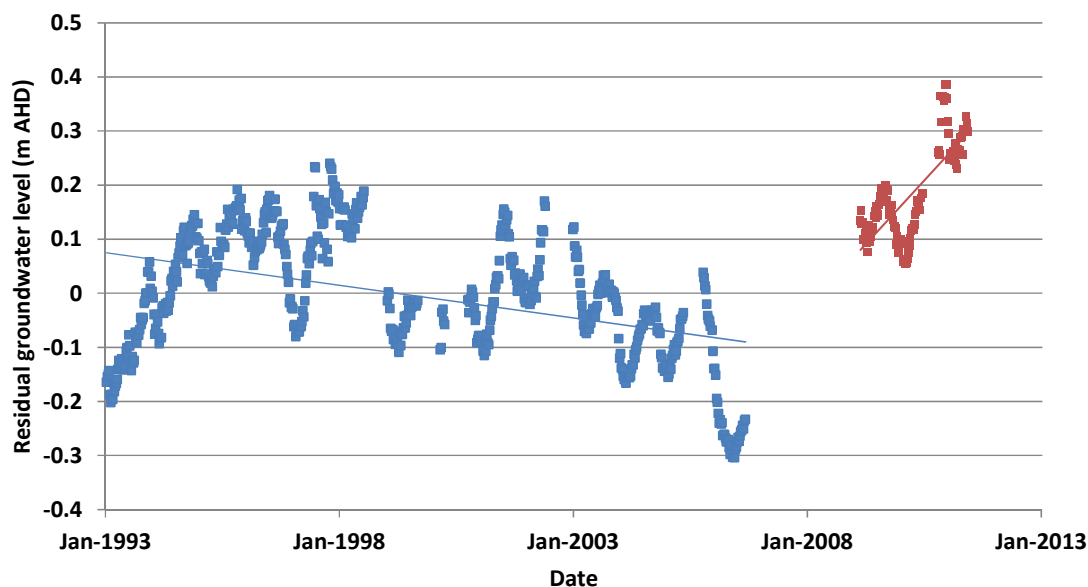
The data for this regional bore site indicates water levels have been generally consistent over the period of the available data, with the exception of two fluctuations over the past decade. In particular, the groundwater levels appear to decline from early 2002, with relatively rapid declines during late 2005 and early 2006. This is postulated to be a result of the severe drought conditions that affected much of the Great Artesian Basin over this time. In addition, an increase in groundwater levels is evident in the last six months of the record, which reflects the significant rainfall and run-off that affected much of southern Queensland during late 2010 and early 2011.

Given these visual observations, a break point analysis was undertaken to determine whether statistically significant changes in the groundwater level occur in the RN 13030613 data set. The break point assessment identified that data collected earlier than 2006 generally has a mean value greater than the data collected more recently. It must be noted that significant periods of missing data occur in the data set, with more than two years of data missing between 2006 and 2009. Hence, the break point analysis identified that data collected before the missing period was different to the data collected after the missing record.

Each of these periods has data available for at least a year, making it suitable for separate analysis. **Figure 3-7** presents the trends identified at the regional bore site, once the raw groundwater level data has been reviewed, processed to an appropriate representative period and barometric pressure and earth tides accounted for, as per the method described in **Section 6**. The resulting data set displays a number of fluctuations. During period 1, the groundwater level varies by approximately 0.5 m, while in period 2, the groundwater levels fluctuate by approximately 0.4 m. The trend analysis outcomes indicate that there is a statistically significant trend in the first period of the data, with the magnitude of the linear change in groundwater level approximately 1 cm/year (in period 1). No statistically significant trend was observed in the second period of data, as a result of high serial correlation in the data set.

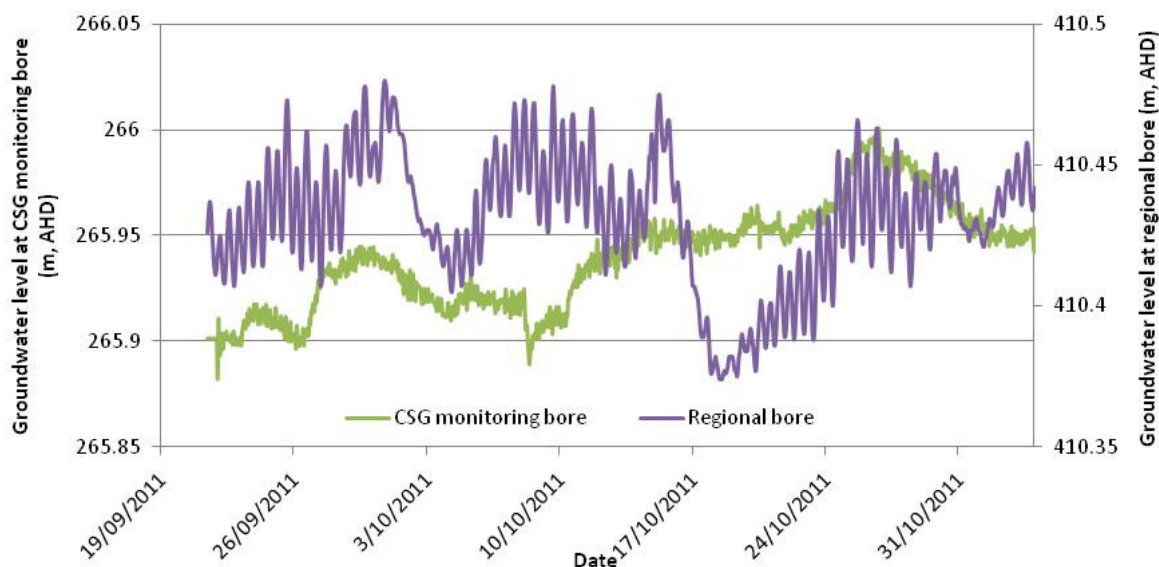
The information from the trend analysis at this regional bore is then used to inform the trend analysis at the case study bore of interest (Berwyndale South GW1), to provide an approach to assess the impacts of regional groundwater activities on the groundwater level data observed in the CSG monitoring bore. The details below provide an example of this application.

Figure 3-7 Groundwater level and trend at regional bore RN 13030613, corrected for barometric pressure and earth tides



A period of concurrent data is required for comparison with the CSG monitoring bore of interest. As an example application, **Figure 3-8** presents adjusted groundwater levels at BWS-GW1 (corrected for air pressure and earth tides) and the regional bore (RN 13030613, presenting the high frequency raw data). Visual inspection of this data indicates that there is appears to be little relationship between these data sets.

Figure 3-8 Comparison of groundwater levels at example CSG monitoring bore (BWS-GW1) and regional bore (RN 13030613), both corrected for barometric pressure and earth tides



A regression relationship between the monitoring bore and regional bore is shown in **Figure 3-9**. The scatter in this figure confirms that there is no clear and consistent relationship between these data sets. In practice, the regression relationship would not be incorporated into the analysis any further. However, for demonstration purposes, this relationship has been used to estimate the groundwater levels at the CSG monitoring bore that are driven by regional influences. This provides an example of the approach, in the instance that a stronger relationship between the CSG monitoring bore and a regional bore is observed.

The line of best fit in **Figure 3-9** is used to estimate the groundwater levels at the CSG monitoring bore that are driven by regional groundwater activities. This relationship is applied for each time step of the data and is compared to the raw monitoring bore data in **Figure 3-10**.

A simple calculation is performed to identify the difference between these two data sets at each time step. This represents the variability in the monitoring bore data that is not explained by regional groundwater behaviour.

Figure 3-9 Regression relationship between example CSG monitoring bore and regional bore

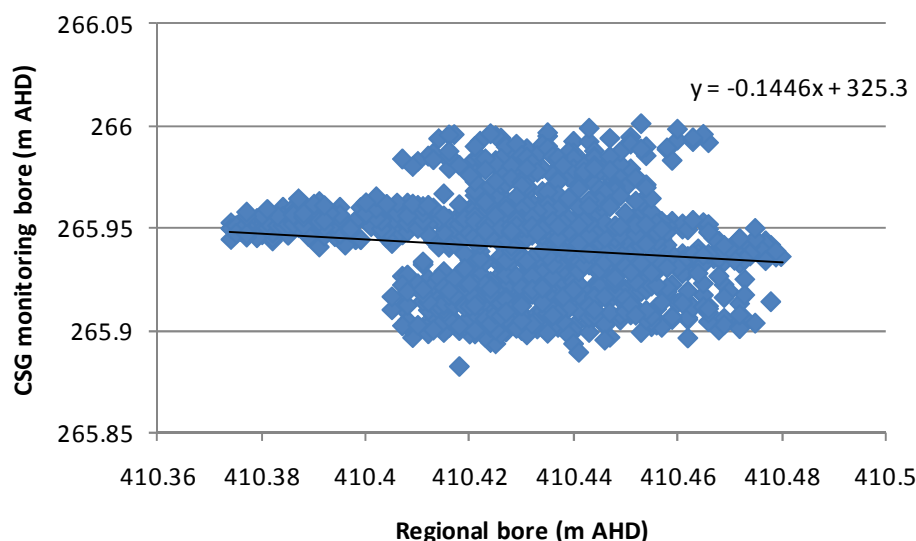
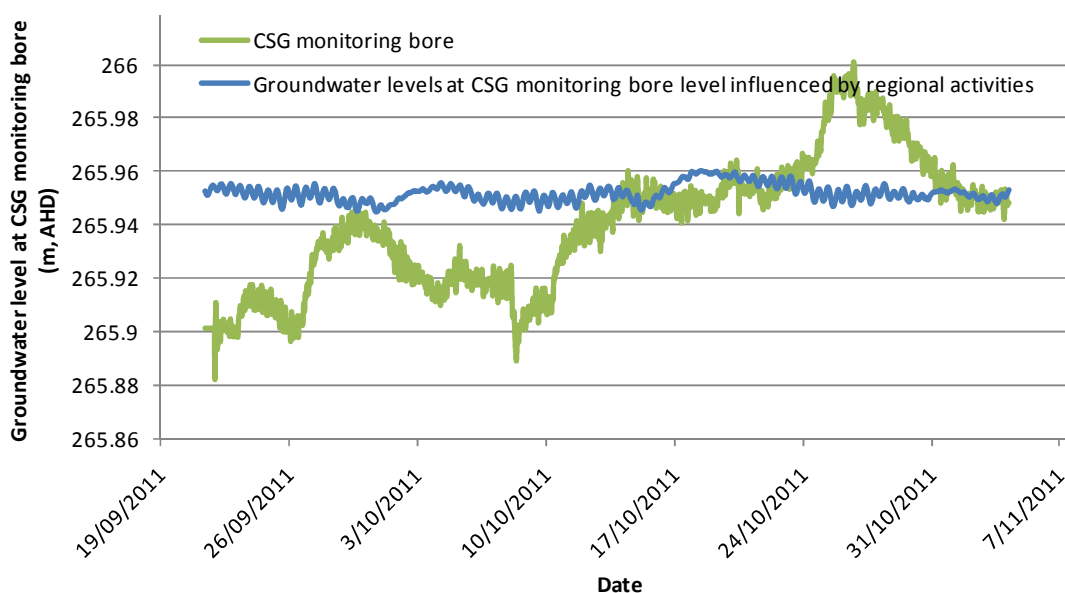


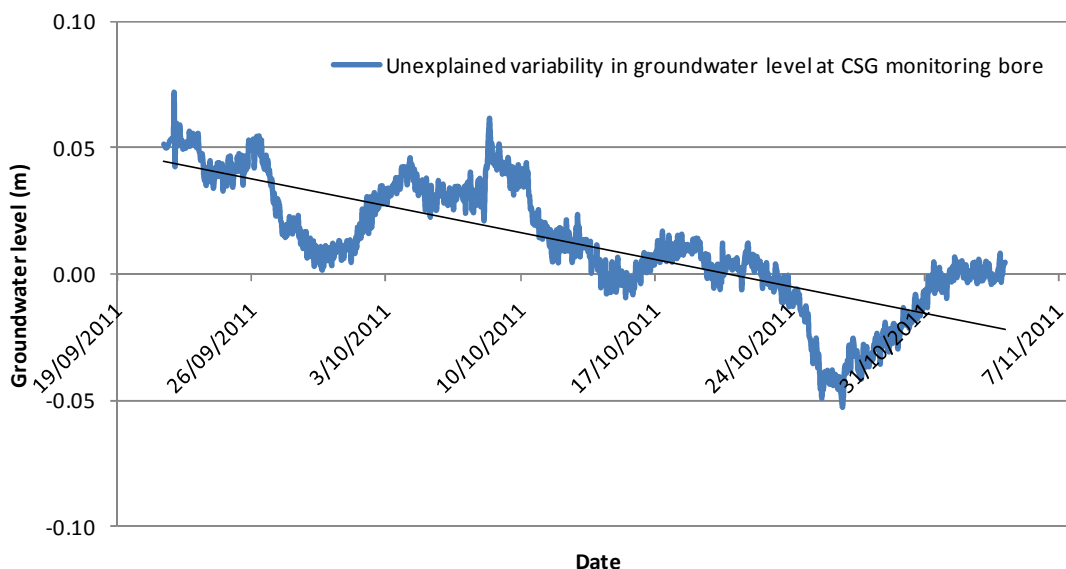
Figure 3-10 Groundwater levels at CSG monitoring bore, showing variability explained by regional groundwater influences



The difference between the two data sets presented in **Figure 3-10** provides an estimate of the unexplained variability in groundwater level at the CSG monitoring bore (**Figure 3-11**). This reflects the residuals between the estimated (using regression relationship) and actual groundwater levels at the CSG monitoring bore, and provides a measure of the groundwater levels that are not influenced by regional groundwater influences (plus barometric pressure,

earth tides and loading, since these influences have already been accounted for in the data presented). This data set is used for subsequent analyses of trends.

Figure 3-11 Groundwater levels at CSG monitoring bore accounting for barometric pressure, earth tides, loading and regional groundwater influences



3.6.5 Local groundwater influences

Local groundwater activities within close proximity to a bore of interest may impact on the groundwater levels and pressures observed. These influences may include groundwater extraction by local farmers and other users, extractions for industry and other CSG activities. The time scale over which these local influences act on a bore of interest will be shorter than the regional influences considered above.

Potential local influences should be identified through the hydrogeological conceptualisation stage (Section 2) and time series data on the timing and magnitude of these activities should be sourced where possible. This data can be incorporated into the trend analysis through the development of a regression relationship between this data and the bore data, consistent with the approach outlined for other external variables above. That is, the two data sets can be directly compared using time series plots and scatter plots. The fit of a trend line to a scatter plot comparing the two data sets provides an indication of the changes in groundwater level that can be explained by local groundwater influences. This relationship equation can be used to generate a time series of the expected variability due to local external influences. The differences between this time-series at a bore of interest provides the unexplained variability. The detailed step by step approach outlined in the section on regional groundwater influences can be applied for any data set that reflects external processes, and should be used to incorporate any local groundwater influences. The data set generated in **Figure 3-11** is used as the starting point for this assessment.

In the absence of any relevant data to account for this influence, comment should be made in the reporting documentation that draws upon contextual information that may help to provide a qualitative assessment of local groundwater impacts.

3.6.6 Other groundwater influences

The sections described above provide an approach to explain some of the significant processes likely to be influencing groundwater levels at CSG monitoring bores. However, a large number of other processes may also influence groundwater levels to varying degrees. These processes may include:

- Earthquakes;
- Illegal bore pumping, either locally or regionally;
- Burst pipes leading to recharge to groundwater systems;
- Loading effects from water storages;
- Changes in groundwater quality that may influence water density and hence groundwater levels; and
- Lack of well integrity, which can promote connectivity between aquifers

The scale and magnitude of these processes is often difficult to identify, monitor or predict, and in most instances, only qualitative assessments of relevant processes will be possible. This highlights the importance of undertaking a supporting hydrogeological conceptualisation and assessment in parallel with the statistical analysis, to provide relevant contextual information and details to support the interpretation of any trend analysis outcomes.

3.7 Frequency of monitoring required for trend analysis

Data at the Berwyndale South GW1 groundwater bore was available on an hourly time step. The process of assessing whether a trend is discernible from the background noise in the data (i.e. the statistical significance of trends) is invalidated when the input data is highly serially correlated. Two steps were undertaken to test and minimise the serial correlation:

- Calculation of the weighted mean drawdown over a representative period; and
- Application of a 'pre-whitening' approach described by Yue et al. (2002).

These two steps may be required a number of times for each data set to generate a time series that is valid within the assumptions of the trend tests (which assumes serial correlation less than 0.2). This approach is described below.

3.7.1 Weighted mean drawdown over a representative period

QGC examined the lag-1 serial correlation (i.e. the correlation between a given data point and the preceding data point) at this bore to identify whether averaging data over a longer time interval may help to avoid serial correlation in the data. A number of different representative periods were tested in this process, including hourly, daily and weekly. In calculating the revised time series, the raw data is averaged over the time step of interest to generate the weighted mean drawdown over a representative period. The results of this analysis are shown in **Table 3-4**.

The hourly data recorded exhibits high serial correlation, reflecting the high frequency of monitoring. A revised time series was generated by taking time weighted averages on a daily and weekly time step (i.e. weighted mean drawdown over a representative period). The Berwyndale South GW1 data is still highly correlated when revised to a daily basis. However the data points were considered independent when the data is revised to a weekly time step. Based on the results presented in **Table 3-4**, weekly averages are considered sufficient for trend analysis at this site over the period of analysis. The range of values observed in both the raw and aggregated data sets should be recorded. This will help to understand the degree of smoothing introduced by the resampling.

A weekly time series was found to be suitable for the Berwyndale South GW1 monitoring bore data, however a different data frequency for analysis may be suitable in other locations or over different periods of analysis. It is suggested that a weekly time step be considered for other locations, with the outcomes from the 'pre-whitening' approach (outlined below) guiding whether a longer time step is necessary.

Data analysed	Serial correlation result
Berwyndale South GW1 bore site	
Hourly groundwater level	Serially correlated
Average daily groundwater level, calculated from hourly data	Serially correlated
Average weekly groundwater level, calculated from hourly data	Independent

Table 3-4 Summary of serial correlation tests

3.7.2 Minimising autocorrelation using a 'pre-whitening' approach

The generation of a revised time series based on the weighted mean drawdown over a representative period, may not always reduce the serial correlation to within the level required by the trend test. 'Pre-whitening' provides an additional approach to reduce the serial correlation of time series data. When applied to the weighted mean drawdown data set, this technique may further reduce serial correlation. The details of the approach are available in Yue et al. (2002) and are summarised below for the application to groundwater data:

- Identify the magnitude of the linear trend** in the data being analysed. A linear trend line can be fitted to a time series plot of the weighted mean draw down over a representative period to estimate the linear trend magnitude (denoted as T in the calculations below). This can be estimated using Water Quality Analyser using the linear regression trend test, or in Excel using the function INDEX (LINEST (range of groundwater levels, range of dates),1).
- De-trend the sample data** by subtracting the linear trend magnitude from the data value at each time step. The generation of a de-trended time series involves the following calculation at each time step:

$$X'_t = X_t - T$$

Where: T is the linear trend magnitude.

X_t is the data being analysed at time step t . This time series reflects the weighted mean drawdown over a representative period that has been adjusted to take into account other external influences from earlier steps in the analysis.

X'_t is the de-trended data at time step t .

- c) **Calculate the lag-1 serial correlation coefficient of the de-trended time series.** This can be calculated using the 'CORREL' function in MS Excel or the serial correlation test in Water Quality Analyser. See the notes in the appendix of this document for the use of the CORREL function in MS Excel.
- d) **Remove the correlation magnitude from the de-trended data set** using the following calculation at each time step:

$$Y'_t = X'_t - rX'_{t-1}$$

Where: X'_t is the de-trended data at time step t .

X'_{t-1} is the de-trended data at time step $t-1$ (ie: the previous time step).

r is the serial correlation.

Y'_t is the trend free pre-whitened data set at time step t

- e) **Re-blend the trend magnitude back into the time series** by adding the linear trend magnitude (from step a) to the trend free pre-whitened time series generated from step d at each time step:

$$Y_t = Y'_t + T$$

3.7.3 Confirming serial correlation

The final time series generated by the 'pre-whitening' process should be tested for serial correlation. The pre-whitening process should help to reduce the serial correlation, however it may not minimise the serial correlation to within the level required by the trend analysis tests. As such, it may be necessary for an alternative representative period to be tested (for instance, consider monthly if weekly data does not comply). Serial correlation should ideally be less than 0.2 for trend test validity. This may not be possible and in these instances the trend analysis test results should be qualified to note that high serial correlation invalidates any statistical significance observed in the data by potentially overstating the level of statistical significance. In time series with no statistically significant trends, high serial correlation will not alter the trend test result.

Once the serial correlation is minimised to within the required levels (or as much as possible) the resulting time series is used to test for statistically significant changes using the linear, Mann-Kendall and Seasonal Kendall tests.

3.7.4 Frequency of monitoring

The interval of monitoring in regional bores is considerably longer than that collected for the bores within the QGC development area, and the two data sets do not always temporally align. Ideally, an increased monitoring frequency would be available for a selection of regional DNRM groundwater bores to better align local and regional data sets for trend analysis. This increased monitoring frequency would enable better comparison across locations for concurrent periods. However, any change in monitoring frequency at a given location can adversely influence the observed trends at that site. In order to minimise the likelihood of false outcomes, it is necessary to ensure the data used for the trend analysis has a reasonably consistent frequency throughout the entire period of record. This may require re-processing the data for some parts of the record to generate a long term data set with a consistent time step. Alternatively, the raw data can be separated into separate periods for analysis to consider any trends before and after the installation of a data logger. An assessment of serial correlation should be undertaken to ensure the appropriate representative period is used in the analysis.

Separate to the frequency of data that is suitable for the assessment of trends, it is relevant to source raw data at an appropriate frequency for the pre-processing requirements. For instance, sub-hourly data is recommended for the determination of the barometric and loading efficiencies, as outlined in **Appendix B**.

3.8 Missing Data

Missing data can confound a trend analysis by introducing bias into the trend results. For example, if data is missing towards the end of the period of analysis and that corresponds to a period of relatively high groundwater levels, then excluding that data from the analysis will reduce any observed trend. If missing data is randomly distributed throughout the period of analysis then it may not necessarily affect the trend analysis results. As a rule of thumb, it is proposed that where groundwater level data in the bore of interest is missing for less than 5% of the record over the period of analysis, that data should be infilled. This missing data criterion relates to the data being analysed for trends rather than the raw groundwater data, as the representative period applied for the calculation of the weighted mean may reduce the proportion of missing data.

If infilling is required, the technique for infilling will depend on the site of interest, however a regression relationship is suggested. This regression relationship will be established between the groundwater level data and other relevant data sets that describe exogenous influences (such as rainfall, air pressure, earth tides), and is also relevant for application in the trend analysis method. In the instance of small periods of missing data, this regression relationship can be assumed to provide a reasonable estimate of the groundwater level conditions taking into account external factors. Where the amount of missing data is more than 5% of the record, particularly where that missing data is at the start or end of the record, then the trend analysis should not be undertaken or the period of analysis should be reconsidered.

4. Interpretation of groundwater level trend analysis

Once complete, the statistical trend analysis process will provide information on the magnitude, direction and statistical significance of any observed changes in groundwater level over time. However, it will not provide information on causality for these changes. An understanding of the local conditions is necessary to interpret the outcomes from the statistical tests. For this purpose, it is necessary to collate:

- Contextual information to support the interpretation of the statistical trend analysis outcomes; and
- Other relevant information for incorporation in the report on trend analysis results.

This information will be obtained through a hydrogeological assessment plus other approaches as relevant. The contextual information obtained through this step is used for guidance and interpretation purposes only. The purpose of statistical trend analysis is to test for evidence of changes in groundwater level and groundwater quality data. The models used in a trend analysis are statistical models using raw data (with only negligible infilling). It is important therefore that any data generated by process models is excluded from the trend analysis, as this can introduce trends reflective of the process model parameters, not observed behaviour.

As an example, **Table 4-1** provides a summary of some contextual information for the Berwyndale South GW1 bore. This table outlines the bore site conditions and a number of factors that may influence the groundwater levels at this location. Interpretation of the trend analysis outcomes should take these issues into account.

Key Factors Influencing Hydrograph Period	Site Conditions	Potential Influence on Hydrograph
Loading/Unloading Influences	Hydrograph period occurs about nine months after the rainfall and stream flow event of 2010/2011 summer. Subsequent rainfall below average.	Possible residual loading post 2010/2011 wet season
Proximity to Recharge Sources	Gubberamunda Sandstone outcrops occur about 20 km to east. Potential recharge from Condamine River flows to overlying aquifer (Mooga Sandstone) about 1 km to north	Possible loading effect and direct recharge to outcrop and other locations where Gubberamunda Sandstone subcrops beneath the Condamine River
Proximity to CSG Production	Bore located within long term producing field (since about 2005). Groundwater extraction for camp supplies from Gubberamunda Sandstone bores occur 1 km to south	Unlikely influences from CSG production. Possible influences from camp water extraction
Other Potential Influences	Major water storage located within 1 km of bore. This has a maximum water depth of about 5 m.	Possible loading effect

Table 4-1 Summary contextual information for Berwyndale South GW1

A site specific assessment will be carried out for each monitoring location to provide the contextual information required for a full trend analysis at each location. This will form part of the Aquifer Surveillance Workflow which will be prepared prior to the onset of major dewatering.

5. Hydrochemistry data trend analysis

5.1 Background

The hydrochemical characterisation of the major ions in groundwater within and immediately surrounding the Surat Basin QCLNG tenements is described in an accompanying report (QGC, 2013a). A preliminary review and interpretation of currently available isotopic data has also been included. The characterisation provides the foundation for a conceptual model of the reaction processes that occur along the regional flow paths, which will be developed further with the continual collection and analysis of water quality and core data. This data is useful to better define the conceptual hydrogeological model and hence to assess vertical and horizontal connectivity.

Preliminary analysis and interpretation of existing datasets shows that the application of major ion hydrochemical signatures does not provide the basis for development of an unequivocal method to calculate fluid flow across flux boundaries. These data do, however; provide important information on the potential controls related to recharge and regional flow vectors that control the distribution of hydrochemical facies. The minor and trace ion solute patterns from the current datasets provide equally ambiguous information.

It is emphasised that the above conclusions are preliminary and are subject to much more data gathering and analysis.

The general statistical concepts introduced earlier for groundwater level data are relevant to the assessment of hydrochemistry trends, and raw data should be processed to ensure that relevant statistical assumptions are valid. This includes the removal of outliers and data treatments for serial correlation. A further element of importance when considering hydrochemistry data relates to the length of the data set. As the monitoring program is still in the early stages of data collection, limited data is available for analysis. The ability to meaningfully assess trends, and verify underlying statistical assumptions of normality and independence of data, will improve as more data is collected. For this reason, a staged approach to hydrochemistry trend analysis is required.

5.2 Limited data (< 5 years) available

QGC's groundwater quality monitoring program will include six monthly sampling of all groundwater monitoring bores for physico-chemical parameters, major ions, trace elements, carbon parameters, nutrients, gas parameters and organics. One round of stable isotope analyses for each bore is planned.

Data will be analysed for trends for those parameters which are of prime significance to the hydrochemistry of the aquifers being assessed but will consist of:

- Field parameters – EC and pH;
- Major ion ratios (eg Na/Cl_l);
- Major ion concentrations (eg Na, Cl, HCO₃);

- Isotope ratios (eg $^{86}\text{Sr}/^{87}\text{Sr}$ $\delta^{18}\text{O}/\delta\text{D}$); and
- Key trace elements, if appropriate.

The extent to which analysis will be carried out will be determined from the development of the QGC conceptual hydrochemical model of the Surat Basin which is being developed under Commitments 10 and 11 of the Stage 2 CSG WMMP.

In the early stages of data collection, groundwater quality observations will be limited, which prevents the use of a formal trend analysis approach to assess the data. Instead, the groundwater quality data will be plotted to visualise general behaviour characteristics. A line of best fit will be applied to identify the nature of any changes over time. However it must be interpreted with care in light of the data limitations. Observations will be qualitative and general in nature, until at least five years of record are available.

5.3 Long term (> 5 years) record available

A number of processes may influence groundwater quality data, such as:

- Local and regional geological conditions and water movements;
- Local and regional land use and land use changes;
- Climate conditions and resulting recharge events;
- Local and regional groundwater pumping; and
- Water quality sampling and laboratory quality control procedures.

Given the depth of the confined aquifer systems of interest, it is unlikely that surface processes will impact on the quality of water in the groundwater system being analysed. Instead, it is likely that the characteristics of the adjacent groundwater systems will be more relevant if considering groundwater quality changes. However any interpretation will depend on the relative location of bores to inferred recharge areas. Note QGC is undertaking a detailed assessment of the hydrochemistry of groundwaters within the various formations in the Surat Basin.

An approach consistent with the groundwater level trend assessment method will be used to assess changes in groundwater quality data once a long term record is available. A reasonable data set is required for the application of this approach, and it is suggested that more than five years of data should be collected before this technique is applicable at the proposed monitoring frequency. In the case of water quality data, external influences to include in the assessment must be relevant for the specific constituents being analysed, but will draw upon those identified through the processes noted above. The method for ongoing application is summarised in **Section 6**, and is consistent with the approach demonstrated in earlier sections of this document.

6. Selected Method of Trend Analysis

This method has been developed and tested using currently available groundwater level data. As more information is collected about groundwater level and water quality behaviour in the vicinity of QGC activities, the method will be refined to provide an adaptive approach to the management of potential groundwater impacts.

6.1 Hydrogeological conceptualisation

Hydrogeologic conceptualisation of the area being monitored will be undertaken to identify factors that will potentially influence trends. This brief context setting will ensure that the data being input into the statistical trend analysis is appropriate and physically relevant.

6.2 Groundwater level and pressure

A method for ongoing application has been developed to provide a mechanism to monitor and assess changes in groundwater levels and/or pressures over time. QGC will apply this method to the eight early warning and trigger monitoring bores in the Northern gas fields, plus additional bores within each of the three active production areas. The approach takes into account DNRM (2012) guidelines on underground water impacts and Geoscience Australia (2012) comments on the approach proposed in the Stage 2 WMMP, and includes the following steps:

- **Collate available data for analysis.** This data will include groundwater levels and pressures in both the target aquifer plus overlying aquifer if confined, rainfall, atmospheric pressure, earth tides, and groundwater pumping data as available. This data may be sourced from external agencies, such as the Bureau of Meteorology and DNRM as required. Data will be reviewed for any obvious data anomalies, such as power failures or an influx of water into the bore during flood events. These erroneous data points should be removed, along with data for about one week following the incident to ensure the data has returned to background levels;
- **Remove the influence of barometric pressure and earth tides.** This **can** help to minimise the 'noise' in the data depending on the overall magnitude of water level changes that take place over time. Existing software tools such as BETCO and TSOFT may be used for this step;
- **Select periods of analysis for raw data trends.** The periods of analysis ideally need to be a minimum of 12 months, however initially the period of analysis should cover the period of all available data. A break-point analysis can be undertaken to identify whether recent periods of data are significantly different to earlier periods, thereby allowing the separate identification of current trends over a shorter, more recent period of analysis;
- **Develop and apply a multiple regression model** between groundwater level and other data sets, such as rainfall, local and regional bore levels, bore data in the appropriate overlying unconfined aquifer as available, over the period of analysis

covering the whole period of available data. This regression can also be applied to infill any missing periods in the data record. A time-series of change in groundwater level independent of fluctuations in known non-QGC influences will be calculated, and the break-point analysis repeated using this time series to confirm the periods for analysis are still appropriate. The above steps should be repeated for a regional bore located outside the influence of CSG activities, and compared with the behaviour at the monitoring bore of interest to assess trends as a result of regional groundwater behaviour. The groundwater level should also be compared to the cumulative deviation from mean rainfall conditions to provide a coarse overview of the relationship (if any) between rainfall and groundwater level, as specifically recommended in DEHP's guidelines;

- **Minimise serial correlation in the data.** The resulting data set will be aggregated to a suitable time step for trend analysis, based on an assessment of the serial correlation of the data. The weighted mean drawdown will be calculated by averaging the data over a representative period. A 'pre-whitening' approach will be applied to further minimise serial correlation. In combination, the weighted mean drawdown and pre-whitening processes may be repeated to consider various time steps (such as daily, weekly, monthly or annual frequencies) until serial correlation issues are suitably resolved; and
- **Undertake statistical analysis to assess trends.** This will utilise statistical tests such as linear regression, the Mann-Kendall trend test and the Seasonal Kendall test. QGC will use the eWater CRC Water Quality Analyser software package to undertake this analysis. As relevant, this analysis may consider the raw data and the corrected data (accounting for external influences) for the full period of record and the data following any break-point.

6.3 Groundwater quality

The method for application when considering groundwater quality data is similar to that presented above, but depends on the data available. The approach assumes that data will be collected at a six-monthly frequency. If automatic water quality samplers are installed an upgraded methodology will be developed for the chemical parameters monitored.

1. **Collate available data for analysis.** This data will include groundwater quality in the aquifer of interest plus adjacent aquifer systems, rainfall, and any other relevant data sets, as available. This data may be sourced from external agencies, such as the Bureau of Meteorology and DNRM as required. Data will be reviewed for any obvious data anomalies, such as sampling or laboratory errors, missing data periods, loss of power to bore loggers. These erroneous data points should be removed. The resulting data set will be aggregated to a suitable time step for trend analysis, based on an assessment of the serial correlation of the data;
2. **Trend analysis.** The approach to assess trends in groundwater quality data depends on the period of record available:
 - a) **Limited data (< 5 years) available.** Data will be plotted to visually assess general behaviour. A line of best fit will be applied to identify the nature of changes over time, but this should be interpreted in light of the limited data being used. Observations will be qualitative;
 - b) **Long term (> 5 years) record available.** A detailed trend analysis assessment will be undertaken, following the steps outlined above for groundwater level and pressure data. In this case, appropriate external influences for incorporation in the regression analysis may include adjacent groundwater quality, local and

regional groundwater pumping, and other influences deemed relevant to the bore of interest.

6.4 Trend Analysis Interpretation and Reporting

Groundwater level data will be available via telemetry on-line to QGC Head Office Brisbane. Data will be routinely processed by QGC's hydrogeologists and technical support team to generate time series bore hydrographs and reviewed for potential trend development and to assess the need to initiate Exceedance Response Plans.

Data collation and reporting will be undertaken at frequencies required by approval and regulatory requirements but at least annually

Where bore level and quality data for both pre- and post-pumping periods are used for analysis, the trend analysis results can provide an indication of changes relative to the conditions prior to any CSG development. In locations where data is only available after pumping has commenced (e.g. in existing QGC domestic gas production areas), the trend analysis outcomes can only provide an indication of changes relative to the conditions at the start of data collection.

In some instances, the different trend analysis tests may produce different results. Any outcome that indicates a statistically significant result will trigger further investigations, regardless of whether this result is consistently obtained across the various trend tests outcomes or not.

Annual reports will outline the methods applied and the results generated from the trend analysis undertaken within the review period. The report will include a qualitative interpretation to provide context for any unusual trends observed. Where necessary, this will consider the hydrogeological setting for the datasets being analysed, as well as other potential influences that cannot be directly accounted for in the analysis. The report will also compare the results with previous trend analysis results to identify any changes in groundwater conditions of interest. Tabulated raw monitoring data will be provided with reports.

Part 2

7. Test Application of the Selected Method

7.1 Introduction

Groundwater level data from four monitoring bores were considered in this analysis, and one groundwater quality data set. The level data includes data from one QGC monitoring bore, one APLNG (Origin) monitoring bore and two Department of Natural Resources and Mines (DNRM) monitoring bores. The groundwater quality data was sourced from a QGC monitoring bore.

The following sections of this document describe the application of the approach undertaken for each monitoring bore location, and the specific steps involved in processing the data, undertaking statistical analysis and assessing whether there is a relationship between groundwater level and other available data in each case. As the objective of the work program is to demonstrate the application of statistical techniques, interpretation has been limited to drawing conclusions from the statistical analysis and does not consider any interpretation of hydrogeological processes or other factors (apart from potential rainfall influences) which may have affected groundwater response in the bores that have been assessed.

Four bores were selected for groundwater level analysis and one for analysis of groundwater quality. The logic for the selection of these bores is outlined in **Table 7-1**.

Monitoring bore site	
Groundwater level analysis	
BWS-GW2	Continuous record of over 12 months of data. Bore monitors Springbok Sandstone in operating gasfield.
RN 422390204	Long term record (over 45 years) from Walloon Coal Measures
RN 13030613	Long term continuous record (18 years) from Hutton Sandstone
RN 10925	Continuous record of 2 years from Gubberamunda Sandstone proximal to operating gas fields.
Groundwater quality analysis	
BEL-WH003	Data collected for more than four years

Table 7-1 Monitoring bores used for trend analysis

7.2 Monitoring bore BWS-GW2

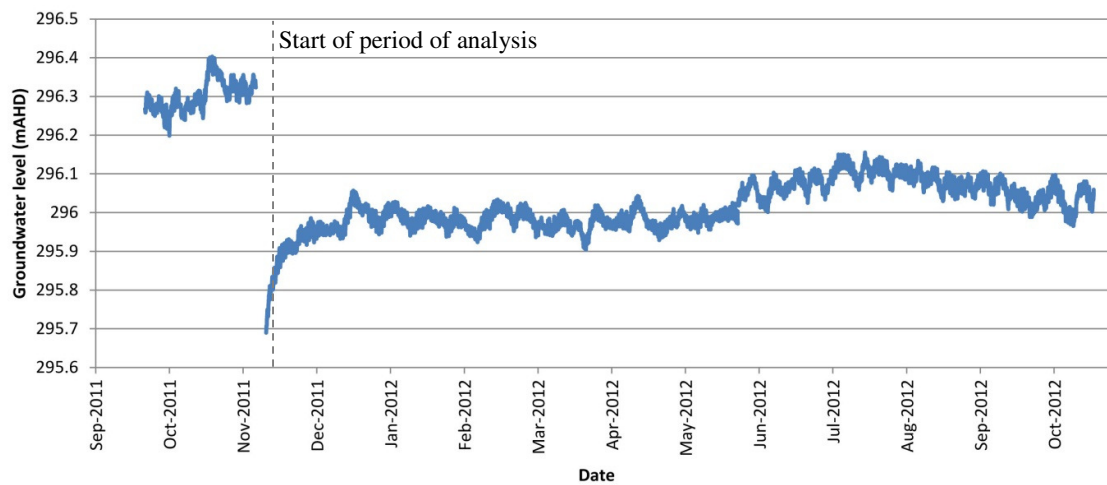
7.2.1 Step 1: Collate available data

Monitoring bore site BWS-GW2 (Berwyndale South GW2) is located in the QGC tenements, and monitors the Springbok Sandstone in a gas production field. It has been in operation since September 2011, recording groundwater level and pressure on an hourly basis. A pump test was undertaken from 6 November 2011 to 10 November 2011 and data collected during this period has been removed.

A visual assessment of the observation bore hydrograph (**Figure 7-1**) indicates that the first six weeks of data prior to pump test are not representative of the longer term record after the pump test was completed. The reasons for this are unclear and could be due to a number of factors. The data collected since the test pumping are considered more reflective of the current baseline conditions. Therefore, the early data has been excluded from further analysis.

In addition, **Figure 7-1** also indicates that the water levels immediately following the pump test took some time to recover to the post-pump test baseline conditions. Data captured for one week following the pump test has also been removed from the record to eliminate the effect of the pump test on the observed bore behaviour.

Table 7-2 provides a summary of key statistics based on the period of record being analysed for trends.

Figure 7-1 Raw groundwater levels at monitoring bore BWS-GW2

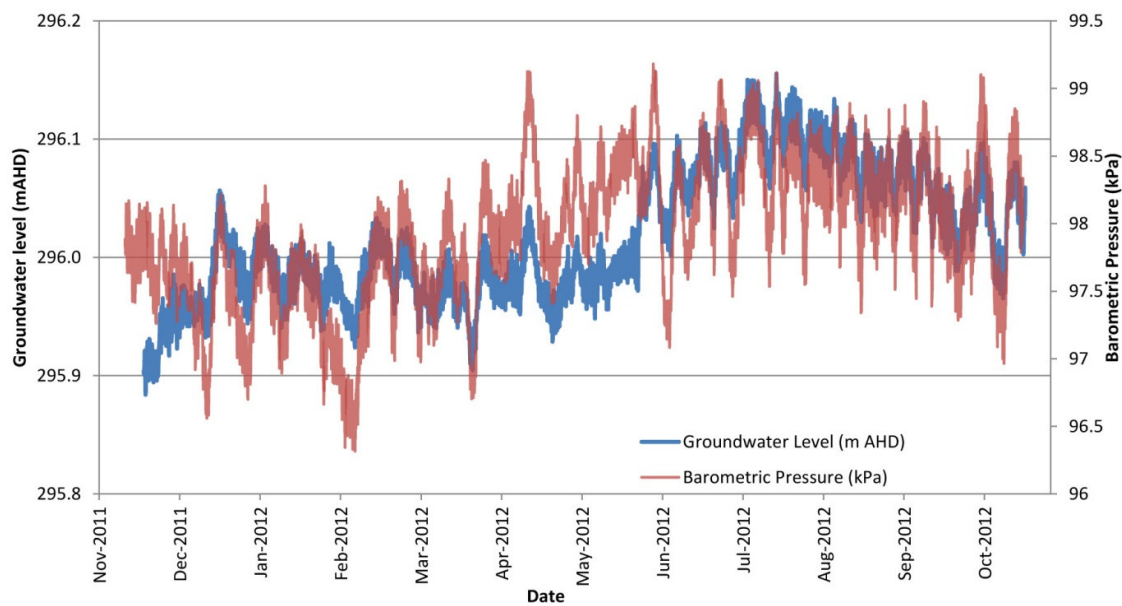
Site: BWS-GW2	
Data availability	
Start of monitoring	21/9/2011
Start of period used for analysis	19/11/2011
Most recent observation point	19/10/2012
Missing data	0% (1 missing observation within record)
Data characteristics	m AHD
Minimum	295.9
Maximum	296.2
Mean	296.0
Median	296.0

Table 7-2 Summary statistics for monitoring bore BWS-GW2, with anomalous data removed

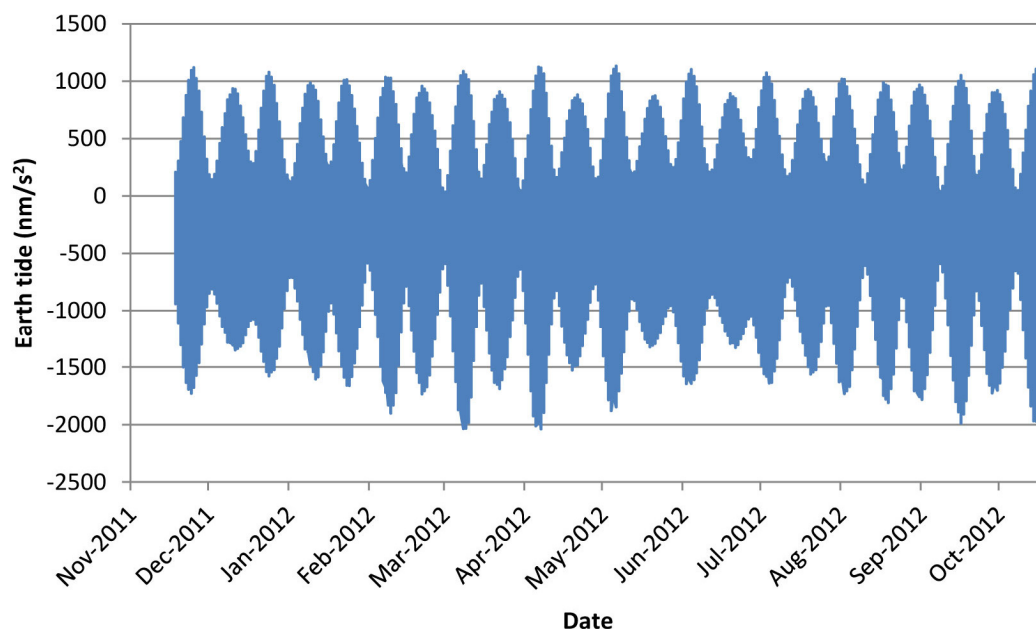
7.2.2 Step 2: Account for barometric pressure and earth tides

Barometric pressure is not monitored at this monitoring bore site, however it is recorded at the LAU-GW1 monitoring (Lauren) bore site located approximately 15 km from the BWS-GW2 monitoring bore. This barometric pressure data has been used in the trend analysis. Barometric pressure has been monitored at this location since September 2011, concurrent with the bore observations. **Figure 7-3** provides the barometric pressure data alongside the groundwater level data.

Figure 7-2 Comparison of groundwater levels at monitoring bore BWS-GW2 and barometric pressure observations from monitoring bore LAU-GW1



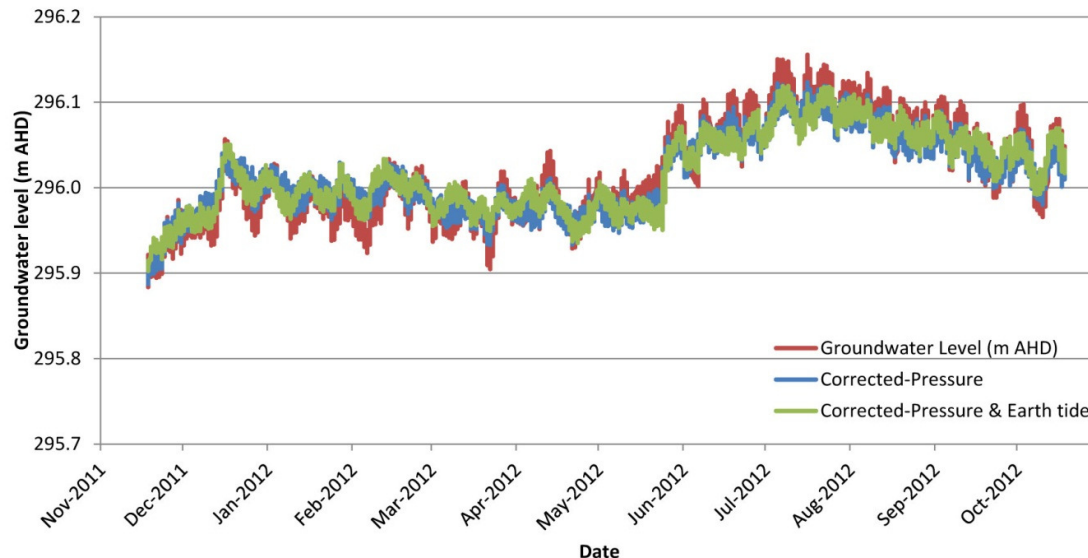
The groundwater level data was used as inputs into the TSOFIT program (Van Camp and Vauterin, 2005; <http://seismologie.oma.be/TSOFIT/tsfit.html>) to generate a synthesised time series of earth tides at the bore location. An hourly time step was used as input into the software. Periods of missing data were identified with a missing data flag (value of 99999.999) to generate a continuous record for input. The TSOFIT synthetic earth tide output for this bore site is displayed in **Figure 7-4**. The units of this data are in nm^2/s , which represents a vertical acceleration due to gravitational effects from the sun and moon.

Figure 7-3 Synthetic earth tide for monitoring bore BWS-GW2

This earth tide data, in addition to the daily groundwater levels and the barometric pressure data, is used as input to the BETCO software (Toll and Rasmussen, 2007; <http://www.hydrology.uga.edu/rasmussen/betco/>) to account for these external processes. BETCO removes fluctuations due to barometric pressure and earth tides in aquifer water level measurements using a multiple regression technique. To run, BETCO requires input data of water level and barometric pressure using consistent units. For this purpose, the LAU-GW1 barometric pressure data was converted from kilopascals (kPa) into metres of water (m H₂O) by assuming standard temperature and pressure conditions so that 1 m H₂O = 9.80665 kPa. This approach ignores changes in water density with elevation and temperature.

The earth tide data is input in nm/s², as output from TSOFT. BETCO outputs provide corrected water levels that take into account the influence of barometric pressure and earth tides, as shown in **Figure 7-4**. The removal of barometric pressure and earth tide influences smooths the groundwater level data compared to the raw data set. The magnitude of this smoothing for this site was up to a maximum of 0.05 m.

Figure 7-4 Groundwater levels at monitoring bore BWS-GW2, taking into account barometric pressure and earth tides



7.2.3 Step 3: Period of analysis

Less than one year of data has been collected at the BWS-GW2 monitoring bore site. As it is suggested that approximately one year of weekly data is necessary for trend analysis, no break point assessment has been undertaken for this data set.

7.2.4 Step 4: Develop and apply multiple regression model

- c) Climate, loading and unloading impacts (including plot of groundwater level against cumulative deviation from mean rainfall conditions). Bureau of Meteorology rainfall data from the vicinity of the bore was reviewed. This included a number of rainfall gauges from the region to observe the variability in rainfall across the region. Rainfall gauge 042078 (Harewood – refer **Figure 3-1**) was selected for more detailed investigations given its location relative to the monitoring bore site.

Figure 7-6 presents the daily rainfall, average daily groundwater level (adjusted for barometric pressure and earth tides, using the outcomes from the steps above) and cumulative deviation from the mean daily rainfall. The cumulative deviation from the mean daily rainfall has been determined by calculating the average daily rainfall over the full period of record. At each time step during the period of interest, the difference between the daily rainfall record and the average daily rainfall has then been calculated. These differences were summed to generate the cumulative deviation from the mean daily rainfall.

The comparison between the groundwater level and the cumulative rainfall indicates some isolated periods with consistent behaviour between the rainfall and groundwater level, however in general, there is low or no correlation between

the rainfall record and the groundwater levels at this location. For example, an increase in rainfall occurs in early 2012 which does not produce a groundwater level response. This is further displayed in Figure 7-7 in the form of scatter plots between the groundwater level and the rainfall (both raw and cumulative deviation from the mean). These figures show a relatively high degree of scatter and little ability to predict groundwater levels based on rainfall conditions. This suggests that the climate conditions are not directly reflected in the groundwater levels at this location.

Figure 7-5 Groundwater level at BWS-GW2, daily rainfall and cumulative deviation from the mean daily rainfall at Harewood (042078)

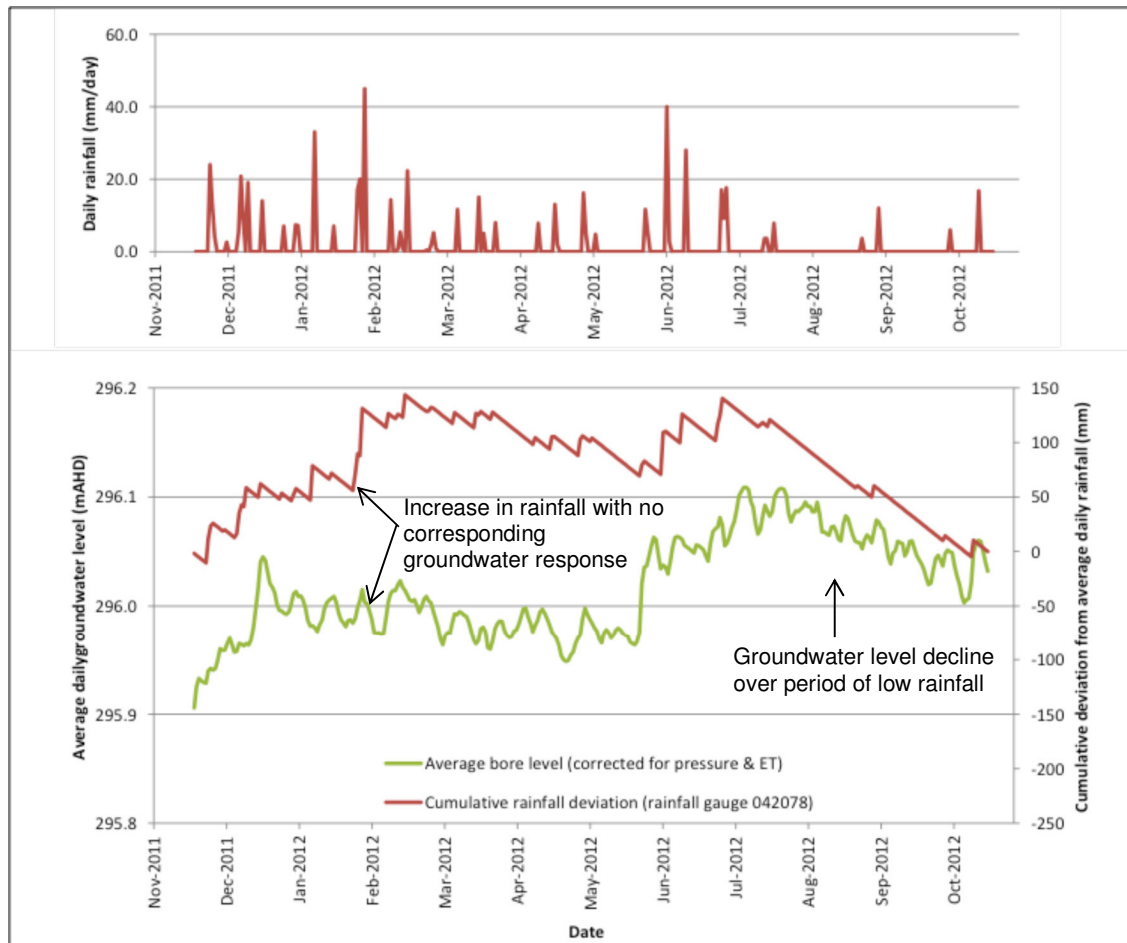
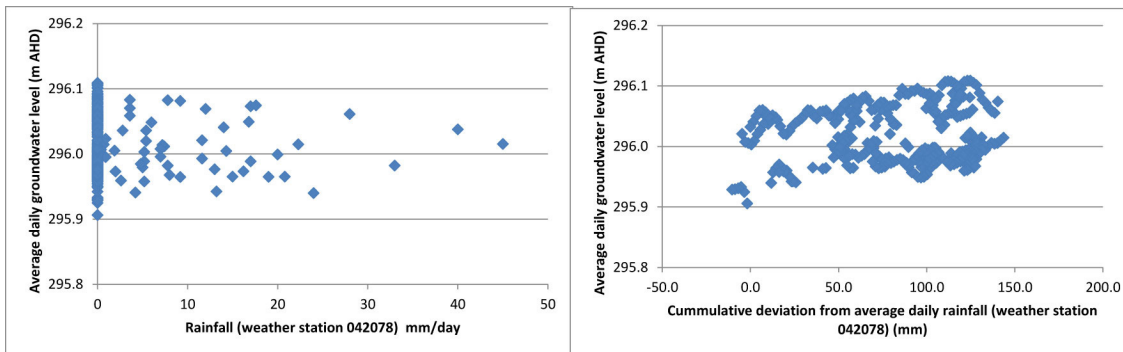


Figure 7-6 Comparison of rainfall data at Harewood (042078) and groundwater levels at monitoring bore site BWS-GW2



In addition, trends in confined aquifer water levels can be influenced by hydraulic loading and unloading caused by water table fluctuations in overlying unconfined aquifers and flooding of the land surface. Accounting for this would ideally draw upon groundwater level data that represents the groundwater levels in the overlying unconfined aquifer. In the absence of this additional groundwater level data set, regional rainfall conditions may be used as a surrogate on the assumption that recharge (and hence, groundwater levels in the unconfined aquifer) is driven by rainfall events. In the case of monitoring bore BWS-GW2, no suitable data for the relevant unconfined aquifer was available at the time of this study. The rainfall analysis presented above provides a surrogate data set to represent the loading and unloading process. In this case, there is little or no correlation between the groundwater level and rainfall.

- d) Local and regional groundwater influences. These have not been assessed here but would need to be considered as a part of the hydrogeological interpretation of hydrograph response.

7.2.5 Step 5: Weighted mean drawdown over a representative period

The groundwater level time series generated at the completion of the step above (accounting for external processes) was tested for serial correlation (the theory of serial correlation is described in **Section 3.2**). The hourly data was observed to have a high serial correlation, and a number of steps were taken to minimise this:

- Calculation of the weighted mean drawdown over a representative period. A number of different time steps were considered during preliminary analysis at this site, including hourly, daily, weekly and monthly. A weekly time step was selected for application, subject to review based on the results obtained from the pre-whitening step outlined below.
- Application of the pre-whitening approach described by Yue et al (2002) (refer **Section 3.8.2**) to remove the effects of autocorrelation in the weighted mean drawdown time series. This generates a time series of independent data for trend assessment. The serial correlation of the resulting time series was tested to confirm the data is no longer influenced by autocorrelation.

Unfortunately the weekly time series generated through this process did not fully reduce the serial correlation to within the recommended limits (correlation coefficient less than 0.2) to maintain the statistical assumptions for the trend analysis tests, so the results presented below must be interpreted in light of this limitation. Alternative data frequencies were assessed (including daily and monthly) with no improvement in the serial correlation. It is considered relevant to reassess the appropriate frequency of analysis for this site once further data is collected, as an extended time series will help to determine the appropriate representative period to calculate the weighted mean drawdown.

7.2.6 Step 6: Trend analysis

The outcomes from the step above were used as input into the trend analysis step, utilising the Water Quality Analyser software (<http://www.ewater.com.au/products/ewater-toolkit/eco-tools/water-quality-analyser/>) to undertake the assessment.

Figure 7-7 presents the trends identified at monitoring bore site BWS-GW2, once the raw groundwater level data has been reviewed, processed to an appropriate representative period and other external influences accounted for. The linear trend assessment indicates an annual change in groundwater level of approximately 12 cm per year. The histogram of linear regression model errors in **Figure 7-8** approximates a normal distribution, indicating that the assumption of normality for the linear regression is not violated. While the analysis indicates that there is a statistically significant trend in the data based on linear trend analysis, this result is invalidated by the high degree of serial correlation in the data.

The Mann-Kendall test was also applied but was found to be not statistically significant (at the 10% level of significance), which confirms that it is unclear whether the trend is statistically discernible from the noise in the data. The Seasonal Kendall test has not been applied at this location as it requires the time series to include multiple data points across all seasons (months). More data must be collected at this location for this criterion to be met.

An understanding of the hydrogeology in the vicinity of the bore locations and other site specific factors are required to provide a detailed interpretation of the hydrograph response to ensure the trend analysis captures all appropriate processes.

Figure 7-7 Trend in groundwater levels at monitoring bore BWS-GW2 after accounting for barometric pressure, earth tide and climate

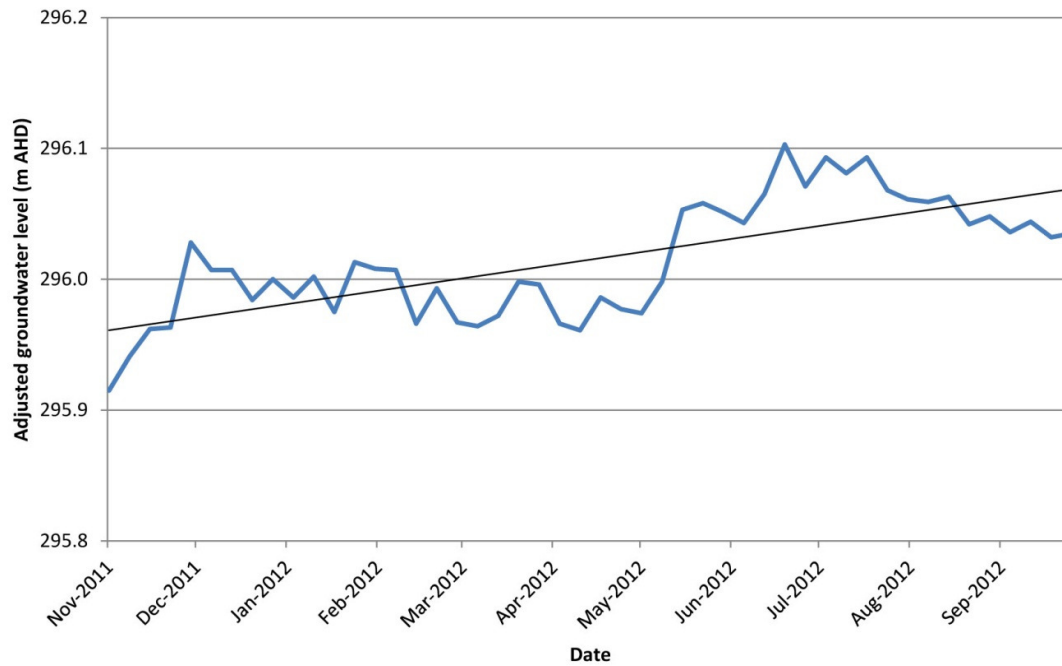
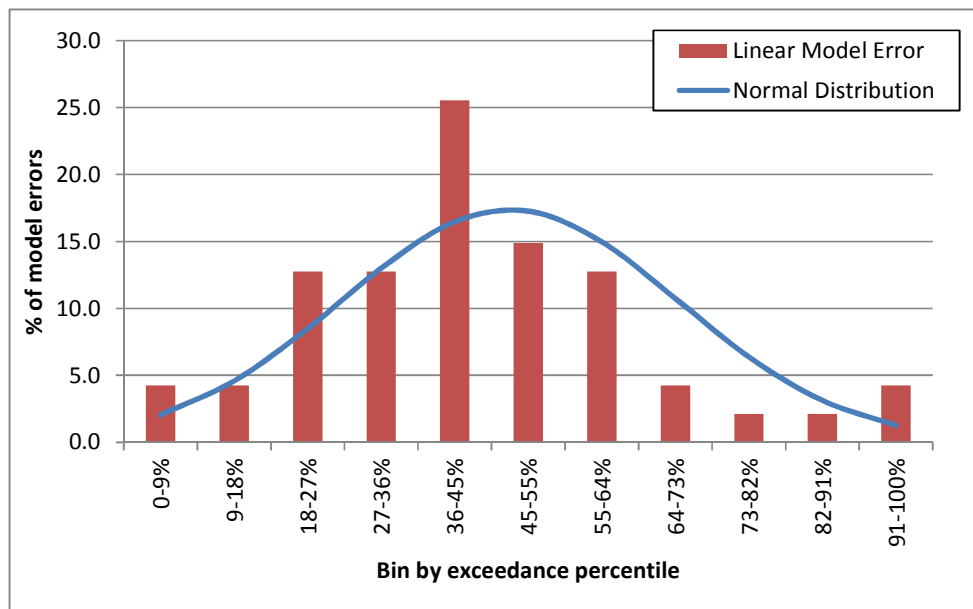


Figure 7-8 Check for Normality



Trend test	Period of analysis	Level of statistical significance	Trend magnitude
Monitoring bore BWS-GW2			
Linear regression	18/11/2011 – 12/10/2011	Not statistically significant *	0.12 m/year
Mann-Kendall		Not statistically significant	N/A
Seasonal Kendall		N/A	N/A

*high serial correlation in trend residuals invalidates statistical significance at the current time

Table 7-3 Summary of trend analysis results for monitoring bore BWS-GW2

7.2.7 Summary of analysis

The processing and analysis of data for monitoring bore BWS-GW2 identified the following key points:

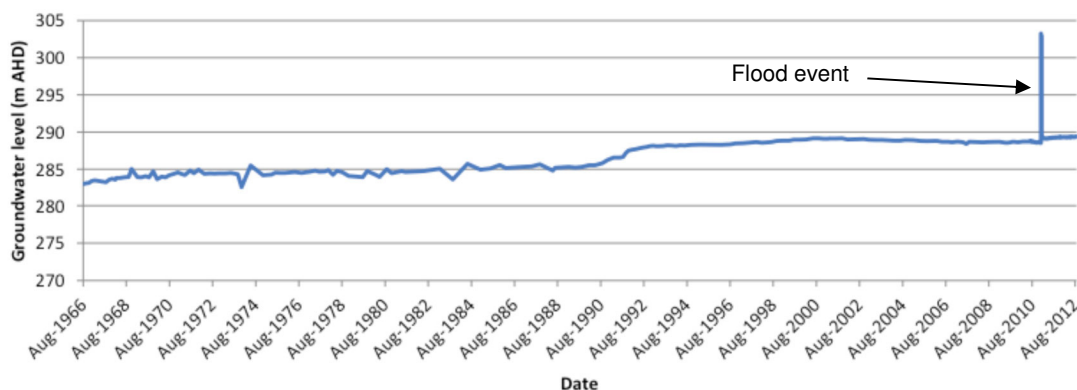
- Bore BWS-GW2 recorded a maximum fluctuation of approximately 0.3 m over the period 19/11/2011 – 19/10/2012.
- High serial correlation is observed in the data at this location. Calculation of the weighted mean drawdown over a representative period and the application of pre-whitening techniques did not improve the serial correlation sufficiently for validity of statistical assumptions.
- Whilst the bore showed an increasing trend of 0.12 m/year by linear regression analysis, a high serial correlation in trend residuals invalidates the statistical significance in the trend. The Mann-Kendall test showed no statistically significant trend (at the 10% level).
- There is no correlation between rainfall and groundwater levels as measured in the Springbok Sandstone at this site.

7.3 Monitoring bore RN 42230204

7.3.1 Step 1: Collate available data

Monitoring bore RN 42230204 is a DNRM monitoring bore located in the Walloon Coal Measures. This bore has been in operation since 1966, with observations made at irregular frequencies until a logger was installed in October 2010. Since then, groundwater levels have been monitored twice daily. **Figure 7-8** presents the data record at this site. A significant but temporary increase in groundwater levels is observed in late 2010, coinciding with the timing of high rainfall and runoff in the area. This data was reviewed in detail and was assumed to be attributable to short term flood impacts. Data points between 30 December 2010 and 19 January 2011 were removed to eliminate this period of abnormal behaviour. **Figure 7-10** presents the final data set used for this analysis and **Table 7-4** provides summary statistics for the site.

Figure 7-9 Raw groundwater levels at monitoring bore RN 42230204

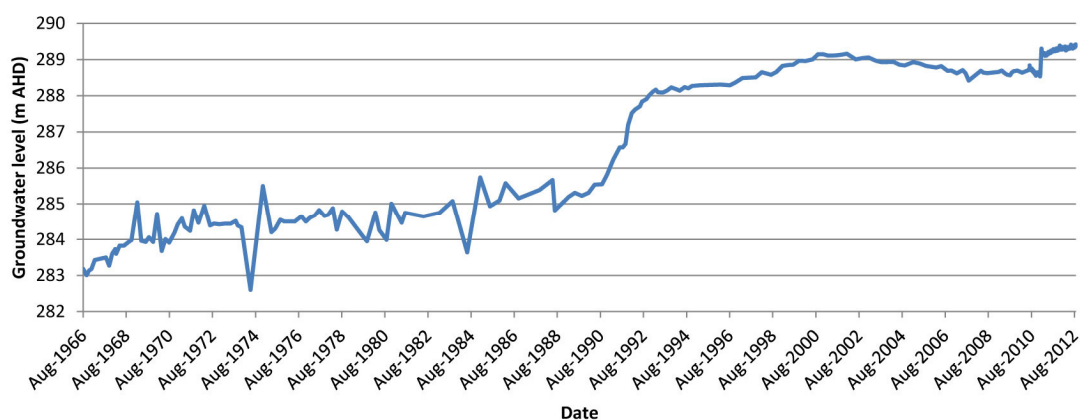


Monitoring bore RN 42230204	
Data availability	
Start of monitoring	1/08/1966
Most recent observation point	24/08/2012
Missing data	2%
Data characteristics	m AHD
Minimum	282.6
Maximum	289.4
Mean	288.9
Median	289.2

Table 7-4 Summary statistics for monitoring bore RN 42230204, with anomalous data removed

The data for this long term monitoring bore indicate several discrete periods of different groundwater behaviour. From the start of the record to the end of the 1980s, data appears to fluctuate between 283 m AHD and 286 m AHD with an increasing trend. During this period, observations are made irregularly, with monitoring frequencies of up to almost one year. In the early 1990s, the groundwater level increases rapidly. Following this, groundwater levels appear to be more consistent, with observations generally in the vicinity of 288 m AHD to 289 m AHD. An exception to this is the data collected since the flood in 2010/2011, which have been at an elevated level compared to the conditions prior to the flood.

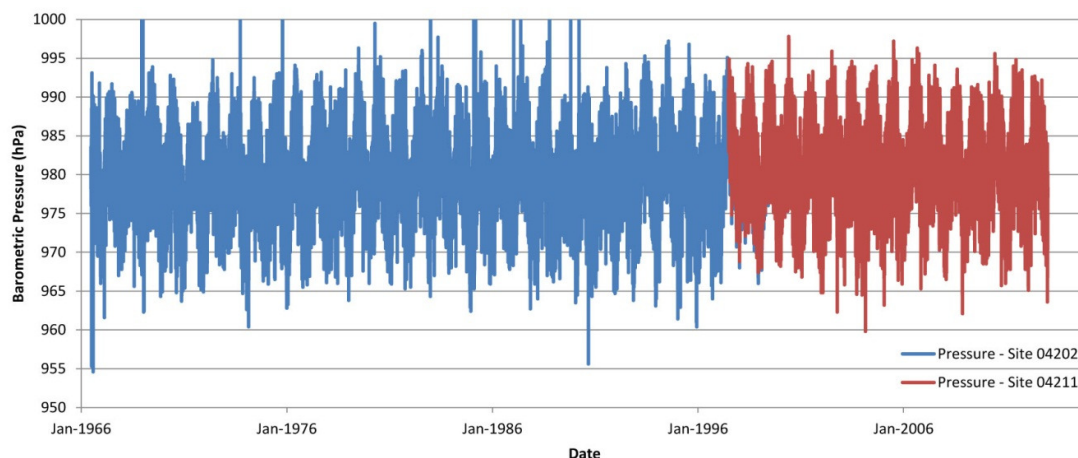
Figure 7-10 Groundwater levels at monitoring bore RN 42230204, with anomalous data removed



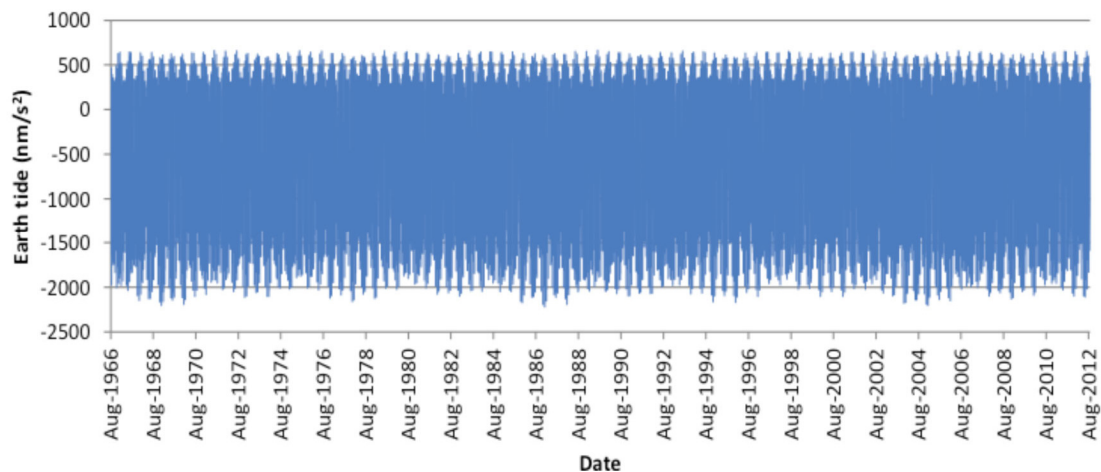
7.3.2 Step 2: Account for barometric pressure and earth tides

Barometric pressure is not monitored at this bore location by DNRM. The closest Bureau of Meteorology weather station with barometric pressure data is located at Miles Post Office (site 042023), approximately 50 km from the bore site. However, the barometric pressure record at this location does not extend for the full period of bore monitoring. An additional barometric pressure site is located at Miles Constance Street (042112), also approximately 50 km away from the bore site. Barometric pressure is monitored at high frequencies, with three-hourly data supplied by the Bureau for this analysis. Comparison of the two barometric pressure records is presented in **Figure 7-11**. Given the consistency between the data at these two locations, a long term barometric pressure data record was generated by combining the data from these two weather stations. Where available, the data from site 042023 was used in preference to the 042112 data.

Figure 7-11 Barometric pressure recorded at Bureau of Meteorology sites 042023 (Miles Post Office) and 042112 (Miles Constance Street)

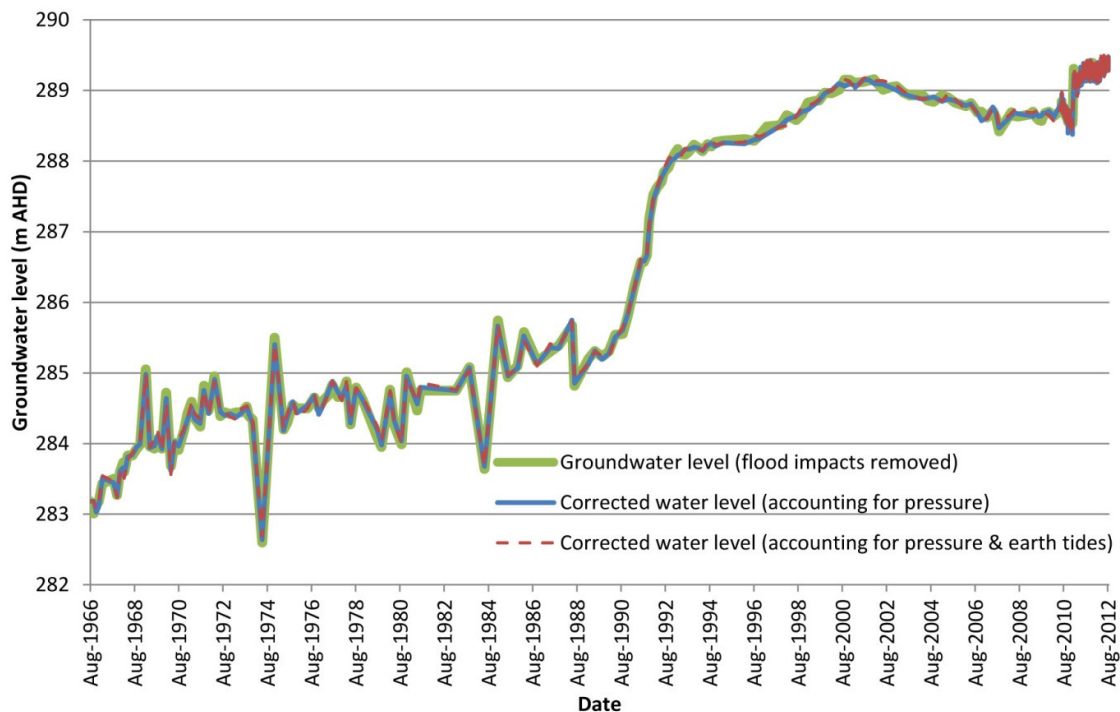


Earth tides (vertical acceleration due to gravitational effects from the sun and moon) were generated in a manner consistent with the approach outlined in **Section 7.2** for monitoring bore BWS-GW2. The TSOFIT synthetic earth tide output for this bore site (RN 42230204) is displayed in **Figure 7-11**. The units of this data are in nm^2/s .

Figure 7-12 Synthetic earth tide for monitoring bore site RN 42230204

This earth tide data, in addition to the daily groundwater levels and the barometric pressure data, is used as input to the BETCO software (Toll and Rasmussen, 2007; <http://www.hydrology.uga.edu/rasmussen/betco/>) to account for these external processes. BETCO removes fluctuations due to barometric pressure and earth tides in aquifer water level measurements. The smoothed hydrograph is shown in **Figure 7-13**. Given the overall magnitude of groundwater elevation change at this location, the influence of barometric pressure and earth tides on the hydrograph is relatively small. The magnitude of this smoothing for this site was up to a maximum of 0.2 m.

Figure 7-13 Groundwater levels at monitoring bore RN 42230204, taking into account barometric pressure and earth tides



7.3.3 Step 3: Period of analysis

Given the visual observations noted in the raw data relating to the obvious changes in groundwater level that have occurred at this location, a break point analysis was undertaken to determine whether the changes are statistically significant and warrant analysis of subsets of the original data record.

A number of tests were undertaken to isolate periods of data considered representative of the conditions at the time. In particular, this identified that data collected after 1993 has a mean groundwater level greater than the period prior to 1993. Given the conditions from 1993 are substantially different from the earlier period and have persisted over a number of decades, this data was considered to be representative of the baseline conditions at this site. No further detailed analysis was undertaken using the pre-1993 data.

Any break point assessment should take into account the practical relevance of the outcomes, and some interpretation of the results is required to consider whether the results are sensible for application. For instance, repeated break point analysis may identify progressively smaller and smaller periods of data for analysis. This should be interpreted based on the length of record and visual assessment of the data set. It is suggested that at least one year of weekly data is required for the subsequent trend analysis steps, which provides a minimum threshold when considering the outcomes from break point analysis. As an example, the break point analysis undertaken for this site identified that the data collected

from 2010 may also reflect a step change in the groundwater conditions. However, since this peak in groundwater levels is considered to be a temporary response to a significant rainfall and runoff event, it is appropriate to collect more data before applying the results of the break point analysis as the groundwater levels may return to pre-flood conditions over time.

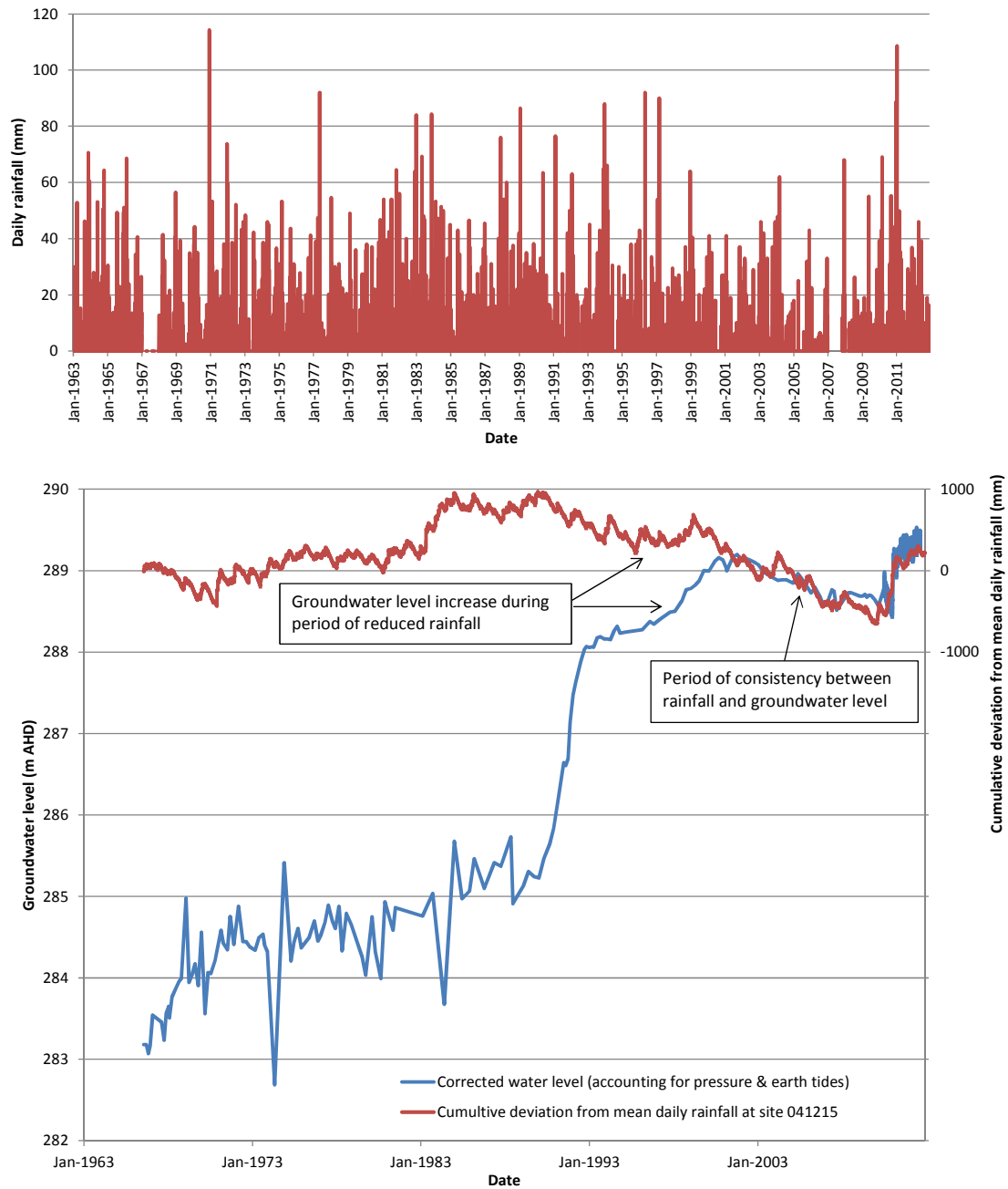
7.3.4 Step 4: Develop and apply multiple regression model

- e) Climate, loading and unloading impacts (including plot of groundwater level against cumulative deviation from mean rainfall conditions)

Bureau of Meteorology rainfall data from the vicinity of the bore was reviewed. This included a number of rainfall gauges from the region to observe the variability in rainfall across the region. Rainfall gauge 041215 (Riverview Hopeland – refer **Figure 3-1**) was selected for more detailed investigations given its close location to the monitoring bore site.

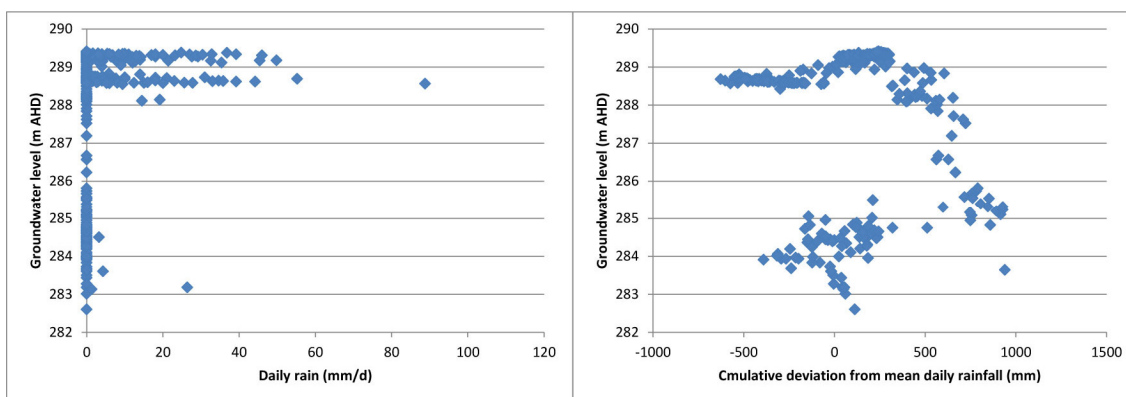
Figure 7-14 presents the daily rainfall, groundwater level (adjusted for barometric pressure and earth tides, using the outcomes from the steps above) and cumulative deviation from the mean daily rainfall. The comparison between the groundwater data and the cumulative rainfall indicates some discrete periods with consistent behaviour between the rainfall and groundwater level. For instance, a groundwater response is observed as a result of the high rainfalls in late 2010 and early 2011. However, at other times the relationship between rainfall and groundwater level at this location is less evident. For instance, a period of persistently dry conditions is observed from the mid-1990s, with a declining trend in the cumulative rainfall data. However, over the same period, groundwater levels increase slightly then change behaviour around the turn of the century before declining slightly.

Figure 7-14 Groundwater level at monitoring bore RN 42230204, daily rainfall and cumulative deviation from the mean daily rainfall at Riverview Hopeland (041215)



The rainfall and groundwater level data was examined in more detail, however no relationship was identified between the two variables (**Figure 7-14**). This comparison also investigated the possibility of a lag between the rainfall data and any direct response in the groundwater data, but no relationship was observed. This suggests that the climate conditions are not a primary driver of the groundwater levels at this location.

Figure 7-15 Comparison of rainfall data at Riverview Hopeland (041215) and groundwater levels at monitoring bore RN 42230204



In addition, trends in confined aquifer water levels are influenced by hydraulic loading and unloading caused by water table fluctuations in overlying unconfined aquifers and flooding of the land surface. Accounting for this would ideally draw upon groundwater level data that represents the groundwater levels in the overlying unconfined aquifer. In the absence of this additional groundwater level data set, regional rainfall conditions may be used as a surrogate on the assumption that recharge (and hence, groundwater levels in the unconfined aquifer) is driven by rainfall events. In the case of monitoring bore RN 42230204, no suitable groundwater level data for the relevant unconfined aquifer was available at the time of this study. The rainfall analysis presented above provides a surrogate data set to represent the loading and unloading process. In this case, there is little or no correlation between the groundwater level and rainfall.

f) Local and regional groundwater influences

Local and regional groundwater influences have not been assessed but would need to be considered as a part of hydrogeological assessment and interpretation of hydrograph response.

7.3.5 Step 5: Weighted mean drawdown over a representative period

The groundwater level time series generated at the completion of the step above (accounting for external processes) was tested for serial correlation. A high serial correlation was noted in the data at the original frequency of observations and the following steps were taken to minimise this:

- A number of different time steps were considered during preliminary analysis to determine the representative period for the calculation of the weighted mean drawdown at this site. This included the generation of time series on 100-day and

annual intervals. Based on a review of the serial correlation for these reprocessed data sets, the 100-day data was determined to be most appropriate for the analysis of trends.

- Application of the pre-whitening approach to the weighted mean drawdown time series to minimise serial correlation such that the statistical assumptions for the trend tests were deemed to be valid.

7.3.6 Step 6: Trend analysis

The outcomes from the step above were used as input into the trend analysis step, utilising the Water Quality Analyser software to undertake the assessment.

Figure 7-16 and **Table 7-5** presents the trends identified at monitoring bore site RN 42230204, once the raw groundwater level data has been reviewed, processed to an appropriate representative period and other external influences accounted for. The linear trend assessment indicates an annual change in groundwater level of approximately 3 cm per year. The histogram of linear regression model errors in **Figure 7-17** approximates a normal distribution (slightly right skewed), indicating that the assumption of normality for the linear regression is not violated. However, the analysis indicates that this is not a statistically significant trend in the data when tested using linear trend analysis, Mann-Kendall test or the Seasonal Kendall test (at the 10% level of significance).

Figure 7-16 displays a long-term cyclical pattern in the data. This response is indicative of the influence of external processes other than those captured in the analysis on the groundwater levels at this location. Accounting for this behaviour requires additional data which may include pumping data from local and regional irrigation bores, monitoring bore data for an overlying unconfined aquifer system (if present) to estimate loading and unloading influences, and other relevant processes. Incorporation of these processes into the trend analysis is also expected to help reduce the serial correlation in the data.

Figure 7-16 Trend in groundwater levels at monitoring bore site RN 42230204 after accounting for barometric pressure, earth tides and climate

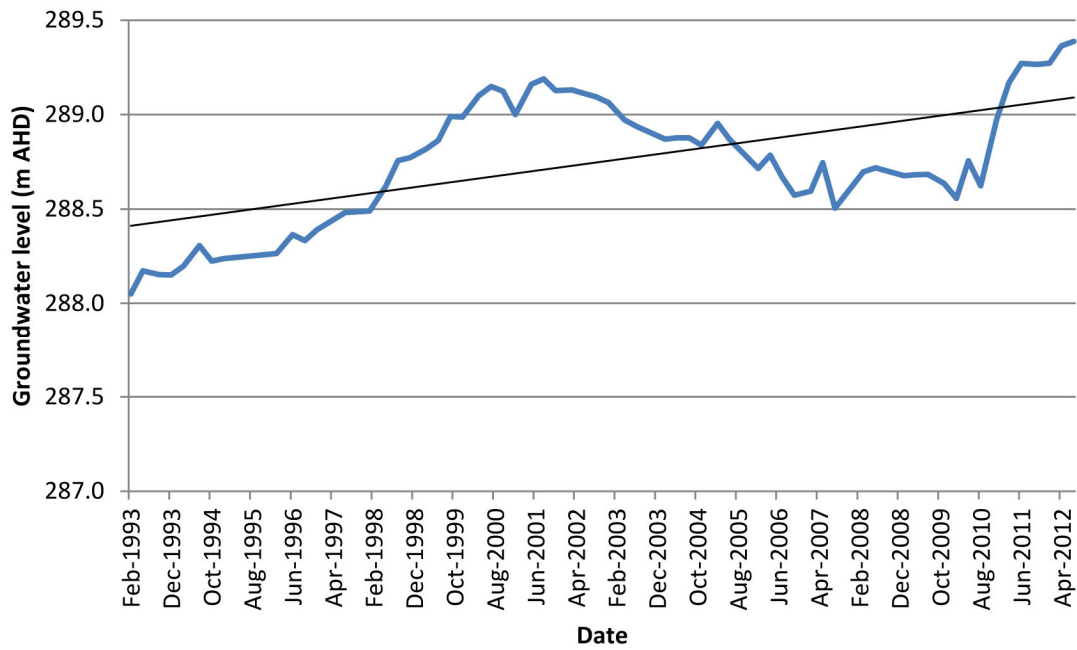
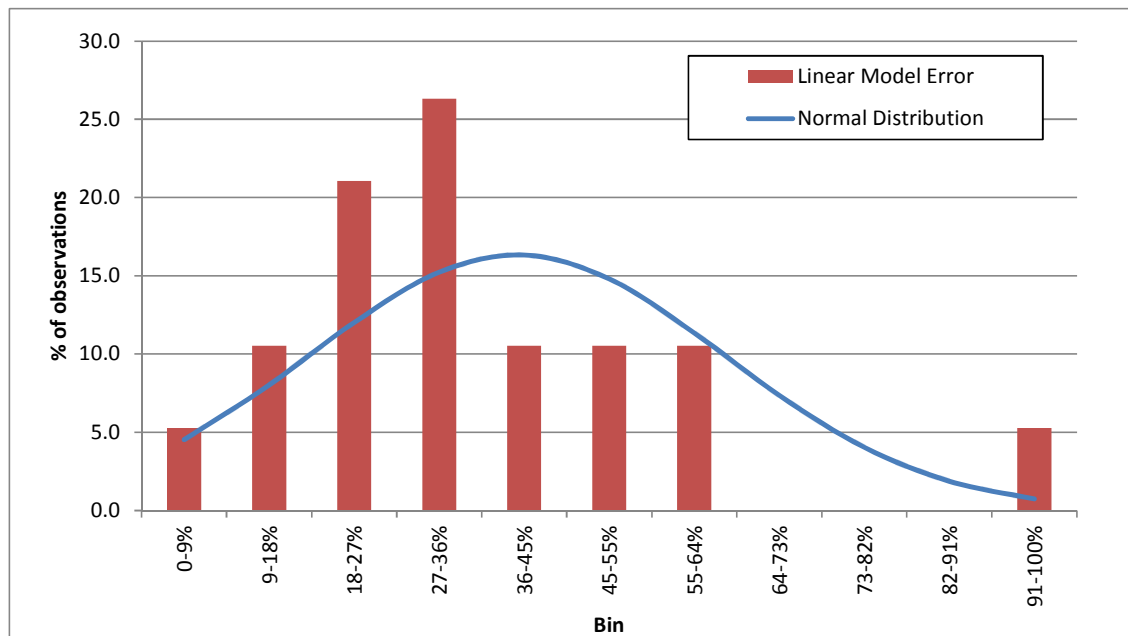


Figure 7-17 Check for Normality



Trend test	Period of analysis	Level of statistical significance	Trend magnitude
Monitoring bore RN 42230204			
Linear regression	20/2/1993 – 30/7/2012	Not statistically significant	0.03 m/year
Mann-Kendall		Not statistically significant	N/A
Seasonal Kendall		Not statistically significant	N/A

Table 7-5 Summary of trend analysis results for RN 42230204

7.3.7 Summary of analysis

The processing and analysis of data for monitoring bore RN 42230204 identified the following key points:

- A significant but temporary increase in groundwater levels was observed in response to the high rainfall and runoff of late 2010. This period of data was removed from the data analysis to eliminate the influence of this event.
- The remaining data for monitoring bore RN 42230204 displays an increase in groundwater levels of over 6.5 m over the period of observations.
- Several discrete periods of groundwater behaviour are evident. During the early 1990s, groundwater levels increased rapidly. Following this, groundwater levels have been more consistent, with fluctuations generally less than 1 m.
- Given the magnitude of the changes in groundwater level, barometric pressure and earth tides have very little influence on the hydrograph.
- Trends at this location were considered for the period since 1993. No statistically significant trend is evident in the data over this period.

7.4 Monitoring bore RN 13030613

7.4.1 Step 1: Collate available data

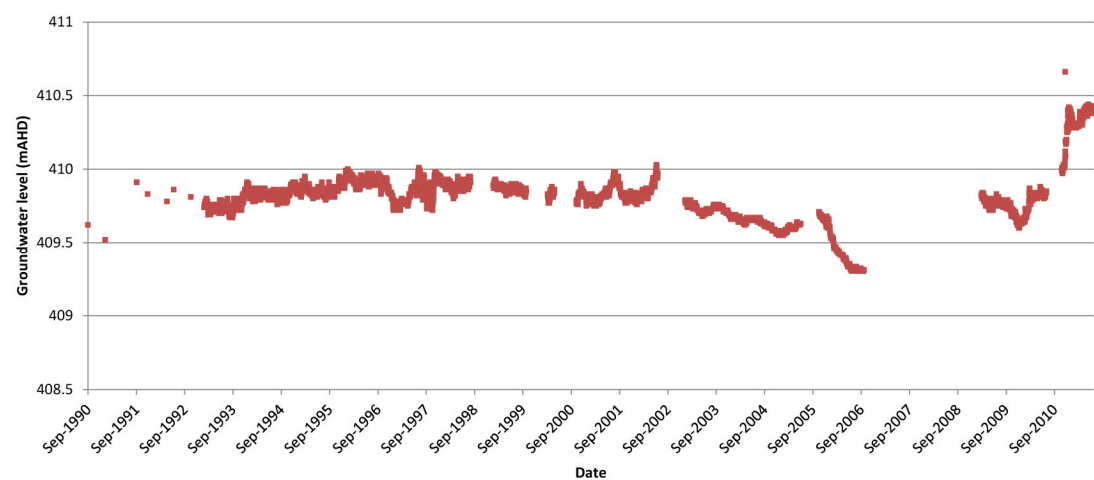
Monitoring bore site RN 13030613 is a DNRM monitoring bore located north of Injune (**Figure 3-1**). This bore is located approximately 120 km west north west of the QCLNG Northern Development Area. The bore monitors the Hutton Sandstone aquifer.

Water levels have been monitored at this location since 1990. Over the first few years, observations were made at very infrequent intervals, and these few points have been excluded from the analysis. Since February 1993, monitoring has generally been on a daily basis, with a few periods of exception. In general, these periods of limited data lasted a few months, however more than two years of data is missing between September 2006 and March 2009. **Figure 7-18** presents the groundwater level behaviour at this location and **Table 7-6** provides summary statistics for the site.

The data for this regional monitoring bore site indicates water levels have been generally consistent over the period of the available data, with the exception of two major fluctuations over the past decade. In particular, the groundwater levels appear to decline from about 2002, with relatively rapid declines during late 2005 and early 2006. This is postulated to be a result of the severe drought conditions (and the associated lack of recharge and increase in groundwater pumping) that affected much of the Great Artesian Basin over this time. In addition, an increase in groundwater levels is evident in the last six months of the record, which reflects the significant rainfall and flooding events that affected much of southern Queensland during late 2010 and early 2011. Other minor fluctuation periods are also evident in the data, such as the increasing groundwater level in the data up to 1998, and the change in the slope of the data between 1997 and 2007.

While there are significant periods of missing data in the raw groundwater level record, these were not infilled. Discussion of the break point analysis in Step 4 below provides an alternative approach to deal with the missing data at this location.

Figure 7-18 Groundwater levels at monitoring bore RN 13030613



Site: RN 13030613	
Data availability	
Start of monitoring	9/09/1990
Start of period used for analysis	3/2/1993
Most recent observation point	30/06/2011
Missing data	37%
Data characteristics	m AHD
Minimum	409.3
Maximum	410.7
Mean	409.8
Median	409.8

Table 7-6 Summary statistics for monitoring bore RN 13030613

7.4.2 Step 2: Account for barometric pressure and earth tides

Barometric pressure is not monitored at this bore location by DNRM. The closest Bureau of Meteorology weather station with barometric pressure data is located at Injune (site 043015), approximately 20 km from the bore site. However, the barometric pressure record at this location does not extend for the full period of bore monitoring. An additional barometric pressure site is located at Roma (043091), approximately 100 km away. Barometric pressure is monitored at high frequencies, with three-hourly data supplied by the Bureau for this analysis. Data was aggregated to a daily time step for the analysis presented in this document. Comparison of the two barometric pressure records is presented in **Figure 7-20**. While the magnitude of the barometric pressure differs at these two locations, the general behaviour is very consistent. **Figure 7-19** displays the relationship between the barometric pressure records at these two meteorological monitoring stations.

Figure 7-19 Barometric pressure recorded at Bureau of Meteorology sites 043015 (Injune) and 043091 (Roma)

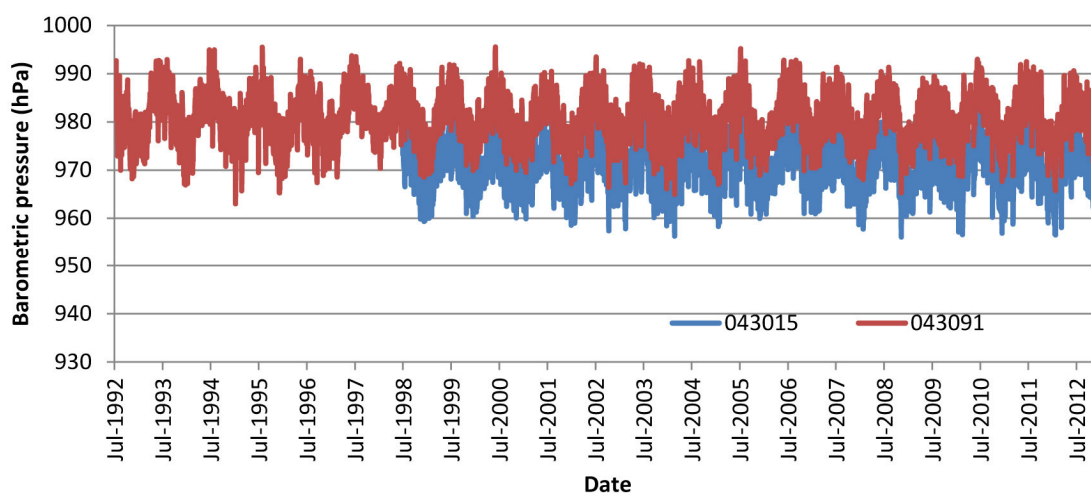
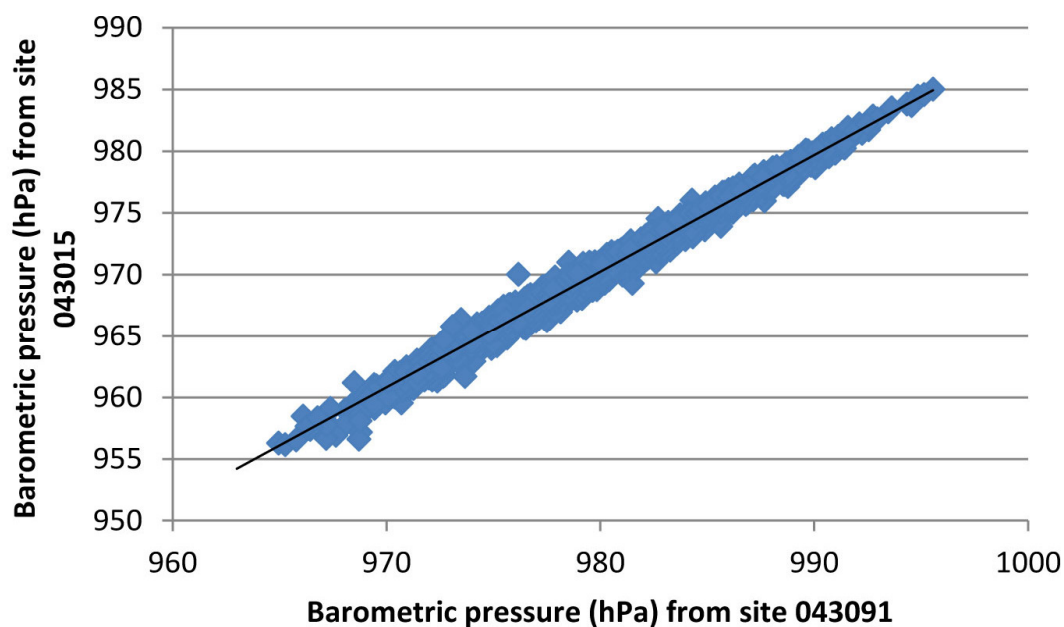
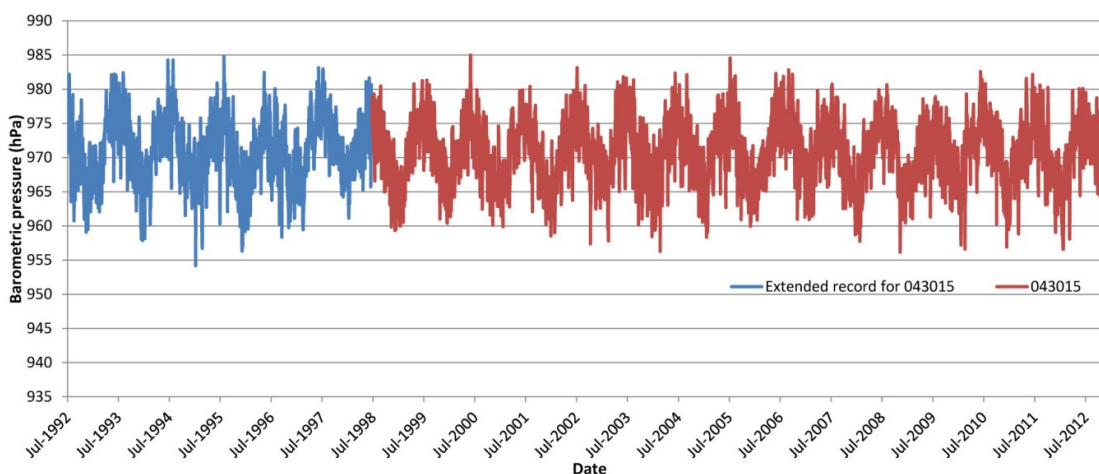


Figure 7-20 Comparison of barometric pressure recorded at Bureau of Meteorology sites 043015 (Injune) and 043091 (Roma)



Given the consistency in barometric pressure variations at these two locations, the relationship from **Figure 7-20** was used to extend the record for site 043015 to generate a long term barometric pressure data set over the period of bore monitoring. The outcomes from this data extension process are displayed in **Figure 7-21**.

Figure 7-21 Recorded and extended barometric pressure at Bureau of Meteorology site 043015 (Injune)



The groundwater level data was adjusted for barometric pressure and earth tides using the methods described previously. The synthetic earth tide output for this bore site is displayed in **Figure 7-22**. The corrected water levels that take into account the influence of barometric pressure and earth tides are shown in **Figure 7-23**. Given the variability observed in the groundwater levels, the influence of the barometric pressure and earth tides is small at this location. The magnitude of this smoothing was up to a maximum of 0.004 m.

Figure 7-22 Synthetic earth tide for monitoring bore RN 13030613

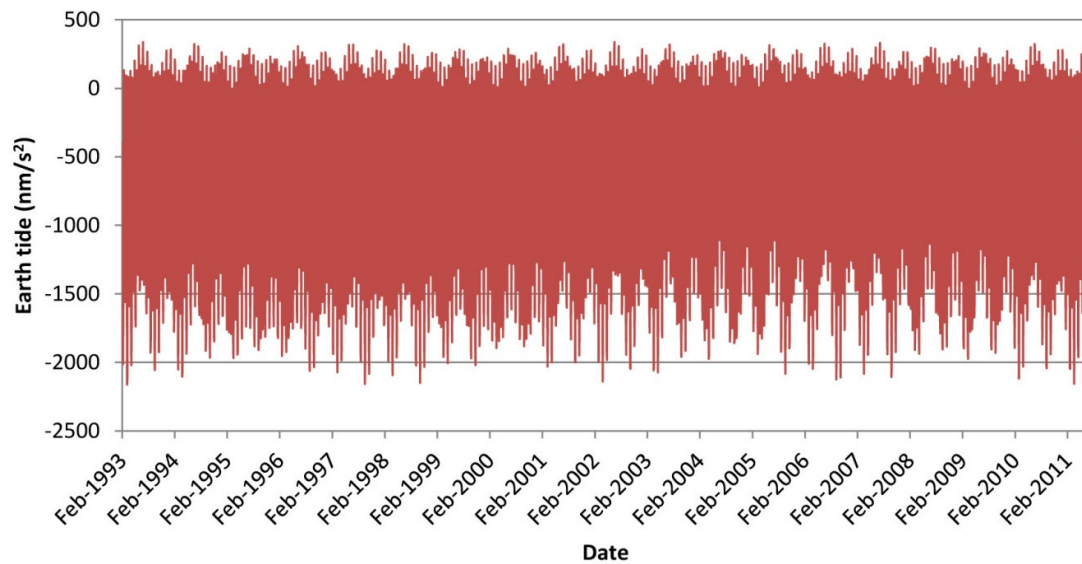
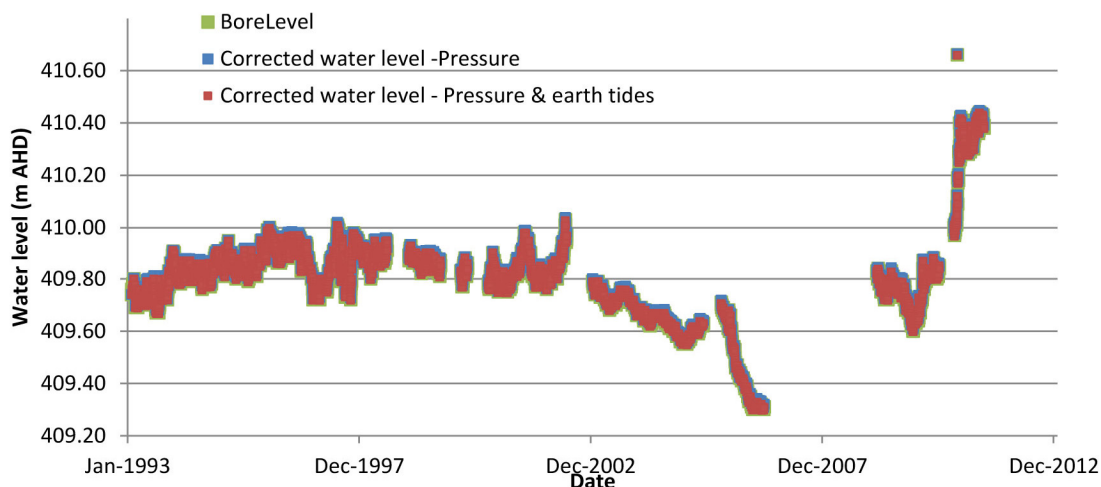


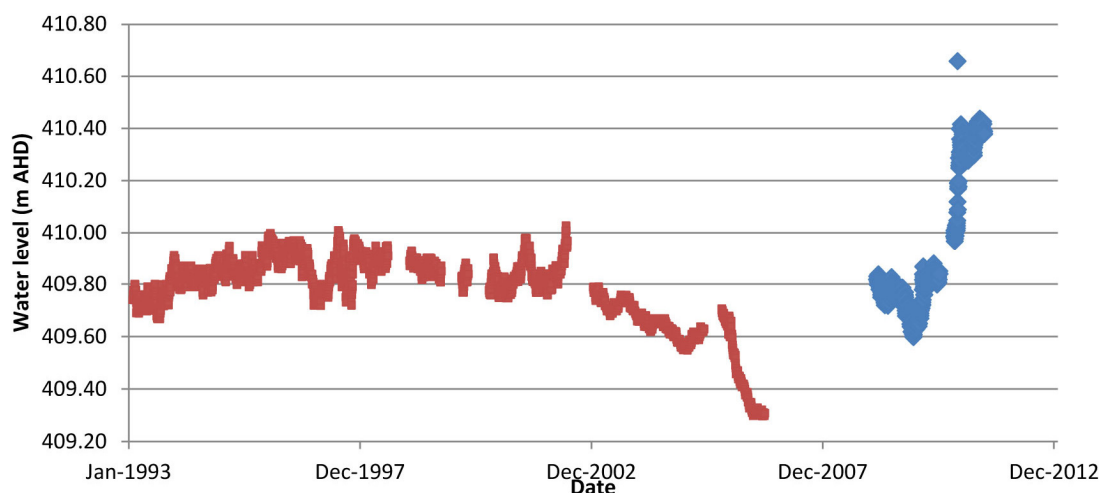
Figure 7-23 Groundwater levels, taking into account barometric pressure and earth tides

7.4.3 Step 3: Period analysis

Given the visual observations noted in the raw data relating to the fluctuations in the data at this location, a break point analysis was undertaken to determine whether statistically significant changes in the groundwater level data occur in the RN 13030613 data set.

The break point assessment identified that data collected earlier than 2006 generally has a mean value greater than the data collected more recently. It is relevant to recall that significant periods of missing data occur in the data set, with more than two years of data missing between 2006 and 2009. Hence, the break point analysis identified that data collected before the missing period was different to the data collected after the missing record. For ongoing analysis, the outcomes from the break point analysis have been applied around the missing data period and two discrete data sets have been used. Further break point analyses could identify shorter periods for analysis, however for the purposes of this example assessment, period 1 was assumed to be representative of baseline conditions.

Figure 7-24 Weekly time series of groundwater levels that are independent of barometric pressure and, earth tides.



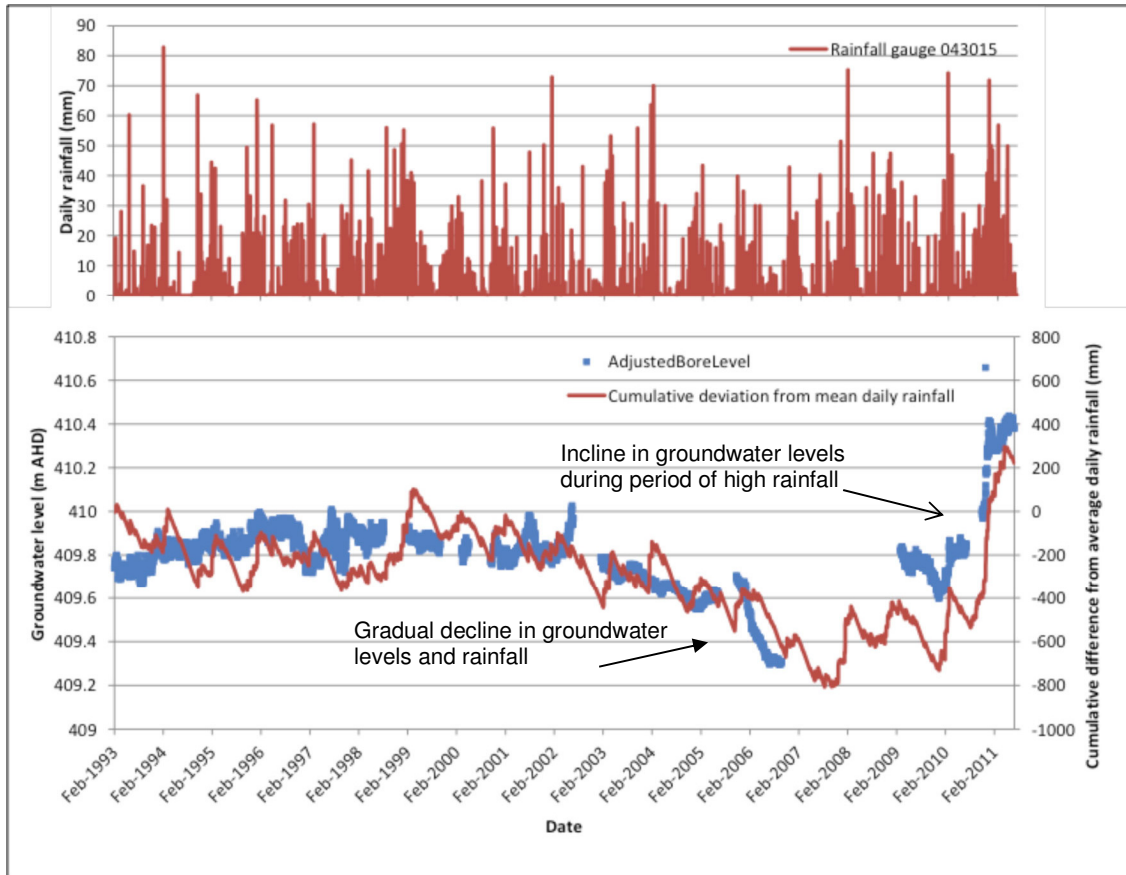
7.4.4 Step 4: Develop and apply multiple regression model

- g) a) Climate, loading and unloading impacts (including plot of groundwater level against cumulative deviation from mean rainfall conditions)

Bureau of Meteorology rainfall data from the vicinity of the bore was reviewed. This included a number of rainfall gauges from the region to observe the variability in rainfall across the region. At each location, the daily rainfall records were reviewed, and the cumulative deviation from the mean daily rainfall calculated. The general behaviour of this data was consistent for each of the four rainfall gauges investigated. Given this, rainfall gauge 043015 (Injune) was selected for more detailed investigations as it is located closest to the monitoring bore site of interest.

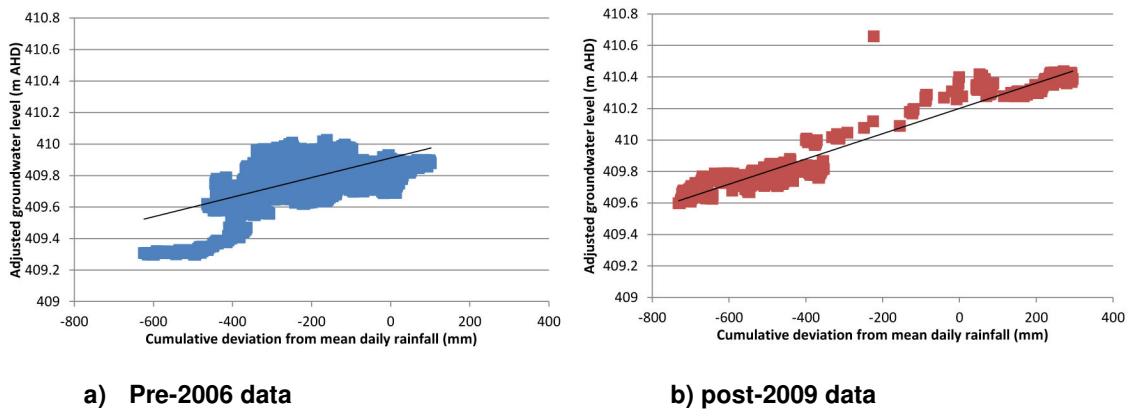
Figure 7-25 presents the daily rainfall, groundwater level (adjusted for barometric pressure and earth tides, using the outcomes from the steps above) and cumulative deviation from the mean daily rainfall. The comparison between the groundwater data and the cumulative rainfall indicates some general consistency in behaviour, with high and low values appearing to occur at similar times in both data sets. Of particular note, the period of groundwater decline from the early 2000s coincides with a period of declining rainfalls. The peak in groundwater level in late 2010 and early 2011 also coincides with a period of persistent rainfall.

Figure 7-25 Groundwater level at monitoring bore RN 13030613, daily rainfall and cumulative deviation from the mean daily rainfall at Injune (043015)



The groundwater data and cumulative rainfall data are directly compared in **Figure 7-26** for the two periods of assessment. While there is some scatter in this data, there is a general trend in the relationship with higher groundwater levels occurring at times of greater rainfall accumulation. **Figure 7-25** suggests that climate (in particular, rainfall) is able to explain some of the fluctuations in the bore level data.

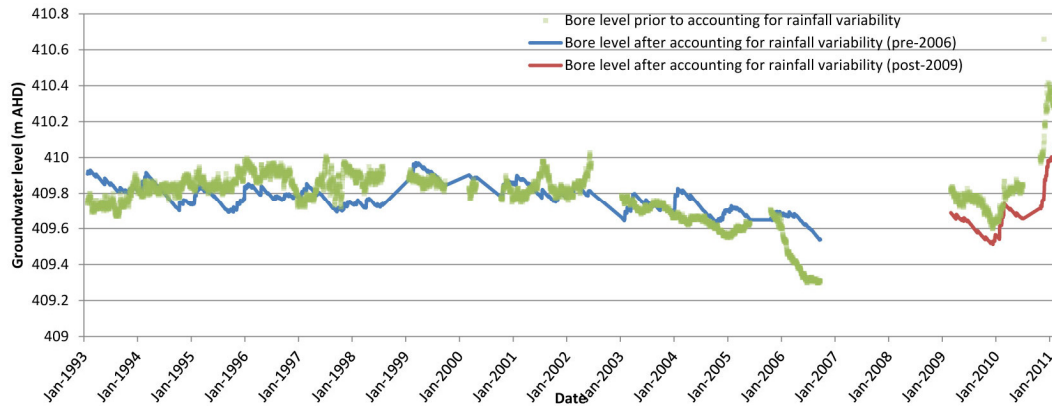
Figure 7-26 Comparison of adjusted groundwater level at monitoring bore RN 13030613 and cumulative deviation from the mean daily rainfall at Injune (043015)



A line of best fit was fitted through this data and used to represent the relationship between groundwater level and rainfall for the two periods of assessment. The regression relationships developed were used to estimate groundwater levels independent of rainfall variability. **Figure 7-28** presents the fitted (using regression relationships from **Figure 7-26a** and **Figure 7-26b**) and observed groundwater levels.

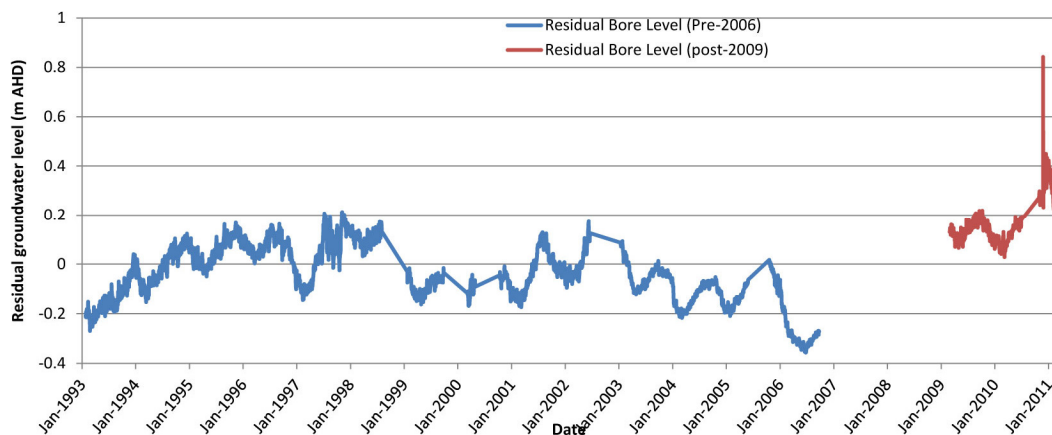
The fitted groundwater data (using regressions from **Figure 7-27**) shows a lesser decline in groundwater levels in the early and mid-2000s than the observed data, suggesting that rainfall only partially explains this decline in the groundwater levels. In addition, the prediction equations also confirm that an increase in groundwater levels is expected in late 2010 and early 2011 based on the persistent rainfall at the time. This is observed in the raw data, although to a greater degree than estimated using the regression.

Figure 7-27 Comparison of predicted and observed groundwater levels, accounting for rainfall influences



The difference between the observed and predicted groundwater data represents the groundwater level variability that is independent of the rainfall. This is calculated as a simple subtraction between the two data sets at each time step, and is shown in **Figure 7-27**. This data set now represents the groundwater level variability that excludes influences from barometric pressure, earth tides and climate. Based on a visual assessment, this data set displays clear variability over time, however no longer appears to have as strong a decline in the early and mid-2000s as the raw data. The influence of high rainfall and associated runoff events in late 2010 is still evident, although also to a lesser degree than in the raw data.

Figure 7-28 Residual groundwater levels that are independent of barometric pressure, earth tides and rainfall influences



h) Local and regional groundwater influences

Local and regional groundwater influences have not been assessed but would need to be considered as a part of hydrogeological assessment and interpretation of hydrograph response.

7.4.5 Step 5: Weighted mean drawdown over a representative period

The groundwater level time series generated at the completion of Step 4 (through the development of a regression model to account for external processes) was tested for serial correlation. A high serial correlation was noted in the data at the original frequency of observations and the following steps were taken to minimise this:

- Daily and weekly time steps were considered during preliminary analysis of the data to determine the representative period for the calculation of the weighted mean drawdown at this location. Based on a review of the serial correlation for these reprocessed data sets, the weekly data was determined to be most appropriate for the analysis of trends.
- Application of the pre-whitening approach to remove the effects of autocorrelation in the weighted mean drawdown time series.

This process was able to appropriately account for the serial correlation in the early period of the data. Unfortunately it did not fully reduce the serial correlation in the second period of data to within the recommended limits to maintain the statistical assumptions for the trend analysis tests, so the results presented below must be interpreted in light of this limitation. Alternative data frequencies were assessed with no improvement in the serial correlation.

7.4.6 Step 6: Trend analysis

The outcomes from the step above were used as input into the trend analysis step, utilising the Water Quality Analyser software to undertake the assessment.

Figure 7-29 and **Table 7-7** presents the trends identified at monitoring bore RN 13030613, once the raw groundwater level data has been reviewed, processed to an appropriate representative period and other external influences accounted for. The linear trend assessment indicates the change in groundwater residuals ranges between -1 cm/year (in period 1) and 9 cm/year (in period 2). The histogram of linear regression model errors in **Figure 7-30** and **Figure 7-31** approximates a normal distribution, indicating that the assumption of normality for the linear regression is not violated. The analysis indicates that there is a statistically significant trend in the data for Period 1, however the result for Period 2 is invalidated by the high degree of serial correlation in this data record.

The first period of record indicates a slight downward trend over time, and the second period indicates a greater increase in a relatively short period of time. **Figure 7-29** indicates that external processes other than those captured in the analysis above may be influencing groundwater levels. For instance, the decline observed in the first period may be a result of increased groundwater pumping for irrigation and stock during the millennium drought. Alternatively, land use changes in the region may have occurred, with different crops and vegetation types extracting groundwater at different rates. While the impact of extreme rainfall and runoff events in late 2010 were partially explained in this analysis, the further

increase in groundwater in Period 2 suggests that there may also be other related processes to consider.

These processes may be better captured with additional data for incorporation into the analysis. This may include pumping data from local and regional irrigation bores, groundwater level data for the overlying unconfined aquifer system to estimate loading and unloading influences, and other relevant processes.

The Seasonal Kendall test has not been applied to the second period of data as it requires the time series to include multiple data points across all seasons for calculation. The missing period of record in the middle of this data prevents this.

Figure 7-29 Trend in groundwater residuals at monitoring bore RN 13030613 after accounting for barometric pressure, earth tide and climate

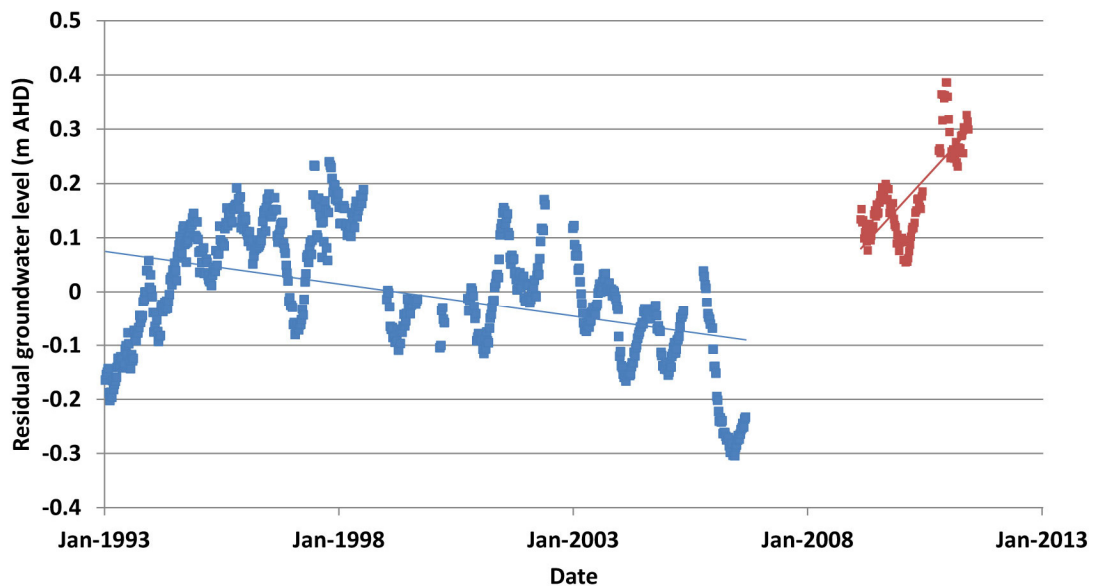


Figure 7-30 Check for Normality (pre-2006)

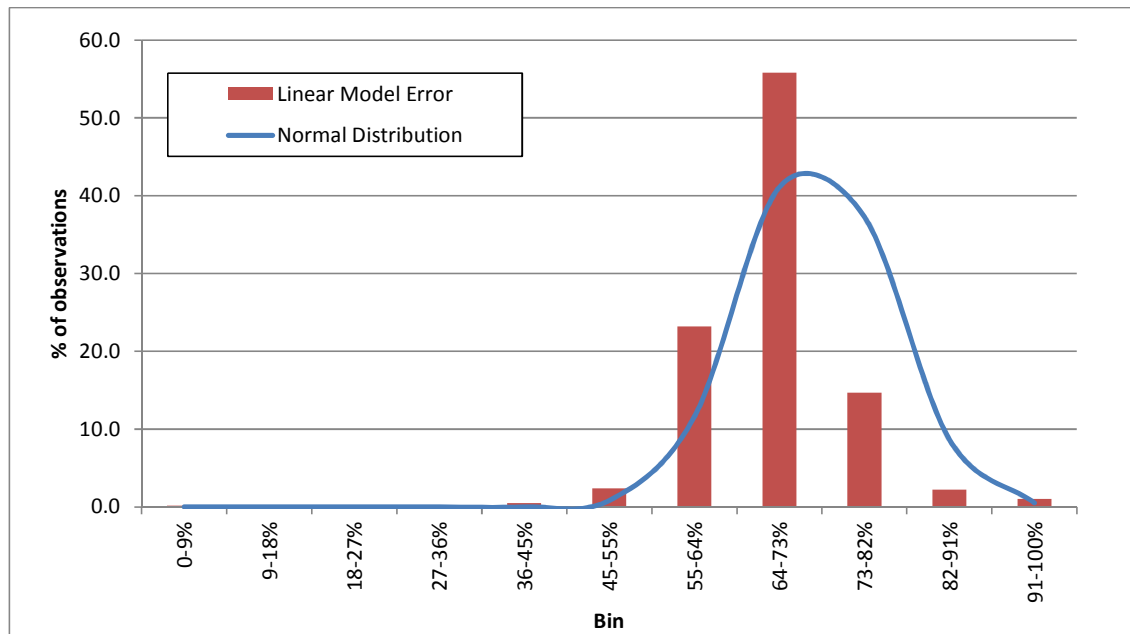
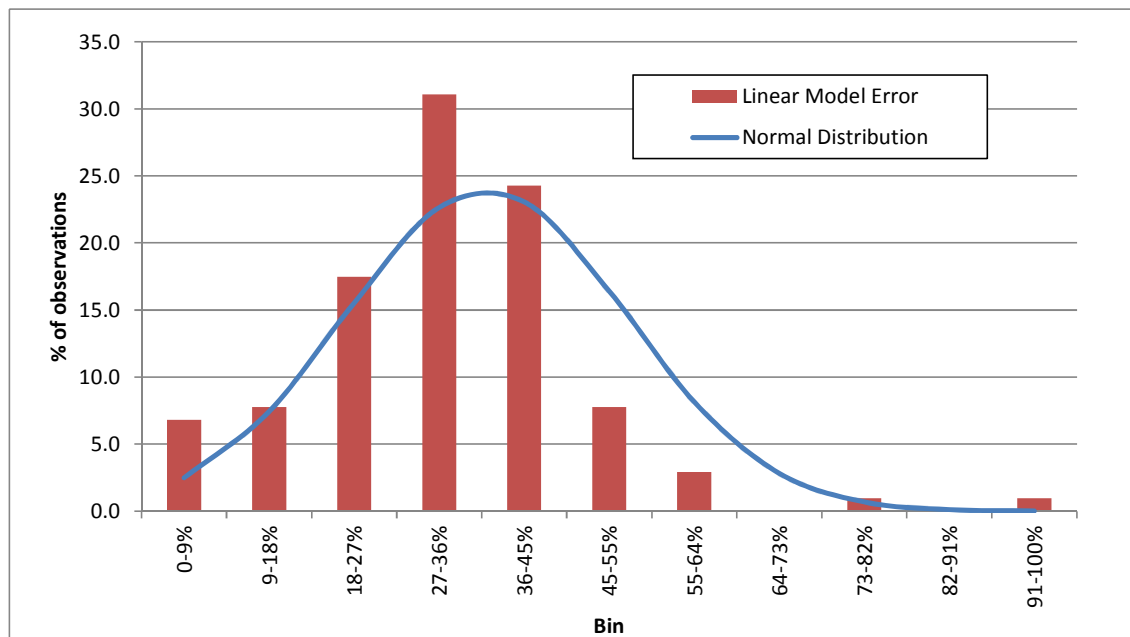


Figure 7-31 Check for Normality (post-2009)



Trend test	Period of analysis	Level of statistical significance	Trend magnitude
Period 1			
Linear regression	31/1/1993 – 24/9/2006	5%	-0.01 m/year
Mann-Kendall		5%	N/A
Seasonal Kendall		5%	N/A
Period 2			
Linear regression	8/3/2009 – 26/6/2011	Not statistically significant *	0.09 m/year
Mann-Kendall		Not statistically significant *	N/A
Seasonal Kendall		N/A	N/A

*high serial correlation in trend invalidates statistical significance at the current time

Table 7-7 Summary of trend analysis results for monitoring bore RN 13030613

7.4.7 Summary of analysis

The processing and analysis of data for monitoring bore RN 13030613 identified the following key points:

- Significant periods of missing data occur at this bore; however the break point analysis was able to be applied to deal with the missing data.
- Groundwater levels only fluctuated by ± 0.2 m over a period of approximately 9.5 years from 1993 to mid-2002.
- Two sizable fluctuations in groundwater level are evident in the data. A decline in groundwater levels from 2002 is likely to be the result of dry conditions (and associated limited recharge and increase in pumping), while an increase in level is evident during the time of high rainfall and run-off events in southern Queensland.
- Given the magnitude of the changes in groundwater level, barometric pressure and earth tides have very little influence on the hydrograph.
- Trends at this location were considered for two discrete periods. The first period, from 1993-2006, indicates a statistically significant decline in groundwater levels using all three trend tests. The second period, from 2009-2011, indicates an increasing trend. However, the result for period 2 is invalidated by the high degree of serial correlation in this data record.

7.5 Monitoring bore RN10925

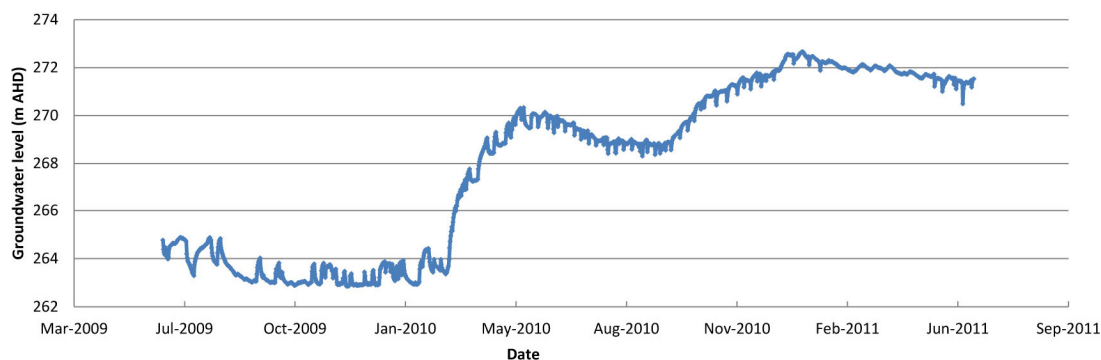
7.5.1 Step 1: Collate available data

Monitoring bore RN10925 (Rockwood Old House) (**Figure 3-1**) is owned by APLNG (Origin) and monitors groundwater levels in the Gubberamunda Sandstone proximal to APLNG and QGC gasfields. It is located in the vicinity of the QGC Berwyndale South and Lauren monitoring bore sites. Water levels have been monitored at this location using a data logger since June 2009 with observations made twice per day.

Figure 7-32 presents the raw data collected at this location since monitoring commenced. Visual assessment of the groundwater level hydrograph indicates that the groundwater levels were relatively constant for the first few months of observations, but rapidly increased by mid-2010. Observations since then have steadily increased in a cyclical manner.

Table 7-8 provides a summary of key statistics for this data set.

Figure 7-32 Raw groundwater levels at monitoring bore RN 10925



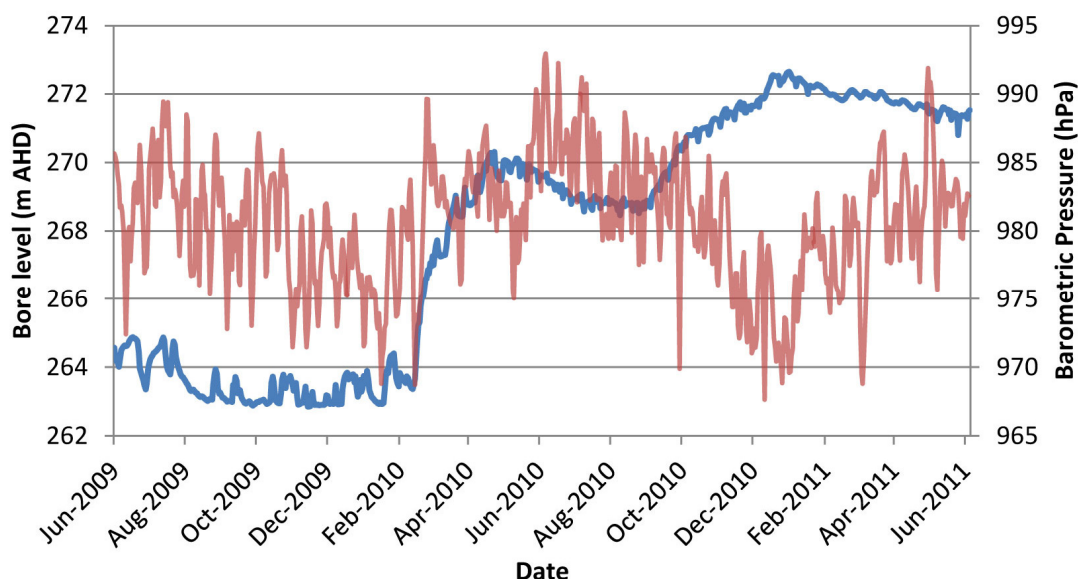
Site: RN 10925	
Data availability	
Start of monitoring	16/6/2009
Most recent observation point	20/6/2011
Missing data	0%
Data characteristics	m AHD
Minimum	262.8
Maximum	272.7
Mean	268.0
Median	268.9

Table 7-8 Summary statistics for monitoring bore RN 10925

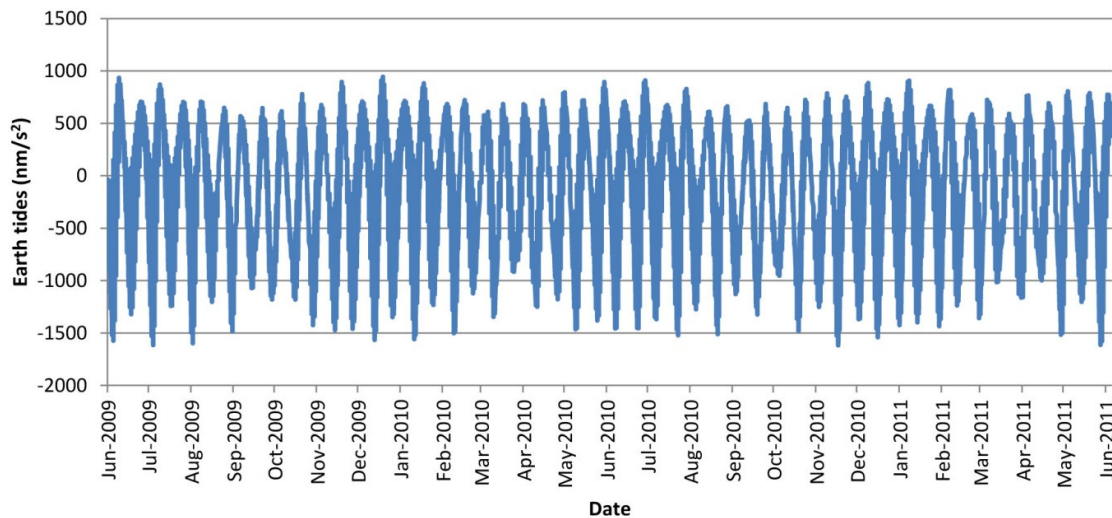
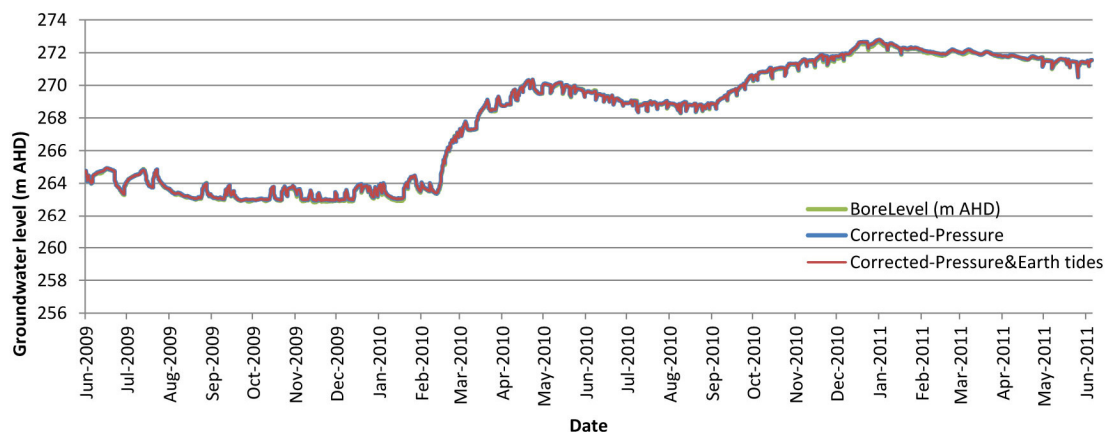
7.5.2 Step 2: Account for barometric pressure and earth tides

Barometric pressure is collected at the nearby Talinga barometer, however this data only commenced in April 2011, and as such is not available for comparison over the full period of the record. Instead, barometric pressure was sourced from the Bureau of Meteorology. Weather station 042112 (Miles Constance Street) provides data over a concurrent period with the groundwater level data. This weather station is located approximately 30 km from the bore. Barometric pressure is monitored at high frequencies, with three-hourly data supplied by the Bureau for this analysis.

Figure 7-33 Barometric pressure recorded at Bureau of Meteorology site 042112 (Miles Constance Street) and comparison with the groundwater level data at monitoring bore RN 10925



The groundwater level data was adjusted for barometric pressure and earth tides by the methods previously described. The synthetic earth tide output for this bore site is displayed in **Figure 7-33**. The corrected water levels that take into account the influence of barometric pressure and earth tides are shown in **Figure 7-35**. The magnitude of this smoothing for this site was up to a maximum of 0.39 m.

Figure 7-34 Synthetic earth tide for bore site RN 10925**Figure 7-35 Groundwater levels at RN 10925, taking into account barometric pressure and earth tides**

7.5.3 Step 3: Period of analysis

Given the visual observations noted in the raw data relating to the obvious changes in groundwater level that have occurred at this location, a break point analysis was undertaken to determine whether the changes are statistically significant and warrant analysis of subsets of the original data record.

A number of tests were undertaken to isolate periods of data considered representative of the conditions at the time. In particular, this identified that data collected after March 2010 has a mean value greater than the period prior to March 2010. However, the break point

assessment must also take into account the practical relevance of the outcomes. This should be interpreted based on the length of record and visual assessment of the data set. It is suggested that at least one year of weekly data is required for the subsequent trend analysis steps, which provides a minimum threshold when considering the outcomes from break point analysis. In this instance, the period of record before March 2010 captures only nine months and is not considered long enough for analysis in isolation. The data collected after March 2010 covers more than 12 months of weekly data and is suitable for analysis. However, it is considered most appropriate to examine the full period of record for the trend analysis at this location. As such, the results from both analyses will be reported for comparison and interpretation.

7.5.4 Step 4: Develop and apply multiple regression model

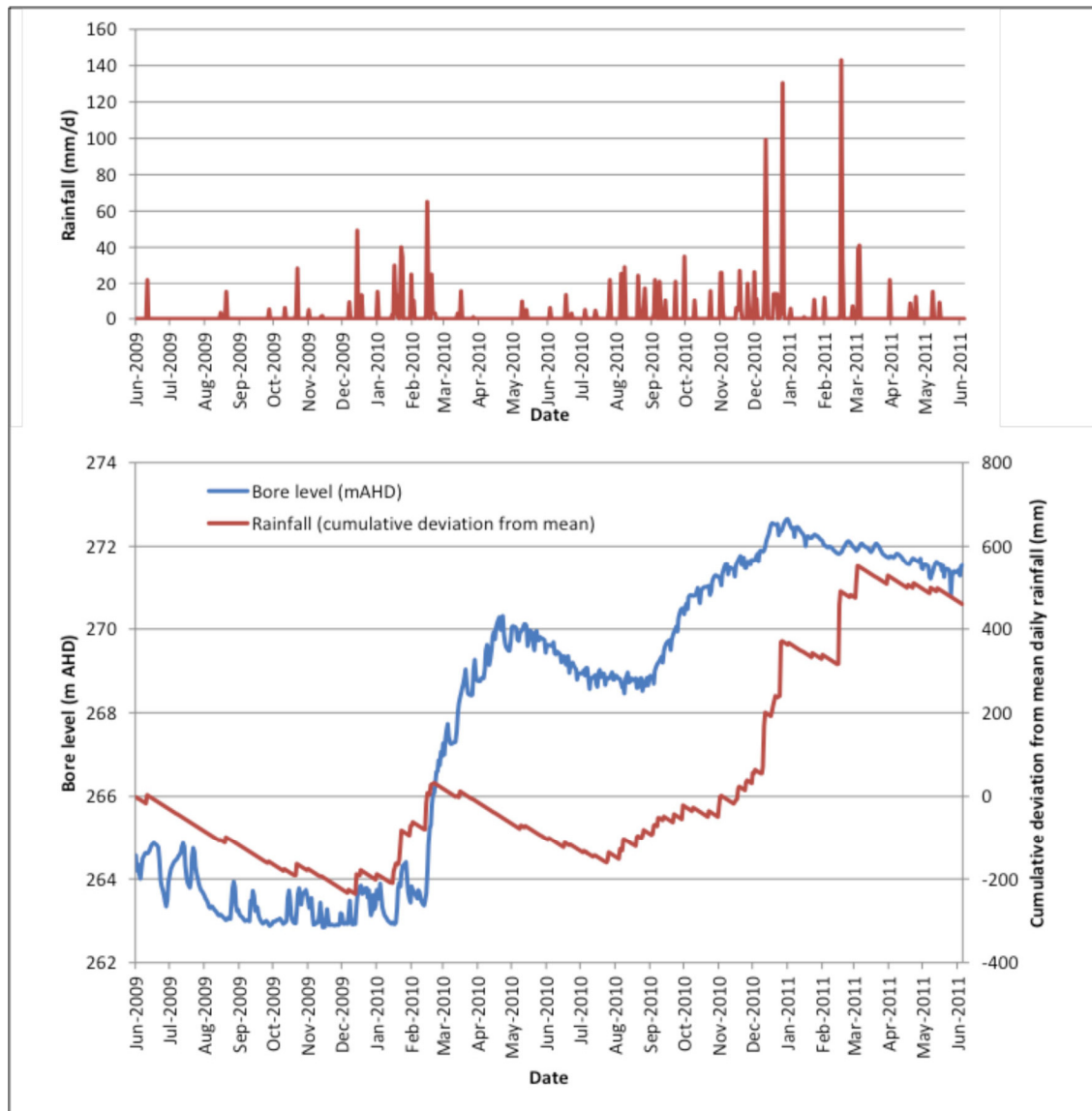
- i) Climate, loading and unloading impacts (including plot of groundwater level against cumulative deviation from mean rainfall conditions)

Bureau of Meteorology rainfall data from the vicinity of the bore was reviewed. This included a number of rainfall gauges from the region to observe the variability in rainfall across the region. The rainfall gauge 042078 (Harewood) was selected for more detailed investigations as it is located closest to this bore site.

Figure 7-36 presents the daily rainfall, groundwater level (adjusted for barometric pressure and earth tides, using the outcomes from the steps above) and cumulative deviation from the mean daily rainfall. The comparison between the groundwater data and the cumulative rainfall indicates periods with consistent behaviour between the rainfall and groundwater level.

Groundwater level rises have occurred in response to rainfall between December 2009 and March 2010 and between August 2010 and January 2011. Groundwater levels did not show a significant response to rainfall in February and March 2012 suggesting that no recharge occurred from the latter event.

Figure 7-36 Groundwater level at monitoring bore RN 10925, daily rainfall and cumulative deviation from the mean daily rainfall at Harewood (042078)



The rainfall and groundwater level data was compared in more detail in an attempt to check for a direct relationship, however no relationship was identified (**Figure 7-37**). This comparison also investigated the possibility of a lag between the rainfall data and any direct response in the groundwater level data, which suggested that a two month lag in groundwater response after rainfall events, however the relationship was still not consistent over different periods of record (**Figure 7-36**). The data was further split into four separate periods (**Figure 7-37**), excluding the period after January 2011 where a groundwater level response to rainfall was already visually known to not be evident. It can be seen in this figure that two periods (March to August 2010 and August 2010 to January 2011) displayed a strong relationship between cumulative rainfall and groundwater level response, but the other two periods did not.

Figure 7-37 Comparison of raw rainfall data at Harewood (042078) and groundwater levels at monitoring bore site RN 10925, all data

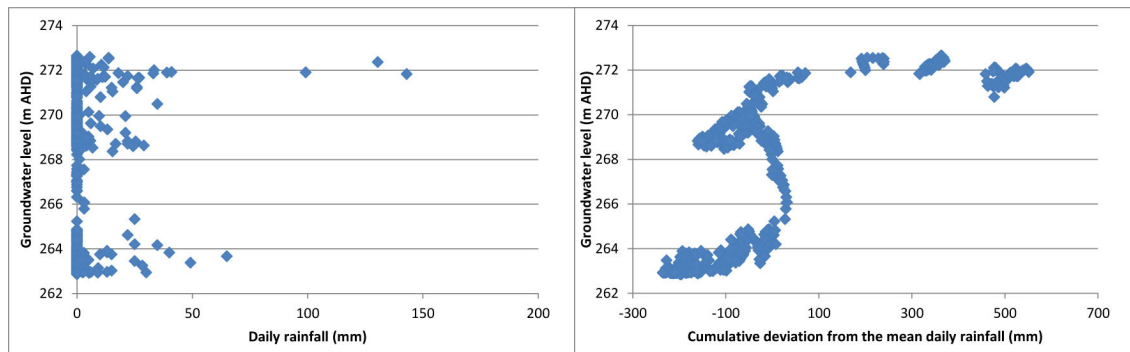


Figure 7-38 Rainfall at Harewood (042078) lagged by two months and groundwater levels at monitoring bore site RN 10925, all data

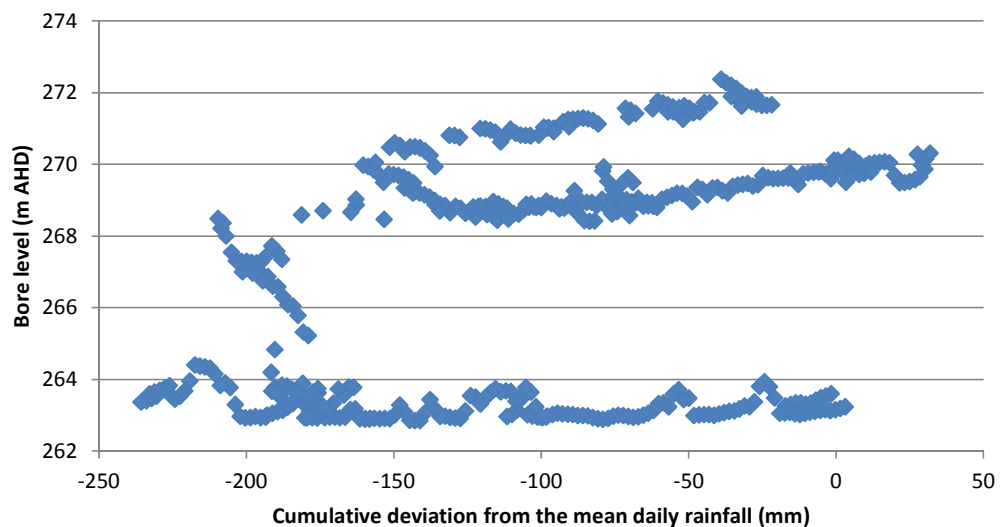
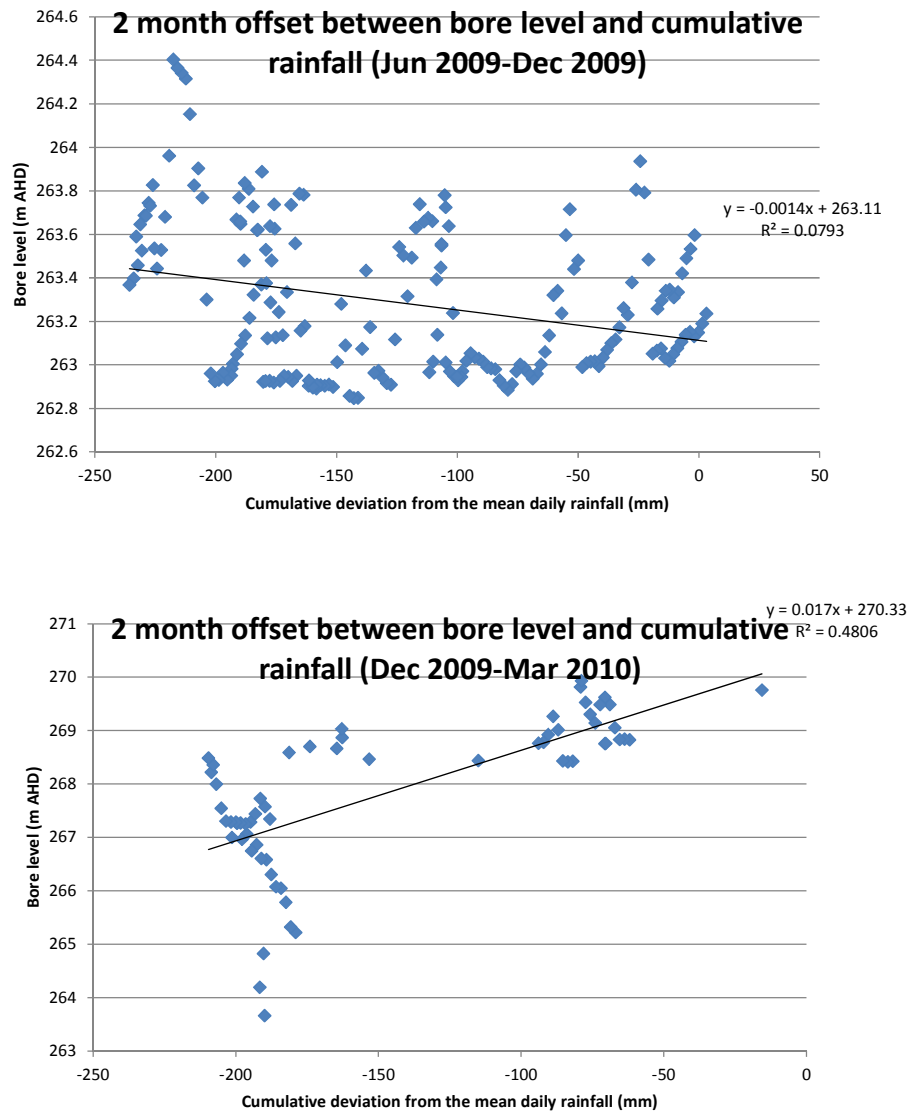
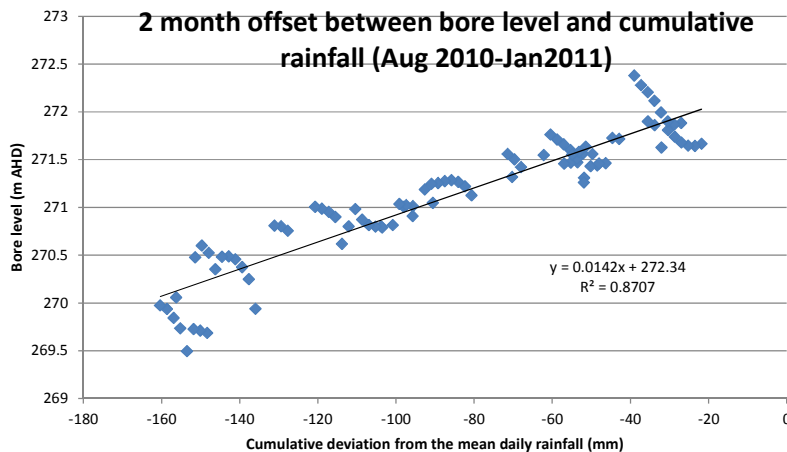
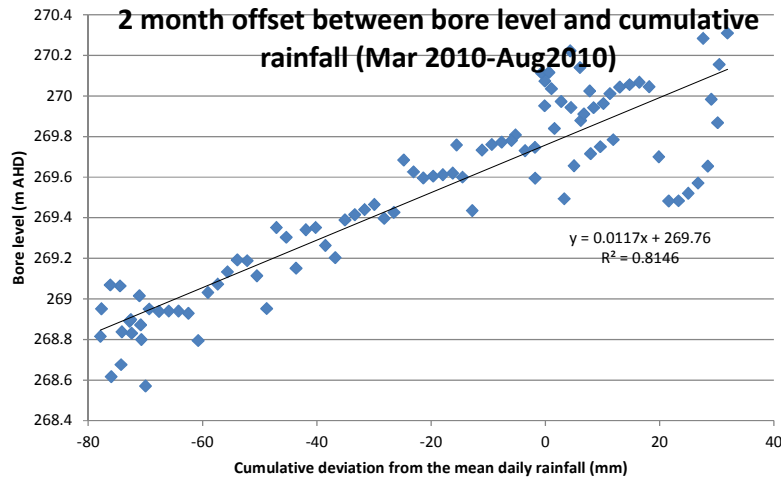


Figure 7-39 Rainfall at Harewood (042078) lagged by two months and groundwater levels at monitoring bore site RN 10925, split into four periods





This information was used to adjust the groundwater level data to remove the influence of rainfall over the period March 2010 to January 2011. This was achieved by estimating the groundwater level based on the input rainfall data as follows:

From August 2009 to February 2010 and from February 2011 onwards:

- Estimated groundwater level = Raw groundwater level

From March 2010 to July 2010:

- Estimated groundwater level = $0.0117 \cdot R_{t-2} + 269.76$

From August 2010 to January 2011:

- Estimated groundwater level = $0.0142 \cdot R_{t-2} + 272.34$

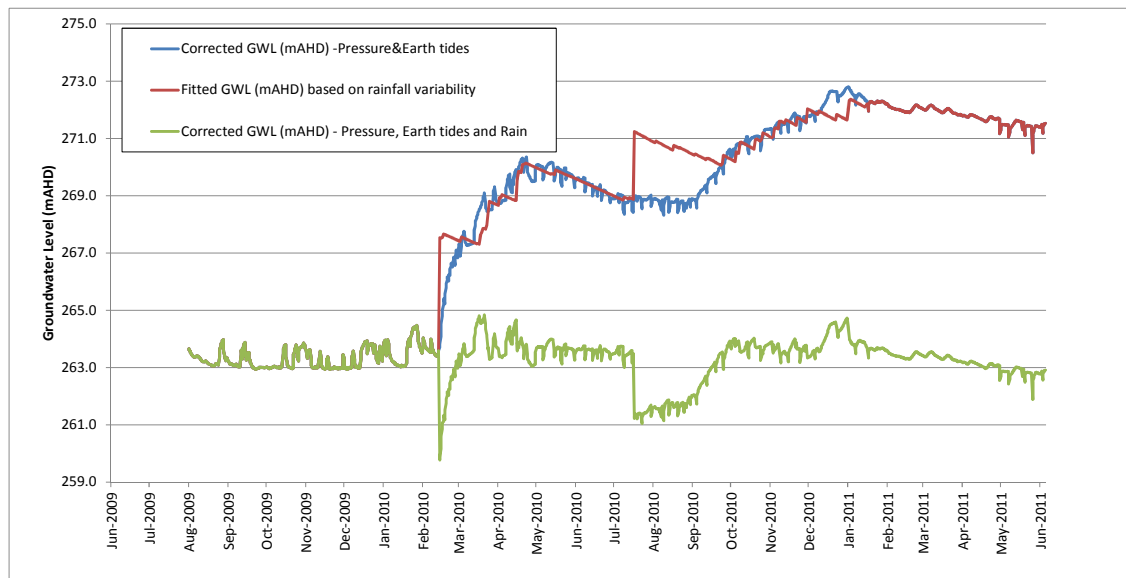
Where R_{t-2} is the cumulative deviation from mean rainfall conditions two months prior to the groundwater level observation. The rain corrected groundwater level was then estimated as

the raw groundwater level (corrected for pressure and earth tides only) plus the residual groundwater level which was unexplained by rainfall variability:

- $(\text{Rain corrected groundwater level})_{t=i} = (\text{Raw groundwater level})_{t=0} + (\text{Fitted groundwater level})_{t=i} - (\text{Raw groundwater level})_{t=i}$

Where $t=i$ is the current time step and $t=0$ is the first time step of analysis.

Figure 7-40 Rain corrected groundwater level



j) Local and regional groundwater influences

Local and regional groundwater influences have not been assessed but would need to be considered as a part of hydrogeological assessment and interpretation of hydrograph response.

7.5.5 Step 5: Weighted mean drawdown over a representative period

The groundwater level time series generated at the completion of Step 4 was tested for serial correlation. A high serial correlation was noted in the data at the original frequency of observations, and the follow steps were taken to minimise this:

- Twice daily, daily, and weekly time steps were considered during preliminary analysis of the data to determine the representative period for the calculation of the weighted mean drawdown at this site. Based on a review of the serial correlation for these data sets, the weekly data was determined to be most appropriate for the analysis of trends; and
- Application of the pre-whitening approach to remove the effects of autocorrelation in the weighted mean drawdown time series.

This process was able to fully account for the serial correlation in the data at this bore location.

7.5.6 Step 6: Trend analysis

The outcomes from the step above were used as input into the trend analysis step, utilising the Water Quality Analyser software to undertake the assessment.

Error! Reference source not found. and **Table 7-9** presents the trends identified at monitoring bore site RN 10925, once the raw groundwater level data has been reviewed, processed to an appropriate representative period and other external influences (barometric pressure, earth tides and rainfall) removed from the data set. The analysis indicates that there is no residual trend evident in the data once the estimated influences on groundwater level fluctuations of barometric pressure, earth tides and rainfall have been removed. The analysis indicates that there is no trend evident in the data. The histogram of linear regression model errors in **Figure 7-42** is heavily left skewed with isolated periods of large negative errors where the groundwater level response from rainfall is over-estimated. Given this behaviour, non-parametric tests for trend are likely to be more reliable for estimating the statistical significance of the trend.

The linear regression, Mann-Kendall and Seasonal Kendall tests indicated no evidence for a trend after rainfall influences have been removed.

APLNG has advised that the bore has not been used for some time. A nearby bore had been used for stock and construction water supply purposes, but its usage ceased approximately 1 year prior to the start of the water level record.

Figure 7-41 Trend in groundwater level at monitoring bore RN 10925 after removal of estimated influences of barometric pressure, earth tides and rainfall on groundwater levels

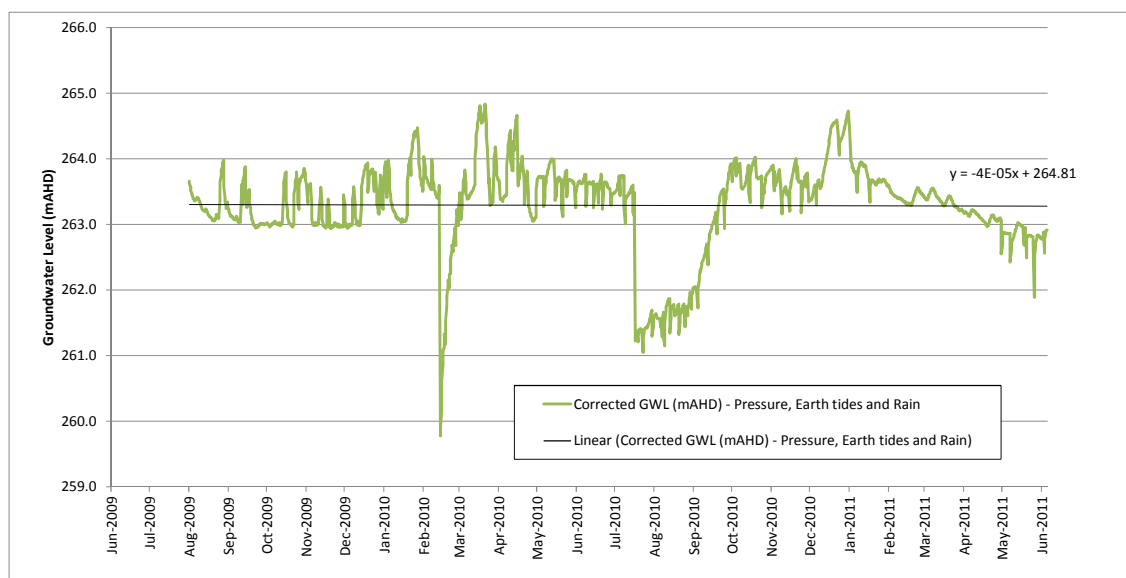
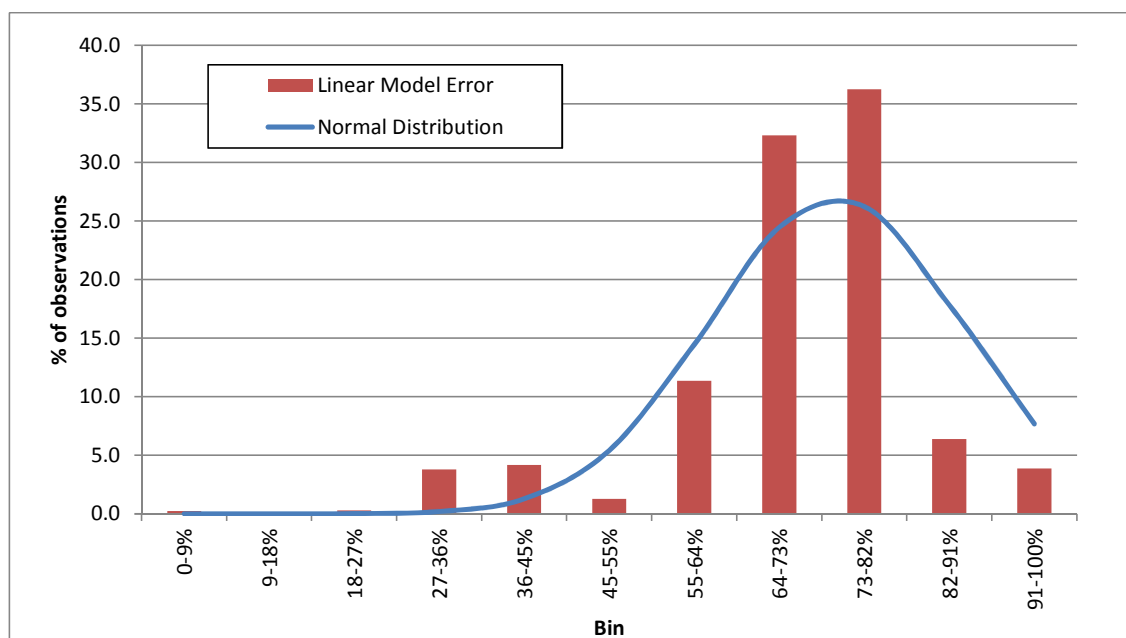


Figure 7-42 Check for Normality



Trend test	Period of analysis	Level of statistical significance	Trend magnitude
Full period			
Linear regression	16/6/2009 – 14/6/2011	Not statistically significant	0.0 m/year
Mann-Kendall		Not statistically significant	N/A
Seasonal Kendall		Not statistically significant	N/A

Table 7-9 Summary of trend analysis results for monitoring bore RN 10925

7.5.7 Summary of analysis

The processing and analysis of data for monitoring bore RN 19025 identified the following key points:

- Groundwater level fluctuations of almost 10 m have been observed at this bore location over the past two years.
- Groundwater level rises have occurred in response to high rainfall between December 2009 and March 2010, and between August 2010 and January 2011. Groundwater levels did not show a significant response to rainfall in February to March 2012 suggesting that no recharge occurred from the latter event.
- Given the magnitude of the changes in groundwater level, barometric pressure and earth tides have very little influence on the hydrograph, but rainfall had a significant influence.
- After accounting for the influence of rainfall, no statistically significant trend was evident in the groundwater level data.

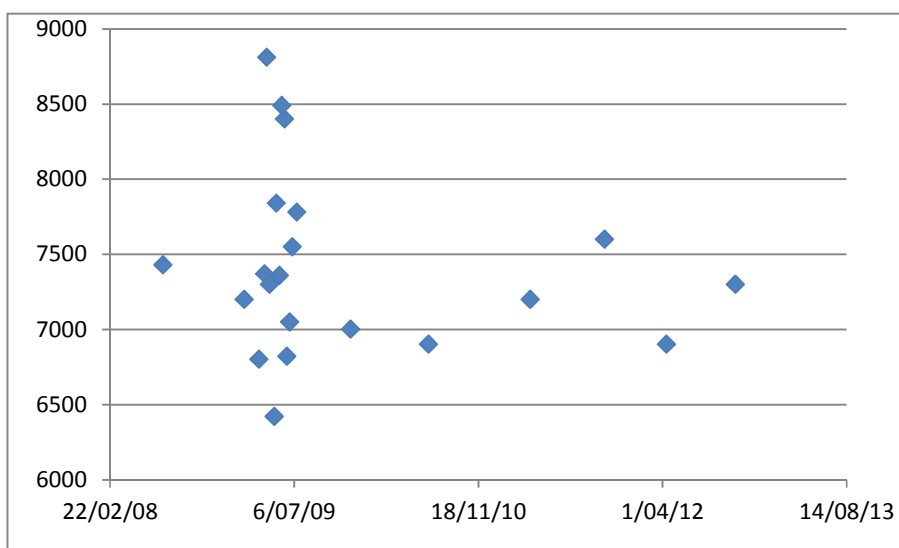
7.6 Groundwater quality trend analysis application

In the early stages of data collection, groundwater quality observations will be limited, which prevents the use of a formal trend analysis approach to assess the data. Instead, the groundwater quality data will be plotted to visualise general behaviour characteristics. A line of best fit will be applied to identify the nature of any changes over time; however it must be interpreted with care in light of the data limitations. Observations will be qualitative and general in nature, until at least five years of record are available. Preliminary data analysis has been undertaken for gas well BEL_WH003, which has just over four years of data collected to date.

7.6.1 Monitoring bore BEL-WH003

Electrical conductivity (EC) data has been collected at well BEL-WH003 since 2008. Over this time, the frequency of data collection has been inconsistent, ranging from one week to nine months. The most frequent data was collected during a pilot test for three months in 2009 (**Figure 7-43**).

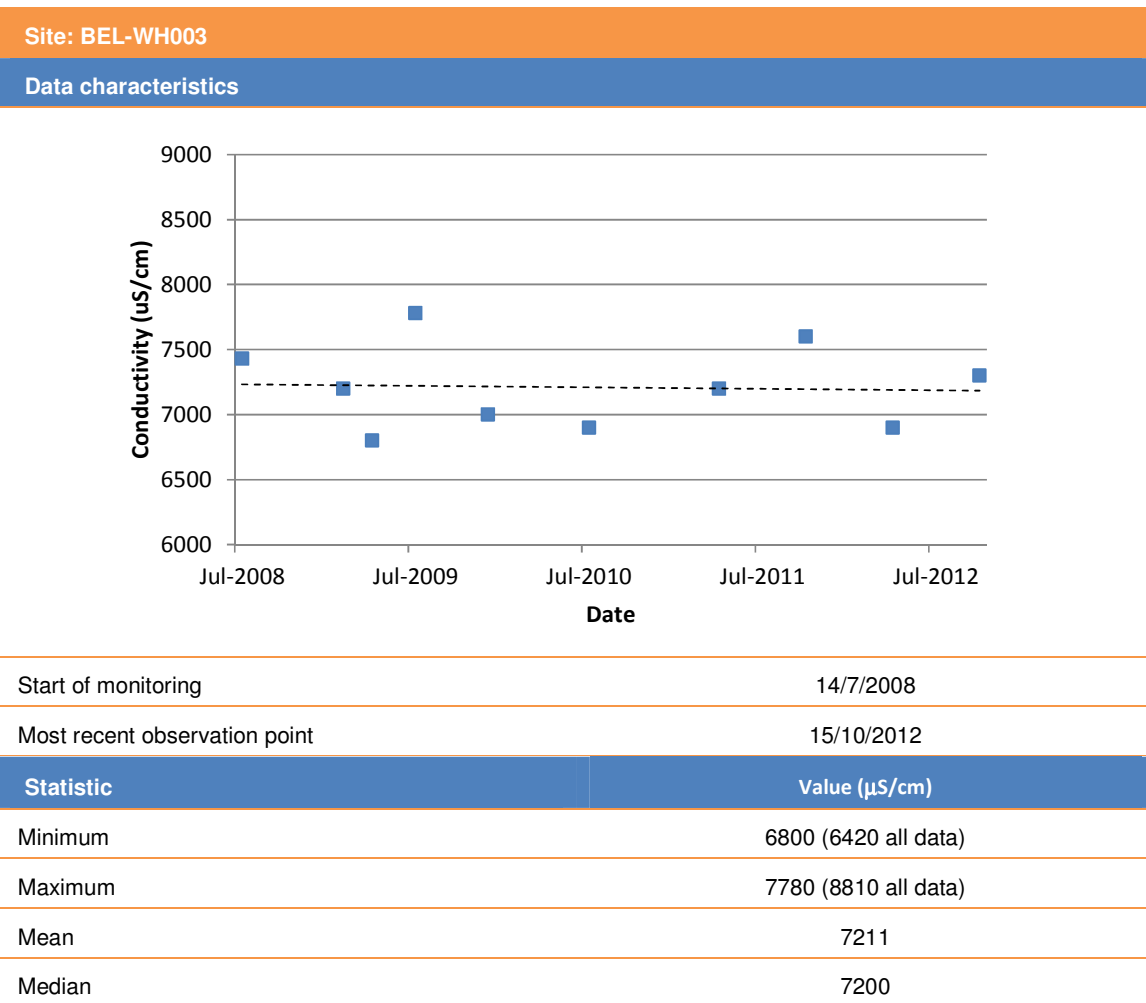
Figure 7-43 Groundwater electrical conductivity at monitoring bore BEL-WH003



The data indicates a range of EC readings between 6,420 and 8,810 $\mu\text{S}/\text{cm}$. The data during this period has been excluded from the analysis presented below.

The remaining data has a collection frequency of approximately five months. This EC data is presented in **Figure 7-44** and summary statistics for this site are presented in **Table 7-10**. Observations of EC (adjusted data set) at this location have ranged from 6800 $\mu\text{S}/\text{cm}$ to 7,780 $\mu\text{S}/\text{cm}$, indicating the relative large range in variability in groundwater EC levels. The mean and median values of the data set are very similar, indicating that the data is not greatly skewed and there are no extreme values in the data set.

Data collected to date indicates no serial correlation between observations. No obvious trend is visually evident in the data, suggesting that there is currently no apparent change in groundwater EC levels over time.

Figure 7-44 Adjusted groundwater electrical conductivity at monitoring bore BEL-WH003**Table 7-10 Summary statistics for monitoring bore BEL-WH003**

8. General observations and conclusions

This document develops a method to assess statistical trends in time series groundwater level and quality data, and applies the method to selected bores in the Surat Basin. The analysis includes climate influences but does not consider hydrogeological or other external influences. Groundwater level data from four monitoring bores were considered in this analysis, and one groundwater quality data set. The groundwater level data includes one QGC operated monitoring bore site (BWS-GW2), one APLNG (Origin) operated monitoring bore site (RN 10925) and two DNRM monitoring bores (RN 13030613 near Injune and RN 42230204 in the Condamine River catchment between Chinchilla and Dalby). The groundwater quality data was sourced from a QGC gas well.

Various sources were used to obtain supporting information for the trend analysis, including Bureau of Meteorology (rainfall and barometric pressure), TSOF (generation and synthetic earth tides), BETCO (accounting for barometric pressure and earth tides) and Water Quality Analyser (assessment of trends in groundwater data).

The information available on each monitoring bore site was found to be highly variable. Some DNRM monitoring bores have been in operation for many decades and provide a long term record. However, these bores have generally been monitored on an infrequent basis particularly in the early years of operation, making it difficult to directly compare observations over time. In other locations, monitoring bore data is only available over a short period of time (in one instance, less than one year of records at the time of analysis). Despite not being active for very long, these recently installed monitoring bore sites also offer large numbers of data points as high frequency data loggers are often installed. In some locations, data is collected on an hourly basis.

A number of steps were undertaken to process and analyse the data (depending on quality and extent) at each location, including:

- Review of monitoring bore level data to identify period of record, missing or anomalous data;
- Generation of synthetic earth tides;
- Account of the influence of barometric pressure and earth tides;
- Consideration of the appropriate period(s) of record for analysis;
- Comparison of adjusted bore level data with rainfall data, and development of regression relationship to estimate rainfall-adjusted groundwater levels where appropriate;
- Assessment of serial correlation in data sets and development of a time series of weighted mean groundwater levels (or residuals if a regression relationship was developed) using an appropriate time step;
- Assessment of trends in adjusted groundwater levels (or residuals if a regression relationship was developed); and
- Checks of normality to determine whether parametric trend tests were still valid

In three instances, the most recent groundwater level trend (generally since 2010) is in an upwards direction. Depending on the location, these trends were identified to range in magnitude from 0.03 m/year to 0.12 m/year. One monitoring bore site (period 1 of monitoring bore RN 13030613 (in Hutton Sandstone near Injune) was observed to have a statistically significant trend in the groundwater level data using all trend tests applied (linear regression, Mann-Kendall and Seasonal Kendall). No statistically significant trend was observed at monitoring bore site RN 42230204 (in Walloon Coal Measures near Chinchilla). At monitoring bore BWS-GW2 (in Springbok Sandstone at Berwyndale South gasfield), the trend results were inconclusive with inconsistent results between the different trend tests and high serial correlation in the data (even after creating weighted mean drawdown values over longer time steps and pre-whitening the data). At monitoring bore RN10925, observed increases in raw groundwater level were approximately 10 m over a two-year period, however after correcting for the influence of climate variability, no trend was evident in the groundwater level data.

The correction made to the raw groundwater level data due to the influence of barometric pressure and earth tides was up to maximum values of between 0.004 m and 0.39 m at individual sites. While this adjustment was small relative to observed groundwater level fluctuations at the sites analysed to date, it is potentially significant relative to QGC exceedance limit drawdown triggers at early warning and trigger monitoring bores (Figure 3-1).

Groundwater quality analysis was undertaken at one gas well from the Bellevue gasfield (BEL-WH003). Given the limited availability of data (10 data points over four years), only a limited assessment could be undertaken. This suggested that there has been no change in EC at this location over the period of monitoring.

Based on this one example, it is clear that a variation from the mean value of EC is likely, albeit with no trend. It is clear that methodology developed in the Response Plan needs to allow for at least such a degree of variation. Hence an EC variation from reading to reading of 20% or deviation from a mean of +/-15 per cent is considered realistic for being within a particular trend.

Appropriately dealing with serial correlation (the relationship between one data point and the next in the time series) was identified as one of the main challenges in the analysis of the groundwater level data sets. Groundwater level data generally displays a high degree of serial correlation, and it may not always be possible to reduce the serial correlation of the data without losing some of the variance within the data. In these instances, it is important to minimise the serial correlation by taking the time weighted groundwater level over a representative period without compromising the characteristics of the data set. For instance, for long data sets, it may be possible to reprocess the data to a monthly or annual time step without losing the variability in groundwater levels over time. In data sets with only a short period of record, reprocessing may be limited to daily or weekly time steps. Pre-whitening of the data to counter the effects of high serial correlation was required in the sites analysed to date, even after calculating the weighted mean drawdown over a representative period. To ensure statistical validity of any trend analysis, an assessment of serial correlation of each groundwater level data set needs to be carried out.

In light of the observations above regarding the availability of data sets, it was sometimes difficult to uniformly apply data analysis techniques across the monitoring bore sites. Some level of contextual information is required for each monitoring bore site to adequately review the available data, make decisions at each step of the analysis and appropriately interpret the trend analysis outcomes. For instance, depending on the period of available data, it may or may not be relevant to undertake a break point analysis.

To support this, it is necessary to have a good hydrogeological conceptualisation and understanding of the site and regional area of interest before undertaking any data processing or analysis. This is relevant to provide information on:

- Local and regional hydrogeology at monitoring bore sites of relevance for incorporation in the statistical analysis;
- Climate stations of relevance for consideration of rainfall/runoff and seasonal influences for incorporation in the statistical analysis;
- Guidance on additional data sets that may be relevant for collection and incorporation in the statistical analysis; and
- Other relevant contextual information of relevance (e.g. extent and patterns of non-CSG groundwater usage proximal to monitoring bores).

This hydrogeological conceptualisation will provide context for the interpretation of the data sets used in the statistical analysis.

Once complete, the statistical trend analysis process provides information on the magnitude, direction and statistical significance of any observed changes in groundwater level over time. However, it does not provide information on causality for these changes. An understanding of the local and regional hydrogeological conditions is also necessary to interpret the outcomes from the statistical tests.

References

- Bardsley W.E. and Campbell D.I. (1994), 'A new method for measuring near-surface moisture budgets in hydrological systems', *Journal of Hydrology* 154:245–254.
- Chiew, F. and Siriwardena, L. (2005) Trend – trend/change detection software. CRC for Catchment Hydrology.
- Clark, W.E., (1967). Computing the barometric efficiency of a well, in *Proceedings of the American Society of Civil Engineers: Journal of the Hydraulics Division*, v. 93, no. HY 4, p. 93–98.
- Department of Environment and Resource Management (2012) Underground water impact reports and final reports. Prepared by Energy Resources, Environment and Natural Resource Regulation, State of Queensland (Department of Environment and Resource Management).
- EPA (2009) Draft Environmental Water Quality Guidelines for Victorian Riverine Estuaries. Publication 1284, June 2009.
- e-water CRC (2011) Water Quality Analyser – User Guide.
- Ferris J.G., Knowles D.B., Brown R.H. and Stallman R.W. (1962), Theory of aquifer tests, US Geological Survey Water-Supply paper 1536-E:69–174.
- Freeze R.A. and Cherry J.A. (1979), *Groundwater*, Prentice Hall, New Jersey.
- Geoscience Australia (2012) Guidance for the Proponent Approach to Monitoring Potential Groundwater Impacts from Coal Seam Gas Activities to EPBC Springs in the Surat Basin. Draft Final Report, November 2012.
- Gibbons, R.D. (1999) Use of Combined Shewhart-CUSUM Control Charts for Ground Water Monitoring Applications. *Groundwater* Volume 37 Number 5.
- Gonthier, G.J. (2007) A Graphical Method for Estimation of Barometric Efficiency from Continuous Data—Concepts and Application to a Site in the Piedmont, Air Force Plant 6, Marietta, Georgia: U.S. Geological Survey Scientific Investigations Report 2007-5111, 29 p., Web-only publication available at <http://pubs.usgs.gov/sir/2007/5111/>.
- Harrington G.A. and Cook P.G. (2011), *Mechanical loading and unloading of confined aquifers: implications for the assessment of long-term trends in potentiometric levels*, Waterlines report, National Water Commission, Canberra.
- Helsel, D.R. and Hirsch, R.M. (2002) Statistical Methods in Water Resources. Chapter A3 of Techniques of Water-Resources Investigations of the United States Geological Survey Book 4, Hydrologic Analysis and Interpretation.
- Jacob, C.E. (1940). On the flow of water in an elastic artesian aquifer: *Transactions, American Geophysical Union*, v. 21, p. 574–586.
- Kellett, J.R., Ransley, T.R., Coram, J. and Jaycock, J. (2003) Groundwater recharge in the Great Artesian Basin Intake Beds, Queensland. Queensland Department of Natural Resources and Mines.

Kirchner (2001) Data Analysis Toolkit #11: Serial Correlation.

http://seismo.berkeley.edu/~kirchner/eps_120/Toolkits/Toolkit_11.pdf

Kruseman, G.P., and de Ridder, N.A. (1991). Analysis and evaluation of pumping test data: The Netherlands, International Institute for Land Reclamation and Improvement, second ed., 377 p.

Merritt, M. L. (2004), *Estimating Hydraulic Properties of the Floridan Aquifer System by Analysis of Earth-Tide, Ocean-Tide, and Barometric Effects, Collier and Hendry Counties, Florida*: U.S. Geological Survey Water-Resources Investigations Report 03-4267, 70 p.

Radziejewski, M. and Kundzewicz, Z. (2004) Detectability of changes in hydrological records. *Hydrological Sciences Journal* Volume 49, pp 39-51.

Radziejewski, M., Bardossy, A. and Kundzewicz, Z. (2000) Detection of river flow using phase randomization. *Hydrological Sciences Journal* Volume 45, pp 547-558.

Sheng, Y., Pilon, P., Phinney, B., and Cavadias, G. (2002) The influence of autocorrelation on the ability to detect trend in hydrological series. *Hydrological Processes* Volume 16 pp 1807-1829.

SKM (2005) Real time reporting against end of valley targets. Final. August 2005, report prepared for the Victorian Department of Sustainability and Environment.

Sophocleous, M.A., Bardsley, W.E., Healey, J. And Engard, B., (2004). Can precipitation loading be detected at 300-meter depth or greater? : KGS Open File Report 2004-46.

http://www.kgs.ku.edu/Hydro/Publications/2004/OFR04_46/index.html

Spane, F.A., Jr. (1999). Effects of barometric fluctuations on well water-level measurements and aquifer test data: Prepared for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830, Pacific Northwest National Laboratory, PNNL-13078, 48 p.

Toll NJ and Rasmussen TC (2007) Removal of barometric pressure effects and Earth tides from observed water levels, *Ground Water* 45(1):101-105

Van Camp, M., and Vauterin, P.(2005) Tsoft: graphical and interactive software for the analysis of time series and Earth tides, *Computers & Geosciences*, 31(5) 631-640, [doi: 10.1016/j.cageo.2004.11.015](https://doi.org/10.1016/j.cageo.2004.11.015).

van der Kamp G. and Schmidt R. (1997), 'Monitoring of total soil moisture on a scale of hectares using groundwater piezometers', *Geophysical Research Letters* 24(6):719-722.

World Meteorological Organization (2000) Detecting trend and other changes in hydrological data. Edited by Z. Kundzewicz and A. Robson. Prepared by the World Climate Program.

Yue, S., Pilon, P., Phinney, B., and Cavadias (2002b) The influence of autocorrelation on the ability to detect trend in hydrological series. *Hydrological Processes*, Volume 16, pp 1807-1829.

Yue, S., Pilon, P., and Cavadias, G. (2002a) Power of the Mann-Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. *Journal of Hydrology* Volume 259, pp 25-271.

Yue, S., Pilon, P., Phinney, B., and Cavadias, G. (2002) The influence of autocorrelation on the ability to detect trend in hydrological series. *Hydrological Processes*, Volume 16, pp 1807-1829.

Appendix A: Notes on statistical trend analysis techniques

Note 1: Parametric and non-parametric trend analysis

For long-term trend analysis, there are two main types of trend analysis method, namely parametric and non-parametric trend tests. Parametric trend analysis techniques (such as linear regression) are those that fit a model to the data to identify the trend required to achieve the best model fit to the data. Parametric trend analysis techniques have the advantage that they can cope with data collected on irregular time steps. They can also include additional independent variables in the model to further explain variability in the time series data, thereby better isolating the residual long-term trend. The disadvantage of parametric tests is that they can be more data intensive if incorporating additional independent variables and that they require the model residuals to be normally distributed for the statistical tests to be valid.

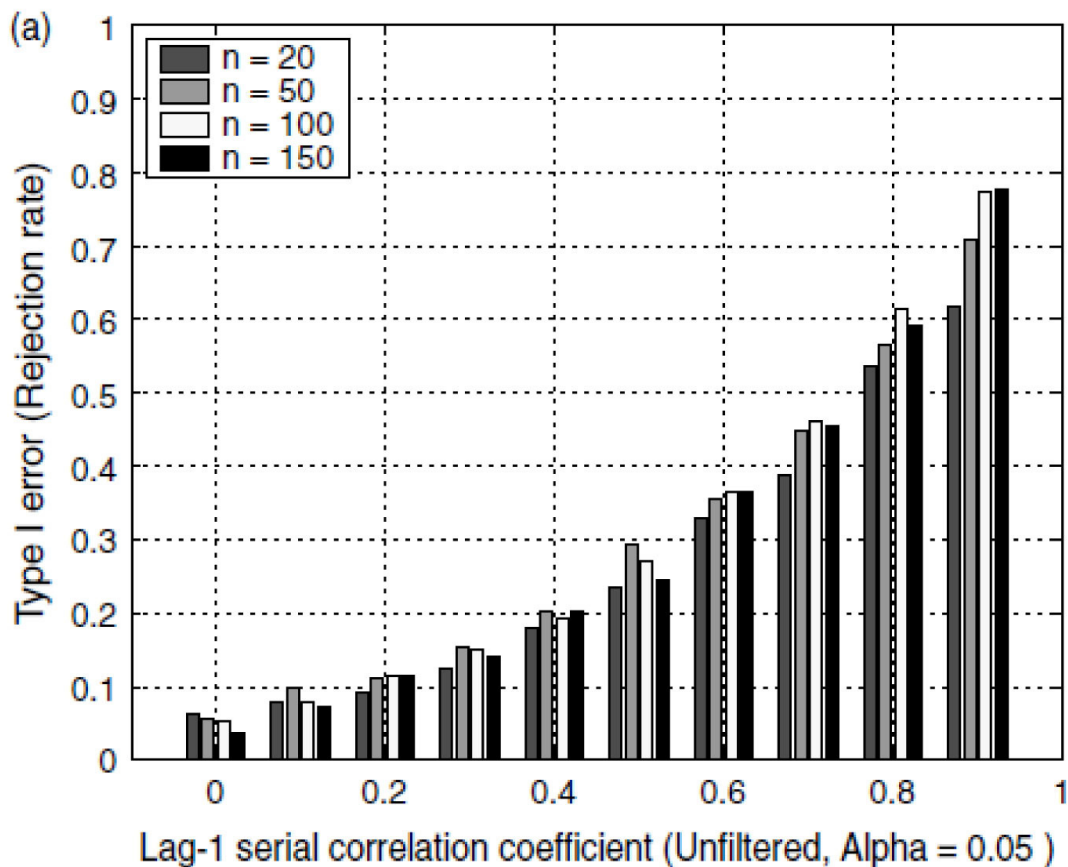
In contrast, non-parametric techniques, such as the Mann-Kendall test, do not assume any particular distribution or model fit to the data. The Mann-Kendall test, for example, simply ranks whether following data points in a time series are higher or lower than the data point of interest. If data points tend to be higher at the end of the record relative to the start, then a trend may be evident. As such, the test does not identify a trend magnitude. It only identifies whether a trend exists at a given level of confidence. Non-parametric tests also do not cope with data collected on irregular time steps.

This study focuses on the identification of long-term trends. Other short-term trend analysis techniques can also be applied and may be more appropriate in certain circumstances. For example, where a step jump in groundwater level occurs at a known date, tests such as a paired t-test can be more appropriate.

Note 2: Serial correlation

All tests for trend assume that the data being analysed is independent from one time step to the next. However, hydrogeologic time series data often exhibits serial correlation over time. That is, the data point on one time step can be related to the data point at the next time step. A run of data points above or below the mean of the dataset at the start or end of a time series will bias the trend analysis results. **Figure Appendix A:1** illustrates how the likelihood of the statistical test falsely identifying a trend (Type I error) increases as serial correlation increases. For example, for a lag-1 serial correlation of 0.9, there is a 60 to 80% chance of falsely identifying a trend compared to the typically assumed 5% chance associated with uncorrelated data.

Figure Appendix A:1 Effect of serial correlation on the Type I error (likelihood of falsely identifying a trend) (Yue, 2002b).



Serial correlation is calculated in most statistical packages or can be calculated in Excel using the CORREL function. For lag-1 serial correlation, array 2 of the CORREL function is offset by one time step relative to array 1. A value of greater than 0.2 can be regarded as a dataset that is serially correlated for the purposes of trend analysis.

If the sampling frequency is high, serial correlation is more likely. High serial correlation can impact on the trend analysis outcomes by overstating the statistical significance of the identified trend. A number of tests are available to quantitatively assess serial correlation (Further details of the various serial correlation tests are also available in Helsel and Hirsch (2002) and Kirchner (2001)).

Durbin-Watson serial correlation test

The Durbin-Watson serial correlation test is calculated as:

$$d = \frac{\sum_{i=2}^n [e_i - e_{(i-1)}]^2}{\sum_{i=1}^n e_i^2}$$

Where e reflects the residual between the predicted and raw data at any given time step. Tabulated critical values are available for comparison, to determine whether the data is serially correlated. In general, small values of d generally indicate correlation. This test requires data to be evenly spaced in time and with few missing data values. It does not provide causality for correlation in the data.

Lag-1 serial correlation coefficient test

This test is also termed Pearson's r or the linear correlation coefficient, and is calculated by fitting a least squares line through the data comparing the residuals between the predicted and raw data. The gradient of this line provides the measure of the correlation coefficient.

Spearman's rank correlation coefficient test

The Spearman rank correlation coefficient is calculated in a similar manner to the lag-1 auto correlation coefficient; however the rank of each residual value is used rather than the value itself.

$$rho = \frac{\sum_{i=1}^n (Rx_i Ry_i) - n(\frac{n+1}{n})^2}{n(n^2 - 1)/12}$$

Where Rx and Ry reflect the ranks of residuals.

If the serial correlation is deemed to be high, a number of steps can be taken to attempt to counter the effects of serial correlation (as suggested by Helsel and Hirsch, 2002):

1. Consider whether additional explanatory variables can explain some of the variability in the data. Incorporating these variables in the analysis may help to eliminate the serial correlation. For instance, serial correlation in groundwater levels may be partly explained by serial correlation in the barometric pressure behaviour that influences it.
2. The serial correlation in the data may be a reflection of redundancy in the information content of the data. If data measurements are taken at high frequency, it may be possible to discard some of the data in a regular manner to produce a sub-sample of the original time series data. For instance, data collected on an hourly time step could be filtered on a daily, weekly, monthly or annual time step in an attempt to minimise serial correlation.
3. A revised time series could be generated by grouping the time series data into a larger time period and calculating a summary statistic, such as time-weighted mean or median. This is appropriate only when a consistent sampling frequency has been applied over the period of analysis. For instance, the average daily groundwater level could be calculated from the hourly data. The most appropriate time step for resampling should be determined using the serial correlation tests above; in order to calculate the weighted mean data set over a representative period.
4. Use more sophisticated trend analysis techniques that can take serial correlation into account. These include a resampling analysis for parametric and non-parametric techniques or autoregressive models for parametric techniques only. Resampling

analysis is a technique which involves randomly generating replicates of the original data set and then comparing whether the test statistic for the original dataset lies within the top 5% (or 10%) of test statistics derived from the randomly generated data. In parametric trend analysis, autoregressive terms can be introduced which fit an error term to the model based on the value of the model error on the previous time step, thereby removing the serial correlation in the model residuals to which the time trend is fitted.

This study has investigated the use of explanatory variables, data filtering and resampling analysis to deal with serial correlation.

Note 3: Interpreting statistical significance

The statistical significance level is a measure of the level of confidence that a detected trend is discernible from the underlying noise in the data. Tests for statistical significance start with a null hypothesis (H_0) of no trend and then seek to determine whether this should be rejected in favour of an alternative hypothesis (H_1) of the existence of trend at a given level of probability. The test statistic (S) is described in the following notes for each individual trend test, which can be standardised and compared to critical thresholds corresponding to each level of statistical significance. Further details of each individual test can be found in the user guide for Water Quality Analyser (e-water CRC, 2011) or TREND (Chiew and Siriwardena, 2005).

Statistical significance is typically interpreted as per **Table Appendix A.1** (adapted from Chiew and Siriwardena, 2005).

Level of statistical significance in p-statistic	Interpretation
$\alpha < 0.05$ (statistically significant at the 5% level of significance)	Strong evidence for trend
$\alpha < 0.1$ (statistically significant at the 10% level of significance)	Moderate evidence for trend
$\alpha > 0.1$ (not statistically significant at the 10% level of significance)	No clear evidence for trend

Table Appendix A.1 Assessment of statistical significance

Two errors can occur in trend analysis:

- Type I errors occur when it is incorrectly assumed that there is a trend in the data
- Type II errors occur when it is incorrectly identified that there is no trend in the data.

A statistical test with low Type II errors are considered powerful.

Note 4: Factors influencing data requirements for trend detection

A number of variables can influence the length of data that is required in order to draw meaningful conclusions, including:

- The desired level of confidence in the trend;
- The variability in the data, which affects the ability to identify long-term trends from noise in the data due to shorter-term fluctuations; and
- The magnitude of the trend to be observed.

In general, the longer the period of record and the less variability in the data, the easier it is to detect long-term trends. That is, a longer period of record is required to identify small trends at a high degree of confidence, or where there is sizable variability in the data. Conversely, a shorter period of record can be used to identify large trends, where the variability in the data is low, or where the required confidence in the trend result is also low. Quantifying the actual length of record required for such a trend analysis is therefore dependent upon the characteristics of the data being considered. These observations are consistent with those noted in Yue et al. (2002a).

Note 5: Trend analysis packages

A wide range of trend analysis packages are available to assess trends in time series data. For this project, QGC has utilised the eWater CRC's Water Quality Analyser package, which is available online (<http://www.toolkit.net.au/Tools/>).

The Water Quality Analyser software package facilitates the testing for trend, change and randomness in hydrological and other time series data. A number of different statistical tests are included in the package, including linear regression, the Mann-Kendall test and the Seasonal Kendall test. The package also provides capabilities to assess serial correlation and supports resampling analysis.

The Water Quality Analyser software was used to measure the trends in groundwater level and water quality data in this study. The following descriptions provide further information on the calculations involved in each statistical test.

Note 6: Linear regression

Linear regression is a parametric test that considers whether there is a relationship between time and another variable of interest. The test statistic (S) is calculated as

$$S = \frac{\text{regression gradient}}{\sigma}$$

Where S is the test statistic calculated to assess the significance of any observed trend and σ is estimated by:

$$\sigma = \sqrt{\frac{12 \sum_{i=1}^n (y_i - a - bx_i)^2}{n(n-2)(n^2-1)}}$$

b is the regression gradient and is estimated by:

$$b = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^n (x_i - \bar{x})^2}$$

a is the intercept estimated by $a = \bar{y} - b\bar{x}$

The linear regression test assumes that the data is normally distributed, and that deviations from the trend are independent as well as normally distributed.

The test statistic S follows a Student-t distribution with n-2 degrees of freedom under the null hypothesis (critical test statistic values for various significance levels can be obtained from Student's t statistic tables). Critical test statistic values at the 5% and 10% level of significance are 2.01 and 1.68 respectively. That is, when S is greater than 2.01 the trend is statistically significant at the 5% level and when it is greater than 1.68 it is statistically significant at the 10% level. If it is less than 1.68 it is not statistically significant.

Note 7: The Mann-Kendall test

The Mann-Kendall test is a non-parametric test that assesses whether a trend is evident in time series data. The test assumes that the data are independent. In this test, the time series data values are ranked ($R_1, R_2, \dots, R_n$) and the test statistic (S) is calculated by:

$$S = \sum_{i=1}^{n-1} \left[\sum_{j=i+1}^n \text{sgn}(R_j - R_i) \right]$$

Where $\text{sgn}(x) = 1$ for $x > 0$

$\text{sgn}(x) = 0$ for $x = 0$

$\text{sgn}(x) = -1$ for $x < 0$

In this calculation, the values i, j and n are values reflecting the position of the current, next and last data point in the time series. $R_1, R_2, \dots, R_n$ represent the time series data values. The abbreviation $\text{sgn}(x)$ reflects a calculation to determine the sign of the difference between two adjacent time series data values.

If the null hypothesis is true, then S is approximately normally distributed with:

$$\mu = 0$$

$$\sigma = n(n-1)(2n+5) / 18$$

The z-statistic is therefore:

$$z = |S| / \sigma^{0.5}$$

A positive value of S indicates that there is an increasing trend and vice versa.

Critical test statistic values for various significance levels can be obtained from normal probability tables. Critical test statistic values at the 5% and 10% level of significance are

1.96 and 1.65 respectively. That is, when S is greater than 1.96 the trend is statistically significant at the 5% level and when it is greater than 1.65 it is statistically significant at the 10% level. If it is less than 1.65 it is not statistically significant.

Note 8: The Seasonal Kendall test

The Seasonal Kendall test is consistent with the Mann-Kendall test, however only data points from the same season are compared. This relaxes the effects of the underlying statistical assumptions, particularly around serial correlation since the data distribution is only relevant within like seasons. The test is weakened if trends in the data change direction or are opposing in different seasons. The test is calculated using the same formula as the Mann-Kendall test with the same critical test statistic values.

Note 9: Resampling

Resampling analysis is a robust method for estimating the significance level of a test statistic particularly when test assumptions are violated. This is of benefit when the original data is serially correlated or not normally distributed. Using this resampling approach, many replicates of the input data are generated, analysed and compared to the original data set. If the trend outcomes from the original data are within the top 5% of the resampled replicates, it is assumed that the trend is accurately detected. A resample population of 1000 replicates is recommended.

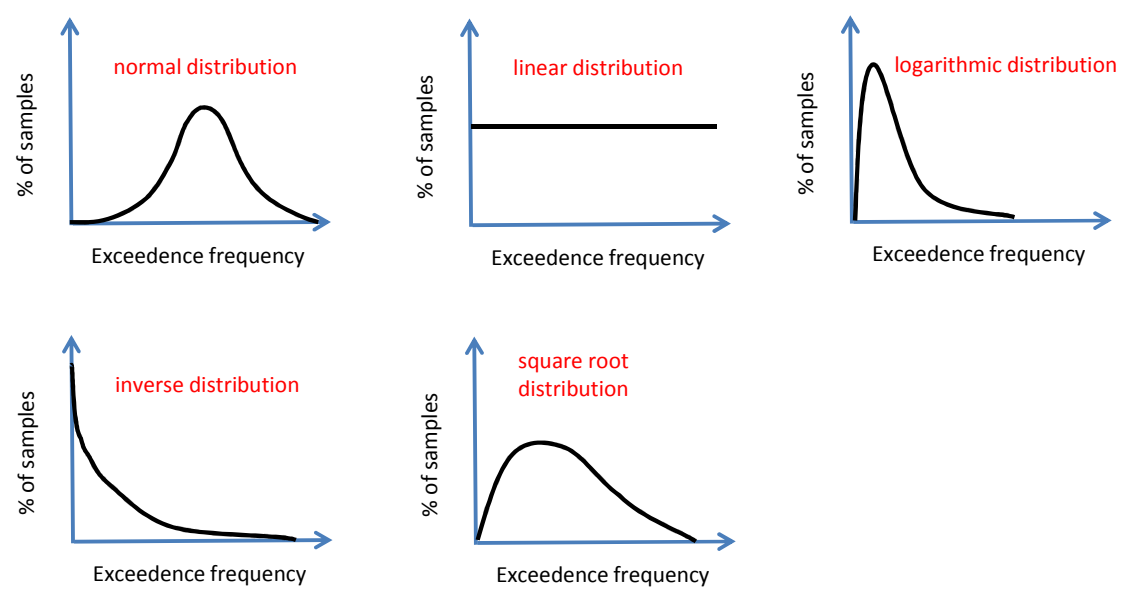
Note 10: Normality

Parametric trend tests assume that model errors (i.e. the difference between the data being analysed and the fitted trend line) are normally distributed. Normality is assessed visually by plotting a histogram of the model errors. This was undertaken using Water Quality Analyser, using 11 bins. The normal distribution was centred on the mean of the dataset when plotting for comparison against the histogram. The normal distribution was plotted in Excel using the NORM.DIST function. NORM.DIST(mid-point of each bin of errors, mean of all errors, standard deviation of all errors) multiplied by the size of the bin in metres and multiplied by 100 to convert into a percentage.

It is difficult to assess precisely when a dataset is no longer normally distributed, because this is largely a subjective decision. Datasets will be clearly not normally distributed when they are linearly distributed (i.e. if all bins have an equal number of samples) or when they are highly skewed (i.e. bins to the left or right of the mean have a higher frequency of samples). Some examples of non-normally distributed data are shown in

Figure Appendix A:2.

Figure Appendix A:2Normal distribution relative to some example datasets that are not normally distributed



Appendix B: Loading and unloading of confined aquifers

Note 11: Influence of overlying unconfined aquifer or flood waters

Trends in confined aquifer water levels are influenced by hydraulic loading and unloading caused by watertable fluctuations in overlying unconfined aquifers. While the maximum possible loading and unloading impact on a confined aquifer is only a fraction of the observed watertable fluctuation in the overlying unconfined aquifer (where this fraction being equivalent to the specific yield; Sophocleous et al. 2004; Harrington and Cook, 2011), this may still be a significant influence in a given hydrogeological environment and/or monitoring and management context. Hence, confined aquifer water levels should be corrected for mechanical loading and unloading effects prior to any analysis and interpretation. The exception is where there is essentially no change in the watertable over the period of interest. Due to the large range in possible values of loading efficiency, it will always be necessary to determine site-specific, or at least aquifer-specific, values (Harrington and Cook, 2011).

Potentiometric level changes caused by overlying watertable fluctuations can be estimated simply by multiplying the change in water storage at the watertable by the loading efficiency of the confined aquifer (e.g. Sophocleous et al. 2004; Harrington and Cook, 2011), such that:

Change in confined aquifer level due to watertable fluctuation = $\Delta SWL \times SY \times \gamma$

Where: ΔSWL = change in watertable level

SY = specific yield of the unconfined aquifer

γ = loading coefficient (or loading efficiency)

The change in watertable level is obtained from monitoring data collected in observation bores in the unconfined (i.e. watertable) aquifer. Selection of suitable monitoring bores which are representative of unconfined conditions at the confined monitoring bore site will require hydrogeological assessment to determine which bores are appropriate for use. Specific yield is the volume of water that can be freely drained from a sediment or rock under the influence of gravity, expressed a percentage of water compared to the bulk aquifer volume. The specific yield can be either estimated based on the lithology of the aquifer, or based on aquifer hydraulic testing (pumping tests) in the unconfined aquifer. For determining the change in potentiometric surface caused by flooding, the specific yield term is removed from the equation, and SWL (standing water level in the unconfined aquifer) is replaced by the height of accumulated water (i.e. depth of flood inundation) near the bore.

There are three ways of determining the loading coefficient (γ):

5. Using laboratory measurements on rock/sediment samples to determine porosity and aquifer compressibility, and use of first principle equations (e.g. Jacob, 1940).
6. Directly via specially designed experiments that can precisely monitor individual natural or artificial loading effects.
7. Indirectly via time-series response of the aquifer to barometric changes.

The main problem with the first approach, aside from the difficulty of obtaining representative field samples, is that aquifer compressibility as determined in the lab is generally not a reliable indicator of in situ compressibility (Harrington and Cook, 2011).

The weighing lysimeter approach (developed by Bardsley and Campbell, 1994) is the most common example of the second method. This involves measuring the change in hydrostatic loading (e.g. as causing by rainfall and evaporation) using large geological weighing lysimeters and measuring the relationship between loading and confined aquifer response. Van der Kamp and Schmidt (1997) used an artificial method of loading an aquifer by parking a 39-ton truck at various distances from monitoring wells and observing the relationship between water level response to loading and unloading. The use of these types of field experiments is not practical or economic in the vast majority of cases.

Barometric efficiency

Determining loading efficiency from barometric efficiency is possible because of the simple mathematical relationship first identified by Jacob (1940) that links these two concepts:

$$BE + \gamma = 1$$

Where: BE = barometric efficiency

γ = loading coefficient (or loading efficiency)

Loading efficiency can be thought of as the fraction of external load change that is borne by the water as a change in pressure, whereas barometric efficiency is the fraction of external load change that is borne by the formation. High barometric efficiencies reflect high strength and rigid formations, whereas low barometric efficiencies indicate highly compressive formations (Spane, 1999).

Once barometric efficiency is known, loading efficiency is easily determined. Harrington and Cook (2011) note that several researchers (e.g. Bardsley and Campbell 1994) have found $BE + \gamma < 1$, however they also note that this reflects uncertainty in the measured values of barometric efficiency and loading efficiency and does not invalidate the mathematical relationship.

Barometric efficiency is the water level change caused by a barometric-pressure change divided by that barometric-pressure change (Clark, 1967). In confined aquifer settings, an increase in barometric pressure will usually cause a decrease in water level in an open well by an amount governed by the barometric efficiency (Freeze and Cherry, 1979; Kruseman and de Ridder, 1991). A number of different methods of determining barometric efficiency are described in the literature. The methods rely on a sampling period and data set of water level changes independent of barometric pressure are minimal, in particular free from groundwater pumping impacts. Gonthier (2007) provides one of the more comprehensive reviews of these methods. These methods, along with Gonthier's own 'graphical' method are briefly described below (note: ΔW = change in water level, ΔB = change in barometric pressure):

- *Average-of-Ratios Method* – Uses the average of ratios of water level change to barometric pressure change ($\Delta W/\Delta B$) for many time intervals

- *Median-of-Ratios Method* - Use the median of ratios of water level change to barometric pressure change ($\Delta W/\Delta B$) for many time intervals
- *Clark Method* - The Clark method (Clark, 1967) estimates barometric efficiency in the presence of a constant ΔW , and time intervals are of a constant length. This method has become a standard for comparing other methods or data-processing techniques (Gonthier, 2007). Essentially the method involves developing concurrent sums of barometric pressure change and head change. A regression line is fitted to the two data sets, with the slope equal to the barometric efficiency. The Clark method applies a sign test to the change in water level compared to the change in pressure, which amongst other functions, removes changes in water level when there is no change in barometric pressure. Merritt (2004) and Gonthier (2007) both outline the equations involved in the Clark method.
- *Slope Method on Water Level and Barometric Pressure Change* – Ferris (1962) first presented the slope method on ΔW and ΔB from several time intervals. Measures of ΔW are plotted on the y-axis, and those of ΔB are plotted on the x-axis. A line is fitted to the plotted points. The slope of the fitted line is the estimate of barometric efficiency.
- *“Graphical” Method* - Gonthier (2007) developed a graphical method that uses continuous water-level and barometric-pressure data to estimate barometric efficiency. A plot is prepared of nearly continuous water level (on the y-axis), as a function of nearly continuous barometric pressure (on the x-axis). This will usually plot as a line curved into a series of connected elliptical loops. Each loop represents a barometric pressure fluctuation. The slope of the major axis of an elliptical loop will be the ratio of water level change to barometric pressure change, which is the sum of the barometric efficiency plus the error. The slope of the preferred orientation of many elliptical loops is an estimate of the barometric efficiency.

There are two important considerations in the above approaches:

8. The time interval – Time intervals of between 10 minutes to 1 hour will be suitable. Gonthier (2007) also discusses the option of optimising the quality of data by focussing on inflection points, which reflect times where barometric pressure is changing most rapidly. However the differences between the two methods (i.e. using all data or data around inflection points) appear fairly small. For example for the Clark method, comparison of use of all 15 minute increments to the inflection centred technique, (for 45 wells) typically indicated only up to 5% difference (Gonthier, 2007).
9. The length of data set – The data set should be long enough to allow at least several significant changes in barometric pressure to occur, but not so long as to be significantly influenced by longer term variables. A period of one to two weeks is recommended. Gonthier (2007) recommends that a long study period should be used (at least 60 days) to ensure ‘that loops that are affected by large amounts of water level changes independent of barometric pressure do not significantly contribute error to the barometric efficiency estimate’. However, this length of time seems unnecessarily long, and increases the likelihood of non-barometric influences impact the data.

Gonthier (2007) concluded that the graphical and median-of-ratios methods, based on median values of water level change divided by barometric pressure change, appeared to be most resistant to error caused by water level changes independent of barometric pressure. However, examination of barometric efficiencies for the different methods in the Gonthier (2007) study (for 45 bores) shows that differences in barometric efficiency across the

methods was relatively small (typically less than 10%). Hence this study does not recommend one single approach for this pre-processing step.

Once the barometric efficiency is estimated, determining the loading efficiency (i.e. coefficient) is straightforward. The change in the confined aquifer level that is due to watertable fluctuation (and associated loading and unloading) can be determined using this efficiency coefficient. Consistent with the approach described for other external influences, a regression model can be fitted between this data and the bore data to obtain a 'loading corrected' data set.

One important consideration in correcting the potentiometric response in confined aquifers for loading effects is the distance at which the effect can be felt at a bore, in particular at what distance from flood waters should the loading effect in an underlying confined aquifer be allowed for. Sopheculeous et al. (2004), cites a 'rule of thumb' from van der Kamp and Schmidt (1997) that notes approximately 90% of the pore pressure response is due to surface loading within a radius equal to 10 times the depth of the bore screen. Therefore deeper formations reflect changes in surface water budget changes across larger land areas. For example, a bore screened at 30 m will reflect hydrological changes up to around 300 m from the bore, and a bore at 300 m represents changes up to 3 km from the bore. Sopheculeous et al. (2004) postulate that some depth limit must exist, beyond which deep formations no longer detect surface loading changes; however, such a limit has not yet been established.

Simplified approach in the absence of data

The approach described above requires a suitable data set to be available for the groundwater levels in the overlying unconfined aquifer and a nearby barometric pressure record. In some instances this will be readily available, however in most locations, this information is limited.

In the absence of a bore record in the overlying unconfined aquifer, rainfall data at the site of recharge of this overlying unconfined aquifer can be used as a surrogate. This assumes that recharge (and hence, groundwater levels in the unconfined aquifer) is driven by rainfall events. In the absence of data for the unconfined aquifer, a regression relationship between this rainfall data and the groundwater levels at the bore of interest (confined aquifer bore) will be developed to isolate the influence of loading and unloading events.

Regardless of the approach employed, it is important that a hydrogeological assessment be undertaken to identify the recharge zones for the relevant overlying unconfined aquifer. This process is necessary to identify the most appropriate monitoring bores or rainfall stations for analysis, to ensure the conditions at the site are representative of unconfined groundwater behaviour at the confined monitoring bore site.