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Memorandum

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Memo Subject	SGP Stage 1 CSG WMMP: GDE and aquatic ecosystem impact assessment technical memorandum

1. Introduction

Groundwater extraction associated with the development of the Surat Gas Project (SGP) has the potential to impact groundwater dependent ecosystems (GDEs) and other aquatic ecosystems which may be supported by groundwater.

Modelling carried out to date indicates limited potential for impact to GDEs as a result of SGP development based on the predicted drawdown in relevant aquifers. This memorandum builds on previous assessments of potential impacts to GDEs, including work completed to address Condition 13b, and presents the assessment of impacts to these ecosystems. This will form the basis of the monitoring network and program required under the SGP Stage 1 Coal Seam Gas (CSG) Water Monitoring and Management Plan (Stage 1 CSG WMMP) in relation to GDEs.

Specifically this memorandum has been developed to address:

Approval Condition 13c: An assessment of potential impacts from the action on non-spring based groundwater dependent ecosystems through potential changes to surface-groundwater connectivity and interactions with the sub-surface expression of groundwater.

Approval Condition 13p: A cumulative impact assessment based on the outputs of the OGIA model which integrates groundwater model outputs with known and potential groundwater dependent ecosystems and presents the outputs in map form. Contribute to investigations coordinated through the OGIA to assess hydrological and ecological characteristics of impacted groundwater dependent ecosystems.

Condition 13p requires assessment of cumulative impacts on potential GDEs. A key function of the Office of Groundwater Impact Assessment (OGIA) is the assessment and management of cumulative impacts in the declared Surat Cumulative Management Area (CMA), which are set out in the Underground Water Impact Report (UWIR).

As the assessment and management of spring GDEs are covered under the UWIR, these are not considered further in addressing Condition 13p here. Accordingly, this document sets out the assessment of potential cumulative impact on non-spring GDEs only. It is noted that the next iteration of the UWIR (expected release in 2019) will incorporate the assessment and management of cumulative impacts to all environmental values, which is expected to include non-spring GDEs.

Both Condition 13c and 13p require an assessment of potential impacts to GDEs. The level of assessment that can be carried out at present identifies where potential impacts may occur, however based on the information currently available, it is not possible to specify the nature of the ecosystem response and whether an adverse impact as a result of altered water availability will actually occur. This will be addressed through further assessment and monitoring as required, and reviewed and revised as part of the Stage 2 CSG WMMP where appropriate.

This memorandum will also be used to underpin other Approval Conditions that will be addressed separately, including Conditions 13e, 13f, 13j and 13k.

1.1. Definition of Groundwater Dependent Ecosystems

The definition of GDEs adopted for the Supplementary Report to the Environmental Impact Statement (SREIS) will be carried through the Stage 1 CSG WMMP development. When considering depressurisation impacts under the requirements of the Stage 1 WWMP, aquatic ecosystems that may not directly receive groundwater contribution, but may be supported by shallow groundwater levels and therefore potentially affected by Project depressurisation activities have been assessed.

The definitions of dependent ecosystems (DEs) that will be considered when addressing Conditions 13c and 13p, where assessment of potential impact will be based on groundwater modelling predictions, are therefore:

- Surface Expression GDEs: Ecosystems dependent on the surface expression of groundwater (i.e. springs, groundwater-fed wetlands and baseflow contribution to watercourses).
- Terrestrial (or vegetation) GDEs (including riparian vegetation): Ecosystems dependent on the subsurface presence of groundwater (i.e. plants accessing shallow groundwater or the capillary fringe, or deeper rooted vegetation accessing deeper groundwater).
- Subterranean GDEs: Ecosystems that are present within pore spaces, fractures or caves within an aquifer.
- Aquatic Ecosystems: Aquatic ecosystems dependent on surface water resources that are maintained by groundwater levels, but not groundwater-fed (i.e. connected but losing streams).

The level of dependency is not implied in these definitions, and such ecosystems may be wholly or partially dependent on the water resources. They may also rely on the water resource only periodically (i.e. greater vegetation reliance on groundwater during drought periods).

2. Method

2.1. Condition 13c

Condition 13c has been addressed based on the framework outlined in Section 8.5.2 of the Supplementary Groundwater Assessment to the SGP EIS (Coffey, 2013). This approach involves:

- Identification of potential GDE landscapes.
- Use of modelling to predict areas of potential impact.
- Carry out a risk assessment to identify GDEs at risk of impact.

2.1.1. Identification of potential GDE landscapes

The identification of GDE landscapes within and surrounding SGP tenements commenced in detail in the SREIS process, where a significant volume of available data was reviewed and incorporated in to the impact assessment.

At the completion of the SREIS in 2013, a conservative assessment of potential GDE landscapes present within the study area was made in recognition of identified data gaps.

Since the completion of the SREIS, further detailed studies and risk assessments have been carried out to improve the understanding of which potential GDEs represent likely or actual GDEs and reduce the level of conservatism that was applied during the SREIS assessment. It is acknowledged that some data gaps remain, and where these cannot currently be closed out with regards to the establishment of an ecosystems dependence on groundwater, the ecosystem remains as a landscape for further consideration in the impact assessment.

To address Condition 13c, the body of knowledge obtained through these assessments has been collated, reviewed and used to identify GDE landscapes. Specifically this has included:

- Review and confirmation of potential non-spring GDEs reported in the SGP SREIS.
- Refinement of the potential non-spring GDEs, and the potential for impact to these, through subsequent studies including AGEs GDE risk assessment (AGE, 2013a), CDM Smith's Condamine Alluvium surface water-groundwater modelling (CDM Smith, 2016), NRAs aquatic ecology study (Attachment 1), 3D Environmental and Earth Search desktop assessment and field work (Attachment 2) and other relevant studies and research papers.

Further detail on the process of GDE landscape identification progressing from SREIS to this Stage 1 CSG WMMP is provided in Section 3.

2.1.2. Use of modelling to predict impacts

Detailed numerical groundwater modelling underpins the prediction of drawdown impact. The basis for numerical modelling to address Condition 13c and 13p has been established in a separate memoranda (Coffey, 2016) and is summarised in Section 4.

For the purpose of addressing Condition 13c, the 1 m drawdown contour for relevant modelling outputs has been adopted as the extent of where GDEs may be at risk of impact where this is predicted in the GDE source aquifer. This relates to the assessment of impact for terrestrial GDEs only, which are the subject of this technical memorandum. Consistent with industry approach and as required under the Water Act (2000) and the Surat CMA UWIR, where drawdown predictions are considered for the assessment of impact to spring GDEs, the 0.2 m drawdown contour in the source aquifer is adopted.

A range of factors have been considered when assessing the appropriateness of adopting the area within the 1 m or greater drawdown prediction in the watertable aquifer for the assessment of potential impact to terrestrial GDEs, including:

- Current and historical groundwater level fluctuations in the watertable.
- The predicted maximum rate of change in groundwater levels in areas beyond the 1 m drawdown contour in the watertable.
- Likely ecosystem water sources.
- Ecosystem resilience and adaptability.

Observed groundwater level fluctuations in the watertable aquifer vary by >1 m (up to 20 m) annually in a number of locations across the project area (refer Attachment 3 RN123130A, RN160518A, RN41620043A, RN42231411A, RN42230210A, RN42230153A, RN42230159, RN42231370, Macalister 7, Kedron 572, Daandine 161 and refer Figure 2.1 for bore locations). A significant baseline of data is available to assess fluctuations with many records commencing in 2011, and some monitoring bore records across the Condamine Alluvium dating back to the 1960's. In these areas there is well documented seasonal response to non-CSG groundwater abstraction, and historically, groundwater levels have steadily declined in the order of tens of metres as a result. These antecedent conditions indicate that where terrestrial GDEs remain present, they are likely to have been established in or adapted to fluctuating and/or declining groundwater levels, and be less sensitive to small declines in groundwater levels (Shafroth *et al*, 2000).

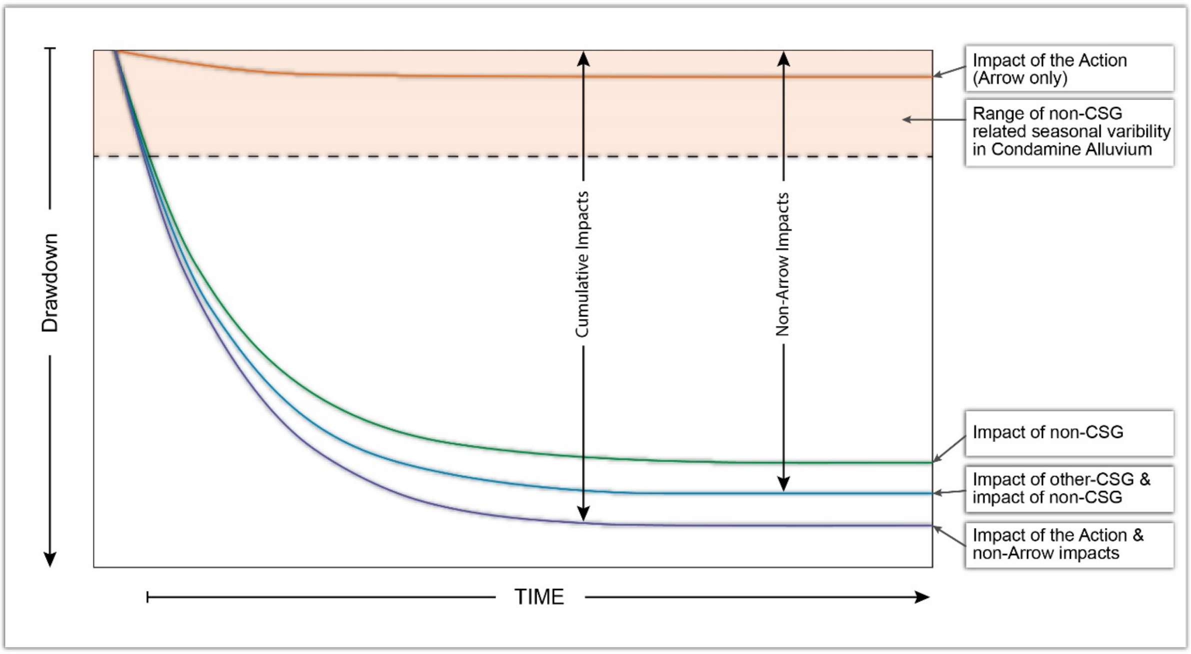
The rate of drawdown where <1 m total drawdown occurs (i.e. the outer extent of the drawdown predictions) is low as the total drawdown does not occur in a single year. The low rate of change of groundwater level is demonstrated in CDM Smith (2016) for the Condamine Alluvium where the rate of change of watertable elevation is predicted to be 1 to 2 mm per year (0.001 – 0.002 m/year). In consolidated aquifers as reported in Appendix F of GHD (2013), the maximum rate of change of watertable elevation is areas of <1 m total drawdown due to the Action (i.e. Arrow only impact) is also low.

Attachment 4 presents hydrographs (reproduced from input data used to develop Appendix F of GHD (2013)) of modelled drawdown at locations beyond the 1 m drawdown extent in relevant aquifers (refer Figure 2.2 for hydrograph locations), adopting the mean drawdown prediction. The maximum rate of drawdown was assessed based on the steepest part of the hydrograph. The maximum rate of groundwater drawdown at these locations is estimated to be:

- Springbok Sandstone: < 0.06 m / year (refer hydrographs HH_1, IJ_1, JK_1, VW_1, WX_1 and U131_1).
- Walloon Coal Measures: <0.09 m / year (refer hydrograph MJ_1 noting there are limited extracted hydrograph locations in areas of <1 m drawdown in the WCM, however there is also limited area where of <1m drawdown in the WCM where the WCM is inferred to be the watertable aquifer).
- Hutton Sandstone: <0.02 m / year (refer hydrographs PM_2, OP_1, QP_1 and UZ_1).
- Precipice Sandstone: <0.0001 m / year (refer hydrograph TR_1).

More typically the rate of drawdown in areas where less than 1 m of drawdown is predicted in the watertable is much less than these maximum estimated rates of change. Therefore the magnitude of total drawdown along with the rate of change that would be experienced in these areas is substantially less than existing variability in watertable levels induced as a result of seasonal fluctuation and/or non-CSG abstraction, and it is reasonable to assume that in these areas vegetation is either adapted to the variability in groundwater levels or disconnected from the watertable and not reliant on groundwater.

Schematic 2.1 presents a conceptual representation of the relative change in groundwater as a result of various factors across the Project area, and demonstrates that the potential influence on groundwater levels the areas of <1 m drawdown prediction in the watertable aquifer is negligible in comparison to historical and current non-CSG influences.



Schematic 2.1: Conceptual representation of drawdown contribution

These small and gradual reductions in groundwater levels also provide a greater opportunity for natural recharge processes to mitigate the effects of water stress and allow terrestrial GDEs (i.e. deep rooted vegetation) to adapt to longer-term changes (Froend and Sommer, 2009; Shafroth, 2000).

The concept of ecological resilience is one of natural systems being in a state of change, rather than equilibrium (Sommer and Froend, 2011). A result of this is that GDEs are necessarily adapted to some degree of groundwater level fluctuations and the terrestrial vegetation community composition will progressively respond to the prevailing conditions. It is reasonable to assume that vegetation would adapt to the very gradual changes that may eventuate over a long period of time in the areas beyond the 1 m watertable drawdown contour interval, as evidenced by adaptation to the historical change in levels and seasonal fluctuation.

Flood plain eucalypts, most notably *Eucalyptus camaldulensis* (River Red Gum) which are the key species of interest across the SGP with regards to potential groundwater reliance, are an adaptable species that have the ability to extract water from multiple sources including shallow soil moisture, river water and groundwater, dependent on availability (Menforth *et al*, 1994) affording this species resilience to small and gradual changes in groundwater availability.

This is also supported by Zolfaghar (2013) who indicates that *Eucalyptus* species more broadly, which dominate the SGP study area, have an ability to adapt to decreased groundwater availability and are adept at utilising both groundwater, surface water and soil moisture, depending on availability.

Many riparian trees have dimorphic root systems which include shallow roots to improve stability, nutrient uptake, and rapid uptake of surface soil water after rainfall events, with deeper sinker roots that can access the capillary fringe of groundwater (Eamus *et al* 2006; Pinto *et al,* 2014). Therefore small fluctuations in the availability of soil moisture from one source (e.g. groundwater) is unlikely to impart any significant ecological response.

Shafroth *et al* (2000, 2002) also propose that terrestrial vegetation that has established in an area of variable groundwater levels, which is reflective of the Condamine River Floodplain environment, will be less sensitive to very small declines in groundwater level than species that have established in an environment with a shallow stable groundwater resource.

Based on these considerations it is reasonable to assume vegetation will be able to adapt to the relatively low magnitude of total drawdown predicted in these areas (<1 m over the life of the project) that will develop very gradually over an extended period of time. Potential GDEs in this area are considered to be at low to no risk of impact as a result of the Action and therefore attention and effort regarding further assessment and management is focussed on higher risk areas where predicted drawdown in the watertable aquifer is greater than 1 m.

It is noted that terrestrial GDEs differ significantly in their ecohydrological function and response from spring GDEs, where a 0.2 m drawdown limit in the source aquifer is adopted as the impact threshold. The adoption of the 0.2 m drawdown trigger for spring GDEs is defined in the Water Act (2000) based on this being the smallest quantifiable drawdown that essentially is reflective of no impact. For some springs, even small reductions in groundwater pressure may have a bearing on the flow rates and the ecosystems supported by this groundwater.

Terrestrial GDEs, however, are fundamentally adapted to some variability in groundwater levels given natural variability, and they also play a part in controlling groundwater levels, as described above. Therefore adoption of a 1 m drawdown contour is considered to be an appropriate and pragmatic position for the ongoing assessment of potential impacts to terrestrial GDEs.

2.1.3. GDE impact assessment

Predicted groundwater drawdown in the shallowest aquifer (dependent on geology subcrop) was overlain with potential GDE landscapes to identify where GDEs may be at risk of impact. For “at risk” GDEs, an assessment of potential impact was carried out to identify where monitoring may be required. The assessment included the following components:

- Detailed assessment of the likelihood the ecosystem is dependent on groundwater, taking into consideration:
    - Depth to groundwater.
    - Borehole logs (soil and lithology).
    - Vegetation mapping and site observations.
    - Landscape position (hydrology and geomorphology).
- Review of available information regarding ecosystem sensitivity and ability to adapt to changes in groundwater availability.
- Assessment of potential impact to a non-spring GDE by considering the predicted rate of change in groundwater levels, historical trends in groundwater level fluctuations and the relative importance of the ecological community.

2.2. Condition 13p

Condition 13p comprises two components:

- Cumulative impact assessment.
- Demonstration of Arrow’s contribution to ongoing OGIA research projects and investigation programs.

2.2.1. Cumulative impact assessment

The OGIA’s core function is to undertake assessment of cumulative groundwater impacts arising from CSG development, set management arrangements and assign responsibilities to tenure holders for implementation of strategies within the Surat CMA. This includes spring-based GDEs (spring vents and complexes, and watercourse springs) as set out in the Surat CMA UWIR Spring Impact Management Strategy (SIMS).

Therefore the assessment carried out here to address Condition 13p relates only to the assessment and management of cumulative impact to non-spring GDEs (i.e. terrestrial GDEs).

Under the current (2016) UWIR, Arrow have no assigned monitoring or management responsibilities for spring vents or watercourse springs. Non-spring GDEs are not currently managed under the UWIR however; recent amendments to the Water Act (2000) and associated guidance on the development of underground water impact reports (DNRM, 2016) require future UWIRs to give consideration to the identification and management of non-spring GDEs. It is therefore expected that under the next Surat CMA UWIR, anticipated to be released in 2019, assessment and identification of management obligations for non-spring GDEs will be undertaken by OGIA also.

Condition 13p has been addressed by adopting the impact assessment approach defined for Condition 13c (Section 2.1), including use of the 1 m drawdown contours for cumulative drawdown predictions (refer Section 4 for model selection basis) and review of where terrestrial GDEs may be at risk of impact from drawdown in the watertable aquifer.

The spatial extent considered for cumulative impact assessment of non-spring GDEs to address Condition 13p includes:

- 1 m drawdown of relevant aquifers predicted within Arrow tenements.
- 1 m drawdown of relevant aquifers predicted within Arrow’s off-tenement area of responsibility i.e. the extent of the Arrow-only drawdown predictions, (where this does not fall on another proponent’s tenements).

The results of the assessment are presented in Section 6.

2.2.2. Contribution to OGIA investigations

Arrow will continue to actively engage in industry and OGIA led research and investigations that further knowledge around GDEs in the Surat CMA. This part of the condition has been addressed by describing Arrow’s contribution to date and proposed ongoing involvement, as presented in Section 6.2.

3. Identification of GDE landscapes

The identification of landscapes that may contain GDEs was initially carried out during the groundwater technical assessment supporting the SGP EIS, with more detailed assessment carried out as part of the SREIS. Refinement of the understanding of these potential landscapes and ecosystems has been gained through improved knowledge of local scale conditions and additional numerical groundwater modelling.

The initial process adopted for the identification of GDE landscapes in the SREIS was appropriately conservative given a number of uncertainties regarding the presence and nature of potentially groundwater dependent ecosystems.

The evolution of the identification of GDE landscapes included the following key steps:

1. Assessment during the SREIS that incorporated the available knowledge at that time within an initial search boundary of:

- The Surat CMA for springs (known spring vents and watercourse springs) and nationally important wetlands that may be groundwater dependent. All identified nationally important wetlands within the Surat CMA, and spring vents and watercourse springs within 30 km of the SGP tenements were described in the SREIS. The impact assessment conservatively included groundwater dependent features within a 10 km buffer zone beyond the 0.2 m drawdown contour for the spring source aquifer as being potentially affected by the Action. This was also consistent with the OGIA approach to the assessment of springs in the 2012 Surat CMA UWIR.
- Arrow tenements and general surrounds for potential surface expression and terrestrial GDEs mapped by BoM. Consistent with the approach for springs, the impact assessment process adopted an assessment area that included a 10 km buffer beyond the 0.2 m drawdown contour in the source aquifer (watertable aquifer for terrestrial GDEs).

2. Refinement of understanding of GDEs in identified risk areas, based on the findings of the SREIS. This included further consideration for the presence of confining layers that would act to limit the propagation of drawdown as a result of the Action to watertable aquifers, and improved landscape conceptualisation. In particular, this step considered the presence and absence of the Westbourne Formation in more detail, and incorporating further assessment in to the separation of the subcrop extent from the generalised Kumbarilla Beds.

3. Development and release of the Queensland GDE mapping dataset, which built on the BoM national assessment and included refinement based on regional ecosystem (RE) mapping and establishment of conceptual landscape models in which GDEs may be situated. Extensive industry consultation was also carried out in the development of this mapping product to incorporate detailed local knowledge in to the system conceptualisation process and definition of dependent ecosystems.

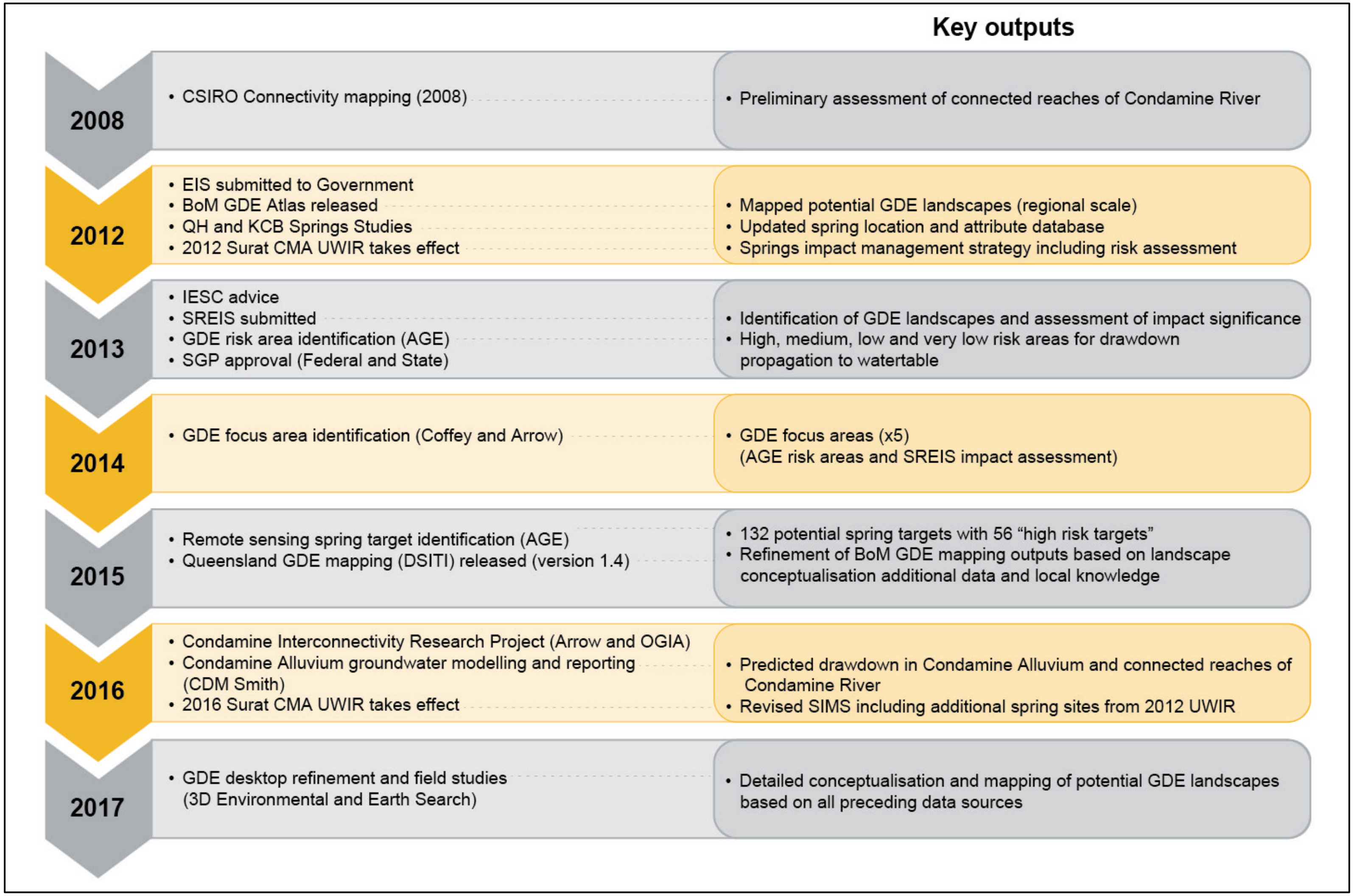
4. Completion of other detailed studies, including:

- Detailed Condamine Alluvium predictive modelling. This modelling aimed to provide an improved tool for the prediction of potential impacts to the Condamine River Alluvium as a result of the Action, focussing on the potential impact on groundwater-surface water connectivity. It was developed specifically to address Approval Condition 13 (b).
- Vegetation mapping, which provided an improved understanding of the presence of potentially groundwater dependent vegetation.
- Ongoing groundwater level and quality monitoring, which supports the assessment of the presence of potential GDE landscapes, and whether they may be at risk of impact as a result of the Action.

5. Incorporation of data made available since the completion of the SREIS in to this Stage 1 CSG WMMP, including the Queensland GDE mapping. This assessment reduces the conservatism applied in the SREIS impact assessment to adopt a practical and pragmatic position for the ongoing assessment of potential impacts to GDEs as a result of the Action. The approach is based on:

- The assessment and management of potential impact to springs (including watercourse springs) being administered under the Surat CMA UWIR.
- The identification of potential terrestrial GDE landscapes based on refinement of the assessment approach adopted in the SREIS. This has enabled the current assessment to better reflect credible impacts to terrestrial GDEs (noting some conservatism still remains) within an area constrained to greater than 1 m predicted drawdown in the source (watertable) aquifer for the potential GDE.

The following sections present an overview of the key studies completed to identify GDE landscapes that may be impacted by drawdown associated with SGP development and their findings, and sets out the GDEs that will be carried through the impact assessment process to identify monitoring and management targets. Schematic 3.1 provides an overview of the evolution of these studies. It is also noted that further field studies have been completed, with ongoing monitoring being carried out, to further refine the understanding of potential groundwater dependence in key risk areas identified through this Stage 1 assessment process.



		Key outputs
2008	• CSIRO Connectivity mapping (2008)	• Preliminary assessment of connected reaches of Condamine River
2012	• EIS submitted to Government • BoM GDE Atlas released • QH and KCB Springs Studies • 2012 Surat CMA UWIR takes effect	• Mapped potential GDE landscapes (regional scale) • Updated spring location and attribute database • Springs impact management strategy including risk assessment
2013	• IESC advice • SREIS submitted • GDE risk area identification (AGE) • SGP approval (Federal and State)	• Identification of GDE landscapes and assessment of impact significance • High, medium, low and very low risk areas for drawdown propagation to watertable
2014	• GDE focus area identification (Coffey and Arrow)	• GDE focus areas (x5) (AGE risk areas and SREIS impact assessment)
2015	• Remote sensing spring target identification (AGE) • Queensland GDE mapping (DSITI) released (version 1.4)	• 132 potential spring targets with 56 “high risk targets” • Refinement of BoM GDE mapping outputs based on landscape conceptualisation additional data and local knowledge
2016	• Condamine Interconnectivity Research Project (Arrow and OGIA) • Condamine Alluvium groundwater modelling and reporting (CDM Smith) • 2016 Surat CMA UWIR takes effect	• Predicted drawdown in Condamine Alluvium and connected reaches of Condamine River • Revised SIMS including additional spring sites from 2012 UWIR
2017	• GDE desktop refinement and field studies (3D Environmental and Earth Search)	• Detailed conceptualisation and mapping of potential GDE landscapes based on all preceding data sources

Schematic 3.1: Evolution of GDE landscape knowledge

3.1. SREIS assessment

The SREIS identified a number of potential GDE landscapes through a review of the following sources:

- CSIRO connectivity mapping.
- Bureau of Meteorology GDE Atlas.
- Queensland Herbarium Springs Database.
- Nationally important wetland database.
- CSIRO river connectivity mapping.

In the process of identifying potential GDE landscapes, a number of search area buffers and screening tools were adopted to ensure an appropriate extent of landscapes were included in the initial assessment, and that ecosystems that were not considered to have the potential to be groundwater dependent were screened out of the assessment process. For the SREIS assessment this included:

Landscape identification

The study area adopted in the SREIS included:

- Review of the whole of the Surat CMA for the identification of nationally important wetlands that may be groundwater dependent.
- Review of the characteristics of springs (known spring vents and watercourse springs) within a 30 km buffer beyond SGP tenements.
- Arrow tenements and general surrounds for potential surface expression and terrestrial GDEs mapped by BoM.
- The Condamine River, as part of a detailed review of the potential for connectivity with groundwater.

Landscape screening

Assessment of the likelihood of these identified landscapes to represent actual GDEs was undertaken to screen out ecosystem that were not considered to be groundwater dependent. Landscapes that were captured for further assessment included:

- Gaining stream reaches of the Condamine River.
- Landscapes where depth to groundwater (watertable, not perched groundwater disconnected from the underlying regional systems that may be influenced by drawdown propagation) is less than 20 m. This was based on a literature review that indicated typical plant rooting depth does not exceed 10 m, therefore 20 m used as a conservative screening tool.
- Landscapes mapped in the BoM GDE Atlas as having a high or moderate potential to be groundwater dependent. Landscapes mapped as having a low potential to be groundwater dependent were not included as they are unlikely to represent actual GDEs.

The desktop assessment of these information sources identified the following known and potential GDEs within the SGP development study area:

- Spring complexes 584 (Wambo), 585 (Bowenville), 601 (Main Range Volcanics 3) and 602 (Main Range Volcanics 4).
- Watercourse spring sites W14 and W15 (Hutton Sandstone source aquifer), W77 and W78 (Mooga / Gubberamunda Sandstone source aquifer), W100 (Quaternary sediments source aquifer) and W160 (Kumbarilla Beds source aquifer).
- Nationally important wetlands with assumed groundwater dependence including the Balonne River Floodplain and Boggomoss Springs.
- Surface expression GDEs (i.e. watercourse spring GDEs) including:

  - Reaches of Roche Creek, north-east of Wandoan.
  - Reaches of Juandah Creek south of Wandoan.
  - Reaches of the Condamine River south of Chinchilla that correlate with gaining river reaches in the CSIRO connectivity study.
  - A tributary of Wyaga Creek in upland areas at the southern tip of the project development area.
- Significant areas of potential terrestrial GDEs across the study area.

The potential GDEs were assessed in the SREIS impact assessment. When considering potentially affected GDE landscapes, a 10 km buffer beyond the 0.2 m drawdown extent for the GDE source aquifer was adopted for the assessment of impacts to both spring and terrestrial GDEs. For springs, this was consistent with the OGIA approach to the assessment of springs in the 2012 Surat CMA UWIR. For terrestrial GDEs, this was a conservative position adopted for consistency with the spring assessment method.

Generally low to very low potential for significant impact was assessed. Some limited locations were identified as having moderate potential for significant impact, and the outcomes of the SREIS impact assessment relating to GDEs formed the basis for the direction of future studies.

3.2. Risk area refinement

Following the completion of the SREIS, Arrow commissioned further desktop assessment to refine the areas of potential risk to GDEs as a result of coal seam depressurisation (AGE, 2013a). The assessment aimed to provide a finer scale assessment of where GDEs may be at risk from groundwater drawdown as a result of Arrow’s proposed activities.

AGE (2013a) interrogated the OGIA 2012 groundwater model layer structure to extract sub-crop extents for the Orallo Formation and Westbourne Formation to assist with sub-dividing the Kumbarilla Beds and refine the areas of potential risk (i.e. where the Westbourne Formation is absent and groundwater drawdown may propagate to shallow layers).

The assessment adopted the Arrow SREIS groundwater model Arrow-only drawdown contours and the Central Condamine Alluvium Model (CCAM) to define areas of potential impact. A 10 km buffer beyond the 1 m drawdown contours for major aquifers was adopted for the assessment of potentially impacted terrestrial GDEs.

The assessment identified high, medium, low and very low risk areas (refer Figure 3.1). Elsewhere, there was considered to be no potential for risk to terrestrial GDEs. The identified risk areas were developed to direct the focus of further GDE assessment, with selected high or moderate risk areas forming the focus of further investigation.

High risk areas identified are:

- >1m drawdown predicted in either the Gubberamunda or Springbok Sandstone, east of the respective inferred subcrop extent.
- The western extent of the Condamine Alluvium.

Moderate risk areas identified are:

- >1m drawdown in the WCM or Springbok Sandstone, east of the inferred subcrop extent.
- <1m drawdown in the Gubberamunda Sandstone, east of the inferred subcrop extent.
- A small area to the east of the Condamine Alluvium where there is >1m drawdown in the WCM and the WCM is close to outcrop.

3.3. GDE focus areas

The AGE identified risk areas, combined with the risk areas identified as part of the SREIS terrestrial GDE impact assessment, were compared against the Bureau of Meteorology (BoM) mapped potential terrestrial GDE landscapes to identify where the potential GDE landscapes coincided with the risk areas and therefore where GDEs may be most at risk of drawdown impact. Through this process five terrestrial GDE “focus areas” were identified by Coffey and Arrow for further targeted investigation (refer Figure 3.2). The rationale for focus area selection is presented in Table 3.1.

Table 3.1: GDE focus area selection

GDE focus area	Selection rationale
1	Areas of mapped high and moderate potential subsurface (terrestrial) GDEs where there is uncertainty around the extent of Springbok Sandstone outcrop / Westbourne Formation subcrop. If Westbourne Formation is absent, GDEs may be at risk from drawdown impact.
2	
3	
4	Confluence of the Condamine River and Wambo Creek where terrestrial ecosystems of high potential groundwater dependence are mapped.
5	Proximity to inferred Westbourne outcrop and predicted 1m drawdown extent, noting difference in interpretation of Westbourne subcrop extent between Arrow and AGE. Considered to warrant further assessment.

3.4. Condamine Interconnectivity Research Project

The Condamine Interconnectivity Research Project (CIRP) (OGIA, 2016b) is an OGIA-directed project that aimed to further quantify the connectivity between the Condamine Alluvium and the WCM. As set out in OGIA (2016b), it involved:

- Interpretation and modelling of the geology to map the transition zone (interface between the Condamine Alluvium and the WCM).
- Surveying and mapping of groundwater levels of the Condamine Alluvium and the WCM to establish historic and current differences in groundwater levels between the two formations.
- Assessment of the hydrochemistry to test hypotheses about mixing groundwater between the Condamine Alluvium and the WCM.
- Aquifer pumping tests and associated drilling at selected sites to establish the physical and hydraulic characteristics of the transition zone and establish high-value long-term monitoring sites.

Arrow contributed significantly to the CIRP with on-site investigations, including installation of groundwater monitoring wells and completion of pump tests. The CIRP concluded (OGIA, 2016b Section 9):

- The geologic data shows that a clay-rich or mudstone horizon at the base of the Condamine Alluvium and the top of the WCM acts as a physical barrier that impedes flow between the formations.
- Persistent differences in groundwater levels between the formations, and the flow patterns within the formations, demonstrate that impediments to flow exist between the formations.
- Hydrochemical data suggests that there has been little past movement of water between the formations, even in areas where significant groundwater level differences have existed over a prolonged period
- Detailed aquifer pumping tests at two sites found no significant flow of water between the formations in response to pumping tests around those sites. The tests show that the vertical hydraulic conductivity for the material between the formations is consistent with that of a highly effective aquitard
- The level of hydraulic connectivity between the Condamine Alluvium and the WCM is low.

3.5. Queensland GDE mapping

The Queensland Department of Science, Information Technology and Innovation (DSITI) developed spatial datasets of potential GDE landscapes (WetlandInfo, 2015), to provide a baseline mapping product at catchment scale. The mapping built on existing information, including the BoM GDE Atlas and Queensland regional ecosystem (RE) mapping. The mapping process included the establishment of conceptual GDE models that underpin GDE landscape identification, and the mapping products were reviewed and rationalised by a range of industry experts prior to public release.

The Queensland WetlandInfo (2015) GDE mapping products represent a refinement of the BoM GDE mapping (BoM, 2013) adopted in the SREIS. A comparison of the mapped extents of terrestrial GDEs is presented in Figure 3.3, and shows that the Queensland mapping predicts substantially fewer potential terrestrial GDE landscapes through consideration of additional information and consultation with local experts. The WetlandInfo mapping, released in December 2015, reflects the existing effects on groundwater levels in the Condamine Alluvium where significant drawdown has already occurred as a result of agricultural activities, resulting in a watertable largely below plant rooting depth in these areas. In addition, WetlandInfo (2015) excludes potential GDE landscapes in pastoral/agricultural areas with known salinisation issues as these are considered to represent “anthropogenic GDEs” that are a function of land clearing and associated groundwater level rise.

The WetlandInfo (2015) product is considered to provide the best available catchment-scale GDE mapping, and will be adopted in preference to the BoM mapping for the purpose of addressing Conditions 13c and 13p.

3.6. Condamine Alluvium and Condamine River modelling

CDM Smith (2016) established an integrated groundwater-surface water model to address Condition 13b and quantify the impact that flux changes to the Condamine Alluvium may have on surface water flow in the Condamine River.

The modelling approach included adopting the 2012 OGIA model, the Central Condamine Alluvium Model (CCAM) and the most recent Integrated Quantity and Quality Modelling (IQQM) (Simons et al, 1996). Further explanation and evaluation of the approach to the CDM Smith modelling and distillation of results is provided in Coffey (2016).

The predicted maximum drawdown across the Condamine Alluvium under the median case[1] is presented in Figure 3.4. The maximum predicted drawdown in any model cell over the simulation period is 1.1 m. The majority of the Condamine Alluvium is predicted to experience <0.75 m of drawdown. The maximum predicted drawdown along the Condamine River and its tributaries is <0.75 m, noting that where the Condamine River is expected to be connected to groundwater the maximum drawdown prediction is <0.1m (refer Figure 3.5).

CDM Smith carried out an assessment of potential impacts to dependent ecosystems, which found:

- No impact to aquatic ecosystems where the surface water features are already disconnected from underlying groundwater systems. The majority of the length of the Condamine River and its tributaries function as disconnected losing streams (refer Figure 3.5, noting the drawdown presented relates to drawdown in the adjacent aquifer, not a reduction in stream level).
- Three small areas of the Condamine River are predicted to be connected to groundwater (refer Figure 3.5). Where surface water systems are connected to groundwater, and flows are in regulated surface water systems, negligible change to surface water flow regimes are predicted therefore negligible impact to aquatic ecosystems and surface expression GDEs will occur.

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[1] Three simulations out of 200 Null Space Monte Carlo realisations of the Surat CMA Groundwater Model were run with the CCAM to predict impacts to the Condamine River. These simulations were selected based on the predicted change in net vertical flux volumes at the base of the Condamine Alluvium, and defined as the high, median and low cases (5%, 50% and 95% probability of exceedance respectively, from 200 realisations). For the assessment under Condition 13c, the median case simulation has been selected. This simulation is consistent with the calibrated model realisation adopted for the SREIS.

- Where surface water systems are connected to groundwater, and flows are unregulated, very limited to no impact is predicted to aquatic ecosystems and surface expression GDEs based on negligible altered leakage rates over a period of hundreds of years. The rate of change in leakage in affected areas is estimated to be 0.0015 mm/d.
- Negligible impacts to terrestrial GDEs due to relatively small predicted drawdown (<1.1 m) over a long period of time. The resultant rate of change is 1 to 2 mm/year which allows terrestrial GDEs to adapt to the changes.
- Negligible impact to subterranean GDEs due to a small magnitude of drawdown prediction over a long time period resulting in a very low rate of change (1 to 2 mm/year) of watertable elevation which is much less than natural variation or changes induced seasonally by irrigation extraction.

The assumption made by CDM Smith of terrestrial GDE ability to adapt to a very slow decline in watertable is referenced as being supported by a research project carried out as a doctoral thesis (Canham, 2011) that assessed root activity and elongation of Banksia in south-west Western Australia in response to changed groundwater availability.

There is currently a lack of data to support the assumption of root elongation in response to watertable decline, in particular in mature trees, however the predicted rate of decline is considered to be imperceptible in comparison to other natural and anthropogenic factors which result in watertable fluctuations in excess of 10 m on a seasonal basis.

In addition, across the Condamine Alluvium in areas south of Dalby and east of Cecil Plains, groundwater level decline of up to 25 m has been observed since the 1960s (OGIA, 2016b). This drawdown has generally stabilised, and in some areas water level recovery has been observed, however the historical drawdown has resulted in a disconnect between the rooting depth of remnant mature trees and the current groundwater levels in many areas.

3.7. GDE field studies

3D Environmental and Earth Search were engaged by Arrow to carry out a staged desktop assessment and subsequent field surveys (Attachment 2) to advance knowledge of the presence and distribution of GDEs in areas at risk of drawdown due to the SGP.

Stage 1 of the assessment (further detail on the refinement steps is provided in Attachment 2) evaluated potential terrestrial and spring GDEs as follows:

- As a starting point to design more targeted and detailed desktop assessment on potential terrestrial GDEs, the Stage 1 assessments considered:
  - The GDE focus areas (refer Section 3.3).
  - Potential spring targets (132 potential targets) identified by AGE (2013b) via the analysis of remote sensing data, aerial imagery and hydrogeological conceptualisation of the Surat Basin.
  - Potential GDE targets identified in CDM Smith (2016).
- To refine the list of potential GDE sites warranting ground-truthing and further field survey:
  - A detailed review of the outputs of a rapid-eye remote sensing assessment (AGE, 2013b) was undertaken.
  - Additional spatial, ecological, hydrogeological, hydrologic and geological data was collated and reviewed.

The desktop review was able to discount some landscapes as being potential GDEs based on hydrogeological and ecological considerations. Figure 3.6 presents the locations of the preliminary targets and the results of the desktop assessment, which formed the basis for the field studies.

Stage 2 of the assessment comprises targeted field studies to further assess and validate the presence or absence of potential GDEs (refer Figure 3.6 for field study locations). Two field surveys have been carried out, and preliminary results of the combined desktop and field assessments include:

- Potential spring targets (AGE, 2013b) visited were not identified as being artesian discharge springs, or recharge springs.
- A spring site was identified on the boundary of Arrow's tenements (refer Figure 3.6), interpreted to be a recharge / watercourse spring on Wambo Creek. This site correlates with spring complex 765 (Orana), which is listed in the 2016 UWIR as being a Type 4a spring. Type 4a springs are semi-permanent fresh to palustrine wetland springs, mainly fed by local groundwater systems and associated with a riverine environment with deep, sandy alluvial deposits (non-GAB). The source aquifer is attributed to Cainozoic sediments, and the 2016 UWIR spring risk assessment resulted in a risk rating of "low".
- Lake Broadwater is conceptualised to be situated on Westbourne Formation colluvium overlying Westbourne Formation regolith. The deeper weathered profile is expected to be lateritised in places, and the lake is described as being a perched depositional feature on a claypan, with the potential for a deep wetting profile below the regolith. Shallow geological and hydrogeological investigations are proposed to further characterise the potential for aquifer connectivity.
- Long Swamp is conceptualised as being situated on a thick layer of clay to loamy clay that is likely to provide significant resistance to tree root penetration. As with Lake Broadwater, Long Swamp is the subject of ongoing hydrogeological investigations to further characterise the potential for aquifer connectivity.
- Riparian vegetation that represent terrestrial GDEs may be present along significant reaches of some watercourses and their tributaries. This assessment was made based on review of Arrow landowner bore baseline assessment data, UWIR monitoring data and detailed vegetation mapping completed as part of the SREIS. These include reaches of (refer also Figure 3.7):
    - Condamine River
    - Wilkie Creek
    - Wambo Creek
    - Kogan Creek
    - Braemar Creek
    - Dogwood Creek

Where the current assessments do not definitively establish groundwater interaction/dependence potential (i.e. Lake Broadwater) a conservative approach has been adopted and the features remain assessed a potential GDE.

The potential GDE landscape dataset produced as a result of the 3D Environmental and Earth Search assessment process (presented in Figure 3.7, refer also Attachment 2) combines spatial data sets and site-specific observations. It builds on the existing GDE landscape mapping (WetlandInfo, 2015), rationalised with site-specific conceptualisation and knowledge. A key advancement from the WetlandInfo (2015) mapping is the incorporation of detailed ecological knowledge around vegetation rooting depths and likelihood to access groundwater.

The assessment has largely focussed on the Condamine River Alluvium and its tributaries, and is considered to provide a reasonable representation of the potential for vegetation interaction with shallow groundwater in these areas. The data has been used to guide the identification of potential risk areas, where further assessment may be required.

3.8. Aquatic ecosystem assessment

A desktop assessment (refer Attachment 1) was carried out by NRA Environmental Consultants (NRA) to provide a current overview of aquatic ecology and ecosystems present within areas that may be affected by groundwater depressurisation.

In general, environmental conditions with regards to aquatic ecology and aquatic ecosystems were assessed as being highly disturbed, and there is not likely to be significant impacts to aquatic ecosystems as a result of the SGP. Therefore, further detailed site assessment is not considered to be required to inform potential impacts to aquatic ecosystems as a result of CSG depressurisation. Key findings supporting this assessment are summarised in the following sections.

3.8.1. Aquatic ecosystems – riverine

Permanent, semi-permanent and ephemeral watercourses are present, with detailed field studies carried out as part of the EIS/SREIS to characterise the range of site conditions. Fifteen of the 33 sites assessed during the EIS/SREIS are located within the current area of assessment, and water quality, aquatic habitats, macrophytes, aquatic macroinvertebrate and fish surveys were carried out at all 15 of these sites.

The assessments found:

- Water quality characterised by reduced dissolved oxygen concentrations and elevated turbidity indicative of drainage basin or catchment land use.
- No macroinvertebrates of conservation significance were reported.
- Macroinvertebrate communities/populations were relatively similar across sampling sites regardless of land use and/or catchment area, and were typically characteristic of watercourses under altered conditions, primarily water extraction.
- Twenty species of native macrophytes were reported across the broader EIS/SREIS study area, with 16 of these in the current area of assessment. A single Aquatic Conservation Assessment (ACA) listed species (Shiny Nardoo) (*Marsilea mutica)* was reported, along with three introduced species.
- Watercourses had generally uniform macrophyte communities of emergent and floating growth forms. The lack of submergent macrophyte communities was representative of higher turbidity and fluctuating water level. Bank erosion and livestock riparian zone disturbance were also factors in observed emergent macrophyte distribution.
- Fifteen of 20 known Condamine-Balonne native fish species were found during the EIS/SREIS field surveys, including EPBC Act species Murray Cod (*Maccullochella peelii peelii*), and the ACA listed Eel-tailed Catfish (*Tandanus tandanus)*. Further species with local conservation significance were also collected (refer Attachment 1 for further detail). Three introduced species were identified as being widespread across the EIS/SREIS study area.
- Two turtle species, the Murray River Turtle (*Emydura macquarii macquarii)* and the Broad-shelled Turtle (*Chelodina expansa)* were found to be widespread throughout the study area. Neither species are EPBC or NC Act listed.
- Aquatic ecosystems within the current study area were in moderately good ‘health’ with the exception of the Braemar Creek and Myall Creek sites which were considered to be in poor ‘health’.
- Ecological communities (fish, macroinvertebrates and aquatic flora) and habitats were similar across most sites in the study area. All permanent watercourses in the study area contained suitable habitat for the Murray Cod.

The permanent/semi-permanent watercourses, including the Condamine River, Wilkie Creek and Oakey Creek were found to:

- Contain water all year round but in many cases reduced to isolated pools during the dry season.
- Have disturbance level ranging from minimal to high.
- Are unique on a local scale with regards to biota, communities and processes.
- Host areas of good quality aquatic habitat that support a relatively diverse range of species. These biological communities tend to be longer lived in comparison to ephemeral systems and less likely to recolonise following disturbance.

The ephemeral watercourses comprise unnamed 1st or 2nd order systems that flow for a very limited period of the year, and:

- Range from moderately to highly disturbed.
- Provide marginal aquatic habitat, lack of connectivity to larger, permanent waterways, and minimal nursery habitat.
- Are not unique on a local scale.
- Are likely to be used by aquatic flora and fauna tolerant of significant disturbance and adapted to rapidly colonise and regenerate when conditions are suitable.

Environmental Flow Requirements are predicted to continue to be met under the Arrow SGP development proposal for regulated watercourses. Therefore impact to riverine ecosystems in these environments is not expected.

In unregulated watercourses (which correlate with ephemeral watercourses) only limited if any impact is predicted. Should impact occur this affects watercourses with only limited aquatic value, that are not unique on a local or regional scale.

3.8.2. Aquatic ecosystems – non-riverine

Lake Broadwater is a Category A Environmentally Sensitive Area (ESA) under the Queensland Environmental Protection Regulation (2008) and a Nationally Important Wetland under the EPBC Act Protected Matters. Lake Broadwater has high conservation value due to its intactness, the importance of its seasonal aquatic habitat and its potential use by the EPBC Act listed Murray Cod.

As presented in the SREIS, Lake Broadwater is not conceptualised as groundwater dependent. This is based on the description of the Lake in the directory of Nationally Important Wetlands (DoEE, 2017) that it is a shallow lake that fills and occasionally floods following summer rainfall, and recedes afterwards. This assessment is supported by the conceptualisation presented in Section 3.7, which also notes that the assessment around the potential for Lake Broadwater groundwater interaction is ongoing.

Further investigations are being carried out to assess the potential for groundwater-surface water interaction including detailed conceptualisation of aquifer-lake connectivity, and site-specific groundwater level and quality investigations. This will help support the assessment of whether groundwater supports ecosystems associated with Lake Broadwater.

Long Swamp is a palustrine wetland to the north-east Lake Broadwater, considered to be an older course of the Condamine River. It is not classified under state or commonwealth protection legislation but is recognised locally as a natural and important wetland.

Long Swamp has a ‘medium’ to ‘high’ conservation status due to the range of riparian vegetation along the length of the wetland as well as the species diversity and richness. Long Swamp is hydrologically connected to Lake Broadwater, and fills during wet periods.

3.8.3. Subterranean GDEs

Stygofauna have been identified in the Condamine Alluvium (CDM Smith, 2016) and found to be heterogeneously distributed. Limited data is publicly available to assess the presence and distribution of stygofauna across the broader Surat CMA.

Stygofauna can be sensitive to changing water levels or disturbance because they adapt to specific groundwater conditions and can have narrow spatial distributions. If a declining groundwater table exceeds the rate at which they can migrate, or reduce available habitat as strata become unsaturated, then impact will occur. Laboratory-based studies, as described in Stumpp and Hose (2013) have indicated that the response of stygofauna to groundwater drawdown (at rates of between 1,000 to 2,600 mm/day) is taxon specific, with Syncarida being shown to move down through sediments with declining water levels, whereas Copepoda was indicated not to move at a rate commensurate with the watertable decline. In addition, survival of stygofauna decreased with decreasing sediment saturation and that there was limited survival in unsaturated sediment beyond 48 hours.

In areas of the Condamine Alluvium stygofauna have been identified where monitoring records indicate current groundwater level decline at a rate greater than 100 mm/year (0.27 mm/day). The predicted rate of decline as a result of Arrow’s SGP development is in the order of 1 to 2 mm/year (0.0027 to 0.005 mm/day). This rate of change will not be discernible from natural variation (i.e. climatic) and in most areas significantly less than anthropogenic affects (i.e. existing groundwater extraction), hence considered to have a negligible impact on stygofauna.

3.9. Influence of faulting

The hydraulic properties of faults and faulted zones can be highly variable, and faults may act as both a conduit for and barrier to groundwater flow. Where faults act as conduits for groundwater flow, a reduction in groundwater pressure in deeper systems such as the Walloon Coal Measures may result in a preferential pathway for groundwater drawdown in the overlying watertable, which could result in impact to terrestrial GDEs.

As not all fault structures can be accurately represented in the regional groundwater flow model due to the limitations of both model cell size and fault data, consideration of the potential for faults to provide a hydraulic connection between depressurised coal formations and overlying aquifers has been made to provide further confidence in the modelling predictions used to assess potential impact to terrestrial GDEs.

A review of the available information shows that regional-scale faults in the Surat CMA with significant displacement are indicated to be restricted to formations in the underlying Bowen Basin and do not typically extend to the overlying formations of the Surat Basin (QWC, 2012, Sliwa, 2013, OGIA 2016). Within the overlying Surat Basin the most common faults are steeply dipping normal faults. These faults are considered to be relatively minor structural features with throws that are generally less than 20 m.

Sliwa (2013) reports that the mild deformation observed in Surat Basin rocks post-dates deposition, and a phase of rift-style normal (extensional) faulting has occurred. This was followed by a return to compressional tectonics that resulted in mild reactivation of the Moonie-Goondiwindi Fault system (located to the west of Arrow’s tenements), partial inversion of some normal faults, tightening of the underlying Bowen Basin folds, and development of gentle folding in overlying younger Surat rocks (Sliwa, 2013).

A low angle unconformity between the upper-most coal seams of the Walloon Coal Measures and the overlying Springbok Sandstone is indicated through seismic analysis. Sliwa (2013) reports that from the seismic data none of the Surat normal faults were found to propagate vertically to an extent sufficient to terminate against the Springbok unconformity. This indicates that the period of normal faulting is likely to have occurred during or prior to the end of Walloons deposition, prior to the subsequent erosional period and low angle unconformity, and prior to the deposition of the Late Jurassic Springbok Sandstone.

Hence, it is concluded, based on the seismic evidence, and also by inference due to the timing constraints that the fault structures do not extend to the Springbok Sandstone. Therefore in the SGP area fault induced drawdown propagation across the Springbok, or younger formations including the Westbourne Formation and Gubberamunda Sandstone is not expected.

In addition, hydrothermal precipitation and induration may have led to sealing of fault damage zones since Jurassic times. Because the Surat Basin remains relatively stable/inactive tectonically, fault permeability is expected to continue to decrease over time (OGIA, 2016a).

The majority of faults in the Surat CMA are therefore not expected to provide a conduit for vertical flow from overlying aquifers to the coal measures. In addition, OGIA (2016a) report that as the coal seams within the major gas reservoirs generally represent less than 10% of the unit thickness, any displacement is likely to result in a barrier to horizontal groundwater flow as the more permeable coal seam is juxtaposed with a low-permeability siltstone, claystone or mudstone.

OGIA modelling of faults

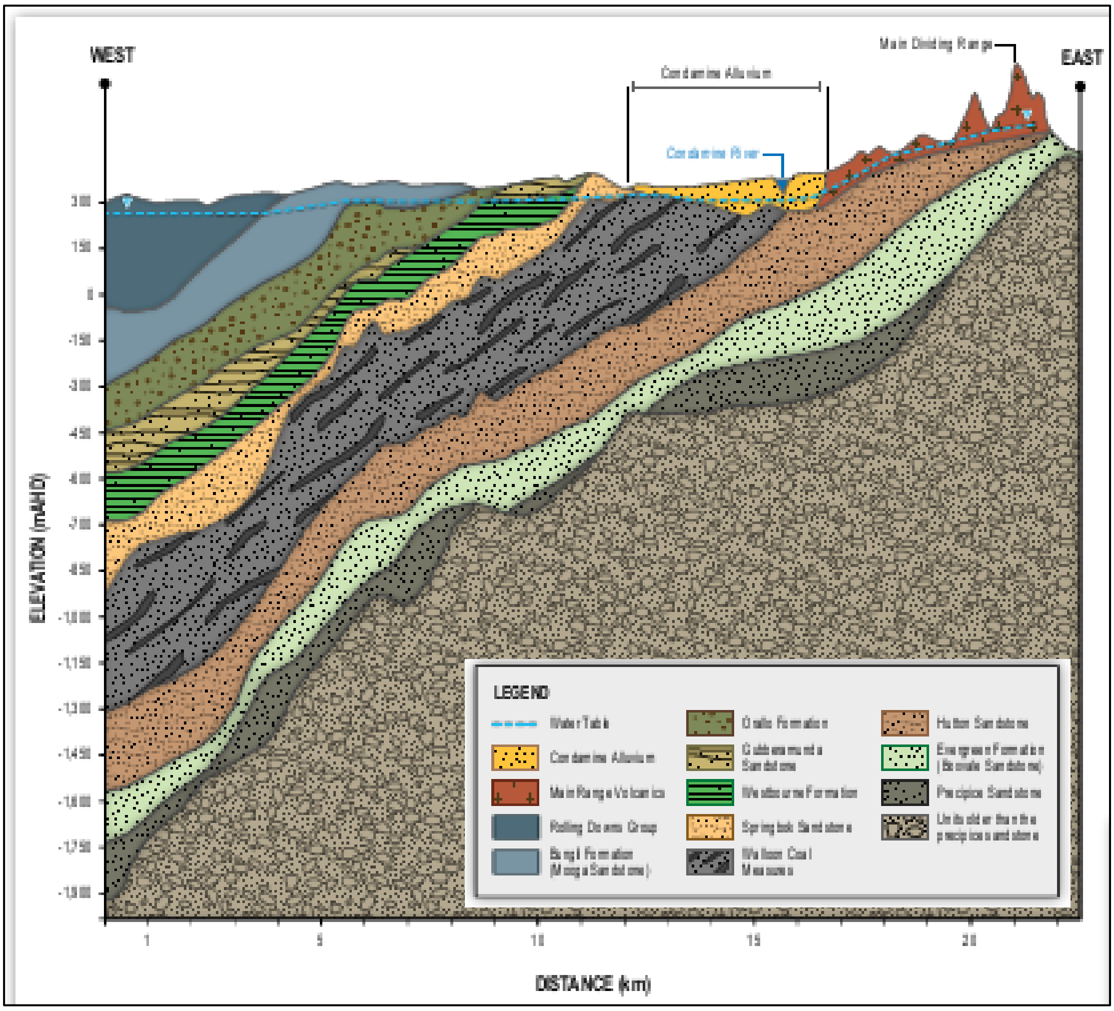
The 2016 OGIA groundwater model adopted a revised geological model which includes the representation of major geologic faults. Coffey (2016) presents a comparison of the 2016 UWIR and the 2012 UWIR modelled drawdown. The Springbok Sandstone long-term affected area (LAA) is smaller in the 2016 UWIR than assessed in 2012. OGIA (2016a) states that this reflects the generally lower vertical permeability resulting from parameterisation and calibration of the new groundwater flow model, which includes an improved representation of faults (refer Figure 3-5 of OGIA, 2016).

As a result fault structures in the Surat Basin are not considered likely to present a significant risk to terrestrial GDEs with regards to the potential for modelling predictions to have under-represented this potential flow pathway. The potential influence of faulting on groundwater flow is continuing to be assessed (OGIA, 2016a).

3.10. Influence of the Westbourne Formation

The presence of the Westbourne Formation plays an important role in the prediction of impact propagation to shallow aquifers. Where present, it will limit the potential for the propagation of drawdown to surficial aquifers, therefore limit the potential for impact to terrestrial GDEs as a result of the Action. Schematic 3.2 illustrates the presence of the Westbourne Formation, and conceptually shows that it is generally present to the west of the Condamine Alluvium, and absent to the east.

Since the SREIS, effort has been directed to refining the understanding of the Westbourne Formation subcrop extent. The interpreted boundary based on work completed by AGE (2013) is presented in Figure 3.1.



Schematic 3.2: Schematic cross section of Condamine Alluvium and underlying units (source: adapted from GHD, 2013)

There remains uncertainty around this extent, and the interpreted boundary will continue to be refined as further data becomes available. The impact assessment completed for this Stage 1 WMMP incorporates some conservatism regarding the inferred subcrop extent of the Westbourne Formation to recognise the uncertainty around the extent. This is discussed in further detail where relevant in Sections 5 and 6.

3.11. Summary of identified or potential GDEs landscapes

Knowledge around potential GDEs in the Surat CMA has developed significantly in recent years. Based on the information presented in the preceding sections, the following potential non-spring GDE landscapes will be carried through further assessment to identify and assess potential impact as a result of Arrow’s proposed SGP (refer also Figure 3.8):

- Potential terrestrial GDE landscapes (WetlandInfo, 2015) with an assigned groundwater dependence potential of either known, high or moderate.
- Riparian environments along the Condamine River, Wilkie Creek, Wambo Creek, Kogan Creek, Braemar Creek and Dogwood Creek.

4. Groundwater modelling

The SGP Stage 1 CSG WMMP Groundwater modelling technical memorandum (Coffey, 2016) sets out the modelling basis that will be adopted for the assessment of impacts. The approved approach is summarised in Table 4.1, and the modelling outputs that will be adopted for addressing Conditions 13c and 13p are also specified.

Consistent with the SREIS where the calibration realisation outputs were adopted for assessment, the median case has been adopted for CDM Smith modelling outputs. The predicted drawdown extents (> 1m) for the major aquifers are presented in the figures referenced in Table 4.1. There is no drawdown >1 m predicted under the Arrow-only calibration realisation in units shallower than the Springbok Sandstone or deeper than the Precipice Sandstone.

Table 4.1: Summary of groundwater modelling bases for assessment of impact

Approval Condition	Model basis	Reliance on	Adopted modelling outputs	Relevant figures
13(c) An assessment of potential impacts from the action on non-spring based GDEs through potential changes to surface groundwater connectivity and interactions with the sub-surface expression of groundwater.	CDM Smith Condamine Alluvium Model	Predicted groundwater drawdown and groundwater-surface water connectivity between the Condamine Aquifer and the Condamine River, at times relevant to monitoring.	Arrow-only maximum drawdown – median case.	Figure 3.4 Figure 3.5
	CDM Smith IQQM model	Predicted groundwater drawdown and groundwater-surface water connectivity between the Condamine Aquifer and the Condamine River, at future times as relevant to monitoring.	Arrow-only maximum drawdown – median case.	-
	Arrow SREIS Groundwater Model	Predicted groundwater drawdown in the surficial aquifers other than the Condamine Alluvium, at future times as relevant to monitoring.	Arrow-only calibration realisation maximum drawdown.	Figure 4.1 Figure 4.2
13(p) A cumulative impact assessment based on the outputs of the OGIA model which integrates groundwater model outputs with known and potential GDEs and presents the outputs in map form. Contribute to investigations coordinated through the OGIA to assess hydrological and ecological characteristics of impacted GDEs.	CDM Smith Condamine Alluvium Model	Predicted cumulative groundwater drawdown.	Cumulative median case.	Figure 4.3

Approval Condition	Model basis	Reliance on	Adopted modelling outputs	Relevant figures
	Arrow SREIS Groundwater Model	Cumulative groundwater drawdown in formations and relationship with known GDEs - for Surat formations such as the Walloon Coal Measures, adjacent GAB formations that may be indirectly depressurised, and the Condamine Alluvium aquifer. To consider SREIS GDE assessment drawdown extents.	Cumulative calibration realisation maximum drawdown.	Figure 4.4

5. Condition 13c: GDE impact assessment

5.1. Potentially affected terrestrial GDEs

The non-spring GDE landscapes defined in Section 3.10 were mapped against Arrow-only maximum drawdown predictions. As non-spring GDEs will be dependent on the watertable aquifer, drawdown predictions were initially assessed against formation outcrop and subcrop to identify where drawdown may be associated with the watertable and have the potential to affect terrestrial GDEs.

As outlined in Section 4, there is no predicted drawdown in the Bungil Formation and Mooga Sandstone, or the Gubberamunda Sandstone under the Arrow-only maximum drawdown scenario. In addition, the Hutton and Precipice Sandstones do not subcrop or outcrop in areas of predicted drawdown. Therefore drawdown impact associated with these formations is not considered further in this assessment for Condition 13c.

5.1.1. Condamine Alluvium

Figure 5.1 presents the predicted drawdown in the Condamine Alluvium under the Arrow-only median case, together with the terrestrial GDE landscapes identified in Section 3.10. This shows that no terrestrial GDEs are associated with the small areas of >0.75 m drawdown in the Condamine Alluvium therefore impact to terrestrial GDEs in the Condamine Alluvium is not considered further in this assessment for Condition 13c.

5.1.2. Springbok Sandstone

Figure 5.2 presents the extent of predicted groundwater drawdown in the Springbok Sandstone overlain with formation outcrop/subcrop extent, and the terrestrial GDEs defined in Section 3.10. The formation subcrop extent is that of the Kumbarilla Beds owing to the poor distinction between the units that make up the Kumbarilla Beds in this part of the Surat CMA.

Figure 5.2 presents the inferred extent of the Westbourne Formation subcrop. To the east of this boundary the Westbourne Formation is not considered to be present (refer Schematic 3.2), therefore the Springbok Formation may form the watertable aquifer. To the west of this boundary the Westbourne Formation is inferred to be present and acts as an aquitard, limiting the potential for the propagation of drawdown impacts to the watertable aquifer. In these areas, the Gubberamunda Sandstone (or shallower formations) are considered to be present and represent the watertable aquifer.

The inferred subcrop boundary shown in Figure 5.2 has been used to identify areas where the Springbok Sandstone may form the watertable aquifer (i.e. east of the Westbourne subcrop boundary) and therefore where drawdown predicted in the Springbok Sandstone may affected terrestrial GDEs.

Some uncertainty around the precise location of this boundary is acknowledged, therefore potential terrestrial GDEs that overlie areas of predicted drawdown (>1m) in the Springbok Sandstone to the east or in the immediately vicinity west of this boundary have been assessed. A buffer of around 5 km to the west of the Westbourne Formation subcrop extent has been adopted as the extent for inclusion in the assessment, however immediately west of Cecil Plains where more significant areas of potential terrestrial GDEs are mapped, the assessment area extends up to 14km west of the Westbourne Formation subcrop extent. This provides a conservative assessment of the potential area where the Springbok Sandstone may represent the watertable aquifer.

Interpreted faults are also presented on Figure 5.2 which indicates the presence of some major fault structures within and in the vicinity of the SGP area, including where drawdown is predicted. As discussed in Section 3.9 the normal faults associated with the Surat Basin are interpreted to terminate below the Springbok Sandstone therefore do not provide a pathway for drawdown propagation to the watertable where hosted in the Springbok Sandstone (or younger formations).

Based on this assessment, three main areas have been identified where terrestrial GDEs may be at risk of drawdown impact (refer Figure 5.2). These areas are described as:

- Risk area 1: located on Arrow tenements between Miles and Wandoan where an area of drawdown predicted in the Springbok Sandstone coincides with Kumbarilla Bed outcrop and potential terrestrial GDEs.
- Risk area 2: west of Dalby on the western extent of Arrow's tenements where uncertainty remains around Westbourne Formation extent and a small number of terrestrial GDEs are mapped over Kumbarilla Bed outcrop. Further south west where larger areas of GDEs are mapped, the likely presence of Westbourne Formation limits potential for drawdown propagation, and risk to terrestrial GDEs is considered very low and therefore not considered further in this assessment.
- Risk areas 3a and 3b: areas west (3a) and south-west (3b) of Cecil Plains where Kumbarilla Beds outcrop and uncertainty remains around extent of Westbourne Formation subcrop. Risk area 3a represents a significant area of mapped potential terrestrial GDEs with this continuing south (Risk area 3b) to the southern-most extent of Springbok Sandstone drawdown prediction.

It is noted that Lake Broadwater and Long Swamp overlie areas of predicted drawdown in the Springbok Sandstone. They are situated close to, but not overlying a region of Springbok Sandstone outcrop therefore are not considered as a risk area under this assessment. As presented in Section 7 it is conceptualised that Lake Broadwater is positioned upon Westbourne Formation and Long Swamp flows across the Condamine Alluvium. Both surface water features are the subject of ongoing investigations and monitoring.

5.1.3. Walloon Coal Measures

Figure 5.3 presents the extent of groundwater drawdown in the WCM overlain with formation outcrop/subcrop extent, and the terrestrial GDEs defined in Section 3.10. The assumed formation extent includes the Injune Creek Group to account for the poor distinction of the WCM in the northern study area.

Figure 5.3 shows an area near Wandoan in the northern-most part of Arrow's tenements where a small area of mapped terrestrial GDEs overlie predicted drawdown in the WCM. These areas are associated with local drainage lines, and review of available borelogs indicates that the Westbourne Formation and/or Springbok Formation generally outcrop in these areas.

However there is the potential for shallow subcrop of the Walloon Coal Measures, and as a conservative approach this small area has been considered further in the assessment of potential impacts (risk area 4).

5.2. Impact assessment

The terrestrial GDEs potentially at risk from drawdown as identified in Section 5.1 have been further assessed to determine their likelihood of being actual GDEs as well as the significance of impact should it occur.

The assessment of impact is based initially on a more detailed assessment of whether the potential GDEs are likely to rely on groundwater. This included a detailed review and conceptualisation of:

- Available groundwater level and pressure data.
- Borehole logs and indicated stratigraphy.
- Soil types and landscape setting.
- Vegetation types present and knowledge around their associated groundwater dependence.

Figure 5.4 presents the locations of referenced boreholes, indicating depth to groundwater where available. Further detail supporting the assessment of individual areas potentially at risk of drawdown is presented in the Figure 5.5 series.

Where there is sufficient data to demonstrate the ecosystems do not rely on groundwater, no further assessment has been made. Where it is considered likely the ecosystem relies in some way on groundwater, or where there is insufficient data to rule it out, an assessment of the potential impact based on the predicted magnitude has been made. This includes consideration for the rate of change, in particular in comparison to historic groundwater level trends, and an assessment of the adaptability of the vegetation present to changing groundwater levels.

The assessment of potential impact to terrestrial GDEs adopted here is based on detailed review of physical data related to each risk area rather than the application of a risk/impact assessment matrix. In this instance it is considered the most appropriate process as it provides a more detailed and site-specific assessment of the potential for impact to occur and provides a robust basis for the identification of ongoing monitoring and management requirements.

5.2.1. Risk area 1

Arrow's monitoring bore (Kedron 570) is located within Risk Area 1 (refer Figure 5.5a) and indicates a potentiometric surface in the Springbok Sandstone of 29.8 m below ground level. The hydrograph for this bore (refer Attachment 3) indicates relatively stable groundwater levels in the Springbok Sandstone since 2013. The borehole stratigraphy for RN160574 to the south of Risk Area 1 indicates Gubberamunda Sandstone underlain by up to 50 m of Westbourne Formation. The borelog for Kedron 570 (RN160348) indicates the Westbourne Formation to a depth of 38.3 m, therefore it can be concluded that in these areas the Springbok Sandstone does not represent the watertable aquifer at a depth that would be utilised by terrestrial or riparian ecosystems.

In addition, to the south-west of Risk Area 1, two additional landowner bores (RN58891 and RN58876) are both listed as screening Gubberamunda Sandstone (OGIA aquifer attribution reports based on best available information) and have groundwater levels of 42 m and 63 m below ground surface respectively. Whilst these bores are around 5 km south-west of Risk Area 1, they demonstrate the likely presence of the Gubberamunda Sandstone at depth and support the assessment of the Springbok Sandstone being beyond the rooting depth of terrestrial vegetation in the area.

The dominant RE types present within Risk Area 1 include RE 11.5.21, 11.7.4, 11.7.5 and 11.7.6 (refer Figure 5.5a) which are listed as being of least concern under the Vegetation Management (VM) Act and of no biodiversity concern at present. These are dominated by Ironbark species which typically have root architecture concentrated in the upper soil layers (<4 m below ground) with limited potential to tap deep groundwater (3D Environmental and Earth Science, 2017, refer Attachment 2). Within the SGP study area, Ironbark species form the dominant canopy species over extensive colluvial outwash, decomposed sandstone and indurated sandstone jump-ups (3D Environmental and Earth Science, 2017), consistent with the landscape setting of Risk Area 1. 3D Environmental and Earth Science (2017) state that in this setting, Ironbark species have limited potential to tap deeper groundwater sources and the species relies on soil moisture in the upper soil profile.

Based on this area-specific information the ecosystems identified in Risk Area 1 as described in Section 5.1.2 are not considered to be dependent on groundwater therefore are not considered to be at risk of drawdown-related impacts.

5.2.2. Risk area 2

Risk area 2 is located west of Dalby (refer Figure 5.5b). UWIR and Arrow monitoring locations to the west of Risk Area 2 indicate groundwater levels in the Springbok Sandstone of between 21-55 m below ground surface. Arrow landowner baseline assessment reports indicate depth to groundwater levels in the order of 38 to 45 m in the northern parts of Risk Area 2. The screened depth is not clear for these three bores, and they're likely to be representative of deeper units and not the watertable.

Importantly though, the bore reports indicate a thick sequence of Westbourne Formation overlying deeper Springbok Sandstone. This is supported across a number of bore reports in the vicinity of Risk Area 2 including RN94461A, RN160350, RN160553, RN160349, RN42231258A. The presence of >30m of Westbourne Formation across this area indicates the Springbok Sandstone does not represent the watertable aquifer at depths accessible to GDEs.

Further south, borehole geology (RN44586, RN94052, RN119423) indicates the presence of Condamine River Alluvium to depth of at least 30 m. It can reasonably be assumed therefore that the Springbok Sandstone does not form the watertable aquifer at a depth that would be accessible to GDEs in this area either.

Figure 5.5b presents the mapped REs along with borehole locations and depth to groundwater information. The dominant RE types present within Risk Area 2 include 11.3.18, 11.5.1, 11.7.4, 11.7.7, 11.5.1a and 11.3.2. Some areas of RE 11.3.25 (River Red Gum) being the less dominant species are also present. 3D Environmental and Earth Search (2017) also indicate the presence of RE 11.3.3, 11.3.4, 11.3.17 and 11.3.27c.

In general the additional REs identified by 3D Environmental and Earth Search (2017) are associated with the western extent of the Condamine River Alluvium therefore do not relate to the assessment of Risk Area 2 (i.e. risk associated with drawdown in the Springbok Sandstone).

The landscape setting of Risk Area 2 is that of elevated, slightly undulating terrain on the eastern slopes of the Kumbarilla Ridge. The Kumbarilla Beds outcrop along this generally north-south trending ridgeline, and in some parts are overlain by alluvial and colluvial sediment (3D Environmental and Earth Search, 2017). These landscapes are characterised by extensive stands of Ironbark forest and as discussed in Section 5.2.1, REs 11.5.1, 11.7.4, 11.7.7 and 11.5.1a are not associated with a deep root architecture and groundwater dependence.

Depth to groundwater data within and in the immediate vicinity of the Risk Area 2, combined with the presence of a thick sequence of Westbourne Formation in the north, the presence of a thick sequence of Condamine River Alluvium in the south and vegetation characteristics, support an assessment that the Springbok Sandstone does not form the watertable aquifer in Risk Area 2 at a depth that would support terrestrial or riparian GDEs.

5.2.3. Risk areas 3a and 3b

Risk Areas 3a and 3b are located west and south-west of Cecil Plains on the western slopes of the Kumbarilla Ridge. Some depth to groundwater data is available along the eastern margins of these risk areas, however limited data exists elsewhere within Risk Areas 3a and 3b (refer Figure 5.5c).

Depth to groundwater data along the eastern margin of Risk Area 3a indicates groundwater in the Springbok Sandstone of around 16-18 m below ground (RN137574 and RN22377). Glenburnie-18 (RN160941) indicates a deeper groundwater level in the Springbok Sandstone of around 44 m below ground, however is not considered to represent the watertable aquifer as the Westbourne Formation is reported from 10 to 57.02 m below ground.

The dominant RE types within Risk Areas 3a and 3b include (refer also Figure 5.5c):

- 11.3.2
- 11.3.14
- 11.3.25
- 11.3.18
- 11.5.1 + 11.5.1a
- 11.5.4 + 11.5.4a
- 11.5.20
- 11.7.4
- 11.7.7

The majority of REs across Risk Areas 3a and 3b are 11.5.4, 11.5.4a, 11.5.1, and 11.5.20 with these REs representing around 97% of the mapped terrestrial GDEs in Risk Areas 3a and 3b. These are dominated by Ironbark species that are not associated as being groundwater dependent due to their shallow rooting depth and tendency to rely on soil moisture in the upper soil profile.

Small areas of REs that contain vegetation that has an established association with groundwater (RE11.3.25 and 11.3.14, and to a lesser degree 11.3.2) are located within the relatively cleared areas of Risk Area 3a immediately west of the Condamine River Alluvium on the eastern slopes of the Kumbarilla Ridge. Borehole geology for nearby RN160732 indicates 16 m of Condamine River Alluvium underlain by 10 m of Westbourne Formation. RN42230091 is logged with Condamine River Alluvium to a depth of >50 m and RN107689 is interpreted as having Condamine River Alluvium to a depth of 27m. The borehole logs indicate that in these areas a sequence of alluvial material typically underlain by the Westbourne Formation is present, which is consistent with the interpreted boundary of the Westbourne Formation subcrop to the east (refer Figure 5.5.c). Therefore it is concluded that these ecosystems in Risk Area 3a are not dependent on a watertable aquifer hosted in the Springbok Sandstone.

In Risk Area 3b, REs 11.3.25 and 11.3.14 are mapped along local drainage lines in the northern part of the area. These REs contain species that are known to have an association with groundwater (River Red Gum and Rough-barked apple respectively). In this area, borehole geology (RN160941) indicates 10m of Condamine River Alluvium underlain by 47m of Westbourne Formation, consistent with this area being west of the Westbourne Formation inferred subcrop extent. The Springbok Sandstone therefore will not represent the watertable aquifer in this area.

In the south of Risk Area 3b RE 11.3.25 is present although not as the dominant RE. Borehole records for RN32726A indicates groundwater depth in the Springbok Sandstone may range from 14.6 to 23.5 m. This borehole is located relatively close to a drainage line. Where River Red Gums are present, they may access deeper groundwater. Other species present such as Poplar Box are unlikely to access groundwater in the Springbok Sandstone in this area due to their limited rooting depth (<12m).

In this part of Risk Area 3b the maximum predicted drawdown is 3.9 m with a rate of change of groundwater drawdown estimated to range between 0.07 to 0.3 m/yr based on hydrographs UW_1, UY_1 and U111_1 (refer Figure 2.2 and Attachment 4). Historically groundwater levels in the Springbok Sandstone measured at Glenburnie-18 have fluctuated in the order of 0.1 to 0.5 m per day, however the Springbok Sandstone does not represent the watertable aquifer at this location. Greater variability is expected where it does, indicating the predicted rate of change is within the historical range of variability. However, the overall drawdown of almost 4 m in this southern part of Risk Area 3b may result in vegetation stress if critical groundwater access thresholds are exceeded. Therefore terrestrial GDEs in the southern part of Risk Area 3b are potentially at risk from groundwater drawdown.

5.2.4. Risk area 4

Risk Area 4 is located to the south and west of Wandoan and is associated with potential areas of shallow Walloon Coal Measures subcrop. The landscape is a steep escarpment that has exposed Injune Creek Group formations, and local drainage lines have incised the landscape. As discussed in Section 5.1.3, the Westbourne Formation and Springbok Sandstone (upper members of the Injune Creek Group) generally outcrop in this area, as well as shallow alluvial deposits along some drainage lines.

3D Environmental and Earth Search (2017) describe characteristic heavy clays and rocky lag deposited on the surface of low rounded hills formed on fine grained sedimentary rock indicating some vegetation species will have difficulty penetrating this soil profile.

In the northern parts of Risk Area 4 depth to groundwater information indicates groundwater in shallow Walloon Coal Measure may be between 13 and 16 m below ground surface (RN123265, RN44044, RN13831). Shallow bores screening the Springbok Sandstone (AES1393, AES1394, RN58519) also demonstrate a relatively shallow watertable (~6.5 to 9.7 m below ground).

RN160677 screens a deep, confined section of the Walloon Coal Measures (Lower Jundah seam) with indicated artesian conditions. Some available bore reports indicate water strikes at depth of around 19m in shale and coal lithology (RN44044).

Further south there is limited groundwater depth information for the Walloon Coal Measures and review of the borehole logs for RN10848 and RN48852 indicates at least 60 m of Orallo Formation therefore shallow subcrop of the Walloon Coal Measures is not present in this area.

The RE types present within Risk Area 4 include 11.3.2, 11.3.25, 11.5.21, 11.7.4, 11.9.5 and 11.9.10. RE 11.3.25 which is dominated by *Eucalyptus camaldulensis* (River Red Gum) is mapped as being present along a number of the gullies within Risk Area 4 and is known to have the potential to access deeper groundwater. As previously discussed, RE 11.3.2 is not expected to be dependent on groundwater >12m below ground surface.

RE 11.3.25 is present in the identified risk area at all locations with the exception of one small area at the southern end of Risk Area 4 where only RE 11.5.21, 11.7.4 and 11.5.4 are mapped. These are not considered to be groundwater dependent.

Maximum predicted drawdown in the Walloon Coal Measures in Risk Area 4 ranges from 1.5 to 10 m. The rate of groundwater drawdown in the Walloon Coal Measures in this area may be up to 4 m/yr early in the project life based on hydrographs GG_1 and HH_1 (refer Figure 2.2 and Attachment 4). Given this potential rate of change and the potential for the presence of River Red Gums, terrestrial GDEs in the northern parts of Risk Area 4 may be at risk of impact from groundwater drawdown in the Walloon Coal Measures.

5.3. Management measures

Specific management measures for non-spring GDEs are not set out in the SREIS. The development of appropriate management measures, including an early warning system for GDEs that may be impacted by the project, is required under Approval Conditions 13(j) and 13(k) and will be addressed in separate memoranda.

5.4. Condition 13c conclusions

The assessment in Section 5.2 demonstrates:

- Ecosystems in Risk Area 1 are not dependent on groundwater, therefore not at risk from Project-related drawdown.
- Ecosystems in Risk Area 2, 3a and the northern parts of 3b are not dependent on a watertable aquifer in the Springbok Sandstone, therefore not at risk from Project-related drawdown.
- Ecosystems in the southern part of Risk Area 3b may be dependent on groundwater in the Springbok Sandstone and may be impacted by project-related groundwater drawdown.
- Ecosystems in the northern parts of Risk Area 4 may be dependent on shallow groundwater in the Walloon Coal Measures and may be impacted by project-related groundwater drawdown.
- Ecosystems in the southern part of Risk Area 4 are either not groundwater dependent or not dependent on a watertable aquifer in the Walloon Coal Measures, therefore not at risk from Project-related drawdown.

Detailed vegetation surveys are currently being carried out across Arrow’s tenements to refine the RE mapping. This will provide for improved knowledge around the presence and distribution of vegetation types that are likely to access groundwater (in particular River Red Gum) in the southern parts of Risk Area 3b and the northern parts of Risk Area 4.

Further site-specific assessment is recommended to refine the conceptual understanding of the potential for ecosystem interaction with groundwater in these two areas. In addition, ongoing monitoring of groundwater levels and quality at defined locations is carried out in accordance with the requirements of the Surat CMA UWIR Water Monitoring Strategy. This provides for the ongoing assessment of all major aquifers, against which future numerical modelling may be calibrated. Future modelling will be used to refine the findings of this assessment (where required) and assess whether monitoring or management measures are needed.

6. Condition 13p: Cumulative impact assessment

As set out in Section 2.2.1, OGIA is responsible for the management of cumulative impact within the Surat CMA, and the UWIR assigns responsible tenure holders for monitoring and management of springs where they may be affected by CSG development.

The extent of predicted maximum cumulative drawdown, defined as the 1 m drawdown contour, is presented in Figure 4.3 (consolidated aquifers) and Figure 4.4 (Condamine Alluvium).

The magnitude and extent of potential drawdown in non-Condamine Alluvium aquifers (Figure 4.3) has increased in comparison to the Arrow-only predicted drawdown (Figures 4.1 and 4.2), primarily extending further west onto other tenure holder land. In accordance with the way in which OGIA assign responsibility of impact assessment and management in the Surat CMA UWIR, this places responsibility in the hands of the relevant other tenure holder in these areas.

A summary of the predicted cumulative impact 1 m drawdown extent is provided in Table 6.1 with commentary on inferred responsible tenure holder.

Table 6.1: Summary of Arrow's cumulative impact assessment requirements

Aquifer	Predicted cumulative drawdown extent – comparison to Arrow-only scenario	Assessment to meet Condition 13p
Condamine Alluvium	Increased magnitude and extent of predicted drawdown across the Condamine, with the majority of the Condamine Alluvium model extent predicting >0.25m drawdown. Maximum predicted drawdown is 1.5 m.	Additional extent assessed.
Bungil Formation / Mooga Sandstone	No Arrow-only drawdown predicted. Cumulative impact is entirely off Arrow tenure.	Not assessed further.
Gubberamunda Sandstone	No Arrow-only drawdown predicted. Cumulative impact is primarily off Arrow tenure, with small areas of drawdown predicted on western margins of Arrow tenements.	Small areas on tenure assessed.
Springbok Sandstone	Predicted cumulative impact is primarily off Arrow tenure, however there is additional extent of predicted impact along western margins of Arrow tenements and to the south.	Additional areas on tenure assessed.
Walloon Coal Measures	Arrow-only scenario predicted drawdown across most of Arrow tenements. Minor increase in extent under cumulative scenario.	Additional areas on tenure assessed.
Hutton Sandstone	Substantially greater drawdown predicted both on and off tenure.	Additional areas on tenure assessed.
Precipice Sandstone	Main area of predicted drawdown located away from Arrow tenure. Small areas of predicted drawdown along western margins on Arrow's tenements.	Small areas on tenure assessed.
Clematis Sandstone	Entirely off Arrow tenure.	Not assessed further.

6.1. Potentially affected terrestrial GDEs

A preliminary screening of predicted drawdown extent against mapped formation outcrop and subcrop shows that there is no predicted drawdown (>1m) in the corresponding locations where the Hutton Sandstone and Precipice Sandstone outcrop or shallow subcrop and may form the watertable aquifer (refer Figures 6.1 and 6.2). Therefore potential impact to terrestrial GDEs (including riparian vegetation) as a result of drawdown in these aquifers has not been assessed further.

6.1.1. Condamine Alluvium

Localised areas exist where there is >1 m drawdown predicted in the Condamine Alluvium under the cumulative scenario (adopting the maximum predicted drawdown under the median case) assessed by CDM Smith (2016). As presented in Figure 6.3, none of these areas coincide with locations of mapped potential terrestrial GDEs therefore impact to terrestrial GDEs in the Condamine Alluvium is not considered further in this assessment for Condition 13p.

6.1.2. Gubberamunda Sandstone

Two small areas (refer Figure 6.4) have been identified where >1 m drawdown is predicted in the Gubberamunda Sandstone that coincides with formation outcrop, WetlandInfo (2015) mapped terrestrial GDEs (high and moderate potential only) and are where Arrow would be considered the responsible tenure holder (i.e. on Arrow tenure). These areas are:

- Cumulative risk area 1 - located in Arrow’s northern tenements on the western boundary where the Kumbarilla Beds are mapped as outcropping.
- Cumulative risk area 2 - due east of Miles on the margin of potential Gubberamunda Sandstone outcrop.

6.1.3. Springbok Sandstone

In addition to those areas identified and assessed under the Arrow-only scenario, four areas have been identified where >1 m drawdown is predicted in the Springbok Sandstone that are coincident with Kumbarilla Bed outcrop, WetlandInfo (2015) mapped terrestrial GDEs (high and moderate potential only) and where Arrow would be considered the responsible tenure holder (i.e. on Arrow tenure) (refer Figure 6.5). These areas are:

- Cumulative risk area 3 - located south of Arrow-only risk area 1, east of Miles. This coincides with cumulative risk area 2 (Gubberamunda Sandstone),. The source aquifer for the potential GDEs will depend on the site-specific stratigraphy.
- Cumulative risk area 4 - a very small area located west of Chinchilla were minor drainage lines are mapped as being potential terrestrial GDEs.
- Cumulative risk area 5 - an extension north to the Arrow-only risk area 2.
- Cumulative risk area 6 - an extension south to the Arrow-only risk area 3b.

6.1.4. Walloon Coal Measures

The Walloon Coal Measures (including Injune Creek Group mapped extent) outcrop in a small area in the north of Arrow’s tenements, as described in Section 5.1.3. The extent of potential terrestrial GDEs in this area that may be impacted by groundwater drawdown based on cumulative impact predictions do not differ from the Arrow-only case (refer Figure 5.5d). Therefore the conclusion of potential for impact as set out in Section 5.1.3, also applies for the cumulative case.

6.1.5. Responsible tenure holder for cumulative impacts

OGIA are responsible for assigning a responsible tenure holder (RTH) for the monitoring and management of cumulative impacts. There is currently no process for assigning the RTH for non-spring GDEs, however it is noted that future iterations of the Surat CMA UWIR are likely to include this aspect.

In the absence of a formal OGIA framework, Arrow consider an appropriate approach to include:

- Where impacts are located on an existing petroleum license (PL) tenure, the relevant tenure holder will be the RTH.
- Where impacts are located off a PL tenure (i.e. off tenure or on an Authority to Prospect), consideration for the proponent causing the first impact in assigning the RTH.

6.2. Impact assessment

6.2.1. Cumulative Risk Area 1

Cumulative Risk Area 1 is located immediately west of Arrow-only Risk Area 1 (refer Figure 6.6a). As described in Section 5.2.1, data from baseline assessments of landowner bores reported as likely to be screening the Gubberamunda Sandstone in this area indicate depth to groundwater of >40m. Borehole RN42220059 to the west of Cumulative Risk Area 1 indicates 125 m of Orallo Formation, however as it is the boundary of the Orallo Formation subcrop extent and reported as being underlain by Injune Creek Group, the lower part of the Orallo Formation may in reality be Gubberamunda Sandstone.

Dominant RE types in the risk area include 11.5.21, 11.7.4 and 11.7.6. As discussed in Section 5.2.1 these are dominated by Ironbark species which typically have root architecture concentrated in the upper soil layers (<4 m below ground), rely on soil moisture in the upper soil profile and limited potential to tap deeper groundwater.

Based on this area-specific information the ecosystems identified in Cumulative Risk Area 1 are not considered to be dependent on groundwater therefore are not considered to be at risk of drawdown-related impacts.

6.2.2. Cumulative Risk Area 2 and 3

Cumulative Risk Areas 2 (Gubberamunda Sandstone drawdown risk) and 3 (Springbok Sandstone drawdown risk) coincide (refer Figure 6.6a) as a result of the assessment process adopting the Kumbarilla Bed outcrop/subcrop geological mapping in this area.

Within this area, the Orallo Formation is reported to at least 65m in the stratigraphic log for RN13602. This conflicts with the approximate subcrop extent of the Orallo Formation being further west. Risk Area 3 is located 3 to 4 km west of the Westbourne Formation subcrop extent, therefore it is inferred there is a significant depth of formation overlying the Springbok Sandstone in this area. Cumulative Risk Area 3 has not been considered further in this assessment.

The dominant RE type in the relatively small Cumulative Risk Area 2 is 11.7.4. As described previously the Ironbark species associated with this RE type are expected to be reliant on shallow soil moisture, not groundwater. 3D Environmental and Earth Science (2017) (refer Attachment 2) describe RE type 11.7.4 as being unlikely GDEs and given the landscape setting on which they are found, groundwater is typically within confined aquifers at depths of >20m. Therefore it is considered unlikely that ecosystems identified in Cumulative Risk Area 2 represent GDEs, and are not expected to be impacted by SPG development.

6.2.3. Cumulative Risk Area 4

Cumulative Risk Area 4 is located directly west of Chinchilla. There is no depth to groundwater information available within this area for the Springbok Sandstone, however RN160547A located 7 km to the west of this area indicates a depth to groundwater in the Springbok Sandstone of >40 m. Whilst this is some distance from the risk area, the borehole log indicates >60m thickness of Cretaceous and Jurassic sediments overlying the Springbok Sandstone. The conceptualisation of the Springbok Sandstone being at a depth not accessible to terrestrial GDEs is also supported by CSG well Talinga 20 located <700m west of Cumulative Risk Area 4 which indicates >20m of alluvium and Westbourne Formation overlying the Springbok Sandstone.

Few mapped potential GDEs exist in this risk area, and the majority are dominated by RE types 11.5.1, 11.7.4, 11.9.4, 11.9.5 and 11.9.7, all of which are not usually associated with the potential for groundwater interaction due to their position in landscape, shallow rooting depths and reliance on shallow soil moisture. RE type 11.3.4 is mapped in a single part of Cumulative Risk Area 4 as a minor (10%) component of the mapped area, and the RE itself has a variable component of River Red Gum. 3D Environmental and Earth Search (2017) do not identify ecosystems in this area as having likely groundwater interaction, consistent with their description that River Red Gums accessing groundwater are likely to occur on lower alluvial terraces rather than the more elevated areas of Cumulative Risk Area 4.

It is therefore considered unlikely that Cumulative Risk Area 4 contains ecosystems that area reliant on a watertable hosted in the Springbok Sandstone.

6.2.4. Cumulative Risk Area 5

Cumulative Risk Area 5 is located north-west of Risk Area 2. Consistent with the discussion presented for Risk Area 2, and supported by Arrow Energy CSG well report for Hopeland 3A (located within this risk area), to the west of the Westbourne Formation subcrop extent drilling records indicate a thick sequence of Westbourne Formation, which does not support the potential for the Springbok Sandstone to act as the watertable aquifer.

The Westbourne Formation thins to the east of this area, with CSG well Wyalla 3, located in the east of Cumulative Risk Area 3a, indicating a 10m thickness of Westbourne Formation, directly underlain by Springbok Sandstone. In this area, RE types are dominated by 11.7.4, 11.7.7, 11.7.5 and 11.5.1. Given these RE types which are not usually associated with the potential for groundwater interaction due to their position in landscape, shallow rooting depths and reliance on shallow soil moisture, and the presence of clayey lithology in the upper 15m, it is considered unlikely that the ecosystems are accessing groundwater in the Springbok Sandstone aquifer.

6.2.5. Cumulative Risk Area 6

Cumulative Risk Area 6 is to the south of Risk Area 3b. As per the discussion for the south of Risk Area 3b, there is the potential for vegetation associated with RE types 11.3.25 and 11.3.2 to be accessing groundwater in this area. Depth to groundwater in RN41620043A, located 800m east of Cumulative Risk Area 6 and which screens the Springbok Sandstone from 21.2 to 24.2m indicates a water level of around 12m below ground. Other borelogs and CSG well report logs indicate the potential for relatively shallow Springbok Sandstone and potentially shallow groundwater levels. This is well within the range of potential access by River Red Gums, and is towards the lower limit of Poplar Box rooting depth.

Predicted cumulative drawdown in this areas ranges from around 2-6 m, therefore if this results in a fall in watertable below a critical threshold, in particular for Poplar Box, GDEs in this area may be at risk of impact.

6.3. Condition 13p impact assessment conclusions

The impact assessment presented in Section 6.2 demonstrates:

- Ecosystems in Cumulative Risk Area 1 are not groundwater dependent.
- Ecosystems in Cumulative Risk Area 2 are unlikely to be groundwater dependent and are not expected to be impacted by SGP development.
- Ecosystems in Cumulative Risk Area 3 are not dependent on a waterable aquifer hosted in the Springbok Sandstone.
- Ecosystems in Cumulative Risk Area 4 are unlikely to be reliant on a watertable hosted in the Springbok Sandstone therefore are not expected to be impacted by SGP development.
- Ecosystems in Cumulative Risk Area 5 are unlikely to be reliant on a watertable hosted in the Springbok Sandstone therefore are not expected to be impacted by SGP development.
- Ecosystems in Cumulative Risk Area 6 may be dependent on groundwater in the Springbok Sandstone and may be impacted by project-related groundwater drawdown.

As noted in Section 5.4, detailed vegetation surveys are being carried out that will assist with the refinement of the RE mapping. Further assessment of Cumulative Risk Area 6, in conjunction with the southern part of Risk Area 3b, is recommended to refine the conceptual understanding of the potential for ecosystem interaction with groundwater.

6.4. Contribution to OGIA investigations

Arrow currently has no assigned spring monitoring or investigation requirements under the 2016 Surat CMA UWIR. Should this change in future revisions of the Surat CMA UWIR (based on new data) Arrow will contribute to investigations as required by the Spring Impact Management Strategy (SIMS) and/or other groundwater dependent ecosystem management requirements that may be included in future versions of the UWIR.

Knowledge gained from Arrow-initiated investigations to date around the presence of GDEs within and around their tenure has been presented in this memorandum, and will contribute to the body of knowledge around GDEs in the Surat CMA.

Arrow’s prior contributions have included:

- The provision of the results of prior spring / GDE assessment work, including remote sensing data, geochemical investigations and GDE impact modelling.
- The Condamine Interconnectivity Research Project (CIRP), which aimed to improve understanding around the connectivity between the Walloon Coal Measures and the Condamine alluvium. Arrow provided major contribution including the completion of groundwater monitoring bore installations and aquifer pumping tests.

The results of ongoing investigations will be made available to OGIA in the future. This is expected to include (at a minimum):

- The results of monitoring programs where monitoring of GDEs is set out in the Stage 1 CSG WMMP.
- The results of further detailed investigations where they may be required in response to exceeding a trigger threshold.
- The results of further studies into aquifer connectivity (i.e. Long Swamp and Lake Broadwater, if required).

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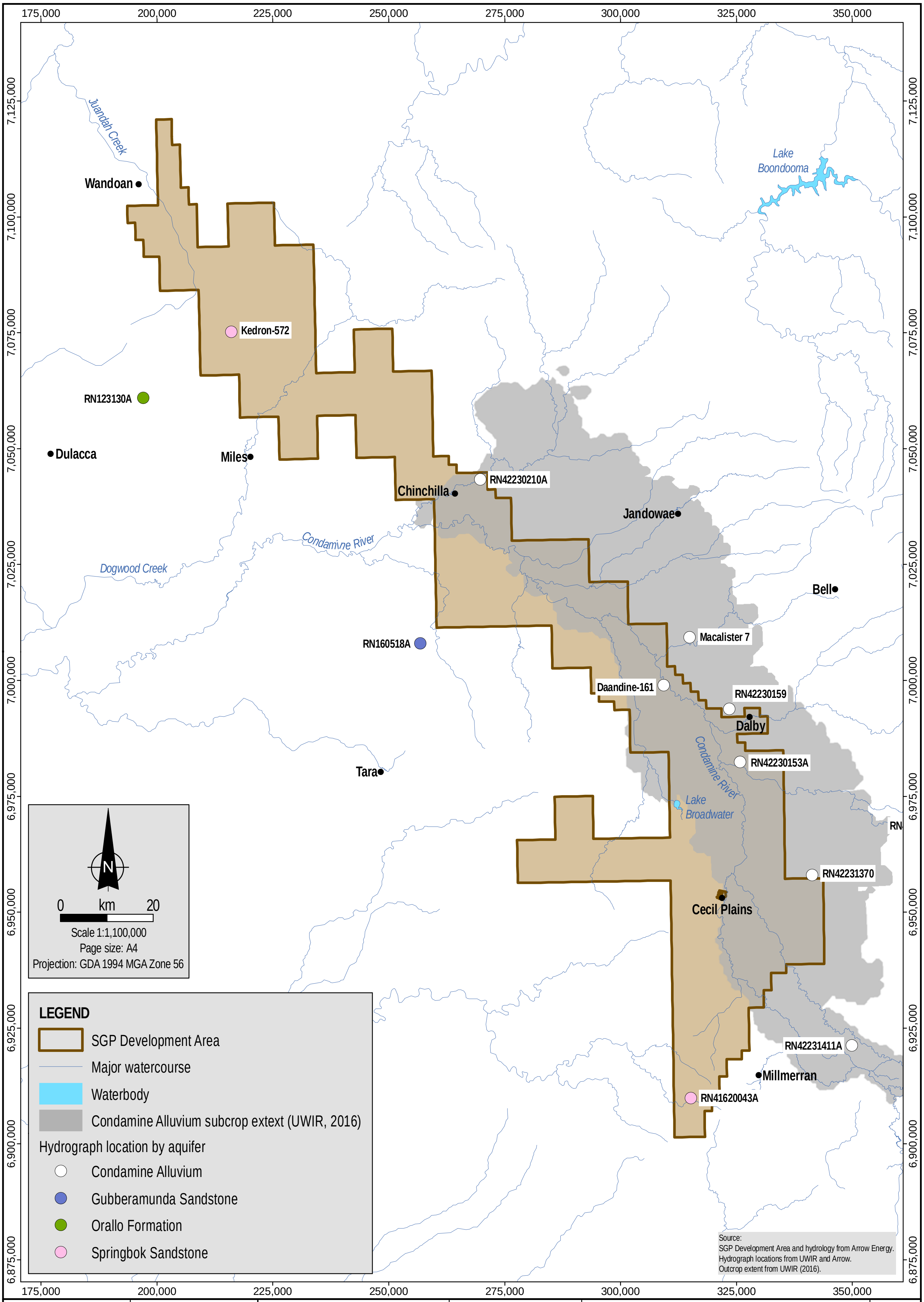
Figures



Source:
SGP Development Area and hydrology from Arrow Energy.
Hydrograph locations from UWIR and Arrow.
Outcrop extent from UWIR (2016).

MXD Reference: 20484AB_M03_GIS027_v0_1

coffey
A TETRA TECH COMPANY

Date: 19.09.2018
Project: ENAUABTF20484AA
File Name: 20484AB_M03_F02.1_GIS

Arrow Energy
Surat Gas Project WMMP

arrow energy
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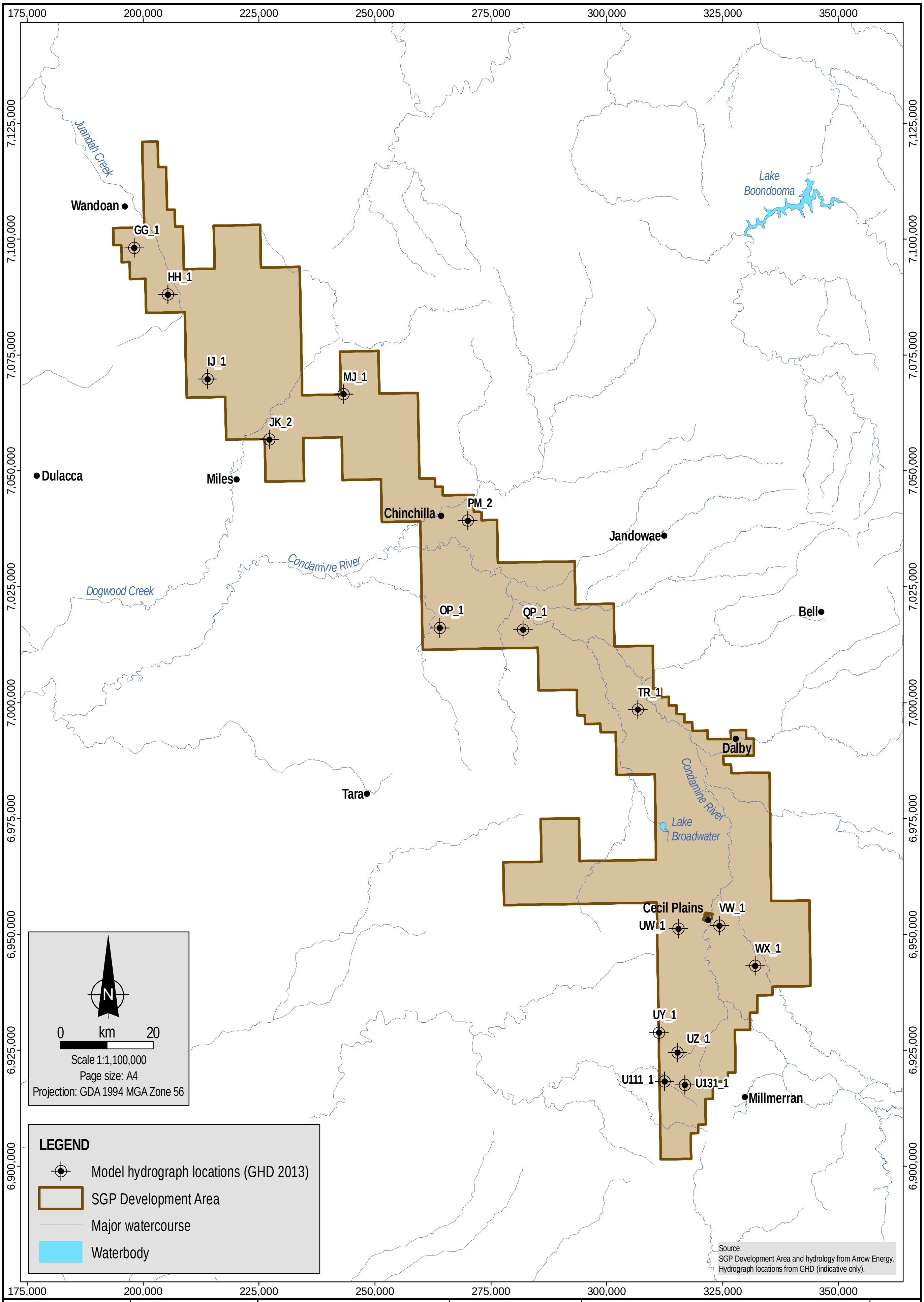
Hydrograph locations

Figure No: 2.1



Source:
SGP Development Area and hydrology from Arrow Energy.
Hydrograph locations from GHD (indicative only).

MXD Reference: 20484AB_M03_GIS028_v0_1

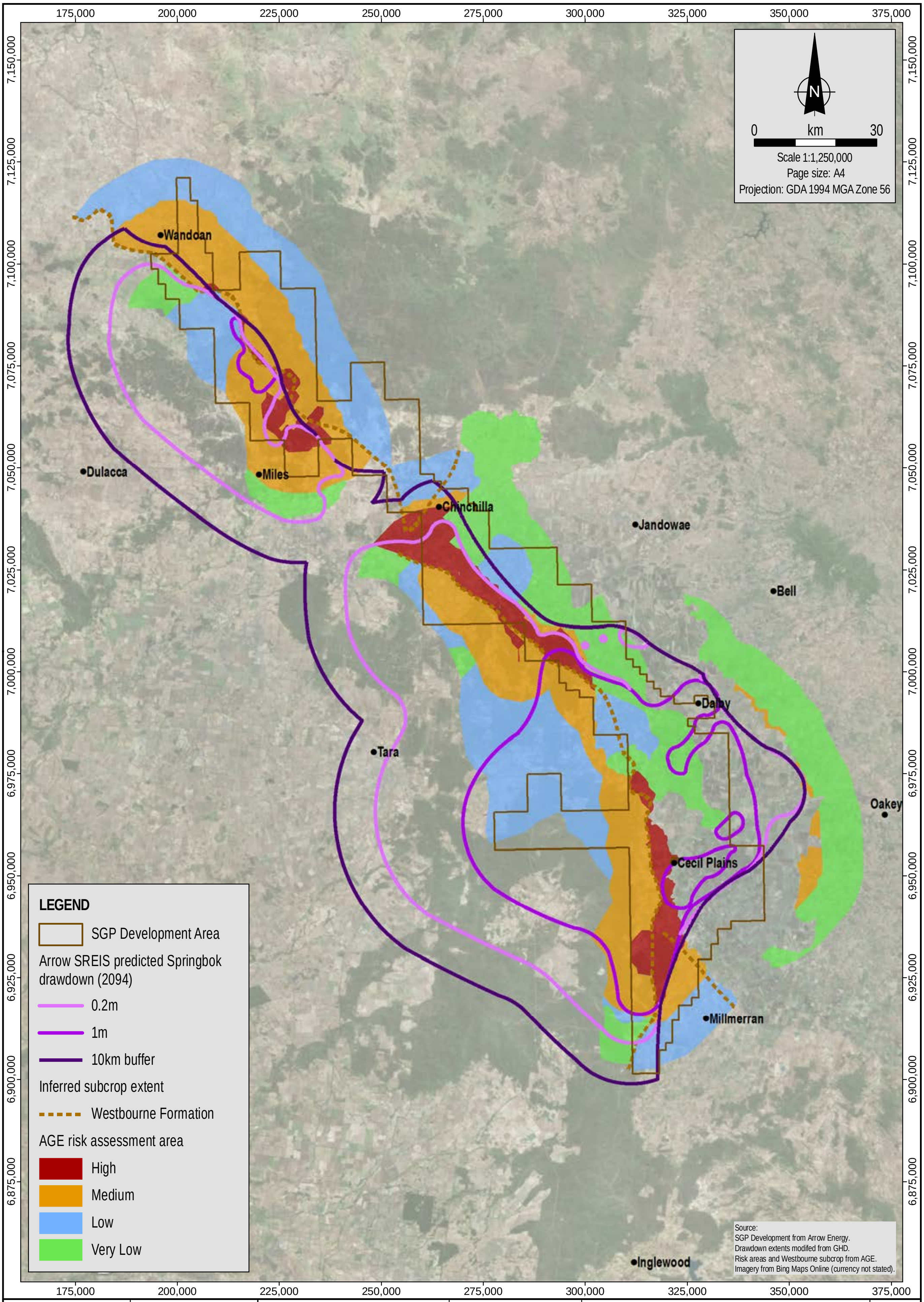
Date:
19.09.2018
Project:
ENAUABTF20484AA
File Name:
20484AB_M03_F02.2_GIS

Arrow Energy

Surat Gas Project WMMP

Attachment 4 hydrograph locations

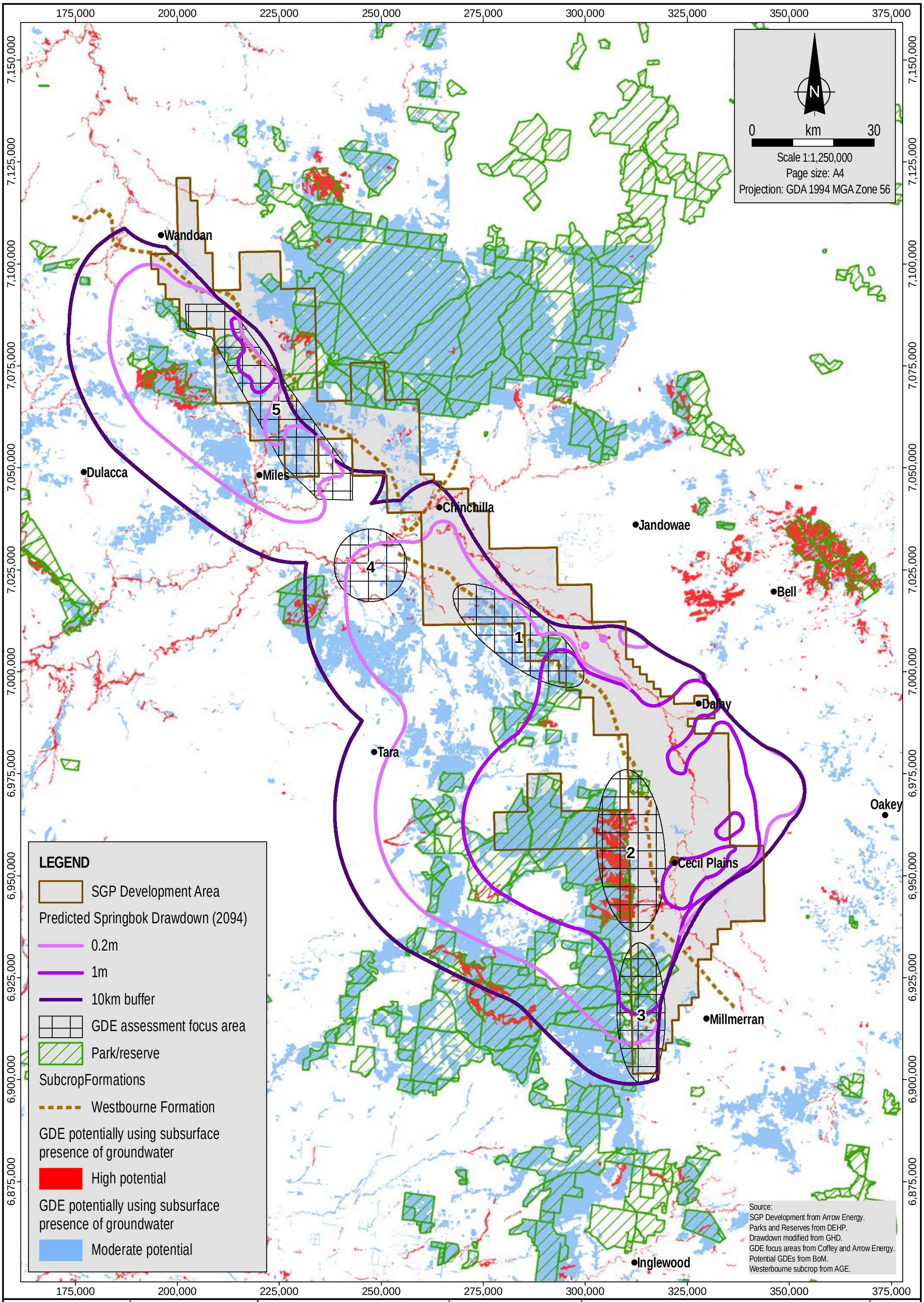
Figure No:
2.2



Source:
SGP Development from Arrow Energy.
Drawdown extents modifed from GHD.
Risk areas and Westbourne subcrop from AGE.
Imagery from Bing Maps Online (currency not stated).

MXD Reference: 20484AA_M03_GIS007_v0_1

coffey	Date: 21.12.2016 Project: ENAUABTF20484AA File Name: 20484AA_M03_F03.1_GIS	Arrow Energy Surat Gas Project WMMP	arrow energy go further	AGE risk assessment area results	Figure No: 3.1



Source:
SGP Development from Arrow Energy.
Parks and Reserves from DEHP.
Drawdown modified from GHD.
GDE focus areas from Coffey and Arrow Energy.
Potential GDEs from BoM.
Westbourne subcrop from AGE.

MXD Reference: 20484AA_M03_GIS008_v0_2

coffey
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Date:
21.12.2016
Project:
ENAUABTF20484AA
File Name:
20484AA_M03_F03.2_GIS

Arrow Energy

Surat Gas Project WMMP

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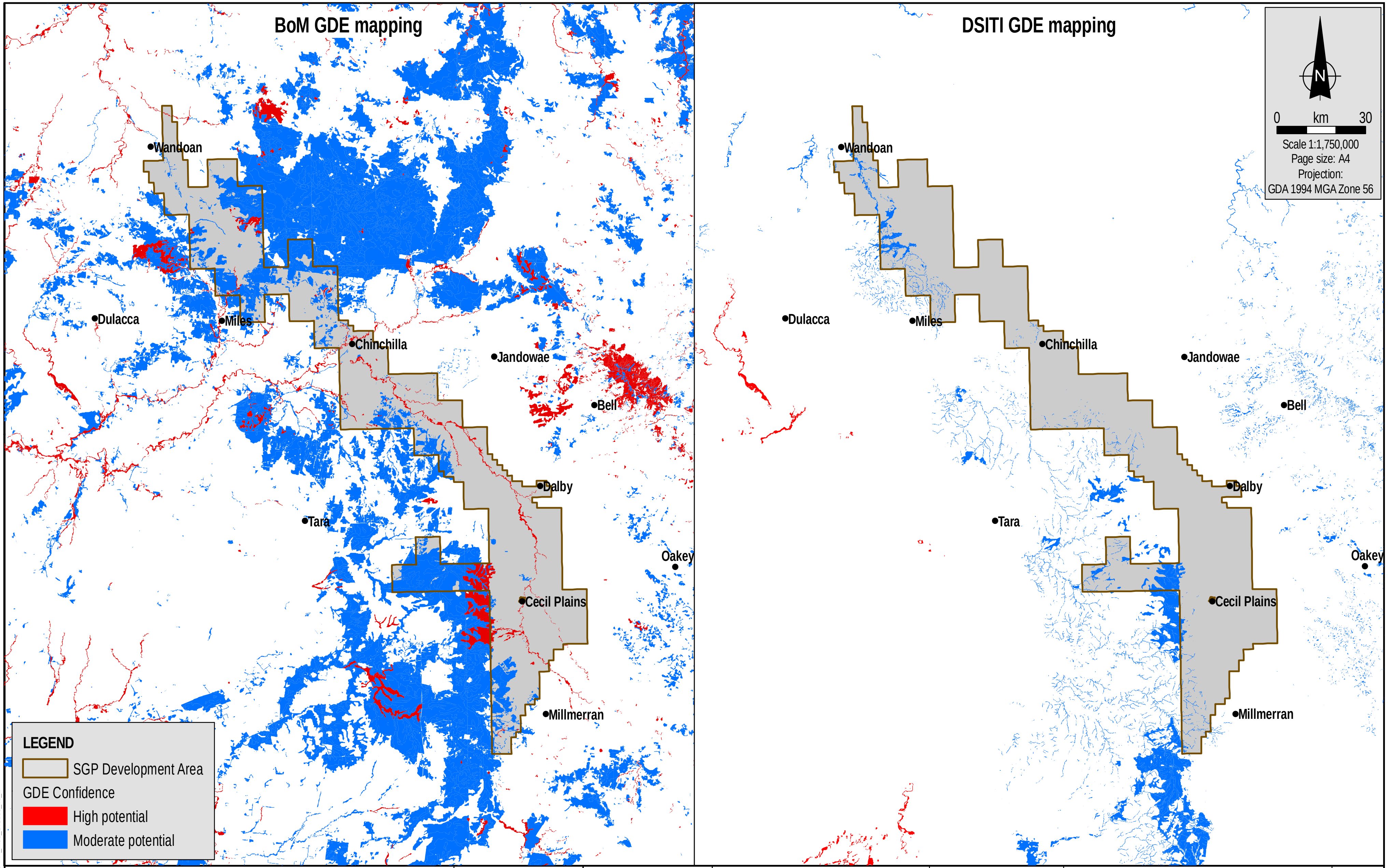
go further

Terrestrial GDE focus areas

Figure No:
3.2



Source:
SGP Development from Arrow Energy.
Potential GDEs from BoM and DSITI.

coffey
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Date:
21.12.2016
Project:
ENAUABTF20484AA
File Name:
20484AA_M03_F009_GIS

Arrow Energy

Surat Gas Project WMMP

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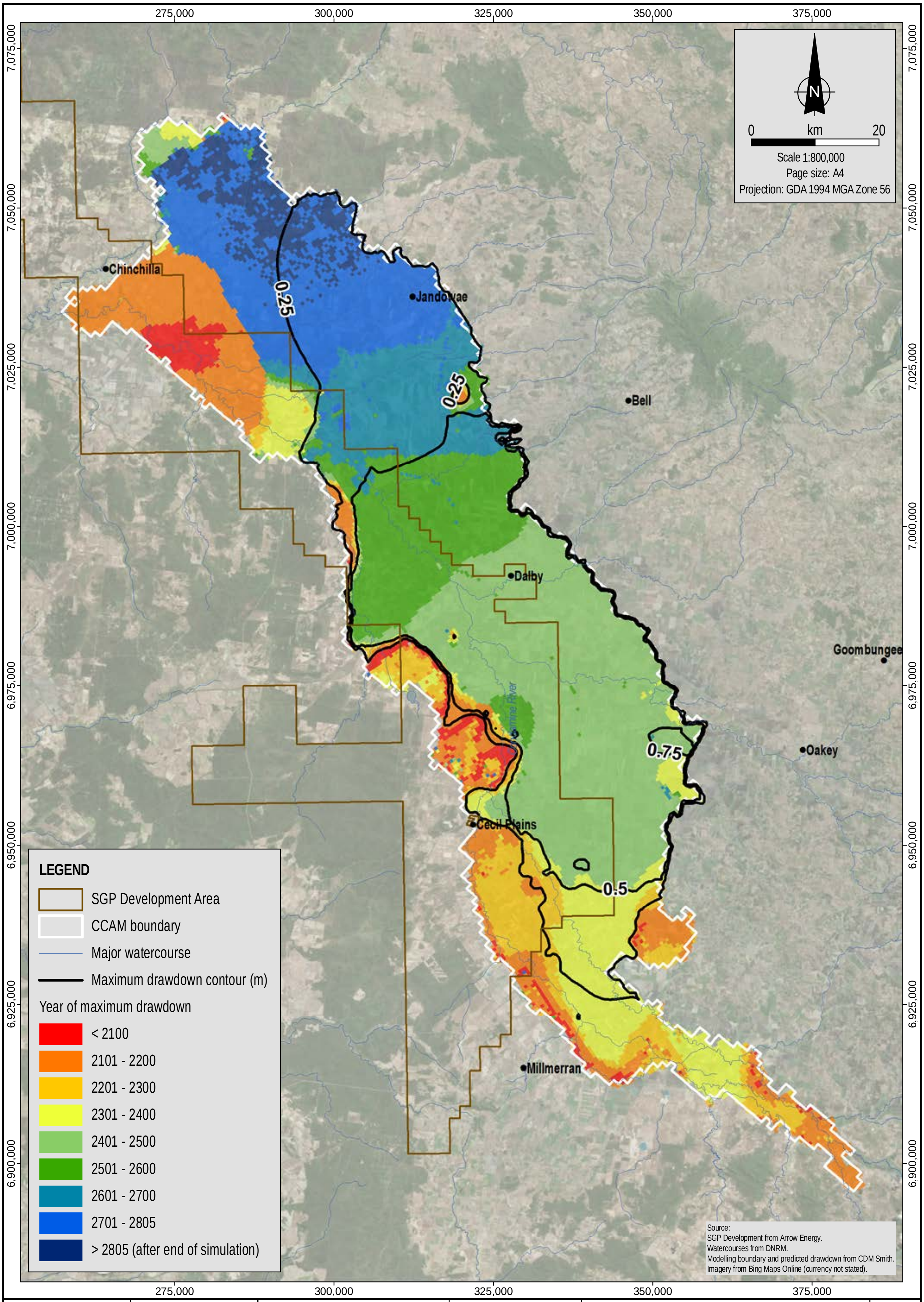
Comaprison of BoM and DSITI
terrestrial GDE mapping

Figure No:
3.3

MXD Reference: 20484AA_M03_GIS009_v0_1



Source:
SGP Development from Arrow Energy.
Watercourses from DNRM.
Modelling boundary and predicted drawdown from CDM Smith.
Imagery from Bing Maps Online (currency not stated).

MXD Reference: 20484AA_M03_GIS010_v0_1

coffey

Date:
21.12.2016
Project:
ENAUABTF20484AA
File Name:
20484AA_M03_F03.4_GIS

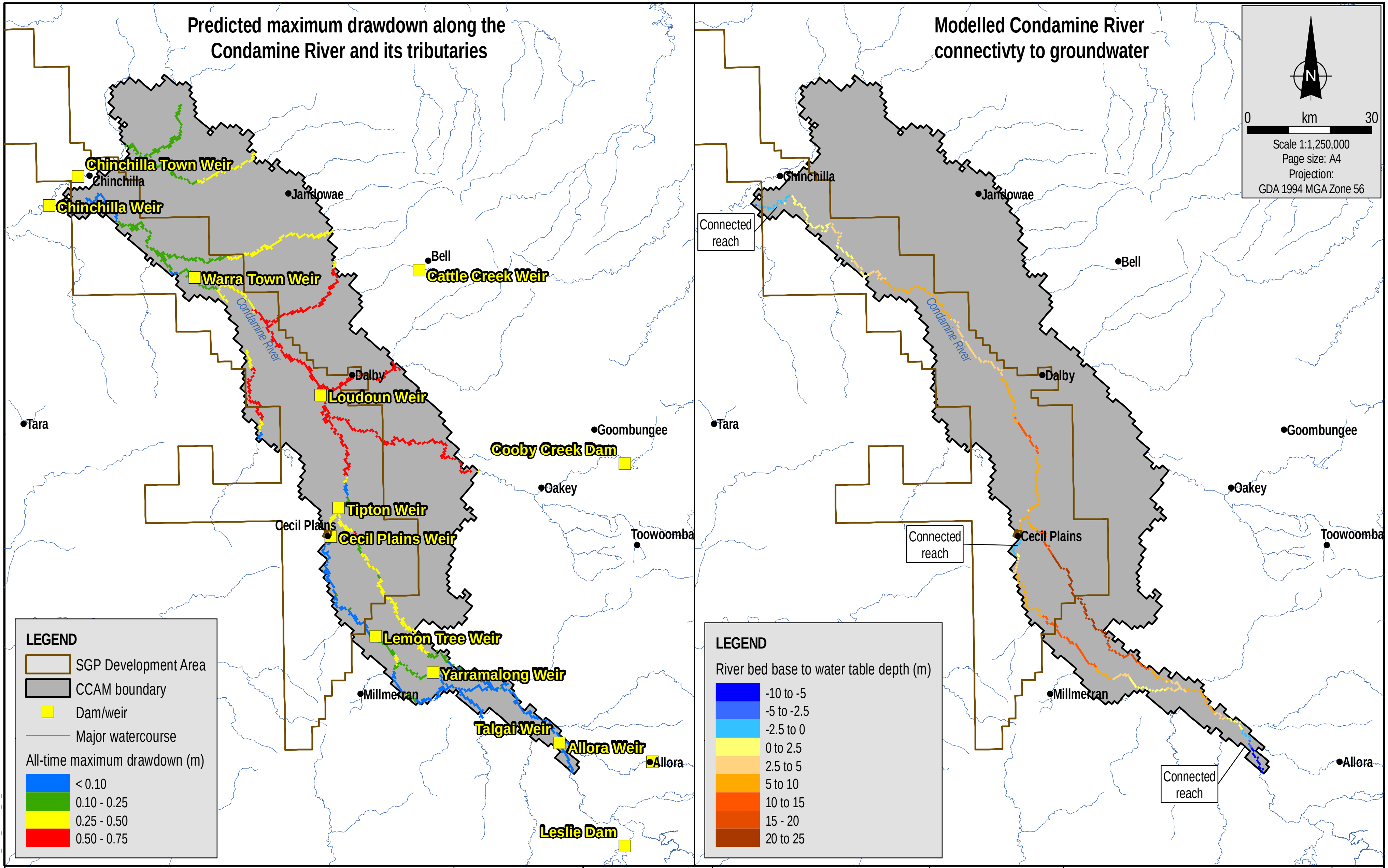
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Condamine Alluvium predicted maximum drawdown and timing Arrow-only (median case)

Figure No:
3.4



Source:
SGP Development from Arrow Energy.
Modelling boundary and water table depth and dams/weirs from CDM Smith.
Imagery from Bing Maps Online (currency not stated).

coffey
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Date:
21.12.2016
Project:
ENAUABTF20484AA
File Name:
20484AA_M03_F03.5_GIS

Arrow Energy

Surat Gas Project WMMP

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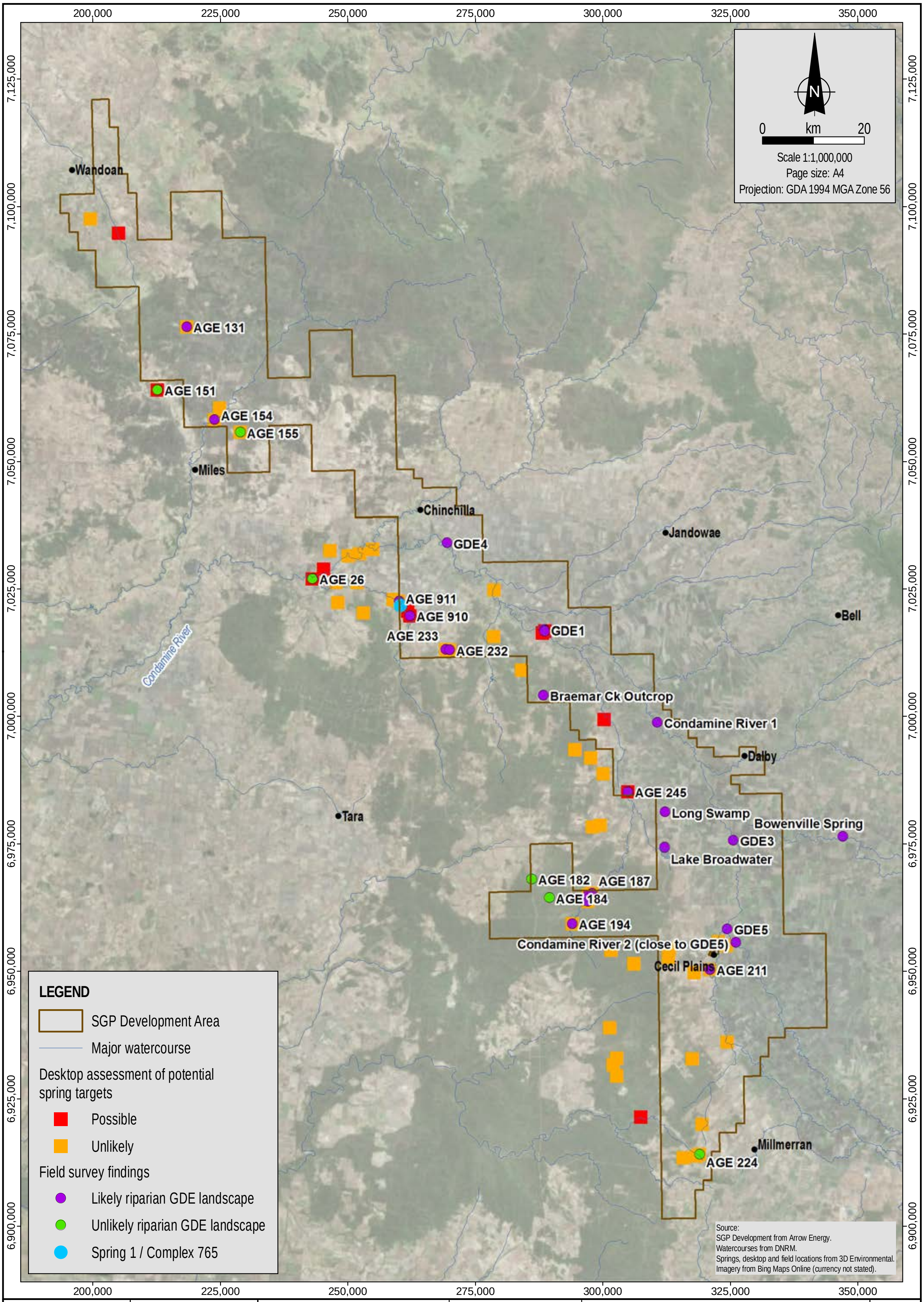
go further

Condamine River predicted drawdown and existing river connectivity to groundwater

Figure No:
3.5

MXD Reference: 20484AA_M03_GIS015_v0_1



Source:
SGP Development from Arrow Energy.
Watercourses from DNRM.
Springs, desktop and field locations from 3D Environmental.
Imagery from Bing Maps Online (currency not stated).

MXD Reference: 20484AA_M03_GIS012_v0_1

coffey

Date: 21.12.2016
Project: ENAUABTF20484AA
File Name: 20484AA_M03_F03.6_GIS

Arrow Energy

Surat Gas Project WMMP

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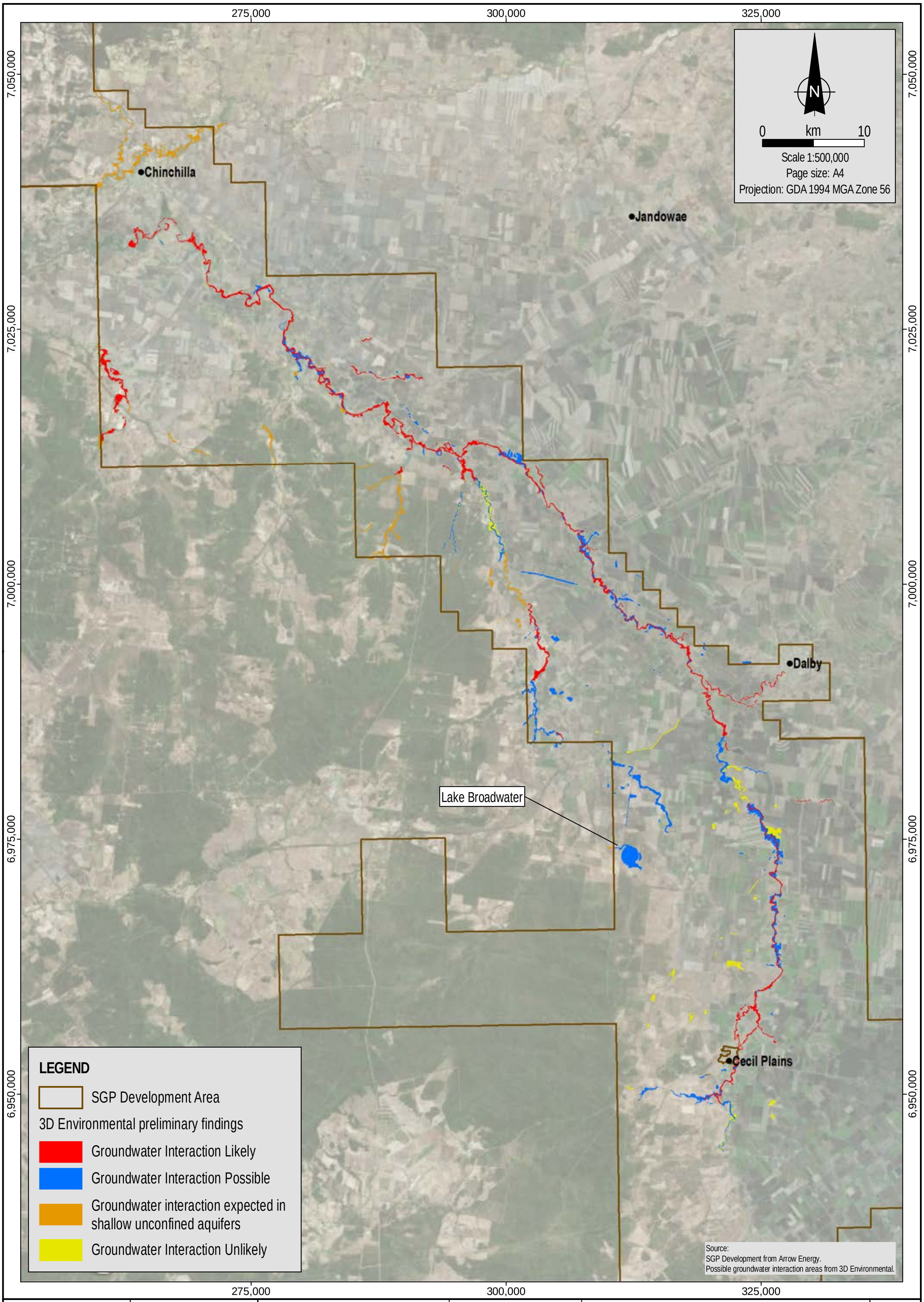
go further

3D Environmental and Earth Search preliminary study findings

Figure No: 3.6



Source:
SGP Development from Arrow Energy.
Possible groundwater interaction areas from 3D Environmental.

coffey

Date:
21.12.2016

Project:
ENAUABTF20484AA

File Name:
20484AA_M03_F03.7_GIS

Arrow Energy

Surat Gas Project WMMP

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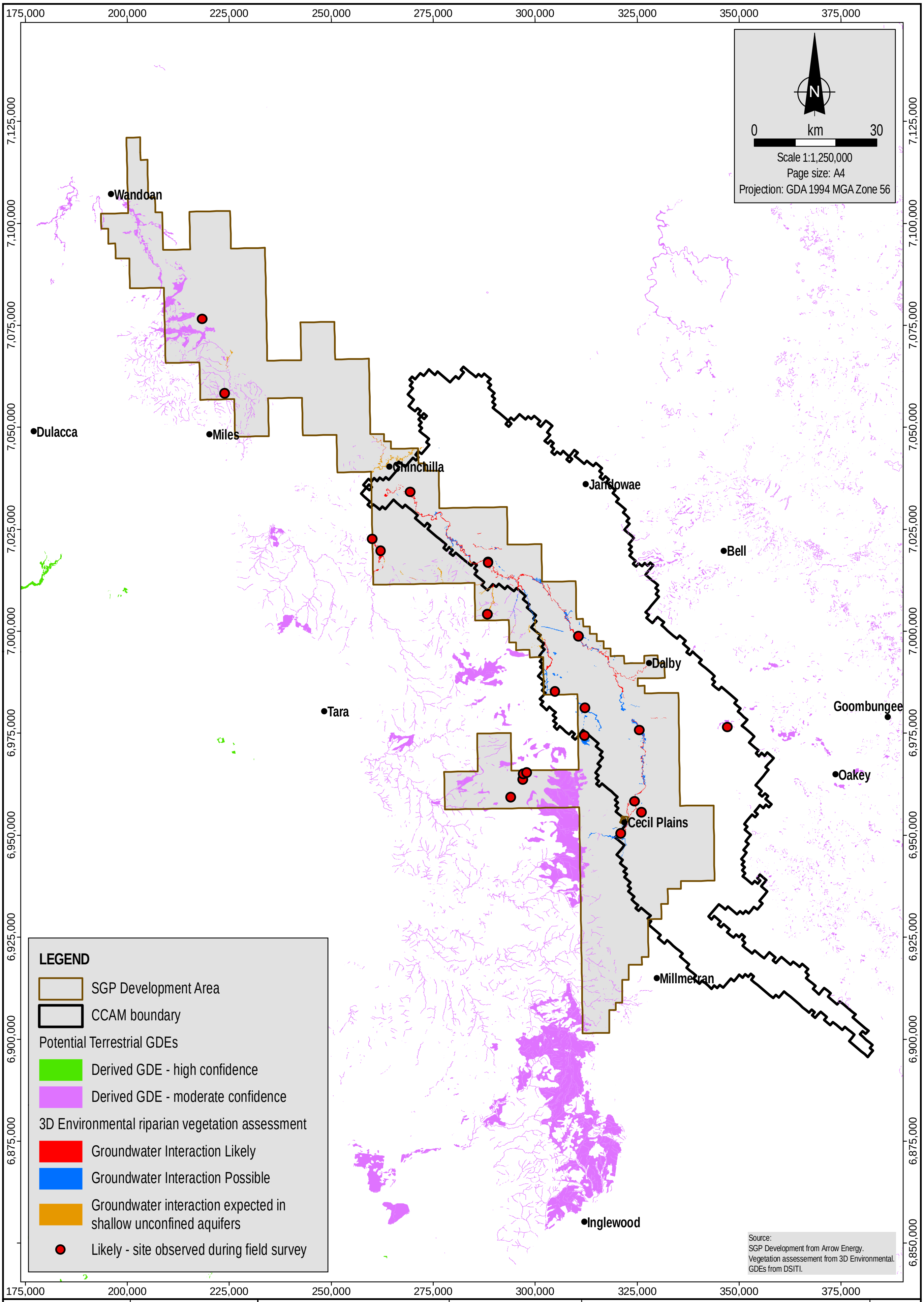
Potential riparian GDE environments

Figure No:
3.7

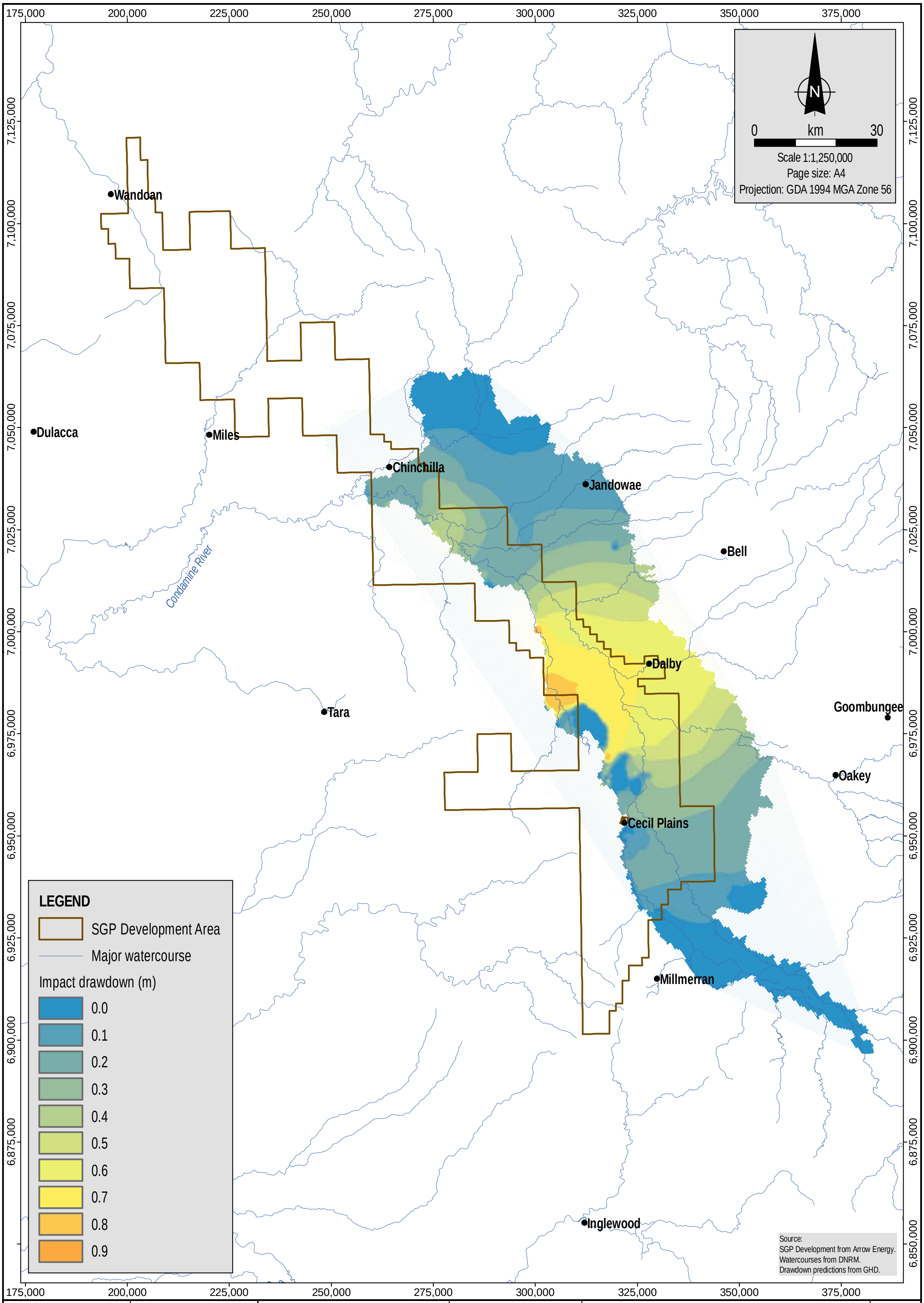
MXD Reference: 20484AA_M03_GIS013_v0_1



Source:
SGP Development from Arrow Energy.
Vegetation assessment from 3D Environmental.
GDEs from DSITI.

MXD Reference: 20484AA_M03_GIS017_v0_1

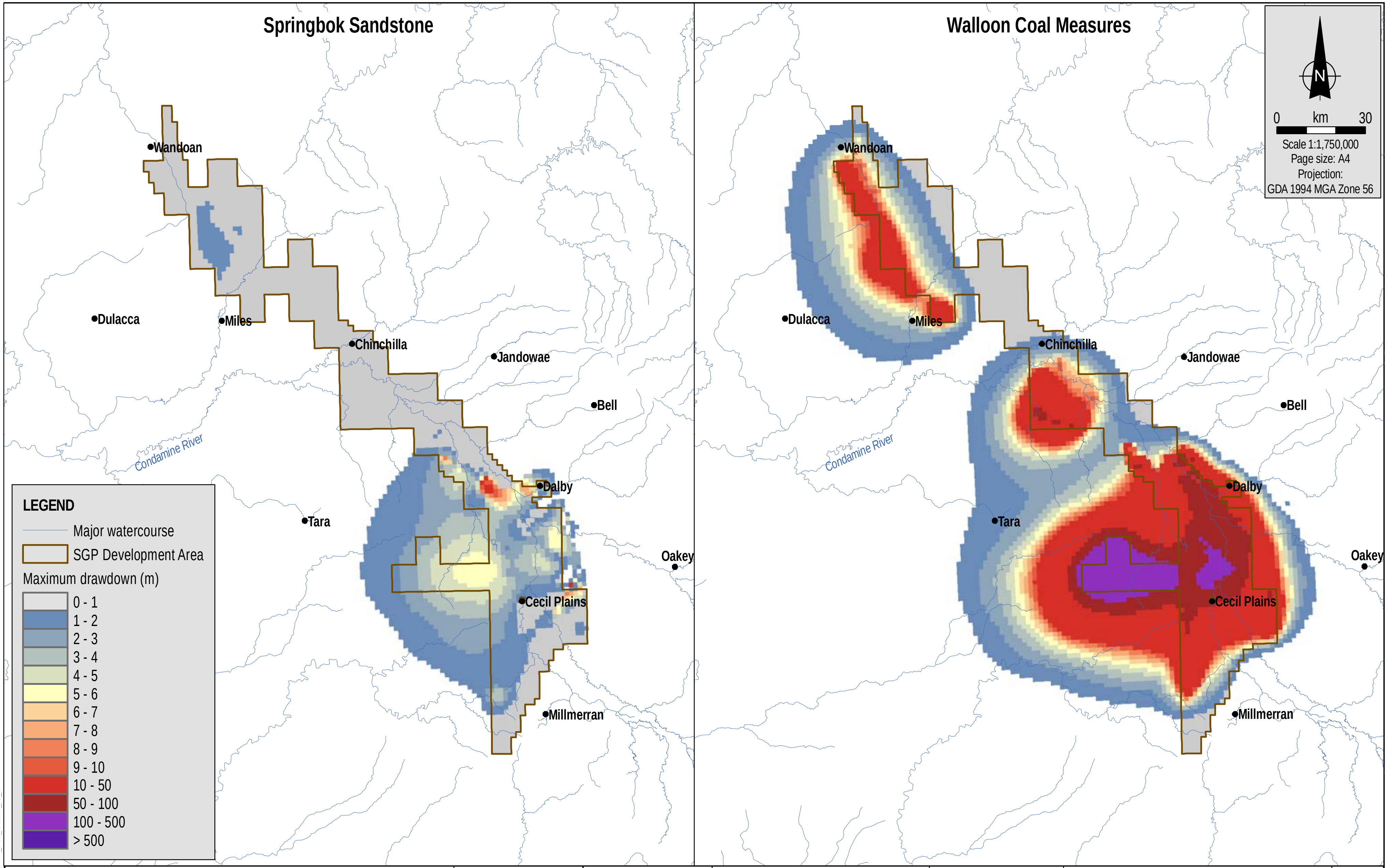
coffey A TETRA TECH COMPANY	Date: 21.12.2016 Project: ENAUABTF20484AA File Name: 20484AA_M03_F03.8_GIS	Arrow Energy Surat Gas Project WMMP	arrow energy go further	Potential terrestrial GDE landscapes	Figure No: 3.8



Source:
SGP Development from Arrow Energy.
Watercourses from DNRM.
Drawdown predictions from GHD.

MXD Reference: 20484AA_M03_GIS018_v0_1

Date: 13.02.2017	Arrow Energy		Condamine Alluvium cumulative maximum drawdown, calibration realisation	Figure No: 4.1
Project: ENAUABTF20484AA	Surat Gas Project WMMP			
File Name: 20484AA_M03_F04.1_GIS				



Source:
Predicted drawdown from GHD.
SGP Development from Arrow Energy.
Watercourses from DNRM.

coffey
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Date:
13.02.2017
Project:
ENAUABTF20484AA
File Name:
20484AA_M03_F04.2_GIS

Arrow Energy

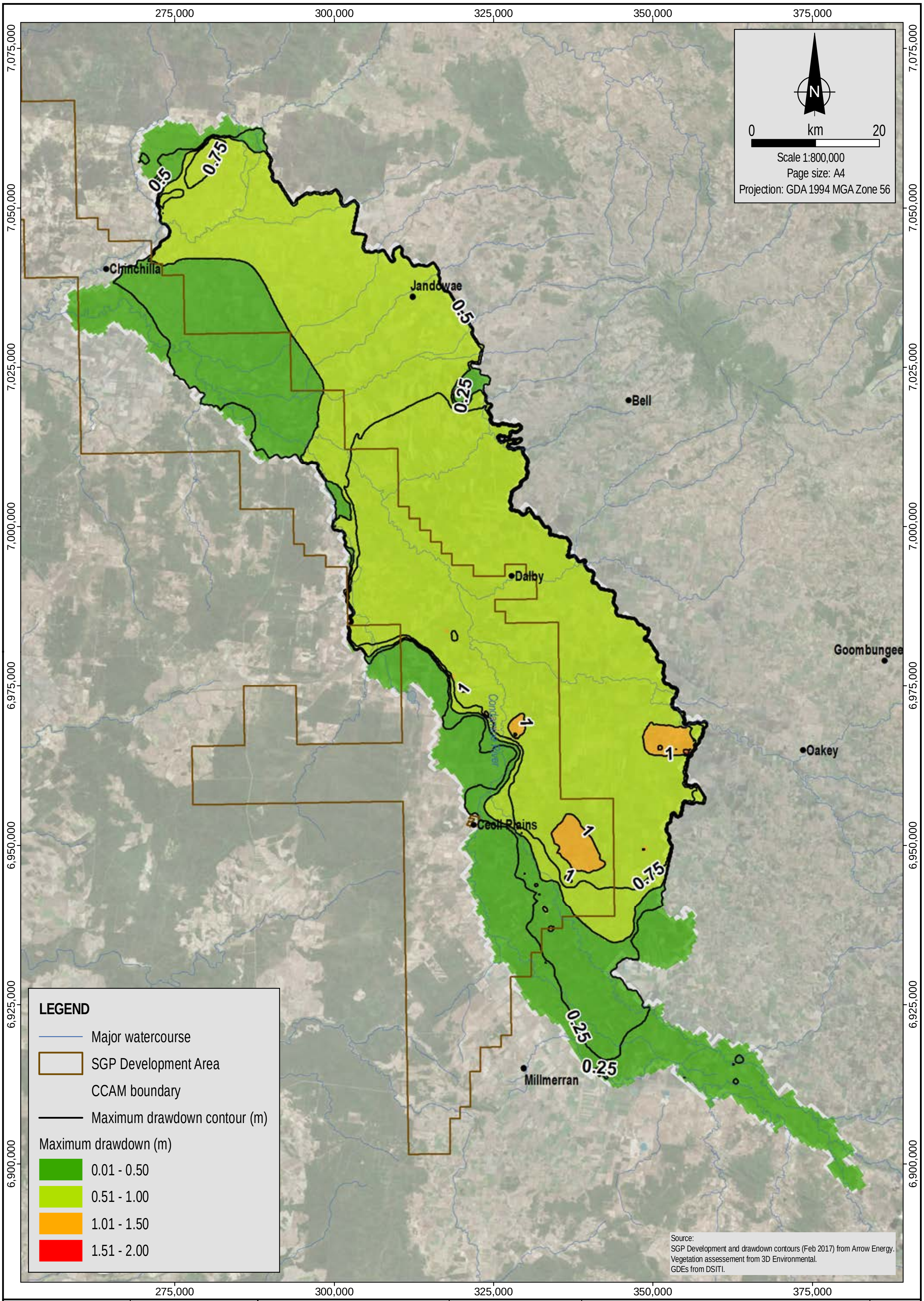
Surat Gas Project WMMP

arrowenergy
go further

Arrow only maximum drawdown calibration realisation

Figure No:
4.2

MXD Reference: 20484AA_M03_GIS001_v0_1



Source:
SGP Development and drawdown contours (Feb 2017) from Arrow Energy.
Vegetation assessement from 3D Environmental.
GDEs from DSITI.

MXD Reference: 20484AA_M03_GIS028_v0_1

coffey
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Date:
28.02.2017
Project:
ENAUABTF20484AA
File Name:
20484AA_M03_F04.3_GIS

Arrow Energy

Surat Gas Project WMMP

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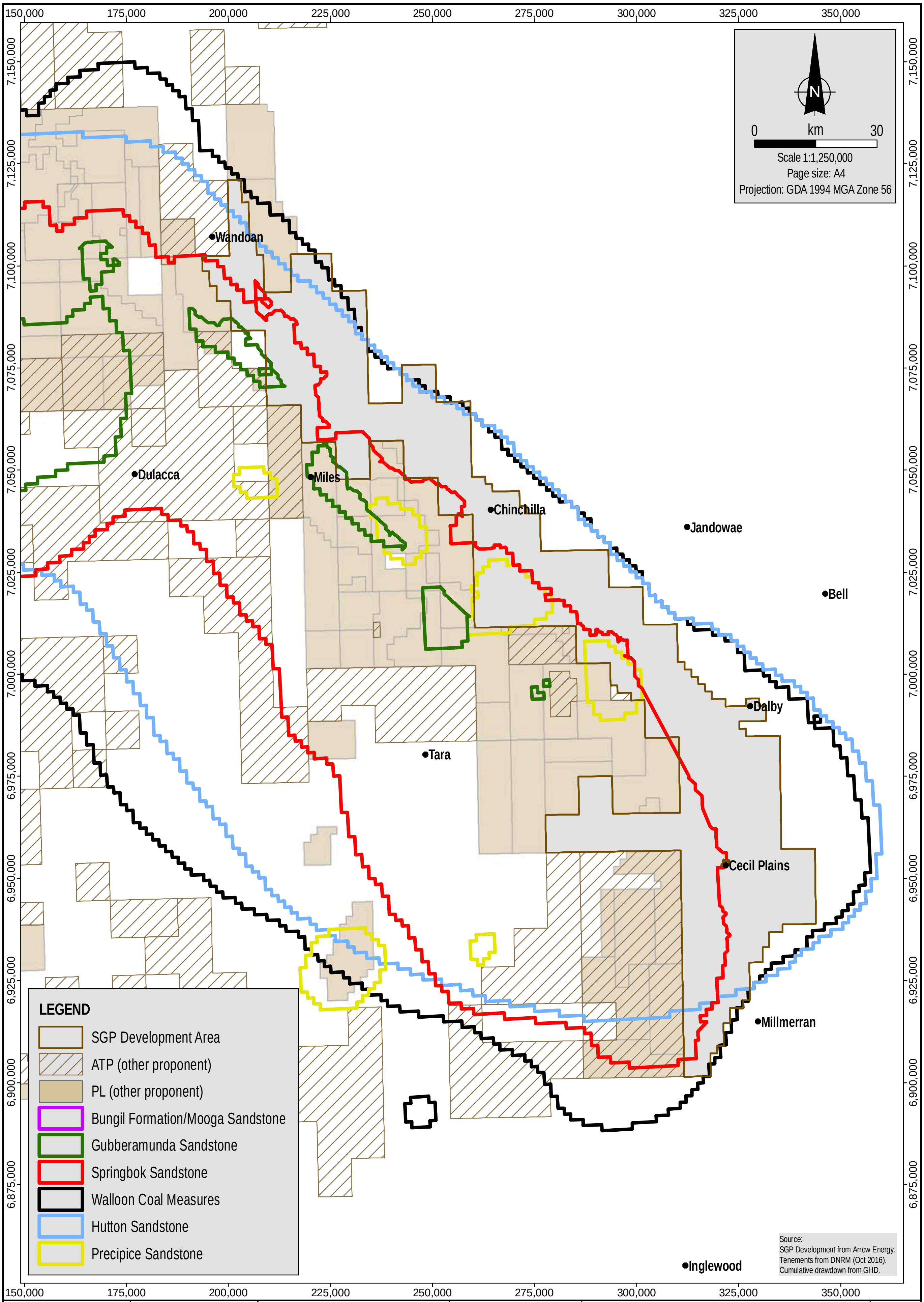
go further

Predicted maximum cumualtive drawdown in the Condamine Alluivum (median case)

Figure No:
4.3



Source:
SGP Development from Arrow Energy.
Tenements from DNRM (Oct 2016).
Cumulative drawdown from GHD.

MXD Reference: 20484AA_M03_GIS014_v0_2

coffey
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Date: 13.02.2017
Project: ENAUABTF20484AA
File Name: 20484AA_M03_F04.4_GIS

Arrow Energy

Surat Gas Project WMMP

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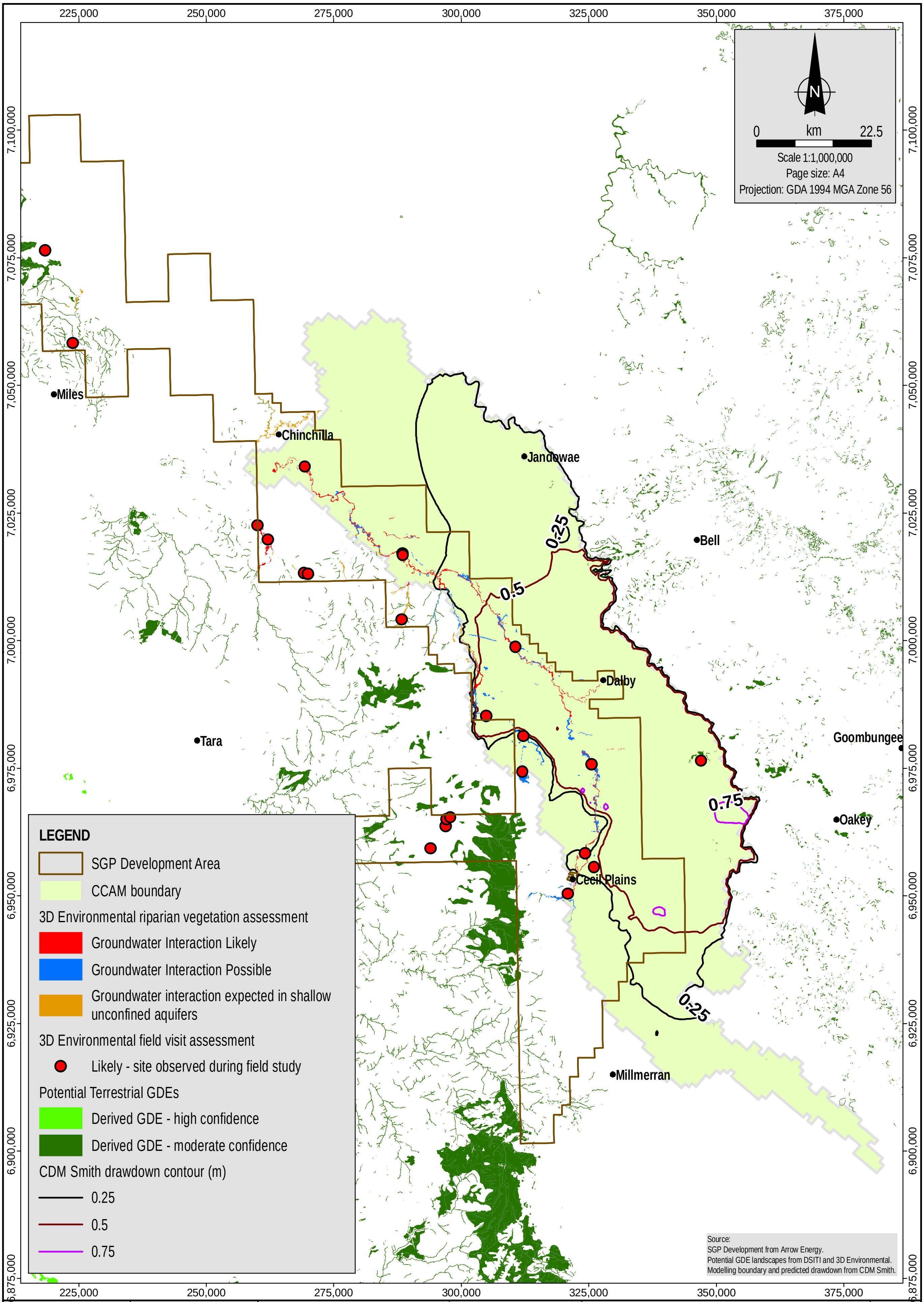
Predicted maximum cumulative drawdown calibration realisation

Figure No: 4.4

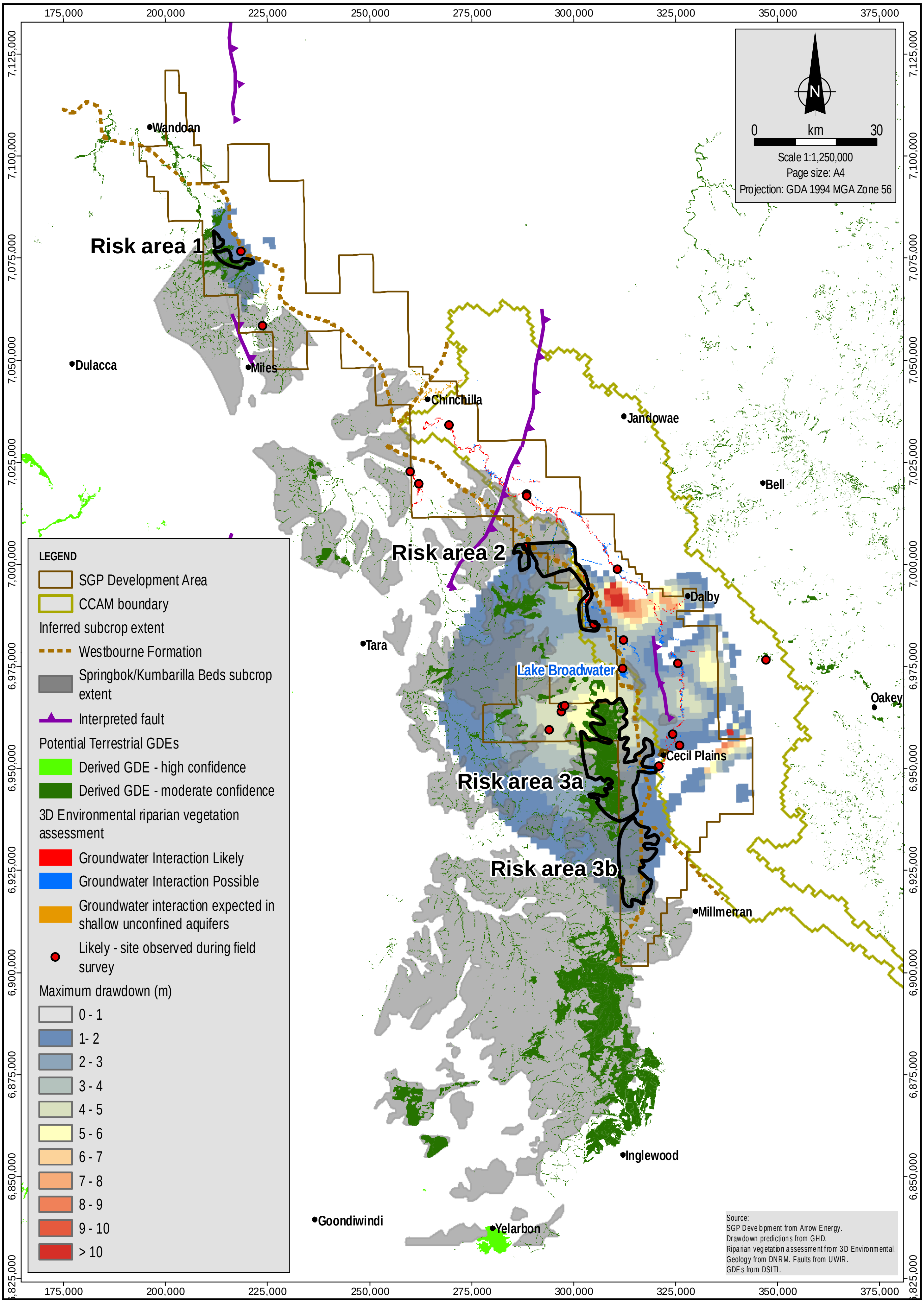


Source:
SGP Development from Arrow Energy.
Potential GDE landscapes from DSITI and 3D Environmental.
Modelling boundary and predicted drawdown from CDM Smith.

MXD Reference: 20484AA_M03_GIS016_v0_3

coffey

Date: 13.02.2017	Arrow Energy	arrow energy go further	**Predicted maximum drawdown in Condamine Alluvium with potential terrestrial GDE landscapes**	Figure No: **5.1**
Project: ENAUABTF20484AA	Surat Gas Project WMMP			
File Name: 20484AA_M03_F016_GIS				



Source:
SGP Development from Arrow Energy.
Drawdown predictions from GHD.
Riparian vegetation assessment from 3D Environmental.
Geology from DNRM. Faults from UWIR.
GDEs from DSITI.

MXD Reference: 20484AA_M03_GIS005_v0_5

coffey
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Date:
14.02.2017
Project:
ENAUABTF20484AA
File Name:
20484AA M03 F05.2 GIS

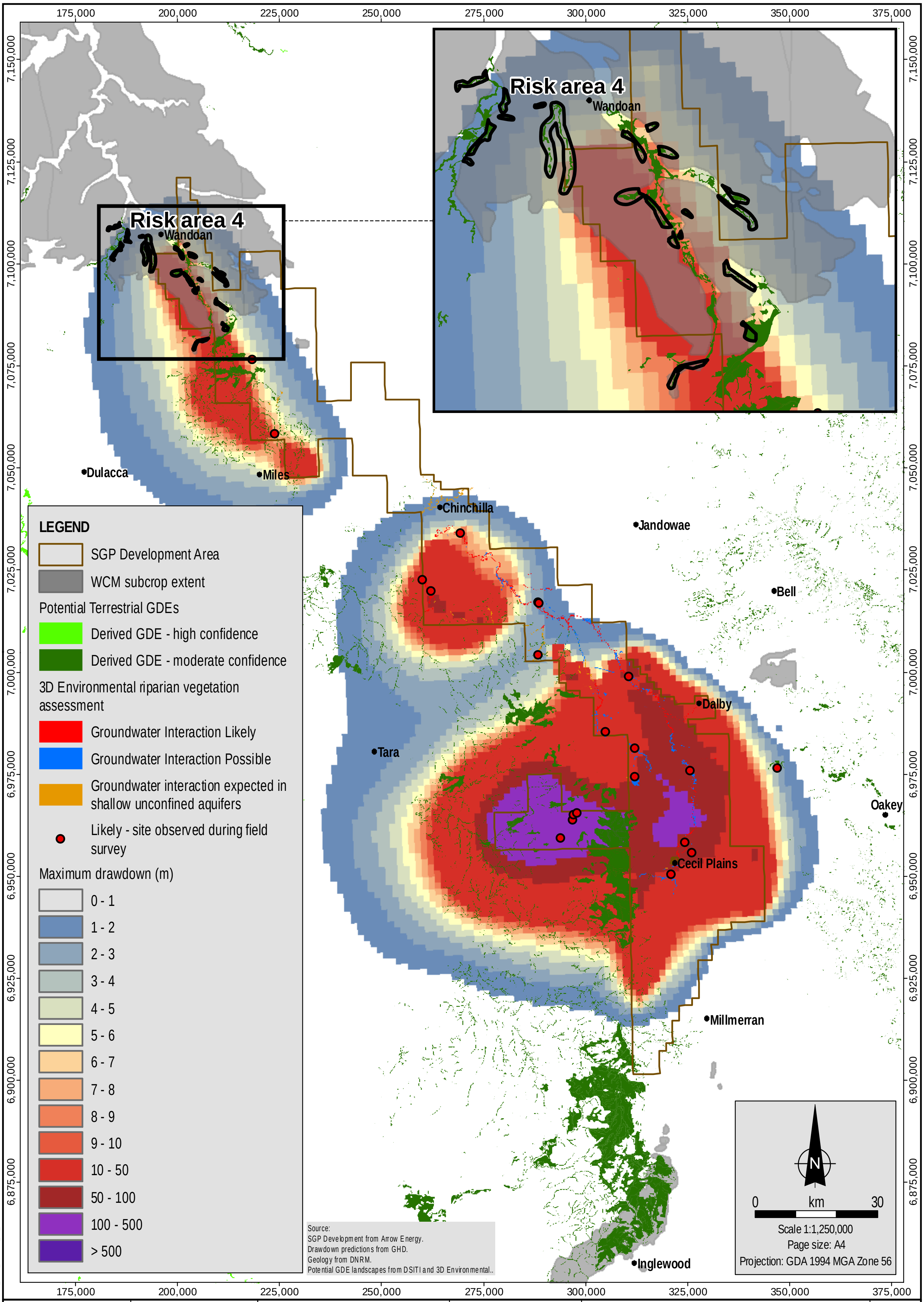
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Springbok Sandstone - GDE risk areas

Figure No:
5.2



Source:
SGP Development from Arrow Energy.
Drawdown predictions from GHD.
Geology from DNRM.
Potential GDE landscapes from DSITI and 3D Environmental..

MXD Reference: 20484AA_M03_GIS006_v0_3

coffey
A TETRA TECH COMPANY

Date:
14.02.2017
Project:
ENAUABTF20484AA
File Name:
20484AA M03 F05.3 GIS

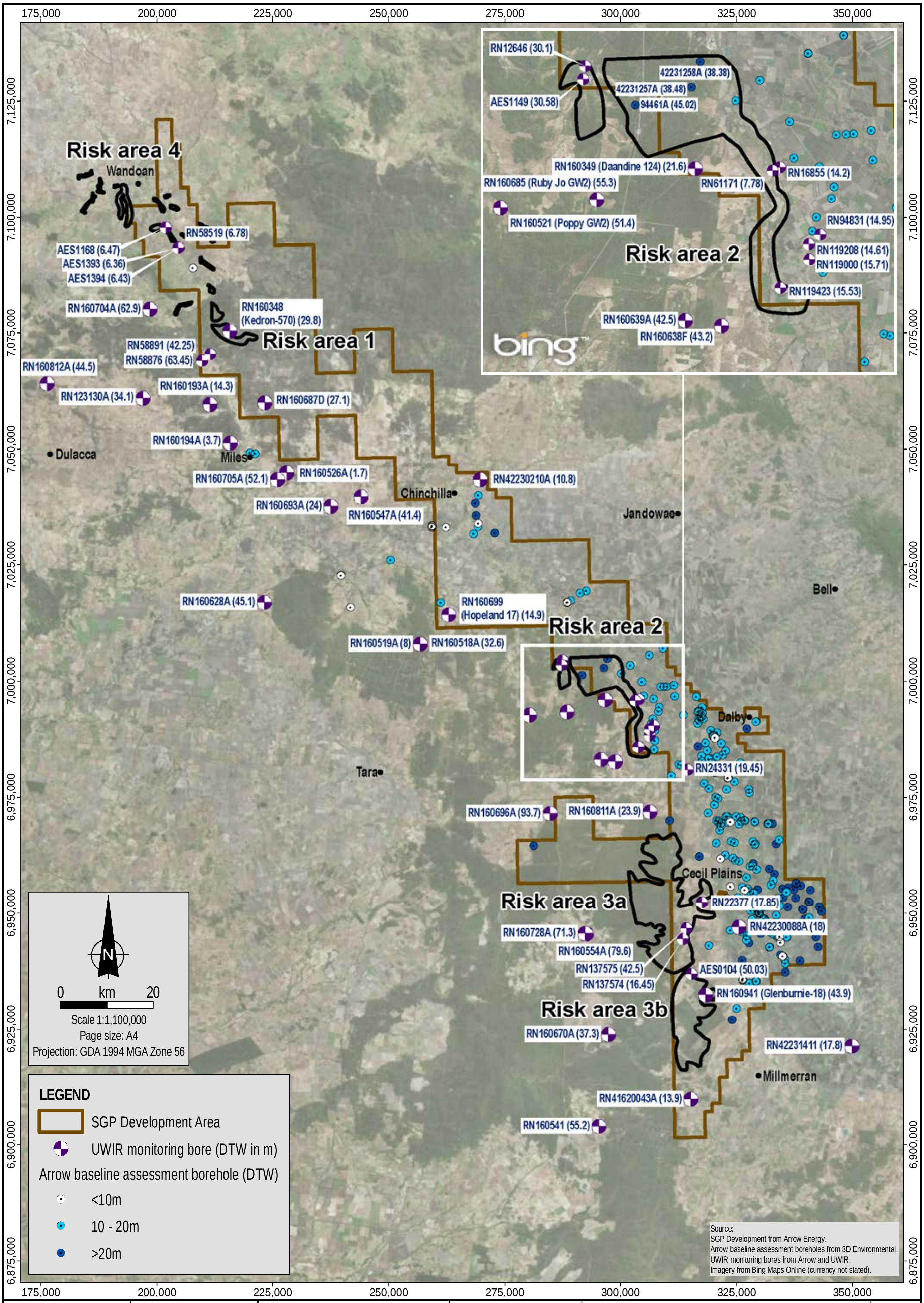
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Walloon Coal Measures
Terrestrial GDE risk areas

Figure No:
5.3



Source:
SGP Development from Arrow Energy.
Arrow baseline assessment boreholes from 3D Environmental.
UWIR monitoring bores from Arrow and UWIR.
Imagery from Bing Maps Online (currency not stated).

MXD Reference: 20484AA_M03_GIS022_v0_4

coffey
A TETRA TECH COMPANY

Date: 22.02.2017
Project: ENAUABTF20484AA
File Name: 20484AA_M03_F04.3_GIS

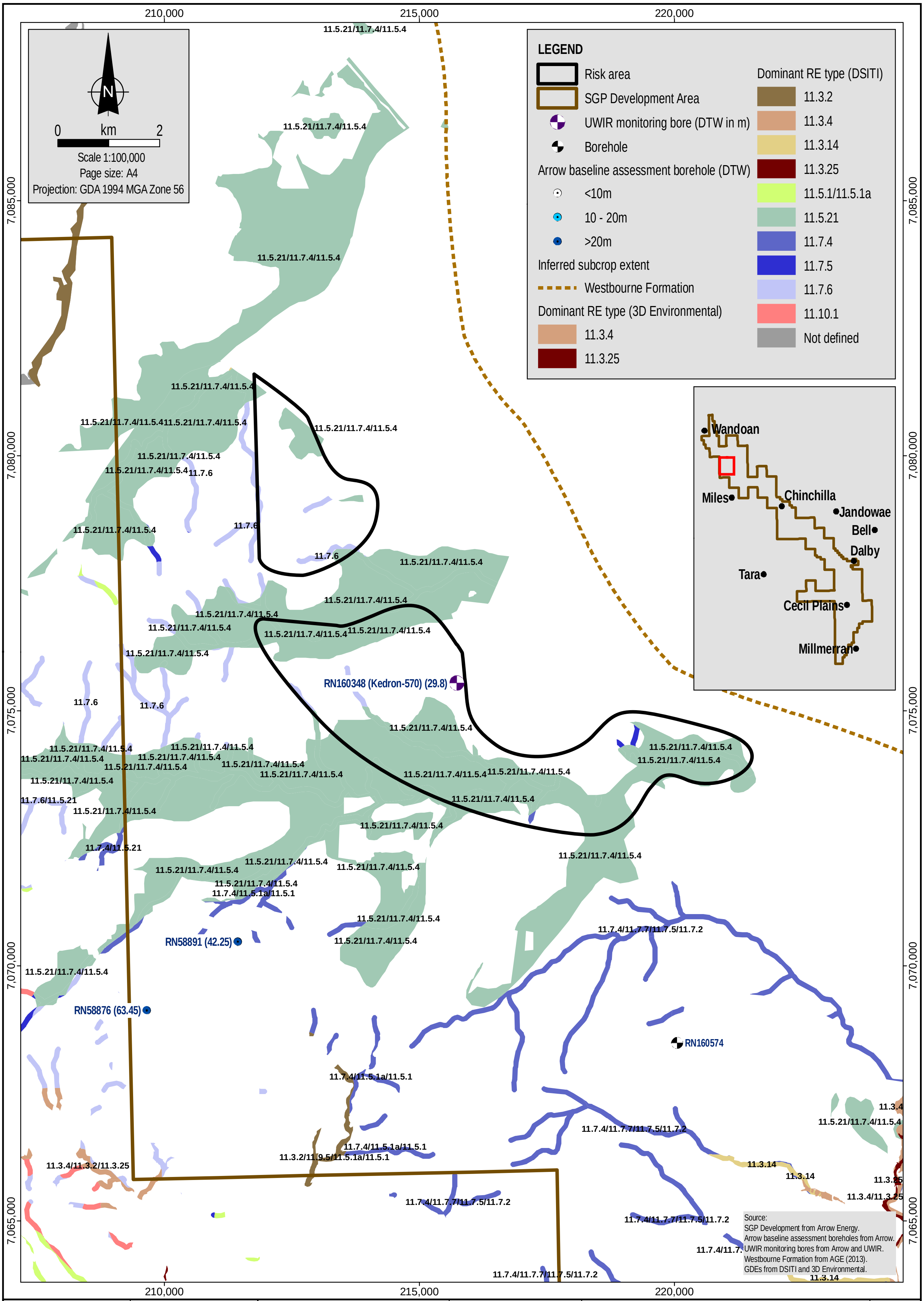
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Depth to watertable and hydrograph assessment locations

Figure No: 5.4



MXD Reference: 20484AA_M03_GIS026_v0_4

coffey
A TETRA TECH COMPANY

Date:
28.02.2017
Project:
ENAUABTF20484AA
File Name:
20484AA_M03_F05.5a_GIS

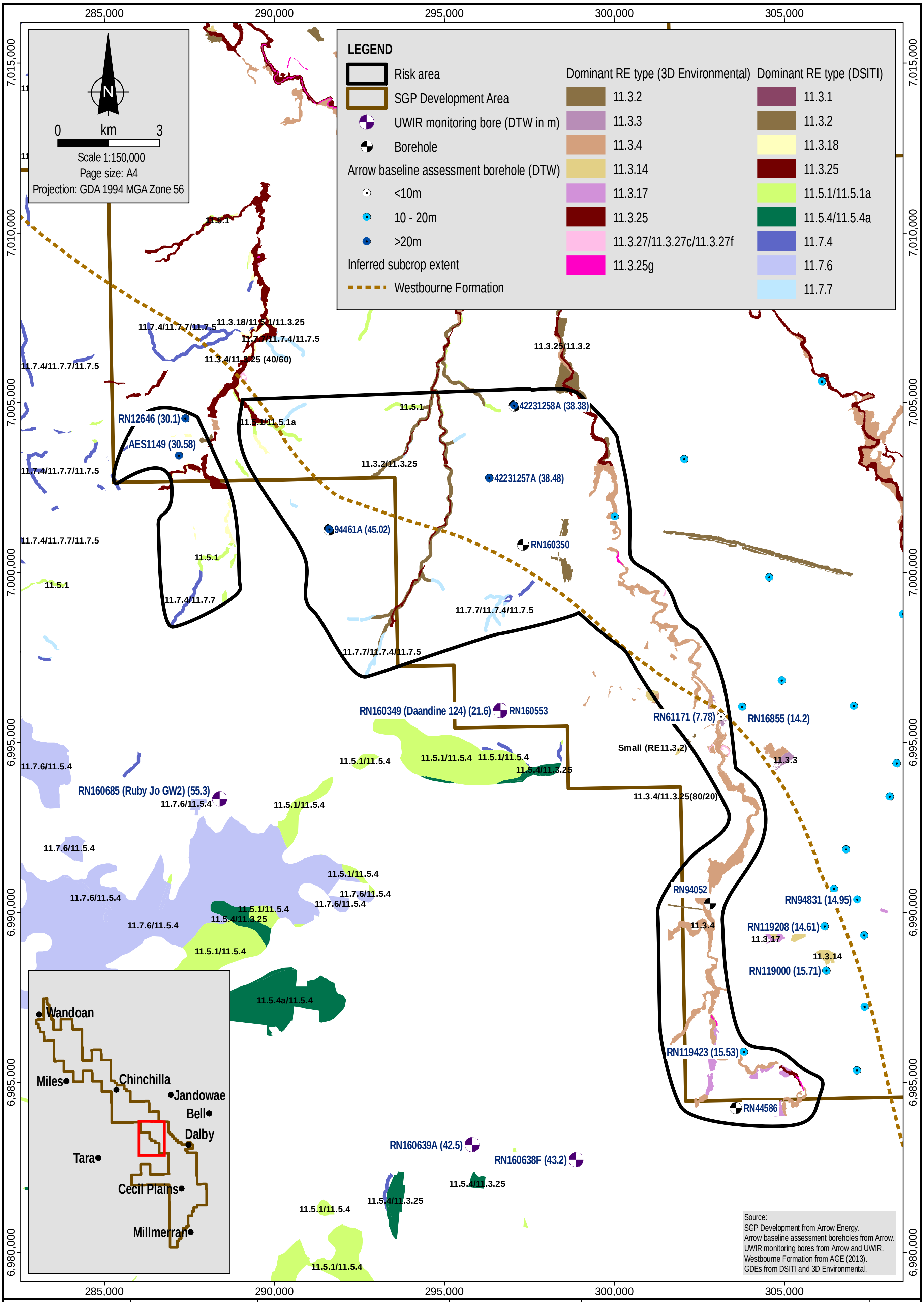
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Risk area 1

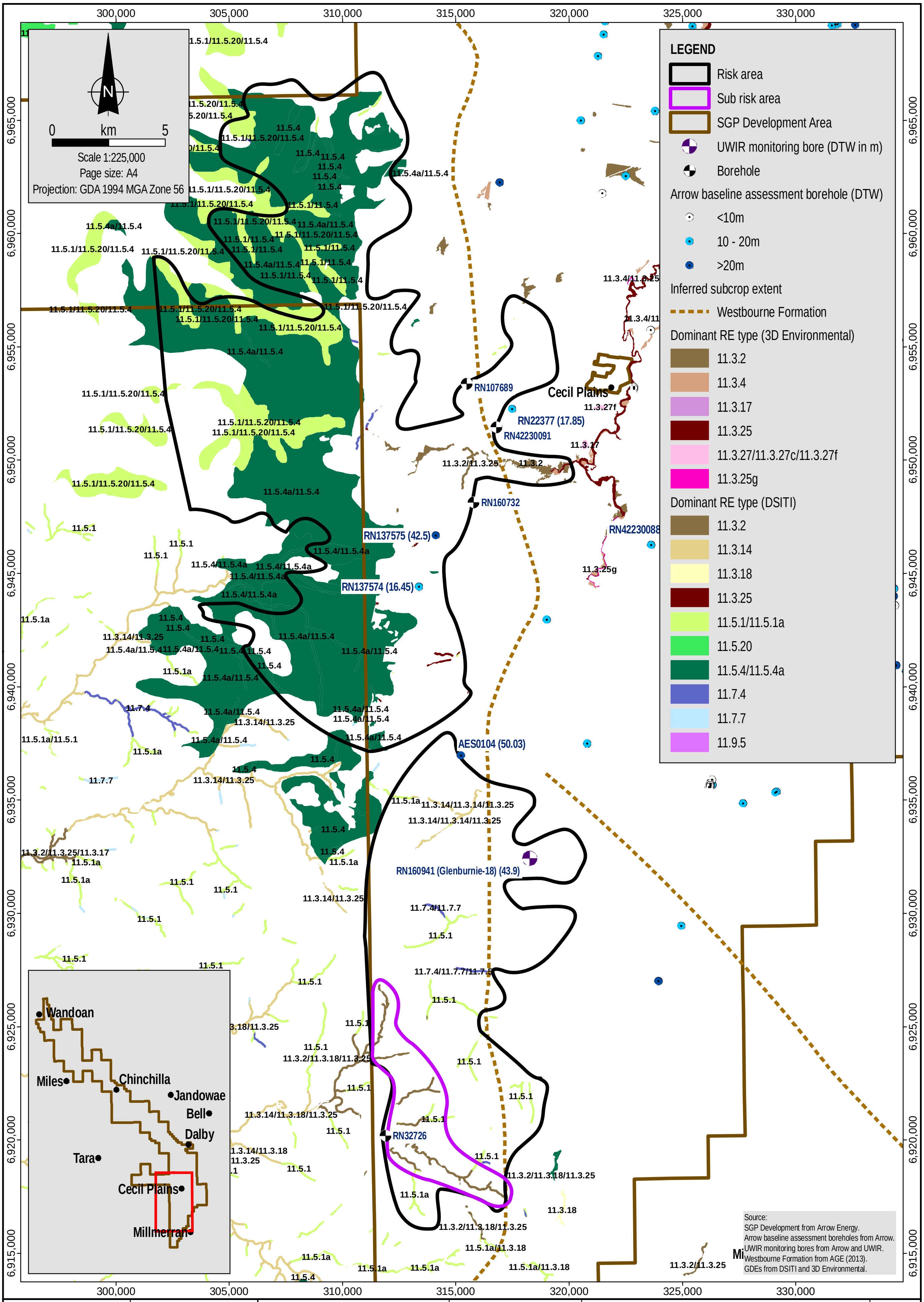
Figure No:
5.5a



Source:
SGP Development from Arrow Energy.
Arrow baseline assessment boreholes from Arrow.
UWIR monitoring bores from Arrow and UWIR.
Westbourne Formation from AGE (2013).
GDEs from DSITI and 3D Environmental.

MXD Reference: 20484AA_M03_GIS026_v0_4

coffey A TETRA TECH COMPANY	Date: 28.02.2017 Project: ENAUABTF20484AA File Name: 20484AA_M03_F05.5b_GIS	Arrow Energy Surat Gas Project WMMP	arrow energy go further	Risk area 2	Figure No: 5.5b



Source:
SGP Development from Arrow Energy.
Arrow baseline assessment boreholes from Arrow.
UWIR monitoring bores from Arrow and UWIR.
Westbourne Formation from AGE (2013).
GDEs from DSITI and 3D Environmental.

coffey
A TETRA TECH COMPANY

Date: 28.02.2017
Project: ENAUABTF20484AA
File Name: 20484AA_M03_F05.5c_GIS

Arrow Energy
Surat Gas Project WMMP

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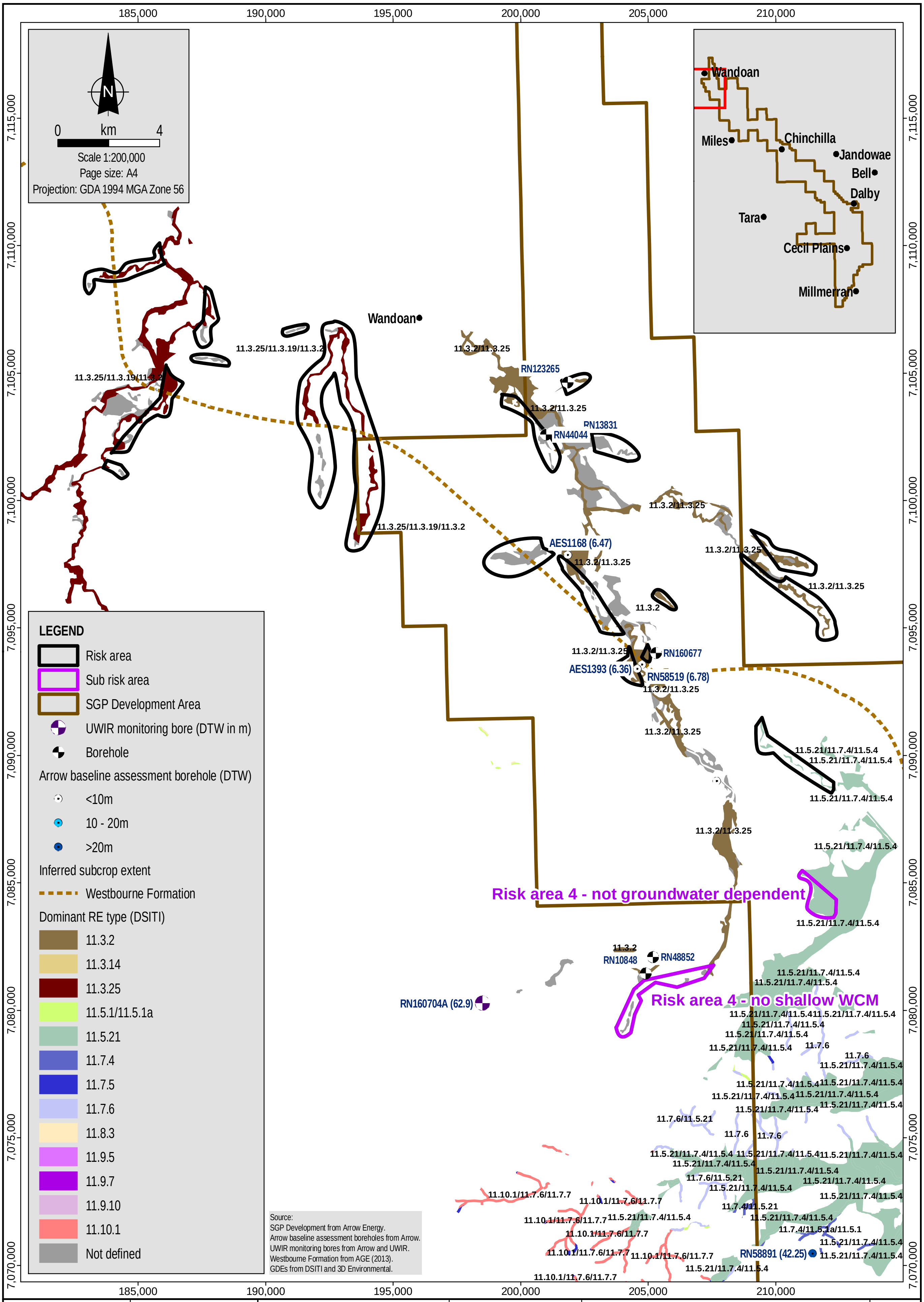
Risk area 3

Figure No:
5.5c

MXD Reference: 20484AA_M03_GIS026_v0_4



Source:
SGP Development from Arrow Energy.
Arrow baseline assessment boreholes from Arrow.
UWIR monitoring bores from Arrow and UWIR.
Westbourne Formation from AGE (2013).
GDEs from DSITI and 3D Environmental.

MXD Reference: 20484AA_M03_GIS026_v0_4

coffey
A TETRA TECH COMPANY

Date: 28.02.2017
Project: ENAUABTF20484AA
File Name: 20484AA_M03_F05.5d_GIS

Arrow Energy

Surat Gas Project WMMP

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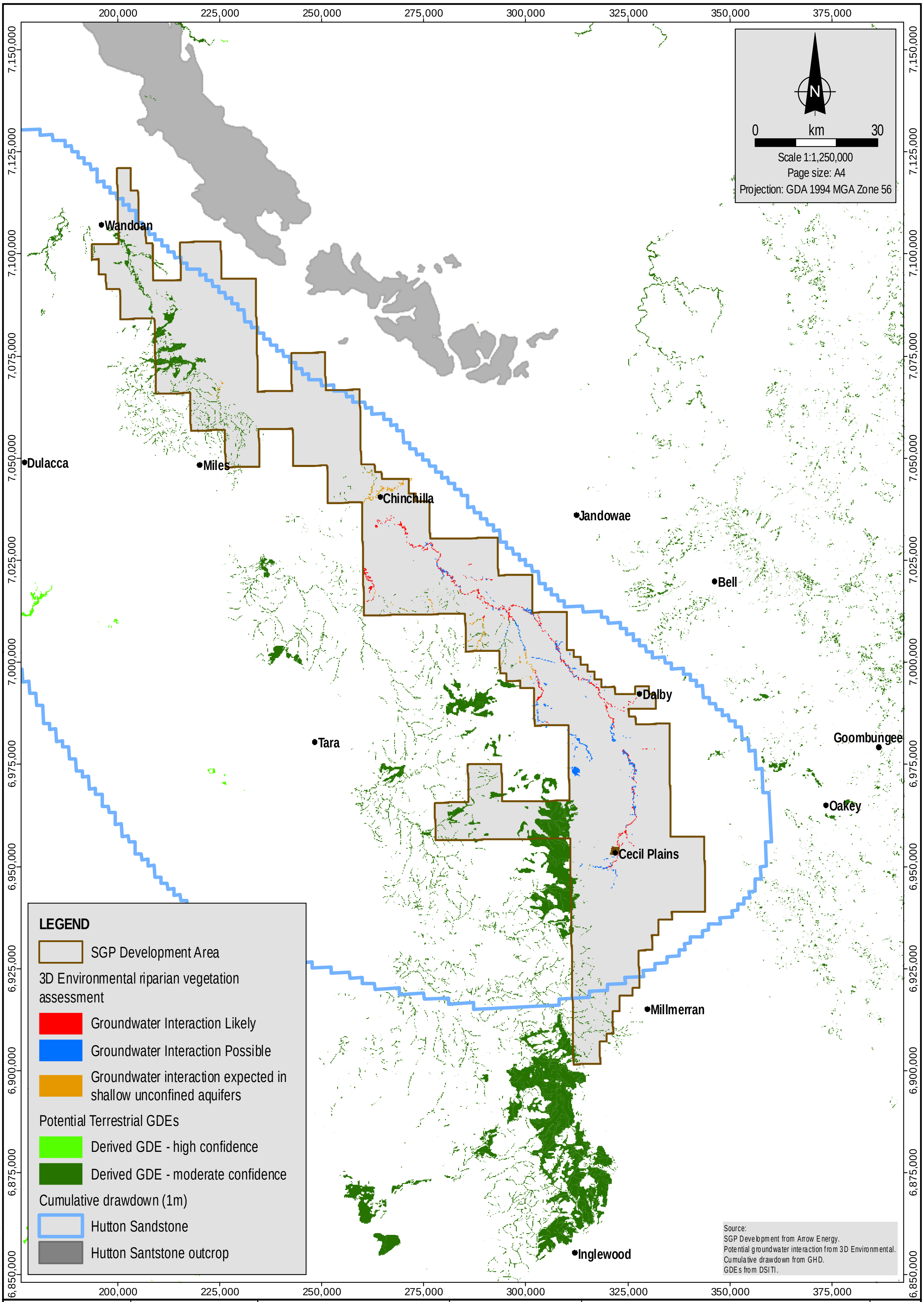
Risk area 4

Figure No:
5.5d



Source:
SGP Development from Arrow Energy.
Potential groundwater interaction from 3D Environmental.
Cumulative drawdown from GHD.
GDEs from DSITI.

MXD Reference: 20484AA_M03_GIS023_v0_1

coffey
A TETRA TECH COMPANY

Date:
13.02.2017
Project:
ENAUABTF20484AA
File Name:
20484AA M03 F06.1 GIS

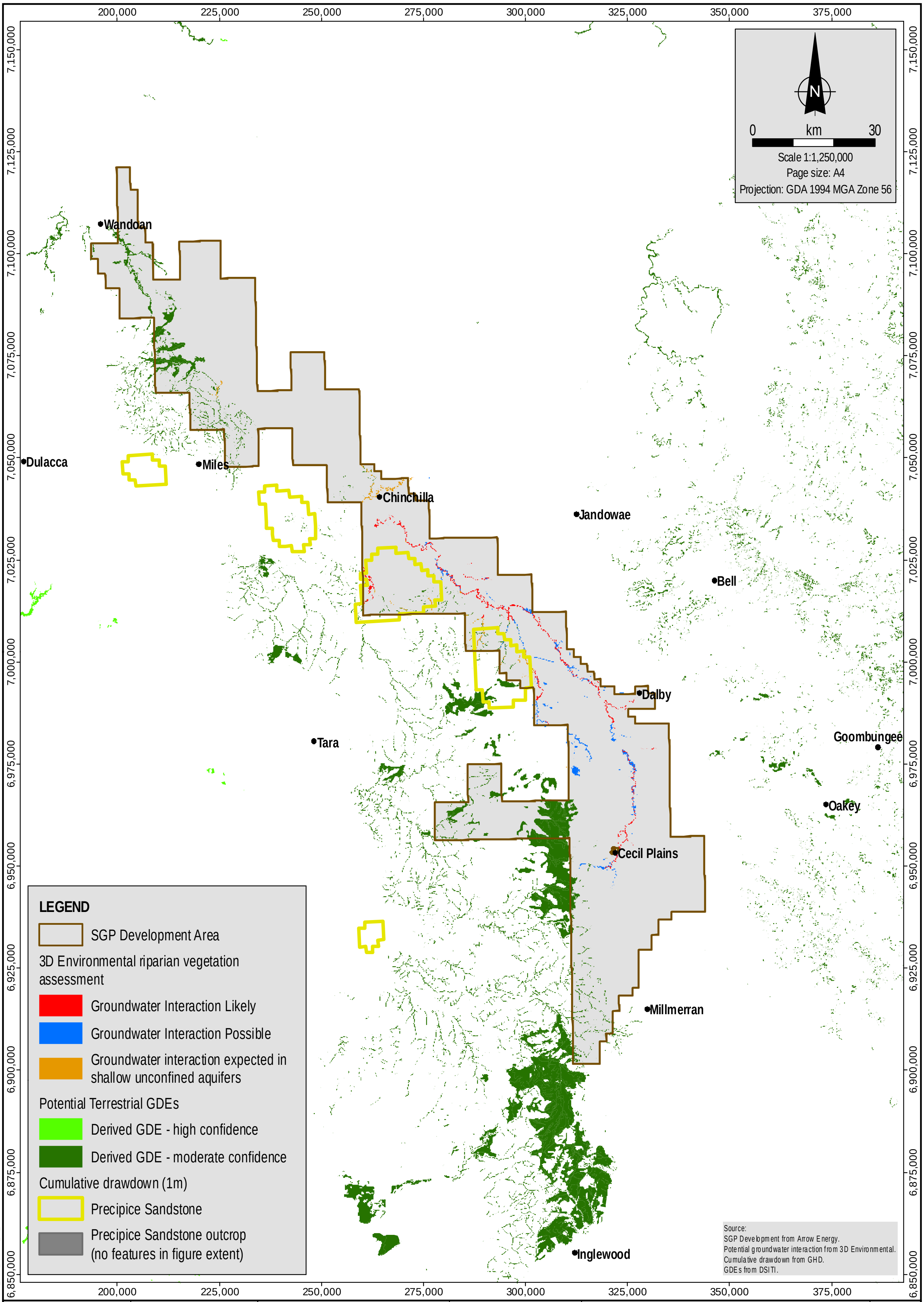
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Hutton Sandstone cumulative drawdown terrestrial GDE impact assessment

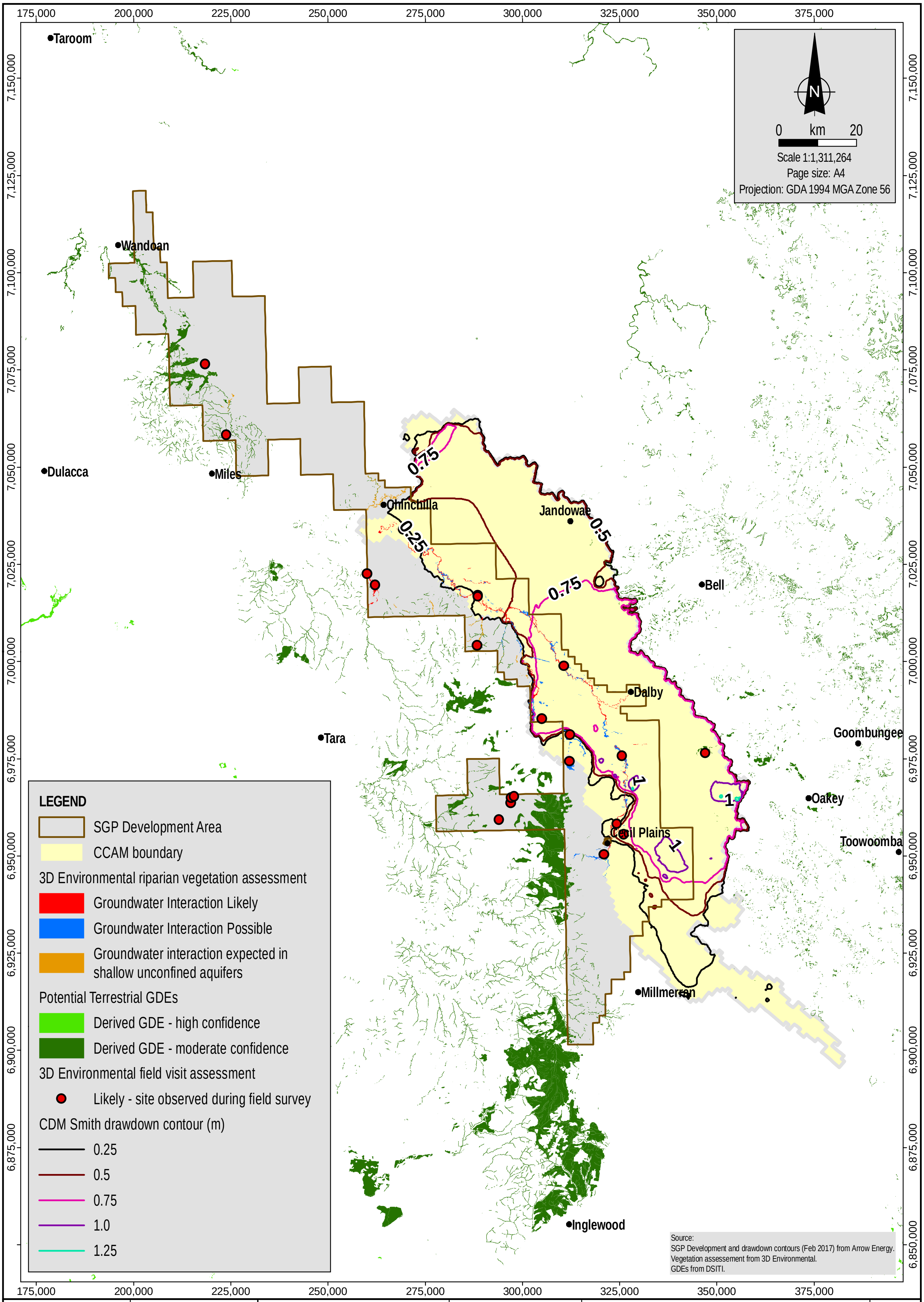
Figure No:
6.1



Source:
SGP Development from Arrow Energy.
Potential groundwater interaction from 3D Environmental.
Cumulative drawdown from GHD.
GDEs from DSITI.

MXD Reference: 20484AA_M03_GIS024_v0_2

Date: 13.02.2017	Arrow Energy	Precipice Sandstone cumulative drawdown terrestrial GDE impact assessment	Figure No: 6.2
Project: ENAUABTF20484AA	Surat Gas Project WMMP		
File Name: 20484AA_M03_F06.2_GIS			



Source:
SGP Development and drawdown contours (Feb 2017) from Arrow Energy.
Vegetation assessement from 3D Environmental.
GDEs from DSITI.

MXD Reference: 20484AA_M03_GIS029_v0_1

coffey
A TETRA TECH COMPANY

Date: 28.02.2017
Project: ENAUABTF20484AA
File Name: 20484AA_M03_F06.3_GIS

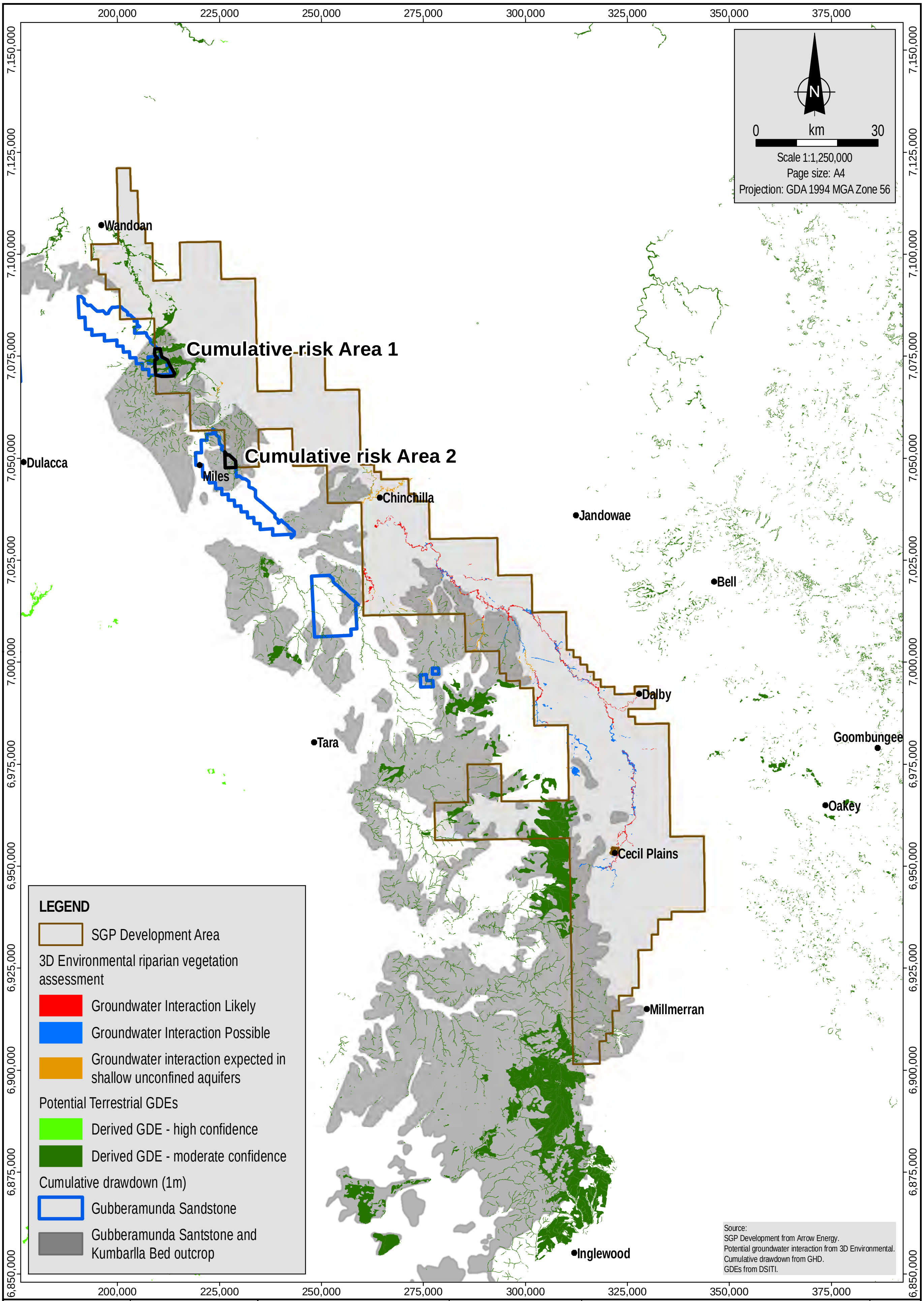
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Predicted maximum cumualtive drawdown in the Condamine Alluivum with potential terrestrial GDE landscapes

Figure No:
6.3



Source:
SGP Development from Arrow Energy.
Potential groundwater interaction from 3D Environmental.
Cumulative drawdown from GHD.
GDEs from DSITI.

MXD Reference: 20484AA_M03_GIS020_v0_3

coffey
A TETRA TECH COMPANY

Date:
28.02.2017
Project:
ENAUABTF20484AA
File Name:
20484AA_M03_F06.4_GIS

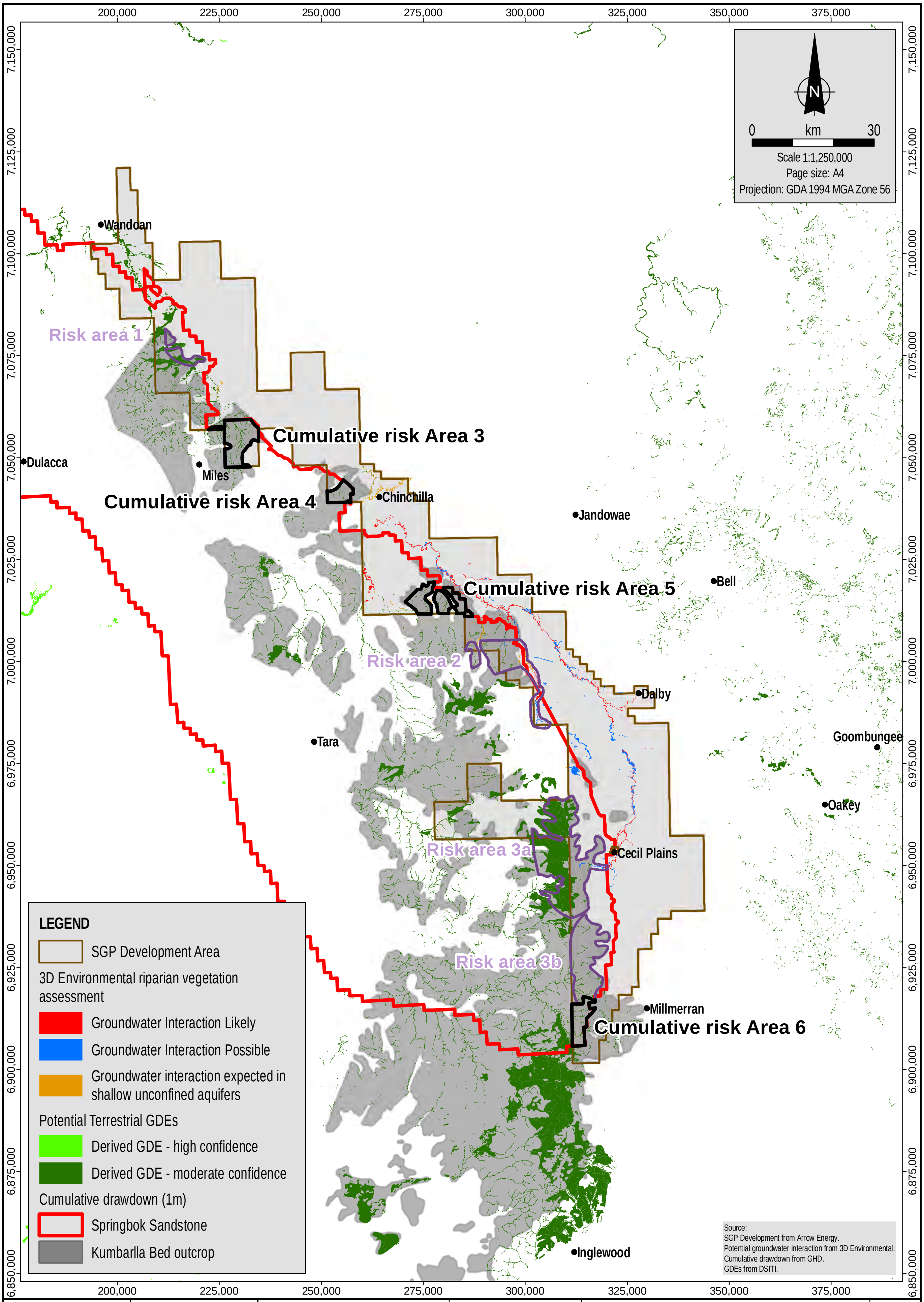
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Gubberamunda Sandstone cumulative drawdown terrestrial GDE impact assessment

Figure No:
6.4



Source:
SGP Development from Arrow Energy.
Potential groundwater interaction from 3D Environmental.
Cumulative drawdown from GHD.
GDEs from DSITI.

MXD Reference: 20484AA_M03_GIS021_v0_4

coffey
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Date:
28.02.2017
Project:
ENAUABTF20484AA
File Name:
20484AA_M03_F06.5_GIS

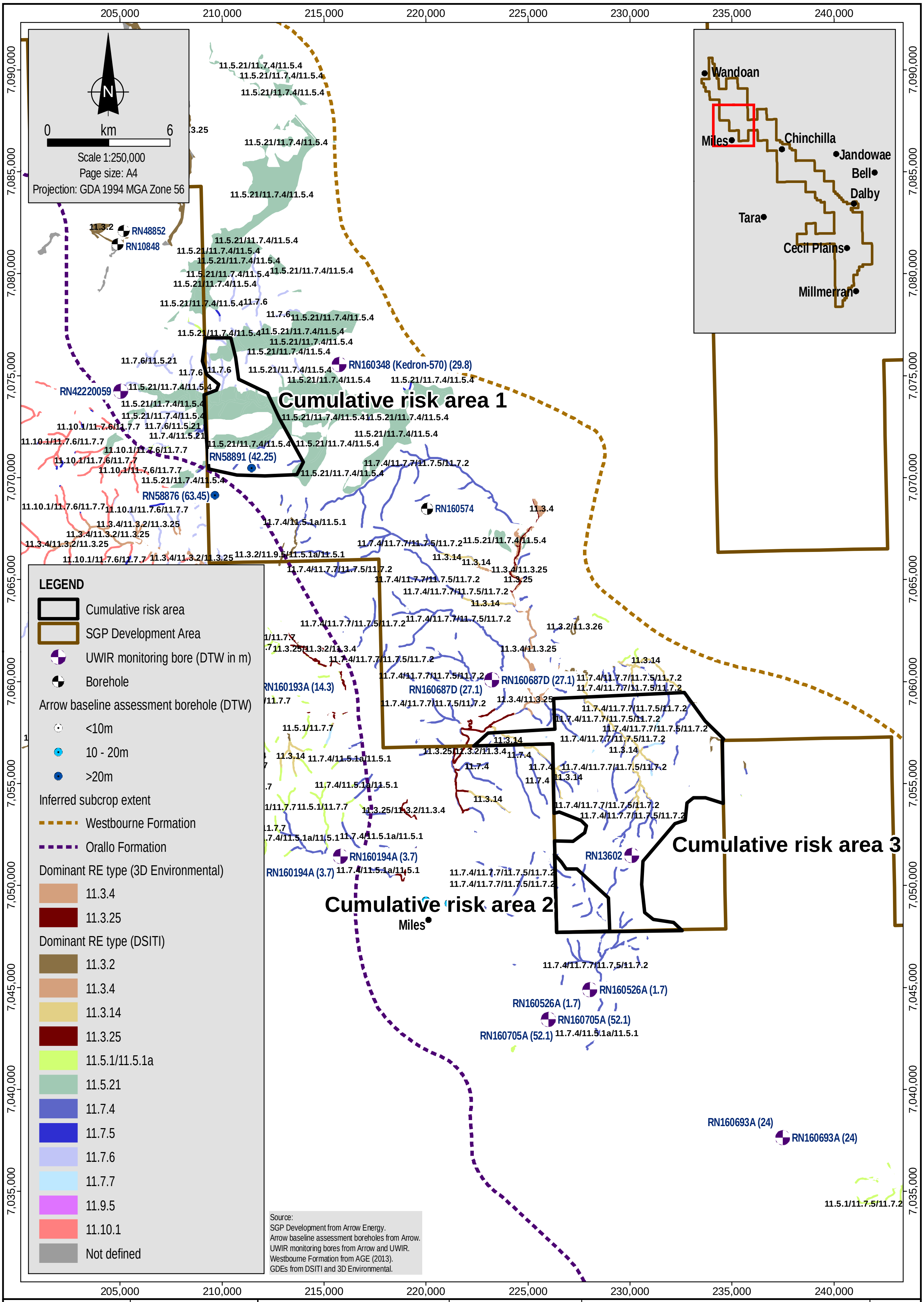
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Springbok Sandstone cumulative drawdown terrestrial GDE impact assessment

Figure No:
6.5



Source:
SGP Development from Arrow Energy.
Arrow baseline assessment boreholes from Arrow.
UWIR monitoring bores from Arrow and UWIR.
Westbourne Formation from AGE (2013).
GDEs from DSITI and 3D Environmental.

MXD Reference: 20484AA_M03_GIS030_v0_2

coffey
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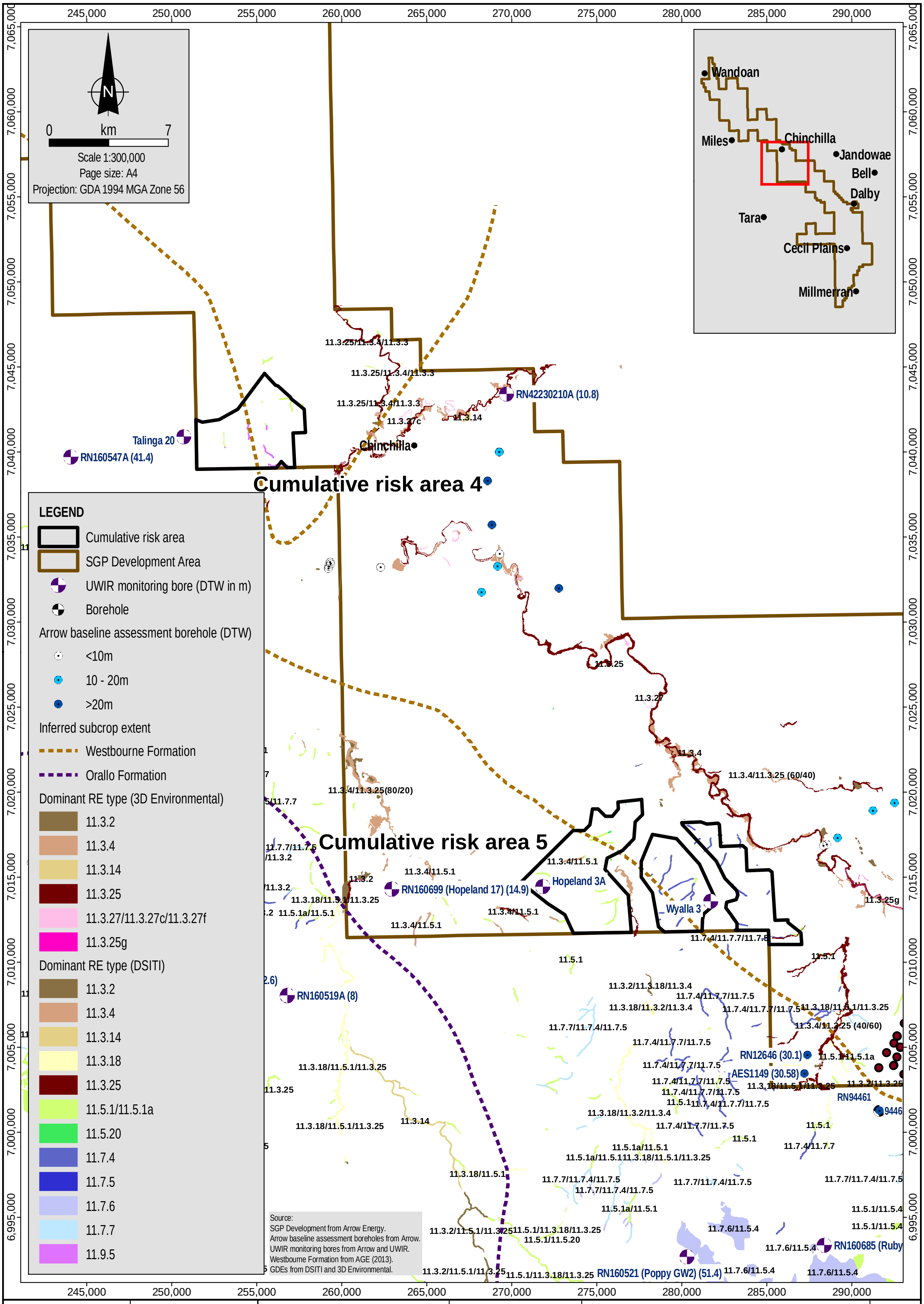
Date: 15.03.2017
Project: ENAUABTF20484AA
File Name: 20484AA_M03_F06.6a_GIS

Arrow Energy
Surat Gas Project WMMP

arrow energy go further

Cumulative risk area 1, 2 & 3

Figure No:
6.6a



Source:
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Arrow baseline assessment boreholes from Arrow.
UWIR monitoring bores from Arrow and UWIR.
Westbourne Formation from AGE (2013).
GDEs from DSITI and 3D Environmental.

MXD Reference: 20484AA_M03_GIS030_v0_2

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Date:
15.03.2017
Project:
ENAUABTF20484AA
File Name:
20484AA_M03_F06.6b_GIS

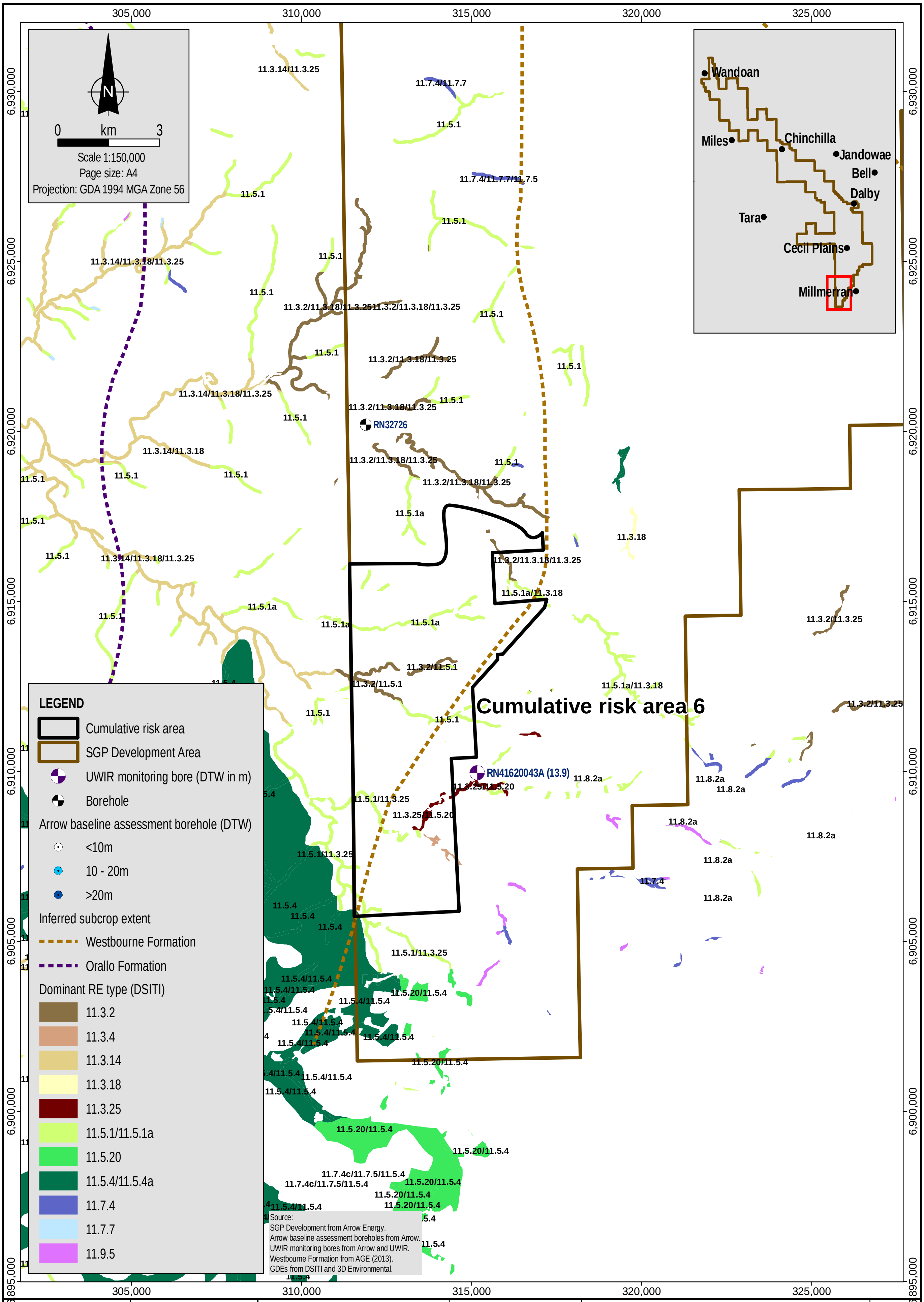
Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Cumulative risk area 4 & 5

Figure No:
6.6b



Source:
SGP Development from Arrow Energy.
Arrow baseline assessment boreholes from Arrow.
UWIR monitoring bores from Arrow and UWIR.
Westbourne Formation from AGE (2013).
GDEs from DSITI and 3D Environmental.

MXD Reference: 20484AA_M03_GIS030_v0_2

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Date:
15.03.2017

Project:
ENAUABTF20484AA

File Name:
20484AA_M03_F06.6c_GIS

Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Cumulative risk area 6

Figure No:
6.6c

Attachment 1: Aquatic Ecosystem Assessment

Environmental Approval & Compliance Solutions

Surat Gas Project - Stage 1
Coal Seam Gas Water Monitoring and Management
Aquatic Ecosystem Assessment

Coffey Services Australia Pty Ltd

Environmental Approval & Compliance Solutions

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www.natres.com.au

NRA Reference: Cover letter_L01

24 January 2017

Coffey Services Australia Pty Ltd
Level 1, 436 Johnston Street
Abbotsford VIC 3067

Attention: Brigid Moriarty, Senior Associate Hydrogeologist

Dear Brigid

RE: Surat Gas Project – Stage 1 Coal Seam Gas Water Monitoring and Management – Aquatic Ecosystem Assessment (Version R02)

Please find enclosed the Surat Gas Project – Stage 1 Coal Seam Gas Water Monitoring and Management – Aquatic Ecosystem Assessment (Version R02). This final version has been updated with comments received from Coffey Services Australia Pty Ltd on 17 January 2017.

If you have any questions please feel free to contact me on (07) 4034 5300 or email at paul@natres.com.au.

Yours sincerely

NRA Environmental Consultants

Paul Godfrey
Senior Environmental Scientist

Encl: Surat Gas Project – Stage 1 Coal Seam Gas Water Monitoring and Management – Aquatic Ecosystem Assessment (Version R02)

Document Control Summary

NRA Environmental Consultants

Job No:	F:\AAA\364_Coffey\364002.00-SGP Aq Ecol Assess\Rpt\SGP WMMP AqEcolAss_R02.docx
Status:	Final
Project Manager:	Dr Paul Godfrey
Title:	Surat Gas Project - Stage 1 Coal Seam Gas Water Monitoring and Management Plan Aquatic Ecosystem Assessment
Author/s:	Dr Paul Godfrey
Client:	Coffey Services Australia Pty Ltd
Client Contact:	Brigid Moriarty, Senior Associate Hydrogeologist
Date of Issue:	24 January 2017
No. of Copies:	1 PDF
Dispatched Via:	Email
Other Info or Requirements:	Final report supersedes and replaces all previous documentation prepared.

Report Summary	
Key Words	Groundwater, coal seam depressurisation, Water Monitoring and Management Plan, aquatic ecosystem assessment, Condamine River, water table, stygofauna, aquatic ecology
Abstract	This report presents the findings of an assessment of potential impacts to aquatic ecosystems in Arrow's Surat Gas Project Development Area due to drawdown in the Condamine Alluvium from coal seam depressurisation.

Quality Assurance					
Author	**Technical Review**	**Editor**	**Document Version**	**Approved for Issue by QA Manager**	
				Date	**Signature**
Paul Godfrey BSc (Hons), PhD	Shannon Wetherall BAppSc (Hons)	Kate Steyn BAgrSc	R01	7/12/16	
			R02	24/01/17	

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SAFETY CERTIFIED COMPANY JAS-ANZ AS/NZS 4801:2001 Registration No: 150
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Figures

Appendices

1. Introduction

Arrow Energy Ltd (Arrow) proposes to expand its coal seam gas operations in the Surat Basin of Queensland through the Surat Gas Project (SGP).

The SGP Approval under the Commonwealth *Environment Protection and Biodiversity Conservation (EPBC) Act* 1999 (EPBC 2010/5344) includes conditions requiring the preparation of a Stage 1 Coal Seam Gas (CSG) Water Monitoring and Management Plan (WMMP). The SGP Approval Condition 13c relates to an aquatic ecosystem impact assessment as follows.

The CSG WMMP Stage 1 must include:

> *(c) an assessment of potential impacts from the action on non-spring based groundwater dependent ecosystems through potential changes to surface-groundwater connectivity and interactions with the sub-surface expression of groundwater.*

NRA Environmental Consultants (NRA) was engaged by Coffey Services Australia Pty Ltd (Coffey) on behalf of Arrow to undertake a desk-based assessment of the potential impact to aquatic ecosystems in Arrow's SGP Development Area resulting from changes to groundwater levels as a result of coal seam depressurisation.

1.1 Scope

The study tasks are described in the Request for Proposal document provided by Coffey (dated 11 November 2016), and are as follows.

Task 1 – desktop assessment

Undertake a desktop review of available information, including:

- *SGP EIS and SREIS aquatic ecology assessments.*
- *Data made available since the submission of the SREIS for relevant ecosystems in the SGP area with a focus on the Condamine Alluvium and Condamine River.*
- *Comparison against groundwater modelling drawdown extents and existing groundwater level data (to be provided by Coffey) to identify aquatic ecosystems that may be at risk from the proposed CSG development.*
- *Preparation of a brief desktop assessment report detailing the findings of the assessment, including recommendations on the need for further detailed assessment (i.e. field studies) if required.*

1.2 Description of the activity

The effect of Arrow's CSG production on surface water-groundwater interactions of the Condamine Alluvium is described in the *Surat Gas Expansion Project – CSG WMMP Section 13(b)* report (CDMSmith 2016) as follows.

Production of CSG by Arrow will require pumping of water from the Walloon Coal Measures. Depressurisation will lead to a tendency for lower discharge from the Walloon Coal Measures to the Condamine Alluvium. In time this will lead to a slight reduction in water table elevation in the Condamine Alluvium, but this may not cause greater leakage from the Condamine River to groundwater, because the river and the water table are already "disconnected", with leakage already occurring at the maximum possible rate along most of the length of surface drainage lines.

CDMSmith (2016) presents the results of numerical surface and groundwater modelling, which simulated the potential impacts to surface water resources and groundwater levels as a result of coal seam depressurisation. The simulation results for: (i) all time maximum water table drawdown and (ii) simulated depth to water table along the Condamine River and tributaries that are presented in CDMSmith (2016) are reproduced on **Figures 1** and **2**. **Figure 2** provides an indication of where along the Condamine River and its tributaries these watercourses may currently be connected to the water table.

Potential hydrological impacts from coal seam depressurisation are described in CDMSmith (2016) as follows.

Ground water

The depressurisation of groundwater from CSG development is predicted to lead to a decline in the water table of the Condamine Alluvium, but one that is small in magnitude and very gradual. The predicted rate of change is of the order of 1 to 2 mm/y and will be almost imperceptible compared to background rates of change which can be more than 1 m per year, with fluctuations of up to tens of metres during an irrigation season, based on historic trends. The very low rate of change compared to other influences indicates negligible impacts to stygofauna from CSG development.

Surface water

The predicted maximum change in surface water-groundwater flux along the Condamine River as a result of CSG development is of the order of 0.2–0.3 ML/d. When introduced to the IQQM hydrological model, this change in flux results in negligible changes to surface water flow. The only detected change was an increase in low flow days by 0.1% at one of the model nodes. The very minor change to flow rates, which is only predicted to occur at one location[1], indicates negligible impacts to Aquatic Flora and Fauna Type DEs[2] in regulated settings.

In unregulated settings (e.g. in tributaries not captured by the IQQM modelling) where groundwater and surface water are connected, water table drawdown may induce some additional surface water leakage which is not buffered by upstream flows. As outlined in Section 6, refugia in these hydrological settings are the most sensitive components of Aquatic Flora Fauna Type DEs to such a threat.

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[1] *ie* Node J Condamine River at the upstream limit of the impounded area of Chinchilla Weir.

[2] *ie* Dependent Ecosystems.

The numerical modelling undertaken is unable to assess changes to surface water conditions in unregulated settings because they are not included in the IQQM modelling. Therefore, a conceptual approach has been used to assess the significance of potential impacts, as follows:

- *Increased surface water leakage as a result of an increased hydraulic gradient from the stream to the water table will be controlled by the hydraulic conductivity of the streambed and the strata which underlie it.*
- *Investigations undertaken by Lane (1979)*[3] *confirmed the presence of clayey strata underlying drainage channels throughout the Condamine Alluvium.*
- *Given that the magnitude of predicted drawdown due to Arrow water production peaks at 1.1 m or less, any increased leakage from surface water would be less than the vertical flux through the clayey strata underlying the drainage channels under a vertical hydraulic gradient of 1.5.*
- *A conservative estimate of the kv*[4] *of clayey sediments is in the order of 0.001 m/d (Fetter 1988)*[5] *implying that any increased leakage would be no more than 1.5 mm/d greater than the baseline leakage rate.*
- *The altered leakage would manifest over hundreds of years, such that the rate of change is of the order of 0.0015 mm/d – an undetectable change compared to other influences such as climatic variation.*
- *These very minor changes in surface water leakage rates indicates negligible impacts to Aquatic Flora and Fauna Type DEs in these settings.*

1.3 Study area

The study area for the aquatic ecosystem assessment was Arrow's SGP Development Area, which is shown on **Figures 1** and **2** (*ie* the SGP Development Area). However, the focus of the study was on areas where the Walloon Coal Measures depressurisation may lower the water table (Request for Proposal document, dated 11 November 2016). These focus areas are described in the Request for Proposal document as follows.

- Areas of >0.25 m drawdown in the Condamine Alluvium.
- Reaches of the Condamine River and tributaries where depth to water table is simulated as being <10 m.
- Areas of >0.2 m drawdown in the Springbok Sandstone for the broader project area.

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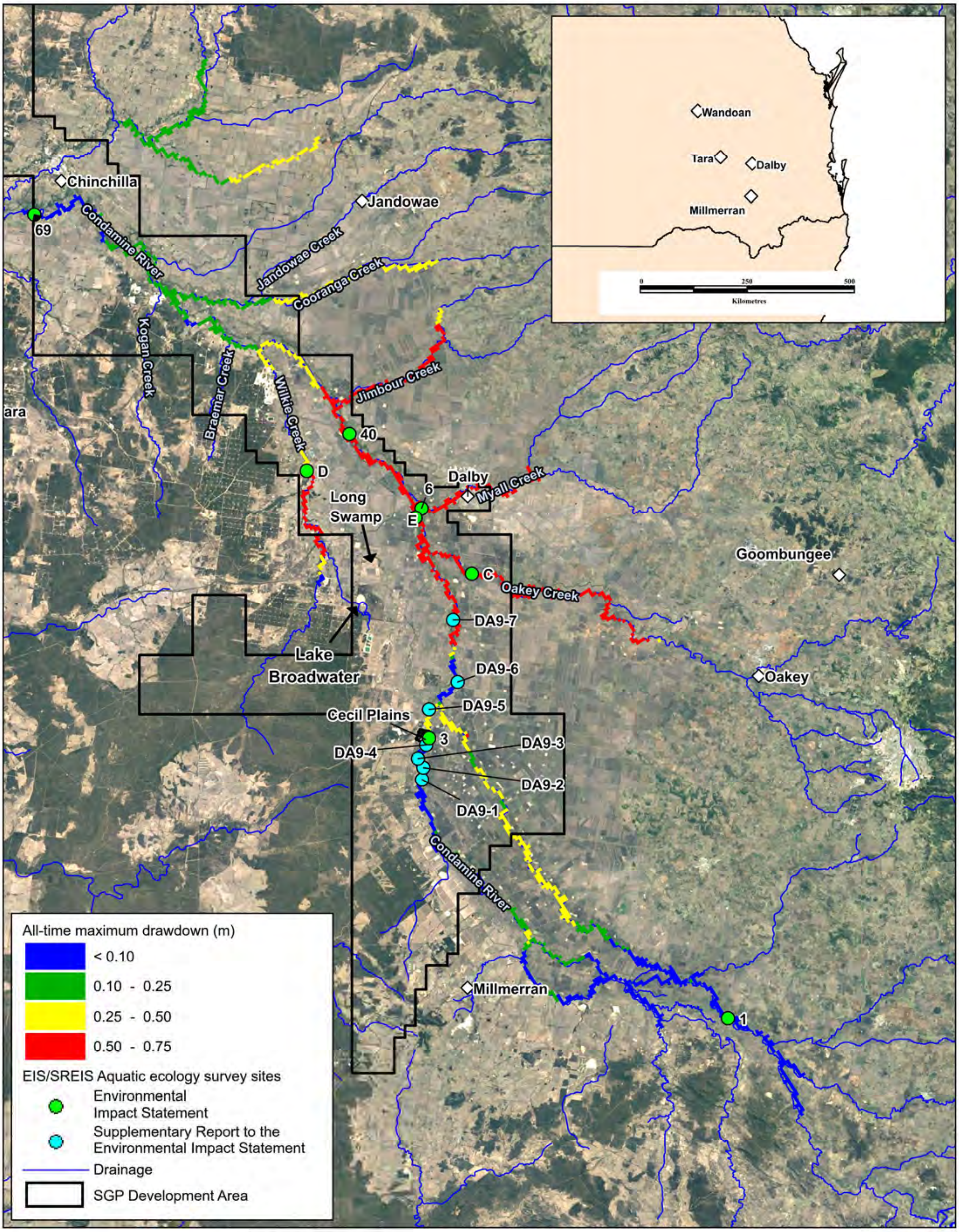
[3] Lane, W.B. 1979, Condamine underground investigation to December 1978, Progress Report Volume 1, Queensland Water Resources Commission.

[4] *ie* vertical hydraulic conductivity.

[5] Fetter, C.W. 1988, Applied hydrogeology, Second Edition, Merrill Publishing Company.



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PROJECT: Surat Gas Project - Stage 1 CSG Water Monitoring and Management Plan Aquatic Ecosystem Assessment

TITLE: Predicted Arrow contribution to maximum drawdown (high case) along Condomine River and its tributaries

SOURCE:
SGP Development Arrow Energy
Modelling boundary and simulated depth from CDM Smith
Google Earth aerial imagery 2016

File Path: T:_AAA\364\WOR\364002_00\364002.00_Drawdown&Water_170119.wor

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JOB NO: 364002
DATE: January 2017

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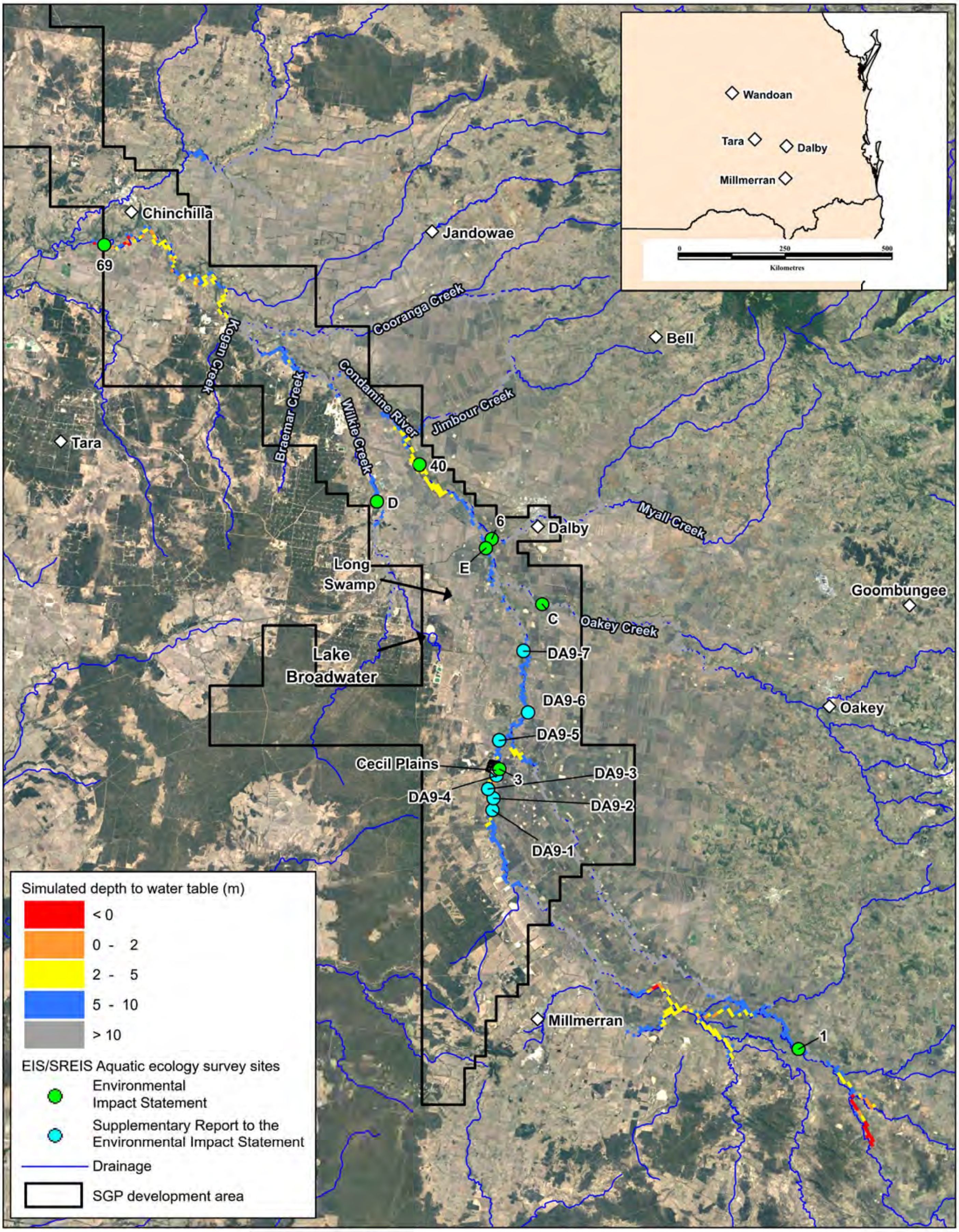
Kilometres

Figure 1

Recommended print size: A4



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PROJECT: Surat Gas Project - Stage 1 CSG Water Monitoring and Management Plan
Aquatic Ecosystem Assessment
TITLE: Simulated depth to groundwater along the Condomine River and its tributaries

SOURCE: SGP Development Arrow Energy
Modelling boundary and simulated depth from CDM Smith
GoogleEarth aerial imagery 2016

File Path: T:_AAA\364\WOR\364002_00\364002 00_Depth_to_GrdWater_170119.wor

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JOB NO: 364002
DATE: January 2017

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Kilometres

Figure 2

Recommended print size: A4

2. Methods

The desk-based assessment involved a review of information obtained from the following sources.

- Specialist SGP Environmental Impact Statement (EIS) Reports and/or SGP Supplementary Reports to the EIS (SREIS):
    - Aquatic ecology (Aquateco 2011, AMEC 2013).
    - Groundwater (Coffey 2013).
- Detailed numerical surface water and groundwater modelling for the Condamine Alluvium and Condamine River (CDMSmith 2016).
- Queensland Department of Natural Resources and Mines groundwater bore reports (Queensland Government 2016a).
- Queensland subterranean aquatic fauna database (Queensland Government 2016b).
- Published aquatic ecology reports and journal articles (**Section 6**).
- Google Earth imagery.

3. Existing Environment

3.1 Location

Arrow's SGP Development Area is located between the townships of Wandoan, Tara, Millmerran and Dalby in southern central Queensland (**Figure 1**).

3.2 Condamine Alluvium

The Condamine Alluvium is described in the *Underground Water Impact Report for the Surat Cumulative Management Area* (DNRM 2016a) as follows.

The Condamine Alluvium is a broad term used to describe the alluvial and sheetwash deposits of the Condamine River and its tributaries. The Condamine alluvial aquifer is comprised of gravels and fine-to-coarse-grained channel sands interbedded with clays. The proportion of clay within the sand and gravel beds increases downstream. The aquifer is generally 30–60 metres thick, although it reaches a maximum thickness of 130 metres in the central floodplain near Dalby. The individual channel sand and gravel aquifers are less than 20 metres thick. Permeability is higher in the central part of the aquifer and ranges from 0.5 to 40 metres per day.

A thick, clayey sequence of sheetwash deposits overlies the productive granular alluvium in the east, causing the aquifer to be semi-confined in nature. The sheetwash is composed of low-permeability finegrained material (Huxley 1982[6]*; KCB 2010a*[7]*).*

Groundwater levels within the Condamine Alluvium show almost no difference in water levels with depth. This implies that although the system is made up of many discrete beds, they are extensively interconnected, with the result that Condamine Alluvium acts for the most part as a single aquifer system (KCB 2010a).

Recharge is primarily infiltration from the Condamine River, with some contribution directly from rainfall and laterally from the surrounding bedrock and alluvium of the tributaries of the Condamine River. The consistent layer of low-permeability black soil (up to 10 metres thick) over most of the Condamine Alluvium restricts rainfall recharge.

Groundwater quality within the Condamine Alluvium is generally good; however, salinity is higher on the alluvial margins which are more distant from the river and in the down-valley direction where permeability is lower. In these areas, the groundwater has resided in the aquifer for longer and there is more potential for the alluvium to interact with the basement (KCB 2010a). The salinity in the aquifer ranges from about 40 mg/L to more than 16,000 mg/L, with an average of about 1,500 mg/L.

The Condamine Alluvium is heavily used for water supply purposes. The groundwater is mainly used for irrigation and town water supply, with minor consumption for domestic,

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[6] Huxley, WJ 1982, *Condamine River groundwater investigation: The hydrogeology, hydrology and hydrochemistry of the Condamine River valley Alluvium*, Queensland Water Resources Commission, Brisbane.

[7] KCB (Klohn Crippen Berger) 2010a, Central Condamine Alluvium, Stage II – Conceptual hydrogeological summary, Final report, Department of Environment and Resource Management, Brisbane.

stock watering, industry, stock-intensive and commercial supplies. Bore yields range up to 60 litres a second (L/s), though most are less than 10 L/s (DERM 2009[8]*; KCB 2010b*[9]*).*

Groundwater extraction from the Condamine Alluvium has caused a considerable fall in groundwater levels. Water levels vary from less than 10 metres below ground level on the edges of the alluvium to more than 40 metres below ground level in the main extraction area in the centre of the alluvium, to the east of Cecil Plains. Water levels have been steadily falling since the 1960s (KCB 2010a). On average, water levels have fallen by about six metres, but in areas further away from the Condamine River, levels have fallen by up to 26 metres.

CDMSmith (2016) describes surface water-groundwater interactions of the Condamine Alluvium as follows.

The Condamine River is disconnected from the underlying water table and losing water along much of its length (CSIRO 2008). This is confirmed by independent analysis of water table elevations relative to bed levels of rivers and streams.

3.3 Springbok Sandstone

The Springbok Sandstone is one of the main aquifers within the Great Artesian Basin (GAB) (DNRM 2016a). GAB aquifers are typically laterally continuous, have significant water storage, are permeable and are extensively developed for water supply (DNRM 2016a). Watercourse spring W160 on Western Creek, which has a source aquifer nominated as Springbok Sandstone, is the only watercourse spring located within 10 km of the area of predicted drawdown associated with Arrow's CSG production (**Figure 3**). The SREIS groundwater assessment (Coffey 2013) determined that the risk of drawdown impact to W160 is considered to be very low as it is located at the outer extent of the conservatively assumed 10 km buffer zone for predicted drawdown in the year 2094. The watercourse spring has not been considered further for this aquatic ecosystem assessment.

3.4 Condamine River and environmental flows

The Condamine River is part of the Murray-Darling Basin and drains the northern portion of the Darling Downs. It flows in a north-easterly direction through the SGP Development Area (**Figure 1**).

Flow in the Condamine River is regulated by a series of weirs. CSIRO (2008) reported that average surface water availability in the Condamine-Balonne was 1,363 GL/y, of which 53% was diverted for use.

Arrow's SGP Development Area falls within the Water Resource (Condamine and Balonne) Plan 2004 (WRP) area (DNRM 2016b). The Condamine-Balonne WRP includes eco-hydrologic performance indicators (defined in the WRP as Environmental Flow Objectives (EFOs)) to measure and compare impacts of different management options. EFOs under the Condamine-Balonne WRP state that the performance indicators need to be within a certain range (66%-133%) of the indicator for the pre-development flow pattern (McGregor *et al*. 2012).

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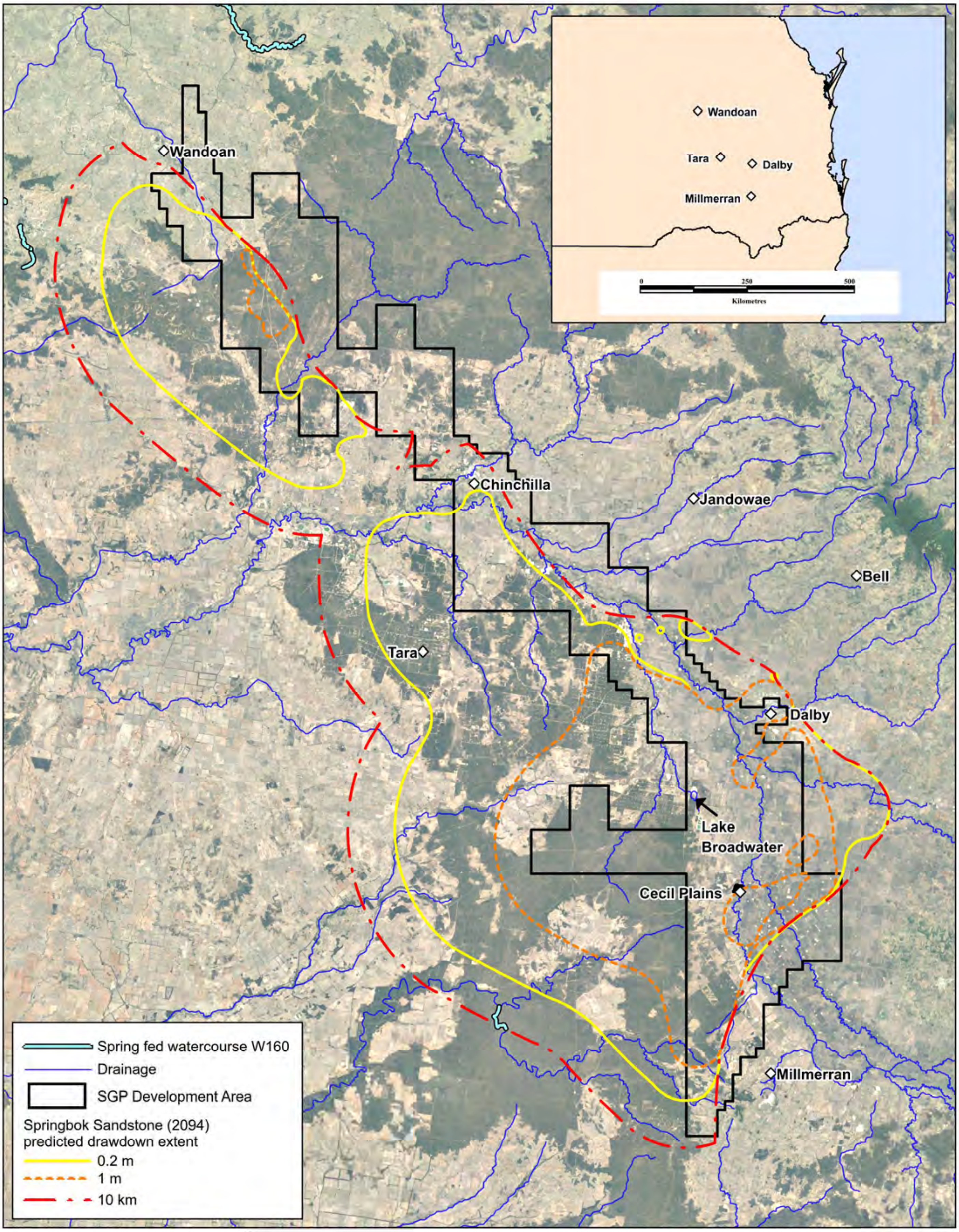
[8] DERM 2009, Condamine and Balonne water resource plan, Department of Environment and Resource Management (DERM), Brisbane, viewed 24 August 2011, http://www.derm.qld.gov.au/wrp/condamine.html.

[9] KCB (Klohn Crippen Berger) 2010b, Central Condamine Alluvium data availability review, Final report, Department of Environment and Resource Management, Brisbane.



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PROJECT: Surat Gas Project - Stage 1 CSG Water Monitoring and Management Plan Aquatic Ecosystem Assessment
TITLE: Groundwater dependant ecosystem assessment drawdown extents including buffer zones Springbok Sandstone

SOURCE: SGP Development Arrow Energy
Modelling boundary and simulated depth from CDM Smith
Google Earth aerial imagery 2016

File Path: T:_AAA\364\WOR\364002_00\364002.00_GDE_170119.wor

JOB NO: 364002
DATE: January 2017

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Figure 3

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3.5 Groundwater dependent ecosystems in the project area

In Queensland, groundwater dependent ecosystems (GDEs) are defined as ecosystems which require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services' (EHP 2016). Ecosystem dependency on groundwater may vary temporally (over time) and spatially (depending on its location in the landscape). GDEs include aquifers, caves, lakes, palustrine wetlands, lacustrine wetlands, rivers and vegetation (EHP 2016).

3.5.1 Aquifer ecosystem and stygofauna

The Condamine Alluvium contains aquifer ecosystems with stygofauna[10] (Hose *et al*. 2015, CDMSmith 2016)[11]. CDMSmith (2016) describes stygofauna studies undertaken in the Condamine Alluvium as follows.

Stygofauna sampling has taken place in the Condamine and over 70 stygofauna sampling records are recorded in the Queensland Subterranean Fauna Database; however, these records are restricted due to IP [intellectual property] *agreements. Fauna found include individuals from the Coleoptera, Copepoda, Syncarida and Oligochaeta taxonomic groups (Katharine Glanville DSITI pers. comm.). DISITI has also recently completed their own sampling in the Condamine Alluvium and have confirmed the presence of a variety of stygofauna, but their results are yet to be published (Cameron Schulz, DSITI, pers. comm.). Results from stygofauna sampling in the nearby Border Rivers region of southern Queensland point to the widespread presence of stygofauna in groundwater with varying physico-chemical parameters (Schulz et al. 2013) and rich and diverse stygofauna ecosystems could be expected to occur in the Condamine Alluvium (Cameron Schulz DSITI pers. comm.).*

Little and colleagues (2014, 2015, 2016) surveyed stygofauna in the alluvium of the Condamine River catchment (*ie* Condamine River, Oakey Creek and Cattle Creek), showing the stygofauna were heterogeneously distributed. **Appendix A** presents the list of recorded stygofauna and water levels of the monitoring bores from these studies. The results show that stygofauna were collected from some bores where water levels have declined more than 100 mm in a year (**Appendix A**[12]).

3.5.2 Riverine ecosystems

The SGP Development Area contains permanent/semi-permanent and ephemeral watercourses (Aquateco 2011, AMEC 2013). Ecological condition and values of surface waterbodies in the SGP Development Area were assessed for the SGP EIS (Aquateco 2011) and SREIS (AMEC 2013) aquatic ecology assessments, and data from these studies has been used in this aquatic ecosystem assessment report.

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[10] 'Stygofauna' encompasses a variety of different types of organisms that are found in groundwater, and includes animals that are obligate, groundwater-adapted organisms (stygobionts), and those that are not specifically groundwater-adapted but are able to survive the harsh conditions in aquifers (stygoxenes) (Hose *et al*. 2015).

[11] CDMSmith (2016) notes that cave ecosystems do not occur in the Condamine Alluvium.

[12] Refer to water level data for DNRM registered bore numbers 4221398, 42231695, 42231354, 42231395 and 42231404.

Thirty-three sites were sampled for the EIS/SREIS, with the site selection process tailored to ensure that all types of watercourses (permanent /semi-permanent and ephemeral) and meso-habitats (run, riffle, pool) in the EIS/SREIS study areas were represented. Of these 33 sites, 15 were located in the study area of the current assessment (**Figures 1** and **2**). Surveys for water quality, aquatic habitats, macrophytes, aquatic macroinvertebrates and fish were undertaken at all sites relevant to the current assessment. In summary, aquatic ecosystems within the current study area were in moderately good 'health' with the exception of Braemar Creek (Site 40) and Myall Creek (Site 6) which were considered to be in poor 'health'(Aquateco 2011). Ecological communities (fish, macroinvertebrates and aquatic flora) and habitats were similar across most sites in the study area. All permanent watercourses in the study area contained suitable habitat for the EPBC Act listed Murray Cod (*Maccullochella peelii peelii*)[13] (Aquateco 2011). Key results of the EIS/SREIS aquatic ecology surveys are as follows.

Water quality

In situ water quality[14] was measured during the EIS/SREIS aquatic ecology surveys to indicate water quality conditions at the time of sampling and to assist in interpretation of the aquatic ecology results. Water quality at most sites was characterised by reduced dissolved oxygen concentrations and elevated turbidity (compared to published water quality guideline values), reflecting drainage basin land use and disturbance (Aquateco 2011, AMEC 2013)..

Aquatic macroinvertebrates

No aquatic macroinvertebrates of conservation significance were recorded during the EIS/SREIS field surveys (Aquateco 2011, AMEC 2013). The aquatic macroinvertebrate results collected for the EIS showed a high degree of similarity in populations between sampling sites across the SGP Development Area, irrespective of drainage basin or catchment land use. The aquatic macroinvertebrate communities sampled were typically characteristic of watercourses experiencing impacts, primarily through water extraction (Aquateco 2011, AMEC 2013).

Macrophytes

EIS/SREIS field surveys recorded 20 species of native macrophyte (**Appendix B**), including the Aquatic Conservation Assessment (ACA) priority listed species Shiny Nardoo (*Marsilea mutica*)[15] which was recorded at Site 6 (**Figures 1** and **2**). Sixteen of the 20 native species recorded during the EIS/SREIS surveys were from sites located in the study area of the current assessment. Three introduced species – Umbrella Sedge (*Cyperus eragrostis*), Curled Dock (*Rumex crispus*) and Barnyard Grass (*Echinochloa crus-galli*) – were recorded but not in dense populations.

In general, watercourses had uniform macrophyte communities across the SGP Development Area. Aquatic macrophytes at the study sites included species predominantly of emergent and floating growth forms. The EIS/SREIS assessments noted that the lack of species with a submerged growth form was symptomatic of high water turbidity and fluctuating water levels, which prevents the establishment of such species (Aquateco 2011, AMEC 2013). Bank erosion and cattle disturbance to the riparian zone were also contributing factors to the distributions of emergent macrophytes across the study areas (AMEC 2013).

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[13] Listed as 'vulnerable' under the EPBC Act.

[14] For dissolved oxygen, temperature, electrical conductivity, turbidity and pH.

[15] Listed as an Aquatic Conservation Assessments priority species within the Condamine-Balonne Basin (Fielder *et al*. 2011).

Fish

Fifteen of the 20 species of native fish known to occur in the Condamine River catchment were collected in the EIS/SREIS surveys (**Appendix C**). Collected species included the EPBC Act listed Murray Cod and the ACA listed Eel-tailed Catfish (*Tandanus tandanus*)[16]. Species of local conservation significance (due to their scarcity in the Condamine-Balonne catchment), including Purple-spotted Gudgeon (*Mogurnda adspersa*), Rendahl's Tandan (*Porochilus rendahli*) and River Blackfish (*Gadopsis marmoratus*) were recorded from EIS/SREIS survey sites.

Three introduced species – Mosquito Fish (*Gambusia holbrooki*), Common Carp (*Cyprinus carpio*) and Goldfish (*Carasius auratus*) – were also recorded during the EIS/SREIS surveys (**Appendix C**), with all three widespread throughout the SGP Development Area and recorded in low or moderate abundances.

Fourteen of the 15 native species caught during the EIS/SREIS surveys were recorded from sites located in the study area of the current assessment. In general, watercourses had uniform fish communities across the SGP Development Area. The Oakey Creek fish community was notable for the presence of suitable habitat for two species of local conservation significance – Purple-spotted Gudgeon and River Blackfish.

Turtles

Two species of turtles – the Murray River Turtle (*Emydura macquarii macquarii*) and Broad-shelled Turtle (*Chelodina expansa*) – were recorded during the EIS/SREIS surveys, including at study sites located in the focus area of the current assessment (Aquateco 2011, AMEC 2013). Both species were widespread throughout the SGP Development Area (Aquateco 2011).

Riverine ecosystem condition and values

The ecosystem condition and values of watercourses in the SGP Development Area are presented in Aquateco (2011) as follows.

Permanent/semi-permanent watercourses

- *Examples of permanent/semi-permanent watercourses include Condamine River, Wilkie Creek and Oakey Creek* [**Figures 1 and 2**].
- *These watercourse types contain water all year, although in many cases they are reduced to isolated pools during the dry season*
- *They provide habitat for the EPBC Act listed Murray cod and several fish species of local conservation significance (eg Eel-tailed catfish).*
- *Levels of disturbance range from minimally disturbed to highly disturbed.*
- *Many contain areas of good quality aquatic habitat and support a relatively diverse range of aquatic species including fish, turtles and invertebrates.*
- *These systems are unique on a local scale in terms of biota, communities and processes.*
- *Deep pools and remnant waterholes provide refugia for a range of aquatic species, and these communities "seed" populations when wet season flows provide connectivity between watercourses.*

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[16] Listed as an Aquatic Conservation Assessments priority species within the Condamine-Balonne Basin (Fielder *et al*. 2011).

- *Biological communities in permanent/ semi-permanent watercourses tend to be longer lived than those from ephemeral systems and were less likely to recolonize following disturbance, hence there is greater possibility of these species or communities becoming locally extinct.*

Ephemeral watercourses

- *A high proportion of ephemeral watercourses in the SGP Development Area comprise unnamed first- or second-order systems that flow for very limited periods each year.*
- *Levels of disturbance range from moderately to highly disturbed.*
- *They provide marginal aquatic habitat due to the short periods during which they contain water, lack of connectivity to larger, permanent waterways, and minimal spawning/ nursery habitat.*
- *They are not unique on a local or regional scale.*
- *They were likely to be used opportunistically by aquatic fauna and flora that are tolerant of significant disturbance events and which are adapted to rapidly colonise and regenerate when conditions are suitable.*

3.5.3 Non-riverine ecosystems

Lake Broadwater[17] is located within the SGP Development Area and is classified as a Category A Environmentally Sensitive Area (ESA) under the Queensland *Environmental Protection Regulation* 2008 and is listed in the Directory of Important Wetlands in Australia (DoEE 2016). The location of Lake Broadwater is shown on **Figures 1** and **2**. The environmental values of Lake Broadwater are described in *Wetland buffer case study: Lake Broadwater* report (EHP 2012) as follows.

- Physical habitats – vary greatly between wet and dry cycles. Species inhabiting or utilising the wetland are limited by and adapted for these cycles (*eg* water level requirements for laying and provision of habitat during juvenile life stages).
- Food webs – reflect a natural state due to the relatively low use of the area and the lake's ephemeral nature.
- Species diversity – the lake's wetlands are extremely diverse in terms of physical characteristics, functions, species and habitat types. These characteristics vary temporally (with the wetting and drying cycle) and spatially. Both large numbers and diverse fauna and flora are associated with the lake including 12 fish species, 21 frog species and 222 bird species. Lake Broadwater supports five wetland communities:
  - open water
  - seasonally rich emergent vegetation
  - fringing grass/sedge vegetation
  - river red gum
  - dry lake bed vegetation
- Naturalness – the lake is primarily a natural wetland due to the fact that it is left to respond to wet/dry events without major management intervention.
- Conservation value – classified 'High' under the Queensland Government's Aquatic Conservation Assessment (ACA) (Clayton *et al*. 2008) due to 'very high' naturalness, species diversity and richness and priority species and ecosystems ratings.

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[17] Listed as a Conservation Park under the Queensland *Nature Conservation Act* 1992 and in the Directory of Nationally Important Wetlands.

For the EIS, Lake Broadwater was assessed to have high conservation value due to the high degree of ‘intactness’, important seasonal aquatic habitat and its potential use by the EPBC Act listed Murray Cod (Aquateco 2011).

The hydrogeology of Lake Broadwater is described in the Supplementary Groundwater Assessment Arrow Energy Surat Gas Project Supplementary Report to the EIS (Coffey 2013), as follow.

It is not considered to be groundwater dependent based on site description details which indicate that it is surface water fed from a local catchment. The lake is shallow (maximum depth around 4 m) and water quality is good. The lake’s water supply is listed as being principally runoff, floodout and stream flow from the catchment. It fills and occasionally floods with the summer rainfall and recedes thereafter and has been known to dry out completely, which support the assessment of it not being groundwater dependent.

Long Swamp is a palustrine wetland that lies approximately 3 km north-east of the associated Lake Broadwater (**Figures 1** and **2**) and is thought to be an older course of the Condamine River (Queensland Government 2013, Australian Government 2016). It is not classified under state or commonwealth protection legislation but is recognised locally as a natural and important wetland (Clayton *et al*. 2008, Aquateco 2011). The conservation value of Long Swamp was rated ‘medium’ to ‘high’ under the ACA program due to the continuum of riparian vegetation along the length of the wetland and ‘very high’ species diversity and richness and priority species and ecosystems ratings (Clayton *et al*. 2008). Long Swamp is hydrologically connected to Lake Broadwater (IESC 2013), filling during wet periods (Queensland Government 2013).

4. Assessment of Potential Impacts

4.1 Potential impacts to aquatic ecosystems

4.1.1 Aquifer ecosystems and stygofauna

Stygofauna are sensitive to groundwater environment disturbance because they are adapted to near steady-state environment conditions and have very narrow spatial distributions. Groundwater drawdown is a potential threat to stygofauna if the rate of water level decline exceeds the rate at which groundwater animals can move/migrate and where declining water levels reduce available habitat as strata become unsaturated (Hose *et al*. 2015). Studies on the effects of drawdown in the water table on stygofauna have been laboratory based, and have involved rates of drawdown that are significantly faster than the rates predicted to occur in the Condamine Alluvium as a result of Arrow's proposed CSG development (Hose *et al*. 2015). Stumpp and Hose (2013) conducted column experiments to test the response of different stygofauna (Syncarida and Copepoda) to declining water levels (1000 mm and 2600 mm per day), and desiccations experiments to examine the effects of stygofauna to different sediment saturation levels. The results of the study indicated that the response of stygofauna to water drawdown was taxon-specific, with Syncarida shown to move downward through the sediment column with declining water levels, although some stranding of some stygofauna above the water level occurred (Stumpp and Hose 2013, Hose *et al*. 2015). Copepoda showed no significant differences in vertical distributions, suggesting that this taxa did not move downward at the water level decline rates (*ie* 1000 mm per day and 2600 mm per day) tested in the study. The same study also revealed that survival of stygofauna decreased with decreasing sediment saturation and that there was limited survival in unsaturated sediment beyond 48 hours.

Results of stygofauna sampling from the Condamine River, Oakey Creek and Cattle Creek alluviums show that stygofauna were collected from some bores in which the water levels have declined in excess of 0.27 mm per day (**Appendix A**). The predicted drawdown of the water table in the Condamine Alluvium as a result of Arrow's CSG development is 0.0027 mm to 0.005 mm per day over the period in which draw-down is predicted to occur (CDMSmith 2016). This shows that stygofauna currently exist in the Condamine Alluvium where water levels have declined at a much greater rate than is predicted to occur by proposed coal seam depressurisation from Arrow's operations. This suggests that the predicted drawdown in the water table from Arrow's CSG development is likely to have negligible impacts on stygofauna.

4.1.2 Riverine ecosystems

Permanent/semi-permanent watercourses in the SGP Development Area contain areas of good quality aquatic habitat and support a relatively diverse range of aquatic species including fish, turtles and macroinvertebrates (Aquateco 2011, AMEC 2013).

Surface water modelling indicates that there will be negligible changes in surface water hydrology along most of the length of the Condamine River and its tributaries resulting from coal seam depressurisation (CDMSmith 2016). The effects of coal seam depressurisation on surface water resources were evaluated against the Environmental Flow Objectives (EFO) of the Condamine-Balonne Water Resource Plan (WRP). Modelling showed that the 'low flow days' performance indicator at Node J on the Condamine River[18] reported a small increase, although this indicator did not exceed the EFO of the WRP (CDMSmith 2016). All other EFO performance indicators reported no changes. This modelling suggests that the water requirements for the Condamine-Balonne WRP will continue to be met under the proposal.

The conceptualisation approach used to assess potential impacts to surface hydrology of unregulated tributaries of the Condamine River determined that surface water leakage to groundwater in these systems is predicted to be 0.0015 mm per year (CDMSmith 2016). Unregulated tributaries correspond with the 'ephemeral watercourse' type included in the EIS aquatic ecology assessment. Ephemeral watercourses in the SGP Development Area were considered to provide marginal aquatic habitat due to the short periods during which they contain water (Aquateco 2011). If hydrological changes occurred to unregulated tributaries in the SGP Development Area, the changes would occur to watercourses that have limited aquatic value and which are not unique on a local or regional scale.

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[18] Node J is located at the upstream limit of the impounded area of Chinchilla Weir.

5. Conclusions

The results of this desk-based assessment suggest that there is not likely to be significant impact to aquatic ecosystems in Arrow's SGP Development Area from changes to groundwater levels as a result of coal seam depressurisation. This conclusion is based on numerical modelling of surface water and groundwater hydrology which predicts that there will be negligible hydrological changes to surface water and groundwater as a result of the proposed CSG development.

Further aquatic ecology assessments are considered not necessary to inform potential impacts of the proposed coal seam depressurisation activities of the SGP for this stage of the project.

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Appendix A:
Stygofauna Records and Water Levels from Monitoring Bores in the Condamine Alluvium

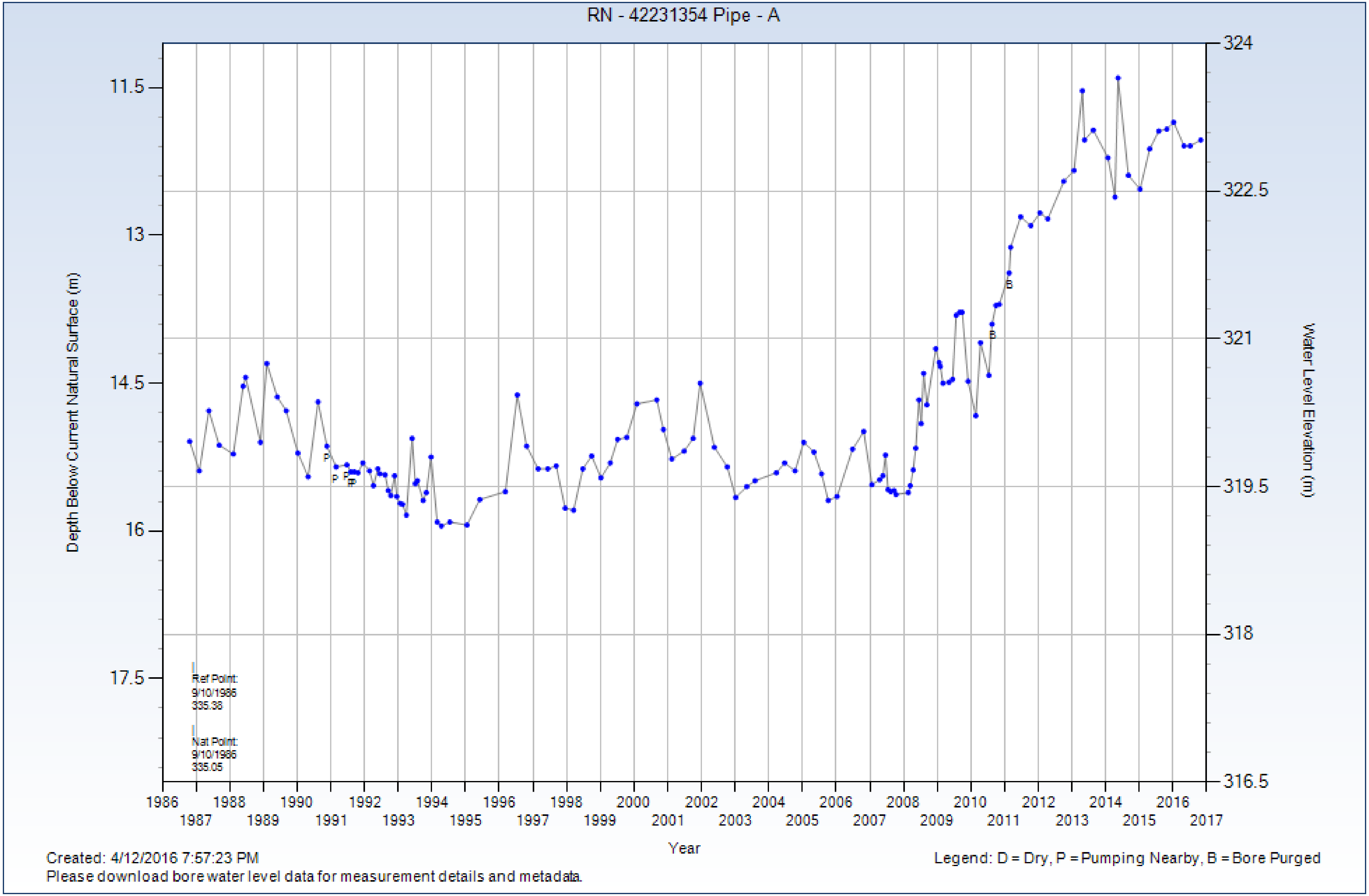
Stygofauna Records and Water Levels from Monitoring Bores in the Condamine Alluvium

Table 1: Stygofauna recorded from the alluvium of the Condamine River catchment

Phylum or Class	Order	Family	DNRM registered bore number	Catchment	Reference
-	Syncarida	Parabathynellidae	42231398	Oakey Creek	Little *et al*. (2016)[1]
-	Syncarida	Bathynellidae	42231395	Oakey Creek	Little *et al*. (2016)
-	Syncarida	Bathynellidae	42231404	Oakey Creek	Little *et al*. (2016)
-	Syncarida	Anaspidacea	42231696	Cattle Creek	Little *et al*. (2016)
-	Syncarida	Bathynellidae	42231695	Condamine River	Little *et al*. (2016)
Copepoda	Cyclopoida	-	42231354	Condamine River	Little (2014)[2]
Insecta	Coleoptera	-	42231354	Condamine River	Little (2014)

[1] Little, J., Schmidt, D.J., Cook, B.D., Page, A.C. and Hughes, J.A. 2016. Diversity and phylogeny of south-east Queensland Bathynellacea. *Australian Journal of Zoology*, January 2016 DOI: 10.1071/ZO16005.

[2] Little, J. 2014. Genetic structure in stygofauna inhabiting alluvial groundwater of adjacent subcatchments, Queensland', B.S. thesis, Griffith University, Nathan.



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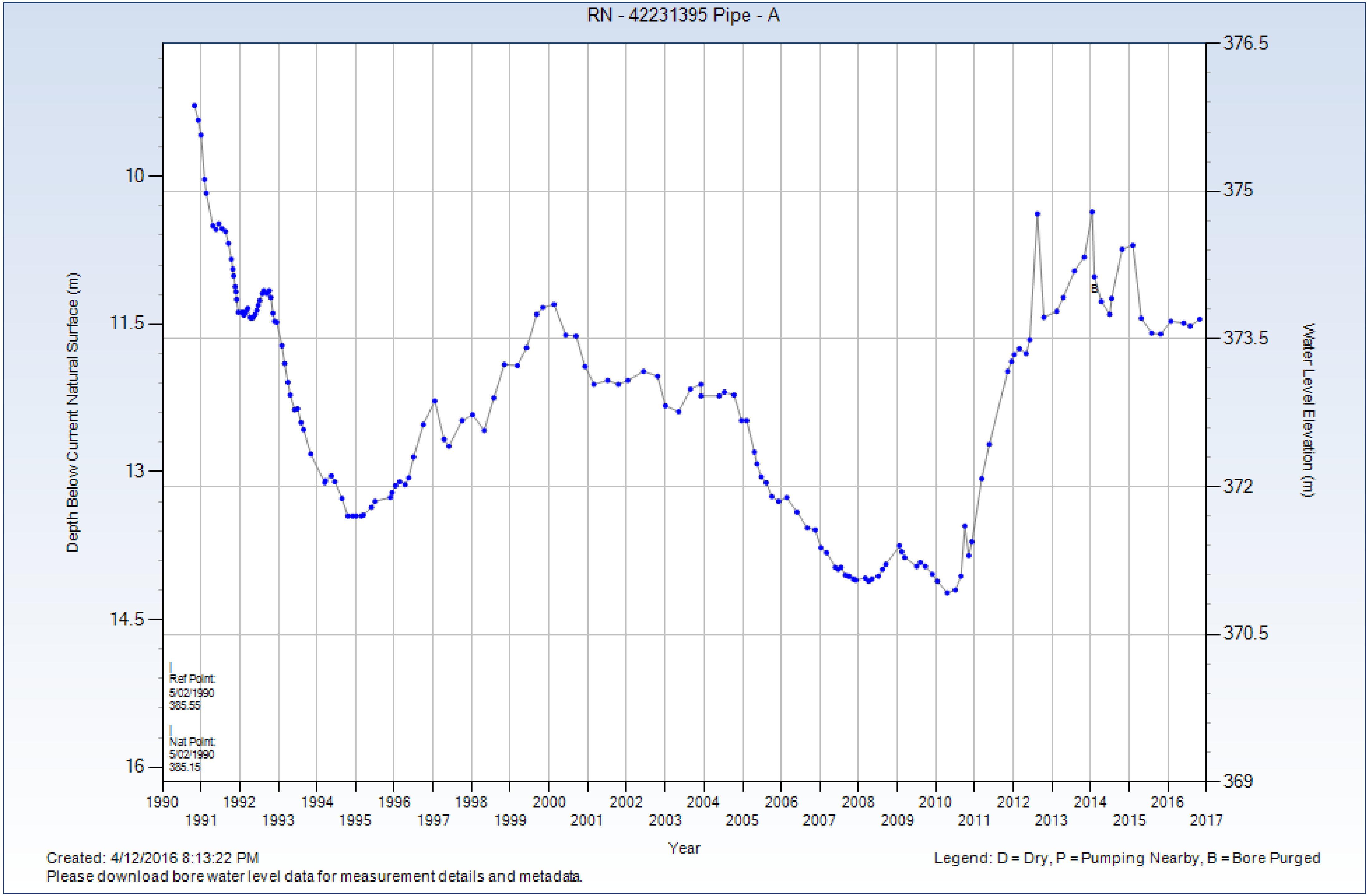
RN - 42231395 Pipe - A



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385.15

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Please download bore water level data for measurement details and metadata.

Legend: D = Dry, P = Pumping Nearby, B = Bore Purged

Warning: Plot cannot be generated for RN 42231395 Pipe X

Because No ref point for measurement -11.99 on date 12/01/1993.
This point will be ignored.

No ref point for measurement -13.35 on date 5/02/1994.
This point will be ignored.

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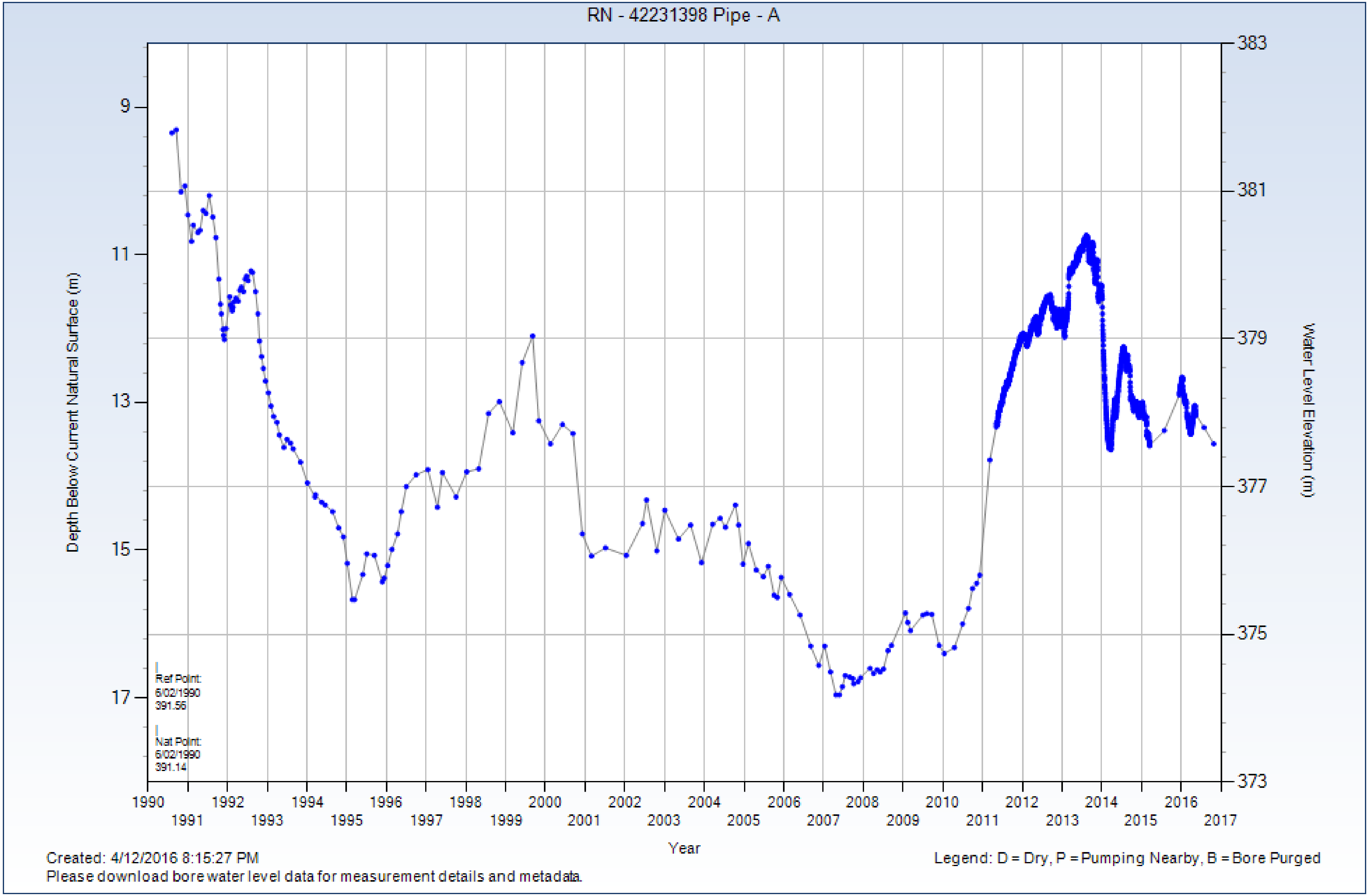

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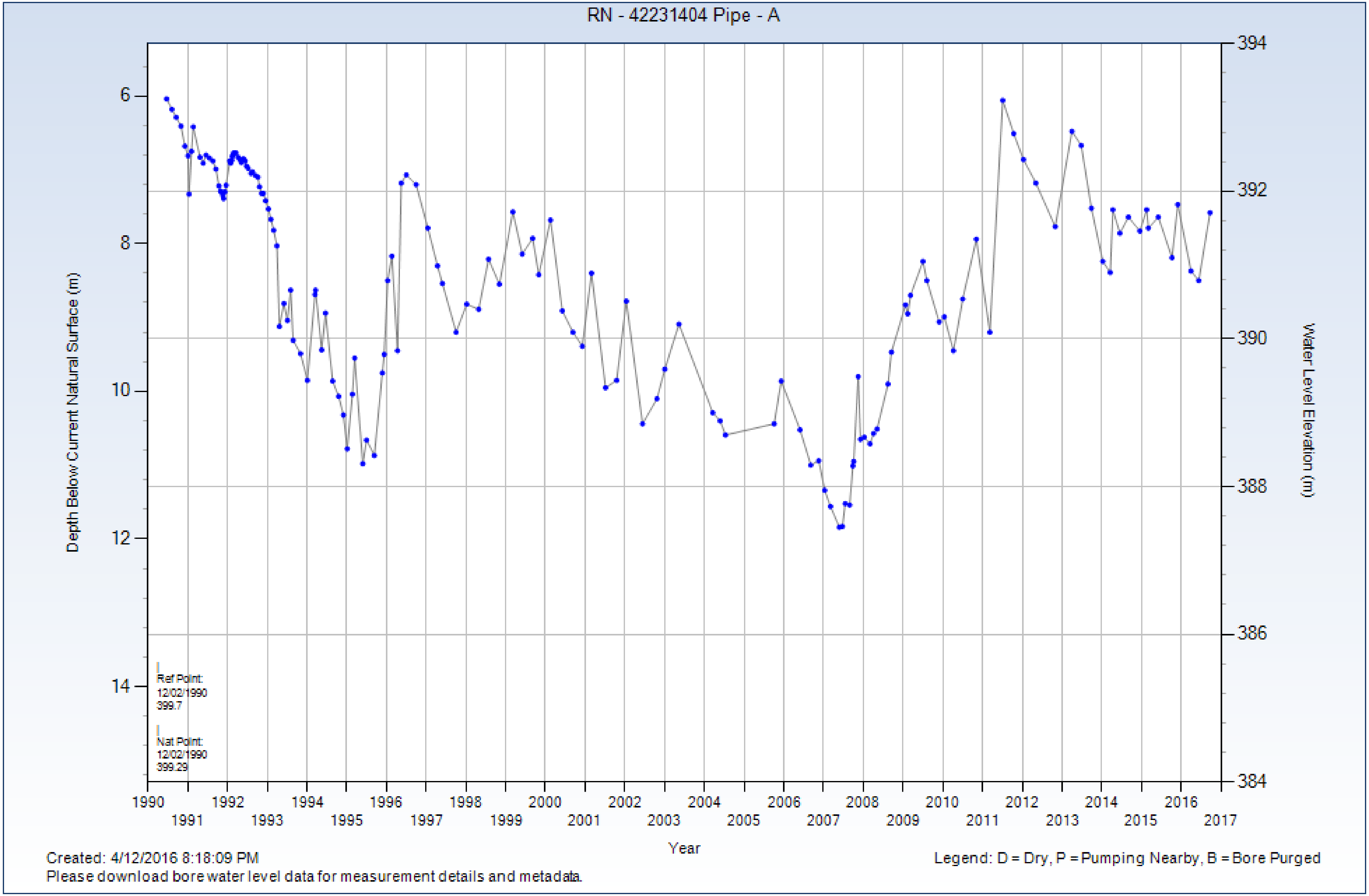

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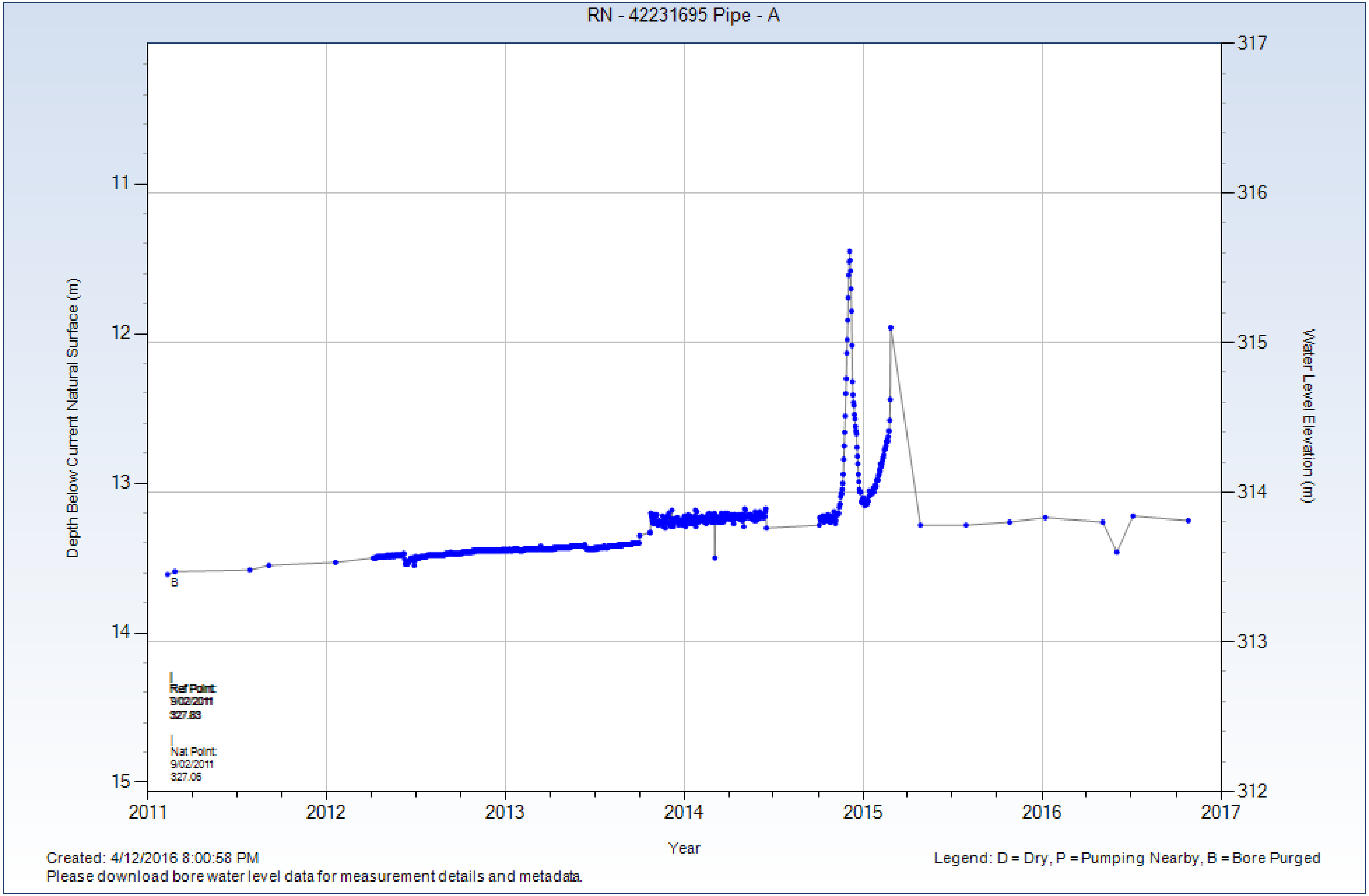

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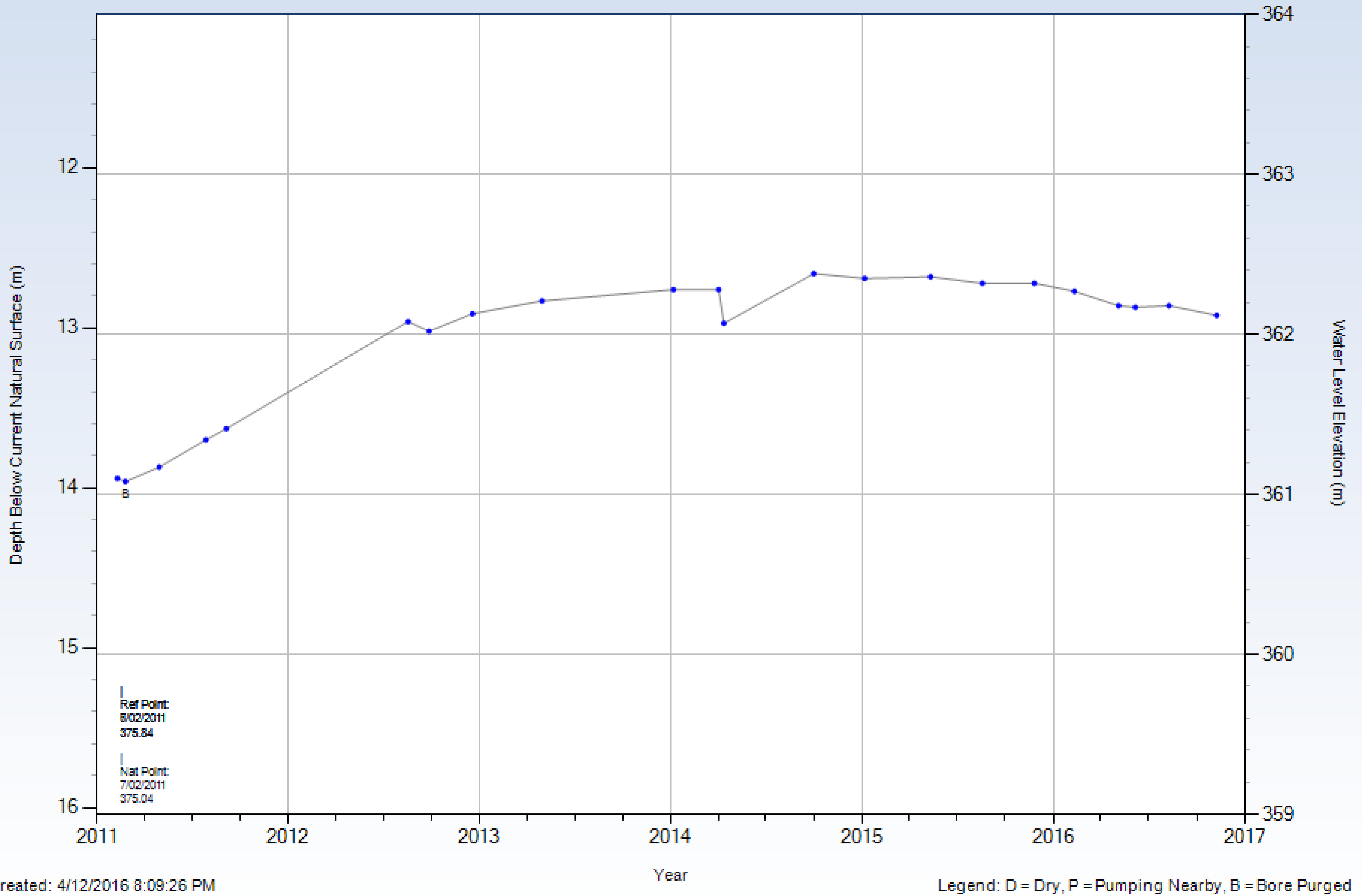

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Please download bore water level data for measurement details and metadata.

Legend: D = Dry, P = Pumping Nearby, B = Bore Purged

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Appendix B:
EIS/SREIS Macrophyte Survey Records

EIS/SREIS Macrophyte Survey Records

Table 1: Macrophytes recorded during the Surat Gas Project EIS/SREIS aquatic ecology assessments (Aquateco 2011[1], AMEC 2013[2])

Scientific name	Common name	Growth form	Focus area[#]
Azolla pinnata	Ferny Azolla	Floating	✓
Bulboschoenus fluviatilis	Marsh Clubrush	Emergent	✓
Cyperus difformis	-	Emergent	✓
*Cyperus eragrostis**	Umbrella Sedge	Emergent	✓
Cyperus exaltus	Giant Sedge	Emergent	✓
Damasonium minus	Starfruit	Emergent	×
Diplachne fusca	Brown Beetle Grass	Emergent	✓
*Echinochloa crus-galli**	Barnyard Grass	Emergent	✓
Eleocharis acuta	Common Spike-rush	Emergent	✓
Juncus usitatus	Common Rush	Emergent	✓
Lemna spp.	Duckweed	Floating	✓
Leptochloa digitata	Umbrella Canegrass	Emergent	✓
Ludwigia peploides	Water Primrose	Floating	✓
Marseilea mutica	Nardoo	Floating	✓
Myriophyllum spp.	-	Submerged	×
Persicaria attenuata	-	Emergent	✓
Persicaria decipiens	Slender Knotweed	Emergent	✓
Phragmites australis	Common Reed	Emergent	✓
Potamageton crispus	Curly Pondweed	-	✓
Potamogeton cf. octandrus		-	×
*Rumex crispus**	Curled Dock	Emergent	✓
Triglochin procera	Ribbon Weed	Emergent	×
Typha orientalis	Cumbungi	Emergent	✓

✓ Recorded
× Not recorded
* Introduced
\# Results for EIS/SREIS sites located in the focus area of the current assessment.

[1] Aquateco 2011. Arrow Energy Surat Gas Project Aquatic Ecology Assessment Final. Report prepared by Aquateco Consulting Pty Ltd for Arrow Energy, November 2011.

[2] AMEC 2013. Surat Gas Project Supplementary Aquatic Ecology Assessment. Report prepared by AMEC Pty Ltd for Coffey Environments, 20 June 2013.

Appendix C:
EIS/SREIS Fish Survey Records

EIS/SREIS Fish Survey Records

Table 1: Fish recorded during the Surat Gas Project EIS/SREIS aquatic ecology assessments (Aquateco 2011[1], AMEC 2013[2])

Scientific name	Common name	Focus study area[#]
Carassius auratus[*]	Goldfish	✓
Cyprinus carpio[*^]	Common Carp	✓
Craterocephalus stercusmuscarum fulvus	Un-specked Hardyhead	✓
Gadopsis marmoratus	Freshwater Blackfish	×
Gambusia holbrooki [*^]	Mosquito fish	✓
Hypseleotris klunzingeri	Western Carp Gudgeon	✓
Hypseleotris Sp. 1	Midgely's Carp Gudgeon	✓
Hypseleotris spp.	Carp Gudgeon Species	✓
Leiopotherapon unicolor	Spangled Perch	✓
Maccullochella peelii peelii[#]	Murray Cod	✓
Macquaria ambigua	Golden Perch	✓
Melanotaenia fluviatilus	Murray Rainbowfish	✓
Mogurnda adspersa	Purple-spotted Gudgeon	✓
Nemetalosa erebi	Bony Bream	✓
Neosilurus hyrtlii	Hyrtl's Tandan	✓
Retropinna semoni	Australian Smelt	✓
Tandanus tandanus [$]	Eel-tailed Catfish	✓

✓ Recorded × not recorded

[*] Introduced

[^] Restricted noxious fish under the *Biosecurity Act 2014.*

[#] Listed as vulnerable under the *EPBC 1999 Act.*

[$] Listed as an Aquatic Conservation Assessments priority species within the Condamine-Balonne Basin (Fielder *et al*. 2011).

[#] Results for EIS/SREIS sites located in the focus area of the current assessment.

[1] Aquateco 2011. Arrow Energy Surat Gas Project Aquatic Ecology Assessment Final. Report prepared by Aquateco Consulting Pty Ltd for Arrow Energy, November 2011.

[2] AMEC 2013. Surat Gas Project Supplementary Aquatic Ecology Assessment. Report prepared by AMEC Pty Ltd for Coffey Environments, 20 June 2013.

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Attachment 2: Identification and Assessment of Groundwater Dependent Ecosystems

3D Environmental
vegetation analysis and mapping specialists

Earth Search

Identification and Assessment of Groundwater Dependent Ecosystems;

Arrow Surat Gas Project

Prepared for Arrow Energy

by

3D Environmental / Earth Search

Final Issue B— 16 July, 2017

Project No. 2016_193

Project Manager: David Stanton

Client: Arrow Energy

Purpose: GDE Assessment report for the Surat Gas Project Area

Draft	Date Issued	Issued By.	Purpose
Draft 1	06 February 2017	David Stanton/ Ned Hamer	Initial draft
Draft1a	07 February 2017	David Stanton/ Ned Hamer	Minor formatting revision
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Final Issue_A	10 July 2017	David Stanton/ Ned Hamer	Final Version addressing further comments from AE and Coffey review
Final Issue_B	16 July 2017	David Stanton/ Ned Hamer	Minor technical revisions

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Executive Summary

The Surat Gas Project (SGP) was approved by the Commonwealth Government in December 2013 under sections 130 (1) and 133 of the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). The approval is subject to conditions, and requires the development of a Stage 1 and Stage 2 CSG Water Monitoring and Management Plan (WMMP). A requirement for the WMMP concerns the assessment and identification of Groundwater Dependent Ecosystem (GDEs) present within the area where groundwater resources might potentially be influenced by Arrow Energy's activities. This report contains an assessment of GDEs and GDE types within the Surat Gas Project Area completed though a process of refinement and further screening of previous relevant works, review of additional available data, and field verification. Field survey included verification of potential spring targets identified by AGE (2015). As per approval conditions, attention has been given to identifying the potential groundwater dependence of Long Swamp and Lake Broadwater.

The study identified:

1. Only one spring GDE within Arrow Energy tenements, being the previously identified Tribelco Spring which is newly described in this document. Two additional springs, Wambo Spring to the south west of Chinchilla, and Bowenville spring complex to the east of Dalby have potential to be influenced by Arrow Energy's activities although both are located outside Arrow Energy tenements.
2. Five sub-surface GDE types were identified during the assessment being 1) shallow alluvial GDE systems 2) Bedrock alluvial GDE systems 3) Deep alluvial GDE systems 4) Shallow drainage sub-surface GDE system and 5) Volcanics subsurface GDE system (see Bowenville Spring).

Integrated ecological and hydrogeological conceptualisations of these features, including Long Swamp and Lake Broadwater are considered within this document.

Springs

Tribelco Spring: Assessment of Tribelco Spring indicates that the spring is associated with a healthy riparian fringe of groundwater dependent vegetation adjacent to Wambo Creek and a minor local tributary which the spring seeps directly into. The groundwater seepage at the spring is likely to be sourced from an adjacent permeable alluvial sand body, facilitated by a steep hydraulic gradient from groundwater storage at a higher elevation. The high point on the alluvial terrace is immediately adjacent to the seepage site below. The major source of recharge to the sandy alluvium is likely to be direct rainfall, as well as run-off from the surrounding lower permeability silty clay flats during, and for some period after, heavy and prolonged rainfall. Total groundwater storage in the connected sand body is likely to be considerable, on a local scale, for recharge to sustain seepage into the adjacent pool and surrounding riparian features for extended periods.

The confirmed elevated presence (5.47 Becquerel/L (Bq/L)) of ^{222}Rn (Radon) in the Trebilco spring sample coupled with dD and d18O (Isotopes of Oxygen and Deuterium) values that are significantly lower than other surface waters sampled supports a groundwater source for the spring.

Subsurface GDEs

Deep Alluvial GDE Systems (Condamine River and associated Condamine River Alluvium): The Condamine River and its associated alluvial plain is an extensively studied feature that has a history of intensive agricultural utilisation. Historical reports suggest that property homesteads along the Condamine Plain pumped groundwater for domestic use as far back as 1946, from depths shallower than 10mbgl. Analysis of data from Arrow Energy baselined groundwater wells indicates substantial declines in the groundwater table, with groundwater levels recorded to have dropped below identified thresholds for groundwater interaction with riparian vegetation. Whilst groundwater levels have fallen substantially on a whole, heaviest drawdown in the Condamine River Alluvium (CRA) aquifer occurs well to the east of the Condamine River, mostly outside of Arrow's tenements, with groundwater table lower by approximately 25m compared with the un-exploited period. Drawdown in vicinity of Arrow's operations, on the western margins of the CRA is by comparison much more moderate due to lower levels of groundwater extraction on the thinning western alluvial margin.

Where groundwater levels fall below 18mbgl on the CRA, connectivity between groundwater and tree roots of mature riparian vegetation is considered at a threshold level where connectivity between mature riparian trees and groundwater is at risk of being lost, and vegetation condition may markedly decline. Significant declines in vegetation have been noted across large areas of the CRA, identified both within published literature as well as observations during the field survey.

Shallow Alluvial and Bedrock GDE systems (Kogan, Wilkie, Braemar and Dogwood Creeks): Numerous tributaries of the Condamine River meander through the low colluvial slopes of the Westbourne and Springbok Sandstone Formations, or are incised directly into bedrock (Springbok Sandstone) in the case of Dogwood Creek, before flowing out onto the Condamine River floodplain. Outside of the CRA, a lack of groundwater dependent vegetation is identified largely by dominance of ironbark woodlands away from the immediate riparian corridor and suggests an absence of shallow permanent soil moisture and alluvium-hosted groundwater. The variable incision of these streams into either weathered or fresh sedimentary rocks is typically associated with thin discontinuous deposits of sandy riverine alluvium which host shallow groundwater lenses that support fringing groundwater dependent vegetation. These discontinuous aquifers that support "Shallow" and "Bedrock GDE" types are considered poorly connected hydraulically to the underlying Jurassic aquifers potentially subject to depressurisation during CSG production. In most cases these ecosystems are likely to be dependent on an aquifer hosted in the unconsolidated alluvium rather than the underlying bedrock.

In many cases underlying bedrock was noted to form a low permeability base to stream channels which were noted to hold water for extended periods. Deeper Great Artesian Basin (GAB) regional aquifer standing water levels are typically well below the base of the alluvium. Any connection is likely to be associated with a deep "wetting front" where, in areas of reasonable bedrock permeability, the shallow "losing" alluvial systems can provide an important source of downward percolating recharge water to underling GAB formations.

Shallow drainage sub-surface GDE system (Long Swamp): Long Swamp is a sinuous hydrological feature (overland flow path) that flows across the Condamine Alluvium in a north-westerly direction to the east and north of Lake Broadwater, before joining with Wilkie Creek to the west. The feature occupies a broad depression with the central portion formed by a heavy vertic clay with surface water present seasonally in response to rainfall. Vegetation is largely native with a groundcover of native grasses and forbs and a canopy formed by tall, broadly spaced river red-gum at approximately 30% cover. The canopy is significantly stressed in some areas with signs of senescence and foliage loss.

Stratigraphy from water bore data indicates a thick layer of clay to loamy clay to a depth of 15m before passing into a variably thick basal sandy alluvium horizon to depths of 21m. The upper surface of the sandy horizon likely indicates the original SWL of the undisturbed aquifer which was at a depth of 15mbgl in the 1950s-60s. Current water levels in the vicinity of Long Swamp show relatively little change compared to drawdown trends elsewhere in the CRA. DNRM monitoring bore 42230155 located in Long Swamp has recorded a clear but relatively modest decline in SWL from 16.01mbgl in 1965 to 18.68mbgl in Jan 2017.

Due to the thick layer of heavy clay which is likely to provide significant resistance to tree root penetration, it is unclear as to whether mature canopy trees have historically had capacity to tap groundwater sources as deep as 15mbgl and it is noted that the current SWL hovers at the lower threshold range for Vegetation GDE impact of 18m. The senescence of mature canopy trees may also be partly or wholly related to changes in surface flow volumes, resulting from observed nearby large-scale surface water extraction for irrigation.

Volcanics subsurface GDE system - Bowenville Spring: The Bowenville Spring site is a Listed Spring Complex (585) located approximately 15km to the east of Arrow's tenements. This site is considered likely to be a watercourse spring (Oakey Creek) associated with underlying Main Range basalts and could also represent a source of recharge to the Condamine Alluvium or Walloon Coal Measures. The spring is fed from a slightly elevated and gently undulating weathered basalt plateau above the Condamine Floodplain, with historical standing water levels ranging from 13.7 to 17.6mbgl. High flow rates (10 litres per second) recorded on drilling logs during testing of nearby Walloon Coal Measures bores indicates that the underlying coal measures may be highly permeable. If high basalt/WCM connectivity exists, this area of contact may represent a recharge area for the Walloon Coal Measures.

Lake Broadwater: Lake Broadwater is a natural shallow lacustrine wetland with surface water on average covering approximately 350ha within the 1212ha Lake Broadwater Conservation Park. It is a seasonal water feature and water levels recede during dry spells, occasionally drying totally. Lake Broadwater is a highly significant ecological feature that is mapped as a Wetland of High Ecological Significance and is listed in the Australian Directory of Important Wetlands (Environment Australia, 2001).

Lake Broadwater is fringed by an open forest of river red gum which is 200m wide at its broadest on the north-eastern portion of the lake. There is no indication from field survey of a permanent shallow perched groundwater table in this locality, either through assessment of nearby groundwater bore logs, or through hand augering undertaken to a depth of 2.3m. While no shallow saturated sands were encountered beneath the immediate lake fringe, including at a depth well below the lake bed, the presence of an indurated sand layer above the underlying clays, suggestive of a zone of fluctuating groundwater levels, indicates that perched groundwater may be seasonally present. This suggests that the red-gum forest is either sustained by deeper groundwater sources, or alternatively was extracting residual groundwater moisture held within the sand and upper clay horizons following capture of rainfall or retreat of the lake margins.

This assessment suggests that Lake Broadwater sits within a transitional landscape of Jurassic-age Westbourne Formation colluvium overlying lower Westbourne regolith, and drains to the Condamine River Floodplain to the north. The lower Westbourne Formation pinches out to the east of the Broadwater area, and the Condamine River alluvium to the east and north is underlain in the area by deeply weathered Jurassic age Springbok Sandstone.

It is noted that although Radon activity of 0.12 Bq/L in the lake surface water sample would almost certainly reflect some recent groundwater source, the high dD and d18O isotope results suggest a history of evaporative enrichment. The source of possible recent groundwater discharge indicated by Radon levels is unclear and it is possible that groundwater may be present within the surrounding sandy foreshore sediments in some localities or some other source of connected groundwater may exist.

Recommendations

An integrated ecological and hydrogeological monitoring programme is recommended which would include a selection of sites in priority "early detection" areas related to Arrow's development, associated potential groundwater drawdown areas, and more vulnerable GDE locations informed by this assessment as well as impact assessment undertaken for the Stage 1 CSG WMMP. The objectives of the monitoring programme would include:

- The critical establishment of background GDE groundwater level, quality vegetation health trends prior to further CSG development.
- Early detection of any adverse trends related to CSG development.
- Ongoing refinement of the integrated ecological/hydrogeological conceptual site models and groundwater-vegetation relationships developed through this assessment.

The fundamental design principle of such a monitoring programme is that through an accurate understanding of the hydrogeological/ecological relationships and stress thresholds (conceptual site model), any changes beyond critical response thresholds are detected early such that potential impacts on GDEs can be prevented or mitigated. For the GDE sites assessed during this assessment, the following recommendations are made:

- **Lake Broadwater:** Biannual monitoring of groundwater level and quality; ecological parameters and surface water monitoring.
- **Long Swamp:** Biannual monitoring of groundwater level and quality; ecological parameters; surface water monitoring if flowing.
- **Wambo Creek including Tribelco Spring:** Biannual monitoring of groundwater level and quality; ecological parameters; surface water quality monitoring; temporary deployment of a v-notch weir or other means of measuring flow rate into and out of the main pool during each monitoring event to assess long term trends; spring discharge rate/groundwater level relationship and other hydraulic responses, plus; water quality sampling at nearby wetland and water table window.
- **Bowenville Spring (Oakey Ck):** Groundwater level and quality; ecological survey; surface water quality sampling; regular measurement and review of gauging station flow rate and water level data.
- **Condamine River:** A review and gap analysis of existing DNRM and Arrow groundwater monitoring locations within the CRA is recommended for higher risk GDE locations and future Arrow development areas. This will determine if the existing groundwater monitoring network is sufficient for early-detection of potential CSG impacts on GDE locations and the establishment of background trends.

At selected monitoring locations, a programme of drilling and coring is recommended to allow detailed logging and sampling of the shallow geology and tree rooting depths, and installation of shallow groundwater monitoring bores. Methods recommended include sonic coring (sonic rig) and push tubing with a geoprobe rig. These methods have been used with significant success to characterise the alluvium and upper weathered rock regolith zone in sensitive areas on the CRA and elsewhere within the Surat basin. The suggested programme of drilling and monitoring bore installation would allow:

- Refinement of the geological and hydrogeological definition of any shallow aquifers and aquitards.
- Estimates of permeability and other hydraulic properties plus assessment of interconnectivity with underlying aquifers.
- Verification of assumed tree rooting depths through direct observations and laboratory analysis of tree root matter in core. This would be particularly effective with a sonic rig.
- Monitoring of shallow groundwater levels and quality for comparison with stressors and responses in adjacent vegetation monitoring sites.

Ecosystem resilience in a changing groundwater regime can best be established through systematically structured monitoring ecological monitoring plots designed to allow for repeatable measurement of canopy foliage vigour and species diversity. Measurements should be undertaken on a biannual basis (end of wet season and late dry season) to identify seasonal trends in ecosystem health and vigour. The assessment of canopy vigour can be supplemented with acquisition and analysis of high resolution Normalised Differentiation Vegetation Index (NDVI) imagery timed to coincide with field measurement. Capture of high resolution NDVI imagery would be a particularly useful tool for monitoring of ecological health in environments associated with Lake Broadwater due to its relatively undisturbed nature and minimal influence of external disturbance regimes.

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1.0 Introduction

The Surat Gas Project (SGP) was approved by the Commonwealth Government in December 2013 under sections 130 (1) and 133 of the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). The approval is subject to conditions, and requires the development of a Stage 1 and Stage 2 Coal Seam Gas (CSG) Water Monitoring and Management Plan (WMMP).

A specific component of the WMMP concerns the identification of Groundwater Dependent Ecosystem (GDEs) present within the area where groundwater resources might potentially be influenced by Arrow Energy's activities. To inform this assessment, 3d Environmental, with the assistance of a specialist hydrogeologist (Earth Search) was engaged to identify GDEs within the Surat Gas Project (SGP) potential groundwater impact areas through a process of refinement and further screening of previous works, review of additional available data, and field verification.

1.1 Study Area

The study area for this assessment is defined by the following features:

1. Arrow Energy's Petroleum Lease (PL) and Authority to Prospect (ATP) tenements in the Surat Basin, particularly for assessment of Vegetation GDEs.
2. The GDE Risk Areas (1 to 5) as defined by Arrow Energy buffered to 10 km's for springs assessment (see Section 1.3.4).
3. Any additional known springs, or springs listed in the Queensland Springs Database (Queensland Herbarium 2016) that may potentially be impacted by Arrow Energy activities.

The location of the study area is shown in Figure 1.

1.2 Previous Works Commissioned by Arrow Energy

A considerable number of prior reports have formed background to this assessment and the concepts documented in these reports have been further screened and developed during the refinement process. Relevant information contained within these reports has been summarised below.

Concepts developed during the below assessments and the significant published scientific research and assessment work that have preceded this work are acknowledged and have been carried forward into this current assessment where feasible. Comprehensive descriptions of the ecological, geological and hydrogeological setting of the project area is presented in these assessments and accompanying reports and this study does not attempt to reproduce these previous findings.

1.2.1 Arrow Surat Gas Project Groundwater Impact and Supplementary Impact Assessments

Coffey Environments, on behalf of Arrow Energy, completed an Environmental Impact Statement (EIS) and supplementary EIS for the Project (Arrow 2012 and 2013). These assessments included geological and hydrogeological interpretation within the Surat Gas Project Area, predicted groundwater level drawdowns based on modelling for a range of aquifers and geological formations; a summary of known registered springs and statutory obligations regarding springs; recognition of potential GDEs within the study area; recommendations for impact mitigation and an assessment of the significance of residual impacts on groundwater resources and dependent ecological components.

1.2.2 Surat GDE Risk Assessment

Arrow commissioned Australian Groundwater and Environmental Consultants (AGE 2013) to develop a risk based assessment to determine where GDEs within the Project may potentially be affected by coal seam depressurisation (AGE, 2013). The report utilised the conceptual hydrogeological model and modelled coal seam drawdowns produced in the EIS and SREIS (Arrow 2013); mapped geological boundaries; sub-crop lines from the Office of Groundwater Impact Assessment (OGIA) model for the Westbourne Formation and Orallo Formation, and; 95th percentile drawdown extents for the various model layers to classify polygons according to assessed risk. Three levels of risk were identified being:

1. **High Risk** where aquifers are outcropping; areas with >1m predicted drawdown in the Gubberamunda formation east of its inferred sub-crop line; > 1m drawdown contour to the east of the inferred sub-crop line of the Springbok Sandstone; and the western margin of the Condamine Alluvium.
2. **Medium Risk** defining areas with <1m predicted drawdown in the Gubberamunda formation east of its inferred sub-crop line; areas of > 1m drawdown in the Walloon Coal Measures and Springbok Sandstone east of the inferred sub-crop line; and a small area to the east of the Condamine Alluvium where there is >1 m drawdown in the Walloon Coal Measures and the Walloon Coal Measures is close to outcrop.
3. **Low Risk** being areas outside the <1 m Gubberamunda Sandstone drawdown, within the >1 m Springbok Sandstone drawdown and east of the Gubberamunda Sandstone inferred sub-crop line; areas in the north-east in the <1 m Walloon Coal Measures drawdown line east of its inferred sub-crop line; an area to the east of the Condamine Alluvium where there is <1 m drawdown in the Walloon Coal Measures and the Walloon Coal Measures is close to outcrop; and areas of the Condamine Alluvium with >1 m drawdown, deemed Low Risk due to significant drawdown from historical activity in the alluvium and relatively deep water table pre-CSG development.

1.2.3 Remote Sensing and Hydrogeological Risk Assessment

AGE (2015) utilised aerial photography and colour composite satellite and NDVI imagery to identify wet features including marshland, ponded water and other wetted areas to compile a list of potential spring and GDE targets. This was further refined using the hydrogeological conceptual model for the Surat Basin, other known hydrogeological attributes and drawdown risk mapping to further refine targets. The approach was considered conservative and likely to result in considerable oversampling.

The remote sensing assessment resulted in a total of 132 potential GDE spring targets identified with 33 being located outside hydrogeological risk zones. Of the 99 spring targets identified within hydrogeological risk areas, 56 were located within areas of High Risk, Medium Risk and Low Risk zones of drawdown from project development. This ‘Top 56’ spring targets formed the focus for ongoing field verification.

1.2.4 Additional Risk Characterisation

Additional investigations were undertaken by Coffey and Arrow to identify areas of potential terrestrial vegetation GDEs reliant on the subsurface presence of groundwater and more specifically areas at risk of being impacted by groundwater drawdown generated by the Project. This process involved;

- Identification of GDE focus areas potentially at risk of being impacted;
- Identification of areas where delineation of the Westbourne outcrop extent is required; and
- Identification of areas to undertake studies to determine the degree of connectivity between the Springbok Sandstone and the Walloon Coal Measures.

Five GDE focus areas were identified as a result of this work as shown in **Figure 1**.

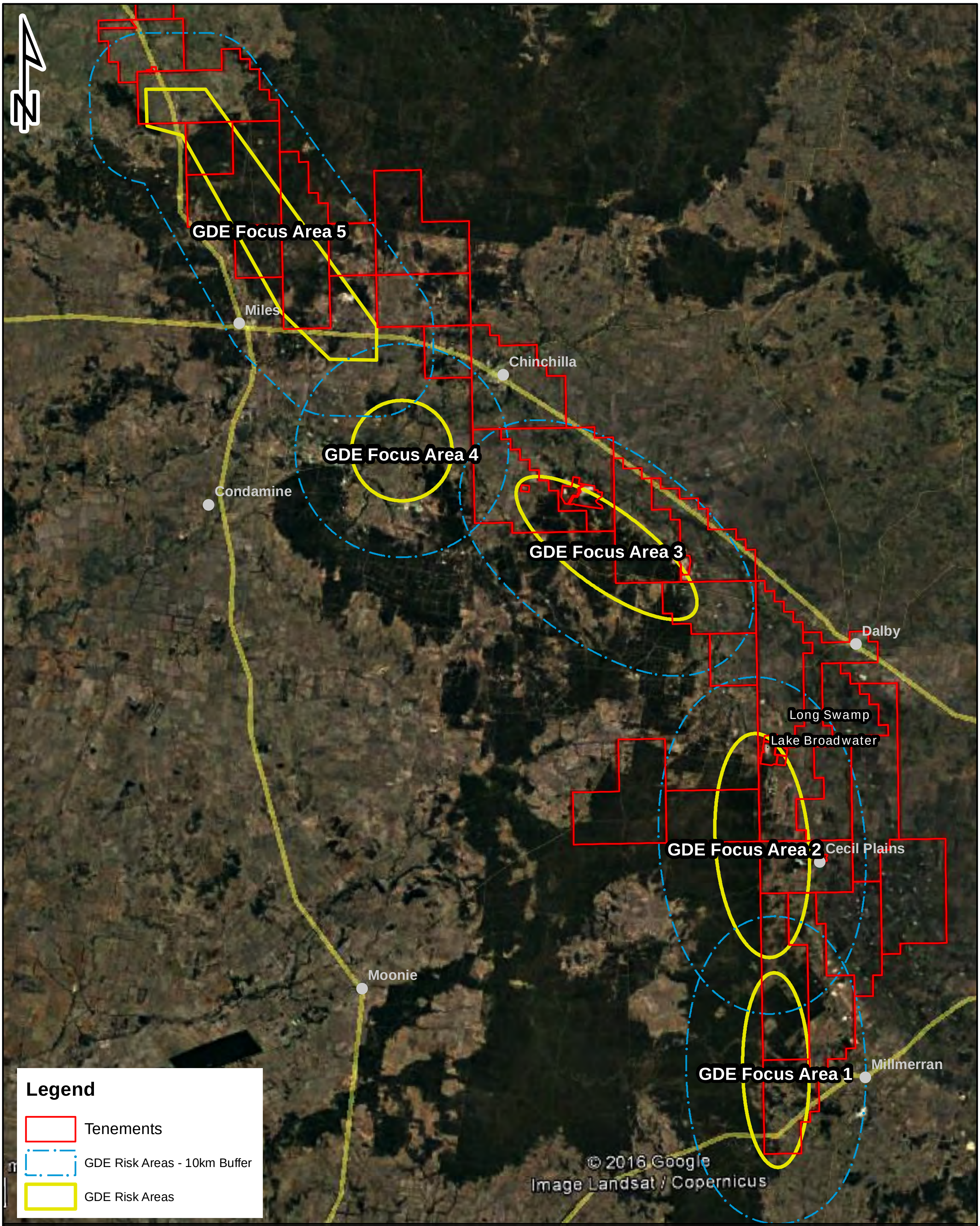

Figure 1. Study area location

Client ARROW ENERGY

0 16 32 48 64
Kilometers

Scale 1:893,747 **Drawn By** DG **Date** 05-Feb-17 A4

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1.2.5 Surat Gas Expansion Project – CSG WMMP

CDM Smith (2015) developed a 'fit for purpose numerical stimulation' to assess impacts arising from the Surat Gas Project on the water resources of the Condamine River Alluvium (CRA) including a summary of water resources, assessment of groundwater – surface water interaction and dependent ecosystems.

The numerical stimulation relied on models developed and / or managed by the OGIA and the Department of Natural Resources and Mines (DNRM) which were developed based on the most comprehensive collations of groundwater data available. CDM Smith notes that 'while the potential impacts of the project have been evaluated rigorously in the past by the developers of existing models, and again during this study, using existing models.

The CDM Smith report indicates:

- The maximum reduction in flux from underlying hydrostratigraphic units to the CRA, caused by Arrow's water production, is predicted to occur around 45 years from now, and to be slightly less than 3 ML/d within the area of the Condamine Alluvium, an area of about 8,000 km2.
- This maximum predicted change of 1 GL/y and can be compared with current licensed abstraction of groundwater in the area of the CRA of 87 GL/y across its four sub-management areas.
- The reduction in flux across the base of the Condamine Alluvium caused by Arrow will increase from zero to 1 GL/y over a period of approximately 45 years, with the time of maximum in around year 2060, and then fall again to zero over almost 3,000 years.
- Disconnection of the Condamine River from the underlying water table through independent analysis of water table elevations relative to bed levels of rivers and streams, confirming the findings of previous studies undertaken by CSIRO (2008).
- The predicted slight lowering of piezometric head in groundwater in the CRA will increase the leakage of surface water from rivers and streams to groundwater although it is predicted that the maximum increase in flux of surface water to groundwater is predicted to be less than 0.13 ML/d (0.05 GL/y).
- The maximum drawdown in the Condamine Alluvium as a result of CSG production is predicted to be of the order of 1 m, and it will take hundreds of years to reach that maximum drawdown, before a long slow recovery. The maximum drawdown is small enough and the rate of change in water table elevation is slow enough for dependent ecosystems to adapt and survive.

1.3 Site Context

1.3.1 General Geology and Hydrogeology

The Surat Gas Project area straddles the divide between the Jurassic age Surat Basin and the Clarence-Moreton Basin to the east. In the south-eastern portion of the project area, the divide between the two basins is covered by the thick sequence of the Quaternary age CRA.

The Jurassic age rocks consist primarily of sandstones, silt, mudstone and coal representative of fluvial depositional environments alternating between high-energy depositional facies with the coarser lithologies and low-energy oxygen depleted swamps during deposition of the coal beds (Day et al, 1983). The Main Range Volcanics are an early Miocene feature which cut and unconformably overly the older sedimentary sequences. Comprising mostly olivine basalt, the Main Range Volcanics outcrop to the east of the CRA and form an erosional landscape feature which has provided a major source of clastic material during CRA deposition. In the central region of the study area, the Tertiary Chinchilla Sands form thick sequences of loosely consolidated red to orange sand that unconformably overlies the Jurassic sedimentary rocks. Surface geology within the Study Area is shown in Figure 2.

Within the Jurassic age lithologies of the Surat Basin, the main aquifers are (with increasing depth):

1. The Kumbarilla Beds, in particular sub-units: Mooga Sandstone, Gubberamunda Sandstone and the Springbok Sandstone, confined by the Westbourne Formation acting as an aquitard.
2. Walloon Coal Measures,
3. Hutton/Marburg Sandstone; and
4. The Precipice Sandstone (absent beneath some of the Arrow study area).

The porous basalts of the Main Range Volcanics is also considered a productive aquifer (Australian Government 2016).

The CRA forms a significant and highly productive aquifer that has been subject to considerable historical groundwater extraction. Hydraulic properties of the CRA are however spatially and vertically variable (Dafny and Silburne 2014). Shallow disconnected aquifers are known to occur throughout the alluvial sequence which complicates the assessment and interpretation of groundwater level data. Recharge of the CRA aquifer occurs through a number of sources being:

1. Flux from the Condamine River: The Condamine River is considered a major source of low salinity groundwater recharge to the Condamine alluvial aquifer, with the rate of recharge largely dependent on lithology. Higher recharge rates appear along sandy river banks than along clayey ones and the occurrence of sandy sediments near the surface correlate to areas where groundwater recharge to underlying alluvial aquifers is likely to be substantial (Dafny and Silburne 2014).
2. Fluxes through alluvial boundaries: Alluvial landforms associated with tributaries on the eastern side of the CRA are known to contribute minor amounts to the water budget of the CRA aquifer (Dafny and Silburne 2014).
3. Fluxes from bedrock: The CRA overlies three aquifers, the Main Range Volcanics and Hutton Sandstone in the east and the Kumbarilla Beds/Walloon Coal Measures in the west (see conceptual setting in Figure 2 below). A positive gradient exists from aquifers into the east of the CRA Aquifer and both the Main Range Volcanics and Hutton Sandstone are considered permanent contributors to the groundwater budget. Flux from the Kumbarilla Beds/Walloon Coal Measures is far less certain with some authors suggesting flux to the CRA was slightly positive in areas (Hillier 2010, Coffey 2012) to negative in other case studies (Lane 1979, SKM 2003).
4. Diffuse recharge: Diffuse recharge, referring to the percolation of water through the soils into the groundwater table following rainfall and irrigation is considered to be variable across the CRA. Irrigated lands allow for more substantial input from diffuse recharge than area with native vegetation where the subsoil is typically much dryer (Tolmie et al 2004; Tolmie et al 2011). Water may also percolate along preferred flow paths such as deep soil cracks (Kurtzman and Scanlon 2011). The OGIA estimates diffuse recharge to be as much as 30mm / yr.

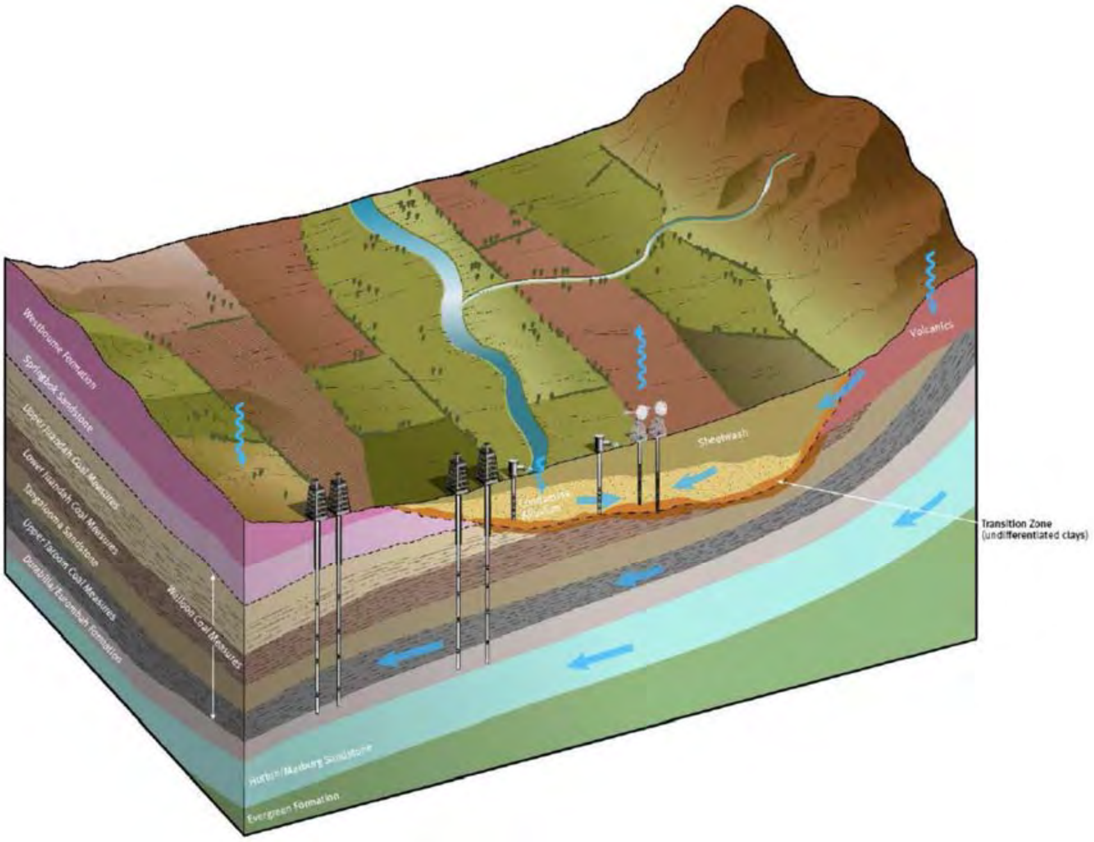

Figure 2. Hydrogeological Setting (From OGIA, 2016).

1.3.2 Surface Geology Mapping

Accurate and detailed surface geological mapping is critical to the assessment of subsurface GDEs and the potential connectivity with underlying formations subject to depressurisation. For GDE assessment this mapping is particularly important where the Walloon Coal Measures, and other formations predicted to be de-pressured, dip upward at basin margins and outcrop at surface or sub-crop under alluvium. The integrity of GDE and other groundwater impact assessment relies on accurate definition of these areas and the thickness and properties of the overlying alluvium.

The existing Geological Survey of Queensland (GSQ) surface geological mapping is largely based on historical data many decades old. There has not been a significant field surface geological mapping exercise conducted for the Arrow project area since a 5-month outcrop mapping campaign in 1967 - The Geology of the Chinchilla 1:250,000 Sheet Area – Southern QLD (and other adjacent sheets) completed by GSQ (Exon et, al) for the Commonwealth Department of National Development. This work appears to have been of an exceptional standard and much of it is still relevant. However significant data has since been acquired by the conventional and unconventional oil and gas industry, the drilling of water supply bores, and the coal industry through seismic, drilling and other subsurface data acquisition campaigns.

The general grouping of multiple geological formations into the “Kumbarilla Beds” and “Injune Creek Group” in current published surface geological mapping often does not allow useful interpretations at the resolution required for assessments such as this. More recently acquired (by industry) formation top data would allow a more useful splitting of the “Kumbarilla Beds” and “Injune Creek Group” into the individual constituent formations described in standard CSG logging.

A current GSQ and industry co-operative project aims at pulling together this available information, undertaking supplementary field verifications and re-mapping the surface geology. Unfortunately the mapping from the GSQ/Industry project was not available for use at the time of this report preparation. Therefore the existing GSQ mapping has been used and complemented with interpretation from more site specific bore log information and field geological outcrop observations where possible. Also interpretations of surface and subcropping geology for this assessment, and in particular splitting of the Injune Creek and Kumbarilla Beds groupings into individual formations, has been sourced from OGIA (2016) - see Figure 3 below which shows subcropping geology in the vicinity of the CRA.

Given the mapping relevance to the study area and focus on Springbok Sandstone and Walloon Coal Measures formation outcrop areas, it is recommended that assumptions made in this GDE assessment should be verified once the updated mapping is available.

1.3.3 Landscape Ecology

The SGP area is characterised by relatively gentle topography. In the larger southern section, the dominant landform is the expansive CRA. Extensive utilisation of the expansive clay plain for agriculture has resulted in a dramatically fragmented landscape where much of the remaining native vegetation exists as narrow attenuations along watercourses, and scattered remnants in road reserves. It is conservatively estimated that greater than 90% of the pre-existing native vegetation has been cleared for grazing on the CRA. Prior clearing has dramatically altered surface hydrology and abstraction has lowered groundwater tables beyond the rooting depth of native vegetation in many areas. The health and vigour of the remaining native stands of River Red Gum (*Eucalyptus camaldulensis)* and Poplar Box (*Eucalyptus populnea)* has been dramatically affected in some areas, and many stands are in a state of decline leading to senescence (Reardon Smith, 2011; Kath et al, 2014).

On the western margins of the study area, to the north of Miles and in Kogan area west of Daandine, the Kumbarilla Beds outcrop over a considerable portion of the landscape. The Kumbarilla Beds is a generic formation term used to describe the heavily weathered outcrop equivalent to the Late Jurassic to Early Cretaceous formations, commonly exposed in a north-south trending high east of Dalby (Kumbarilla Ridge). Outcropping basement rock is overlain in some localities by a weakly consolidated blanket of Tertiary aged alluvial and colluvial sediments to form a gently undulating landscape of low stony rises, broad gently incised gullies and intermittent streams. Native vegetation is much better preserved in the rockier areas with extensive stands of ironbark forest and the characteristic pervasiveness of cypress pine in the understory layers. Drainage lines, including the larger features of Dogwood Creek and are typically associated with shallow and narrow alluvial systems, often constricted around bedrock incisions into exposures of the Springbok Sandstone and Westbourne Formations.

In the northern portion of the SGP Study area between Miles and Wandoan, a steep breakaway escarpment exposes the fine grain metasedimentary rocks of the Injune Creek Group sub-formations. The landscape in vicinity of Wandoan has much more pronounced topography with low rounded hills formed on fine grained sedimentary rock, characteristic heavy clay soils and rounded rocky lag deposited on the soil surface. The arable nature of these lands has contributed to the extensive vegetation land clearing in the vicinity of Wandoan.

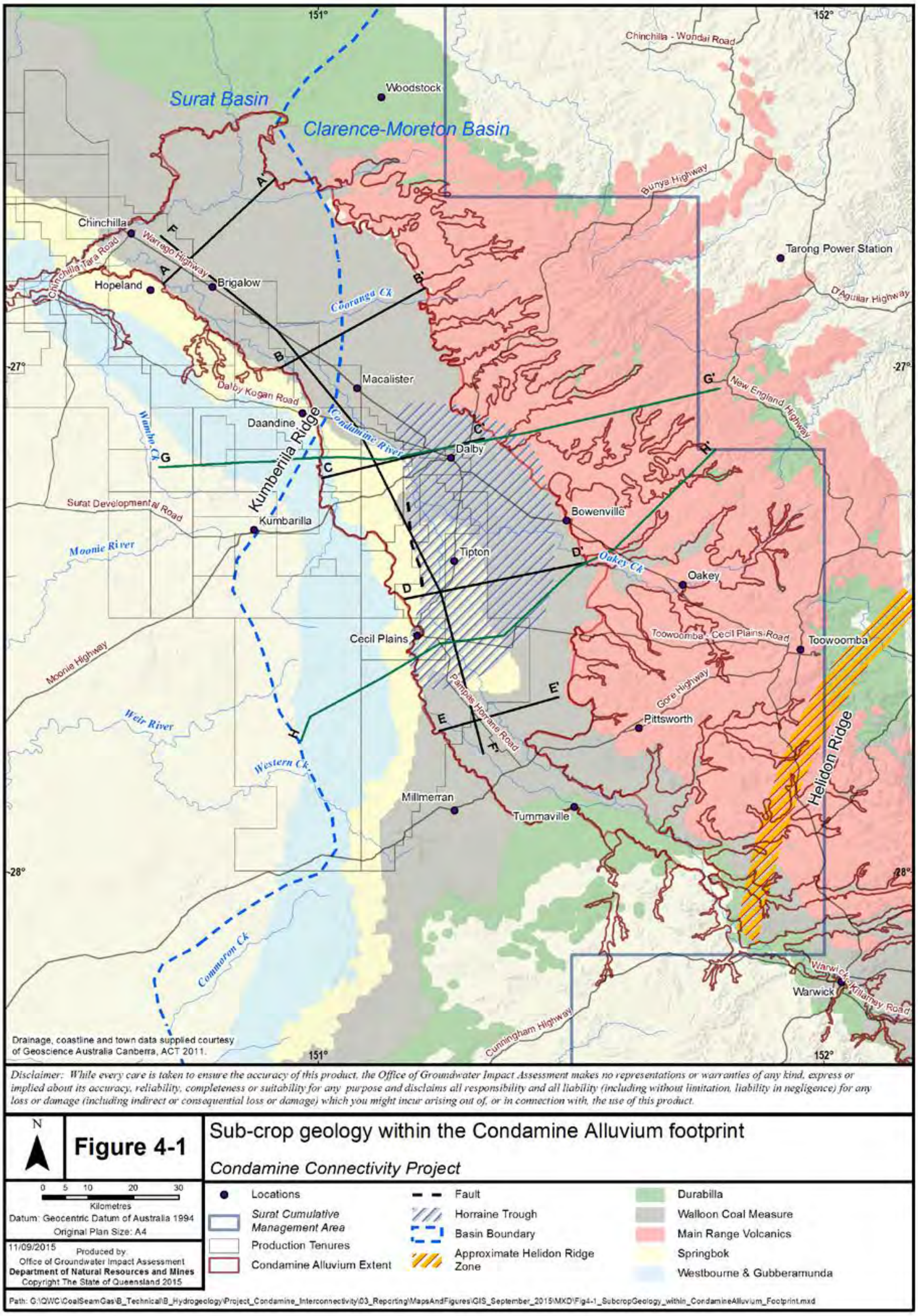

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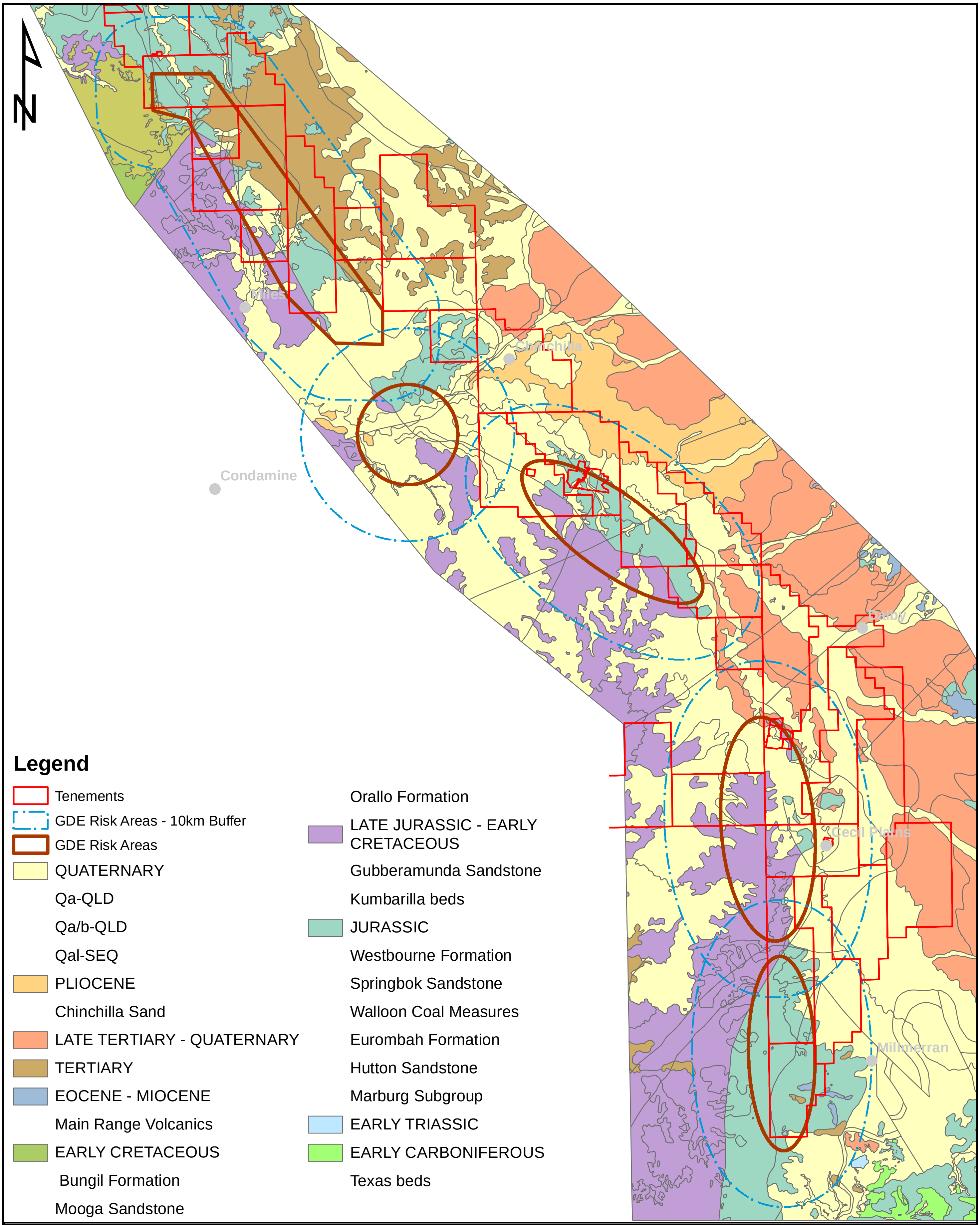
Figure 3. Outcropping and Subcropping Geology (From OGIA (2016).



Legend

☐ Tenements
☐ GDE Risk Areas - 10km Buffer
☐ GDE Risk Areas
🟨 QUATERNARY
Qa-QLD
Qa/b-QLD
Qal-SEQ
🟧 PLIOCENE
Chinchilla Sand
🟧 LATE TERTIARY - QUATERNARY
🟫 TERTIARY
🟦 EOCENE - MIOCENE
Main Range Volcanics
🟩 EARLY CRETACEOUS
Bungil Formation
Mooga Sandstone
Orallo Formation
🟪 LATE JURASSIC - EARLY CRETACEOUS
Gubberamunda Sandstone
Kumbarilla beds
🟩 JURASSIC
Westbourne Formation
Springbok Sandstone
Walloon Coal Measures
Eurombah Formation
Hutton Sandstone
Marburg Subgroup
🟦 EARLY TRIASSIC
🟩 EARLY CARBONIFEROUS
Texas beds

N O T E S:
Data source: Coal Seam Gas Units 2017 - Northern Surat and Clarence Moreton Basins, Queensland Government 2017

Figure 4. Surface geology mapping in the study area and surrounds

Client ARROW ENERGY

0 15 30 45 60
Kilometers

Scale 1:893,747	**Drawn By** DG	**Date** 26-Jun-17	A4

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1.3.4 Ecological Considerations and Thresholds Applied in this Assessment and Rationale

Eco-hydrological Concepts of Plant Water Use

The dependency of plants on groundwater sources may span a spectrum from complete dependency (obligate phreatophyte) to dependency during drier seasonal periods (facultative phreatophyte), to no dependency. For species with obligate groundwater dependency, the withdrawal of groundwater will generally result in death of a population of plants. Species with facultative dependency will utilise groundwater if it is available, although will utilise other sources of moisture, such as surface flow, when groundwater is withdrawn.

Much of the variation in groundwater dependency will relate to fluctuations in groundwater availability throughout seasonal cycles. A typical pattern followed by facultative phreatophytes in a tropical savanna would be utilisation of soil moisture from rainfall in wetter periods, with moisture sourced from groundwater in drier periods when the soil moisture above the groundwater table is depleted.

Groundwater Dependency of Flora and Ecological Communities in the Surat Gas Project Area

There is considerable conjecture in the available literature regarding the ability of native remnant vegetation to tap deep groundwater sources. Much of this conjecture relates to the potential rooting depth of riparian trees, influencing their ability to tap deeper groundwater sources during times of drought stress. The following is a brief synopsis of the best available knowledge on several dominant tree species that typify woodland and open forest vegetation in the SGP Study Area. While there are no obligate phreatophytes known to occur in the SGP, a number are considered to be facultative, including several of the eucalypt species listed below.

River red gum (*Eucalyptus camaldulensis*): River red gum is the characteristic riparian tree along much of the Condamine River Flood plain. It is typically associated with the area from stream bed level to the top of the inner river bench, often extending across the lower flood terrace on the larger river systems such as the Condamine. River. River red gum are large trees that typically dominate the canopy reaching heights of greater than 35m in some localities. River red gum are also one of the tree species that is showing considerable signs of stress and dieback along large reaches of the Condamine River, attributed at least in part to historical drawdown of groundwater in the CRA (Reardon Smith, 2011; Kath et al 2014).

River red gum have deep sinker roots, hypothesised to grow down towards zones of higher water supply (Bren et al., 1986) and the species obtains its water requirements from three main sources being ground water, rainfall and river flooding. It is river flooding which enables the species to survive in semi-arid areas (ANBG 2004) and stands of river red gum are intimately associated with the surface-flooding regime of the watercourses and related ground water flow. The high water use of river red gums contributes to maintaining watertables at depth (Dalton, 1990).

River red gum are considered partially opportunistic in their use of water and are considered a facultative phreatophyte, shifting between a combination of surface soil moisture and groundwater during periods of high rainfall, shifting to exclusive use of groundwater during drier periods. They are likely to achieve this shift through inactivation surface roots during drier periods with increased reliance on deeper tap roots. In the Murray Floodplain, it has been demonstrated that river red gum, even in times of flooding, preferentially source deeper groundwater rather than surface water, even when groundwater was slightly saline (Thorburn et al, 1994; Mensforth et al 1994). This may suggest that river red gum may be more susceptible to changes in groundwater levels than fluctuations in surface hydrology.

River red gum are the dominant tree in Regional Ecosystem 11.3.25 as well as forming a major although more variable component of Regional Ecosystem 11.3.4. These ecosystems represent the dominant riparian vegetation in the assessment area and are generally associated with the inner benches and lower river terrace of the Condamine River and larger tributaries respectively. In natural situations, river red gum is almost universally associated with watercourses and occurs throughout much of inland Australia where the species is likely to be partially dependent on groundwater resources. The species has however been observed to grow on hillslopes in rehabilitation plantings where groundwater is absent and it is expected that young plants can adapt to survival without reliance on groundwater interaction

Poplar box (*Eucalyptus populnea*): Poplar box is a characteristic tree in large areas of remnant floodplain woodland forming the dominant species in Regional Ecosystem 11.3.2 and Regional Ecosystem 11.3.17. The species occupies the upper flood terrace, typically above the highest flood levels and has an ecological preference for heavy clay soils, generally at some distance from the riverine flood channel. Fensham and Fairfax (2007) suggest that poplar box has a relatively low investment in deep root architecture compared to bloodwood species (*Corymbia dallachiana, Corymbia clarksoniana* and most likely *Corymbia tessellaris*) which makes it particularly susceptible to drought induced stress, and it is considered unlikely that rooting depth would penetrate much beyond 10m depth, particularly in heavy clay soils. Poplar box is considered likely to be a facultative phreatophyte although is known to occur on hillier localities where groundwater levels are likely to be beyond rooting depth.

Pink bloodwood, Moreton Bay ash (*Corymbia intermedia, Corymbia tessellaris*): Fensham and Fairfax (2007) note the much greater investment bloodwoods have made in respect to deep root architecture than poplar box. Clarkson's bloodwood (*Corymbia clarksoniana*), which is ecologically similar to pink bloodwood was observed to be using groundwater below depths of 11m in a tropical floodplain woodland (north-eastern Queensland) (O'Grady et al 2006) and it is considered likely that pink bloodwood would have similar ecological capacity. Moreton Bay ash was observed to be using groundwater to depths of 4m although was not assessed in locations where groundwater was deeper. Pink bloodwood is a common tree within Regional Ecosystem 11.3.4 which is typically associated with the lower flood terrace of the Condamine River. Both pink bloodwood and Moreton Bay ash are considered likely to be facultative phreatophytes although both occur on landforms where access to groundwater is unlikely.

Rough barked apple (*Angophora floribunda):* Rough barked apple is a common tree in riparian woodlands and open forests on the major drainage systems of the Condamine Floodplain including the Condamine River, Wambo and Wilkie Creeks. The species has an observed preference for well drained soils on sandy / loamy locations and dominates riparian forest is some localities. There is very little information published on groundwater usage by this species although ecologically, its preference for better drained soils suggests its root architecture is adapted to extraction of moisture from deeper in the soil profile. It is most likely that the species is a facultative phreatophyte as it also occurs on landforms where groundwater accessibility is limited. Rough-barked apple is typically associated with Regional Ecosystem 11.3.4 and 11.3.14 which occupy lower river flood terraces

River she-oak (*Casuarina cunninghamiana)*: A scattered tree on the inner terraces of the Condamine River, O'Grady et al (2006) suggests river she-oak is opportunistic in its use of groundwater, utilising groundwater when the tree occurred in lower positions in the landscape, and soil moisture when it occurred on higher levees. Such a scenario would suggest a shallow root architecture that might make the tree particularly susceptible to hydrological changes in river flow and changes to shallow groundwater levels. River she-oak is considered a facultative phreatophyte.

Coolabah (*Eucalyptus coolabah*): A scattered tree within the SGP study area which is largely confined to small remnants within the Regional Ecosystem 11.3.3 on lower to middle flood terraces and overflow channels. A 5ha occurrence occurs over a kilometre from the Wilkie Creek near the Theten field. The species is entirely confined to the Condamine River Floodplain where it is associated with heavier clay soils with poor internal drainage. There is little information on the ecology of this species nor its use of groundwater, or potential rooting depth. Studies by Costelloe et al (2008) indicate coolabah has capacity to utilise soil moisture above highly saline groundwater in the Diamantina Catchment suggesting that there is no specific reliance of the species on groundwater for sustenance. The species also has capacity to adapt to much lower transpiration rates, meaning much greater capacity to survive during periods of drought stress.

Ironbark species (*Eucalyptus crebra, Eucalyptus elegans, Eucalyptus fibrosa)*: Fensham and Fairfax (2007) describe the root architecture of ironbark species as being concentrated in the upper soil layers, typically <4m. Ironbarks form the dominant canopy species over extensive areas of colluvial outwash, decomposed sandstone and indurated sandstone jump-ups which host Regional Ecosystems 11.5.1, 11.7.4 and 11.7.7. It is expected in this scenario that ironbark would have limited potential to tap deep groundwater sources and the species is reliant on soil moisture in the upper soil profile. It is considered unlikely that ironbark's have any strong reliance on groundwater for sustenance.

The SGP area comprises up to 27 regional ecosystems (3d Environmental 2013) of which only a few have capacity or opportunity to tap groundwater resources. Those considered to potentially access groundwater resources based on species composition are typically associated with riparian ecosystems and alluvial soil. Based on the preceding information, ecosystems in the SGP study area, have been considered in relation to their eco-hydrological characteristics of constituent tree species in conjunction with their position in the landscape. Based on this information, a predicted likelihood of significant ecosystem dependency on groundwater has been constructed as described below:

1. **Regional Ecosystem 11.3.25** - Highly likely GDE along the Condamine River within Arrow's tenements based on the dominance of river red gum. The ecosystem sites in a topographically low landscape position within river channels. Hence in the thick deposits of the Condamine River, it is possible that the roots of river red gum may penetrate to depths of 25m, well within reach of the majority of groundwater surfaces in the region.
2. **Regional Ecosystem 11.3.4** - Likely GDE where it occurs on lower alluvial terraces of the Condamine River. Deep tap roots of river red gum have capacity to penetrate beyond depths of 12m below the upper alluvial terrace intersecting areas where the water table shallows.
3. **Regional Ecosystem 11.3.2** – Possible GDE although expected that groundwater has been largely withdrawn below rooting depth. This is due to its landscape position on the upper alluvial terrace and likely inability of tree roots to penetrate to depths below 12m.
4. **Regional Ecosystem 11.3.3** - Possible GDE although expected that groundwater has been largely withdrawn of falls below the general rooting depth. Species does not require groundwater for survival.
5. **Regional Ecosystem 11.3.14** - Likely GDE where it occurs on lower alluvial terraces of the Condamine River and larger water courses of Wambo and Wilke Creeks. The deep tap roots of river red gum, a component of this regional ecosystem, have capacity to penetrate beyond depths of 12m below the upper alluvial terrace intersecting areas where the water table shallows. Rough barked apple is known to access groundwater resources in riparian localities.
6. **Regional Ecosystem 11.5.1** and other regional ecosystems on colluvial plains– Unlikely GDE. Shallow rooting depths of ironbark do not facilitate interaction with groundwater.

7. **Regional Ecosystem 11.7.4, 11.7.7** and other ecosystem on ironstone- Unlikely GDE. Shallow rooting depths of ironbark do not facilitate interaction with groundwater. Groundwater typically within confined aquifers at depths of > 20m below the land surface in these systems.

Threshold Depths for Vegetation Response and Hydrologic Controls on Tree Rooting Depth

Reardon Smith (2011) and Kath et al (2014) defined critical thresholds in groundwater level, beyond which drawdown might precipitate a dramatic decline in vegetation condition. Threshold groundwater depths were calculated for vegetation condition within *Eucalylptus camaldulensis* (river red gum) and *Eucalyptus populnea* (poplar box) dominant woodlands. Simplified explanations for these thresholds is provided below for both species:

- River red gum:
  - Groundwater depths < 12.45 m: Groundwater is within the tree root zone and is being utilised as a predominant water resource. Vegetation is healthy and condition is stable.
  - Groundwater depths >12.45 to 20.75m: Groundwater or the capillary fringe may be within reach of tree root zone. A reduced water table level may result in a threshold response with a dramatic decline in vegetation condition.
  - Groundwater depths >20.75m: Groundwater has fallen well below rooting depth and vegetation condition is in a state of rapid decline.
- Poplar Box:
  - Groundwater depths < 14.33 m: Groundwater is within the tree root zone and is being utilised as a predominant water resource. Vegetation is healthy and condition is stable.
  - Groundwater depths >14.33 to 26.5m: Groundwater or the capillary fringe may be within reach of tree root zone. A reduced water table level between these depths may result in a threshold response with a dramatic decline in vegetation condition.
  - Groundwater depths >26.5m: Groundwater has fallen well below rooting depth and vegetation condition is in a state of rapid decline.

Adopted Standing Water Level (SWL) thresholds in this study: The following vegetation response thresholds have been adopted for all tree species in this study:

1. **Upper Threshold with SWL >12 metres below ground level (mgbl):** Below this SWL depth, mature canopy trees which are facultative phreatophytes may demonstrate a threshold response evident as a decline in canopy vigour, loss of foliage or slow senescence.

2. **Lower Threshold with SWL> 18mgbl:** Below this SWL depth, mature canopy trees will likely demonstate a state of decline which is evident in loss of canopy vigour and senescence of mature trees.

The thresholds have been adjusted from Reardon Smith (2011) and Kath et al (2014) due in part to field observation (further information provided in **Section 3.2**) and findings of Fensham and Fairfax (2007) who note the limited investment in deep root architecture for poplar box when compared to other eucalyptus species; plus criteria of DNRM (2013) which uses 20mgbl as the threshold point below which tree roots / groundwater interaction is unlikely to occur. It should be noted also that Reardon Smith (2011) noted a significant decline in vegetation condition where groundwater has fallen below depths of 12 – 15mgbl.

1.4 Study Scope and Objectives

The primary purpose of this GDE assessment study is to identify terrestrial vegetation GDEs that may be impacted by the project and determine the groundwater dependence of those GDEs. This includes the identification of any potential unregistered spring GDEs that fall within the GDE focus areas (as per **Figure** 1). The scope of work included the following phases:

1. Target refinement through review of existing data and desktop assessment.
2. On ground field survey of refined targets to include:
    a. Hydrogeological assessment;
    b. Ecological assessment;
    c. Water quality sampling;
    d. Hand augering.
3. Interpretation and reporting of the above tasks.

The work objectives (as per Arrow Energy Project Scope) are listed as follows:

1. Build on existing work to defensibly assess GDEs in a staged manner to comply with regulatory conditions and provide data that demonstrates defensible methods for monitoring and assessing appropriate trigger levels and management measures.
2. Implement scientifically robust and defensible sampling procedures, in accordance with industry standards and guidelines
3. A key factor for surface water groundwater connectivity is likely to be rainfall and/or groundwater levels. Data should be presented to establish whether a relationship exists between rainfall levels, groundwater pressure and GDE areas (i.e. establish whether a relationship exists between rainfall levels, groundwater pressure and GDE areas).
4. Establish baseline conditions for GDE areas and identify any relationship between GDE expression and seasonal climatic variation (e.g. rainfall). Document the relationship between the GDE area and biodiversity and establish the resilience of the system to change.
5. Provide sufficient data to assess potential effects of non-CSG anthropogenic activities (including ground/surface water takes) on GDEs.
6. Provide sufficient data to support the development of early warning indicators and trigger thresholds.

Throughout the course of the assessment, the understanding of hydrological concepts as they relate to GDEs in the SGP Study Area continued to evolve. As a result, some departures from this scope were made dependent on availability of data, conditions of site access, or the nature of GDEs identified during the assessment. The departures were necessary to ensure outcomes were practical, achievable, and allocated the best use of available resources. This included an increased focus on the identification and assessment of "subsurface" (or "vegetation") GDEs - see definitions below, rather than springs, the latter proving largely absent from the assessment area.

1.5 GDE Definition Used for Assessment

The definition of a GDE applied to this assessment is provided in the *Supplementary Assessment – Arrow Energy Surat Gas Project – Supplementary Report to the EIS* (Coffey 2013):

- *Ecosystems dependent on the surface expression of groundwater including:*
    - *Springs, spring wetlands, spring fed watercourses.*
    - *Groundwater discharge to rivers and wetlands.*
- *Ecosystems dependent on the subsurface presence of groundwater, including plant roots accessing shallow groundwater. These are termed Vegetation GDEs.*

This is broadly consistent with the definition of GDEs provided in the guidance document *Modelling water-related ecological responses to coal seam gas extraction and coal mining* prepared by Commonwealth of Australia

(2015) on the advice from the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC). This definition is described below:

*Groundwater dependent ecosystems (GDEs): Natural ecosystems which require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services (Richardson et al. 2011). The broad types of GDE are (*from *Eamus et al. 2006):*

- *Ecosystems dependent on surface expression of groundwater*
- *Ecosystems dependent on subsurface presence of groundwater*
- *Subterranean ecosystems*

Importantly, the DoE (2015) definition of groundwater incorporates the saturated zone and the associated capillary fringe. The assessment of potential subterranean ecosystems (such as stygofauna populations) is not covered in this assessment scope.

The general GDE assessment and characterisation principals utilised here have also been derived from this document wherein an integrated ecological and hydrogeological site model is developed through a series of desk top and field refinements.

2.0 Assessment Method and Approach

A structured hierarchical approach was applied to facilitate refinement of existing targets and identification of new or additional areas that might represent GDEs. The approach included:

1. A comprehensive review of existing assessment reports and available data to assist the screening process and identify any new targets.
2. An initial phase of field assessment of accessible targets including those identified as potential springs by AGE (2015).
3. Analysis and screening of field data from the initial phase of field survey.
4. A supplementary phase of field assessment targeted to:
    a. Assess high potential GDE targets that were not accessible during the initial phase of survey.
    b. Assess additional GDE targets that were identified during the screening process.
    c. Complete field groundwater and surface water analyte sampling at selected locations considered to be likely or high potential GDEs.
5. Analysis of data collected during the supplementary phase of field survey to further screen GDE targets and identify GDE localities for hydrogeological conceptualisation.

This process from initial screening to conceptualisation is described more fully in the following sections.

2.1 Desktop Assessment

2.1.1 Refinement of AGE Spring Targets

An initial phase of desktop refinement of AGE spring targets was undertaken in an attempt to filter out targets into targets that were considered either 'Possible' and 'Unlikely' springs. This was undertaken through a number of risk-based data assessment and mapping steps, specifically:

1. **Initial Risk-Based Prioritisation**: Filter AGE GDE targets into those that fall within higher risk GDE Focus Areas plus a 10km buffer (higher priority) as in **Figure 1**and those that don't (lower priority).

2. **Ecology – Aerial Photograph Interpretation:** Review each GDE spring target identified in the AGE (2015) report through inspection of high resolution recent and historical aerial photography and filter into "Possible" and "Unlikely" prioritisation categories. This assessment was aided with the use of stereoscopic historical imagery, with capture dates ranging from 1969 to 1981, to identify historical land use trends and disturbance.
3. **Satellite Imagery Analysis:** Processing of NDVI datasets, mapping NDVI signature and examination in conjunction with high resolution aerial photography.

Refinement steps 2 and 3 focused specifically on filtering those targets generated through analysis of NDVI datasets where vegetation signature or landform feature could be readily explained through processes other than expression of surface water. A simplified description of the process is as follows:

1. Is the feature apparent on historical imagery (1989) and is there evidence for significant landform modification or excavation?
2. Is there bunding evident on paleo channels and overland flow paths?
3. Are there windmills / pumps and other water infrastructure apparent adjacent to the feature?.
4. Can the NDVI signature of vegetation be attributed to factors other than surface water expression?

Based on this process, AGE Spring targets were assigned as either 'Unlikely' to represent a spring or 'Possible' that the target site represents a spring. Targets assessed to be 'Possible' springs were subsequently targeted for field assessment (see Section 2.2.1).

2.1.2 Sub-surface GDEs Target Refinement

Refinement of sub-surface GDE targets utilised several datasets aimed specifically at identifying where vegetation root zones were likely to intersect shallow groundwater. These areas are almost entirely confined to alluvial areas, typically the CRA, and older Tertiary alluvium where there is outcropping Chinchilla Sands. The initial stage of assessment concerned compilation of datasets and literature considered pertinent to the assessment. Datasets utilised and processing requirements are described below:

1. Relevant spatial datasets which included:
    a. Queensland Groundwater Dependent Ecosystems and Potential GDE Aquifer Mapping (DSITIA 2015). This data set is also located on the Federal Government "Bioregional Assessments"
    b. Groundwater bore and groundwater data derived from National Groundwater Information System (NGIS) (http://www.bom.gov.au/water/groundwater/ngis/) operated by the Federal Government Bureau of Meteorology (BOM), and QLD Globe - Coal Seam Gas Globe (further discussed in Section 2.1.3).
    c. Vegetation mapping databases derived from previous studies (detailed Surat Gas vegetation mapping - 3D Environmental 2013).
    d. Academic publications dealing with vegetation and groundwater interactions on the Condamine Alluvium and broader Murray River Catchment (Kath et al 2014; Cunningham et al 2007).
    e. Surface geology mapping layers from Geological Survey of Queensland at 1: 500 000 (DNRM 2013).
    f. Supplementary Report to the Surat Gas Project Environmental Impact Statement (SREIS) (Coffey, 2013) groundwater drawdown layers to gain an understanding and spatial awareness of the scale of groundwater impacts, along with the unpublished assessment of CRA drawdown impacts (including additional modelling) completed by CDM Smith (2016).

g. Baseline assessments of groundwater wells on completed by Arrow Energy across Arrow Energy tenements.

2. Processing of Rapid Eye 6x6m Resolution Satellite Imagery to produce an NDVI dataset representing NDVI value ranges in a vector format.
3. Review of other high-resolution aerial imagery and Lidar produced specifically for the Surat Gas Project.

Sub-surface GDEs present some difficulty for assessment and monitoring as the groundwater / root interactions are not obvious through general observation. Hence during the process of target refinement, the following questions and processes were considered to filter sub-surface GDE assessment sites:

1. Is the identified sub-surface GDE within an area of potential drawdown impact?
2. Is the vegetation in remnant condition, broadly unaffected by severe structural alteration?
3. Is the landform / geology an appropriate host for a sub-surface GDE? Appropriate hosts are typically alluvial landforms within the Surat Gas Project area.
4. Is there a potentially useful groundwater bore in close proximity (typically < 500m) or is SWL within the the range of likely rooting depths of the associated vegetation?
5. Does groundwater borehole level data support an inherent capacity for riparian vegetation to interact and utilise groundwater?
6. What is the state of vigour of the GDE vegetation in terms of canopy health?

A full list of processes used to refine Vegetation GDE targets and synergies between datasets is provided in Table 1. Based on these processes, a suite of Vegetation GDE sites were specifically targeted for field assessment.

It is noted that analysis of NDVI data did not provide any additional resolution to the assessment or identification of sub-surface GDE targets. The highest NDVI values associated with thickets of cypress pine (*Callitris glaucophylla)* and belah (*Casuarina cristata)* well away from riparian margins, and the imagery dataset provided insufficient resolution to differentiate more productive riparian habitats from those that were significantly degraded.

Table 1. Datasets and processes applied to refine sub-surface GDE targets..

Dataset / Process	General Processing Requirement / Process	Application	Dataset Used in Conjunction With:
Rapid Eye 6x6m resolution NDVI dataset	• NDVI image processing using ArcGIS Image Analysis Tool. • Conversion of raster to vector data for generation of NDVI Values (-1 to 1) for 90 individual tiles for October 2012 and August 2013 imagery. Application of multipliers to NDVI values • Generation of Polygons for Grouped Spectral Reflectance Ranges (High: >0.390, Medium 0.200 – 0.389)	Identification of. Vegetation with high spectral reflectance in the NIR wavelength indicative of vegetation with high foliage density and vigourous growth (high photosynthetic capacity). Applied to identify vegetation where canopy vigour is sustained through dry periods as a result of access to groundwater. Although NDVI data was processed for both 2012 and 2013 capture periods, 2012 proved	1. Groundwater level data from NGIS datasets. 2. Queensland Govt GDE Potential Risk Mapping (DSITIA 2015). 3. Detailed vegetation mapping from Surat EIS (3D Environmental 2015).

Dataset / Process	General Processing Requirement / Process	Application	Dataset Used in Conjunction With:
		most useful as it followed a preceding 9 months of limited rainfall. The 2013 imagery identified a much greater extent of high NDVI Values (i.e > 0.39) than 2012 imagery due to moister preceding months and capture during a cooler period.	
Queensland Groundwater Dependent Ecosystems and Potential GDE Aquifer Mapping (DSITIA 2015).	Only polygons with High Potential for Groundwater Interaction were assessed in data filtering process. Medium potential GDE target areas were largely located on hillslopes and in habitats mostly occupied by shallow rooted ironbark forests with limited potential for groundwater interaction.	Applied as a general guide for the potential occurrence of sub-surface GDEs. High Potential targets were largely restricted to alluvial areas with some located on colluvial fringes. Medium potential GDE target areas were located largely on hillslopes.	1. Groundwater level data from NGIS datasets. 2. Generated NDVI datasets to identify vegetation with uncommon vigour that intersects High Value NDVI polygons (see Appendix F). 3. Surface Geology from GSQ Draft Mapping (2015).
Kath et al (2014)	Kath et al (2014) defined the threshold groundwater levels for the floodplain trees *Eucalyptus camaldulensis* and *Eucalyptus populnea* occurring within the Condamine Alluvium. The following thresholds were defined beyond which would potentially initiate a response manifest as decline in vegetation condition. Threshold response: *Eucalyptus camaldulensis* – GW depth from 12.5 – 20.75mgbl would potentially initiate threshold response. > 20.75 mbgl and *E. camaldulensis* would decline in condition. *Eucalyptus populnea* – GW depth from 14.33 – 26.5mbgl would potentially initiate threshold response. > 26. 5 mbgl and *E. populnea* would decline in condition.	Data reproduced to identify those areas where the root zone of floodplain vegetation intersect and fall below the groundwater table. Also used to identify those areas where groundwater levels have fallen below threshold depths and vegetation is in declining condition.	1. Threshold data levels from Kath et al reproduced in Appendix G). 2. Compared with other vegetation mapping datasets to refine GDE status of remnant vegetation (e.g 3d Environmental detailed vegetation mapping for Surat EIS).

2.1.3 Review of Available Groundwater Level Data

Groundwater data sets were collated and assessed for potential use in identtifying the presence of artesian or shallow groundwater. Areas where groundwater levels less were >20mbgl below ground surface (as described above) were assigned a higher priority for potentially supporting a GDE. Groundwater was considered to potentially flow to and support GDEs through the following subsurface hydrogeological mechanisms:

1. Artesian springs (classical discharge springs) whereby artesian pressurised groundwater discharges through a natural geological pathway (e.g. fault/fracture zone) to one or more vents at the ground surface.
2. Recharge spring where groundwater may recharge a geological formation and exit the same geological formation at a lower elevation, with subsurface flow often confined above and/or below through a unit of lower permeability.
3. Subsurface GDE (or vegetation GDE) where shallow groundwater (<20mbgl) may be permanently or seasonally present within vegetation root zones.

Groundwater data sets were initially assessed to identify geological formations and areas that may sustain artesian flow or permanent shallow groundwater. The following groundwater data sets were screened for useful data from bores located in the GDE Focus areas:

- **NGIS/QLD Groundwater Database** - Only a small subset of groundwater bores in the GDE focus areas had reliable geological descriptions and groundwater levels. In the absence of recent shallow groundwater bore level data (eg from Arrow landholder bore baseline sampling – see below), historical groundwater levels were extracted from DNRM Groundwater Database bore cards for groundwater bores located within the Lake Broadwater and other focus areas to facilitate a more accurate assessment of local hydrogeological conditions.
- **Arrow Groundwater and Reservoir Monitoring bores** – Only a small number of the monitoring bores were located within the GDE focus areas and none were targeting shallow aquifers.
- **Arrow Landholder Bore Baseline Assessments:** Baseline assessments for landowner wells contained within 19 properties surrounding sites that were considered to be high potential GDEs were collated. Selection of properties for data extraction was based on an initial screening of the DNRM database which provided an indication of those properties located in areas where vegetation / groundwater interaction is considered likely, and contained groundwater bores which had both a geological description, depth and standing water level recorded in the DNRM Groundwater Database. In total, useful baseline data was collected from 30 bores. Data extracted from the baseline assessment reports included:
    - date bore was established,
    - historical groundwater depth at date of drilling,
    - depth of groundwater at date of drilling,
    - depth of groundwater at baseline assessment,
    - total borehole depth,
    - geological formation (aquifer/s) being tapped.

All groundwater bores utilised in the assessment across the study area are shown in **Figure 5**.

2.1.4 Mapping of Vegetation GDEs

Detailed vegetation mapping datasets covering area of the Condamine Alluvium (3d Environmental 2013) coupled with GDE Potential Aquifer Mapping (DSITIA, 2016) in areas outside the Condamine Alluvium was assessed against SWLs derived from NGIS boreholes. A combination of this data was utilised to produce Vegetation GDE status maps over Arrow's PL tenements (see **Section 3.2**).

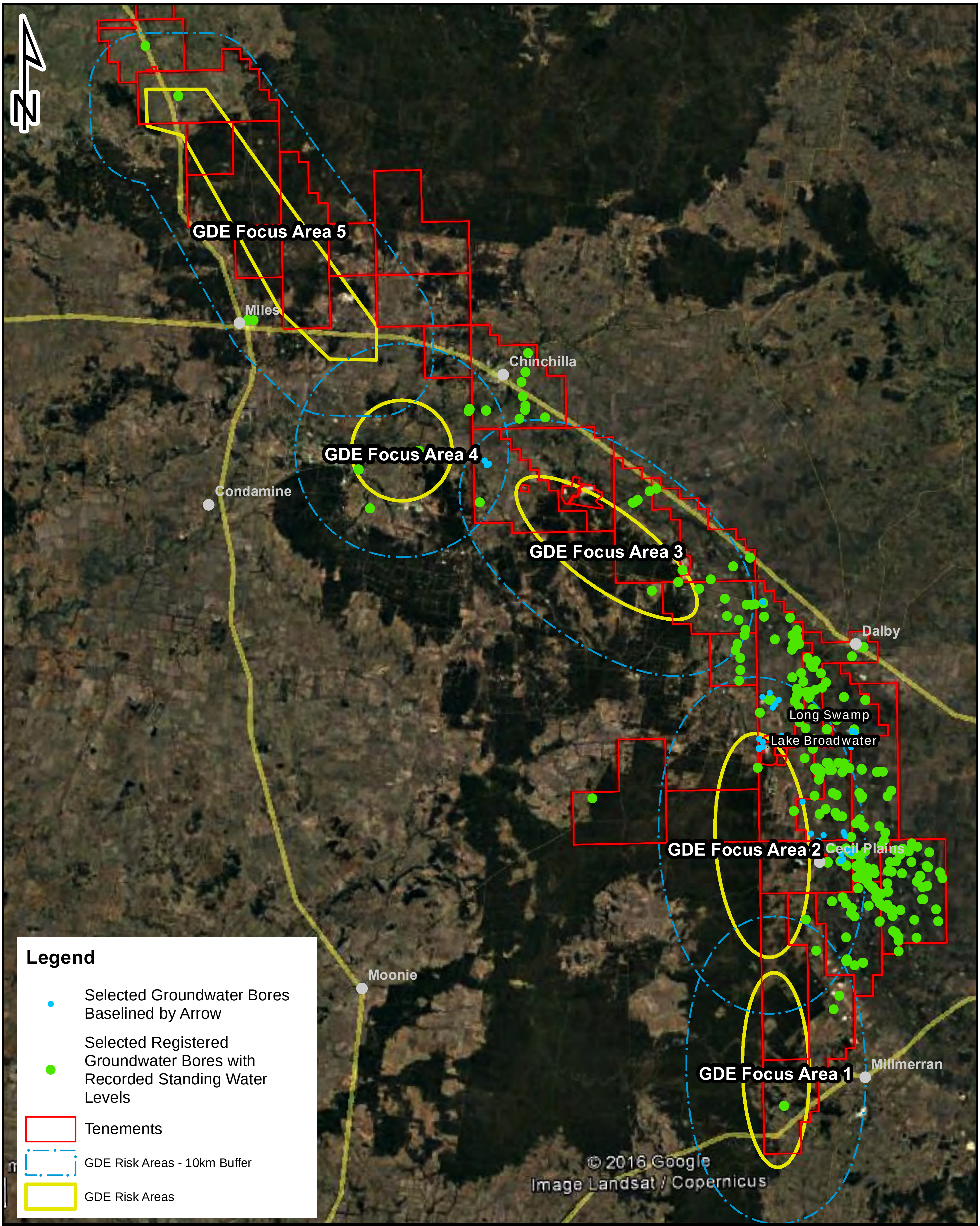

Figure 5. Location of Groundwater Bores with Standing Water Level (SWL)

Client ARROW ENERGY

0 16 32 48 64
Kilometers

Scale 1:893,747 **Drawn By** DG **Date** 05-Feb-17 A4

3D Environmental

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2.2 Field Assessment

An initial phase of field assessment was completed from 12th to 19th September, 2016. Conditions were extremely wet during the survey with 108.8 mm of rainfall falling in Miles between the 15th and 19th and 165.9 mm falling for the month of September. Conditions were slightly drier in Dalby with 42 mm recorded during the same period and 82mm falling for the month. Wet conditions also coincided with the supplementary phase of field assessment undertaken between 28th November and 1st December 2016 with 47.2 mm falling in a single storm in Dalby on the morning of the 28th, although this event largely missed Miles with only 2.8mm falling (BOM 2017). The broad location of GDE sites assessed during field survey is shown in Figure 6 with further clarification provided in following sections.

The initial phase of assessment in September:

1. Was completed broadly throughout the SGP assessment area focusing on spring and subsurface GDE targets that largely fell within ‘Priority Ecology Properties’ that had been pre-approved for access.
2. Aimed to field verify the AGE spring targets where property access was available and refine the assessment and identification of sub-surface GDE targets.

The follow- up assessment completed in late November:

1. Assessed sites throughout the entirety of the SGP assessment area from Cecil Plains northward to Wandoan. The assessment focused on target areas that were filtered during desktop and field assessment as presenting a high risk of groundwater interaction.
2. Provided a much more detailed assessment of GDE features including Long Swamp, Lake Broadwater and additional AGE ‘high potential’ spring targets and other GDE features that could not be accessed during the initial survey.
3. Allowed for water analyte sampling at those localities where the procedure benefited characterisation of the potential GDE feature.

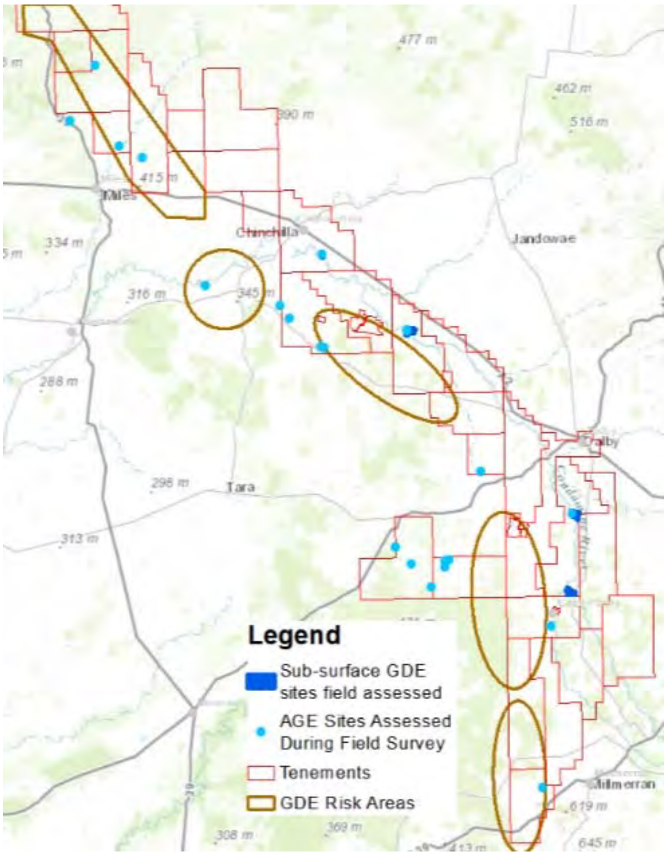

Figure 6. Location of GDE sites assessed during field survey.

2.2.1 Assessment of Potential Spring Sites

The sampling of potential springs, including AGE spring targets followed a hierarchical approach which was dependent on likelihood of spring occurrence based on initial field observation. Table 2 provides a summary of the approach taken, derived in part from sampling protocols detailed in UWIR (2016) and more detailed method adapted from the Joint Industry Plan (JIP) for springs assessment which is included in Appendix A.

Table 2. Assessment and sampling procedure at potential springs

Field Survey Method / Component	Comments	Field Survey Stage
All Potential Spring Targets – AGE Targets and Additional Sub-surface GDE Targets		
• Local geomorphological site setting and identified nearby rock outcrop sites will be described to determine likelihood of spring GDE and allow development of conceptual ecological/hydrogeological models as deemed necessary • Anthropogenic disturbance recorded including excavation and other landform modification. • Evidence of discharge or unexplained flow	• Used as an initial screening process in the field to determine spring likelihood • Used to assist in development of ecological/hydrogeological conceptual site models following Stage 2 assessment.	Stage 1 Survey Stage 2 Survey for non-repeat sites.
• Descriptions of flora composition of the GDE target and surrounding vegetation will be recorded as well as vertebrate fauna species present.	• Assessment of habitat condition and assess the presence of any unique ecological assemblages	Stage 1 Survey Stage 2 Survey for non-repeat sites.
Localities Assessed to be Likely Spring GDEs		
• Visual estimates of spring discharge rates, flow direction and general water movement characteristics will be made. • Assessment of spring size.	• Facilitate appropriate recommendations for discharge monitoring methods and equipment for subsequent monitoring programmes.	Stage 2 Survey
• Hand Auger Assessment	• Assess depth of groundwater table and geology to confirm groundwater depth and source of spring	Stage 2 Survey
• Water Analyte Sampling (see Section 2.2.3).	• Geochemical characterisation of spring as a baseline for ongoing monitoring	Stage 2 Survey

2.2.2 Vegetation GDEs (alluvium or volcanics with shallow permanent groundwater)

The above-described methods were generally followed for subsurface GDEs, although the targeting of potential subsurface GDEs was strongly influenced by desktop assessment, in particular hydrogeological datasets with confirmed depth to groundwater, or any terrestrial vegetation type considered likely to interact with groundwater based on ecological characteristics where suitable groundwater data was not available. The following assessment protocols are also relevant:

1. Assessment of vegetation condition followed standard assessment methods as described in Neldner et al (2012). Assessment included
    a. Description of vegetation composition in all structural layers
    b. Health and vigour of vegetation, in particular foliage cover and evidence of canopy senescence
    c. Additional anthropogenic disturbance including evidence of ringbarking or clearing.

2. Analyte sampling was only undertaken in those localities where desktop survey confirmed the presence of shallow groundwater and there was evidence of possible baseflow from groundwater into the watercourse (see Section 2.2.3).
3. Hand auger sampling was undertaken in a restricted number of localities where groundwater was suspected as being close to surface and it would significantly benefit hydrogeological characterisation. Hand auger sampling in the Lake Broadwater Conservation Reserve was completed under Scientific Permit WITK17580216.

A total of 7 sites were selected within the CRA from the desktop screening process specifically to assess potential status as a Vegetation GDE with details of selected sites provided in Table 3. Lake Broadwater and Long Swamp were also visited due to their status as Wetlands of High Ecological Significance (EHP 2014), and proximity to modelled drawdown in the Condamine River Alluvium. Additional sites were added opportunistically throughout the field survey. The screening process filtered sub-surface GDE targets to identify areas where:

1. Associated riparian vegetation retained original canopy structure with predominance of mature canopy trees.
2. Riparian vegetation was assessed to be in otherwise good condition (from aerial photography) and relatively contiguous along a significant stretch of the watercourse.
3. Groundwater was above a threshold SWL of 18mbgl depth where interaction between vegetation and groundwater was considered likely (based on refinement of groundwater thresholds as per Kath et al 2014).
4. The sub-surface GDE occurred within an area of predicted groundwater drawdown as per CDM Smith (2016) with 0.2m interval adopted as the lower contour of significance for Arrow only drawdown (Predicted Maximum Drawdown Case R35).

GDE 3 with an SWL of 19mbgl was also included in the second stage of field visitation to provide a direct comparison with other potential GDE localities where vegetation / groundwater interaction is considered more likely. The assessed sites were universally located within the CRA where impact to groundwater resources is predicted and existing groundwater infrastructure is located that has resulted in significant drawdown in the Condamine Alluvium. Outside the CRA, sub-surface GDE sites with potential to be impacted by Arrow's activities were assessed opportunistically during assessment of AGE spring targets.

Table 3. Vegetation GDE sites specifically selected through desktop screening process for field assessment.

Vegetation GDE Locality	Lot/Plan	East/ North	Point of Interest
Condamine River 1	Road Reserve	310665/ 6998812	Well-developed riparian complex of open forests and wetlands (RE11.3.25 and 11.3.27) associated with Condamine River channel and floodplain. SWL at 13.8mbgl (2012) at position of upper threshold. Predicted drawdown 0.5 to 0.75m*.
Condamine River 2	Road Reserve	326058/ 6955610	Remnant riparian vegetation (RE11.3.25). SWL at 9.5 – 15.1mbgl (above or slightly below upper threshold). Predicted drawdown 0.2m*.
GDE 1	4/SP225638	288525/ 7017029	Reserve on Condamine River (just north of Tong Park). Well-developed intact riparian vegetation (RE11.3.25). SWL at 5.8mbgl, well above upper threshold for vegetation response. Predicted drawdown at 0.2m*.
GDE 2	*1/RP32845*	288567/ 7016747	Reserve on Condamine River (just north of Tong Park). Well-developed intact riparian vegetation comprising RE11.3.25 and RE11.3.4. SWL at 5.8mbgl, well above

Vegetation GDE Locality	Lot/Plan	East/ North	Point of Interest
			upper threshold for vegetation response. Predicted drawdown at 0.2m*.
GDE 3	*288/A341480*	325593/6975735	Located in Council Reserve contiguous with frontage of the Condamine River. Well-developed mosaic of remnant riparian woodlands and wetlands including REs 11.3.25, 11.3.2 and 11.3.27. SWL at 19.6mbgl (below lower vegetation threshold). Predicted drawdown at 0.6m*.
GDE 4	269407	269407/ 7034063	Located in Council Reserve contiguous with frontage of the Condamine River. Broad Well-developed riparian vegetation frontage to the river in good condition with limited canopy disturbance. Well-developed mosaic of remnant riparian woodlands and wetland (REs 11.3.25 and 11.3.27). SWL at 8.6mbgl, well above upper threshold for vegetation response. Predicted drawdown 0m*
GDE 5	240/AG2873	324351/ 6958294	Floodplain of the Condamine River with well- developed riparian vegetation including RE11.3.25 and RE11.3.4. Vegetation is continuous, remnant and relatively intact. SWL at 9.5 – 15.1mbgl (above or slightly below upper threshold). Predicted drawdown 0.2m*.
Lake Broadwater	68/SP139357	312076/ 6974311	Conservation Park with significant wetland values. Well preserved fringing riparian vegetation dominated by red gum (RE11.3.27). Located on decomposed basement rock (Kumbarilla Beds). SWL at 16.2mbgl (1980) approaching lower threshold depth. Predicted drawdown 0.6m* – east side of lake only.
Long Swamp	Several localities although predominantly 2/RP74646	312207/ 6981260	Wetland of High Ecological Significance. Native remnant vegetation moderately well preserved with emergent river red gum (RE11.3.27). Located on CRA with SWL at 18.6mbgl at position of lower threshold. Predicted drawdown 0.5 m*.

*Predicted 'Arrow Only' drawdown as per CDM Smith (2016) – "Predicted Maximum Drawdown Case R35" for the Condamine River Alluvium (maximum predicted drawdown case as used as a conservative assessment).

2.2.3 Surface Water Analyte Sampling

Surface water samples were collected from a selection of GDE sites where it was decided, based on field observations, that water quality characterisation may assist with assessing potential groundwater/surface water interactions at some of the more "likely" GDE sites. Due to the heavy rainfall prior to and during both field surveys surface water was present at most sites visited. So professional judgement had to be applied to the selection of a subset of sites for sampling. Surface water samples were analysed for the OGIA "Spring Suites B and C" at the primary laboratory ALS Laboratories, which undertook the majority of the analyses and are NATA-registered for these analyses (except Radon and Isotope analyses). ALS had depots in Roma and Chinchilla which were utilised for the daily dispatch of samples to Brisbane ALS and then by air freight to secondary (sub-contracted) labs (ANSTO for Radon (to ensure 3 day holding times were adhered to), Environmental Isotopes Laboratory for C13, and Mawson Laboratories (University of Adelaide) for Strontium isotopes). "Suite A" parameters (as per the QWC 2012) Underground Water Impact Report 2012) were measured in the field with a water quality meter (see Table H8 below). Results of water quality sampling are summarised and discussed in Section 3.1.1 and in other sections where relevant.

Full laboratory reports, Chain of Custody (COC) documentation, QA/QC reports, and calibration certificates are provided in Appendix H.

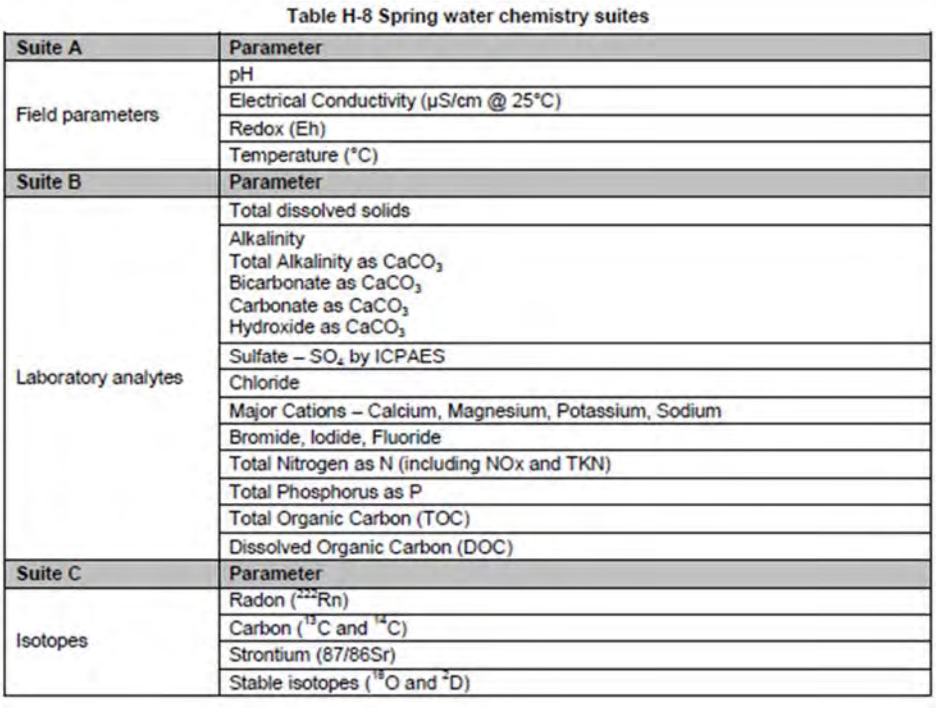

Table H-8 Spring water chemistry suites

Suite A	**Parameter**
Field parameters	pH
	Electrical Conductivity (µS/cm @ 25°C)
	Redox (Eh)
	Temperature (°C)
Suite B	**Parameter**
Laboratory analytes	Total dissolved solids
	Alkalinity Total Alkalinity as $CaCO_3$ Bicarbonate as $CaCO_3$ Carbonate as $CaCO_3$ Hydroxide as $CaCO_3$
	Sulfate – SO_4 by ICPAES
	Chloride
	Major Cations – Calcium, Magnesium, Potassium, Sodium
	Bromide, Iodide, Fluoride
	Total Nitrogen as N (including NOx and TKN)
	Total Phosphorus as P
	Total Organic Carbon (TOC)
	Dissolved Organic Carbon (DOC)
Suite C	**Parameter**
Isotopes	Radon (^{222}Rn)
	Carbon (^{13}C and ^{14}C)
	Strontium (87/86Sr)
	Stable isotopes (^{18}O and ^{2}D)

2.3 Limitations

The following limitations apply to the assessment:

1. The initial stage of field assessment coincided with an episode of intense rainfall which made it difficult to distinguish groundwater discharge from surface runoff. This is further discussed in the Results and Discussion Section below.

2. The capacity to make detailed hydrogeological interpretation, particularly linkages between rainfall and recharge, hydrogeological controls on Lake Broadwater, Long Swamp and some other sites was severely restricted by the limited number of suitably located monitoring bores with baseline data, and the short timeframe allocated to the assessment. Hence a conservative approach was applied throughout the course of the assessment in regard to the likelihood of vegetation / groundwater interaction. Detailed interpretation will be more feasible once permanent monitoring bores (based on recommendations from this assessment) are installed.

3. Interpretation of Vegetation GDEs, particularly those located on the CRA have been made based on best available information obtained from available datasets and Arrow Energy Landholder Bore Baseline Assessment Reports. The location of groundwater bores with measured standing water levels is extremely limited outside the area of the CRA and conceptualisation is largely interpretive.

4. The following data sets were not available for review in the timeframe available:

    a. Piezometric surfaces – intersection of piezometric surfaces for all GAB formations with ground surface elevations to assess areas of potential artesian flow and stream baseflows. These data sets were not available. The Queensland Government have historically undertaken such an exercise and have generated potential baseflow locations as described in the SREIS (Coffey, 2013), and this process is currently being refined. During the course of this assessment, the Queensland Government were approached for this data and also data available on areas of remaining artesian flow within the Surat basin. However at the time of reporting, the Queensland Government had not been able to supply this data set. Figure 7 below from the recently published DNRM Hydrogeological Assessment of the Great Artesian Basin - Characterisation of Aquifer Groups (KCB, 2016) indicates that there are very few artesian flowing bores within the Arrow study area in the north-east Surat Basin. This suggests that there is a low likelihood of the existence of discharge springs within the majority of Arrow's tenements. The Government were approached to provide the data set used to create this figure. This data was not provided within the reporting timeframe.

b. Structural geology data (including seismic interpretations) which images locations and orientation of shallow/surface faults which may indicate higher risk areas for artesian springs. The UWIR Report (OGIA, 2016a) only includes major regional scale faults in the numerical modelling. Mapping of numerous small-scale faults evident in existing seismic and downhole logs (eg image logs) in some areas of the Surat Basin, may be a useful area of refinement for future connectivity assessment.

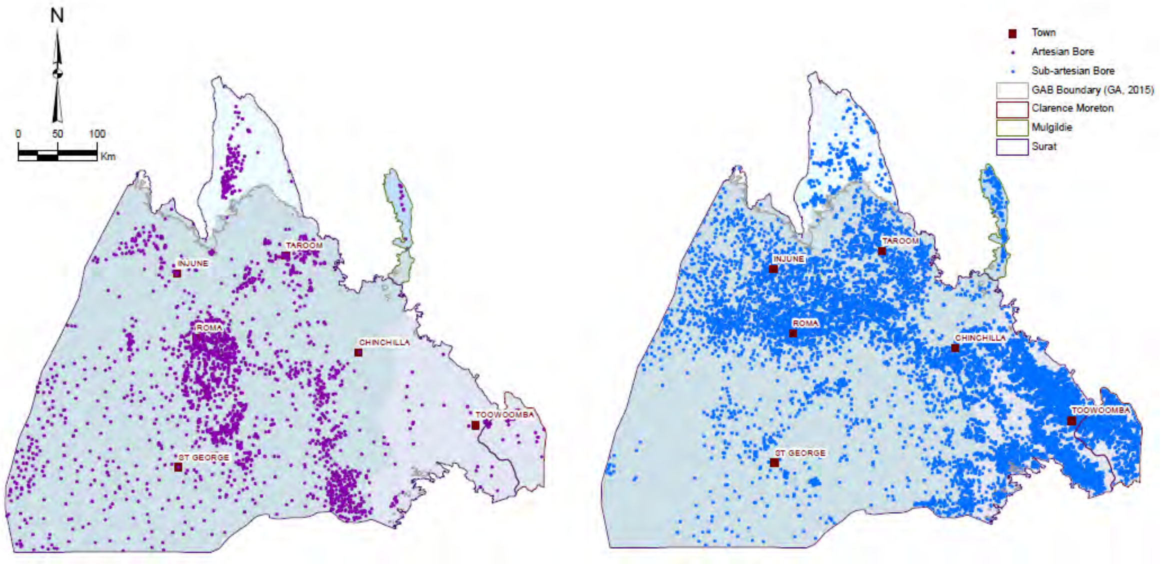

Figure 7. Location Of Sub-Artesian and Artesian Bores in the Surat, Clarence Moreton and Mulgildie Basins (From KCB, 2016)

3.0 Results and GDE Conceptualisations

Section 3 provides representation of the results of the GDE screening and assessment process, including desktop and field assessment of AGE spring targets (**Section 3.1**), identification of any additional springs (**Section 3.2**), and analysis of DNRM Groundwater Bore Database data, landholder bore baseline assessments and field inspections to identify vegetation GDEs (**Section 3.3**). Integrated ecological and hydrogeological conceptual site models are presented for the springs and major GDE types encountered.

3.1 Assessment of AGE Spring Targets

Of the 59 AGE spring targets located within the SGP study area, 11 targets were identified as 'possible' springs based on the desktop screening process. This includes AGE Spring Targets 241, 908, 238,910, 907, 172, 26, 29, 112, 151 and 245. A summary of springs assessed during the desktop screening process and the assessment outcomes are provided in **Appendix B**. AGE targets considered to be possible springs are represented spatially in **Appendix C**. Possible springs were targeted specifically during field survey for further assessment.

A representative suite of 20 AGE targets were assessed during field survey including the 11 AGE targets considered to represent possible springs and a further 9 that were considered unlikely based on desktop screening. Based on field survey, it is considered that none of the spring target sites located within the area of this assessment represent spring GDEs. The location of AGE spring targets assessed during field survey is provided in **Figure 8**.

Photograph 1. AGE Spring Site 155 showing excavated wall of a constructed water feature built to capture overland flow and not representative of a spring.

Photograph 2. AGE Spring Target 908 showing shallow ponding of surface water following rainfall. No obvious points of discharge were noted and the feature is assessed to represent an ephemeral waterbody and part of a larger shallow drainage system.

3.2 Springs Identified

Three springs were identified in the assessment area which may be subject to impacts from Arrow's activities. This includes the newly described Tribelco Spring, Wambo Spring and the Bowenville Spring to the east of Arrows tenements. Both Wambo Spring and Bowenville Spring are listed on the Queensland Springs Database (Queensland Herbarium 2016) as Listed Springs Complex 584 and 585 respectively. The location of springs potentially influenced by Arrow's activities is shown in **Figure 9**. Further discussion is provided in the following sections. Access to Wambo Spring was not granted. A summary of field data collected during field visits to the Tribelco Spring and Bowenvale Spring is provided in **Appendix E**.

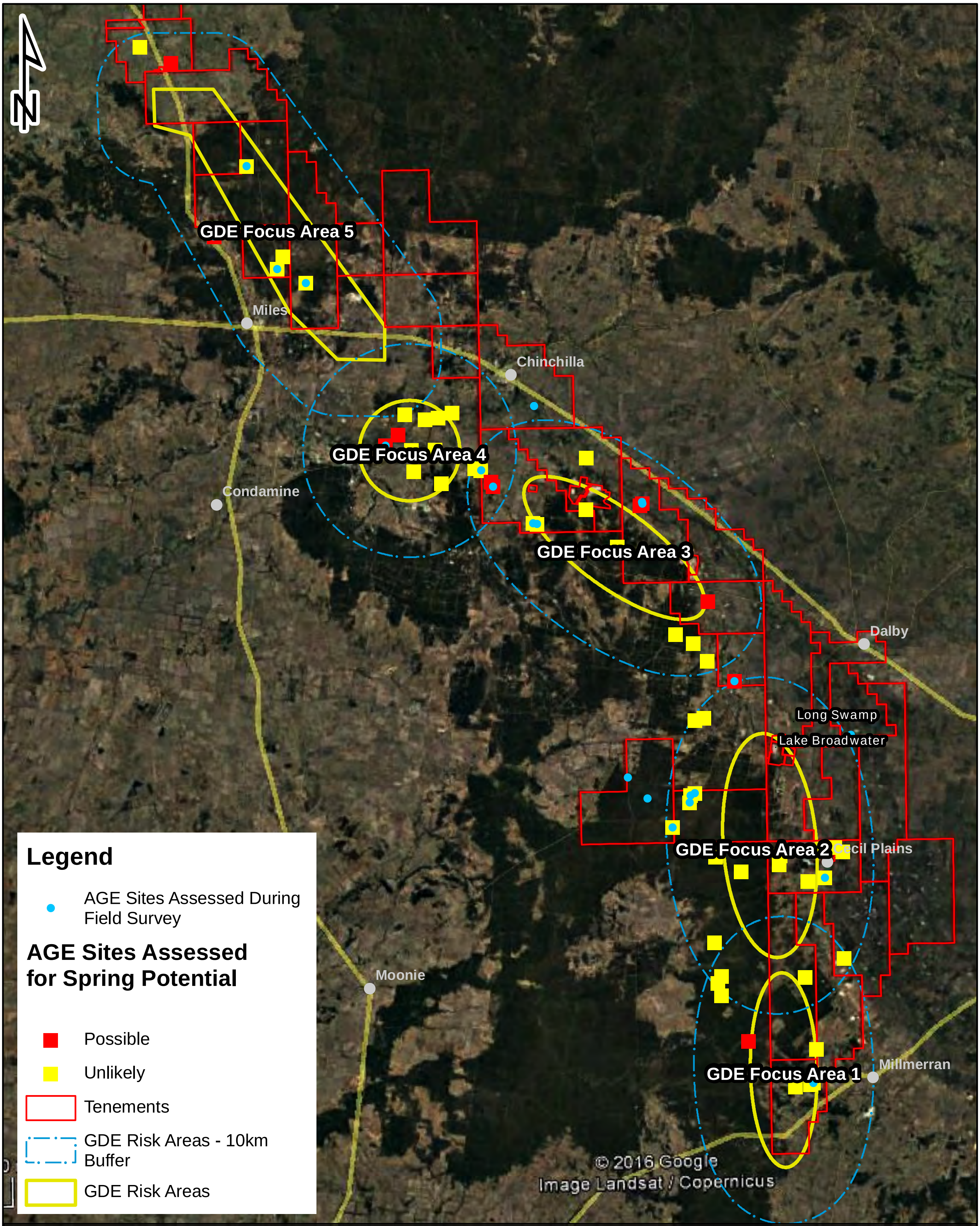

Figure 8. AGE spring targets assessed during field survey

Client ARROW ENERGY

0 16 32 48 64
Kilometers

Scale 1:893,747 **Drawn By** DG **Date** 06-Feb-17 A4

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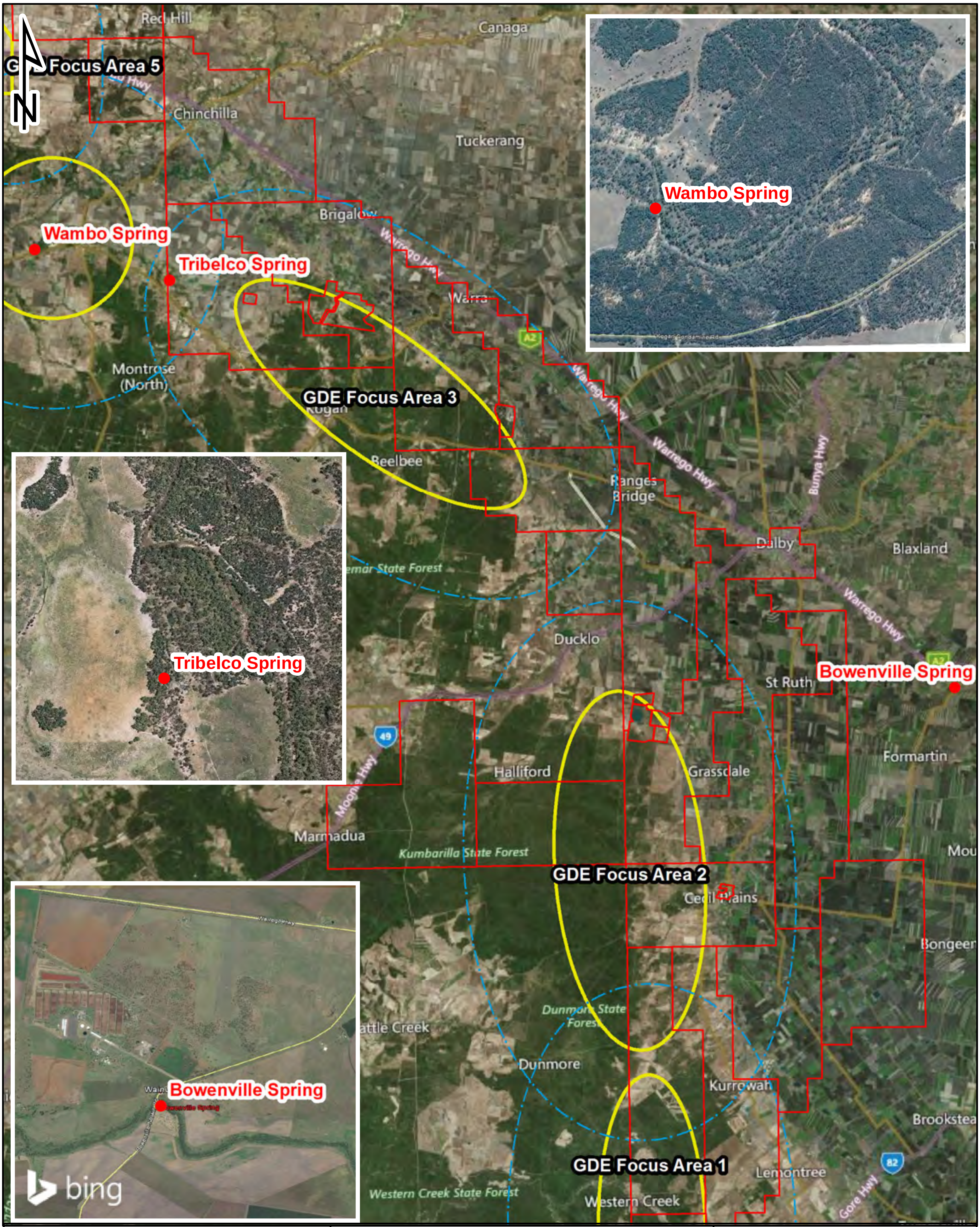

Figure 9. Location of springs potentially influenced by Arrow activities

Legend

● Spring Localities

▭ Tenements

▭ GDE Risk Areas - 10km Buffer

▭ GDE Risk Areas

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Kilometers

Scale 1:557,925 **Drawn By** DG **Date** 05-Feb-17 A4

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3.2.1 Tribelco Spring and Surrounding Wambo Creek Alluvium

A spring was identified on the Tribelco property (Lot 27 / RG653 herein referred to as the Tribelco Spring) with the identification facilitated by Arrow Energy Land Liaison Officer (Richard McLean) through discussions with the landowner. The spring discharges to a small tributary of Wambo Creek. This spring has been included in the list of Springs in the UWIR (OGIA, 2016a). It is listed as Spring Complex 765 “Orana”, with a “Low” confidence categorisation associated with site understanding and classification.

Vegetation

Vegetation associated with the spring comprised native aquatic herbs and grasses including Carex apressa, frogsbit (*Phyllidrium lanuginosum),* spiny mud grass (*Leersia hexandra), Cyperus laevis* and *Juncus continuous* fringed by a narrow band of *Leptospermum poligaliifolium.* Although the point of discharge is formed by native species, cattle have impacted the locality and the landowner has fenced the spring in an attempt at cattle exclusion.

Adjacent riparian vegetation on Wambo creek retains relatively undisturbed natural condition forming a tall open forest of rough barked apple (*Angophora floribunda),* minor red gum (*Eucalyptus camaldulensis)* and ground cover formed predominantly by the native grass *Arundinella nepalensis.* The mature canopy trees would almost certainly be tapping a shallow groundwater table at a depth of 2.5 – 3mbgl, extrapolated following intersection of groundwater in a series of nearby soil auger holes to 2.2 m depth (sampled in a lower position in the landscape within the creek bank).

A large tree had fallen directly adjacent to the spring which exposed an extremely shallow root architecture consistent with Eamus (2006) who suggested root growth is generally arrested somewhere between the upper level of the capillary fringe and the zone of saturation.

Photograph 3. Seepage zone of Tribelco Spring on a small tributary of Wambo Creek

Photograph 4. Fallen canopy tree adjacent to Tribelco Spring exposing extremely shallow root architecture.

Hydrology Geology and Geomorphology

As indicated in the conceptual cross section shown in **Figure 10**, and local detail shown in **Figure 11**, spring seepage was noted in the river bank beneath a high point in the sandy alluvial plain. This area was considered to be a location where the phreatic surface intercepts the lower slope of the creek bank and presents as a zone of major seepage located slightly above and adjacent to the main pool, and approximately 4m directly below the overlying highest point in the sandy rise. Hand augering and observations of the surrounding and underlying soils and geology suggested that this sandy rise consisted of an unconsolidated orange/brown, poorly sorted, fine to medium quartz sand (likely Chinchilla Sands) with high storage and permeability properties. Finer grey silty-sand around the creek bank is indicative of more recent flood deposition. Hand augering through the sands (collapsing below the groundwater table) indicated an observed 400-500mm fall in SWL measured in hand auger bores, across a 6m transect perpendicular to the creek bank at the main pool. This represents a steep hydraulic gradient, particularly for a sandy aquifer.

It was observed that the groundwater source sand body is continuous for at least several kilometres based on field and air photo observations, and may be more continuous beneath the thin covering of more recent flood over-bank silt and clay. The sand deposits would likely receive significant direct rainfall recharge, as well as run-off from the surrounding lower permeability silty clay flats during, and for some period after, heavy and prolonged rainfall. This would occur particularly at times of flooding where additional recharge gains may occur through connections to the Wambo Creek and tributary system. It is considered that the total storage in the connected sand body is likely to be considerable and recharge would likely sustain seepage into the main pool and surrounding riparian features for extended periods. Anecdotal information obtained from the landholder suggests that historically the seepage has ceased only once (during an undisclosed period of extended drought), although moisture was still present at a shallow depth beneath the ground surface.

At the time of the first survey (17 September 2016) the spring-fed stream was noted to be gently flowing in a south to northerly direction. Some flow was noted to entering the main flow from recent rainfall, with a significantly higher flow rate exiting the pool. The largest pool at the discharge point is approximately 30m long and 20m wide. It was estimated that based on the difference between the flow rate exiting compared with entering the pool that the overall seepage gain within the main pool was between 1 and 5 litres per second. During the 30 November site visit the pool had slightly receded, no flow was entering the main pool, and the exiting flow rate was visibly lower (estimated at <1 litre per second).

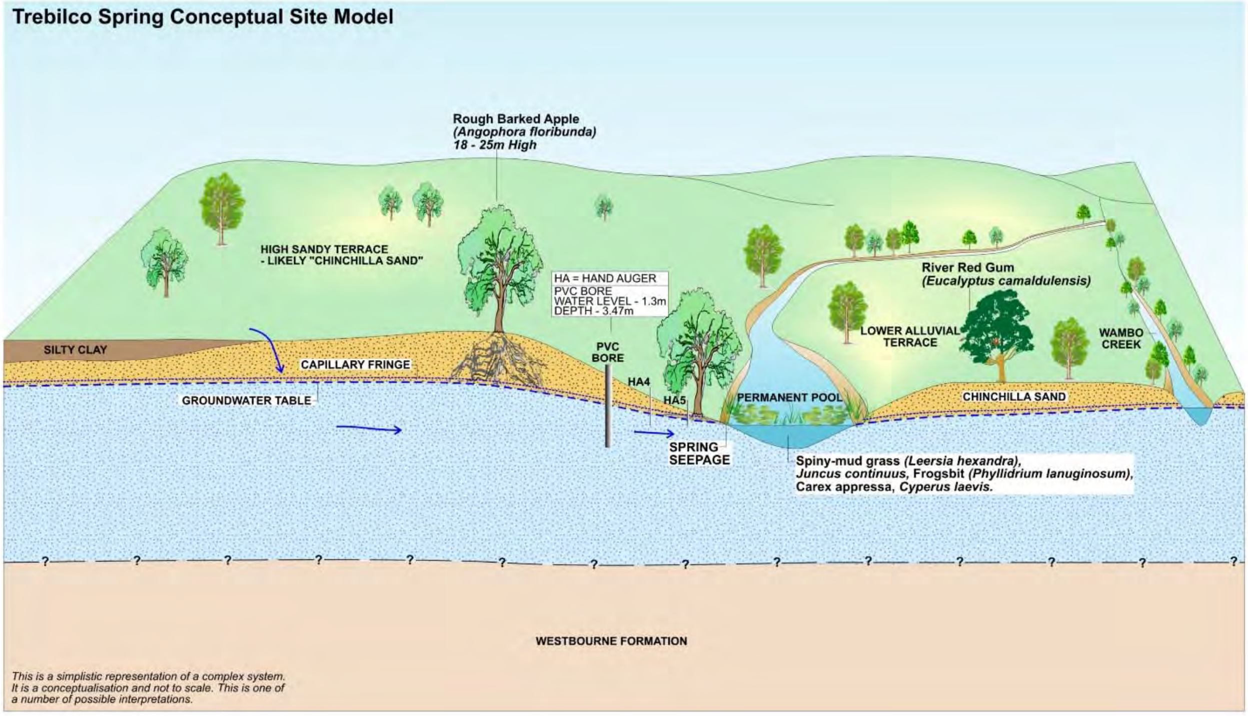

Figure 10. Conceptual cross section of Tribelco Spring.

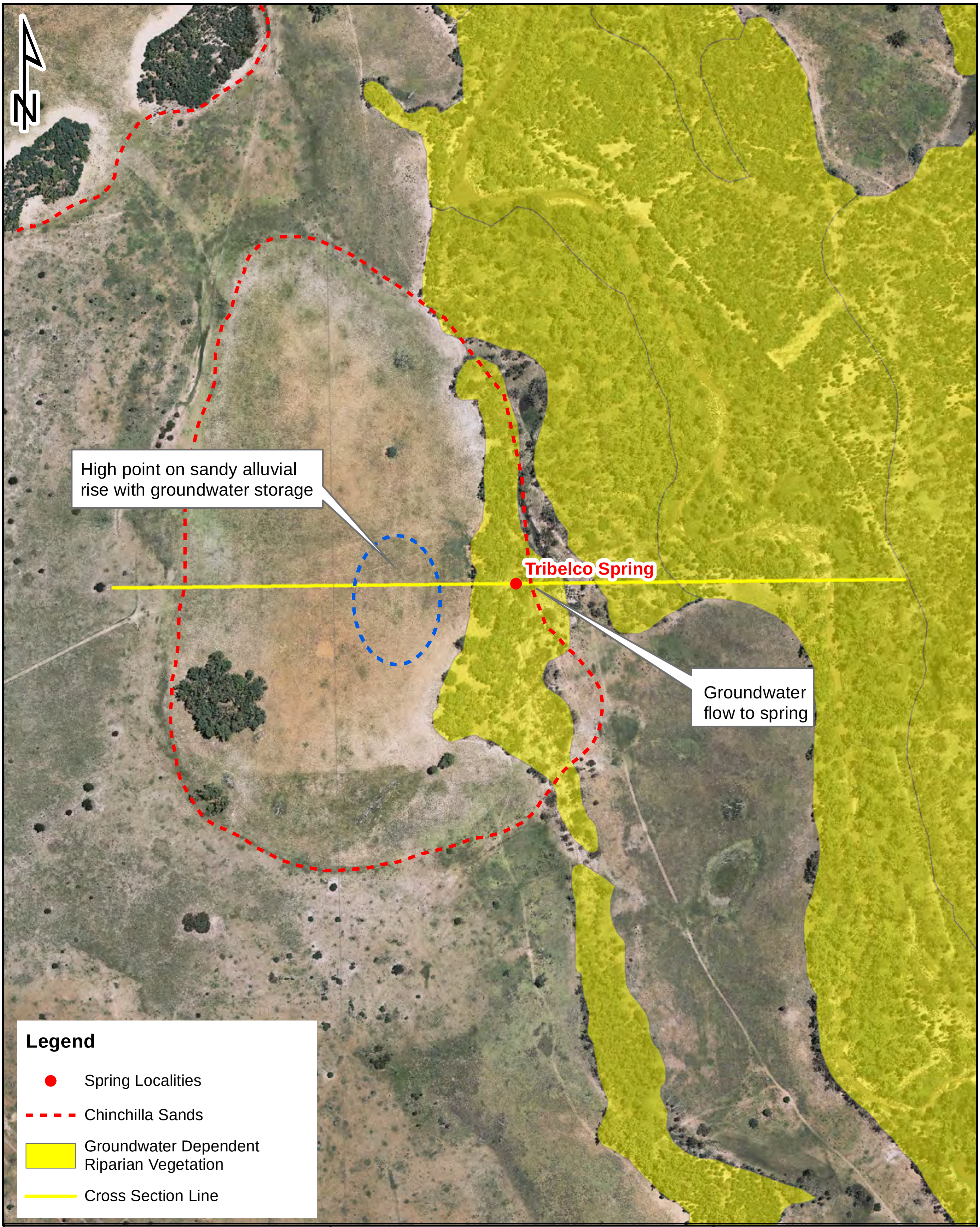

Figure 11. Local features surrounding Tribelco's Spring

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Kilometers

Scale 1:5,500 **Drawn By** DG **Date** 05-Feb-17 A4

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Water Chemistry

Field water quality measurements collected during the 30 November survey are summarised below in **Table** 4 with graphical representation provided in **Figure** 12.

Table 4. Field water quality measurements from Tribelco Spring.

	Shallow excavation in seepage zone	Main pool	70m downstream
Dissolved Oxygen (ppm)	0.72	0.18	2.25
Conductivity (μs/cm)	151.7	237	246
pH	5.36	5.88	6.75
Redox (mV)	217	95	79
Temp (^{o}C)	24	27	29.4
TDS (ppm)	97.1	151.7	157.4

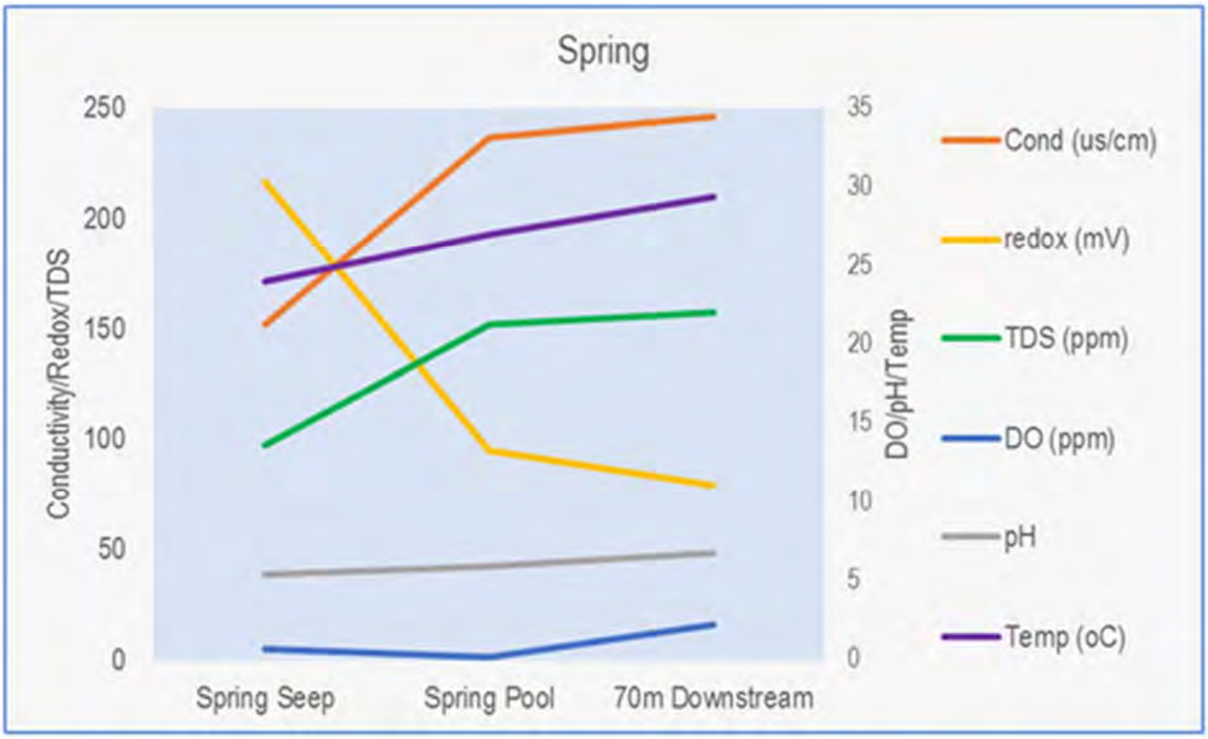


Figure 12. Trebilco seep, receiving pool and downstream field water quality characteristics.

Notable observations from the field water quality data include:

- pH, TDS/conductivity, and temperature increased with distance from the seep.
- Redox declined with distance from the seep.

All of the above observations support a fresh and slightly acidic groundwater source discharging to surface water.

Dissolved oxygen (DO) at the seep was elevated above the DO in the receiving pool, but lower than 70m downstream. Elevated DO at the seep may reflect some atmospheric mixing with seepage water during hand excavation of the small sampling sump in the creek bank. This was despite the sump being excavated some hours before the sample was collected and an adequate flow of seepage through the sump.

A surface water sample was collected from a shallow excavation in the seepage zone, stored on ice and sent on the same day to a NATA-registered laboratory for a suite of analytical parameters selected to comply with the OGIA (2016) "springs suite" and assist in the characterisation. Given the short half-life (3.824 days) for radon (^{222}Rn), a separate water sample was collected and field-extracted into a mineral oil-based scintillant and dispatched directly by air freight to the Australian Nuclear Science and Technology Organisation (ANSTO) Laboratory at Lucas Heights. The method followed for field extraction was the "PET" method developed by CSIRO (Leaney & Herczeg, 2006).

Full laboratory reports (these are still in a preliminary status until Strontium isotope analyses are completed), Chain of Custody (COC) documentation, QA/QC reports, and calibration certificates are provided in **Appendix H**. It should be noted that not enough sample was available for the C14 isotope analyses due to the splitting of samples and dispatch to multiple labs, which was not foreseen by the lab until after samples had been received. Laboratory analyses summary tables comparing results of the Trebilco Spring (Sample ID:Spring 1) with other surface water samples collected, including Piper and Durov water chemistry plots and a summary of major water types, are provided in **Tables 5 to 7**.

^{222}Rn is a radioactive gas produced by the decay of radium (^{226}Ra). In groundwater, radon activity originates from ^{226}Ra adsorbed on mineral surfaces in the aquifer with little contribution from dissolved ^{226}Ra. Natural ^{222}Rn is a very useful tracer because of its inert chemical behaviour, its elevated concentrations in groundwater, and its "lack of memory" (short half-life of 3.824 days). ^{222}Rn has been successfully used for assessing the discharge of groundwater streams (Cook, 2003).

The elevated presence (5.47 Becquerel/L (Bq/L)) of ^{222}Rn in the Trebilco spring sample compared with all other surface water samples collected during the field survey confirmed a groundwater source.

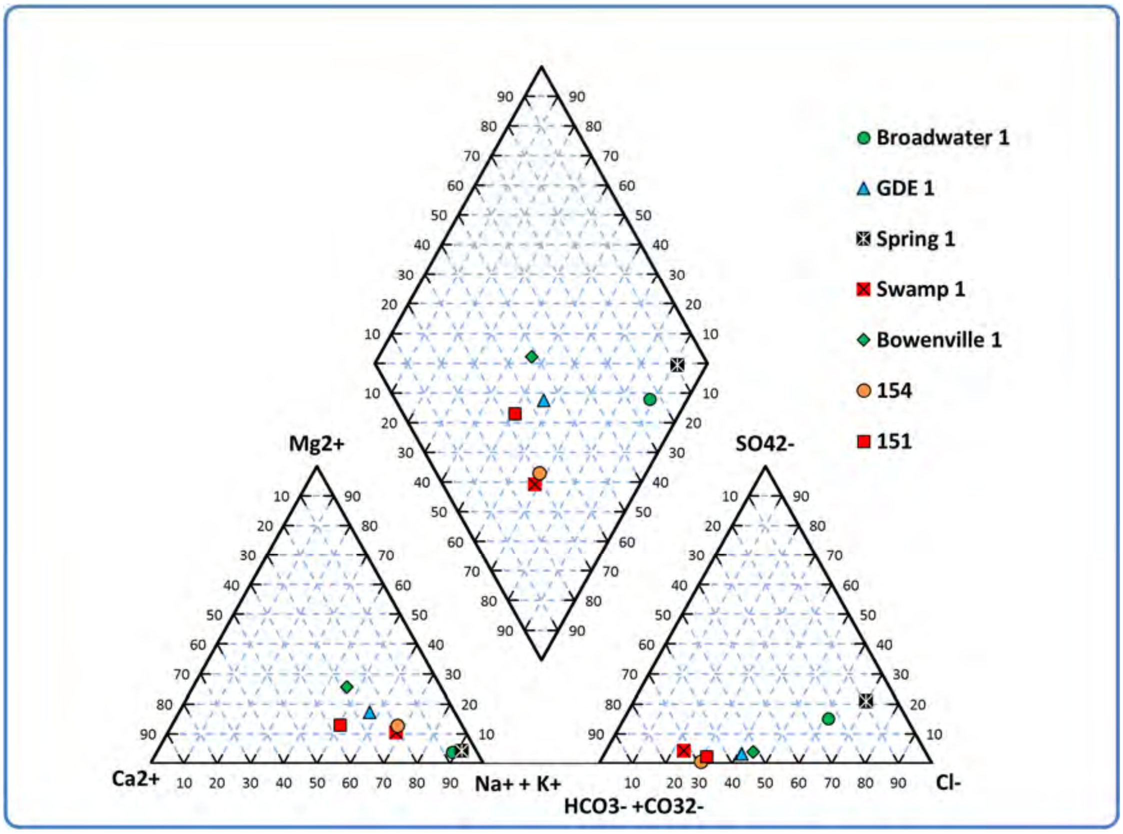
In addition, the dD and d18O values for Spring 1 are significantly lower than the other surface waters which could also indicate a groundwater influence due to low evaporative enrichment.

It should be noted that rainfall in the area needs to be factored into the interpretation. Therefore the assumption for this investigation is that all surface waters received the same amount of rainfall (within the same events).

As noted earlier in the report, significant rainfall occurred in the assessment area prior to both field visits and therefore the water chemistry results should be viewed as indicative of a wet period where the water chemistry characteristics of recent rainfall would likely significantly mask any contributions from groundwater sources. The water sample collected from the spring site was the only sample collected by "intercepting" groundwater directly from a seepage zone prior to mixing with the surface water body. Further sampling from a number of sites during a monitoring period which captures a representative selection of dry to wet conditions would be required to more adequately characterise water quality trends and groundwater/surface water interactions.

Table 5. Water Chemistry Summary Table.

Sub-Matrix			WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER
Sample Name			**Broadwater 1**	**GDE 1**	**Spring 1 (Trebilco)**	**Swamp 1**	**Bowenville 1**	**154**	**151**	**DUP**
Analyte			**29/11/2016 10:00**	**29/11/2016 13:30**	**30/11/2016 13:00**	**30/11/2016 14:30**	**1/12/2016 0:00**	**1/12/2016 0:00**	**1/12/2016 0:00**	**1/12/2016 0:00**
	Units	**Rep. LOR**	**EB1628281-001**	**EB1628281-002**	**EB1628373-001**	**EB1628373-002**	**EB1628486-001**	**EB1628486-002**	**EB1628486-003**	**EB1628486-004**
Total Dissolved Solids @180°C	mg/L	10	3570	366	146	144	681	146	310	305
Total Dissolved Solids (Calc.)	mg/L	1	251							
Bromide	mg/L	0.01	0.356	0.393	0.049	0.01	0.28	0.025	0.094	0.1
Iodide	mg/L	0.01	<0.010	<0.010	<0.010	<0.010	<0.100	<0.010	<0.020	<0.020
Hydroxide Alkalinity as CaCO3	mg/L	1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as CaCO3	mg/L	1	32	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as CaCO3	mg/L	1	28	149	4	34	245	48	163	163
Total Alkalinity as CaCO3	mg/L	1	60	149	4	34	245	48	163	163
Sulfate as SO4 2-	mg/L	1	18	9	9	2	18	<1	6	
Chloride	mg/L	1	73	110	30	11	211	21	76	79
Calcium	mg/L	1	6	31	1	4	59	6	42	41
Magnesium	mg/L	1	3	21	1	2	53	4	15	15
Sodium	mg/L	1	70	69	21	13	96	21	58	58
Potassium	mg/L	1	12	6	5	8	11	7	6	6
Fluoride	mg/L	0.1	0.1	0.2	<0.1	<0.1	0.2	<0.1	2.2	2.2
Nitrite + Nitrate as N	mg/L	0.01	0.02	<0.01	0.22	<0.01	<0.01	<0.01	0.02	
Total Kjeldahl Nitrogen as N	mg/L	0.1	5.7	1.3	1.7	2.1	0.6	1	7	
Total Nitrogen as N	mg/L	0.1	5.7	1.3	1.9	2.1	0.6	1	7	
Total Phosphorus as P	mg/L	0.01	1.19	0.21	0.12	0.27	0.16	0.05	0.69	
Total Anions	meq/L	0.01	3.82	6.31	1.13	0.99	11.3	1.55	5.55	5.63
Total Cations	meq/L	0.01	3.9	6.43	1.17	1.13	11.8	1.72	6.01	5.96
Ionic Balance	%	0.01	1.01	0.95			2.08		3.98	2.81
Dissolved Organic Carbon	mg/L	1	10	27	2	23	6	16	18	
Total Organic Carbon	mg/L	1	11	25	<1	22	6	16	21	
Radon 222	Bq/L	0.05	0.12	0.03	5.47	0.09	0.06	0.04	NA	
C13 Isotope	per mil VPDB	0.01	-7.27	-7.01	-17.27	-4.94	-8.65	-7.53	-9.89	
C13 Isotope Average	per mil VPDB	0.01	-7.05	-6.94	-17.43	-5	-8.41	-7.26	-9.68	
C13 Isotope Duplicate	per mil VPDB	0.01	-6.83	-6.88	-17.6	-5.05	-8.16	-6.98	-9.47	
Deuterium	VSMOW	0.1	44.88	-1.83	-35.79	34.53	3.46	33.28	11.65	
Oxygen-18	VSMOW	0.1	7.91	0.43	-5.93	7.18	1.22	8	1.75	
87/86Sr			0.70706175	0.705176055	0.708862487	0.706974465	0.705001784	0.707965931	0.708142436	
Sr - 2se			0.000004	0.000002	0.000005	0.000004	0.000003	0.000003	0.000003	
Sr - 2sd			0.000040	0.000034	0.000065	0.000051	0.000029	0.000042	0.000035	



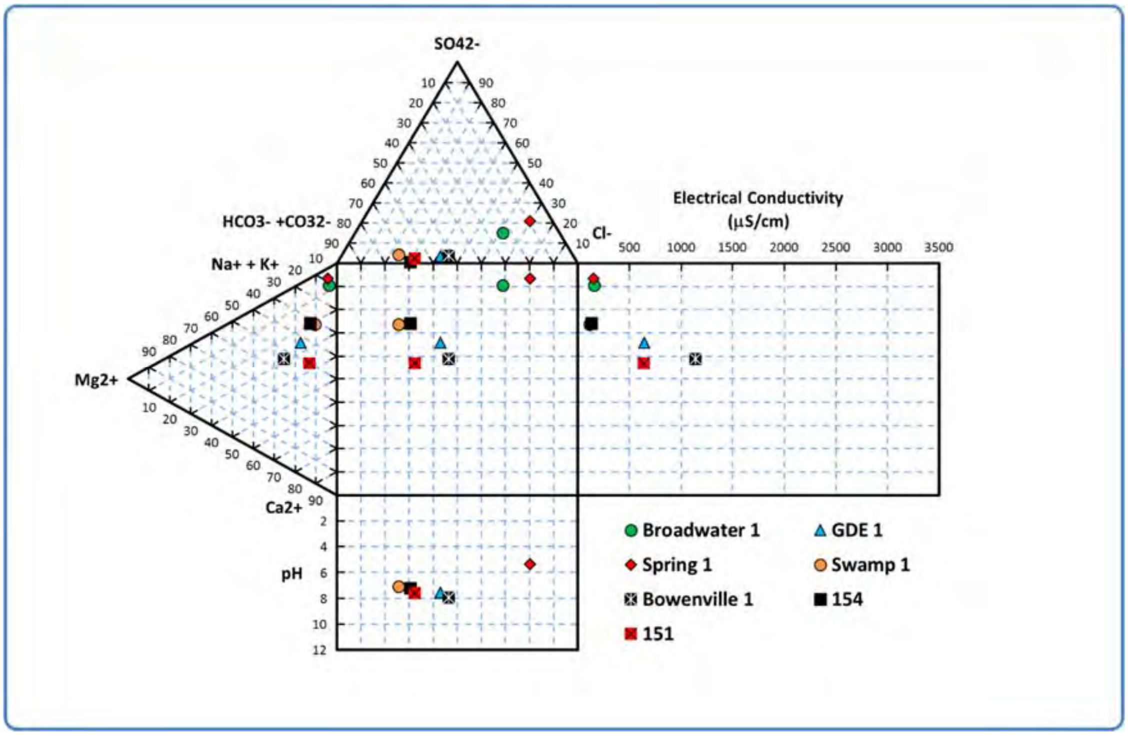


Table 6 Piper and Durov Water ChemistryPlots.

Table 7 Water chemistry major types.

Sample Name	HCO3-	SO42-	Cl	Ca	Mg	Na	K	Major water type
Broadwater 1	0.46	0.38	2.09	0.30	0.25	3.04	0.31	Na-Cl
GDE 1	2.44	0.19	3.14	1.55	1.75	3.00	0.15	Na-Cl
Spring 1	0.07	0.19	0.86	0.05	0.08	0.91	0.13	Na-Cl
Swamp 1	0.56	0.04	0.31	0.20	0.17	0.57	0.21	Na-HCO3-
Bowenville 1	4.02	0.38	6.03	2.95	4.42	4.17	0.28	Mg-Cl
154	0.79	0.01	0.60	0.30	0.33	0.91	0.18	Na-HCO3-
151	2.67	0.13	2.17	2.10	1.25	2.52	0.15	Na-HCO3-

The above observations and data have resulted in a preliminary conceptual site model for the spring (illustrated in Figure 10) which suggests that:

- Associated vegetation is groundwater dependent;
- Groundwater discharging at the spring is likely to be sourced from the adjacent permeable alluvial sand body;
- The mechanism for spring seepage is a steep hydraulic gradient from groundwater storage at a higher elevation, with the high point on the alluvial terrace immediately adjacent to the seepage site below;
- The adjacent alluvial sand body is a substantial local feature;
- Sources of recharge to the sand alluvium is likely to be direct rainfall recharge, as well as run-off from the surrounding lower permeability silty clay flats during, and for some period after, heavy and prolonged rainfall. Recharge to the alluvium would be significant at times of flooding where additional recharge gains may occur through connections to the Wambo creek and tributary system;
- Total groundwater storage in the connected sand body is likely to be considerable enough (on a local scale) for recharge to sustain seepage into the main pool and surrounding riparian features for extended periods.

The alternative possibility for the source of groundwater at the spring is upward discharge of artesian groundwater from an underlying bedrock aquifer into the overlying alluvial sands. Based on a review of CSG well completion reports and water bore logs it is considered likely that the shallowest underlying Surat Basin formation would be the Westbourne Formation. While the possibility of some artesian contribution cannot currently be completely dismissed, it is considered unlikely due to the spring water chemistry (low salinity which is inconsistent with Westbourne and other underlying GAB formations, and isotopic signature), lack of artesian flowing bores and other artesian springs in this part of the Surat Basin, and anecdotal evidence for historical changes in discharge rates.

Nearby GDE features

Other surrounding features of note in the Wambo Creek area, as shown on Figure 13, visited and described during the field survey (see Appendix D) included:

A shallow wetland (site 911) approximately one kilometre to the north of the spring, with discharge from the nearby Chinchilla Sand body sustaining a broad flat swampy wetland perched above a hard clay pan. Hand auguring confirmed the presence of the clay base to the wetland and a groundwater sample was collected for additional characterisation.

A “water table window pool” (site 910) was located approximately 2.5 kilometres to the south east of the spring. This pool was isolated from the nearby Wambo Creek channel and fringed by a well-developed open forest of *Angophora floribunda* and scattered *Eucalyptus tereticornis* in excellent health. The water level in the pool was approximately 2 m below the surrounding flood plain. Water was noted to be considerably clearer and deeper than water in surrounding pools and overland flow paths, and fish visible (possibly boney bream) suggesting the pool may have been sustained by a more permanent source of groundwater. Hand augering confirmed the presence of a deep sandy horizon overlying a sandy clay at a depth of 2.3mbgl, likely representing the base of the pond.

Very few groundwater bores were present in the area. Based on a review of DNRM Groundwater Bore Database information, those that existed typically tapped deeper GAB formations (Walloon Coal Measures and the Springbok Sandstones). Several shallower bores interpreted to have been drilled into and were tapping the Wambo Creek alluvium, and/or which had lithologies and standing water levels (RN# 16137, 61171, 119871, 160252, 42230193) were identified and can be summarised as follows:

- The drilled depths ranged from 12-17.7mbgl.
- Geology encountered included assorted clays, sands and gravels,
- Historical standing water levels ranged from 8.5 to 12.8mbgl.

These results and field observations of the geological and geomorphic setting suggest that the Wambo Creek alluvial system is a relatively broad but shallow assemblage of alluvium types associated with deposition of the current and former creek channels, possibly overprinted on an older (Tertiary) alluvium of Chinchilla Sands or equivalents. The Wambo Creek alluvium most resembles Type 1 Shallow GDE System depicted in Figure 14 discussed later in this section.

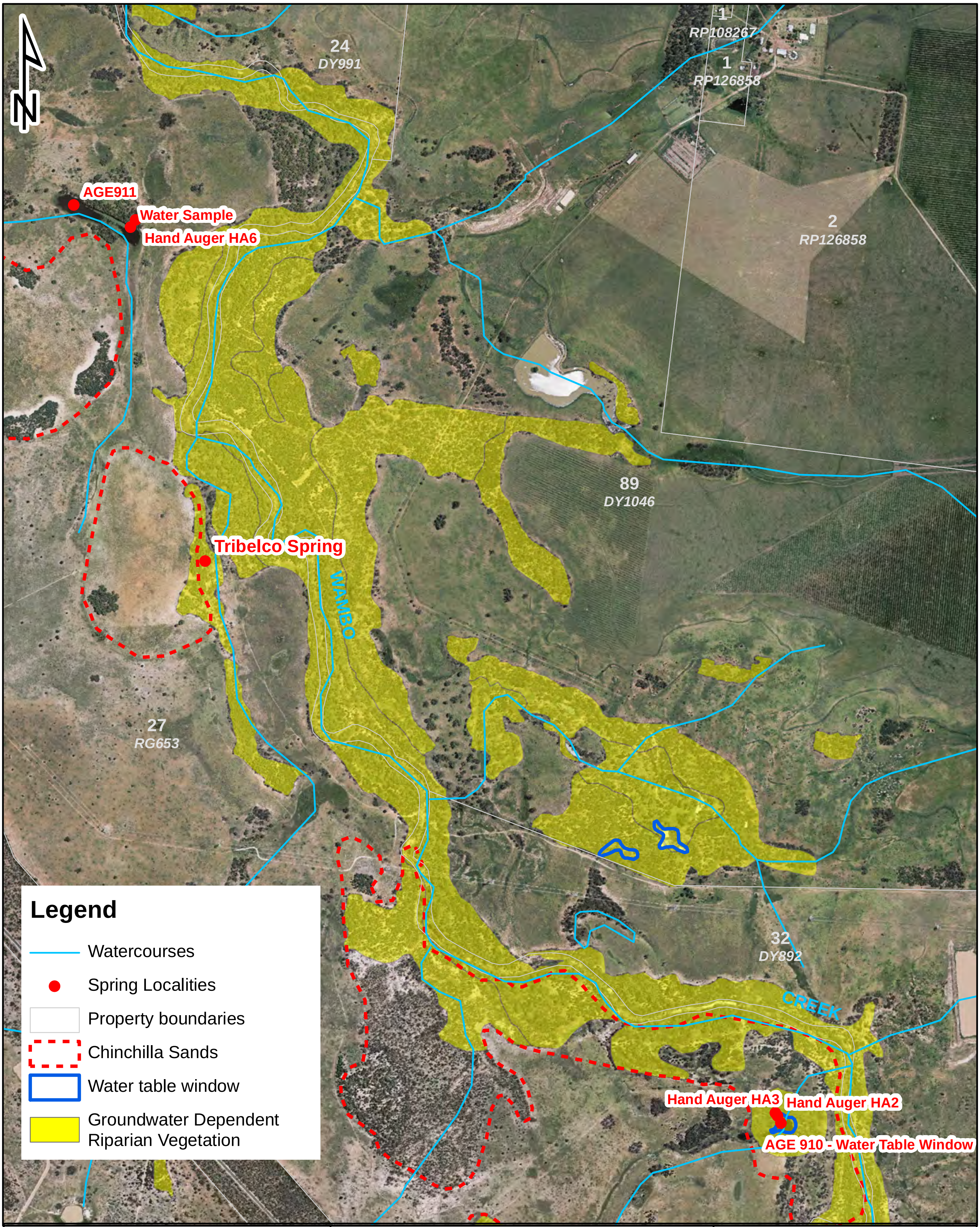


Figure 13. Features of Wambo Creek on the Tribelco property within the SGP study area

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Kilometers

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3.2.2 Wambo Spring

Access to this spring was requested but not granted by the landholder during the field assessment. Spring complex 584 (Wambo Creek) is located to the west of the project development area and consists of several spring vents and seep areas. The springs emerge from the western bank of Wambo Creek. Previous field and desktop surveys suggested that the spring vent is sourced from a local flow system through sediments (shallow alluvial sediments or Orallo Formation) at outcrop, rather than discharge from deeper underlying GAB formations (KCB, 2012). This assessment was based on the following:

- Low salinity (231 μS/cm) which is inconsistent with Surat Basin aquifers;
- Anecdotal evidence that the vent reacts to climatic patterns, which is inconsistent with a deeper confined artesian aquifer source.
- Dominant groundwater age of modern water, which is inconsistent with a deeper confined artesian aquifer source.
- Possible anthropogenic influence on groundwater with elevated nitrate levels above background, a common indicator of impact from agricultural activity on local scale flow systems.
- Lack of artesian aquifers in the upper GAB formations in the area.

We consider that the source is unlikely to be the Orallo formation, which does not outcrop in the area. The shallow geology of the area includes alluvium (Chinchilla Sands and recent alluvium associated with Wambo Creek) directly overlying the Westbourne Formation.

Spring complex 584 was assessed during the Queensland Herbarium and KCB 2011 field surveys, and has been assigned a conservation ranking of 3, noting that no EPBC listed communities or EPBC / NCA listed species were identified at the site by the Queensland Herbarium. Spring Complex 584 has been assigned to QGC as the responsible tenure holder under the UWIR.

3.2.3 Bowenville Spring

The Bowenville Spring site (Listed Spring Complex 585) located off tenement (approximately 15km to the east) is the closest listed spring site to Arrow's tenements. This site is considered likely to be a watercourse spring (Oakey Creek) associated with underlying Main Range basalts, and could also represent a source of recharge to the Condamine Alluvium (as per Lane 1979) or Walloon Coal Measures (see below).

Vegetation

The vegetation associated with the site is formed by an open forest dominated by river red gum (*Eucalyptus camaldulensis*) with a thick shrub layer of river myall (*Acacia stenophylla*). Ground layers are mostly native, comprising aquatic sedges *Baumea rubignosa, Carex appressa, Juncus continuus, Cyperus sp.,* and thickets of *Panicum decompositum* on the creek margins. Although demonstrating good health, the vegetation has been reduced to a narrow margin directly adjacent to the drainage channel of Oakey Creek.

Hydrology, Hydrogeology and Geomorphology

Oakey Creek at the Bowenville Reserve was flowing off an elevated and gently undulating weathered basalt plateau above the Condamine Floodplain. During the field survey water was noted to be clearer and flowing at a significantly greater rate than the nearby reaches of the Condamine River. It should be noted that Oakey Creek receives treated effluent from the Toowoomba Sewage Treatment plant. There was no clear evidence for groundwater contributions within the surface water quality sampling results (Tables 5-7).

Photograph 5. Riparian vegetation associated with Oakey Creek in the vicinity of Bowenville Spring.

The basalt geology (Main Range Volcanics) was confirmed through a review of drilling logs from nearby groundwater bores, soil observations and observations of outcrop at a nearby quarry. Drilling logs (eg RN#87486 & 87935) suggests that the volcanics (and possibly alluvium) overly the Walloon Coal Measures at relatively shallow depths (coal recorded at 27m in RN#87935). Historical standing water levels ranged from 13.7 to 17.6mbgl. High flow rates (10 litres per second) recorded on drilling logs during testing of the Walloon Coal Measures bores indicates that the underlying coal measures may be highly permeable. If high basalt/WCM connectivity exists, this area of contact may represent a recharge area for the Walloon Coal Measures.

3.3 Potential Subsurface (Terrestrial Vegetation) GDEs Identified

The definition of a Subsurface GDE (previously described in **Section 1.5**) includes all vegetation that either permanently or seasonally utilises groundwater to satisfy its water requirements. The primary considerations in determining potential for groundwater usage of plants are:

1. Depth to groundwater with DNRM (2013) considering 20mbgl as the general threshold depth below which tree roots / groundwater interaction is unlikely to occur.
2. Rooting depth and architecture, or the ability of plants to tap deep water sources based largely on vegetation composition or regional ecosystem.
3. Site history including prior alterations to the groundwater table.

Potential subsurface GDEs identified in the SGP study during this assessment are:

1. The Condamine River and other mature vegetation associated with the CRA .
2. Numerous streams across the broader study area are considered likely to meet the definition of a Subsurface (or Terrestrial Vegetation) GDE. These streams, including smaller tributaries of the Condamine River comprise riparian corridor GDE vegetation which is localised to the immediate vicinity of the stream channel and associated alluvium. These included significant reaches of the following waterways and their tributary systems:
    c. Wilkie Creek
    d. Wambo Creek

        e. Kogan Creek
        f. Braemar Creek
        g. Dogwood Creek
3. Long Swamp.
4. Lake Broadwater

Characteristic features, trends and condition of these features are identified in the following sections and confirmed during site inspection at various locations (see previous Table 3). Pictorial ecological/ hydrogeological conceptualisations of the interpreted major sub-surface GDE types encountered during the survey are shown in Figure 14 which includes:

1. Shallow alluvial GDE systems.
2. Bedrock alluvial GDE systems.
3. Deep alluvial GDE systems.
4. Shallow drainage sub-surface GDE system.
5. Volcanics subsurface GDE system.

A summary of field survey data gathered for GDEs throughout the assessment is provided in Appendix F with the location of field survey sites shown in Figure 15.

It should be noted that in the 5 GDE Risk areas (see Figure 1), alluvial systems are relatively poorly developed and associated groundwater tables would be localised shallow alluvium systems and bedrock alluvium systems (see cross section 1 and cross section 2 below).

Figure 14. GDE systems identified in the assessment area.

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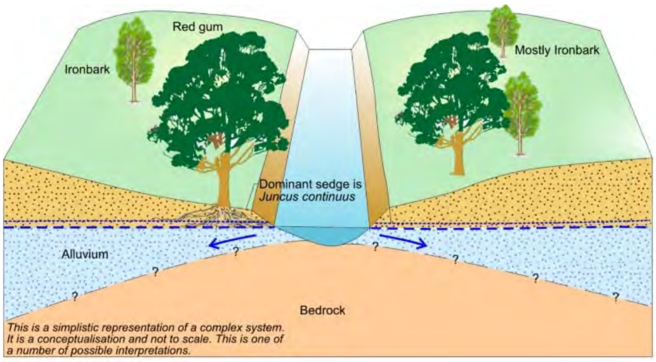


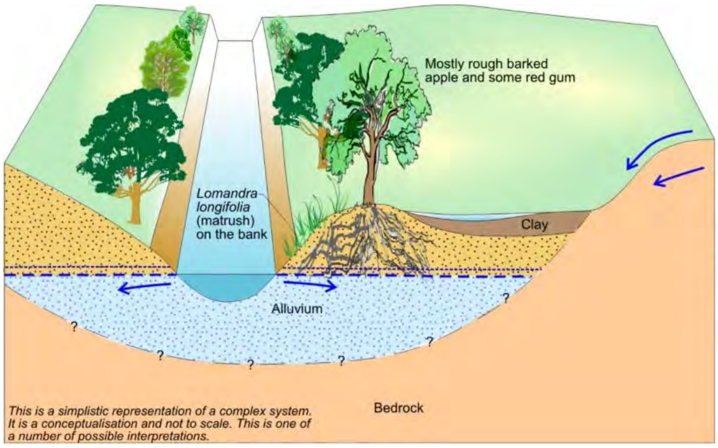
This is a simplistic representation of a complex system. It is a conceptualisation and not to scale. This is one of a number of possible interpretations.

①

SHALLOW ALLUVIUM SYSTEM

- Shallow depth to bedrock
- Broad shallow alluvium
- Shallow incisions
- Sometimes bedrock base to pools and banks

e.g. Kogan Creek
Wilkie Creek
Braemar Creek



This is a simplistic representation of a complex system. It is a conceptualisation and not to scale. This is one of a number of possible interpretations.

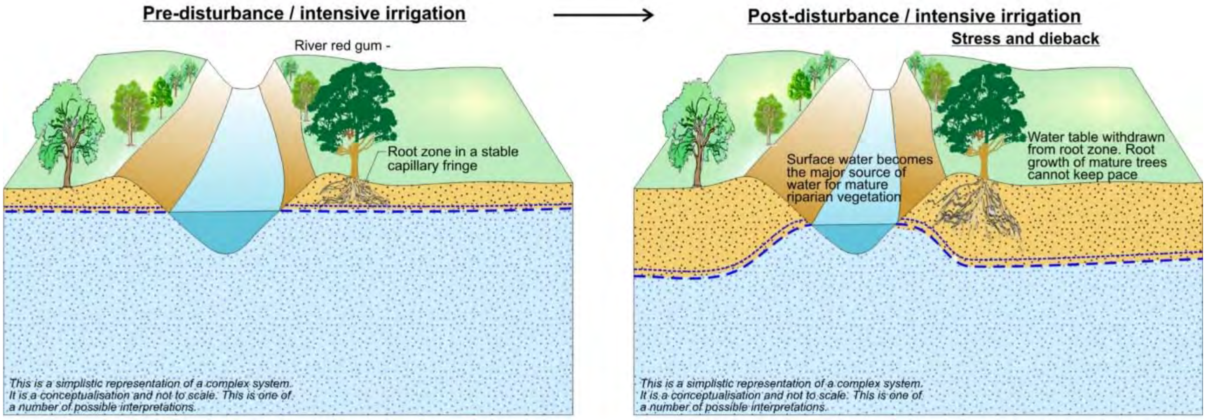
②

BEDROCK ALLUVIUM SYSTEM

- Shallow and narrow alluvium extent localised around stream channel
- Steeply incised into bedrock

e.g. Dogwood Creek (site 154)

③ DEEP ALLUVIUM SYSTEM e.g. Condamine River

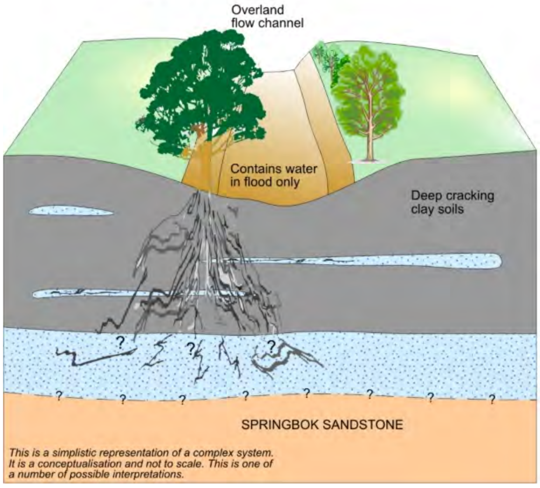


'Stable' system e.g. Site GDE4 upstream from Chinchilla Weir

'Losing' system e.g. near Site GDE3

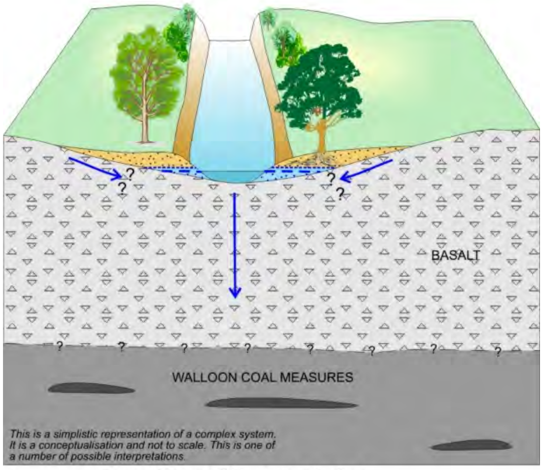
④ SHALLOW DRAINAGE SUBSURFACE GDE SYSTEM

e.g. Long Swamp



⑤ VOLCANICS SUBSURFACE GDE SYSTEM

e.g. Bowenville Spring
Oaky Creek



- **Permeable basalt flow over alluvium and / or bedrock**
- **'Perched' creek system minimal incision into basalt**

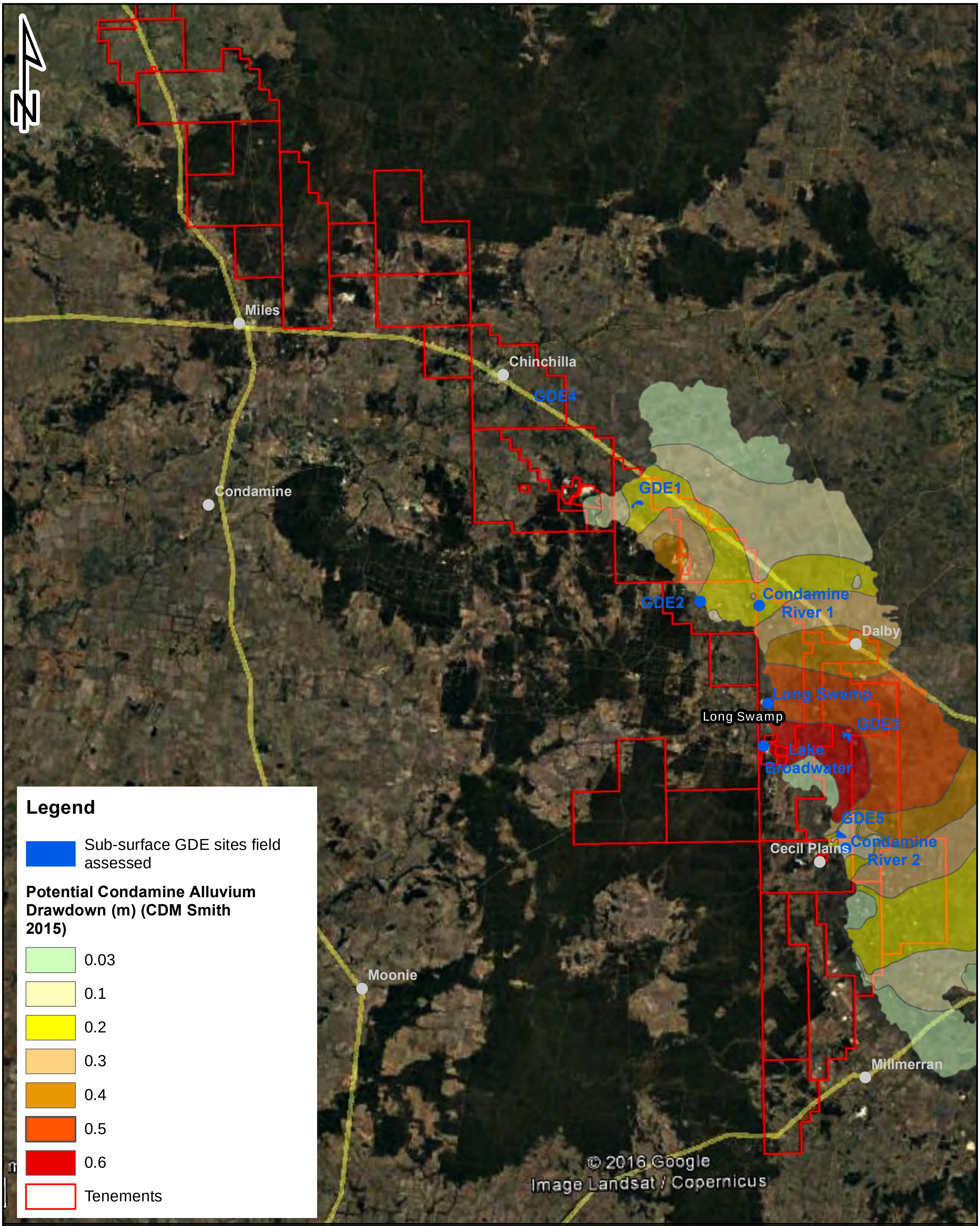


Figure 15. Locality of Specific Sub-surface GDE sites assessed during field assessment.

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0	16	32	48	64	Kilometers

Scale 1:893,747 **Drawn By** DG **Date** 05-Feb-17 A4

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3.3.1 Condamine River and associated CRA

Shallow Geology and Hydrogeology of the Condamine River Alluvium

This report does not intend to reproduce, as context, the large amount of hydrogeological conceptualisation previously undertaken by others. Much of this previous work is summarised in OGIA (2016a & b), Coffey (2012, 2013), CDM Smith (2016), and Dafny and Silburne (2013). The focus of information presented here is specifically on features and processes relevant to assessing groundwater/surface water interactions and potentially dependent ecosystems in the Arrow study area.

The Condamine Plain is an extensive area of fertile alluvium subject to intensive agricultural activity reliant on groundwater extraction. Historical reports suggest that property homesteads along the Condamine Plain pumped groundwater for domestic use as far back as 1946, from depths shallower than 10 mbgl. The Condamine Plain is known to be a heterogeneous alluvial formation with hydraulic properties that are spatially and vertically variable (Dafny and Silburne 2013). The CRA aquifer is typically conceptualised and modelled as a single vertically and laterally continuous and connected aquifer. Shallower “perched” aquifers which are located higher in the CRA geological profile than the regional CRA aquifer are known to occur. This further complicates the assessment and interpretation of groundwater level data.

However, analysis of baseline bore data in the vicinity of visited potential GDE areas within Arrow tenements indicates the presence of a relatively consistent sandy horizon sitting below the upper layer of heavy clays at depths of typically between 7 and 12 mbgl (most likely aligned to ‘Layer A’ in Barnett and Muller (2008), with a deeper coarse sandy horizon occurring from depths of around 18m. The upper sandy horizons are considered relatively permeable and would function as aquifers which have historically been heavily exploited for their groundwater resources.

The Condamine River is considered a major source of low salinity groundwater recharge to the Condamine alluvial aquifer, although the rate of recharge is dependent on lithology. Higher recharge rates occur along sandy river banks than along clayey ones, and the occurrence of sandy sediments near the surface correlate to areas where groundwater recharge to underlying alluvial aquifers is likely to be substantial (Dafny and Silburne 2013). It is noted during the field survey that the depth of incision from the high bank of the Condamine River to water level was consistently in the range of 7 – 9mbgl, corresponding with the general position of the upper sandy horizon (Layer A) in the Condamine alluvium. Hence, it is highly probable that the Condamine River contributes significantly to seasonal recharge of this shallow aquifer, particularly during high flow events when recharge would be greatest (Lane, 1979). Percolation of river water down to sandy interbeds at lower stratigraphic levels is also highly probable.

Mapping of Vegetation in Relation to SWL thresholds

Two thresholds critical to the assessment of groundwater dependence of vegetation associated with the CRA (both present and past) were described in in Section 1.3.4 being:

- SWL falling below 12mbgl as an upper threshold below which vegetation impacts might be initiated.
- SWL falling below 18mgbl where vegetation impacts are imminent or are occurring.

Hence critical to the assessment of groundwater dependence is an analysis of SWLs (both current and historical level) to determine the likelihood that tree roots intersect the groundwater table. SWLs for landholder boreholes within the area of the CRA are shown in Figure 16, which also includes SWLs derived from Arrow’s landholder bore baseline assessments from selected properties.

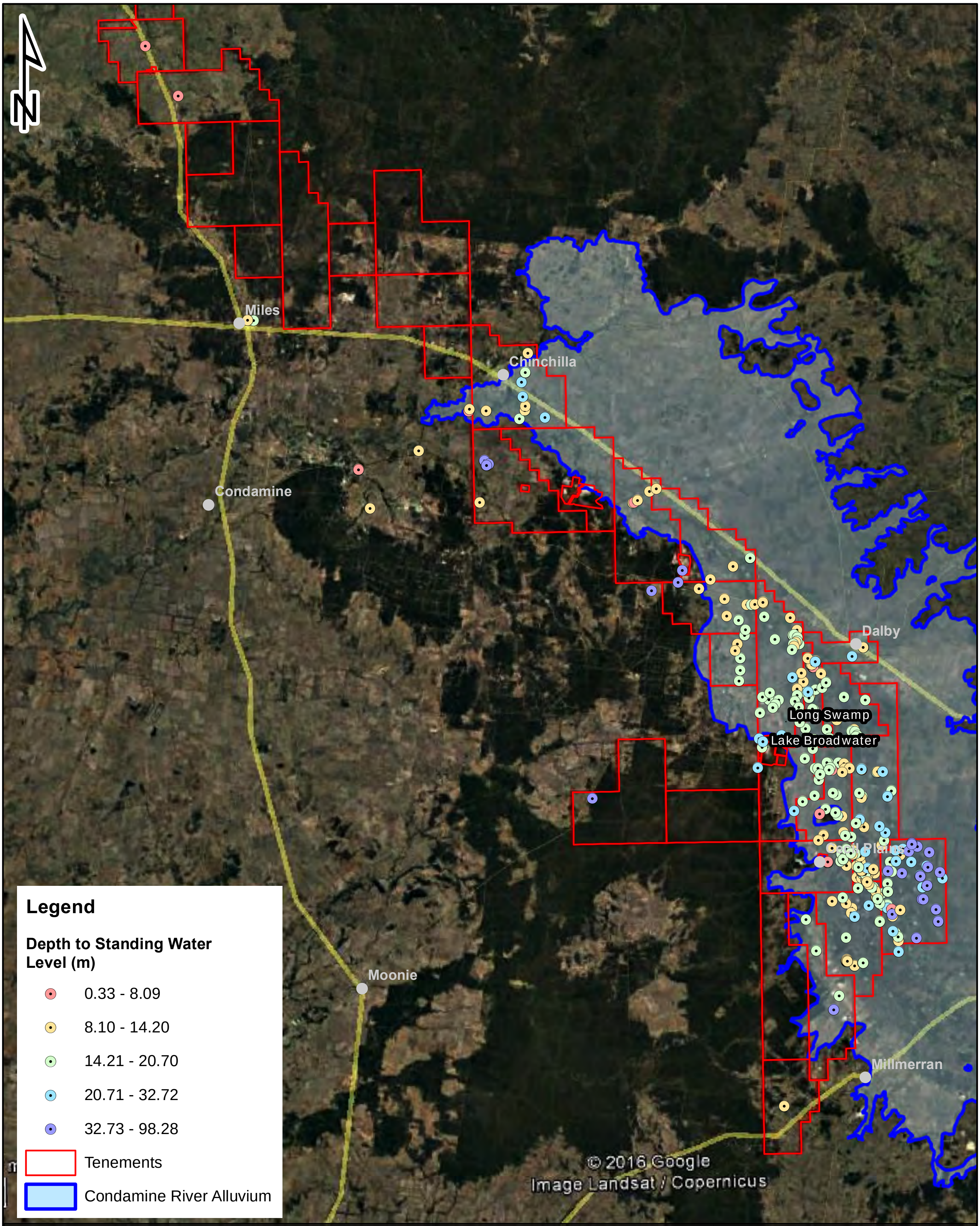

Figure 16. SWLs from NGIS bores and selected well baseline assessments

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Based on this information, in conjunction with detailed vegetation mapping completed as a component of the SREIS (3d Environmental 2013), Sub-surface GDE status maps were produced over areas of the CRA within Arrow's tenements to indicate the status of vegetation with respect to groundwater threshold levels. This information is spatially represented in Figure 17 whilst Figure 18 presents mapping of vegetation on the CRA that falls outside tenement areas as well as several smaller streams and tributaries in tenement areas that are not associated with the CRA. These minor streams and catchments are discussed further in Section 3.3.2. Rules applied during the mapping process are shown in Table 8 for those regional ecosystems associated with the CRA. Regional ecosystems that were considered unlikely to be GDEs, particularly those dominated by Ironbark, have not been considered in the mapping assessment as they are not associated with the CRA.

Additional Uncertainty Regarding Tree Rooting Depth and Response

It should also be noted that historically prior to broad-scale groundwater extraction, the Condamine Alluvium, would have presented a relatively consistent, stable and well defined SWL with an upper surface at around 10m - 15m maximum groundwater depth (based on historical groundwater bore SWLs and current SWLs in low groundwater extraction areas). This would have set the rooting depth of trees on the upper alluvial terrace at around this level, with no impetus for trees to push roots below the zone of permanent saturation as tree root growth is generally arrested in the zone between the capillary fringe and saturated zone (Eamus el al 2006). Trees that have matured during periods of high water availability may be less tolerant of water stress than those which have survived water deficit as they were growing, indicating a limit to further adaptation in older trees (Kozlowski and Pallardy 2002). Hence mature trees may be particularly prone to the impacts of groundwater drawdown due to an inability to adapt. The capacity of trees to adapt to a falling water table is also influenced heavily by soil type. Heavy clay is highly resistant to root penetration due the tightness of the grain and compaction which increases with depth. Alternatively, coarse sands or gravels dry very rapidly and there is considerable risk of a hydraulic disconnect developing between root matter and a retreating groundwater table. Roots will not be able to respond with downward growth if water has evacuated soil pore spaces and in very coarse sand or gravel, the capillary fringe might only be a few centimetres above the saturated zone.

For Regional Ecosystem 11.3.25, assessment is influenced by topographic position within confines of the river channel incision, generally sitting at seven to nine metres below the level of the broader floodplain where the majority of groundwater bores are located meaning rooting zones are generally closer to groundwater table than other ecosystems. It does not consider the general maturity of the trees in this ecosystem and their potential inability to respond to rapidly falling water tables through increased root growth (see Section 1.3.3).

Table 8. Likelihood of groundwater dependency for regional ecosystems associated with the Condamine River and associated CRA.

Regional Ecosystem	Depth to Groundwater (SWL in mbgl)		
	<12	>12 to <18	>18
11.3.2	Groundwater Interaction Likely	Groundwater Interaction Possible (Threshold Zone)	Groundwater Interaction Unlikely
11.3.3	Groundwater Interaction Likely	Groundwater Interaction Possible (Threshold Zone)	Groundwater Interaction Unlikely
11.3.4	Groundwater Interaction Likely	Groundwater Interaction Possible (Threshold Zone)	Groundwater Interaction Unlikely
11.3.14	Groundwater Interaction Likely	Groundwater Interaction Possible (Threshold Zone)	Groundwater Interaction Unlikely
11.3.17	Groundwater Interaction Likely	Groundwater Interaction Possible (Threshold Zone)	Groundwater Interaction Unlikely
11.3.25	Groundwater Interaction Likely	Groundwater Interaction Likely	Groundwater Interaction Possible (Threshold Zone)
11.3.27	Groundwater Interaction Likely	Groundwater Interaction Possible (Threshold Zone)	Groundwater Interaction Unlikely

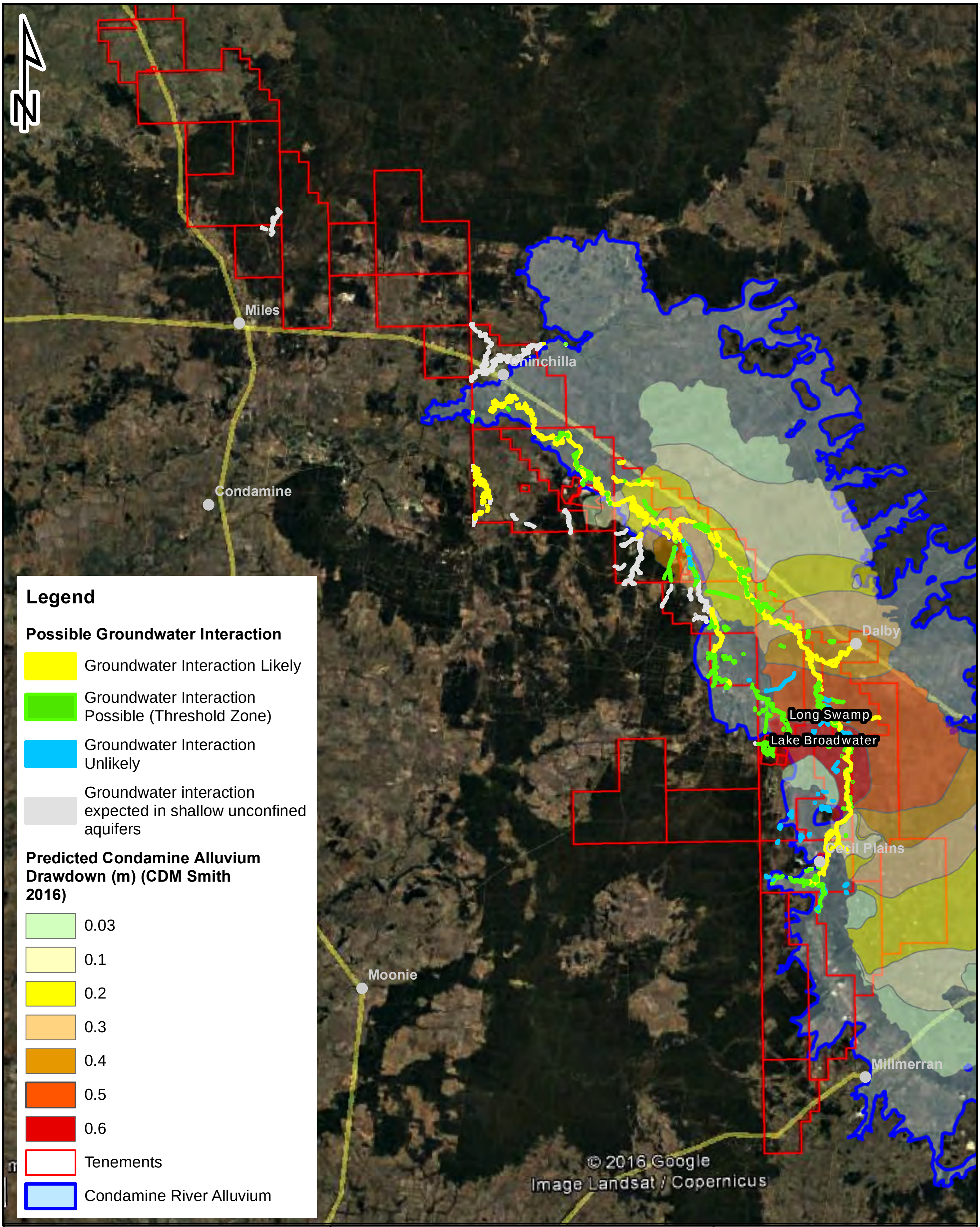

Figure 17. Status of Sub-surface GDEs on the CRA in relation to groundwater level thresholds.

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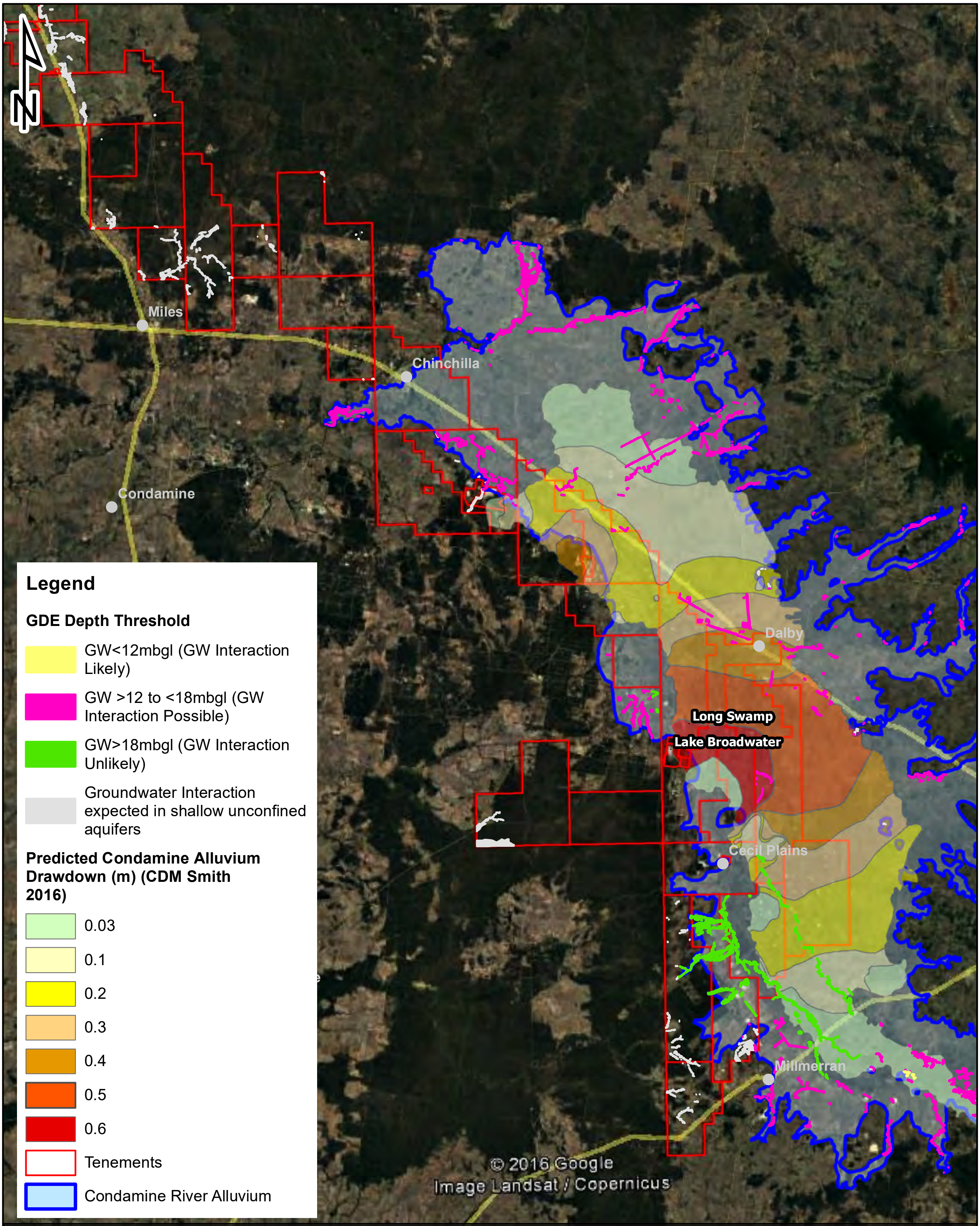

Figure 18. Location of streams with potential to host Sub-surface GDEs outside area of detailed vegetation mapping.

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0 16 32 48 64
Kilometers

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Historical Trends in SWL

Well baseline assessments completed by Arrow Energy provided critical information to allow assessment of historical trends in groundwater table movement, and assist interpretation of trends in vegetation response and condition. SWL hydrographs (Figure 19) over the period from bore drilling to recent Arrow baseline assessment for the majority of CRA groundwater bores assessed as part of this program indicates a clear background decline in groundwater levels. This declining trend is most likely due mostly to groundwater abstraction as well as harvesting of surface water and overland flow (reduction in natural recharge rates). This has resulted in a general fall in SWLs across most of the study area to below the lower root depth threshold zone where severe decline in vegetation condition would be expected. These findings are consistent with those of Kath et al (2014), Reardon Smith (2011) and Dafny and Silburne (2014) which all identify significant declines in groundwater levels across the CRA prior to CSG activities.

The one hydrograph that does not show a declining trend is possibly related to an error with respect to measurement or recording the original SWL measured during drilling (or an error in the recent baseline measurement). The DNRM Groundwater Database has been noted to contain some unverified and erroneous data. Another possibility is that the first SWL was measured after or during pumping.

It is noted that heaviest drawdown in the CRA aquifer occurs well to the east of the Condamine River, mostly outside of Arrow's tenements, with groundwater table lower by approximately 25mbgl compared with the un-exploited period (Daphy and Silburn, 2013). Drawdown in the vicinity of Arrows operations is by comparison much more moderate. This moderation in drawdown is due to lower levels of groundwater extraction in the thinning western edge of the Condamine Alluvium. As an example, several wells (eg RN 24332, 30670) in the vicinity of Long Swamp had SWLs measured around 15mgbl below ground survface in the 1960s and current water levels show relatively minimal change (SWL of 16 to 18mbgl) when compared with drawdown trends elsewhere in the CRA. DNRM monitoring bore 42230155 located in Long Swamp has recorded a clear but relatively modest decline in SWL from 16.01mbgl in 1965 to 18.68mbgl in Jan 2017. It is therefore surmised that the declining trends noted in CRA groundwater levels may be more pronounced further east towards the CRA depocentre.

It is likely that declines in SWL have 'disconnected' deep rooted riparian vegetation from the groundwater table along some, or possibly large areas of the Condamine River and its associated alluvium, leading to declines in the health of associated riparian vegetation (see section below). This scenario is indicated in Figure 20.

Vegetation Condition

It is acknowledged that most of the potential GDE vegetation assessed is located on riparian corridors and floodplains associated with ephemeral systems with significant seasonal variability in surface and groundwater availability. This will result in some natural level of vegetation stress and variability in condition. Vegetation condition is variable along the length of the Condamine River, influenced in part by associated land management and also by topographic position. A few general observations are noted below:

1. Vegetation associated with the upper flood terrace, sitting typically at 7 – 9mbgl above the level of the river incision is typically heavily degraded with loss of foliage and a large proportion of senescing trees.
2. Vegetation within the confines of the channel incisions (typically RE11.3.25 dominated by river red gum) typically demonstrated better condition, due to potential for these habitats to access water proximal to surface pools. There is still considerable evidence of canopy senescence in mature trees which may be influenced by a number of factors including historic groundwater drawdown and changes to surface flow regimes.
3. Where riparian vegetation intersects shallow groundwater tables above the upper threshold level (ie <12m SWL), condition of mature canopy trees tends to improve. Deeper rooted vegetation in these

areas displayed increased foliage cover and a reduced proportion of senescing canopy trees. Field inspected GDE sites GDE4, GDE1 and GDE2 all demonstrate riparian vegetation in good to moderate condition.

In some reaches, typically towards the Condamine Alluvium central areas where the alluvium thickens and non-CSG groundwater extraction activities are more intensive, GDE vegetation was typically stressed away from the immediate river channel and permanent or deeper pools. In these areas, the root architecture of trees along the river channel seemed to be laterally spreading for harvesting of shallow groundwater in the capillary zone around the channel and pools, a typical feature of *Eucalyptus camaldulensis* described by Mensforth (1994). Vegetation above and set back away from the river channel on the flood plain terraces typically showed signs of stress. An example of this was GDE 3 located in a conservation reserve where 50% of the mature remnant vegetation on the flood plain terraces were heavily stressed or dead, while vegetation within the river channel showed some signs of stress but was largely intact.

Within the south-western margins of the Condamine River Floodplain, the alluvium forms an increasingly shallow wedge over the underlying up-dipping consolidated Jurassic bedrock and ultimately pinches out against the low colluvium covered slopes of the Springbok Sandstone and Westbourne formations. At some locations (eg GDE1) where the current channel of the Condamine River meanders close to the thinning alluvium “pinch-out” and overlies relatively shallow Condamine alluvium, or incises through to underlying bedrock, there is minimal extraction of groundwater from the Condamine alluvium (sequence is too thin for high extraction rates), and GDE vegetation appears to be healthy. Riparian GDE vegetation was also noted to be in good health south of Chinchilla where the alluvium thins and consequently there is minimal extraction of groundwater and there is a permanent back up of surface water in the Condamine River above the Chinchilla Weir (as at site GDE4).

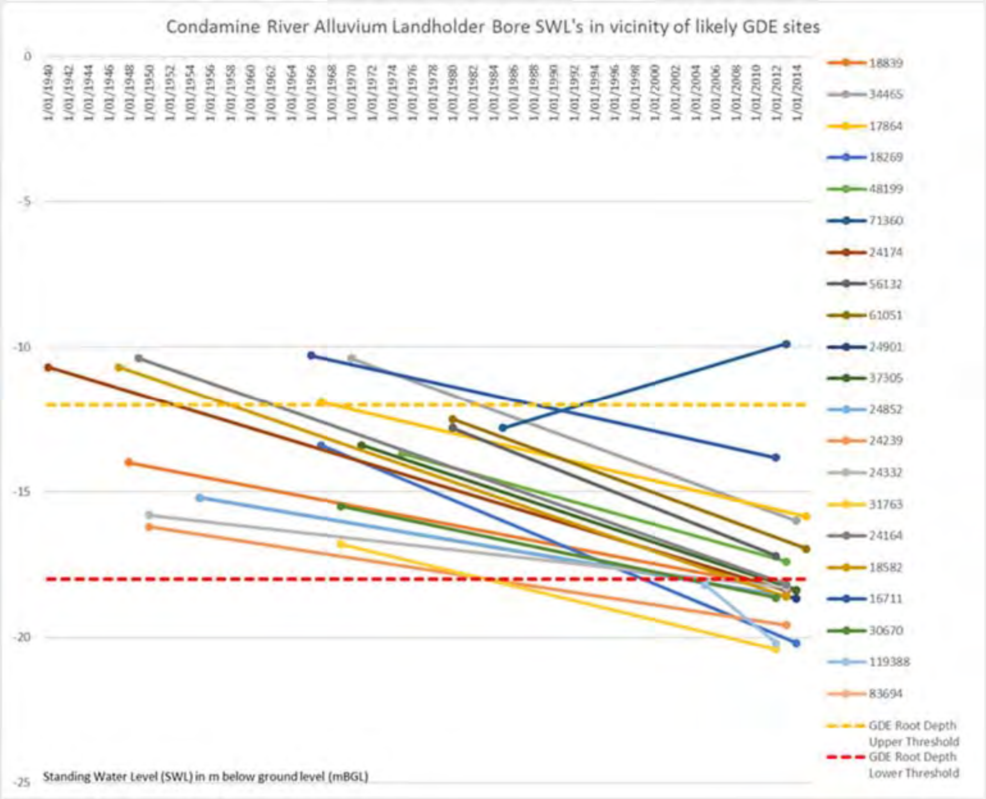


Figure 19. Hydrographs produced from historical and recent Arrow baseline bore assessments shows declines in SWL relative to vegetation response thresholds.

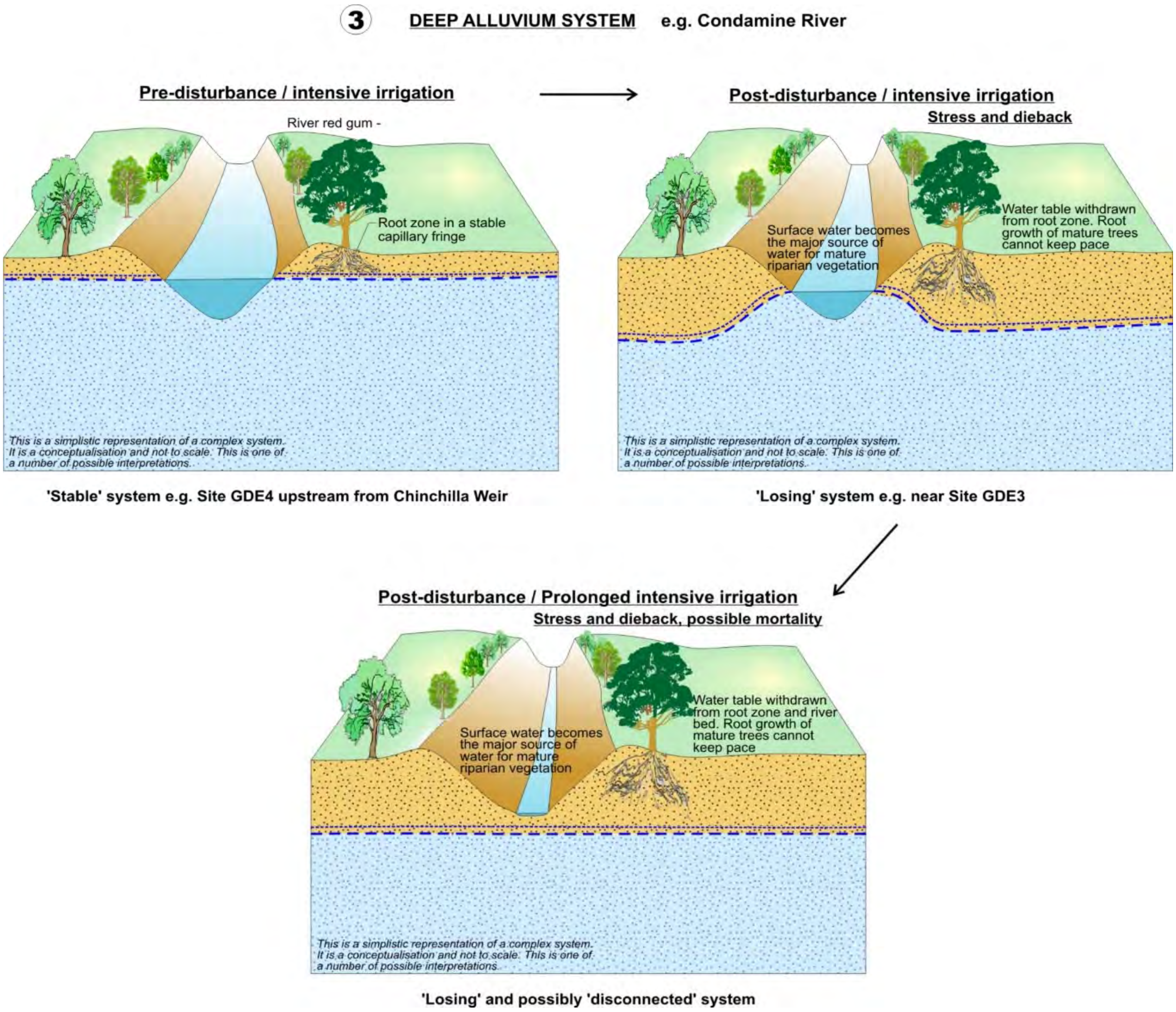


Figure 20. Scenario for loss of connectivity between deep rooted riparian vegetation and groundwater.

Photograph 6. Degraded floodplain vegetation (RE11.3.2) on the upper floodplain terrace at site GDE3 with evidence of senescence (SWL 19.8mbgl).

Photograph 7. River red gum on the banks of the Condamine River at GDE5 showing signs of stress with foliage loss (SWL 13.2 mbgl).

Photograph 8. Riparian vegetation in good condition at GDE 4 (SWL at 8.6mbgl)

Photograph 9. Riparian vegetation in good condition at GDE 1 (SWL at 5.6mbgl).

3.3.2 Watercourses and drainage lines not associated with CRA

Numerous watercourses and ephemeral streams intersect the SGP assessment area which all have potential to host shallow groundwater tables associated with disconnected alluvial deposits. The extent of these watercourses in the study area has previously been shown in **Figure 18** which is derived from GDE risk mapping produced by DSITIA (2015). General characteristics of the major streams are described briefly below. Similar to those within the CRA, regional ecosystems that are likely to represent GDEs in these ephemeral watercourses include REs 11.3.14, 11.3.4 and 11.3.25.

Wambo Creek

Vegetation: Riparian vegetation associated with Wambo Creek is typically formed by a broad, well-developed fringe of open forest dominated by rough-barked apple (RE11.3.14) with riparian forest of red gum (RE11.3.25) on the immediate stream channels and lower terraces. Ground covers generally comprise native grasses.

Geology and Hydrology: The creek in this locality is incised into a relatively broad flat of clayey river alluvium with lenses of sand forming low surface rises across the floodplain surface, and occasional deeper sandy profiles adjacent to the creek margins. The features of Wambo Creek within Arrow tenements have been previously described in **Section 3.2.2** (**Figures 11 and 13**) with the associated Tribelco Spring and other features noted in the vicinity. Some examples of these features are shown in the photographs below.

Photograph 10. Permanent lagoon identified as an expression of a shallow groundwater table.

Photograph 11. Riparian vegetation on Wambo Creek representing a healthy example of a Subsurface (Vegetation) GDE.

Wilkie Creek, Braemar Creek, Kogan, Dogwood Creek and associated tributaries of the Condamine River

Vegetation: Vegetation on these streams varies in response to local geomorphology although is most typically dominated by red gum on the stream margins (RE11.3.25) variably fringed by open forest of poplar box (RE11.3.2), rough barked apple and smooth barked apple (RE11.3.14) on localised channel overflows. Ground covers generally comprise native grasses.

Geology and Hydrology: In the Arrow Energy tenement study areas, most of the tributary systems typically meander through the low colluvial slopes of the Westbourne and Springbok Sandstone Formations before flowing out onto the southern margins of the Condamine River floodplain. Outside of the CRA a lack of groundwater dependent vegetation away from the immediate riparian corridor suggests an absence of shallow permanent soil moisture and alluvium-hosted groundwater.

Except for a considerable length of Wilkie Creek which is associated with the CRA, these tributary streams are variably incised into weathered sediments of the Kumbarilla Beds with thin discontinuous deposits of associated riverine alluvium. This alluvium will seasonally host groundwater and associated riparian vegetation and warrant recognition as subsurface (terrestrial vegetation) GDEs. As previously shown in Figure 14, aquifers that support “Shallow” and “Bedrock GDE” types are considered to be typically poorly connected hydraulically to the underlying Jurassic aquifers which may be subject to depressurisation during CSG production. In most cases these ecosystems are considered to be dependent on an aquifer hosted in the unconsolidated alluvium rather than the underlying bedrock.

In many cases underlying bedrock was noted to form a low permeability base to pools which were noted from air photos to hold water for extended periods. Deeper GAB aquifer standing water levels are typically well below the base of the alluvium. Any connection is likely to be associated with a deep “wetting front” where, in areas of reasonable bedrock permeability, the shallow “losing” alluvial systems can provide an important source of downward percolating recharge water to underling GAB formations.

	
Photograph 12. Upper Wilkie Creek with associated narrow band of sandy alluvium (SWL at 8.6mbgl)	**Photograph 13.** Channel overflow on Dogwood Creek (Site 154) with narrow band of alluvium, incised into Springbok SSt

3.3.3 Long Swamp

Long Swamp is a sinuous hydrological feature (overland flow path) that flows across the Condamine Alluvium in a north-westerly direction to the east and north of Lake Broadwater, before joining with Wilkie Creek to the west. The feature occupies a broad depression with the central portion formed by heavy clay. Surface water is present seasonally and following dry spells, the associated vertosol soils form deep hummocks and cracks. There was no flow, nor significant pooled water within Long swamp during the field visits, despite heavy recent rains. These observations together with the observations of deep, open cracks in the central swamp channel soil surface confirmed that the feature is only active during flooding. The features of Long Swamp are indicated in Figure 21.

Vegetation

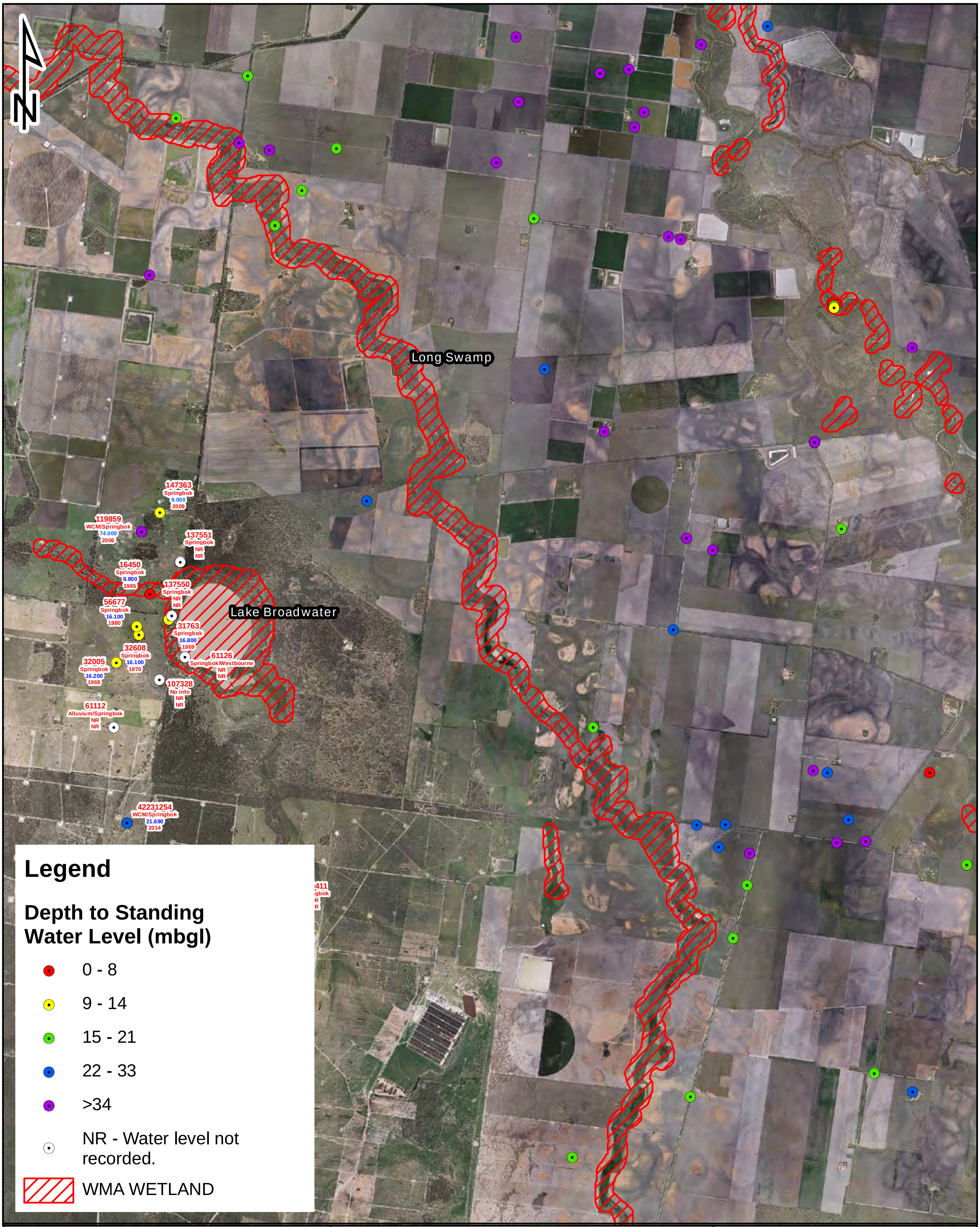
Vegetation is largely native with a groundcover of water chestnut (*Eleocharis dulcis),* nardoo (*Marsillea drummondii)* and patch covering of the exotic Condamine Couch (*Phylla canescens).* The canopy is formed by tall, broadly spaced red-gum at approximately 30% cover. The canopy is significantly stressed in some areas with signs of senescence and foliage loss.

Geology and Hydrogeology

Stratigraphy from water bore data (Bore RN#24332, 24329 & 24853) indicates a thick layer of clay to loamy clay to a depth of 15m before passing into a variably thick sandy horizon to depths of 21mbgl. The upper surface of the sandy horizon likely indicates the original SWL of the undisturbed aquifer. As noted previously, several groundwater bores (e.g. RN 24332, 30670) in vicinity of Long Swamp had SWLs of around -15m in the 1950s-60s, and current water levels show relatively little change (SWL of 16 to 18mbgl when baselined recently) compared to drawdown trends elsewhere in the CRA (see Figure 19). DNRM monitoring bore 42230155 located in Long Swamp has recorded a clear but relatively modest decline in SWL from 16.01mbgl in 1965 to 18.68mbgl in Jan 2017.

Ecological/Hydrogeological Conceptual Site Model

A potential conceptualisation for Long Swamp and other smaller overland flow paths on the CRA was previously presented, and is shown in Figure 22. Due to the thick layer of heavy clay which is likely to provide significant resistance to tree root penetration, it is unclear as to whether mature canopy trees have historically had capacity to tap groundwater sources as deep as 15mbgl, and it is noted that the current SWL hovers at the lower threshold range for Vegetation GDE impact. The senescence of mature canopy trees may also be partly or wholly related to changes in surface flow volumes, as a result of observed nearby large-scale surface water extraction for irrigation. Further shallow geological investigations and the installation of monitoring sites are recommended to better define this preliminary conceptualisation.



NOTES:
Source: Vegetation management wetlands
map - version 2.37

Figure 21. Features of the Long Swamp GDE assessment area

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0 1.5 3 4.5 6
Kilometers

Scale 1:90,000 **Drawn By** DG **Date** 06-Feb-17 A4

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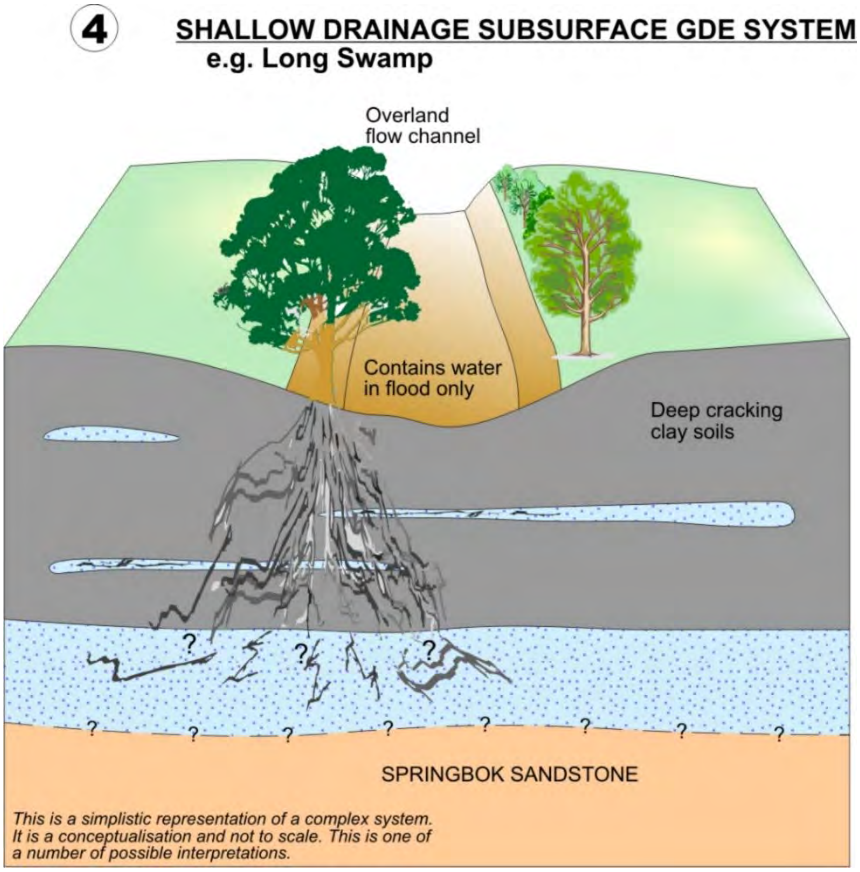

Figure 22. Conceptualisation of the Long Swamp sub-surface GDE system.

3.3.4 Lake Broadwater

Lake Broadwater is a natural shallow lacustrine wetland with surface water on average covering approximately 350ha within the 1212 hectares Lake Broadwater Conservation Park (QLD Government DEHP, 2012). The Lake is seasonal and water recedes during dry spells, occasionally drying totally. Lake Broadwater is a highly significant ecological feature that is mapped as a Wetland of High Ecological Significance (EHP 2014) and is listed in the Australian Directory of Important Wetlands (EHP, 2006a). Lake Broadwater's catchment is approximately 6000 hectares with inlet streams located to the south and west. The general features of Lake Broadwater are indicated in Figure 23.

Vegetation

The Lake is fringed by an open forest of river red gum (*Eucalyptus camaldulensis*) (RE11.3.27d) which is broadest (approx. 200m) on the north-eastern portion of the lake grading into an open forest of rough barked apple passing abruptly into a woodland of ironbark (*Eucalyptus crebra)* with a sub-canopy of bulloke (*Allocasuarina leuhmannii)* (RE11.5.1).

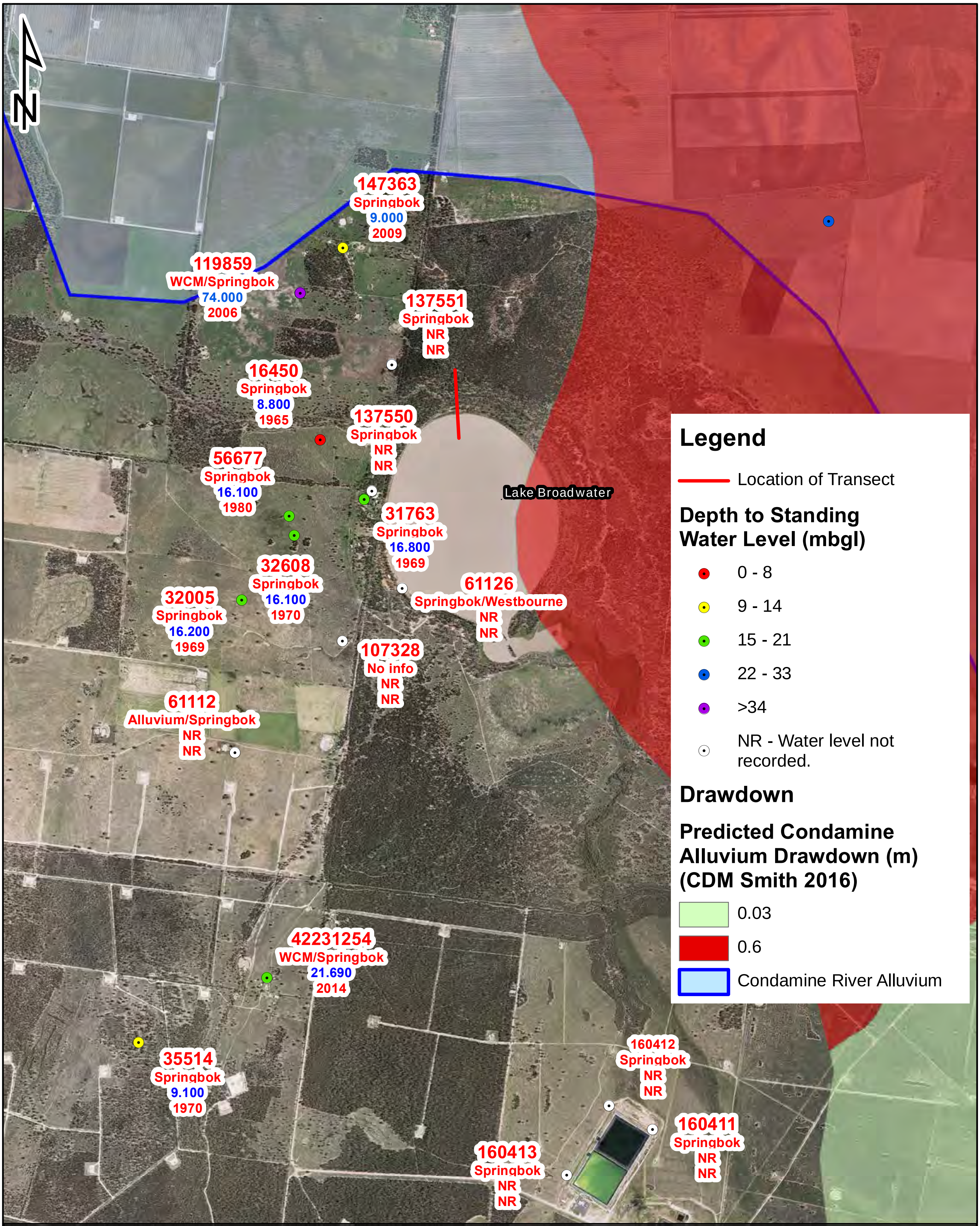

Figure 23. Features of the Lake Broadwater GDE assessment area.

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0 0.6 1.2 1.8 2.4
Kilometers

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Photograph 14. Long Swamp with characteristic red gum showing moderates signs of stress as suggested by foliage loss.

Photograph 15. Northern margin of Lake Broadwater showing sandy ridges and associated red gum forest.

Hydrology, Geology and Geomorphology

The red gum open forest is associated with a sandy apron which forms a series of concentric sand ridges, which have geomorphically similarities to coastal beach ridges. Hand auger sampling indicates that the layer of friable sand is relatively thin (approx. 60 – 80cm) before it passes into a sequence of indurated sand and clay with bands of Fe-oxide. This partially cemented horizon was relatively consistent down to a depth of 2.3m when the auger hole was abandoned in tight clay. Taylor and Eggeleton (2001) identified similar Fe Oxide bands in sand dunes surrounding Lake George (Central NSW), thought to be formed by the illuviation of clay material into bands which act as a permeability barrier leading to precipitation of Fe-oxides in ephemeral perched water tables. At the time of field survey, the lake level was relatively high and receiving overland flow run-off from the south, but was not approaching flooding levels. Previous higher-level shore strand lines were exposed. Poorly developed shallow outlet drainage channels to the north east (to Long Swamp) and to the north west (to Wilkie Creek) suggest that these features are only active during flooding due to high evaporation rates compared with inflow rates.

There was no indication of a permanent shallow perched groundwater table in this locality, either through assessment of nearby groundwater bore logs, and also through hand augering undertaken to a depth of 2.3m. While there is no shallow saturated sands encountered beneath the immediate lake fringe, including at a depth well below the lake bed, the presence of an indurated sand layer above the underlying clays (suggesting a zone of fluctuating groundwater levels), indicates that perched groundwater may be seasonally present. This suggests that the red-gum forest is either sustained by deeper groundwater sources, or alternatively was extracting residual groundwater moisture held within the sand and upper clay horizons following capture of rainfall or retreat of the lake margins.

Ecological/Hydrogeological Conceptual Site Model

An existing Ecological Conceptual Model has been developed by the QLD Government (DEHP 2012), but does not describe the geological setting or connectivity. The preliminary conceptualisation below integrates the ecological and hydrogeological observations and data collated during this assessment. The desk top and field assessments suggests that Lake Broadwater sits within a transitional landscape of Jurassic-age Westbourne Formation colluvium overlying lower Westbourne regolith, and drains to the Condamine River Floodplain to the north. The lower Westbourne Formation pinches out to the east of the Broadwater area, and the Condamine River alluvium to the east and north is underlain in the area by deeply weathered Jurassic age Springbok sandstone. A conceptual model for the Lake Broadwater GDE system in shown in Figure 24.

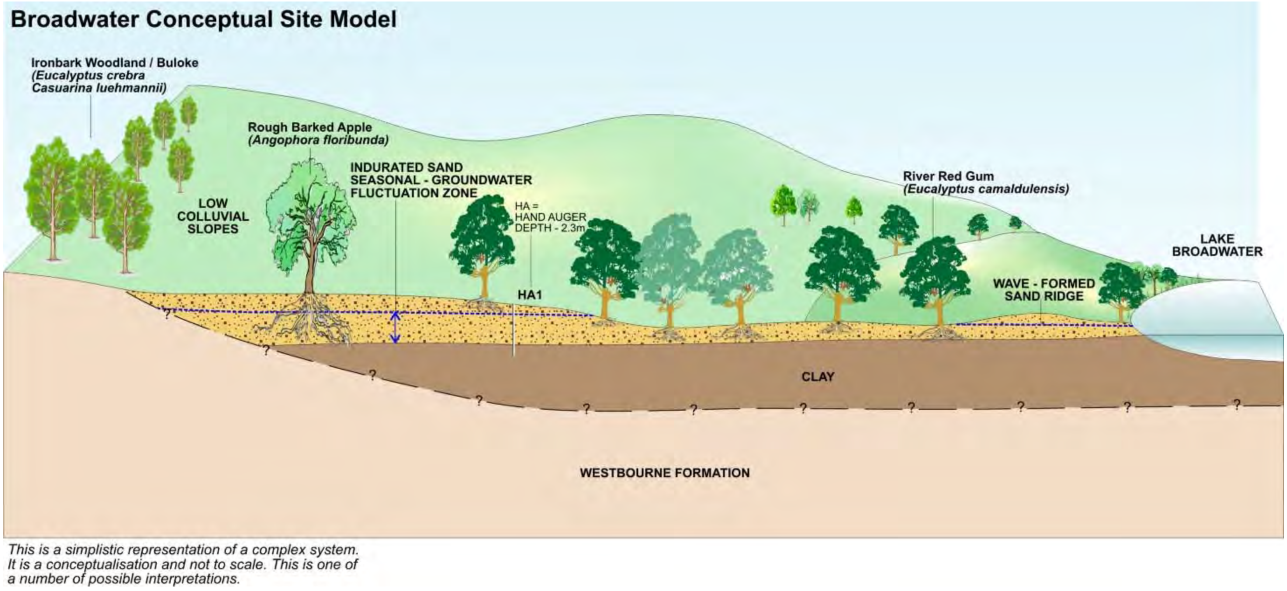

Figure 24. Ecohydrological conceptual model for Lake Broadwater.

Geological information from numerous groundwater bores drilled in the area suggests that there is a deep weathering profile, likely laterised in places through deep leaching. Underlying Westbourne Formation siltstone and claystone has weathered to a series of clay-rich horizons. Lake Broadwater is a perched depositional feature on this claypan, likely receiving further infilling lacustrine sedimentation as wash from local colluvium. There is likely a deep wetting front extending downwards into the regolith.

Most bores in the area are drilled to 40-140m depth into the deeper, less weathered Springbok Sandstone aquifer, and historical groundwater levels stand at around 9-16m below ground level (bgl). Groundwater levels in the Walloon Coal Measures (>140m depth) are generally >40m bgl. Historical groundwater yields from bores in the area are relatively low <0.5l/sec), and brackish (>1000ppm total dissolved solids (TDS)). A number of bores in the area are listed in the DNRM Groundwater Database as tapping the Condamine River Alluvium aquifer. Based on a review of the available stratigraphy and bore logs, these are in fact likely tapping the upper weathered Springbok Sandstone.

While the Radon activity of 0.12 Bq/L in the lake surface water sample (see Table 5 to Table 7) would almost certainly reflect some recent groundwater source, high dD and d18O isotope results suggest a history of evaporative enrichment. The source of possible recent groundwater discharge indicated by Radon levels is unclear. As noted above, hand augering in a localised area suggested that the thin sand body located at the lake fringe was dry at the time of assessment, indicating that any groundwater within this horizon was likely to be seasonally present. This suggests that there may be some other potential areas of groundwater connectivity to the Lake. Only a relatively small area of the shallow lake margin geology was assessed by hand augering and groundwater may be present within the surrounding sandy foreshore sediments elsewhere within the lake margin, or some other source of connected groundwater may exist.

Observations from hand augering and a review of bore logs support the likelihood that the lake is perched on a relatively low permeability clay pan associated with a weathered surface of the Westbourne Formation. Regardless, relatively shallow (9-16mbgl for SWL) in the underlying Springbok Sandstone groundwater on the western margins of the lake, and the presence of Radon in the surface water suggests that the subsurface conceptualisation would be enhanced through further shallow geological investigations to assess the potential for hydraulic connectivity and allow further refinement of the conceptual site model developed here.

4.0 Conclusions and Recommendations

4.1 Conclusions

This report provides an assessment of GDE types contained within the SGP area. Identification of GDEs was completed through a process of refinement and screening of previous relevant works, review of additional available data, supplemented with field investigation. The area for field assessment and verification was somewhat limited primarily to properties in Arrow's "Priority Ecology Areas" where land access had been granted by the landholders. Although the field survey focused primarily on the verification of potential spring targets identified by AGE (2015), it also aimed to provide further definition and description of sub-surface GDEs that occur throughout Arrow Energy's PL and ATP tenements and adjacent areas that might be under the influence of Arrow's activities. The study also assessed the potential groundwater dependence of Long Swamp and Lake Broadwater as per Federal Government conditions of approval. No artesian discharge springs were identified in the visited study area.

The follow GDE systems were identified throughout the course of this assessment:

1. One spring GDE was confirmed within Arrow Energy tenements, the Tribelco Spring which is described in detail in this document. Two additional springs, Wambo Spring to the south west of Chinchilla (where access for field inspection was not granted), and Bowenville spring complex to the east of Dalby have potential to be influenced by Arrow Energy's activities although both are located outside Arrow Energy tenements.
2. Five sub-surface GDE types were identified and described during the assessment being:
    a. Shallow alluvial GDE systems
    b. Bedrock alluvial GDE systems
    c. Deep alluvial GDE systems
    d. Shallow drainage sub-surface GDE systems
    e. Volcanics subsurface GDE systems.

Preliminary Integrated ecological and hydrogeological conceptualisations of these features, including Long Swamp and Lake Broadwater have been prepared within this document, along with an assessment of the likely potential for impact to associated GDEs from CSG operations.

Whilst CDM Smith (2016) identifies the potential for groundwater drawdown in the CRA, the only 'deep alluvial system' identified in the assessment area, it is not known whether the case of maximum predicted drawdown (0.75m in vicinity of Lake Broadwater) will result in increased impacts on associated GDEs which in places exist in a variably degraded state, likely due to a long history of groundwater extraction for agricultural purposes.

It is considered unlikely that there will be any ecological impact to the sole spring GDE identified within Arrow's tenements (Tribelco Spring). This conclusion considers that groundwater seepage is likely sourced from the adjacent permeable alluvial sand body and is not likely sourced from the underlying GAB aquifers subject to potential impact through Arrow's activities. Similarly, GAB regional aquifer SWL's are typically well below the influence of 'shallow alluvial' and 'bedrock alluvial' GDE systems and any connection is more likely to be associated with a deep "wetting front" where, in areas of reasonable bedrock permeability, the shallow "losing" alluvial systems can provide an important source of downward percolating recharge water to underling GAB formations. It cannot be ruled out however that in some localities, riparian vegetation associated with these systems may have their roots into underlying GAB aquifer systems where they occur closer to the surface (<18mbgl). There is currently insufficient data from existing groundwater bores to assess such vegetation /

groundwater interactions comprehensively across Arrow's tenements. Recommendations for further assessment and monitoring of possible areas of connection beneath a subset of GDE locations has been provided in this report.

Although Long Swamp occurs on the CRA's western margins, SWLs recorded in groundwater bores located in vicinity of this feature demonstrate little change when compared to drawdown trends elsewhere on the CRA. For example, only modest declines are recorded in DNRM monitoring bore 42230155 (16.01mbgl in 1965 to 18.68mbgl in 2017). Due to the thick layer of heavy clay associated with the feature, which is likely to provide significant resistance to tree root penetration, it is unclear as to whether mature canopy trees have historically had capacity to tap groundwater sources as deep as 18mbgl. The senescence of mature canopy trees may also be partly or wholly related to changes in surface flow volumes, resulting from observed nearby large-scale surface water extraction for irrigation. Hence further information is recommended to determine the potential for Arrow's activities to impact on this system.

Information gathered during this assessment suggests that Lake Broadwater lies on a transitional landscape of Jurassic-age Westbourne Formation colluvium overlying lower Westbourne regolith, and drains to the Condamine River Floodplain to the north. The lower Westbourne Formation pinches out to the east of Lake Broadwater and the Condamine River alluvium to the east and north is underlain in the area by deeply weathered Jurassic age Springbok Sandstone. The 'well developed' forest of river red gum associated with the margins of Lake Broadwater is likely either sustained by deeper groundwater sources, or alternatively relies on extraction of residual groundwater moisture held within the sand and upper clay horizons following capture of rainfall or retreat of the lake margins. Ongoing monitoring and assessment of this feature will be required to identify any potential for ecological impact that might be associated with Arrow's operations.

4.2 Recommendations

4.2.1 General Recommendations

Recommendations for work to further refine the integrated ecological/hydrogeological conceptual models for GDE systems developed in this assessment include:

- Undertake a true dry season survey to revisit a relatively small sub-set of "likely" GDE target sites during a dry period. It would be advisable, and more scientifically robust, to document true dry season conditions to capture a more complete description of background conditions prior to further CSG development. As noted earlier in the report, significant rainfall occurred in the assessment area prior to both field visits. The amount of pooled and flowing water as well as the green flush of vigorous vegetation growth in response to the heavy rainfall made it difficult to differentiate recent rainfall from persistent seeps. The water chemistry results from this survey should be viewed as indicative of a wet period where the water chemistry characteristics of recent rainfall would likely significantly mask any contributions from groundwater sources. Further sampling from a number of sites during a monitoring period which captures a representative selection of dry to wet conditions would be required to more adequately characterise water quality trends and groundwater/surface water interactions.
- Verification of geological assumptions for each site setting and if necessary refinement of conceptual site models is recommended through a review and incorporation of any material changes from the updated GSQ surface geology mapping (see Section 1.3.2) due to be published imminently.
- Undertake a shallow geological investigation and establishment of a GDE monitoring network and programme – see Section 4.2.2 below.

4.2.2 Vegetation/Groundwater Monitoring Sites

An integrated ecological and hydrogeological monitoring programme is recommended which would include a selection of sites in priority "early detection" areas related to Arrows development, associated potential groundwater drawdown areas, and more vulnerable GDE locations informed by this assessment as well as impact assessment undertaken for the Stage 1 CSG WMMP. The objectives of the monitoring programme would include:

- the critical establishment of background GDE groundwater level, quality vegetation health trends prior to further CSG development.
- Early detection of any adverse trends related to CSG development.
- Ongoing refinement of the integrated ecological/hydrogeological conceptual site models and groundwater-vegetation relationships developed through this assessment.

The fundamental design principle of such a monitoring programme is that through an accurate understanding of the hydrogeological/ecological relationships and stress thresholds (conceptual site model), any changes beyond critical response thresholds are detected early such that potential impacts on GDEs can be prevented or reversed (mitigated).

Further detail on suggested monitoring areas and activities is provided in the table below and an overview of suggested methods is provided in the following sections. A review of monitoring locations and methods should be undertaken periodically with references to modified groundwater drawdown modelling outputs. These monitoring locations should be verified based on outcomes of Stage 1 CSG WMMP risk assessment.

Table 9. Specific recommendations for individual localities.

GDE	No. of GDE Monitoring Sites	Bi-annual monitoring activities
Lake Broadwater	2	• Groundwater level and quality • Ecological survey • Surface water monitoring (level and quality).
Long Swamp	2	• Groundwater level and quality • Ecological survey • Surface water monitoring if flowing • Utilise existing disused bore for water level monitoring.
Wambo Ck	2 (incl Trebilco spring) within Chinchilla Sands	• Groundwater level and quality • Ecological survey • Surface water quality monitoring • Utilise existing PVC bore • Temporarily deploy a v-notch weir or other means of measuring flow rate into and out of the main pool during each monitoring event to assess long term trends, spring discharge rate/groundwater level relationship and other hydraulic responses • Water quality sampling at nearby wetland (site 911), and water table window (site 910)
Bowenville Spring (Oakey Ck)	1	• Groundwater level and quality • Ecological survey • Surface water quality sampling. • Review gauging station flow rate and level data.

GDE	No. of GDE Monitoring Sites	Bi-annual monitoring activities
Condamine River	TBA – At least 5 locations recommended in the vicinity of sites GDE 1-5.	A review and gap analysis of existing DNRM and Arrow groundwater monitoring locations within the CRA is recommended wrt higher risk GDE locations and future Arrow development plans. This will determine if the existing groundwater monitoring network is sufficient for early-detection of potential CSG impacts on GDE locations and the establishment of background trends.

4.2.3 Additional Geological Characterisation and Groundwater Monitoring

A programme of drilling and coring of the shallow geology is recommended to allow detailed logging and sampling of the shallow geology and tree rooting depths, and installation of shallow groundwater monitoring bores. Methods recommended include sonic coring (sonic rig) and push tubing with a geoprobe rig. These methods have been used with significant success to characterise the alluvium and upper weathered rock regolith zone in sensitive areas on the CRA and elsewhere within the Surat basin. These rigs have an extremely small footprint (see photographs below), and are very quick, cheap and efficient compared with conventional CSG and water bore rigs. The permanent monitoring infrastructure footprint is insignificant. The suggested programme of drilling and monitoring bore installation would allow:

- a refined geological and hydrogeological definition of any shallow aquifers and aquitards;
- estimates of permeability and other hydraulic properties;
- better assessment of interconnectivity with underlying aquifers;
- where cored adjacent to mature trees – verification of assumed tree root depths through direct observations and lab analysis of tree root matter in core. This would be particularly effective with a sonic rig (ultra-high frequency vibration penetration);
- Monitoring of shallow groundwater levels and quality for comparison with stressors and responses in adjacent vegetation monitoring sites.

It was noted during the field survey that a number of disused and operational landholder groundwater bores were located within or near useful GDE monitoring sites. A number of such locations could be identified and equipped with pressure sensors for monitoring to complement the purpose-built monitoring bores.

Photograph 16. Geoprobe rig coring and installing monitoring bores on the CRA.

Photograph 17. Core produced from geoprobe rig.

Photograph 18 & 19. Sonic Rig coring and installing monitoring bores on Wambo Ck.

4.2.4 Ecological Monitoring

Ecosystem resilience in a changing groundwater regime can best be established through systematically structured monitoring plots designed to allow for repeatable measurement of canopy foliage vigour and species diversity / complexity with measurements taken on a bi-annual basis (end of wet season and late dry season). The assessment of canopy vigour can be supplemented with acquisition of high resolution NDVI imagery timed to coincide with field measurement.

Due to the considerable number of overlapping potential impact sources, including agricultural extraction from bores, extraction of surface water flows and other CSG operation, it will be difficult to find specific vegetation monitoring sites that exclude other influences except for Arrow's activities. It will also be difficult to locate suitable replicate analogue sites due to the widespread nature of impacts to both vegetation and groundwater in the SGP study area. Hence, the following recommendations are proposed:

1. At the location of each identified GDE groundwater monitoring bore, whether these be installed specifically for the purpose or utilise an existing borehole, a single vegetation monitoring site be installed in the best representation of intact native vegetation in the vicinity (preferably < 100m distance).
2. Vegetation monitoring sites should consist of a minimum transect length of 50m (as per Neldner et al 2017). Monitoring sites should include measurements of the following parameters:
    a. Canopy cover
    b. Foliage cover expressed as Foliage Index (i.e living leaf area expressed as % of total canopy cover).
    c. Living stem counts for canopy, sub-canopy and shrub structural layers.
    d. Quantitative assessment of the nature of groundcovers.
3. Vegetation monitoring should be completed bi-annually in the late dry season as well as late wet season and should coincide with groundwater monitoring events.
4. The utility of high-resolution NDVI imagery captured for specific localities to support the on-ground ecological monitoring program should also be investigated.

Whilst limitations have been previously identified, it is important to choose at the minimum a single locality for establishment of an analogue site, although three localities would be preferable for statistical robustness. The camping reserve at the locality of site GDE4 presents the best opportunity as it falls outside the area of Arrow's predicted drawdown and groundwater is likely to be more evenly sustained due to back-up in the Condamine River above the weir. The vegetation in this locality has also been identified as being in good condition.

Leaf water potential measurements should also be considered in those localities where the relationship between vegetation and groundwater is less certain. This would include both Lake Broadwater and Long Swamp. Leaf water potential should be measured at the time of installation of any groundwater monitoring bores.

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6.0 Appendices

Appendix A. Spring Sampling Procedures as per Santos, Origin Energy, QGC, JIP.

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.* • *Calibrate all monitoring equipment.*
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.* • *Avoid walking on the potential spring structure.* • *Note and photograph a nominated sampling point.*
3. Field Observations	• *Complete the Spring Sample Information Sheet).*
4. Spring Flow Measurements	• *During initial/ first visit to a spring:* - *Identify if the method required by the Surat UWIR is Identify a suitable control point.* - *Photograph the control points each time the flow is measured.*
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.*
	<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.* • *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* - *More than 50% of the total spring wetland area shows animal disturbance*
	<u>*WATERCOURSE SPRINGS:*</u> • *A physical condition assessment is not required.*
7. 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.*

	• *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.* • *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*
9. Collection of Water Samples (non-isotopic analyses)	• *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.*
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 exposer 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.* • *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

Appendix B. AGE Spring Target Refinement and Desktop Screening Process

AGE Spring No	AGE Spring Potential	Feature Characteristic	Geomorphic/ Geologic Setting	Approximate Size of Feature (ha)	Vegetation	Evidence of Anthropogenic alteration	Vegetation Response	Proximity to Drainage	Likely Spring?	Reason	Field Visit in Stage 1
912	19	Permanent water, generally non-turbid with no visible emergent aquatic vegetation	Tertiary Rise - Upper Surface, generally flat and featureless	0.172	11.5.1/11.5.4	Visible scrape mechanical removal of topsoil in 2006 aerial photograph	No visible structural change in vegetation on feature margins	Less that 100m from ephemeral drainage line	Unlikely	Visible earthworks and gravel scraping in 1989 aerial photographs	No
242	19	Elongated sem-circular feature with semi-permanent water	Tertiary Rise - Upper Surface, generally flat and featureless	0.087	11.5.1/11,5,4/11.5.20	Some evidence of mechanical disturbance and gravel extraction on stream bed in 2006 aerial photography	No visible structural change in vegetation on feature margins	On ephemeral drainage line	Unlikely	Mechanical disturbance and gravel extraction on stream bed in 2006 aerial photography	No
244	17	Oxbow on margins of larger watercoarse	Alluvial Plain	0.272	11.3.25	No strong evidence of mechanical disturbance, although oxbow finishes on fenceline with potential damming of the watercourse feature	No visible structural change in vegetation on feature margins	On overflow channel	Unlikely	Mechanical disturbance and gravel extraction on stream bed in 2006 aerial photography	No
242	17	Shallow depression on alluvial plain with no water visible in 2006 and 2014 aerial photography	Alluvial plain within 200m of Wilkie Creek	0.17	11.3.2	On margins of clearing. Appears as shallow scrape on alluvial surface	Evidence of low shrubby weedy growth on margins	Approximate 200m	Unlikely	Mechanical disturbance and gravel extraction on stream bed evident in historical imagery	No
239	19	Indiscernable feature on margins of breakaway. No visible evidence of water	Margins of gentle breakaway on laterite escarpment	NA	11.7.7	Site had been heavily disturbed in 2006 with vegetation existing as regrowth	No visible structural change in any location	Removed from watercoarse	Unlikely	Canopy is very thin in 2006 due to clearing. No visible signs of surface expression of water	No

AGE Spring No	AGE Spring Potential	Feature Characteristic	Geomorphic/ Geologic Setting	Approximate Size of Feature (ha)	Vegetation	Evidence of Anthropogenic alteration	Vegetation Response	Proximity to Drainage	Likely Spring?	Reason	Field Visit in Stage 1
241	17	Minor, almost indescernable circular feature on flood overflow channel. Appears as shallow overflow depression	Condamine alluvium - Alluvial plain	0.127	11.3.25	Remnant vegetation on site in 1981 with no evidence of disturbance on the on the habitat margins although clearing is evident on the margins in 2013	Vegetation in robust on margins	Approximate 180m from margins of Wilkie Creek	Possible	No visible expression of surface water.	Yes
908	??	Overflow of the main river with numerous small drainage depressions	Condamine alluvium, adjacent to the Condamine River	0.399	11.3.25 / 11.3.27	Vegetation has been partially cleared and regenerated	Vegetation is robust adjacent to main waterbody	Overflow into river	Possible	No evidence of major disturbance with water overflow back into Condamine River evident	No
238	??	Very small circular overflow depression. Wet in 2013 athough dry in 1989 and 2006.	Condamine alluvium adjacent to Condamine River. Direct linkage to overland flow path of river	0.077	11.3.27 / 11.3.25	Remnant vegetation on site with limited disturbance on riparian margins	Vegetation is robust adjacent to the river although no specific response adjacent to wetland	10 - 15m	Possible	No evidence of major disturbance with water overflow back into Condamine River via a series of broad, wet drainage depressions	No
231	??	Appears as scald on rocky surface	Indurated sedimentary rock	0.08	11.7.5 b- Shrubland on scald	Possibly gravel extraction. Vegetation is regrowth from disturbance	Dense regrowth wattle	300 m from ephemeral drainage line	Unlikely	Vegetation is dense regrowth wattle from disturbance	Yes
232	15	Very turbid circular farm dam	Indurated sedimentary rock on gently	0.119	Non-remnant clearing on	Placed in a clearing along fenceline evident	Vegetation has been cleared on	> 1km from drainage	Unlikely	Historical farm dam placed on fenceline. No evidence of	Yes

AGE Spring No	AGE Spring Potential	Feature Characteristic	Geomorphic/ Geologic Setting	Approximate Size of Feature (ha)	Vegetation	Evidence of Anthropogenic alteration	Vegetation Response	Proximity to Drainage	Likely Spring?	Reason	Field Visit in Stage 1
			undulation land surface.		margins of alluvial area, RE11.3.25	in 1989 aerial photography	margins with no response			overflow from locality with no increase in stream flow downstream. No vegetation response	
233	19	Elongated water feature on drainage line	Shallow alluvial sediment incised by watercourse	0.14	Non-remnant clearing on margins of alluvial area, RE11.3.25	Clearing on margins and adjacent fenceline. Watercourse has been dammed with spoil evidenced in 1989 imagery	Riparian vegetation adjacent to creekline	> 1km from drainage	Unlikely	Water feature created by low bund wall on watercourse.	Yes
910	15	Circular dam with turbid water	Shallow alluvial plane adjacent to minor watercourse	0.228	Small patch of E.populnea woodland - RE11.3.2	Yes. Clearing of adjacent vegetation with access tracks to water feature adjacent to fenceline	No visible response evident in adjacent vegetation	> 1km from drainage	Possible	Circular farm dam with turbid water adjacent to clearing. Formed on narrow drainage depression although no visible excavation.	Yes
907	20	Shallow circular depression with turbid water	Shallow alluvial plane adjacent to minor watercourse	0.156	Small patch of E.populnea woodland - RE11.3.2	Yes. Access track has been created and bunding of a narrow drainage channel has occurred downstream	On a swampy complex with numerous overflows and wetlands	> 1km from drainage	Possible	No evidence of land disturbance and abundant surface water at head of shallow drainage depression	Yes
911	??	Elongated wetland feature on alluvial plane	Shallow alluvial outwash plane	2.7	Cleared on margins with a small patch of Poplar Bow	Yes. Vegetation has been totally cleared. Evidence that a low bund wall has been	No evident vegetation response	300m from larger watercourse	Unlikely	Evidence of bunding of an	Yes

AGE Spring No	AGE Spring Potential	Feature Characteristic	Geomorphic/ Geologic Setting	Approximate Size of Feature (ha)	Vegetation	Evidence of Anthropogenic alteration	Vegetation Response	Proximity to Drainage	Likely Spring?	Reason	Field Visit in Stage 1
					woodland adjacent - RE11.3.2	placed across an overland flow path				overland flow path.	
49	15	Elongated water feature with permanent water	Shallow alluvial plane on overland flow path adacent to minor watercourse	0.06	Remnant riparian vegetation - most likely RE11.3.25	Yes. Adjacent to roadside with evidence of bunding and drainage alteration	Natural riparian vegetation	Less than 100m from ephemeral drainage line	Unlikely	Located on overland flow path with evidence of drainage alteration.	No
164	17	Large, shallow waterbody with turbid water in recent imagery (2014)	Condamine alluvium on broad flood overflow	2.35	Regrowth eucalyptus woodland - non remnant vegetation	Yes. Margins of waterbody are angular and have been shaped by machinery. Dead trees remain standing in central portions of the waterbody.	None evident	170m from main channel of the Condamine.	Unlikely	Located on overland flow path with evidence of drainage alteration and excavation. Dead trees visible in middle of water feature.	No
247	19	Small body of open water with squared boundaries	Weathered clay plain	0.29	Within patch of remnant RE11.5.1	Yes. Squared boundaries of the waterbody provide clear evidence of excavation	None evident	Within broad drainage depression	Unlikely	Significant evidence of excavation on overland flow path suggests a farm dam	No
248	19	Circular body of relatively clear water	Weathered clay plain	0.14	Occupies cleared area within broader patch of RE11.5.1. Currently mapped as non-remnant	Yes. Turkey's nest constructed of square earthen wall clearly evident with overflow constructed	Cleared to margins	>1km	Unlikely	Significant evidence of excavation with construction of earth walls	No
187	??	Riparian vegetation adjacent to drainage line	Narrow alluvial flood plain	NA	RE11.3.25	Limited disturbance to vegetation. River has	Well-formed riparian vegetation	Adjacent to river	Unlikely	Linked to overland flow path. River. Permanent water in river associated	No

AGE Spring No	AGE Spring Potential	Feature Characteristic	Geomorphic/ Geologic Setting	Approximate Size of Feature (ha)	Vegetation	Evidence of Anthropogenic alteration	Vegetation Response	Proximity to Drainage	Likely Spring?	Reason	Field Visit in Stage 1
						been bunded downstream				with bunded stream.	
186	??	Riparian vegetation adjacent to drainage line	Narrow alluvial flood plain	NA	RE11.3.25	Limited disturbance to vegetation. River has been bunded downstream	Well-formed riparian vegetation	Adjacent to river	Unlikely	Linked to overland flow path. River. Permanent water in river associated with bunded stream.	No
191	??	Riparian vegetation adjacent to drainage line	Narrow alluvial flood plain	NA	RE11.3.25	Limited disturbance to vegetation. River has been bunded downstream	Well-formed riparian vegetation	Adjacent to river	Unlikely	Linked to overland flow path. River. Permanent water in river associated with bunded stream.	No
194	??	Riparian vegetation adjacent to drainage line with series of wetted channel overflows	Narrow alluvial flood plain	NA	RE11.3.25	Limited disturbance to vegetation. Appears river may have been bunded downstream	Well-formed riparian vegetation	Within channel	Unlikely	Linked to overland flow path. River. Permanent water in river associated with bunded stream.	Yes
195	??	Circular waterhole directly adjace to stream channel. Riparian vegetation is Well-formed adjacent to channel.	Narrow alluvial flood plain	NA	RE11.3.25	Limited disturbance to vegetation. Appears to have a bunded wall downstream	Well-formed riparian vegetation	Within channel	Unlikely	Linked to overland flow path. River. Permanent water in watercourse that may have been influenced by stream bunding.	Yes
204	22	In stream gravel bed with free water evident downstream	Narrow drainage channel formed on	NA	RE11.5.1	Limited disturbance to vegetation. Riparian	Riparian vegetation is not Well-developed	Within channel	Unlikely	Linked to watercourse. Water in channel possibly from	Yes

AGE Spring No	AGE Spring Potential	Feature Characteristic	Geomorphic/ Geologic Setting	Approximate Size of Feature (ha)	Vegetation	Evidence of Anthropogenic alteration	Vegetation Response	Proximity to Drainage	Likely Spring?	Reason	Field Visit in Stage 1
			indurated loamy plain			vegetation is not Well-developed				seepage in the stream channel.	
199	??	Circular water feature / dam in cleared paddock	Loamy plain - old colluvium / alluvium	0.17	Non-remnant / cleared	Strong evidence of excavation with windmill adjacent to dam. Has been fenced	Vegetation totally cleared	>1 km from nearest stream	Unlikely	Farm dam with strong evidence of excavation	Yes
203	??	Circular water feature / dam in cleared paddock	Loamy plain - old colluvium / alluvium	0.17	Non-remnant / cleared	Strong evidence of excavation. Numerous similar features scattered across adjacent landforms	Vegetation totally cleared	>1 km from nearest stream	Unlikely	Farm dam with strong evidence of excavation	Yes
210	15	Squared water feature / dam in cleared paddock	Loamy plain - old colluvium / alluvium	0.14	Non-remnant / cleared	Strong evidence of excavation. Numerous similar features scattered across adjacent landforms. Piled earth surrounding dam	Vegetation totally cleared	>1 km from nearest stream	Unlikely	Farm dam with strong evidence of excavation	Yes
200	15	Linear water feature linked to former flood channel	Condamine alluvium	0.09	Non-remnant / cleared	Vegetation has been cleared. Some evidence of excavation and bunding of older paleo channel	Vegetation totally cleared	600m from active stream channel although located on an older paleo channel	Unlikely	Excavated paleo channel	No
201	??	Alluvial overflow on river margins	Condamine alluvium	0.08	Non-remnant adjacent to RE11.3.25	Vegetation has been cleared to margins of feature	Vegetation cleared to margins with no response evident	Adjacent to river	Unlikely	River overflow channel that has been modified	No
213	??	Alluvial overflow on river margins	Condamine alluvium	0.08	Non-remnant adjacent to RE11.3.25	Vegetation has been cleared to margins of feature	Vegetation cleared to margins with no response evident	Adjacent to river	Unlikely	River overflow channel that has been modified	No

AGE Spring No	AGE Spring Potential	Feature Characteristic	Geomorphic/ Geologic Setting	Approximate Size of Feature (ha)	Vegetation	Evidence of Anthropogenic alteration	Vegetation Response	Proximity to Drainage	Likely Spring?	Reason	Field Visit in Stage 1
212	19	Small body of open water with squared boundaries	Weathered clay plain	0.09	Within patch of remnant RE11.5.1	Yes. Squared boundaries of the waterbody provide clear evidence of excavation	None evident	>1 km from nearest stream	Unlikely	Significant evidence of excavation suggests a farm dam	No
209	??	Small body of open water with regular circular boundaries	Weathered clay plain	0.1	Within patch of remnant RE11.5.1	Yes. Strong evidence of excavation with regular margins and absense of any developed vegetation	None evident	Adjacent to drainage channel of minor stream	Unlikely	Significant evidence of excavation suggests a farm dam	No
207	??	Base / margins of laterite jump-up	Indurated lateritic sediments	NA	RE11.7.7	No. Undisturbed locality	No evidence for any response in vegetation	>1 km from nearest stream	Unlikely	No evidence for surface expression of water	No
206	19	Minor rise in lateritic landform	Indurated lateritic sediments	NA	RE11.7.7	No. Undisturbed locality	No evidence for any response in vegetation. Vegetation appears associated with a change in soil type / landform rather than surface expression of water	>1 km from nearest stream	Unlikely	No evidence for surface expression of water	No
208	??	Base / margins of laterite jump-up	Indurated lateritic sediments	NA	RE11.7.7	No. Undisturbed locality	No evidence for any response in vegetation	>1 km from nearest stream	Unlikely	No evidence for surface expression of water	No
172	28	Overflow of major watercourse holding	Fluvial sediments of	NA	RE1.3.25	Yes. Major earthworks and	Riparian vegetation is	On overflow channel	Possible	No sufficient explanation for volumes of	Yes - not

AGE Spring No	AGE Spring Potential	Feature Characteristic	Geomorphic/ Geologic Setting	Approximate Size of Feature (ha)	Vegetation	Evidence of Anthropogenic alteration	Vegetation Response	Proximity to Drainage	Likely Spring?	Reason	Field Visit in Stage 1
		significant surface water	major watercourse			gravel extraction on river bed	moderately developed			surface water present	requested
223	19	Shallow water feature / dam in cleared paddock	Loamy plain - old colluvium / alluvium	0.01	Non-remnant / cleared	Strong evidence of excavation. Numerous similar features scattered across adjacent landforms.	Vegetation totally cleared	Located on shallow drainage depression which has been subject to minor excavation	Unlikely	Farm dam with strong evidence of excavation	Yes
225	19	Area of forest (regrowth) with very tight green crowns	Loamy plain - old colluvium / alluvium	NA	Mapped as area containing dense cypress pine (RE11.3.17)	Strong evidence of timber extraction	Either regrowth from total clearing or severely disturbed natural habitat	>1 km from nearest stream	Unlikely	Regrowth vegetation with no evidence of surface water	Yes
224	22	Area of forest (regrowth) with very tight green crowns	Loamy plain - old colluvium / alluvium	NA	Mapped as area containing dense cypress pine (RE11.3.17)	Strong evidence of timber extraction	Either regrowth from total clearing or severely disturbed natural habitat	Adjacent to alluvial channel of watercourse	Unlikely	Regrowth vegetation with no evidence of surface water	Yes
222	??	Small body of open water with squared boundaries	Weathered clay plain	0.09	Within patch of remnant RE11.5.1	Clear evidence of excavation	None evident	>1 km from nearest stream	Unlikely	Significant evidence of excavation suggests a farm dam	No
26	28	A number of shallow depressions holding some water on alluvial clay soils	Alluvium associated with river	1.5	Disturbed patch of RE11.3.2 / 11.3.3	Thinning of adjacent vegetation although no evidence of mechanical disturbance	Possibly lippia growing on margins of waterbody	Adjacent to Condamine River	Possible	Appears to be associated with flood overflows on river flood plain	Yes

AGE Spring No	AGE Spring Potential	Feature Characteristic	Geomorphic/ Geologic Setting	Approximate Size of Feature (ha)	Vegetation	Evidence of Anthropogenic alteration	Vegetation Response	Proximity to Drainage	Likely Spring?	Reason	Field Visit in Stage 1
29	19	A large shallow depression occupying an overflow on the Condamine flood plain.	Alluvium associated with river	3	Disturbed patch of RE11.3.2 / 11.3.3 with riparian vegetation developed on margin	Vegetation cleared to margins with some evidence of regrowth on edges of waterbody	Thickening on edge of waterbody	Adjacent to Condamine River	Possible	Associated with flood overflow on river flood plain	Yes
27	??	Overflow channel of Condamine River tributary	Alluvium associated with river	<1	Very narrow margin of RE11.3.25. Heavily disturbed	Flood overflow channel which has been modified through excavation and some bunding	Thickening on edge of waterbody	Tributary of the Condamine River	Unlikely	Associated with flood overflow on river flood plain	Yes
44	??	Turkeys nest with adjacent overflow dam and windmill	Alluvium associated with river	1	Non-remnant /cleared	Heavily altered water feature with dam wall modified	No vegetation	>1 km from nearest stream	Unlikely	Farm dam with associated windmill - adjacent to water bore.	No
50	??	Small circular dam	Older clay-loam plain	0.08	Undisturbed bushland	Excavated farm dam	No apparent thickening on margins	>1 km from nearest stream	Unlikely	Farm dam with associated windmill - adjacent to water bore.	No
28	??	Overflow channel on Condamine River floodplain	Alluvium associated with river	<1	Cleared to margins of waterbody	Feature has been bunded	No vegetation	400m from tributary of Condamine River	Unlikely	Bund wall clearly evident	No
30	21	Excavated water feature	Older clay-loam plain	0.08	Moderately disturbed bushland - RE11.5.1	Clear evidence of excavation with regular waterbody boundaries. Spoil has been mounded on southern side	No apparent thickening on margins	>1 km from nearest stream	Unlikely	Farm dam with associated windmill - adjacent to water bore.	No

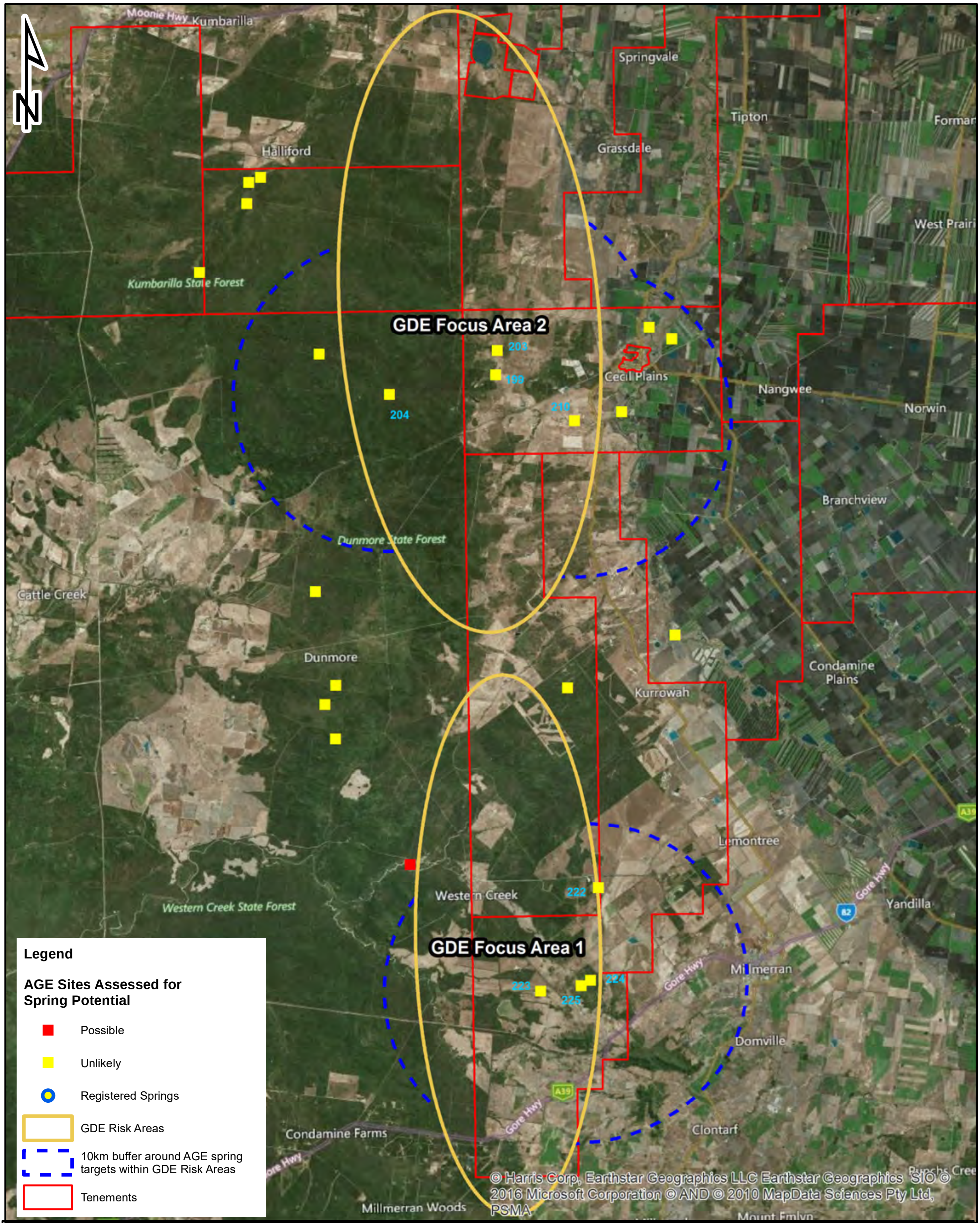
AGE Spring No	AGE Spring Potential	Feature Characteristic	Geomorphic/ Geologic Setting	Approximate Size of Feature (ha)	Vegetation	Evidence of Anthropogenic alteration	Vegetation Response	Proximity to Drainage	Likely Spring?	Reason	Field Visit in Stage 1
33	19	A shallow depression holding some water on alluvial clay soils adjacent to Condamine River	Alluvium associated with river	1	Disturbed patch of RE11.3.25	Thinning of adjacent vegetation although no evidence of mechanical disturbance	Thickening on edge of waterbody	Adjacent to Condamine River	Unlikely	Appears to be associated with flood overflow on river flood plain with direct link to river channel	No
35	19	A shallow depressions holding some water on alluvial clay soils adjacent to Condamine River	Alluvium associated with river	1	Disturbed patch of RE11.3.25	Thinning of adjacent vegetation	Thickening on edge of waterbody	Adjacent to Condamine River	Unlikely	Appears to be associated with flood overflow on river flood plain with direct link to river channel	No
37	19	A shallow depressions associated with river overflow channel	Alluvium associated with river	1	Disturbed patch of RE11.3.3	Thinning of adjacent vegetation	Thickening on edge of waterbody	Adjacent to Condamine River	Unlikely	Associated with flood overflow on river flood plain with direct link to river channel. This area has been subject to ground suvey in August 2016 and did not hold water at the period.	No
155	19	Excavated water feature	Older clay-loam plain	1.3	Moderately disturbed bushland - RE11.5.1 with cleared margins around the waterbody	Clear evidence of excavation with regular waterbody boundaries. Spoil has been mounded around waterbody	Vegetation has been cleared on margins with no response	>1 km from nearest stream	Unlikely	Farm dam with associated windmill - adjacent to water bore.	Yes

AGE Spring No	AGE Spring Potential	Feature Characteristic	Geomorphic/ Geologic Setting	Approximate Size of Feature (ha)	Vegetation	Evidence of Anthropogenic alteration	Vegetation Response	Proximity to Drainage	Likely Spring?	Reason	Field Visit in Stage 1
154	22	Narrow overflow channel adjacent to watercourse	Narrow sliver of alluvium adjacent to intermittent stream	<1	Cleared vegetation adjacent to watercourse with RE11.3.25 on fringes	No evidence of alteration or landform modification	Minor thickening on habitat margins	Adjacent to coure of minor stream	Unlikely	Overflow of minor stream	Yes
152	19	Excavated water feature	Older clay-loam plain	1.3	Moderately disturbed bushland - RE11.5.1 with cleared margins around the waterbody	Evidence of excavation with clearing of vegetation around waterbody margins	No vegetation response noted	>1 km from nearest stream	Unlikely	Farm dam with associated windmill - adjacent to water bore.	Yes
131	19	Narrow watercourse at head of waterhole	Narrow watercourse incised into old loamy alluvium	<0.06	Intact vegetation	Evidence that the creek channel has been modified downstream with a low bund	Minor thickening on margins of waterbody	Associated with stream channel	Unlikely	Modified stream channel	Yes
112	21	Large natural wetland in drainage depression	Wetland formed on basement rock (fine grained sedimentary	12.3	Cleared - Non remnant	Wetland structure appears natural	Well-formed aquatic vegetation apparent	Associated with minor ephemeral watercourse	Possible	No modification of landform with abundant water present in gully depression	Yes
108	15	Circular dam with turbid water	Formed on broad gully adjacent to ephemeral watercourse	0.27	Cleared - Non remnant	Evidence of bunding to form dam	Regrowth vegetation surrounding dam	Associated with minor ephemeral watercourse	Unlikely	No modification of landform with abundant water present in gully depression	No
151	22	Circular water feature / dam in cleared	Formed in broad ephemeral drainage line on the lower slopes	0.25	Cleared - Non remnant	Appears to be evidence of excavation	No vegetation	Associated with minor	Possible	Possible excavation	No

AGE Spring No	AGE Spring Potential	Feature Characteristic	Geomorphic/ Geologic Setting	Approximate Size of Feature (ha)	Vegetation	Evidence of Anthropogenic alteration	Vegetation Response	Proximity to Drainage	Likely Spring?	Reason	Field Visit in Stage 1
		paddock. Water relatively clear	of fine grained sandstone					ephemeral watercourse			
245	21	Shalllow depression on flood plain with permanent water at time of capture	Flood plain of larger watercourse formed on flood overflow channel.	0.3	11.3.2/ 11.3.4	Natural habitat and landform	Vegetation is natural and robust with undisturbed structure	100m from tributary of Condamine	Possible	Unmodified landform and abundance on surface water	Yes
211	19	Linear water feature linked to main Condamine River flood channel	Condamine alluvium. Flood plain of Condamine River	0.4	11.3.25	Overflow has been bunded to form dam	Disturbed remnant vegetation	Adjacent to River	Unlikely	Modified flood overflow channel	No

NB. Shaded text indicates spring targets considered ‘possible springs’ prior to field suvey.

Appendix C. AGE Spring Targets considered to represent ‘Possible Springs’ during the screening process.



Appendix C. Likelihood of Spring Occurrence

Client ARROW ENERGY

Scale 1:321,203

Drawn By DG

Date 02-Sep-16

A4

3D Environmental

Vegetation Assessment
& Mapping Specialists

P. O. Box 959
Kenmore, Qld 4069
Mobile: 0447 8227 119
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Mobile: 0429 049 154

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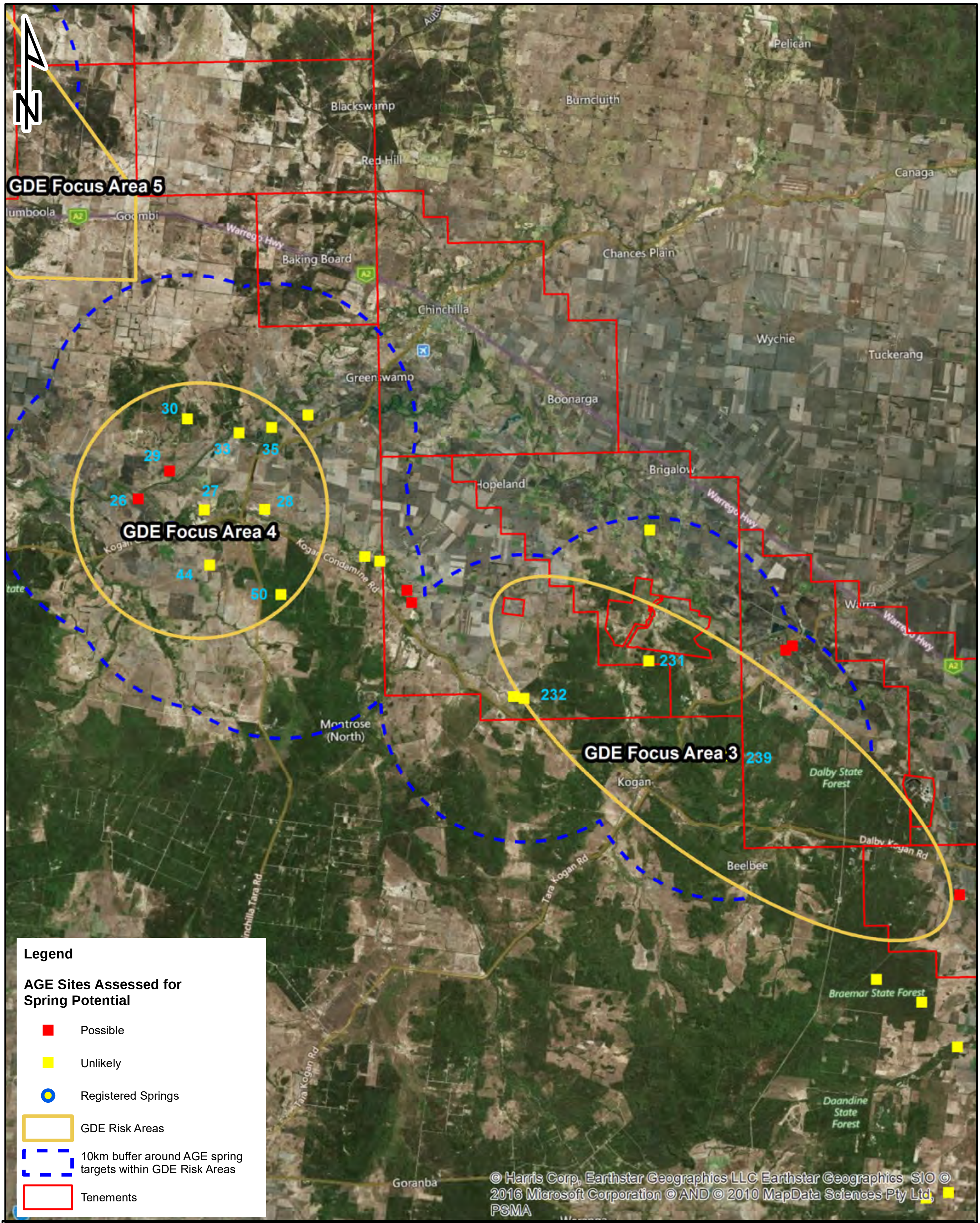

Appendix C. Likelihood of Spring Occurrence

Client ARROW ENERGY

0 4 8 12 16
Kilometers

Scale 1:350,000 | **Drawn By** DG | **Date** 02-Sep-16 | A4

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3D ENVIRONMENTAL

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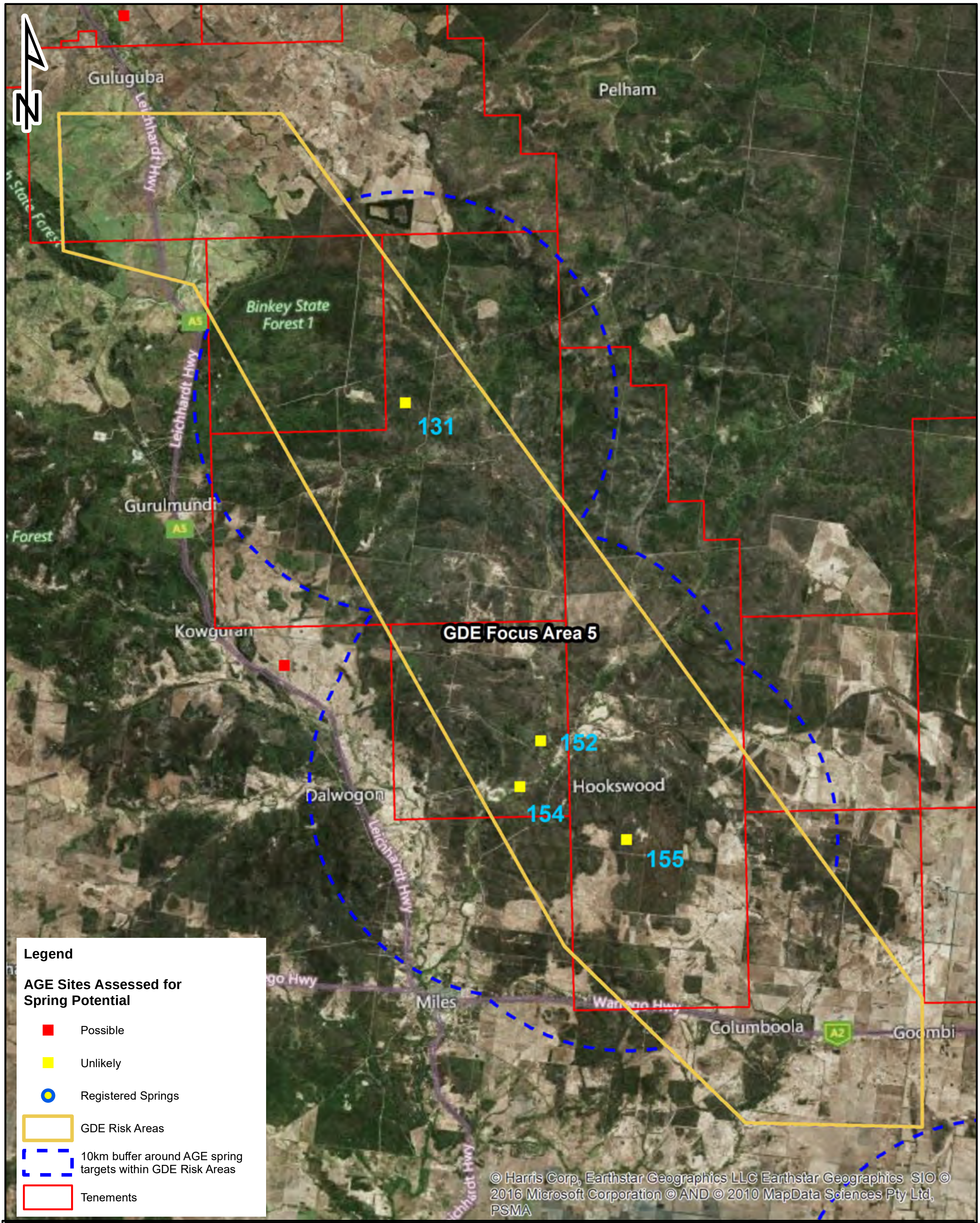

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Appendix C. Likelihood of Spring Occurrence

Client ARROW ENERGY

0 4 8 12 16

Kilometers

Scale 1:238,310 **Drawn By** DG **Date** 02-Sep-16 A4

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Appendix D. Field Assessment Summary of AGE Spring Targets.

Site No.	Landholder/ Property	Date	East	North	Initial GDE Potential	Vegetation	Geology	Geomorphology	Hydrology	Assessment
AGE 191	Kumbarilla State Forest	13/09/2016	297000	6963697	**Unlikely** (Localised to Wilkie Ck channel and tributaries)	NDVI signature possibly from sedge, herb and angophora presence. Well formed riparian vegetation dominated by *Eucalyptus camaldulensis* and scattered *Angorphora floribunda*. Ground cover of *Lomandra longifolia* and Juncus continuous. Predominantly native.	**Subcropping /outcropping geology:** None. **Cover rock geology/soils:** Silty sand with some sand and gravel banks	4-5 m deep incised channel on gently undulating colluvium slopes (weathered Westbourne (Kumbarilla)). Deep silty sand alluvium channel and overbank deposits. Vegetation transect at marked Spring Target site on sand bank at meander bend.	Isolated, more deeply incised waterhole. 200 m in length, 5 m wide. Note: had 5-7 mm rain 3 days prior. Part of Wilke Creek main channel. Flows north into Condamine River. Degraded from regular and recent cattle access.	Sand bank mid-stream may appear to look like a mound spring from aerial photography. No evidence of spring discharge **Not a Spring**
AGE 186	Kumbarilla State Forest	13/09/2016	297131	6965039	**Unlikely** (Localised to Wilkie Ck channel and tributaries)	Open waterbody with Nymphea spp., *Ludwigea pepaloide*s and *Ottellia ovalifolia*. Fringing woodland of Eucalyptus woollsii is heavily burnt.	**Subcropping /outcropping geology:** None outcrops at site, Highly weathered siltstone and sandstone Westbourne (Kumbarilla) regolith 200 m away in central channel. **Cover rock geology/soils:** Grey, organic rich clayey silt.	Creek overflow lagoon 20 m west of main channel. Perched on lower perm silts/clays detritus within alluvium above main creek channel. Separated by North-South oriented alluvium ridges.	Isolated shallow water hole, drainage likely to North during flood/flow. 150 m long and 15 m wide.	Regular access by cattle. Feed bins adjacent pools. No evidence of permnanent discharge **Not a Spring**
AGE 187	Kumbarilla State Forest	13/09/2016	297889	6965371	**Possible** (Localised to Wilkie Ck channel and tributaries)	Open forest with dominant Eucalyptus camaldulensis and lower canopy layer of Angophora floribunda.	**Subcropping /outcropping geology:** Minor, highly weathered outcrop of lateritic conglomerate in creek bank. Possibly tertiary equivalent of Chinchilla Sands. **Cover rock geology/soils:** Deep silt and sand alluvium.	Deeper waterhole in Wilkie Creek meander bend which may hold water for extended periods/permanently.	Isolated pool 200 m long by 20 m wide.	Significant dieback of canopy trees with up to 30% dead crowns. No evidence of permanent discharge **Not a Spring**

Site No.	Landholder/ Property	Date	East	North	Initial GDE Potential	Vegetation	Geology	Geomorphology	Hydrology	Assessment
AGE 194	Kumbarilla State Forest	13/09/2016	293988	6959297	Possible (Localised to Wilkie Ck channel and tributaries)	Shrubby woodland with overstory of Eucalyptus camaldulensis over a dense shrub and sub-canopy layer of Callitris glaucophylla. Predominantly native species	Subcropping /outcropping geology: Weathered sandstone outcrop in secondary channel bank. Brown, poorly sorted fine to coarse grained. Cover rock geology/soils: Silt and sand alluvium around main channel. Colluvium wash away from channel.	Incised waterhole in main Wilkie Creek channel. Scoured to bedrock base (siltstone and sandstone) evident at southern end of pool.	Isolated string of small pools. Largest 50 m long. Disturbance from cattle access.	Disturbed remnant habitat Not a Spring
AGE 184	Kumbarilla State Forest	13/09/2016	289528	6964494	Unlikely	Woodland of Eucalyptus woollsiana on broad loamy clay plain. Moderately disturbed	Subcropping /outcropping geology: Highly weathered sandstone and siltstone.Cover rock geology/soils: Sandy colluvium	Excavated dam 75 m x 25 m	Very small catchment, not much larger than excavation and spoil	Disturbed remnant habitat Not a Spring
AGE 182	Kumbarilla State Forest	13/09/2016	286038	6968186	Unlikely	Dense regrowth of Casuarina cristata with scattered remnant Eucalyptus populnea.¶Likely high chlorophyll NDVI signature due to dense stand of Casuarina cristata..	Subcropping /outcropping geology: Nearby ridge under powerlines: medium to conglomeritic sandstone Cover rock geology/soils: sand and gravel colluvium.	No surface water present. No waterway or depression in landscape.	Dry with no significant sign of surface water	Likely artefact of NDVI mapping. Not a Spring
AGE 224	Arrow	16/09/2016	318954	6914074	unlikely	Riparian vegetation dominated by Angophora floribunda on he margins of an excavated drainage basin. Drainage area has native aquatic vegetation including Eleocharis sp. and Juncus continuous	Subcropping /outcropping geology: Springbok sandstone outcrop 300 m south from target site. Poorly sorted, fine to coarse grained sandstone.	Transitional drainage basin with overflow to flowing creek. Likely to be typically dry. Clay and vegetation in basin desiccated.	2-3 mm pooling in drainage basin from recent rainfall - 30 mm and 15 mm over previous 2 days. Fast moving flow in creek.	

Site No.	Landholder/ Property	Date	East	North	Initial GDE Potential	Vegetation	Geology	Geomorphology	Hydrology	Assessment
AGE 211		16/09/2016	320955	6950409	Possible (part of Condamine R riparian corridor)	Degraded riparian vegetation dominated by Eucalypts camaldulensis and scattered Angophora floribunda. Margins of overflow stream channel. Numerous large turtles noted	Subcropping /outcropping geology: None Cover rock geology/soils: Silty clay flood over-bank deposits..	Overflow/oxbow channel west of main Condamine River channel. 150x40m.¶May receive seepage/ pressure relief from higher floodplain alluvium and capillary fringe in cracked clay could sustain moisture for extended periods	Isolated pool full of recent rainfall run-off. Cracked clay above and below water line indicates may have been much smaller pool or dry before recent rainfall.	Associated with surface flow of Condamine River. Not a Spring
AGE 245	Rutledge	16/09/2016	304950	312076	Possible (Localised to Wilkie Ck channel and tributaries)	Overflow channel fringed by Eucalyptus camaldulensis with a sub-canopy mixed with Acacia harpophylla and Casuarina christata, Acacia salicinia	Subcropping /outcropping geology: None Cover rock geology/soils: Clayey silt flood over bank deposits.	Creek overflow channel. Dish shaped depression approx., 2 m below adjacent floodplain terrace and 1-2 m above main channel (dry) to north east in Wilkie Creek.	Dry even after recent rain. Deep cracking soils in base of depression, likely absorbing recent run-off.	Degraded from cattle access. Associated with surface flow of Wilkie Creek Not a Spring
AGE 233	Reserve	17/09/2016	269210	7013231	Possible (localised to alluvium associate with tributary of Wambo Ck)	Natural waterbody in dry watercourse with fringing vegetation occupied by Juncus continuus and Cyperus laevis. Numerous very large old Euc.Cameldulensis and Angophora Leiocarpa in Ironbark and Cypress vege type.	Subcropping /outcropping geology: None Cover rock geology/soils: Grey/brown clayey sandy silt.	Elongated shallow depression in drainage channel. Retention basin 60x30m. Likely to have been dry prior to recent rainfall. Some modification by excavation possible, but not clear.	Isolated shallow pool of recent rainfall fun-off. No flow.	
AGE 232		17/09/2016	269952	7013095	Possible (localised to alluvium associate with tributary of Wambo Ck)	Open drainage line with woodland of Eucalyptus camaldulensis. Minor Callitris glaucophylla. Groundcovers native with Lomandra longifolia and Cyperus sp.	Subcropping /outcropping geology: None Cover rock geology/soils: Clayey sandy silt/silty sand (loamy)	Excavated dam 80x40m. Excavated in shallow, broad drainage feature.	No flow from dam or in narrow incised channel that flows around. Full sinuous shallow drainage channel with reasonable flow rate 300 m south of 232. Flowing water ends abruptly (continues as baseflow at 270049, 7013083 into sandy alluvium subsurface.	No evidence of discharge. Not a Spring

Site No.	Landholder/ Property	Date	East	North	Initial GDE Potential	Vegetation	Geology	Geomorphology	Hydrology	Assessment
AGE 911	Trebilco	17/9/16 30/11/16	260054	7022591	Possible	Open wetland with Eleocharis dulcis, Ottellia ovalifolia, Lemna minor, Nymphea sp.	Subcropping /outcropping geology: None Cover rock geology/soils: Floodplain above spring site is brown/orange poorly sorted fine to medium silica sand (Chinchilla sand origin?). Finer grey silty sand around creek bank.Hand auger HA6 encountered Clayey silt with approx. 5-10% sand to 1.3m refusal in very tight silt. Likely to represent clay base for retention of seepage and overland flow.	Natural wetland. Surface expression of sandy seepage zone in low point in landscape. East – west orientated broad shallow pool approx. 300 x 50m.Pool underlain by silt and organic material forming retention basin. This was supported by hand auger which encountered tight clayey silt.	No flow. Likely water table window.DO 3.98ppm, Cond 115.9us/cm; pH 7.1; Redox 111mV; Temp 36^{0}C; TDS 50.2ppm	Water samples collected. Cattle observed in wetland.
AGE 910	Trebilco	17/9/16 30/11/16	262134	7019740	Possible	Open wetland fringed by well-developed open forest of Angophora floribunda and scattered Eucalyptus tereticornis. Mostly native groundcovers. Habitat in excellent condition.	Subcropping /outcropping geology: None Cover rock geology/soils: Sandy rises/terraces and swampy depressions underlain by silty clay.Hand auger HA2 – 15m from pond 0-2.3m: SAND; Brown, poorly sorted fine to medium, sub-angular to sub-rounded quartz sand. Moist, <5% organic matter, 5% silt.Hand Auger HA3 – Adjacent to pool (3m) and 1.6m elevation below HA2 0-0.45 SILTY SAND 0.45 – 1.4 SAND as above, moist to wet.1.4 – 2.3 Grey	Round dish shaped depression in sandy plain.	No flow. Water level approx. 2 m below surrounding plain. Water relatively clear (in sandy soil) and fish visible (boney bream?). Likely water table window	

Site No.	Landholder/ Property	Date	East	North	Initial GDE Potential	Vegetation	Geology	Geomorphology	Hydrology	Assessment
							Clayey sand, saturated, low organic content. Likely base of pond?			
AGE 154	Vonhoffen "Vonhaven"	22/9/16 1/12/16	223846	7058316	Possible (Localised to alluvium associate with Dogwood Ck and tributaries)	Water lillies and other aquatic plants	Subcropping /outcropping geology: Medium to coarse Springbok sandstone outcropping in 6m+ high ridge on southern side of pond. Same sandstone commonly outcropping on higher ridges and in Dogwood creek. Cover rock geology/soils: Silty sand.	Natural retention basin perched above main dogwood Creek channel and adjacent weathered sandstone escarpment outcrop.	Deep clear pool in overland flow path parallel to main creek channel. Likely receiving seepage from base of sandstone which borders pool to the west. Likely subsurface baseflow exiting pool to lower elevation main channel to east and overland flow to south. Within possible broader Dogwood Ck alluvium subsurface GDE system. DO 2.1ppm; Cond. 130us/cm; pH 7.2; Redox 211mV; Temp 27^{0}C; TDS 87.1ppm	Water samples collected. Possible discharge from Springbok Sandstone outcrop.

Site No.	Landholder/ Property	Date	East	North	Initial GDE Potential	Vegetation	Geology	Geomorphology	Hydrology	Assessment
AGE 131	Frank	18/09/2016	218404	7076517	Possible (Localised to alluvium associate with Dogwood Ck and tributaries)	Rocky pavement with woodland of Angophora leiocarpa, Corymbia bloxomei and shrub layer of Leptospermum polygalifolium. Vegetation in good condition	Subcropping /outcropping geology: shallow dipping to horizontal siltstone and fine to medium rounded sandstone with some thin coarse sands and conglomerate beds. Springbok sandstone. Cover rock geology/soils: Poorly sorted fine to coarse sand.	Weathered horizontal rocky terraces, thin sandy soil cover. Gently sloping towards relatively fast flowing narrow streams over bedrock base.	Shallow rock pools and channels scoured into weathered siltstone and sandstone terraces with thin sandy soil cover. Fast flowing narrow streams over bedrock base. Alternating fast flowing and non-flowing reaches indicative of subsurface baseflow. Likely “losing stream” reach within weathered Springbok sandstone bedrock. Indicates Springbok Sandstone recharge area.Water relatively clear with 150-200 mm sized fish observed. Wider pools linked by narrow fast flowing channels. Flowing in an easterly direction.	No evidence of discharge – Not a Spring
AGE 155		18/09/2016	228901	7055808	Unlikely	Degraded weedy vegetation with cover of Cynodon dactylon on disturbed banks. Eleocharis dulcis growing on margins of dam	Subcropping /outcropping geology: Very weathered sandstone and conglomerate. Cover rock geology/soils: Sandy gravelly scree.	Excavated dam in a swampy silt retention basin on sandy and gravelly colluvium. Gentle slope from west to east.	Ponded water in isolated pool. 80x40 m. No flow, shallow.	Not a Spring
AGE 908 - Close to GDE1 & GDE2	Hayward	29/11/2016	288567	7016747	Possible (part of Condamine R riparian corridor)	Permanent wetland with dense groundcover of Carex appressa on fringes. Adjacent woodland habitat dominated by Eucalyptus coolabah on high bank of Condamine River. Riparian vegetation in good health.	Subcropping /outcropping geology: Nearby outcrop of medium grained sandstone (likely Springbok) in eastern bank of river (in eroded gully) with exposure of massive (approx. 2.5m) beds. Cover rock geology/soils: Sandy silt and silty sand alluvium. Some pebbly colluvium lag deposits.	Overflow wetland perched above main Condamine River channel with clay/detritus base (confirmed through shallow hand-dug excavation of pond base).	Shallow pool 15 x 50m with relatively clear water likely to have accumulated and run into depression during recent rainfall (43mm in Warra gauge within last 48 hours). No flow.	Possible baseflow identified at base of CRA in river bed. Not a Spring Likely Vegetation GDE

Site No.	Landholder/ Property	Date	East	North	Initial GDE Potential	Vegetation	Geology	Geomorphology	Hydrology	Assessment
AGE 29	QGC – Leased to Stanbroke	30/11/2016	245264	7028915	Unlikely	Broad drainage depression with groundcover dominated by Phylla canescens (Lippia). Woodland on margins of depression formed by Eucalyptus coolabah. Fringing vegetation in good health.	Subcropping /outcropping geology: None Cover rock geology/soils: deeply cracked black clay.	Broad shallow depression in overland flow path. Likely only to contain water during flood or after protracted rainfall.	300 x 100m depression dry at time of visit.	Associated with overfflow of Condamine River. Not a Spring
AGE 26	QGC – Leased to Stanbroke	1/12/2016	243082	7026986	Unlikely	Broad drainage depression with groundcover dominated by Phylla canescens (Lippia). Woodland on margins of depression formed by Eucalyptus coolabah. Fringing vegetation in good health.	Subcropping /outcropping geology: None Cover rock geology/soils: deeply cracked black clay.	Broad shallow depression in overland flow path. Likely only to contain water during flood or after protracted rainfall.	30Dry overland flow path at time of visitation.	Associated with surface flow of Condamine River. Not a Spring
AGE 151	Little	1/12/2016	212685	7064059	Unlikely	No significant remnant veg. remaining. Dam occupied by fringe of Carex apressa, Eleocharis dulcis and ludwigia pepaloides	Subcropping /outcropping geology: None Cover rock geology/soils: Sandy silt loam with occasional well rounded quartzose gravel and cobbles colluvium. Gravel quarry nearby with pebbles and cobbles weathered out of underlying sandstone (Springbok?)	Excavated dam in gully capturing overland flow from significant catchment prior to discharge to adjacent creek. Isolated pool in creek. No obvious seepage zones.	Dam full from recent rainfall/run-off. DO 2.06ppm; Cond. 636us/cm; pH 7.6; redox 39mV Temp 22.8^{0}C; TDS 298ppm.	See sketch Not a Spring

Appendix E. Field Assessment Summary of Vegetation GDE Sites and Identified Springs

Site No./Name	Landholder/Property	Date	Time	East	NOrth	GDE Potential	Vegetation	Geology	Geomorphology	Hydrology	Other Comments
Long Swamp	Arrow – adjacent L. Broadwater Road on west side.	14/9/16	13.45	312207	6981260	Likely	Open woodland of Eucalyptus camaldulensis over mixed native and exotic groundcovers. Dominant species include Eleocharis plana, Marsillea drummondii, Ereochloa sp.	Subcropping /outcropping geology: None Cover rock geology/soils: Quaternary alluvium. Cracking clay soils. Sandy silty clay. Minor rounded gravel.	Visited a number of sites on Long Swamp ephemeral wetland. Meandering shallow drainage depression on western margin of Condamine Alluvium floodplain. Wide shallow channels divided by lenticular alluvial terraces up to 2m higher than channels. No flow in swamp at time of field survey, but numerous isolated pools and dams noted. SWL 18.3mbgl	Dry. Regularly contains water and floods. Flows NW into Condamine River. Established dam 80x40 m collecting overland flow from SE. Dam full. Located on broad reach of swamp. Recently excavated dam 50x10m in Long Swamp on east side of road.	Springvale Road DNRM monitoring site 322719, 6976684 Disused water bores (x2), one with derelict windmill. Located on slightly elevated ground to SE of drainage channel. One collapsed and dry at 2.3m; The other SWL 18mbgl; DTB = 21.4mbgl (collapsed?) Another windmill 800 m from 315610E, S6975982S in area of Long Swamp showing sign of eucalyptus stress and another near homestead to north. Possible eucalyptus stress monitoring site. Good comparison with no stress site on Arrow property. Need to get annual irrigation rate used at Arrow Broadwater property extracted from Broadwater Swamp (3000 ML? dam).
Lake Broadwater	Reserve	15/9/16	15:00	312076	6974311	Likely	Woodland of Eucalyptus camaldulensis with	Subcropping/outcropping geology: none	Very large circular drainage basin fringed by low wave-formed	Sandy soils with high permeability	Water sample collected.

Site No./Name	Landholder/Property	Date	Time	East	NOrth	GDE Potential	Vegetation	Geology	Geomorphology	Hydrology	Other Comments
							native dominant groundcovers. Associated with sandy Aeolian sheet on margins of the lake.	Cover rock geology/soils: Hand auger HA1 in NW corner of lake. Elevation of ground at HA1 1.35m above elevation of lake water surface (rangefinder tipsometer). 0-0.65 Dark brown SAND; Very fine to fine, subangular to angular quartose, organic rich, moist. 0.65 – 1.35 Dark Brown indurated silty sand, orange mottling, sand as above. 1.35 – 2.3 Sandy Silty CLAY: Grey to orange, iron-rich, mottled, sub-plastic, with 5-10% sand content, moist. 2.3m – extent of auger lengths.	sandy rises. Likely to be a perched intermittent depositional and scouring feature, receiving lacustrine sedimentation as wash from local colluvium, and draining to the north during periods of prolonged rainfall/flooding. Possibly connected to a localised and shallow alluvium GDE overlying weathered Jurassic bedrock.		SWL 16.2mbgl to west of Lake
Condamine River 1	Reserve - Kogan-Condamine Road Crossing of Condamine River	17/9/16	07.50.	310665	6998812	Likely (part of Condamine R riparian corridor)	Open riparian forest of Eucalyptus camaldulensis with canopy height to 25m. Significant dieback of Casuarina cunninghamiana and Eucalyptus camldulensis showing visible stress in some localities	Subcropping /outcropping geology: Cover rock geology/soils: Clay, sandy silt bank and over bank with lenticular sands and gravel banks in river bed. Poorly sorted sub-angular to rounded.	7-8 m high incised channel with isolated waterholes. Approx. 30 m wide, NNW orientated reach.	No flow	Degraded by trailbike and 4WD access. Publicly accessible. SWL = 13.3mbgl (2013)
Braemar Ck Outcrop	Road Reserve	17/9/16	8:30	288349	7004147	Likely (localised to Braemar Creek channel and tributaries)	Riparian open forest of Eucalyptus camaldulensis on lower creek benches. Anagophora leiocarpa woodland growing on exposed sandstone jump-up. Vegetation healthy.	Subcropping /outcropping geology: Fresh road cutting through weathered Springbok Sandstone . Poorly sorted fine to coarse, with minor conglomeritic bands. 1m high cross bedding truncated on relatively	Near vertical creek incision though Springbok Sandstone beds. Rocky sided bank to east approximately 2 m higher than low bank to east.	Minor flow to North between series of deeper pools	

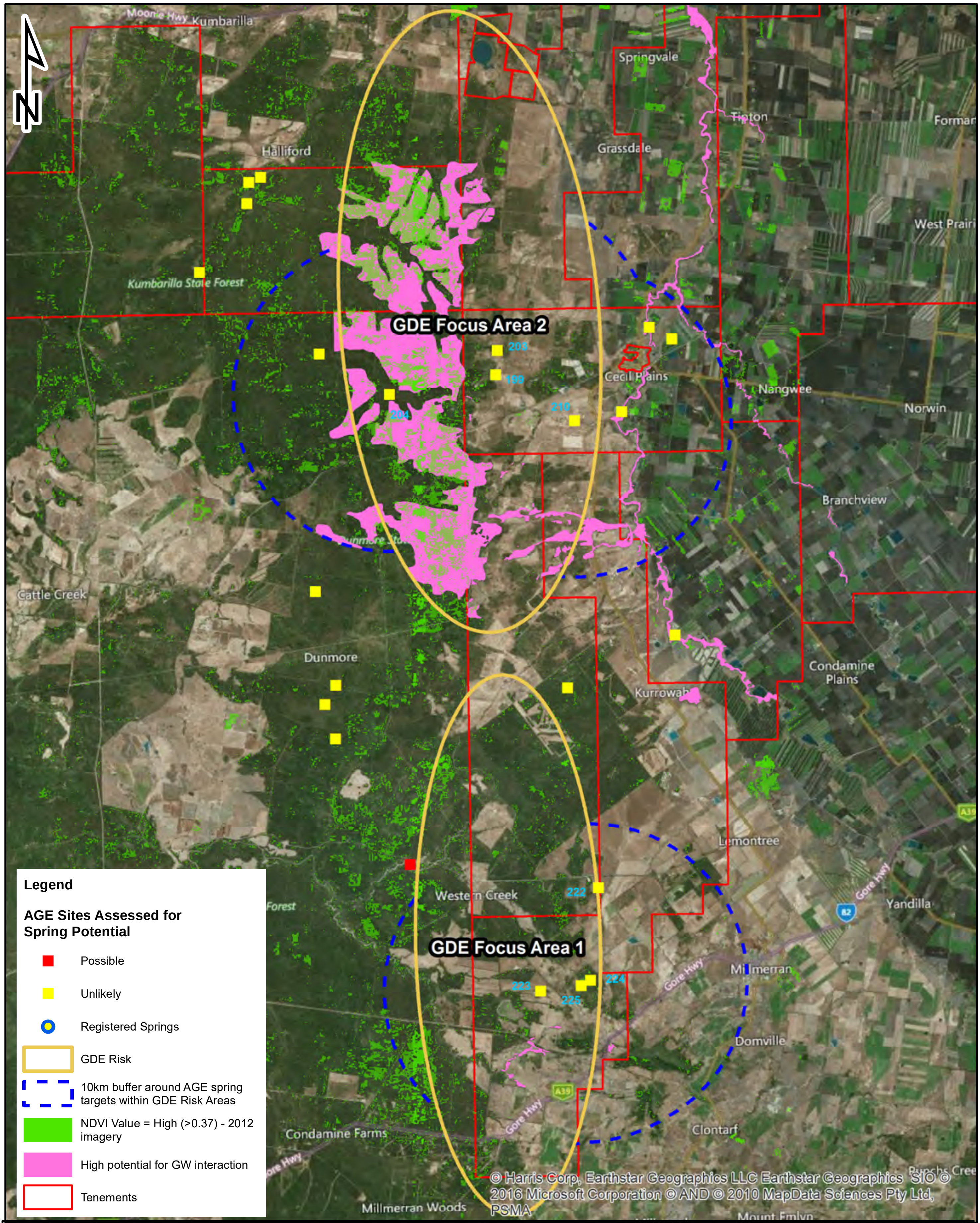
Site No./Name	Landholder/Property	Date	Time	East	NOrth	GDE Potential	Vegetation	Geology	Geomorphology	Hydrology	Other Comments
								horizontal bedding planes. Minor fracturing. Occasional siltstone inclusions to 300mm diameter in sandstone (possibly overbank slump). Some siltstone beds in cutting on north side of road. Cover rock geology/soils:Thin localised sandy and gravelly alluvium directly over Sandstone bedrock. Creek meandering through sandy weathered bedrock colluvium			
Spring 1 (Tribelco Spring)	Trebilco	17/9/16 30/11/16	12.15 13:00	260300	7021517	Likely	Small area of Well-developed aquatic vegetation dominated by Leersia hexandra, Juncus continuus, Carex appressa, Phyllidrium lanuginosum	Subcropping /outcropping geology: None Cover rock geology/soils: Floodplain above spring site is brown/orange poorly sorted fine to medium silica sand (Chinchilla sand origin?). Finer grey silty sand around creek bank indicative of more recent flood deposition. 2 hand augers (HA4 and HA5) near spring encountered fine to medium sand which repeatedly collapsed below the water table. Saturated at 0.5-0.8m 2m from seep, and 1.1m 4m from the seep. Elevation difference suggests a 400-500mm	Unregistered spring site in creek bank discharging from sandy alluvial plain. See sketch.	Gentle flow from south to north. Main pool approx.. 30m long x 20 m wide. Very minor flow out of pool during 30/11/16 visit. Surface Water Quality in seep; main pool; 70m downstream DO(ppm): 0.72; 0.18; 2.25 Cond(us/cm); 151.7; 237; 246 pH: 5.36; 5.88; 6.75 Redox(mV): 217; 95; 79 Temp(^{0}C): 24; 27; 29.4 TDS(ppm): 72.9; 107; 110	PVC bore near spring: DTW = 1.92mbgl TOC; DTB = 4.09 Stick-up = 0.62. Landholder would like to know more about springs and may be open to monitoring according to Richard. Access by cattle, although attempt has been made to fence off main pool. Water samples collected

Site No./Name	Landholder/Property	Date	Time	East	NOrth	GDE Potential	Vegetation	Geology	Geomorphology	Hydrology	Other Comments
								fall in SWL across 6m – steep hydraulic gradient.			
Bowenville Spring	Bowenville Reserve on Oakey Creek	19/9/16 1/12/16	10.40 16:30	347093	6976423	Likely	Riparian open forest with dominant Eucalyptus tereticornis. Well-developed SI of Acacia stenophylla with margins of creek fringed by Baumea rubiginosa and Carex apressa. Riparian vegetation in good condition.	Subcropping /outcropping geology: Main Range Volcanics? Nearby basalt quarry on Condamine Alluvium floodplain. Nearby groundwater bore logs show significant subcropping coal under volcanics Cover rock geology/soils: Clayey sandy silt alluvium.	Shallow incised in broader Oakey Creek channel. Located on Condamine Alluvium floodplain. This system seems to be sitting much higher in the floodplain and flowing much faster than the Condamine. Oakey creek is flowing off an elevated gently undulating weathered basalt plateau above the Condamine Floodplain.	Fast flowing stream (Oakey Creek) discharging from deep pool over small weir under bridge (road). Still flowing strongly (visually at similar rate) during second visit during dryer period. DO 6.35ppm; Cond. 1140us/cm; pH 7.94; Redox 92mV; Temp 25.8^{0}C; TDS 554ppm	Water sample collected. Potential subsurface volcanics GDE connected to broader Condamine River Alluvium.
GDE5	Cross "Barrington"	28/11/16	13.50	324351	6958294	Likely (part of Condamine R riparian corridor)	Remnant riparian vegetation. Tall open forest with Eucalyptus camaldulensis, Angophora leiocarpa and Corymbia intermedia. Groundcover dominated by exotic grasses including Megathyrsus maximum. Var. trichoglume. Remnant vegetation in good condition with only minor dieback evident	Subcropping /outcropping geology: None Cover rock geology/soils: No outcrop. Condamine River Alluvium. Sandy silt loam; sand and gravel banks within river and on terraces (banks) within.	Confluence of Condamine River and tributary. Survey site in an isolated slightly deeper channel incision pool.	Meandering channels within a 500m wide vegetated pool 100 m long. Likely received runoff form overnight rainfall.	Moderately degraded by cattle access.
Condamine River 2 (close to GDE5)	Road reserve adjacent river crossing	28/11/16	15.00	326058	6955610	Likely (part of Condamine R riparian corridor)	Riparian vegetation in very poor condition. Dominated by degraded woodland of Eucalyptus camaldulensis with a dense shrub and sub-canopy layer of Acacia stenophylla.	Subcropping /outcropping geology: No outcrop. On Condamine Alluvium. Cover rock geology/soils: Sandy silt (loam). Sand and gravel banks in main channel.	Southern continuation of GDE5. 4-5m channel, 4-5 m below surrounding flood plain.	Shallow incision 100 m wide with isolated pools. Not main Condamine River. Condamine North Branch.	Visited another road crossing of Condamine River North nearby (328280E,6952354S) – similar to CR1. Pump intake nearby pumping into dam adjacent road.

Site No./Name	Landholder/Property	Date	Time	East	NOrth	GDE Potential	Vegetation	Geology	Geomorphology	Hydrology	Other Comments
							Severe dieback noted in both canopy and shrub layers. Canopy has been thinned to margins of watercourse				
GDE3	In Conservation Reserve.	28/11/16	16.00	325593	6975735	Likely (part of Condamine R riparian corridor)	Vegetation adjacent river in good health. Most vegetation on higher floodplain terrace away from channel and pools is in very poor health with severe dieback noted. Dominant canopy in Eucalyptus populnea woodland is extremely degraded with up to 50% canopy senescence.	Subcropping /outcropping geology: No outcrop. On Condamine Alluvium Cover rock geology/soils: Sandy silt on flood plain and upper banks. Large sand and gravel deposits on inside of meander bends.	Deeply incised meander bend of Condamine River. Bed of river 10+ m below flood plain.	Flow between deeper pools – likely due to 100 mm of rain overnight.	No cattle access.
GDE1	Reserve on Condamine River (just north of Tong Park)	29/11/16	12.15	288525	7017029	Likely (part of Condamine R riparian corridor)	Tall open riparian forest with dominant Eucalyptus camaldulensis, Corymbia tessellaris and Eucalyptus coolabah on fringes. Mixture of native and exotic grasses in groundcover. Canopy health excellent with minimal dieback noted.	Subcropping /outcropping geology: Weathered siltstone/sandstone and conglomerate in bamk on western meander bend. Cover rock geology/soils:	Deeply incised meander bend in Condamine. Condamine Alluvium Floodplain to North; jump up in elevation to slightly undulating weathered Springbok Sandstone/WCM to south. Rocky (base of weathered outcrop) and sandy river bed, silty sandy loam on terrace above.	Isolated pool, no flow. 2 seepage zone on northern bank, east of pump intake. DO 2.2ppm; pH 7.55; Redox 104mV; Temp 32.9^0C; TDS 307ppm.	Water sample collected. Minimal evidence of cattle access. Some vehicle access. Nearby DNRM monitoring bore (locked).
GDE4	Camping Reserve	30/11/15	16.00	269407	7034063	Likely	Well-developed riparian forest with dominant Angophora floribunda and Eucalyptus camaldulensis. Groundcover formed by a mix of native and exotic grasses including	Subcropping /outcropping geology: No outcrop. On Condamine Alluvium Cover rock geology/soils: Alluvial clay loam on flood plain and upper banks. Lower terrace on river.	Broad meander on Condamine River. Lower river terrace approximately 6m below upper terrace.	River is full to near overflow with back-up a result of Condamine Weir approximately 12km down the river	Water monitoring bores installed on lower terrace of river.

Site No./Name	Landholder/Property	Date	Time	East	NOrth	GDE Potential	Vegetation	Geology	Geomorphology	Hydrology	Other Comments
							Megathyrsus maximum var. trichoglume* and Chionachne cyathopoda. Canopy in excellent condition with no visible dieback				

Appendix F. NDVI datasets with GDE Risk Mapping.



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Appendix F. High NDVI Values over High Potential GDE Areas

Client ARROW ENERGY

0 4 8 12 16
Kilometers

Scale 1:321,203 **Drawn By** DG **Date** 02-Sep-16 A4

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Kenmore, Qld 4069
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ENVIRONMENTAL 3D

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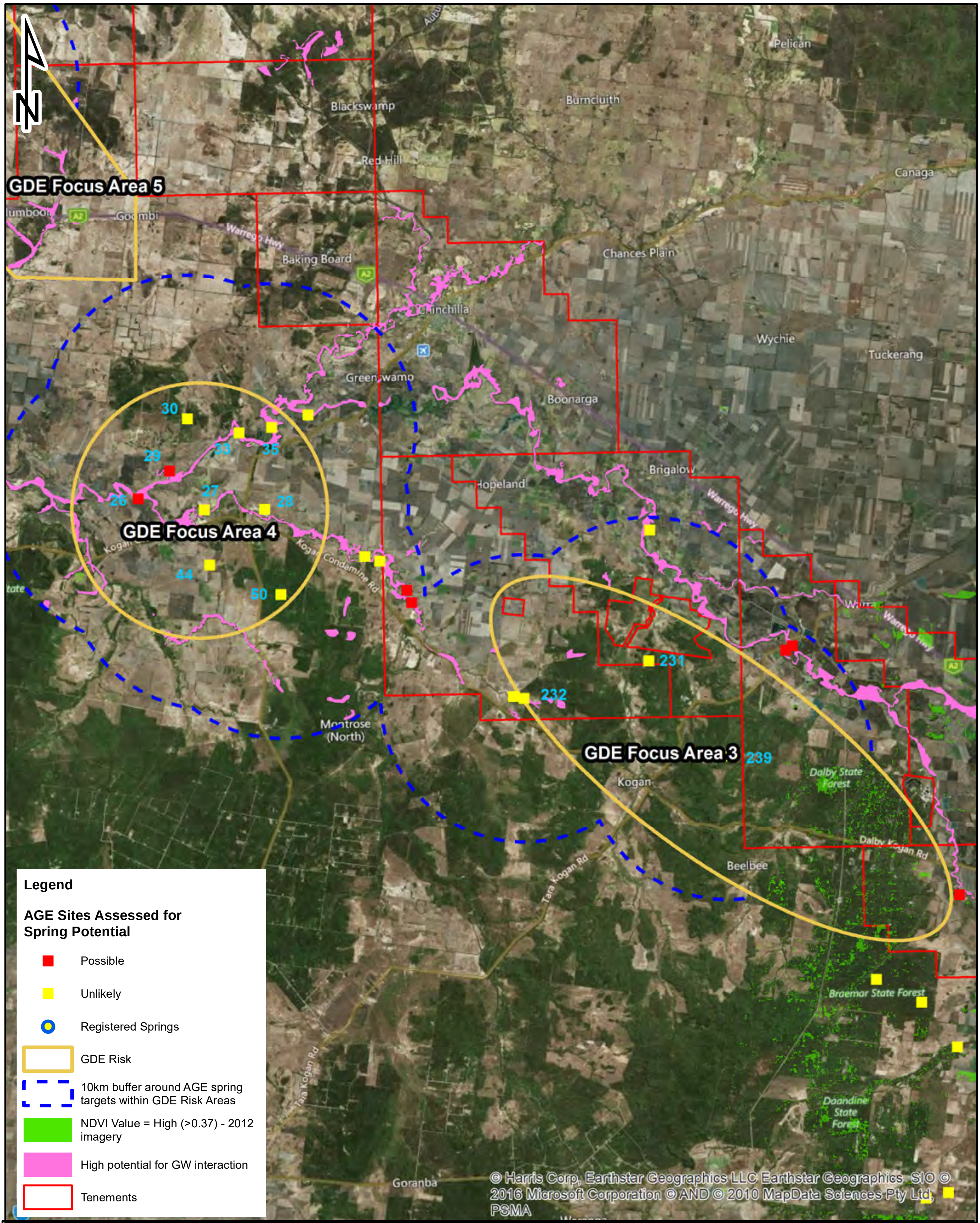

Appendix F. High NDVI Values over High Potential GDE Areas

Client ARROW ENERGY

Scale 1:350,000 **Drawn By** DG **Date** 02-Sep-16 A4

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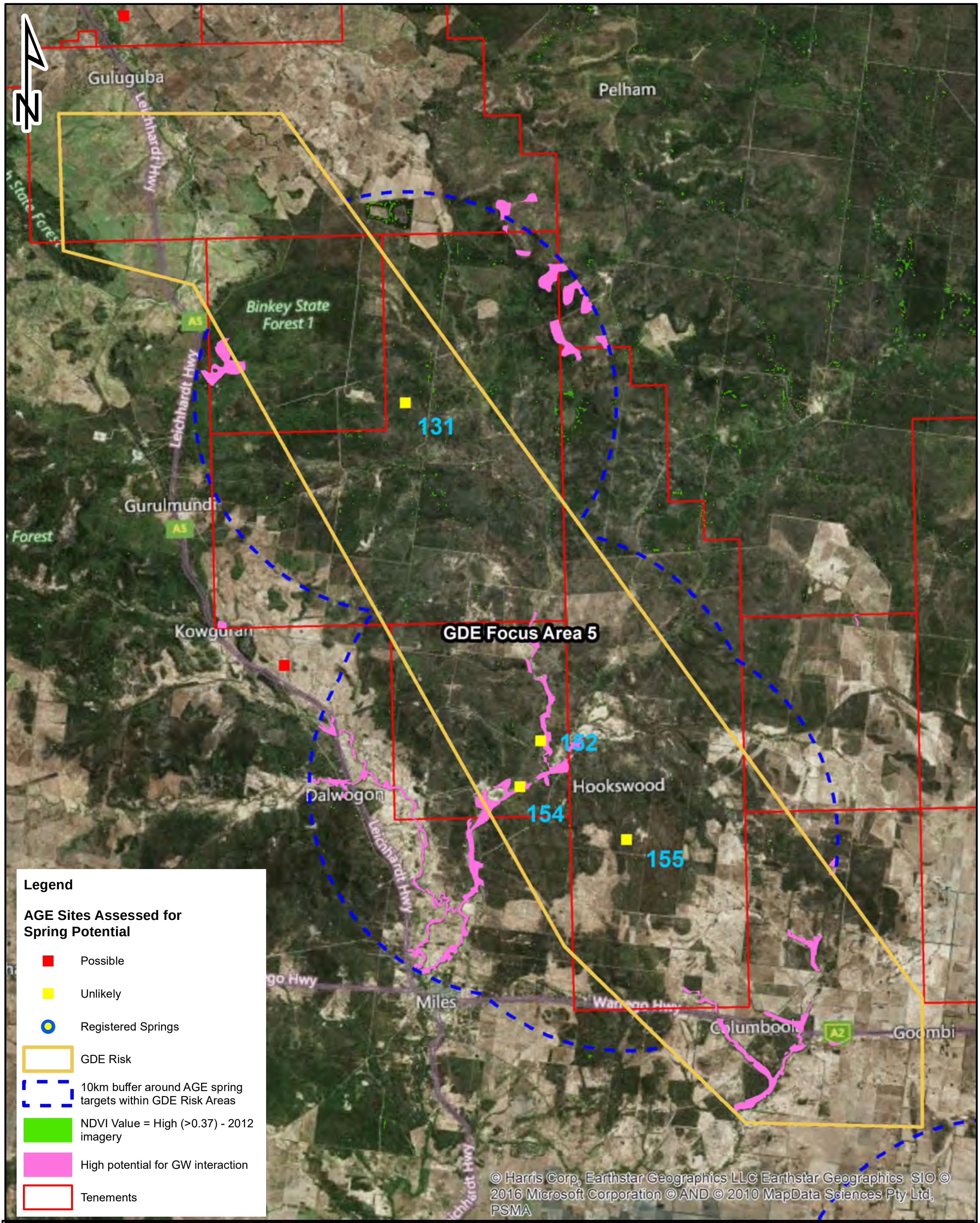

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Appendix F. High NDVI Values over High Potential GDE Areas

Client ARROW ENERGY

0 4 8 12 16
Kilometers

Scale 1:238,310 **Drawn By** DG **Date** 02-Sep-16 A4

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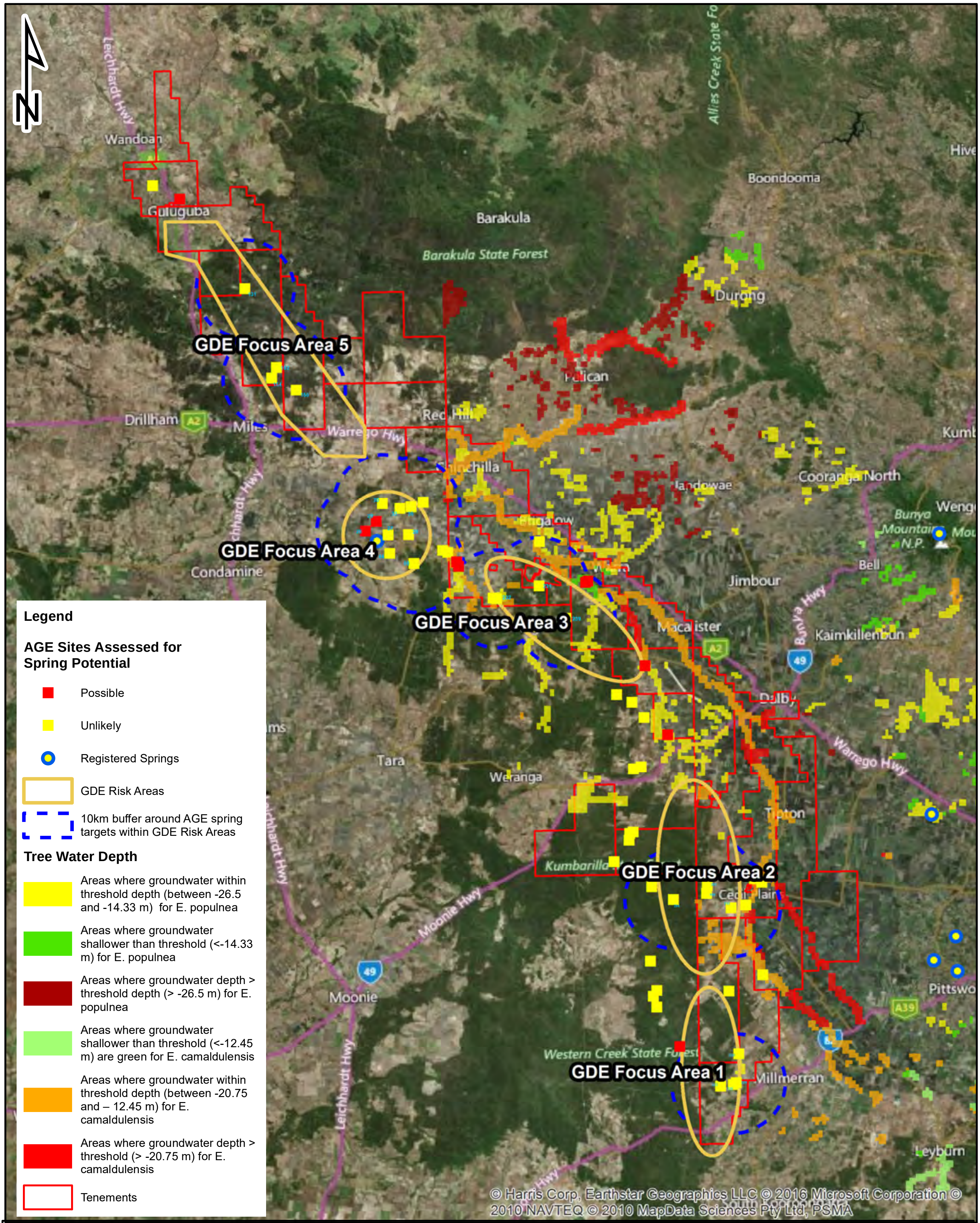
Appendix G. Vegetation Threshold Mapping on CRA from Kath et al (2014)



Appendix G. Groundwater Threshold depths for GDE Vegetation (from Kath et al 2014)

Client ARROW ENERGY

Scale 1:1,027,534 **Drawn By** DG **Date** 02-Sep-16 A4

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Appendix H. Water chemistry laboratory reports and QA/QC documentation

Isotope Tracing in Natural Systems Analytical Report

Client:	**Earth Search** **15 Hampson st** **Kelvin grove** **QLD 4059**
Contacts:	**Ned Hamer**
email:	ned@earthsearch.com.au
Report Number:	**2016/0338**
Batch Description:	**Radon in water**
Samples Received:	**6**
Registration Date:	**1-Dec-2016**
Report Date:	**7-Dec-2016**
Logged By:	**Robert Chisari**
Funds Type:	**Commercial: Earth Search**
Supervising Analyst:	**Robert Chisari**

Signature: Robert Chisari Date 07-Dec-2016
Robert Chisari

Sample Identification

LIMS ID	Client Identification	Sample Description
2016/0338-1	Broadwater 1	Groundwater
2016/0338-2	GDE 1	Groundwater
2016/0338-3	Spring 1	Groundwater
2016/0338-4	Swamp 1	Groundwater
2016/0338-5	154	Groundwater
2016/0338-6	Bowenville 1	Groundwater

Institute for Environmental Research
Analytical Report

Report Number: 2016/0338

Radon-222 Concentration at Sampling Date

Client Identification	Sample No.	Date Sample Collected	Radon Activity Bq/L	Uncertainty[1] Bq/L	MDA[2] Bq/L
Broadwater 1	1	29-Nov-2016	0.12	0.01	0.05
GDE 1	2	29-Nov-2016	0.03 ^	0.01	0.05
Spring 1	3	30-Nov-2016	5.47	0.27	0.05
Swamp 1	4	30-Nov-2016	0.09	0.01	0.05
154	5	1-Dec-2016	0.04 ^	0.01	0.05
Bowenville 1	6	1-Dec-2016	0.06	0.01	0.05

Notes:

1. Values reported are combined standard uncertainty, calculated to 1 sigma. A Coverage factor, *k*, of 2 may be used to calculate Expanded Uncertainty to 95% confidence.

2. The MDA (Minimum Detectable Activity) is calculated to 95% confidence.

^ This result is below the MDA and therefore has an unacceptable level of uncertainty. Hence, the data should only be used as an indicator of the true concentration

Signature: Robert Chisari Date: 07-Dec-2016
Robert Chisari

CHAIN OF CUSTODY

Att:

Due Date: 30/11/2016

Purchase Order #: 502287

ALS Batch #: EB1628281

PLEASE RETURN ESKY TO ALS BRISBANE

From: Australian Laboratory Services Pty Ltd (ABN 84 009 936 029)
2 Byth st
Stafford QLD 4053
PH: 07 3243 7222
FAX: 07 3352 3662

To: **ANSTO Enviro Isotopes Lab**
NEW ILLAWARA RD
LUCAS HEIGHTS NSW 2234 ATTN: Attn: Ba
PH: **02 9717 3987 or 02 9717 3283**

Please email results to: ***subresults.bri@alsenviro.com***

SAMPLE IDENTIFICATION		CONTAINER DATA #			LABORATORY PARAMETERS	
ALS sample	SAMPLE ID.	DATE	TYPE	NO.	Radon 222	COMMENTS
1	Broadwater 1	29/11/16	W	1	x	
2	~~DOE1~~ GDE 1	29/11/16	W	1	x	

NOTES:
1. Please ensure that a signed copy is emailed back immediately to subresults.bri@alsenviro.com acknowledging receipt.
2. Contact John Pickering if the requested TAT cannot be met .07 3552 8634

RELINQUISHED BY (SIGN / PRINT):
OF: ALS
DATE:
TIME:

RECEIVED BY (SIGN / PRINT):
OF: Robert Chisari
(ARRIVAL TEMP: deg. C)
DATE: 1-Dec-2016
TIME: 8:00

RELINQUISHED BY (SIGN / PRINT):
OF:
DATE:
TIME:

RECEIVED BY (SIGN / PRINT):
OF:
(ARRIVAL TEMP: deg. C)
DATE:
TIME:

AUSTRALIAN LABORATORY SERVICES P/L

CHAIN OF CUSTODY

Att:

Due Date: **12/01/2017**

Purchase Order #: **502292**

ALS Batch #: **EB1628373**

PLEASE RETURN ESKY TO ALS BRISBANE

From: Australian Laboratory Services Pty Ltd (ABN 84 009 936 029)
2 Byth st
Stafford QLD 4053
PH: 07 3243 7222
FAX: 07 3352 3662

To: **ANSTO Enviro Isotopes Lab**
NEW ILLAWARA RD
LUCAS HEIGHTS NSW 2234 ATTN: Attn: Ba
PH: **02 9717 3987 or 02 9717 3283**

Please email results to: ***subresults.bri@alsenviro.com***

	SAMPLE IDENTIFICATION	CONTAINER DATA #			LABORATORY PARAMETERS	
ALS sample	SAMPLE ID.	DATE	TYPE	NO.	Radon 222	COMMENTS
1	Spring 1	30/11/16	W	1	x	
2	Swamp 1	30/11/16	W	1	x	

NOTES:

1. Please ensure that a signed copy is emailed back immediately to subresults.bri@alsenviro.com acknowledging receipt.
2. Contact John Pickering if the requested TAT cannot be met .07 3552 8634

RELINQUISHED BY (SIGN / PRINT):
OF: ALS
DATE:
TIME:

RECEIVED BY (SIGN / PRINT):
OF: Robert Chisari
(ARRIVAL TEMP: deg. C)
DATE: 2-Dec-2016
TIME: 13:15

RELINQUISHED BY (SIGN / PRINT):
OF:
DATE:
TIME:

RECEIVED BY (SIGN / PRINT):
OF:
(ARRIVAL TEMP: deg. C)
DATE:
TIME:

AUSTRALIAN LABORATORY SERVICES P/L

1 of 1

9800 0785 7976

CHAIN OF CUSTODY

Att:

Due Date: **8/01/2017**

Purchase Order #: **502295**

ALS Batch #: **EB1628486**

PLEASE RETURN ESKY TO ALS BRISBANE

From: Australian Laboratory Services Pty Ltd (ABN 84 009 936 029)
2 Byth st
Stafford QLD 4053
PH: 07 3243 7222
FAX: 07 3352 3662

To: **ANSTO Enviro Isotopes Lab**
NEW ILLAWARA RD
LUCAS HEIGHTS NSW 2234 ATTN: Attn: Ba
PH: **02 9717 3987 or 02 9717 3283**

Please email results to: ***subresults.bri@alsenviro.com***

LABORATORY PARAMETERS

	SAMPLE IDENTIFICATION	CONTAINER DATA #				
ALS sample	SAMPLE ID.	DATE	TYPE	NO.	Radon 222	COMMENTS
001	Bowenville 1	01/12/16	W	1	x	2 x Vial
002	154	01/12/16	W	1	x	

NOTES:

1. Please ensure that a signed copy is emailed back immediately to subresults.bri@alsenviro.com acknowledging receipt.
2. Contact John Pickering if the requested TAT cannot be met .07 3552 8634

RELINQUISHED BY (SIGN / PRINT):
OF: ALS
DATE:
TIME:

RECEIVED BY (SIGN / PRINT):
OF: Robert Chisari
(ARRIVAL TEMP: deg. C)
DATE: 2-Dec-2016
TIME: 13:15

RELINQUISHED BY (SIGN / PRINT):
OF:
DATE:
TIME:

RECEIVED BY (SIGN / PRINT):
OF:
(ARRIVAL TEMP: deg. C)
DATE:
TIME:

AUSTRALIAN LABORATORY SERVICES P/L

CERTIFICATE OF ANALYSIS

Work Order	: **EB1628281**	Page	: 1 of 4
Client	: **EARTH SEARCH**	Laboratory	: Environmental Division Brisbane
Contact	: MR NED HAMER	Contact	: Customer Services EB
Address	: 15 HAMPSON STREET KELVIN GROVE QUEENSLAND 4059	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: ----	Telephone	: +61-7-3243 7222
Project	: GDE Assess	Date Samples Received	: 30-Nov-2016 10:00
Order number	: ----	Date Analysis Commenced	: 30-Nov-2016
C-O-C number	: ----	Issue Date	: 09-Mar-2017 14:21
Sampler	: NED HAMER		
Site	: ----		
Quote number	: BNBQ/101/16		
No. of samples received	: 2		
No. of samples analysed	: 2		

NATA

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Diana Mesa	2IC Organic Chemist	Brisbane Organics, Stafford, QLD
Greg Vogel	Laboratory Manager	Brisbane Inorganics, Stafford, QLD
Greg Vogel	Laboratory Manager	WB Water Lab Brisbane, Stafford, QLD
Martina Louw	Inorganic Chemist	Brisbane External Subcontracting, Stafford, QLD
Tom Maloney	Nutrients Section Supervisor	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When no sampling time is provided, the sampling time will default 00:00 on the date of sampling. If no sampling date is provided, the sampling date will be assumed by the laboratory and displayed in brackets without a time component.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- EP005: Result for sample may bias low due to large amounts of sediment. The sample was decanted before analysis.
- It is recognised that EP005 (Total Organic Carbon) is less than EP002 (Dissolved Organic Carbon) for sample. However, the difference is within experimental variation of the methods.
- TDS by method EA-015 may bias high due to the presence of fine particulate matter, which may pass through the prescribed GF/C paper.
- EA016: Calculated TDS is determined from Electrical conductivity using a conversion factor of 0.65.
- Subcontracted analysis reported in this work order is conducted by Environmental Isotopes. Environmental Isotopes does not hold NATA Accreditation for these parameters.

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**Broadwater 1**	**GDE 1**	**----**	**----**	**----**
			Client sampling date / time	29-Nov-2016 10:00	29-Nov-2016 13:30	----	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**EB1628281-001**	**EB1628281-002**	--------	--------	--------
				Result	Result	----	----	----
EA015: Total Dissolved Solids dried at 180 ± 5 °C								
Total Dissolved Solids @180°C	----	10	mg/L	**3570**	**366**	----	----	----
EA016: Calculated TDS (from Electrical Conductivity)								
Total Dissolved Solids (Calc.)	----	1	mg/L	**251**	----	----	----	----
ED009: Anions								
Bromide	24959-67-9	0.01	mg/L	**0.356**	**0.393**	----	----	----
Iodide	20461-54-5	0.01	mg/L	<0.010	<0.010	----	----	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	----	----	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	**32**	<1	----	----	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**28**	**149**	----	----	----
Total Alkalinity as CaCO3	----	1	mg/L	**60**	**149**	----	----	----
ED040F: Dissolved Major Anions								
Sulfate as SO4 2-	14808-79-8	1	mg/L	**18**	**9**	----	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**73**	**110**	----	----	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**6**	**31**	----	----	----
Magnesium	7439-95-4	1	mg/L	**3**	**21**	----	----	----
Sodium	7440-23-5	1	mg/L	**70**	**69**	----	----	----
Potassium	7440-09-7	1	mg/L	**12**	**6**	----	----	----
EK040P: Fluoride by PC Titrator								
Fluoride	16984-48-8	0.1	mg/L	**0.1**	**0.2**	----	----	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	**0.02**	<0.01	----	----	----
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	0.1	mg/L	**5.7**	**1.3**	----	----	----
EK062G: Total Nitrogen as N (TKN + NOx) by Discrete Analyser								
^ **Total Nitrogen as N**	----	0.1	mg/L	**5.7**	**1.3**	----	----	----
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	0.01	mg/L	**1.19**	**0.21**	----	----	----
EN055: Ionic Balance								
Total Anions	----	0.01	meq/L	**3.82**	**6.31**	----	----	----
Total Cations	----	0.01	meq/L	**3.90**	**6.43**	----	----	----

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**Broadwater 1**	**GDE 1**	**----**	**----**	**----**
			Client sampling date / time	29-Nov-2016 10:00	29-Nov-2016 13:30	----	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**EB1628281-001**	**EB1628281-002**	**--------**	**--------**	**--------**
				Result	Result	----	----	----
EN055: Ionic Balance - Continued								
Ionic Balance	----	0.01	%	**1.01**	**0.95**	**----**	**----**	**----**
EP002: Dissolved Organic Carbon (DOC)								
Dissolved Organic Carbon	----	1	mg/L	**10**	**27**	**----**	**----**	**----**
EP005: Total Organic Carbon (TOC)								
Total Organic Carbon	----	1	mg/L	**11**	**25**	**----**	**----**	**----**
Subcontracted Analysis								
ø **C13 Isotope**	----	0.01	per mil VPDB	**-7.27**	**-7.01**	**----**	**----**	**----**
ø **C13 Isotope Average**	----	0.01	per mil VPDB	**-7.05**	**-6.94**	**----**	**----**	**----**
ø **C13 Isotope Duplicate**	----	0.01	per mil VPDB	**-6.83**	**-6.88**	**----**	**----**	**----**
ø **Deuterium**	----	0.1	VSMOW	**44.88**	**-1.83**	**----**	**----**	**----**
ø **Oxygen-18**	----	0.1	VSMOW	**7.91**	**0.43**	**----**	**----**	**----**

QUALITY CONTROL REPORT

Work Order : **EB1628281**

Client : **EARTH SEARCH**
Contact : MR NED HAMER
Address : 15 HAMPSON STREET
KELVIN GROVE QUEENSLAND 4059
Telephone : ----
Project : GDE Assess
Order number : ----
C-O-C number : ----
Sampler : NED HAMER
Site : ----
Quote number : BNBQ/101/16
No. of samples received : 2
No. of samples analysed : 2

Page : 1 of 5

Laboratory : Environmental Division Brisbane
Contact : Customer Services EB
Address : 2 Byth Street Stafford QLD Australia 4053
Telephone : +61-7-3243 7222
Date Samples Received : 30-Nov-2016
Date Analysis Commenced : 30-Nov-2016
Issue Date : 09-Mar-2017

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Quality Control Report contains the following information:

- Laboratory Duplicate (DUP) Report; Relative Percentage Difference (RPD) and Acceptance Limits
- Method Blank (MB) and Laboratory Control Spike (LCS) Report; Recovery and Acceptance Limits
- Matrix Spike (MS) Report; Recovery and Acceptance Limits

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Diana Mesa	2IC Organic Chemist	Brisbane Organics, Stafford, QLD
Greg Vogel	Laboratory Manager	Brisbane Inorganics, Stafford, QLD
Greg Vogel	Laboratory Manager	WB Water Lab Brisbane, Stafford, QLD
Martina Louw	Inorganic Chemist	Brisbane External Subcontracting, Stafford, QLD
Tom Maloney	Nutrients Section Supervisor	Brisbane Inorganics, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis. Where the LOR of a reported result differs from standard LOR, this may be due to hig

Key :
Anonymous = Refers to samples which are not specifically part of this work order but formed part of the QC process lot
CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
RPD = Relative Percentage Difference
# = Indicates failed QC

Laboratory Duplicate (DUP) Report

The quality control term Laboratory Duplicate refers to a randomly selected intralaboratory split. Laboratory duplicates provide information regarding method precision and sample heterogeneity. The permitted ranges for the Relative Percent Deviation (RPD) of Laboratory Duplicates are specified in ALS Method QWI-EN/38 and are dependent on the magnitude of results in comparison to the level of reporting: Result < 10 times LOR: No Limit; Result between 10 and 20 times LOR: 0% - 50%; Result > 20 times LOR: 0% - 20%.

Sub-Matrix: **WATER**

				Laboratory Duplicate (DUP) Report					
Laboratory sample ID	*Client sample ID*	*Method: Compound*	*CAS Number*	*LOR*	*Unit*	*Original Result*	*Duplicate Result*	*RPD (%)*	*Recovery Limits (%)*
EA015: Total Dissolved Solids dried at 180 ± 5 °C (QC Lot: 674829)									
EB1627881-001	Anonymous	EA015H: Total Dissolved Solids @180°C	----	10	mg/L	3780	3820	0.987	0% - 20%
EB1628275-007	Anonymous	EA015H: Total Dissolved Solids @180°C	----	10	mg/L	386	400	3.56	0% - 20%
ED009: Anions (QC Lot: 674785)									
EB1628232-001	Anonymous	ED009-X: Bromide	24959-67-9	0.01	mg/L	0.556	0.552	0.722	0% - 20%
		ED009-X: Iodide	20461-54-5	0.01	mg/L	0.440	0.424	3.70	0% - 20%
EB1628322-001	Anonymous	ED009-X: Bromide	24959-67-9	0.01	mg/L	0.036	0.038	5.40	0% - 20%
		ED009-X: Iodide	20461-54-5	0.01	mg/L	<0.010	<0.010	0.00	0% - 20%
ED037P: Alkalinity by PC Titrator (QC Lot: 676879)									
EB1628171-001	Anonymous	ED037-P: Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	0.00	No Limit
		ED037-P: Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	0.00	No Limit
		ED037-P: Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	634	627	1.25	0% - 20%
		ED037-P: Total Alkalinity as CaCO3	----	1	mg/L	634	627	1.25	0% - 20%
EB1628236-002	Anonymous	ED037-P: Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	0.00	No Limit
		ED037-P: Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	0.00	No Limit
		ED037-P: Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	202	203	0.756	0% - 20%
		ED037-P: Total Alkalinity as CaCO3	----	1	mg/L	202	203	0.756	0% - 20%
ED040F: Dissolved Major Anions (QC Lot: 674378)									
EB1628254-001	Anonymous	ED040F: Sulfate as SO4 2-	14808-79-8	1	mg/L	<1	<1	0.00	No Limit
EB1628243-001	Anonymous	ED040F: Sulfate as SO4 2-	14808-79-8	1	mg/L	1	<1	0.00	No Limit
ED045G: Chloride by Discrete Analyser (QC Lot: 674377)									
EB1628254-001	Anonymous	ED045G: Chloride	16887-00-6	1	mg/L	<1	<1	0.00	No Limit
EB1628243-001	Anonymous	ED045G: Chloride	16887-00-6	1	mg/L	382	381	0.352	0% - 20%
ED093F: Dissolved Major Cations (QC Lot: 676380)									
EB1628281-001	Broadwater 1	ED093F: Calcium	7440-70-2	1	mg/L	6	5	0.00	No Limit

Sub-Matrix: **WATER**

				Laboratory Duplicate (DUP) Report					
Laboratory sample ID	*Client sample ID*	*Method: Compound*	*CAS Number*	*LOR*	*Unit*	*Original Result*	*Duplicate Result*	*RPD (%)*	*Recovery Limits (%)*
ED093F: Dissolved Major Cations (QC Lot: 676380) - continued									
EB1628281-001	Broadwater 1	ED093F: Magnesium	7439-95-4	1	mg/L	3	3	0.00	No Limit
		ED093F: Sodium	7440-23-5	1	mg/L	70	66	6.18	0% - 20%
		ED093F: Potassium	7440-09-7	1	mg/L	12	11	9.41	0% - 50%
EB1628380-001	Anonymous	ED093F: Calcium	7440-70-2	1	mg/L	3	3	0.00	No Limit
		ED093F: Magnesium	7439-95-4	1	mg/L	26	26	0.00	0% - 20%
		ED093F: Sodium	7440-23-5	1	mg/L	84	80	4.31	0% - 20%
		ED093F: Potassium	7440-09-7	1	mg/L	4	4	0.00	No Limit
EK040P: Fluoride by PC Titrator (QC Lot: 676880)									
EB1628171-001	Anonymous	EK040P: Fluoride	16984-48-8	0.1	mg/L	2.3	2.2	0.00	0% - 20%
EB1628236-002	Anonymous	EK040P: Fluoride	16984-48-8	0.1	mg/L	4.2	4.3	0.00	0% - 20%
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser (QC Lot: 676685)									
EB1628213-002	Anonymous	EK059G: Nitrite + Nitrate as N	----	0.01	mg/L	<0.01	<0.01	0.00	No Limit
EB1628298-001	Anonymous	EK059G: Nitrite + Nitrate as N	----	0.01	mg/L	<0.01	<0.01	0.00	No Limit
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser (QC Lot: 677064)									
EB1628169-001	Anonymous	EK061G: Total Kjeldahl Nitrogen as N	----	0.1	mg/L	0.7	0.7	0.00	No Limit
EB1628299-003	Anonymous	EK061G: Total Kjeldahl Nitrogen as N	----	0.1	mg/L	3.0	2.7	11.1	No Limit
EK067G: Total Phosphorus as P by Discrete Analyser (QC Lot: 677063)									
EB1628169-001	Anonymous	EK067G: Total Phosphorus as P	----	0.01	mg/L	0.20	0.20	0.00	0% - 50%
EB1628299-003	Anonymous	EK067G: Total Phosphorus as P	----	0.01	mg/L	0.53	0.38	32.6	0% - 50%
EP002: Dissolved Organic Carbon (DOC) (QC Lot: 674872)									
EB1628280-005	Anonymous	EP002: Dissolved Organic Carbon	----	1	mg/L	<1	<1	0.00	No Limit
EP005: Total Organic Carbon (TOC) (QC Lot: 677423)									
EB1628222-001	Anonymous	EP005: Total Organic Carbon	----	1	mg/L	1	1	0.00	No Limit
EB1628240-007	Anonymous	EP005: Total Organic Carbon	----	1	mg/L	<1	<1	0.00	No Limit

Method Blank (MB) and Laboratory Control Spike (LCS) Report

The quality control term Method / Laboratory Blank refers to an analyte free matrix to which all reagents are added in the same volumes or proportions as used in standard sample preparation. The purpose of this QC parameter is to monitor potential laboratory contamination. The quality control term Laboratory Control Spike (LCS) refers to a certified reference material, or a known interference free matrix spiked with target analytes. The purpose of this QC parameter is to monitor method precision and accuracy independent of sample matrix. Dynamic Recovery Limits are based on statistical evaluation of processed LCS.

Sub-Matrix: **WATER**

				Method Blank (MB) Report	Laboratory Control Spike (LCS) Report			
					Spike	Spike Recovery (%)	Recovery Limits (%)	
Method: Compound	CAS Number	LOR	Unit	Result	Concentration	LCS	Low	High
EA015: Total Dissolved Solids dried at 180 ± 5 °C (QCLot: 674829)								
EA015H: Total Dissolved Solids @180°C	----	10	mg/L	<10	293 mg/L	99.1	88	112
				<10	2000 mg/L	95.8	88	112
ED009: Anions (QCLot: 674785)								
ED009-X: Bromide	24959-67-9	0.01	mg/L	<0.010	0.2 mg/L	96.5	80	115
ED009-X: Iodide	20461-54-5	0.01	mg/L	<0.010	0.2 mg/L	98.0	80	113
ED037P: Alkalinity by PC Titrator (QCLot: 676879)								
ED037-P: Total Alkalinity as CaCO3	----	----	mg/L	----	200 mg/L	97.6	80	120
ED040F: Dissolved Major Anions (QCLot: 674378)								
ED040F: Sulfate as SO4 2-	14808-79-8	1	mg/L	<1	----	----	----	----
ED045G: Chloride by Discrete Analyser (QCLot: 674377)								
ED045G: Chloride	16887-00-6	1	mg/L	<1	10 mg/L	91.7	90	115
				<1	1000 mg/L	91.3	90	115
ED093F: Dissolved Major Cations (QCLot: 676380)								
ED093F: Calcium	7440-70-2	1	mg/L	<1	----	----	----	----
ED093F: Magnesium	7439-95-4	1	mg/L	<1	----	----	----	----
ED093F: Sodium	7440-23-5	1	mg/L	<1	----	----	----	----
ED093F: Potassium	7440-09-7	1	mg/L	<1	----	----	----	----
EK040P: Fluoride by PC Titrator (QCLot: 676880)								
EK040P: Fluoride	16984-48-8	0.1	mg/L	<0.1	10 mg/L	100	80	117
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser (QCLot: 676685)								
EK059G: Nitrite + Nitrate as N	----	0.01	mg/L	<0.01	0.5 mg/L	99.5	89	115
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser (QCLot: 677064)								
EK061G: Total Kjeldahl Nitrogen as N	----	0.1	mg/L	<0.1	10 mg/L	82.8	70	111
EK067G: Total Phosphorus as P by Discrete Analyser (QCLot: 677063)								
EK067G: Total Phosphorus as P	----	0.01	mg/L	<0.01	4.42 mg/L	86.7	77	109
EP002: Dissolved Organic Carbon (DOC) (QCLot: 674872)								
EP002: Dissolved Organic Carbon	----	1	mg/L	<1	10 mg/L	85.2	80	112
				<1	100 mg/L	92.0	80	112
EP005: Total Organic Carbon (TOC) (QCLot: 677423)								
EP005: Total Organic Carbon	----	1	mg/L	<1	10 mg/L	90.5	79	113
				<1	100 mg/L	94.8	79	113

Matrix Spike (MS) Report

The quality control term Matrix Spike (MS) refers to an intralaboratory split sample spiked with a representative set of target analytes. The purpose of this QC parameter is to monitor potential matrix effects on analyte recoveries. Static Recovery Limits as per laboratory Data Quality Objectives (DQOs). Ideal recovery ranges stated may be waived in the event of sample matrix interference.

Sub-Matrix: **WATER**

				Matrix Spike (MS) Report			
				Spike	SpikeRecovery(%)	Recovery Limits (%)	
Laboratory sample ID	Client sample ID	Method: Compound	CAS Number	Concentration	MS	Low	High
ED009: Anions (QCLot: 674785)							
EB1628232-002	Anonymous	ED009-X: Bromide	24959-67-9	0.5 mg/L	106	70	130
		ED009-X: Iodide	20461-54-5	0.5 mg/L	108	70	130
ED045G: Chloride by Discrete Analyser (QCLot: 674377)							
EB1628243-002	Anonymous	ED045G: Chloride	16887-00-6	400 mg/L	79.2	70	130
EK040P: Fluoride by PC Titrator (QCLot: 676880)							
EB1628171-002	Anonymous	EK040P: Fluoride	16984-48-8	5 mg/L	90.8	70	130
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser (QCLot: 676685)							
EB1628243-001	Anonymous	EK059G: Nitrite + Nitrate as N	----	0.4 mg/L	101	70	130
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser (QCLot: 677064)							
EB1628169-002	Anonymous	EK061G: Total Kjeldahl Nitrogen as N	----	5 mg/L	75.9	70	130
EK067G: Total Phosphorus as P by Discrete Analyser (QCLot: 677063)							
EB1628169-002	Anonymous	EK067G: Total Phosphorus as P	----	1 mg/L	99.6	70	130
EP002: Dissolved Organic Carbon (DOC) (QCLot: 674872)							
EB1628280-006	Anonymous	EP002: Dissolved Organic Carbon	----	100 mg/L	89.9	70	130
EP005: Total Organic Carbon (TOC) (QCLot: 677423)							
EB1628222-002	Anonymous	EP005: Total Organic Carbon	----	100 mg/L	92.9	70	130

Environmental

QA/QC Compliance Assessment to assist with Quality Review

Work Order	: **EB1628281**	Page	: 1 of 7
Client	: **EARTH SEARCH**	Laboratory	: Environmental Division Brisbane
Contact	: MR NED HAMER	Telephone	: +61-7-3243 7222
Project	: GDE Assess	Date Samples Received	: 30-Nov-2016
Site	: ----	Issue Date	: 09-Mar-2017
Sampler	: NED HAMER	No. of samples received	: 2
Order number	: ----	No. of samples analysed	: 2

This report is automatically generated by the ALS LIMS through interpretation of the ALS Quality Control Report and several Quality Assurance parameters measured by ALS. This automated reporting highlights any non-conformances, facilitates faster and more accurate data validation and is designed to assist internal expert and external Auditor review. Many components of this report contribute to the overall DQO assessment and reporting for guideline compliance.

Brief method summaries and references are also provided to assist in traceability.

Summary of Outliers

Outliers : Quality Control Samples

This report highlights outliers flagged in the Quality Control (QC) Report.

- **NO Method Blank value outliers occur.**
- **NO Duplicate outliers occur.**
- **NO Laboratory Control outliers occur.**
- **NO Matrix Spike outliers occur.**
- **For all regular sample matrices, NO surrogate recovery outliers occur.**

Outliers : Analysis Holding Time Compliance

- **Analysis Holding Time Outliers exist - please see following pages for full details.**

Outliers : Frequency of Quality Control Samples

- **NO Quality Control Sample Frequency Outliers exist.**

Outliers : Analysis Holding Time Compliance

Matrix: **WATER**

Method **Container** / Client Sample ID(s)	Extraction / Preparation *Date extracted*	*Due for extraction*	**Days overdue**	Analysis *Date analysed*	*Due for analysis*	**Days overdue**
EP002: Dissolved Organic Carbon (DOC)						
Clear Plastic Bottle - Natural						
Broadwater 1, GDE 1	----	----	----	01-Dec-2016	30-Nov-2016	**1**

Analysis Holding Time Compliance

If samples are identified below as having been analysed or extracted outside of recommended holding times, this should be taken into consideration when interpreting results.

This report summarizes extraction / preparation and analysis times and compares each with ALS recommended holding times (referencing USEPA SW 846, APHA, AS and NEPM) based on the sample container provided. Dates reported represent first date of extraction or analysis and preclude subsequent dilutions and reruns. A listing of breaches (if any) is provided herein.

Holding time for leachate methods (e.g. TCLP) vary according to the analytes reported. Assessment compares the leach date with the shortest analyte holding time for the equivalent soil method. These are: organics 14 days, mercury 28 days & other metals 180 days. A recorded breach does not guarantee a breach for all non-volatile parameters.

Holding times for ***VOC in soils*** vary according to analytes of interest. Vinyl Chloride and Styrene holding time is 7 days; others 14 days. A recorded breach does not guarantee a breach for all VOC analytes and should be verified in case the reported breach is a false positive or Vinyl Chloride and Styrene are not key analytes of interest/concern.

Matrix: **WATER**

Evaluation: × = Holding time breach ; ✓ = Within holding time.

Method ***Container*** */ Client Sample ID(s)*	***Sample Date***	Extraction / Preparation ***Date extracted***	*Due for extraction*	*Evaluation*	Analysis ***Date analysed***	*Due for analysis*	*Evaluation*
EA015: Total Dissolved Solids dried at 180 ± 5 °C							
Clear Plastic Bottle - Natural (EA015H)							
Broadwater 1, GDE 1	**29-Nov-2016**	**----**	----	----	**05-Dec-2016**	06-Dec-2016	✓
ED009: Anions							
Clear Plastic Bottle - Natural (ED009-X)							
Broadwater 1, GDE 1	**29-Nov-2016**	**----**	----	----	**01-Dec-2016**	27-Dec-2016	✓
ED037P: Alkalinity by PC Titrator							
Clear Plastic Bottle - Natural (ED037-P)							
Broadwater 1, GDE 1	**29-Nov-2016**	**----**	----	----	**03-Dec-2016**	13-Dec-2016	✓
ED040F: Dissolved Major Anions							
Clear Plastic Bottle - Natural (ED040F)							
Broadwater 1, GDE 1	**29-Nov-2016**	**----**	----	----	**30-Nov-2016**	27-Dec-2016	✓
ED045G: Chloride by Discrete Analyser							
Clear Plastic Bottle - Natural (ED045G)							
Broadwater 1, GDE 1	**29-Nov-2016**	**----**	----	----	**30-Nov-2016**	27-Dec-2016	✓
ED093F: Dissolved Major Cations							
Clear Plastic Bottle - Natural (ED093F)							
Broadwater 1, GDE 1	**29-Nov-2016**	**----**	----	----	**03-Dec-2016**	06-Dec-2016	✓
EK040P: Fluoride by PC Titrator							
Clear Plastic Bottle - Natural (EK040P)							
Broadwater 1, GDE 1	**29-Nov-2016**	**----**	----	----	**03-Dec-2016**	27-Dec-2016	✓

Matrix: **WATER**

Evaluation: × = Holding time breach ; ✓ = Within holding time.

Method *Container / Client Sample ID(s)*		*Sample Date*	*Extraction / Preparation*			*Analysis*		
			Date extracted	*Due for extraction*	*Evaluation*	*Date analysed*	*Due for analysis*	*Evaluation*
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Clear Plastic Bottle - Sulfuric Acid (EK059G)								
Broadwater 1,	GDE 1	**29-Nov-2016**	**----**	----	----	**05-Dec-2016**	27-Dec-2016	✓
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Clear Plastic Bottle - Sulfuric Acid (EK061G)								
Broadwater 1,	GDE 1	**29-Nov-2016**	**02-Dec-2016**	27-Dec-2016	✓	**02-Dec-2016**	27-Dec-2016	✓
EK067G: Total Phosphorus as P by Discrete Analyser								
Clear Plastic Bottle - Sulfuric Acid (EK067G)								
Broadwater 1,	GDE 1	**29-Nov-2016**	**02-Dec-2016**	27-Dec-2016	✓	**02-Dec-2016**	27-Dec-2016	✓
EP002: Dissolved Organic Carbon (DOC)								
Clear Plastic Bottle - Natural (EP002)								
Broadwater 1,	GDE 1	**29-Nov-2016**	**----**	----	----	**01-Dec-2016**	30-Nov-2016	×
EP005: Total Organic Carbon (TOC)								
Amber VOC Vial - Sulfuric Acid (EP005)								
Broadwater 1,	GDE 1	**29-Nov-2016**	**----**	----	----	**02-Dec-2016**	27-Dec-2016	✓

Quality Control Parameter Frequency Compliance

The following report summarises the frequency of laboratory QC samples analysed within the analytical lot(s) in which the submitted sample(s) was(were) processed. Actual rate should be greater than or equal to the expected rate. A listing of breaches is provided in the Summary of Outliers.

Matrix: **WATER**

Evaluation: × = Quality Control frequency not within specification ; ✓ = Quality Control frequency within specification.

Quality Control Sample Type		*Count*		*Rate (%)*			*Quality Control Specification*
Analytical Methods	*Method*	*QC*	*Regular*	***Actual***	***Expected***	*Evaluation*	
Laboratory Duplicates (DUP)							
Alkalinity by PC Titrator	ED037-P	2	18	**11.11**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Chloride by Discrete Analyser	ED045G	2	17	**11.76**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Organic Carbon	EP002	1	6	**16.67**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Fluoride by PC Titrator	EK040P	2	18	**11.11**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Major Anions - Dissolved	ED040F	2	6	**33.33**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Major Cations - Dissolved	ED093F	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Nitrite and Nitrate as N (NOx) by Discrete Analyser	EK059G	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Standard Anions -by IC (Extended Method)	ED009-X	2	11	**18.18**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Dissolved Solids (High Level)	EA015H	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Kjeldahl Nitrogen as N By Discrete Analyser	EK061G	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Organic Carbon	EP005	2	19	**10.53**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Phosphorus as P By Discrete Analyser	EK067G	2	19	**10.53**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Laboratory Control Samples (LCS)							
Alkalinity by PC Titrator	ED037-P	1	18	**5.56**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Chloride by Discrete Analyser	ED045G	2	17	**11.76**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Organic Carbon	EP002	2	6	**33.33**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Fluoride by PC Titrator	EK040P	1	18	**5.56**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Nitrite and Nitrate as N (NOx) by Discrete Analyser	EK059G	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Standard Anions -by IC (Extended Method)	ED009-X	1	11	**9.09**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Dissolved Solids (High Level)	EA015H	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Kjeldahl Nitrogen as N By Discrete Analyser	EK061G	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Organic Carbon	EP005	2	19	**10.53**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Phosphorus as P By Discrete Analyser	EK067G	1	19	**5.26**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Method Blanks (MB)							
Chloride by Discrete Analyser	ED045G	1	17	**5.88**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Organic Carbon	EP002	1	6	**16.67**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Fluoride by PC Titrator	EK040P	1	18	**5.56**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Major Anions - Dissolved	ED040F	1	6	**16.67**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Major Cations - Dissolved	ED093F	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Nitrite and Nitrate as N (NOx) by Discrete Analyser	EK059G	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Standard Anions -by IC (Extended Method)	ED009-X	1	11	**9.09**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Dissolved Solids (High Level)	EA015H	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Kjeldahl Nitrogen as N By Discrete Analyser	EK061G	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Organic Carbon	EP005	1	19	**5.26**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Phosphorus as P By Discrete Analyser	EK067G	1	19	**5.26**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Matrix Spikes (MS)							

Matrix: **WATER**

Evaluation: × = Quality Control frequency not within specification ; ✓ = Quality Control frequency within specification.

Quality Control Sample Type		Count		Rate (%)			Quality Control Specification
Analytical Methods	*Method*	*QC*	*Regular*	***Actual***	***Expected***	*Evaluation*	
Matrix Spikes (MS) - Continued							
Chloride by Discrete Analyser	ED045G	1	17	**5.88**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Organic Carbon	EP002	1	6	**16.67**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Fluoride by PC Titrator	EK040P	1	18	**5.56**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Nitrite and Nitrate as N (NOx) by Discrete Analyser	EK059G	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Standard Anions -by IC (Extended Method)	ED009-X	1	11	**9.09**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Kjeldahl Nitrogen as N By Discrete Analyser	EK061G	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Organic Carbon	EP005	1	19	**5.26**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Phosphorus as P By Discrete Analyser	EK067G	1	19	**5.26**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard

Brief Method Summaries

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the US EPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request. The following report provides brief descriptions of the analytical procedures employed for results reported in the Certificate of Analysis. Sources from which ALS methods have been developed are provided within the Method Descriptions.

Analytical Methods	*Method*	*Matrix*	*Method Descriptions*
Total Dissolved Solids (High Level)	EA015H	WATER	In house: Referenced to APHA 2540C. A gravimetric procedure that determines the amount of `filterable` residue in an aqueous sample. A well-mixed sample is filtered through a glass fibre filter (1.2um). The filtrate is evaporated to dryness and dried to constant weight at 180+/-5C. This method is compliant with NEPM (2013) Schedule B(3)
Calculated TDS (from Electrical Conductivity)	EA016	WATER	In house: Calculation from Electrical Conductivity (APHA 2510 B) using a conversion factor specified in the analytical report. This method is compliant with NEPM (2013) Schedule B(3)
Standard Anions -by IC (Extended Method)	ED009-X	WATER	In house: Referenced to APHA 4110. This method is compliant with NEPM (2013) Schedule B(3)
Alkalinity by PC Titrator	ED037-P	WATER	In house: Referenced to APHA 2320 B This procedure determines alkalinity by automated measurement (e.g. PC Titrate) using pH 4.5 for indicating the total alkalinity end-point. This method is compliant with NEPM (2013) Schedule B(3)
Major Anions - Dissolved	ED040F	WATER	In house: Referenced to APHA 3120. The 0.45µm filtered samples are determined by ICP/AES for Sulfur and/or Silcon content and reported as Sulfate and/or Silica after conversion by gravimetric factor.
Chloride by Discrete Analyser	ED045G	WATER	In house: Referenced to APHA 4500 Cl - G.The thiocyanate ion is liberated from mercuric thiocyanate through sequestration of mercury by the chloride ion to form non-ionised mercuric chloride.in the presence of ferric ions the librated thiocyanate forms highly-coloured ferric thiocynate which is measured at 480 nm APHA 21st edition seal method 2 017-1-L april 2003
Major Cations - Dissolved	ED093F	WATER	In house: Referenced to APHA 3120 and 3125; USEPA SW 846 - 6010 and 6020; Cations are determined by either ICP-AES or ICP-MS techniques. This method is compliant with NEPM (2013) Schedule B(3) Sodium Adsorption Ratio is calculated from Ca, Mg and Na which determined by ALS in house method QWI-EN/ED093F. This method is compliant with NEPM (2013) Schedule B(3) Hardness parameters are calculated based on APHA 2340 B. This method is compliant with NEPM (2013) Schedule B(3)
Fluoride by PC Titrator	EK040P	WATER	In house: Referenced to APHA 4500-F C: CDTA is added to the sample to provide a uniform ionic strength background, adjust pH, and break up complexes. Fluoride concentration is determined by either manual or automatic ISE measurement. This method is compliant with NEPM (2013) Schedule B(3)
Nitrite and Nitrate as N (NOx) by Discrete Analyser	EK059G	WATER	In house: Referenced to APHA 4500-NO3- F. Combined oxidised Nitrogen (NO2+NO3) is determined by Chemical Reduction and direct colourimetry by Discrete Analyser. This method is compliant with NEPM (2013) Schedule B(3)
Total Kjeldahl Nitrogen as N By Discrete Analyser	EK061G	WATER	In house: Referenced to APHA 4500-Norg D (In house). An aliquot of sample is digested using a high temperature Kjeldahl digestion to convert nitrogenous compounds to ammonia. Ammonia is determined colorimetrically by discrete analyser. This method is compliant with NEPM (2013) Schedule B(3)
Total Nitrogen as N (TKN + Nox) By Discrete Analyser	EK062G	WATER	In house: Referenced to APHA 4500-Norg / 4500-NO3-. This method is compliant with NEPM (2013) Schedule B(3)

Analytical Methods	*Method*	*Matrix*	*Method Descriptions*
Total Phosphorus as P By Discrete Analyser	EK067G	WATER	In house: Referenced to APHA 4500-P H, Jirka et al (1976), Zhang et al (2006). This procedure involves sulphuric acid digestion of a sample aliquot to break phosphorus down to orthophosphate. The orthophosphate reacts with ammonium molybdate and antimony potassium tartrate to form a complex which is then reduced and its concentration measured at 880nm using discrete analyser. This method is compliant with NEPM (2013) Schedule B(3)
Ionic Balance by PCT DA and Turbi SO4 DA	EN055 - PG	WATER	In house: Referenced to APHA 1030F. This method is compliant with NEPM (2013) Schedule B(3)
Dissolved Organic Carbon	EP002	WATER	In house: Referenced to APHA 5310 B. This method is compliant with NEPM (2013) Schedule B(3) . Samples are combusted at high termperature in the presence of an oxidative catalyst. The evolved carbon dioxide is quantified using an IR detector.
Total Organic Carbon	EP005	WATER	In house: Referenced to APHA 5310 B, The automated TOC analyzer determines Total and Inorganic Carbon by IR cell. TOC is calculated as the difference. This method is compliant with NEPM (2013) Schedule B(3)
Stable Isotopes - Carbon C12/13 ratio in water matrices	* STABISO-WAT	WATER	Isotopes in water matrices subcontracted to an external supplier (Environmental Isotopes). NATA accreditation does not cover performance of this service.

Preparation Methods	*Method*	*Matrix*	*Method Descriptions*
TKN/TP Digestion	EK061/EK067	WATER	In house: Referenced to APHA 4500 Norg - D; APHA 4500 P - H. This method is compliant with NEPM (2013) Schedule B(3)

CHAIN OF CUSTODY

ALS Laboratory: please tick →

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☐BRISBANE 2 Byth Street Stafford QLD 4053 Ph: 07 3243 7222 E: samples.brisbane@alsglobal.com
☐GLADSTONE 46 Callemondah Drive Clinton QLD 4680 Ph: 07 7471 5600 E: gladstone@alsglobal.com
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☐WOLLONGONG 99 Kenny Street Wollongong NSW 2500 Ph: 02 4225 3125 E: wollongong@alsglobal.com

CLIENT: Earth Search
OFFICE: Brisbane
PROJECT: GDE Assess
PROJECT NO.:
ORDER NUMBER:
PURCHASE ORDER NO.:
PROJECT MANAGER: Ned Hamer
CONTACT PH: 0429 049 154
SAMPLER: Ned Hamer
SAMPLER MOBILE: 0429 049 154
COC Emailed to ALS? (YES / NO)
EDD FORMAT (or default):
Email Reports to (will default to PM if no other addresses are listed): ned@earthsearch.com.au
Email Invoice to (will default to PM if no other addresses are listed): ned@earthsearch.com.au

TURNAROUND REQUIREMENTS : (Standard TAT may be longer for some tests e.g., Ultra Trace Organics)
☐ Standard TAT (List due date):
☐ Non Standard or urgent TAT (List due date):
ALS QUOTE NO.:
COUNTRY OF ORIGIN:

COC SEQUENCE NUMBER (Circle)
COC: 1 2 3 4 5 6 7
OF: 1 2 3 4 5 6 7

FOR LABORATORY USE ONLY (Circle)
Custody Seal Intact? Yes No N/A
Free ice / frozen ice bricks present upon receipt? Yes No N/A
Random Sample Temperature on Receipt: °C
Other comment:

RELINQUISHED BY:	RECEIVED BY:	RELINQUISHED BY:	RECEIVED BY:
	J. Day		
DATE/TIME: 29/11/16 16:00	DATE/TIME: 29/11/16 1600	DATE/TIME:	DATE/TIME: 30/11/16 10:15

COMMENTS/SPECIAL HANDLING/STORAGE OR DISPOSAL:

ALS USE ONLY	SAMPLE DETAILS MATRIX: Solid(S) Water(W)			CONTAINER INFORMATION		ANALYSIS REQUIRED including SUITES (NB. Suite Codes must be listed to attract suite price) Where Metals are required, specify Total (unfiltered bottle required) or Dissolved (field filtered bottle required).								Additional Information
LAB ID	SAMPLE ID	DATE / TIME	MATRIX	TYPE & PRESERVATIVE (refer to codes below)	TOTAL BOTTLES	TDS	Alkalinity Total, Bicarb Carb, Hydrox	Sulphate -SO4 by ICPAES	Chloride Major Cats	Bromide Iodide Fluoride	Total Nitrogen as N Total Phosphorus as P	TOC DOC Field Filtered	Carbon 13C 14C Strontium (87/86Sr) Stable Isotopes 18O 2D	Comments on likely contaminant levels, dilutions, or samples requiring specific QC analysis etc. ✱ Radon (222Rn) to ANSTO
	Broadwater 1	29/11/16 10:00	W		6	X	X	X	X	X	X	X	X	X Vial labelled "B"
	GDE 1	29/11/16 13:30	W		6	X	X	X	X	X	X	X	X	X Vial labelled "G"
														✱ Urgent 3 day H.T.
					TOTAL									

Environmental Division
Brisbane
Work Order Reference
EB1628281

Telephone : + 61-7-3243 7222

Attn: Robert Chisari
ANSTO Laboratories
New Illawarra Rd
Lucas Heights
(Go to reception)

Air Freight overnight to ANSTO in Canberra

Water Container Codes: P = Unpreserved Plastic; N = Nitric Preserved Plastic; ORC = Nitric Preserved ORC; SH = Sodium Hydroxide/Cd Preserved; S = Sodium Hydroxide Preserved Plastic; AG = Amber Glass Unpreserved; AP - Airfreight Unpreserved Plastic
V = VOA Vial HCl Preserved; VB = VOA Vial Sodium Bisulphate Preserved; VS = VOA Vial Sulfuric Preserved; AV = Airfreight Unpreserved Vial SG = Sulfuric Preserved Amber Glass; H = HCl preserved Plastic; HS = HCl preserved Speciation bottle; SP = Sulfuric Preserved Plastic; F = Formaldehyde Preserved Glass;
Z = Zinc Acetate Preserved Bottle; E = EDTA Preserved Bottles; ST = Sterile Bottle; ASS = Plastic Bag for Acid Sulphate Soils; B = Unpreserved Bag; LI = Lugols Iodine Preserved Bottles; STT = Sterile Sodium Thiosulfate Preserved Bottles.

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order : **EB1628373**
Client : **EARTH SEARCH**
Contact : MR NED HAMER
Address : 15 HAMPSON STREET
KELVIN GROVE QUEENSLAND 4059
Telephone : ----
Project : GDE Assess
Order number : ----
C-O-C number : ----
Sampler : NED HAMER
Site : ----
Quote number : BNBQ/101/16
No. of samples received : 2
No. of samples analysed : 2

Page : 1 of 4
Laboratory : Environmental Division Brisbane
Contact : Customer Services EB
Address : 2 Byth Street Stafford QLD Australia 4053
Telephone : +61-7-3243 7222
Date Samples Received : 01-Dec-2016 10:00
Date Analysis Commenced : 02-Dec-2016
Issue Date : 01-Mar-2017 10:36

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Andrew Epps	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD
Andrew Epps	Senior Inorganic Chemist	WB Water Lab Brisbane, Stafford, QLD
Diana Mesa	2IC Organic Chemist	Brisbane Organics, Stafford, QLD
Greg Vogel	Laboratory Manager	Brisbane Inorganics, Stafford, QLD
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD
Martina Louw	Inorganic Chemist	Brisbane External Subcontracting, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When no sampling time is provided, the sampling time will default 00:00 on the date of sampling. If no sampling date is provided, the sampling date will be assumed by the laboratory and displayed in brackets without a time component.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key :
CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- EP002 (Dissolved Organic Carbon) was found to be higher than EP005 (Total Organic Carbon) for sample. This has been confirmed by re-analysis.
- It is recognised that EP005 (Total Organic Carbon) is less than EP002 (Dissolved Organic Carbon) for sample. However, the difference is within experimental variation of the methods.
- TDS by method EA-015 may bias high due to the presence of fine particulate matter, which may pass through the prescribed GF/C paper.
- Subcontracted analysis reported in this work order is conducted by Environmental Isotopes. Environmental Isotopes does not hold NATA Accreditation for these parameters.

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**Spring 1**	**Swamp 1**	**----**	**----**	**----**
			Client sampling date / time	30-Nov-2016 13:00	30-Nov-2016 14:30	----	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**EB1628373-001**	**EB1628373-002**	--------	--------	--------
				Result	Result	----	----	----
EA015: Total Dissolved Solids dried at 180 ± 5 °C								
Total Dissolved Solids @180°C	----	10	mg/L	**146**	**144**	----	----	----
ED009: Anions								
Bromide	24959-67-9	0.01	mg/L	**0.049**	**0.010**	----	----	----
Iodide	20461-54-5	0.01	mg/L	<0.010	<0.010	----	----	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	----	----	----	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	----	----	----	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**4**	----	----	----	----
Total Alkalinity as CaCO3	----	1	mg/L	**4**	----	----	----	----
ED040F: Dissolved Major Anions								
Sulfate as SO4 2-	14808-79-8	1	mg/L	**9**	**2**	----	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**30**	**11**	----	----	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**1**	**4**	----	----	----
Magnesium	7439-95-4	1	mg/L	**1**	**2**	----	----	----
Sodium	7440-23-5	1	mg/L	**21**	**13**	----	----	----
Potassium	7440-09-7	1	mg/L	**5**	**8**	----	----	----
EK040P: Fluoride by PC Titrator								
Fluoride	16984-48-8	0.1	mg/L	<0.1	<0.1	----	----	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	**0.22**	<0.01	----	----	----
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	0.1	mg/L	**1.7**	**2.1**	----	----	----
EK062G: Total Nitrogen as N (TKN + NOx) by Discrete Analyser								
^ **Total Nitrogen as N**	----	0.1	mg/L	**1.9**	**2.1**	----	----	----
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	0.01	mg/L	**0.12**	**0.27**	----	----	----
EN055: Ionic Balance								
Total Anions	----	0.01	meq/L	**1.13**	**0.99**	----	----	----
Total Cations	----	0.01	meq/L	**1.17**	**1.13**	----	----	----
EP002: Dissolved Organic Carbon (DOC)								
Dissolved Organic Carbon	----	1	mg/L	**2**	**23**	----	----	----

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**Spring 1**	**Swamp 1**	**----**	**----**	**----**
			Client sampling date / time	30-Nov-2016 13:00	30-Nov-2016 14:30	----	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**EB1628373-001**	**EB1628373-002**	**--------**	**--------**	**--------**
				Result	Result	----	----	----
EP005: Total Organic Carbon (TOC)								
Total Organic Carbon	----	1	mg/L	<1	**22**	**----**	**----**	**----**
Subcontracted Analysis								
ø **C13 Isotope**	----	0.01	per mil VPDB	**-17.27**	**-4.94**	**----**	**----**	**----**
ø **C13 Isotope Average**	----	0.01	per mil VPDB	**-17.43**	**-5.00**	**----**	**----**	**----**
ø **C13 Isotope Duplicate**	----	0.01	per mil VPDB	**-17.60**	**-5.05**	**----**	**----**	**----**
ø **Deuterium**	----	0.1	VSMOW	**-35.79**	**34.53**	**----**	**----**	**----**
ø **Oxygen-18**	----	0.1	VSMOW	**-5.93**	**7.18**	**----**	**----**	**----**

QUALITY CONTROL REPORT

Work Order	: **EB1628373**	Page	: 1 of 5
Client	: **EARTH SEARCH**	Laboratory	: Environmental Division Brisbane
Contact	: MR NED HAMER	Contact	: Customer Services EB
Address	: 15 HAMPSON STREET KELVIN GROVE QUEENSLAND 4059	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: ----	Telephone	: +61-7-3243 7222
Project	: GDE Assess	Date Samples Received	: 01-Dec-2016
Order number	: ----	Date Analysis Commenced	: 02-Dec-2016
C-O-C number	: ----	Issue Date	: 01-Mar-2017
Sampler	: NED HAMER		
Site	: ----		
Quote number	: BNBQ/101/16		
No. of samples received	: 2		
No. of samples analysed	: 2		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Quality Control Report contains the following information:

- Laboratory Duplicate (DUP) Report; Relative Percentage Difference (RPD) and Acceptance Limits
- Method Blank (MB) and Laboratory Control Spike (LCS) Report; Recovery and Acceptance Limits
- Matrix Spike (MS) Report; Recovery and Acceptance Limits

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Andrew Epps	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD
Andrew Epps	Senior Inorganic Chemist	WB Water Lab Brisbane, Stafford, QLD
Diana Mesa	2IC Organic Chemist	Brisbane Organics, Stafford, QLD
Greg Vogel	Laboratory Manager	Brisbane Inorganics, Stafford, QLD
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD
Martina Louw	Inorganic Chemist	Brisbane External Subcontracting, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis. Where the LOR of a reported result differs from standard LOR, this may be due to high

Key : Anonymous = Refers to samples which are not specifically part of this work order but formed part of the QC process lot
CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
RPD = Relative Percentage Difference
# = Indicates failed QC

Laboratory Duplicate (DUP) Report

The quality control term Laboratory Duplicate refers to a randomly selected intralaboratory split. Laboratory duplicates provide information regarding method precision and sample heterogeneity. The permitted ranges for the Relative Percent Deviation (RPD) of Laboratory Duplicates are specified in ALS Method QWI-EN/38 and are dependent on the magnitude of results in comparison to the level of reporting: Result < 10 times LOR: No Limit; Result between 10 and 20 times LOR: 0% - 50%; Result > 20 times LOR: 0% - 20%.

Sub-Matrix: **WATER**

				Laboratory Duplicate (DUP) Report					
Laboratory sample ID	*Client sample ID*	*Method: Compound*	*CAS Number*	*LOR*	*Unit*	*Original Result*	*Duplicate Result*	*RPD (%)*	*Recovery Limits (%)*
EA015: Total Dissolved Solids dried at 180 ± 5 °C (QC Lot: 679243)									
EB1628330-003	Anonymous	EA015H: Total Dissolved Solids @180°C	----	10	mg/L	690	788	13.3	0% - 20%
ED009: Anions (QC Lot: 677330)									
EB1628348-001	Anonymous	ED009-X: Bromide	24959-67-9	0.01	mg/L	0.183	0.187	2.16	0% - 20%
		ED009-X: Iodide	20461-54-5	0.01	mg/L	<0.010	<0.010	0.00	0% - 20%
EB1628486-003	Anonymous	ED009-X: Bromide	24959-67-9	0.01	mg/L	0.094	0.098	4.17	0% - 20%
		ED009-X: Iodide	20461-54-5	0.01	mg/L	<0.020	<0.020	0.00	0% - 20%
ED037P: Alkalinity by PC Titrator (QC Lot: 681097)									
EB1628197-001	Anonymous	ED037-P: Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	0.00	No Limit
		ED037-P: Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	0.00	No Limit
		ED037-P: Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	175	176	0.00	0% - 20%
		ED037-P: Total Alkalinity as CaCO3	----	1	mg/L	175	176	0.00	0% - 20%
EB1628197-011	Anonymous	ED037-P: Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	0.00	No Limit
		ED037-P: Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	0.00	No Limit
		ED037-P: Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	121	120	0.00	0% - 20%
		ED037-P: Total Alkalinity as CaCO3	----	1	mg/L	121	120	0.00	0% - 20%
ED040F: Dissolved Major Anions (QC Lot: 676628)									
EB1628373-001	Spring 1	ED040F: Sulfate as SO4 2-	14808-79-8	1	mg/L	9	10	0.00	No Limit
ED045G: Chloride by Discrete Analyser (QC Lot: 676629)									
EB1628373-001	Spring 1	ED045G: Chloride	16887-00-6	1	mg/L	30	30	0.00	0% - 20%
EB1628475-005	Anonymous	ED045G: Chloride	16887-00-6	1	mg/L	13100	13200	0.885	0% - 20%
ED093F: Dissolved Major Cations (QC Lot: 678329)									
EB1628373-001	Spring 1	ED093F: Calcium	7440-70-2	1	mg/L	1	2	0.00	No Limit
		ED093F: Magnesium	7439-95-4	1	mg/L	1	1	0.00	No Limit
		ED093F: Sodium	7440-23-5	1	mg/L	21	21	0.00	0% - 20%

Sub-Matrix: **WATER**

Laboratory sample ID	Client sample ID	Method: Compound	CAS Number	LOR	Unit	Original Result	Duplicate Result	RPD (%)	Recovery Limits (%)
				Laboratory Duplicate (DUP) Report					
ED093F: Dissolved Major Cations (QC Lot: 678329) - continued									
EB1628373-001	Spring 1	ED093F: Potassium	7440-09-7	1	mg/L	5	5	0.00	No Limit
EB1628522-005	Anonymous	ED093F: Calcium	7440-70-2	1	mg/L	3	3	0.00	No Limit
		ED093F: Magnesium	7439-95-4	1	mg/L	2	2	0.00	No Limit
		ED093F: Sodium	7440-23-5	1	mg/L	17	17	0.00	0% - 50%
		ED093F: Potassium	7440-09-7	1	mg/L	<1	<1	0.00	No Limit
EK040P: Fluoride by PC Titrator (QC Lot: 681096)									
EB1628197-001	Anonymous	EK040P: Fluoride	16984-48-8	0.1	mg/L	<0.1	<0.1	0.00	No Limit
EB1628197-011	Anonymous	EK040P: Fluoride	16984-48-8	0.1	mg/L	<0.1	<0.1	0.00	No Limit
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser (QC Lot: 676710)									
EB1628445-001	Anonymous	EK059G: Nitrite + Nitrate as N	----	0.01	mg/L	0.02	0.02	0.00	No Limit
EB1628445-011	Anonymous	EK059G: Nitrite + Nitrate as N	----	0.01	mg/L	0.06	0.06	0.00	No Limit
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser (QC Lot: 680480)									
EB1628328-001	Anonymous	EK061G: Total Kjeldahl Nitrogen as N	----	0.1	mg/L	3.1	3.0	3.87	0% - 20%
EB1628472-001	Anonymous	EK061G: Total Kjeldahl Nitrogen as N	----	0.1	mg/L	87.2	101	14.9	0% - 20%
EK067G: Total Phosphorus as P by Discrete Analyser (QC Lot: 680479)									
EB1628328-001	Anonymous	EK067G: Total Phosphorus as P	----	0.01	mg/L	0.45	0.44	0.00	0% - 20%
EB1628472-001	Anonymous	EK067G: Total Phosphorus as P	----	0.01	mg/L	10.5	10.9	4.05	0% - 20%
EP002: Dissolved Organic Carbon (DOC) (QC Lot: 676616)									
EB1628367-001	Anonymous	EP002: Dissolved Organic Carbon	----	1	mg/L	16	18	11.4	No Limit
EB1628475-003	Anonymous	EP002: Dissolved Organic Carbon	----	1	mg/L	2	4	43.3	No Limit
EP005: Total Organic Carbon (TOC) (QC Lot: 676617)									
EB1628367-001	Anonymous	EP005: Total Organic Carbon	----	1	mg/L	16	14	12.1	No Limit
EB1628475-003	Anonymous	EP005: Total Organic Carbon	----	1	mg/L	3	4	31.0	No Limit

Method Blank (MB) and Laboratory Control Spike (LCS) Report

The quality control term Method / Laboratory Blank refers to an analyte free matrix to which all reagents are added in the same volumes or proportions as used in standard sample preparation. The purpose of this QC parameter is to monitor potential laboratory contamination. The quality control term Laboratory Control Spike (LCS) refers to a certified reference material, or a known interference free matrix spiked with target analytes. The purpose of this QC parameter is to monitor method precision and accuracy independent of sample matrix. Dynamic Recovery Limits are based on statistical evaluation of processed LCS.

Sub-Matrix: **WATER**

				Method Blank (MB) Report	*Laboratory Control Spike (LCS) Report*			
					Spike	*Spike Recovery (%)*	*Recovery Limits (%)*	
Method: Compound	*CAS Number*	*LOR*	*Unit*	*Result*	*Concentration*	*LCS*	*Low*	*High*
EA015: Total Dissolved Solids dried at 180 ± 5 °C (QCLot: 679243)								
EA015H: Total Dissolved Solids @180°C	----	10	mg/L	<10	293 mg/L	96.0	88	112
				<10	2000 mg/L	99.2	88	112
ED009: Anions (QCLot: 677330)								
ED009-X: Bromide	24959-67-9	0.01	mg/L	<0.010	0.2 mg/L	92.0	80	115
ED009-X: Iodide	20461-54-5	0.01	mg/L	<0.010	0.2 mg/L	107	80	113
ED037P: Alkalinity by PC Titrator (QCLot: 681097)								
ED037-P: Total Alkalinity as CaCO3	----	----	mg/L	----	200 mg/L	113	80	120
ED040F: Dissolved Major Anions (QCLot: 676628)								
ED040F: Sulfate as SO4 2-	14808-79-8	1	mg/L	<1	----	----	----	----
ED045G: Chloride by Discrete Analyser (QCLot: 676629)								
ED045G: Chloride	16887-00-6	1	mg/L	<1	10 mg/L	94.2	90	115
				<1	1000 mg/L	96.1	90	115
ED093F: Dissolved Major Cations (QCLot: 678329)								
ED093F: Calcium	7440-70-2	1	mg/L	<1	----	----	----	----
ED093F: Magnesium	7439-95-4	1	mg/L	<1	----	----	----	----
ED093F: Sodium	7440-23-5	1	mg/L	<1	----	----	----	----
ED093F: Potassium	7440-09-7	1	mg/L	<1	----	----	----	----
EK040P: Fluoride by PC Titrator (QCLot: 681096)								
EK040P: Fluoride	16984-48-8	0.1	mg/L	<0.1	10 mg/L	102	80	117
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser (QCLot: 676710)								
EK059G: Nitrite + Nitrate as N	----	0.01	mg/L	<0.01	0.5 mg/L	97.3	89	115
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser (QCLot: 680480)								
EK061G: Total Kjeldahl Nitrogen as N	----	0.1	mg/L	<0.1	10 mg/L	74.7	70	111
EK067G: Total Phosphorus as P by Discrete Analyser (QCLot: 680479)								
EK067G: Total Phosphorus as P	----	0.01	mg/L	<0.01	4.42 mg/L	90.5	77	109
EP002: Dissolved Organic Carbon (DOC) (QCLot: 676616)								
EP002: Dissolved Organic Carbon	----	1	mg/L	<1	10 mg/L	87.4	80	112
				<1	100 mg/L	91.8	80	112
EP005: Total Organic Carbon (TOC) (QCLot: 676617)								
EP005: Total Organic Carbon	----	1	mg/L	<1	10 mg/L	83.1	79	113
				<1	100 mg/L	92.0	79	113

Matrix Spike (MS) Report

The quality control term Matrix Spike (MS) refers to an intralaboratory split sample spiked with a representative set of target analytes. The purpose of this QC parameter is to monitor potential matrix effects on analyte recoveries. Static Recovery Limits as per laboratory Data Quality Objectives (DQOs). Ideal recovery ranges stated may be waived in the event of sample matrix interference.

Sub-Matrix**: WATER**

				Matrix Spike (MS) Report			
				Spike	*SpikeRecovery(%)*	*Recovery Limits (%)*	
Laboratory sample ID	*Client sample ID*	*Method: Compound*	*CAS Number*	*Concentration*	*MS*	*Low*	*High*
ED009: Anions (QCLot: 677330)							
EB1628348-002	Anonymous	ED009-X: Bromide	24959-67-9	0.5 mg/L	99.8	70	130
		ED009-X: Iodide	20461-54-5	0.5 mg/L	96.0	70	130
ED045G: Chloride by Discrete Analyser (QCLot: 676629)							
EB1628373-002	Swamp 1	ED045G: Chloride	16887-00-6	400 mg/L	106	70	130
EK040P: Fluoride by PC Titrator (QCLot: 681096)							
EB1628197-002	Anonymous	EK040P: Fluoride	16984-48-8	5 mg/L	103	70	130
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser (QCLot: 676710)							
EB1628445-002	Anonymous	EK059G: Nitrite + Nitrate as N	----	0.4 mg/L	90.8	70	130
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser (QCLot: 680480)							
EB1628328-002	Anonymous	EK061G: Total Kjeldahl Nitrogen as N	----	5 mg/L	81.0	70	130
EK067G: Total Phosphorus as P by Discrete Analyser (QCLot: 680479)							
EB1628328-002	Anonymous	EK067G: Total Phosphorus as P	----	1 mg/L	106	70	130
EP002: Dissolved Organic Carbon (DOC) (QCLot: 676616)							
EB1628367-002	Anonymous	EP002: Dissolved Organic Carbon	----	100 mg/L	92.4	70	130
EP005: Total Organic Carbon (TOC) (QCLot: 676617)							
EB1628367-002	Anonymous	EP005: Total Organic Carbon	----	100 mg/L	75.9	70	130

Environmental

QA/QC Compliance Assessment to assist with Quality Review

Work Order	: **EB1628373**	Page	: 1 of 7
Client	: **EARTH SEARCH**	Laboratory	: Environmental Division Brisbane
Contact	: MR NED HAMER	Telephone	: +61-7-3243 7222
Project	: GDE Assess	Date Samples Received	: 01-Dec-2016
Site	: ----	Issue Date	: 01-Mar-2017
Sampler	: NED HAMER	No. of samples received	: 2
Order number	: ----	No. of samples analysed	: 2

This report is automatically generated by the ALS LIMS through interpretation of the ALS Quality Control Report and several Quality Assurance parameters measured by ALS. This automated reporting highlights any non-conformances, facilitates faster and more accurate data validation and is designed to assist internal expert and external Auditor review. Many components of this report contribute to the overall DQO assessment and reporting for guideline compliance.

Brief method summaries and references are also provided to assist in traceability.

Summary of Outliers

Outliers : Quality Control Samples

This report highlights outliers flagged in the Quality Control (QC) Report.

- **NO Method Blank value outliers occur.**
- **NO Duplicate outliers occur.**
- **NO Laboratory Control outliers occur.**
- **NO Matrix Spike outliers occur.**
- **For all regular sample matrices, NO surrogate recovery outliers occur.**

Outliers : Analysis Holding Time Compliance

- **NO Analysis Holding Time Outliers exist.**

Outliers : Frequency of Quality Control Samples

- **NO Quality Control Sample Frequency Outliers exist.**

Analysis Holding Time Compliance

If samples are identified below as having been analysed or extracted outside of recommended holding times, this should be taken into consideration when interpreting results.

This report summarizes extraction / preparation and analysis times and compares each with ALS recommended holding times (referencing USEPA SW 846, APHA, AS and NEPM) based on the sample container provided. Dates reported represent first date of extraction or analysis and preclude subsequent dilutions and reruns. A listing of breaches (if any) is provided herein.

Holding time for leachate methods (e.g. TCLP) vary according to the analytes reported. Assessment compares the leach date with the shortest analyte holding time for the equivalent soil method. These are: organics 14 days, mercury 28 days & other metals 180 days. A recorded breach does not guarantee a breach for all non-volatile parameters.

Holding times for ***VOC in soils*** vary according to analytes of interest. Vinyl Chloride and Styrene holding time is 7 days; others 14 days. A recorded breach does not guarantee a breach for all VOC analytes and should be verified in case the reported breach is a false positive or Vinyl Chloride and Styrene are not key analytes of interest/concern.

Matrix: **WATER**

Evaluation: × = Holding time breach ; ✓ = Within holding time.

Method	*Sample Date*	*Extraction / Preparation*			*Analysis*		
Container / Client Sample ID(s)		*Date extracted*	*Due for extraction*	*Evaluation*	*Date analysed*	*Due for analysis*	*Evaluation*
EA015: Total Dissolved Solids dried at 180 ± 5 °C							
Clear Plastic Bottle - Natural (EA015H) Spring 1, Swamp 1	**30-Nov-2016**	**----**	----	----	**05-Dec-2016**	07-Dec-2016	✓
ED009: Anions							
Clear Plastic Bottle - Natural (ED009-X) Spring 1, Swamp 1	**30-Nov-2016**	**----**	----	----	**02-Dec-2016**	28-Dec-2016	✓
ED037P: Alkalinity by PC Titrator							
Clear Plastic Bottle - Natural (ED037-P) Spring 1	**30-Nov-2016**	**----**	----	----	**06-Dec-2016**	14-Dec-2016	✓
ED040F: Dissolved Major Anions							
Clear Plastic Bottle - Natural (ED040F) Spring 1, Swamp 1	**30-Nov-2016**	**----**	----	----	**02-Dec-2016**	28-Dec-2016	✓
ED045G: Chloride by Discrete Analyser							
Clear Plastic Bottle - Natural (ED045G) Spring 1, Swamp 1	**30-Nov-2016**	**----**	----	----	**02-Dec-2016**	28-Dec-2016	✓
ED093F: Dissolved Major Cations							
Clear Plastic Bottle - Natural (ED093F) Spring 1, Swamp 1	**30-Nov-2016**	**----**	----	----	**05-Dec-2016**	07-Dec-2016	✓
EK040P: Fluoride by PC Titrator							
Clear Plastic Bottle - Natural (EK040P) Spring 1, Swamp 1	**30-Nov-2016**	**----**	----	----	**06-Dec-2016**	28-Dec-2016	✓
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser							
Clear Plastic Bottle - Sulfuric Acid (EK059G) Spring 1, Swamp 1	**30-Nov-2016**	**----**	----	----	**06-Dec-2016**	28-Dec-2016	✓
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser							
Clear Plastic Bottle - Sulfuric Acid (EK061G) Spring 1, Swamp 1	**30-Nov-2016**	**06-Dec-2016**	28-Dec-2016	✓	**06-Dec-2016**	28-Dec-2016	✓
EK067G: Total Phosphorus as P by Discrete Analyser							
Clear Plastic Bottle - Sulfuric Acid (EK067G) Spring 1, Swamp 1	**30-Nov-2016**	**06-Dec-2016**	28-Dec-2016	✓	**06-Dec-2016**	28-Dec-2016	✓

Matrix: **WATER**

Evaluation: × = Holding time breach ; ✓ = Within holding time.

Method Container / Client Sample ID(s)		Sample Date	Extraction / Preparation			Analysis		
			Date extracted	Due for extraction	Evaluation	Date analysed	Due for analysis	Evaluation
EP002: Dissolved Organic Carbon (DOC)								
Amber DOC Filtered- Sulfuric Preserved (EP002)								
Spring 1,	Swamp 1	**30-Nov-2016**	**----**	----	----	**02-Dec-2016**	28-Dec-2016	✓
EP005: Total Organic Carbon (TOC)								
Amber TOC Vial - Sulfuric Acid (EP005)								
Spring 1,	Swamp 1	**30-Nov-2016**	**----**	----	----	**02-Dec-2016**	28-Dec-2016	✓

Quality Control Parameter Frequency Compliance

The following report summarises the frequency of laboratory QC samples analysed within the analytical lot(s) in which the submitted sample(s) was(were) processed. Actual rate should be greater than or equal to the expected rate. A listing of breaches is provided in the Summary of Outliers.

Matrix: **WATER**

Evaluation: × = Quality Control frequency not within specification ; ✓ = Quality Control frequency within specification.

Quality Control Sample Type		Count		Rate (%)			Quality Control Specification
Analytical Methods	*Method*	*QC*	*Regular*	***Actual***	***Expected***	*Evaluation*	
Laboratory Duplicates (DUP)							
Alkalinity by PC Titrator	ED037-P	2	15	**13.33**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Chloride by Discrete Analyser	ED045G	2	16	**12.50**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Organic Carbon	EP002	2	15	**13.33**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Fluoride by PC Titrator	EK040P	2	19	**10.53**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Major Anions - Dissolved	ED040F	1	5	**20.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Major Cations - Dissolved	ED093F	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Nitrite and Nitrate as N (NOx) by Discrete Analyser	EK059G	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Standard Anions -by IC (Extended Method)	ED009-X	2	11	**18.18**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Dissolved Solids (High Level)	EA015H	1	8	**12.50**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Kjeldahl Nitrogen as N By Discrete Analyser	EK061G	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Organic Carbon	EP005	2	15	**13.33**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Phosphorus as P By Discrete Analyser	EK067G	2	19	**10.53**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Laboratory Control Samples (LCS)							
Alkalinity by PC Titrator	ED037-P	1	15	**6.67**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Chloride by Discrete Analyser	ED045G	2	16	**12.50**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Organic Carbon	EP002	2	15	**13.33**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Fluoride by PC Titrator	EK040P	1	19	**5.26**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Nitrite and Nitrate as N (NOx) by Discrete Analyser	EK059G	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Standard Anions -by IC (Extended Method)	ED009-X	1	11	**9.09**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Dissolved Solids (High Level)	EA015H	2	8	**25.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Kjeldahl Nitrogen as N By Discrete Analyser	EK061G	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Organic Carbon	EP005	2	15	**13.33**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Phosphorus as P By Discrete Analyser	EK067G	1	19	**5.26**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Method Blanks (MB)							
Chloride by Discrete Analyser	ED045G	1	16	**6.25**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Organic Carbon	EP002	1	15	**6.67**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Fluoride by PC Titrator	EK040P	1	19	**5.26**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Major Anions - Dissolved	ED040F	1	5	**20.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Major Cations - Dissolved	ED093F	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Nitrite and Nitrate as N (NOx) by Discrete Analyser	EK059G	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Standard Anions -by IC (Extended Method)	ED009-X	1	11	**9.09**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Dissolved Solids (High Level)	EA015H	1	8	**12.50**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Kjeldahl Nitrogen as N By Discrete Analyser	EK061G	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Organic Carbon	EP005	1	15	**6.67**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Phosphorus as P By Discrete Analyser	EK067G	1	19	**5.26**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Matrix Spikes (MS)							

Matrix: **WATER**

Evaluation: × = Quality Control frequency not within specification ; ✓ = Quality Control frequency within specification.

Quality Control Sample Type		Count		Rate (%)			Quality Control Specification
Analytical Methods	*Method*	*QC*	*Regular*	***Actual***	***Expected***	*Evaluation*	
Matrix Spikes (MS) - Continued							
Chloride by Discrete Analyser	ED045G	1	16	**6.25**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Organic Carbon	EP002	1	15	**6.67**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Fluoride by PC Titrator	EK040P	1	19	**5.26**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Nitrite and Nitrate as N (NOx) by Discrete Analyser	EK059G	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Standard Anions -by IC (Extended Method)	ED009-X	1	11	**9.09**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Kjeldahl Nitrogen as N By Discrete Analyser	EK061G	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Organic Carbon	EP005	1	15	**6.67**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Phosphorus as P By Discrete Analyser	EK067G	1	19	**5.26**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard

Brief Method Summaries

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the US EPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request. The following report provides brief descriptions of the analytical procedures employed for results reported in the Certificate of Analysis. Sources from which ALS methods have been developed are provided within the Method Descriptions.

Analytical Methods	*Method*	*Matrix*	*Method Descriptions*
Total Dissolved Solids (High Level)	EA015H	WATER	In house: Referenced to APHA 2540C. A gravimetric procedure that determines the amount of `filterable` residue in an aqueous sample. A well-mixed sample is filtered through a glass fibre filter (1.2um). The filtrate is evaporated to dryness and dried to constant weight at 180+/-5C. This method is compliant with NEPM (2013) Schedule B(3)
Standard Anions -by IC (Extended Method)	ED009-X	WATER	In house: Referenced to APHA 4110. This method is compliant with NEPM (2013) Schedule B(3)
Alkalinity by PC Titrator	ED037-P	WATER	In house: Referenced to APHA 2320 B This procedure determines alkalinity by automated measurement (e.g. PC Titrate) using pH 4.5 for indicating the total alkalinity end-point. This method is compliant with NEPM (2013) Schedule B(3)
Major Anions - Dissolved	ED040F	WATER	In house: Referenced to APHA 3120. The 0.45µm filtered samples are determined by ICP/AES for Sulfur and/or Silcon content and reported as Sulfate and/or Silica after conversion by gravimetric factor.
Chloride by Discrete Analyser	ED045G	WATER	In house: Referenced to APHA 4500 Cl - G.The thiocyanate ion is liberated from mercuric thiocyanate through sequestration of mercury by the chloride ion to form non-ionised mercuric chloride.in the presence of ferric ions the librated thiocyanate forms highly-coloured ferric thiocyanate which is measured at 480 nm APHA 21st edition seal method 2 017-1-L april 2003
Major Cations - Dissolved	ED093F	WATER	In house: Referenced to APHA 3120 and 3125; USEPA SW 846 - 6010 and 6020; Cations are determined by either ICP-AES or ICP-MS techniques. This method is compliant with NEPM (2013) Schedule B(3) Sodium Adsorption Ratio is calculated from Ca, Mg and Na which determined by ALS in house method QWI-EN/ED093F. This method is compliant with NEPM (2013) Schedule B(3) Hardness parameters are calculated based on APHA 2340 B. This method is compliant with NEPM (2013) Schedule B(3)
Fluoride by PC Titrator	EK040P	WATER	In house: Referenced to APHA 4500-F C: CDTA is added to the sample to provide a uniform ionic strength background, adjust pH, and break up complexes. Fluoride concentration is determined by either manual or automatic ISE measurement. This method is compliant with NEPM (2013) Schedule B(3)
Nitrite and Nitrate as N (NOx) by Discrete Analyser	EK059G	WATER	In house: Referenced to APHA 4500-NO3- F. Combined oxidised Nitrogen (NO2+NO3) is determined by Chemical Reduction and direct colourimetry by Discrete Analyser. This method is compliant with NEPM (2013) Schedule B(3)
Total Kjeldahl Nitrogen as N By Discrete Analyser	EK061G	WATER	In house: Referenced to APHA 4500-Norg D (In house). An aliquot of sample is digested using a high temperature Kjeldahl digestion to convert nitrogenous compounds to ammonia. Ammonia is determined colorimetrically by discrete analyser. This method is compliant with NEPM (2013) Schedule B(3)
Total Nitrogen as N (TKN + Nox) By Discrete Analyser	EK062G	WATER	In house: Referenced to APHA 4500-Norg / 4500-NO3-. This method is compliant with NEPM (2013) Schedule B(3)

Analytical Methods	*Method*	*Matrix*	*Method Descriptions*
Total Phosphorus as P By Discrete Analyser	EK067G	WATER	In house: Referenced to APHA 4500-P H, Jirka et al (1976), Zhang et al (2006). This procedure involves sulphuric acid digestion of a sample aliquot to break phosphorus down to orthophosphate. The orthophosphate reacts with ammonium molybdate and antimony potassium tartrate to form a complex which is then reduced and its concentration measured at 880nm using discrete analyser. This method is compliant with NEPM (2013) Schedule B(3)
Ionic Balance by PCT DA and Turbi SO4 DA	EN055 - PG	WATER	In house: Referenced to APHA 1030F. This method is compliant with NEPM (2013) Schedule B(3)
Dissolved Organic Carbon	EP002	WATER	In house: Referenced to APHA 5310 B. This method is compliant with NEPM (2013) Schedule B(3) . Samples are combusted at high termperature in the presence of an oxidative catalyst. The evolved carbon dioxide is quantified using an IR detector.
Total Organic Carbon	EP005	WATER	In house: Referenced to APHA 5310 B, The automated TOC analyzer determines Total and Inorganic Carbon by IR cell. TOC is calculated as the difference. This method is compliant with NEPM (2013) Schedule B(3)
Stable Isotopes - Carbon C12/13 ratio in water matrices	* STABISO-WAT	WATER	Isotopes in water matrices subcontracted to an external supplier (Environmental Isotopes). NATA accreditation does not cover performance of this service.

Preparation Methods	*Method*	*Matrix*	*Method Descriptions*
TKN/TP Digestion	EK061/EK067	WATER	In house: Referenced to APHA 4500 Norg - D; APHA 4500 P - H. This method is compliant with NEPM (2013) Schedule B(3)

CHAIN OF CUSTODY

ALS Laboratory: please tick →

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Ph: 08 8359 0890 E: adelaide@alsglobal.com
☐BRISBANE 2 Byth Street Stafford QLD 4053
Ph: 07 3243 7222 E: samples.brisbane@alsglobal.com
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Ph: 07 4796 0600 E: townsville.environmental@alsglobal.com
☐WOLLONGONG 99 Kenny Street Wollongong NSW 2500
Ph: 02 4225 3125 E: wollongong@alsglobal.com

CLIENT: Earth Search
OFFICE: Brisbane
PROJECT: GDE Assessment **PROJECT NO.:**
ORDER NUMBER: **PURCHASE ORDER NO.:**
PROJECT MANAGER: Ned Hamer **CONTACT PH:** 0429 049 154
SAMPLER: Ned Hamer **SAMPLER MOBILE:** 0429049154
COC Emailed to ALS? (YES / [✓ NO]**)** **EDD FORMAT (or default):**
Email Reports to (will default to PM if no other addresses are listed): ned@earthsearch.com.au
Email Invoice to (will default to PM if no other addresses are listed): as above

TURNAROUND REQUIREMENTS : (Standard TAT may be longer for some tests e.g.. Ultra Trace Organics)
☐ Standard TAT **(List due date):**
☒ Non Standard or urgent TAT **(List due date):** See below
ALS QUOTE NO.:
COUNTRY OF ORIGIN:

COC SEQUENCE NUMBER (Circle)
COC: [✓ 1] 2 3 4 5 6 7
OF: [✓ 1] 2 3 4 5 6 7

FOR LABORATORY USE ONLY (Circle)
Custody Seal Intact? Yes No N/A
Free ice / frozen ice bricks present upon receipt? Yes No N/A
Random Sample Temperature on Receipt: °C
Other comment:

RELINQUISHED BY:
DATE/TIME: 30/11/16 15:45

RECEIVED BY: J. Day
DATE/TIME: 30/11/16 1545

RELINQUISHED BY:
DATE/TIME:

RECEIVED BY:
DATE/TIME: 10.55 1/12

LAB OF ORIGIN
CHINCHILLA

COMMENTS/SPECIAL HANDLING/STORAGE OR DISPOSAL:

ALS USE ONLY	SAMPLE DETAILS MATRIX: Solid(S) Water(W)			CONTAINER INFORMATION		ANALYSIS REQUIRED including SUITES (NB. Suite Codes must be listed to attract suite price) Where **Metals** are required, specify **Total** (unfiltered bottle required) or **Dissolved** (field filtered bottle required).								Additional Information
LAB ID	SAMPLE ID	DATE / TIME	MATRIX	TYPE & PRESERVATIVE *(refer to codes below)*	TOTAL BOTTLES	TDS	Alkalinity Total, Bicarb Carb, Hydrox	Sulphate - SO4 by ICPAES	Chloride, Major Cats	Bromide, Iodide, Flouride	Total Nitrogen as N Total Phosphorus as P	TOC DOC (Field Filtered)	Carbon ^{13}C ^{14}C Strontium ($^{87}/^{86}Sr$) Stable Isotopes ^{18}O ^{2}D	Comments on likely contaminant levels, dilutions, or samples requiring specific QC analysis etc. Radon (222 Rn) to ANSTO Laboratories ⊛
	Spring 1	30/11/16 13:00	W		6	X	X	X	X	X	X	X	X	X Vial labelled "Sp"
	Swamp 1	30/11/16 14:30	W		6	X	X	X	X	X	X	X	X	X Vial labelled "Sw"
					TOTAL									

Environmental Division
Brisbane
Work Order Reference
EB1628373

Telephone : + 61-7-3243 7222

Attn: Robert Chisari
Building B21
ANSTO
New Illawarra Rd
Lucas Heights
2234

⊛ URGENT
3 day H.T.

Air Freight
overnight to
ANSTO
Lucas Heights

Water Container Codes: P = Unpreserved Plastic; N = Nitric Preserved Plastic; ORC = Nitric Preserved ORC; SH = Sodium Hydroxide/Cd Preserved; S = Sodium Hydroxide Preserved Plastic; AG = Amber Glass Unpreserved; AP - Airfreight Unpreserved Plastic
V = VOA Vial HCl Preserved; VB = VOA Vial Sodium Bisulphate Preserved; VS = VOA Vial Sulfuric Preserved; AV = Airfreight Unpreserved Vial SG = Sulfuric Preserved Amber Glass; H = HCl preserved Plastic; HS = HCl preserved Speciation bottle; SP = Sulfuric Preserved Plastic; F = Formaldehyde Preserved Glass;
Z = Zinc Acetate Preserved Bottle; E = EDTA Preserved Bottles; ST = Sterile Bottle; ASS = Plastic Bag for Acid Sulphate Soils; B = Unpreserved Bag; LI = Lugols Iodine Preserved Bottles; STT = Sterile Sodium Thiosulfate Preserved Bottles.

CERTIFICATE OF ANALYSIS

Work Order	: **EB1628486**	Page	: 1 of 4
Client	: **EARTH SEARCH**	Laboratory	: Environmental Division Brisbane
Contact	: MR NED HAMER	Contact	: Customer Services EB
Address	: 15 HAMPSON STREET KELVIN GROVE QUEENSLAND 4059	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: ----	Telephone	: +61-7-3243 7222
Project	: GDE Assess	Date Samples Received	: 01-Dec-2016 20:50
Order number	: ----	Date Analysis Commenced	: 02-Dec-2016
C-O-C number	: ----	Issue Date	: 09-Mar-2017 14:21
Sampler	: NED HAMER		
Site	: ----		
Quote number	: BNBQ/101/16		
No. of samples received	: 4		
No. of samples analysed	: 4		

NATA
Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Andrew Epps	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD
Andrew Epps	Senior Inorganic Chemist	WB Water Lab Brisbane, Stafford, QLD
Diana Mesa	2IC Organic Chemist	Brisbane Organics, Stafford, QLD
Kim McCabe	Senior Inorganic Chemist	WB Water Lab Brisbane, Stafford, QLD
Martina Louw	Inorganic Chemist	Brisbane External Subcontracting, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When no sampling time is provided, the sampling time will default 00:00 on the date of sampling. If no sampling date is provided, the sampling date will be assumed by the laboratory and displayed in brackets without a time component.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- ED009-X (Standard Anions - Extended Method –by IC): Some samples were diluted due to matrix interference. LOR adjusted accordingly.
- TDS by method EA-015 may bias high due to the presence of fine particulate matter, which may pass through the prescribed GF/C paper.
- Subcontracted analysis reported in this work order is conducted by Environmental Isotopes. Environmental Isotopes does not hold NATA Accreditation for these parameters.

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**Bowenville 1**	**154**	**151**	**DUP**	**----**
			Client sampling date / time	01-Dec-2016 00:00	01-Dec-2016 00:00	01-Dec-2016 00:00	01-Dec-2016 00:00	----
Compound	*CAS Number*	*LOR*	*Unit*	**EB1628486-001**	**EB1628486-002**	**EB1628486-003**	**EB1628486-004**	**--------**
				Result	Result	Result	Result	----
EA015: Total Dissolved Solids dried at 180 ± 5 °C								
Total Dissolved Solids @180°C	----	10	mg/L	**681**	**146**	**310**	**305**	----
ED009: Anions								
Bromide	24959-67-9	0.01	mg/L	**0.280**	**0.025**	**0.094**	**0.100**	----
Iodide	20461-54-5	0.01	mg/L	<0.100	<0.010	<0.020	<0.020	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	<1	----	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	<1	----	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**245**	**48**	**163**	----	----
Total Alkalinity as CaCO3	----	1	mg/L	**245**	**48**	**163**	----	----
ED040F: Dissolved Major Anions								
Sulfate as SO4 2-	14808-79-8	1	mg/L	**18**	<1	**6**	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**211**	**21**	**76**	**79**	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**59**	**6**	**42**	**41**	----
Magnesium	7439-95-4	1	mg/L	**53**	**4**	**15**	**15**	----
Sodium	7440-23-5	1	mg/L	**96**	**21**	**58**	**58**	----
Potassium	7440-09-7	1	mg/L	**11**	**7**	**6**	**6**	----
EK040P: Fluoride by PC Titrator								
Fluoride	16984-48-8	0.1	mg/L	**0.2**	<0.1	**2.2**	**2.2**	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	<0.01	<0.01	**0.02**	----	----
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	0.1	mg/L	**0.6**	**1.0**	**7.0**	----	----
EK062G: Total Nitrogen as N (TKN + NOx) by Discrete Analyser								
^ **Total Nitrogen as N**	----	0.1	mg/L	**0.6**	**1.0**	**7.0**	----	----
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	0.01	mg/L	**0.16**	**0.05**	**0.69**	----	----
EN055: Ionic Balance								
Total Anions	----	0.01	meq/L	**11.3**	**1.55**	**5.55**	**5.63**	----
Total Cations	----	0.01	meq/L	**11.8**	**1.72**	**6.01**	**5.96**	----
Ionic Balance	----	0.01	%	**2.08**	----	**3.98**	**2.81**	----
EP002: Dissolved Organic Carbon (DOC)								

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER**)

			Client sample ID	**Bowenville 1**	**154**	**151**	**DUP**	**----**
			Client sampling date / time	01-Dec-2016 00:00	01-Dec-2016 00:00	01-Dec-2016 00:00	01-Dec-2016 00:00	----
Compound	CAS Number	LOR	Unit	**EB1628486-001**	**EB1628486-002**	**EB1628486-003**	**EB1628486-004**	**--------**
				Result	Result	Result	Result	----
EP002: Dissolved Organic Carbon (DOC) - Continued								
Dissolved Organic Carbon	----	1	mg/L	**6**	**16**	**18**	**----**	**----**
EP005: Total Organic Carbon (TOC)								
Total Organic Carbon	----	1	mg/L	**6**	**16**	**21**	**----**	**----**
Subcontracted Analysis								
ø **C13 Isotope**	----	0.01	per mil VPDB	**-8.65**	**-7.53**	**-9.89**	**----**	**----**
ø **C13 Isotope Average**	----	0.01	per mil VPDB	**-8.41**	**-7.26**	**-9.68**	**----**	**----**
ø **C13 Isotope Duplicate**	----	0.01	per mil VPDB	**-8.16**	**-6.98**	**-9.47**	**----**	**----**
ø **Deuterium**	----	0.1	VSMOW	**3.46**	**33.28**	**11.65**	**----**	**----**
ø **Oxygen-18**	----	0.1	VSMOW	**1.22**	**8.00**	**1.75**	**----**	**----**

Environmental

QUALITY CONTROL REPORT

Work Order	: **EB1628486**	Page	: 1 of 5
Client	: **EARTH SEARCH**	Laboratory	: Environmental Division Brisbane
Contact	: MR NED HAMER	Contact	: Customer Services EB
Address	: 15 HAMPSON STREET KELVIN GROVE QUEENSLAND 4059	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: ----	Telephone	: +61-7-3243 7222
Project	: GDE Assess	Date Samples Received	: 01-Dec-2016
Order number	: ----	Date Analysis Commenced	: 02-Dec-2016
C-O-C number	: ----	Issue Date	: 09-Mar-2017
Sampler	: NED HAMER		
Site	: ----		
Quote number	: BNBQ/101/16		
No. of samples received	: 4		
No. of samples analysed	: 4		

NATA

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Quality Control Report contains the following information:

- Laboratory Duplicate (DUP) Report; Relative Percentage Difference (RPD) and Acceptance Limits
- Method Blank (MB) and Laboratory Control Spike (LCS) Report; Recovery and Acceptance Limits
- Matrix Spike (MS) Report; Recovery and Acceptance Limits

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Andrew Epps	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD
Andrew Epps	Senior Inorganic Chemist	WB Water Lab Brisbane, Stafford, QLD
Diana Mesa	2IC Organic Chemist	Brisbane Organics, Stafford, QLD
Kim McCabe	Senior Inorganic Chemist	WB Water Lab Brisbane, Stafford, QLD
Martina Louw	Inorganic Chemist	Brisbane External Subcontracting, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis. Where the LOR of a reported result differs from standard LOR, this may be due to hig

Key : Anonymous = Refers to samples which are not specifically part of this work order but formed part of the QC process lot
CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
RPD = Relative Percentage Difference
# = Indicates failed QC

Laboratory Duplicate (DUP) Report

The quality control term Laboratory Duplicate refers to a randomly selected intralaboratory split. Laboratory duplicates provide information regarding method precision and sample heterogeneity. The permitted ranges for the Relative Percent Deviation (RPD) of Laboratory Duplicates are specified in ALS Method QWI-EN/38 and are dependent on the magnitude of results in comparison to the level of reporting: Result < 10 times LOR: No Limit; Result between 10 and 20 times LOR: 0% - 50%; Result > 20 times LOR: 0% - 20%.

Sub-Matrix: **WATER**

				Laboratory Duplicate (DUP) Report					
Laboratory sample ID	*Client sample ID*	*Method: Compound*	*CAS Number*	*LOR*	*Unit*	*Original Result*	*Duplicate Result*	*RPD (%)*	*Recovery Limits (%)*
EA015: Total Dissolved Solids dried at 180 ± 5 °C (QC Lot: 680613)									
EB1628592-001	Anonymous	EA015H: Total Dissolved Solids @180°C	----	10	mg/L	1540	1510	1.95	0% - 20%
EB1628531-001	Anonymous	EA015H: Total Dissolved Solids @180°C	----	10	mg/L	6660	6680	0.382	0% - 20%
ED009: Anions (QC Lot: 677330)									
EB1628348-001	Anonymous	ED009-X: Bromide	24959-67-9	0.01	mg/L	0.183	0.187	2.16	0% - 20%
		ED009-X: Iodide	20461-54-5	0.01	mg/L	<0.010	<0.010	0.00	0% - 20%
EB1628486-003	151	ED009-X: Bromide	24959-67-9	0.01	mg/L	0.094	0.098	4.17	0% - 20%
		ED009-X: Iodide	20461-54-5	0.01	mg/L	<0.020	<0.020	0.00	0% - 20%
ED037P: Alkalinity by PC Titrator (QC Lot: 681097)									
EB1628197-001	Anonymous	ED037-P: Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	0.00	No Limit
		ED037-P: Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	0.00	No Limit
		ED037-P: Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	175	176	0.00	0% - 20%
		ED037-P: Total Alkalinity as CaCO3	----	1	mg/L	175	176	0.00	0% - 20%
EB1628197-011	Anonymous	ED037-P: Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	0.00	No Limit
		ED037-P: Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	0.00	No Limit
		ED037-P: Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	121	120	0.00	0% - 20%
		ED037-P: Total Alkalinity as CaCO3	----	1	mg/L	121	120	0.00	0% - 20%
ED040F: Dissolved Major Anions (QC Lot: 676628)									
EB1628373-001	Anonymous	ED040F: Sulfate as SO4 2-	14808-79-8	1	mg/L	9	10	0.00	No Limit
ED045G: Chloride by Discrete Analyser (QC Lot: 676629)									
EB1628373-001	Anonymous	ED045G: Chloride	16887-00-6	1	mg/L	30	30	0.00	0% - 20%
EB1628475-005	Anonymous	ED045G: Chloride	16887-00-6	1	mg/L	13100	13200	0.885	0% - 20%
ED045G: Chloride by Discrete Analyser (QC Lot: 676640)									
EB1628366-001	Anonymous	ED045G: Chloride	16887-00-6	1	mg/L	8	8	0.00	No Limit
EB1628464-004	Anonymous	ED045G: Chloride	16887-00-6	1	mg/L	22500	22500	0.175	0% - 20%

Sub-Matrix: **WATER**

				Laboratory Duplicate (DUP) Report					
Laboratory sample ID	Client sample ID	Method: Compound	CAS Number	LOR	Unit	Original Result	Duplicate Result	RPD (%)	Recovery Limits (%)
ED093F: Dissolved Major Cations (QC Lot: 678339)									
EB1628585-001	Anonymous	ED093F: Calcium	7440-70-2	1	mg/L	88	89	0.00	0% - 20%
		ED093F: Magnesium	7439-95-4	1	mg/L	47	47	0.00	0% - 20%
		ED093F: Sodium	7440-23-5	1	mg/L	180	179	0.00	0% - 20%
		ED093F: Potassium	7440-09-7	1	mg/L	10	10	0.00	0% - 50%
EK040P: Fluoride by PC Titrator (QC Lot: 681096)									
EB1628197-001	Anonymous	EK040P: Fluoride	16984-48-8	0.1	mg/L	<0.1	<0.1	0.00	No Limit
EB1628197-011	Anonymous	EK040P: Fluoride	16984-48-8	0.1	mg/L	<0.1	<0.1	0.00	No Limit
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser (QC Lot: 678046)									
EB1628514-001	Anonymous	EK059G: Nitrite + Nitrate as N	----	0.01	mg/L	12.1	11.9	1.20	0% - 20%
EB1628519-005	Anonymous	EK059G: Nitrite + Nitrate as N	----	0.01	mg/L	0.03	<0.01	89.2	No Limit
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser (QC Lot: 680480)									
EB1628328-001	Anonymous	EK061G: Total Kjeldahl Nitrogen as N	----	0.1	mg/L	3.1	3.0	3.87	0% - 20%
EB1628472-001	Anonymous	EK061G: Total Kjeldahl Nitrogen as N	----	0.1	mg/L	87.2	101	14.9	0% - 20%
EK067G: Total Phosphorus as P by Discrete Analyser (QC Lot: 680479)									
EB1628328-001	Anonymous	EK067G: Total Phosphorus as P	----	0.01	mg/L	0.45	0.44	0.00	0% - 20%
EB1628472-001	Anonymous	EK067G: Total Phosphorus as P	----	0.01	mg/L	10.5	10.9	4.05	0% - 20%
EP002: Dissolved Organic Carbon (DOC) (QC Lot: 676616)									
EB1628367-001	Anonymous	EP002: Dissolved Organic Carbon	----	1	mg/L	16	18	11.4	No Limit
EB1628475-003	Anonymous	EP002: Dissolved Organic Carbon	----	1	mg/L	2	4	43.3	No Limit
EP005: Total Organic Carbon (TOC) (QC Lot: 676617)									
EB1628367-001	Anonymous	EP005: Total Organic Carbon	----	1	mg/L	16	14	12.1	No Limit
EB1628475-003	Anonymous	EP005: Total Organic Carbon	----	1	mg/L	3	4	31.0	No Limit

Method Blank (MB) and Laboratory Control Spike (LCS) Report

The quality control term Method / Laboratory Blank refers to an analyte free matrix to which all reagents are added in the same volumes or proportions as used in standard sample preparation. The purpose of this QC parameter is to monitor potential laboratory contamination. The quality control term Laboratory Control Spike (LCS) refers to a certified reference material, or a known interference free matrix spiked with target analytes. The purpose of this QC parameter is to monitor method precision and accuracy independent of sample matrix. Dynamic Recovery Limits are based on statistical evaluation of processed LCS.

Sub-Matrix: **WATER**

				Method Blank (MB) Report	Laboratory Control Spike (LCS) Report			
					Spike	Spike Recovery (%)	Recovery Limits (%)	
Method: Compound	CAS Number	LOR	Unit	Result	Concentration	LCS	Low	High
EA015: Total Dissolved Solids dried at 180 ± 5 °C (QCLot: 680613)								
EA015H: Total Dissolved Solids @180°C	----	10	mg/L	<10	293 mg/L	103	88	112
				<10	2000 mg/L	92.5	88	112
ED009: Anions (QCLot: 677330)								
ED009-X: Bromide	24959-67-9	0.01	mg/L	<0.010	0.2 mg/L	92.0	80	115
ED009-X: Iodide	20461-54-5	0.01	mg/L	<0.010	0.2 mg/L	107	80	113
ED037P: Alkalinity by PC Titrator (QCLot: 681097)								
ED037-P: Total Alkalinity as CaCO3	----	----	mg/L	----	200 mg/L	113	80	120
ED040F: Dissolved Major Anions (QCLot: 676628)								
ED040F: Sulfate as SO4 2-	14808-79-8	1	mg/L	<1	----	----	----	----
ED045G: Chloride by Discrete Analyser (QCLot: 676629)								
ED045G: Chloride	16887-00-6	1	mg/L	<1	10 mg/L	94.2	90	115
				<1	1000 mg/L	96.1	90	115
ED045G: Chloride by Discrete Analyser (QCLot: 676640)								
ED045G: Chloride	16887-00-6	1	mg/L	<1	10 mg/L	97.6	90	115
				<1	1000 mg/L	95.1	90	115
ED093F: Dissolved Major Cations (QCLot: 678339)								
ED093F: Calcium	7440-70-2	1	mg/L	<1	----	----	----	----
ED093F: Magnesium	7439-95-4	1	mg/L	<1	----	----	----	----
ED093F: Sodium	7440-23-5	1	mg/L	<1	----	----	----	----
ED093F: Potassium	7440-09-7	1	mg/L	<1	----	----	----	----
EK040P: Fluoride by PC Titrator (QCLot: 681096)								
EK040P: Fluoride	16984-48-8	0.1	mg/L	<0.1	10 mg/L	102	80	117
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser (QCLot: 678046)								
EK059G: Nitrite + Nitrate as N	----	0.01	mg/L	<0.01	0.5 mg/L	98.2	89	115
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser (QCLot: 680480)								
EK061G: Total Kjeldahl Nitrogen as N	----	0.1	mg/L	<0.1	10 mg/L	74.7	70	111
EK067G: Total Phosphorus as P by Discrete Analyser (QCLot: 680479)								
EK067G: Total Phosphorus as P	----	0.01	mg/L	<0.01	4.42 mg/L	90.5	77	109
EP002: Dissolved Organic Carbon (DOC) (QCLot: 676616)								
EP002: Dissolved Organic Carbon	----	1	mg/L	<1	10 mg/L	87.4	80	112
				<1	100 mg/L	91.8	80	112
EP005: Total Organic Carbon (TOC) (QCLot: 676617)								

Sub-Matrix: **WATER**

Method: Compound	CAS Number	LOR	Unit	Method Blank (MB) Report Result	Laboratory Control Spike (LCS) Report Spike Concentration	Spike Recovery (%) LCS	Recovery Limits (%) Low	Recovery Limits (%) High
EP005: Total Organic Carbon (TOC) (QCLot: 676617) - continued								
EP005: Total Organic Carbon	----	1	mg/L	<1	10 mg/L	83.1	79	113
				<1	100 mg/L	92.0	79	113

Matrix Spike (MS) Report

The quality control term Matrix Spike (MS) refers to an intralaboratory split sample spiked with a representative set of target analytes. The purpose of this QC parameter is to monitor potential matrix effects on analyte recoveries. Static Recovery Limits as per laboratory Data Quality Objectives (DQOs). Ideal recovery ranges stated may be waived in the event of sample matrix interference.

Sub-Matrix: **WATER**

Laboratory sample ID	Client sample ID	Method: Compound	CAS Number	Matrix Spike (MS) Report Spike Concentration	SpikeRecovery(%) MS	Recovery Limits (%) Low	Recovery Limits (%) High
ED009: Anions (QCLot: 677330)							
EB1628348-002	Anonymous	ED009-X: Bromide	24959-67-9	0.5 mg/L	99.8	70	130
		ED009-X: Iodide	20461-54-5	0.5 mg/L	96.0	70	130
ED045G: Chloride by Discrete Analyser (QCLot: 676629)							
EB1628373-002	Anonymous	ED045G: Chloride	16887-00-6	400 mg/L	106	70	130
ED045G: Chloride by Discrete Analyser (QCLot: 676640)							
EB1628366-002	Anonymous	ED045G: Chloride	16887-00-6	400 mg/L	102	70	130
EK040P: Fluoride by PC Titrator (QCLot: 681096)							
EB1628197-002	Anonymous	EK040P: Fluoride	16984-48-8	5 mg/L	103	70	130
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser (QCLot: 678046)							
EB1628514-002	Anonymous	EK059G: Nitrite + Nitrate as N	----	0.4 mg/L	92.0	70	130
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser (QCLot: 680480)							
EB1628328-002	Anonymous	EK061G: Total Kjeldahl Nitrogen as N	----	5 mg/L	81.0	70	130
EK067G: Total Phosphorus as P by Discrete Analyser (QCLot: 680479)							
EB1628328-002	Anonymous	EK067G: Total Phosphorus as P	----	1 mg/L	106	70	130
EP002: Dissolved Organic Carbon (DOC) (QCLot: 676616)							
EB1628367-002	Anonymous	EP002: Dissolved Organic Carbon	----	100 mg/L	92.4	70	130
EP005: Total Organic Carbon (TOC) (QCLot: 676617)							
EB1628367-002	Anonymous	EP005: Total Organic Carbon	----	100 mg/L	75.9	70	130

QA/QC Compliance Assessment to assist with Quality Review

Work Order	: **EB1628486**	Page	: 1 of 7
Client	: **EARTH SEARCH**	Laboratory	: Environmental Division Brisbane
Contact	: MR NED HAMER	Telephone	: +61-7-3243 7222
Project	: GDE Assess	Date Samples Received	: 01-Dec-2016
Site	: ----	Issue Date	: 09-Mar-2017
Sampler	: NED HAMER	No. of samples received	: 4
Order number	: ----	No. of samples analysed	: 4

This report is automatically generated by the ALS LIMS through interpretation of the ALS Quality Control Report and several Quality Assurance parameters measured by ALS. This automated reporting highlights any non-conformances, facilitates faster and more accurate data validation and is designed to assist internal expert and external Auditor review. Many components of this report contribute to the overall DQO assessment and reporting for guideline compliance.

Brief method summaries and references are also provided to assist in traceability.

Summary of Outliers

Outliers : Quality Control Samples

This report highlights outliers flagged in the Quality Control (QC) Report.

- **NO Method Blank value outliers occur.**
- **NO Duplicate outliers occur.**
- **NO Laboratory Control outliers occur.**
- **NO Matrix Spike outliers occur.**
- **For all regular sample matrices, NO surrogate recovery outliers occur.**

Outliers : Analysis Holding Time Compliance

- **NO Analysis Holding Time Outliers exist.**

Outliers : Frequency of Quality Control Samples

- **NO Quality Control Sample Frequency Outliers exist.**

Analysis Holding Time Compliance

If samples are identified below as having been analysed or extracted outside of recommended holding times, this should be taken into consideration when interpreting results.

This report summarizes extraction / preparation and analysis times and compares each with ALS recommended holding times (referencing USEPA SW 846, APHA, AS and NEPM) based on the sample container provided. Dates reported represent first date of extraction or analysis and preclude subsequent dilutions and reruns. A listing of breaches (if any) is provided herein.

Holding time for leachate methods (e.g. TCLP) vary according to the analytes reported. Assessment compares the leach date with the shortest analyte holding time for the equivalent soil method. These are: organics 14 days, mercury 28 days & other metals 180 days. A recorded breach does not guarantee a breach for all non-volatile parameters.

Holding times for ***VOC in soils*** vary according to analytes of interest. Vinyl Chloride and Styrene holding time is 7 days; others 14 days. A recorded breach does not guarantee a breach for all VOC analytes and should be verified in case the reported breach is a false positive or Vinyl Chloride and Styrene are not key analytes of interest/concern.

Matrix: **WATER**

Evaluation: × = Holding time breach ; ✓ = Within holding time.

Method	*Sample Date*	*Extraction / Preparation*			*Analysis*		
Container / Client Sample ID(s)		*Date extracted*	*Due for extraction*	*Evaluation*	*Date analysed*	*Due for analysis*	*Evaluation*
EA015: Total Dissolved Solids dried at 180 ± 5 °C							
Clear Plastic Bottle - Natural (EA015H) Bowenville 1, 154, 151, DUP	**01-Dec-2016**	**----**	----	----	**07-Dec-2016**	08-Dec-2016	✓
ED009: Anions							
Clear Plastic Bottle - Natural (ED009-X) Bowenville 1, 154, 151, DUP	**01-Dec-2016**	**----**	----	----	**02-Dec-2016**	29-Dec-2016	✓
ED037P: Alkalinity by PC Titrator							
Clear Plastic Bottle - Natural (ED037-P) Bowenville 1, 154, 151	**01-Dec-2016**	**----**	----	----	**06-Dec-2016**	15-Dec-2016	✓
ED040F: Dissolved Major Anions							
Clear Plastic Bottle - Natural (ED040F) Bowenville 1, 154, 151	**01-Dec-2016**	**----**	----	----	**02-Dec-2016**	29-Dec-2016	✓
ED045G: Chloride by Discrete Analyser							
Clear Plastic Bottle - Natural (ED045G) Bowenville 1, 154, 151, DUP	**01-Dec-2016**	**----**	----	----	**02-Dec-2016**	29-Dec-2016	✓
ED093F: Dissolved Major Cations							
Clear Plastic Bottle - Natural (ED093F) Bowenville 1, 154, 151, DUP	**01-Dec-2016**	**----**	----	----	**05-Dec-2016**	08-Dec-2016	✓
EK040P: Fluoride by PC Titrator							
Clear Plastic Bottle - Natural (EK040P) Bowenville 1, 154, 151, DUP	**01-Dec-2016**	**----**	----	----	**06-Dec-2016**	29-Dec-2016	✓
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser							
Clear Plastic Bottle - Sulfuric Acid (EK059G) Bowenville 1, 154, 151	**01-Dec-2016**	**----**	----	----	**06-Dec-2016**	29-Dec-2016	✓

Matrix: **WATER**

Evaluation: × = Holding time breach ; ✓ = Within holding time.

Method		***Sample Date***	*Extraction / Preparation*			*Analysis*		
***Container** / Client Sample ID(s)*			***Date extracted***	*Due for extraction*	*Evaluation*	***Date analysed***	*Due for analysis*	*Evaluation*
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Clear Plastic Bottle - Sulfuric Acid (EK061G)								
Bowenville 1, 151	154,	**01-Dec-2016**	**06-Dec-2016**	29-Dec-2016	✓	**06-Dec-2016**	29-Dec-2016	✓
EK067G: Total Phosphorus as P by Discrete Analyser								
Clear Plastic Bottle - Sulfuric Acid (EK067G)								
Bowenville 1, 151	154,	**01-Dec-2016**	**06-Dec-2016**	29-Dec-2016	✓	**06-Dec-2016**	29-Dec-2016	✓
EP002: Dissolved Organic Carbon (DOC)								
Amber DOC Filtered- Sulfuric Preserved (EP002)								
Bowenville 1, 151	154,	**01-Dec-2016**	**----**	----	----	**02-Dec-2016**	29-Dec-2016	✓
EP005: Total Organic Carbon (TOC)								
Amber TOC Vial - Sulfuric Acid (EP005)								
Bowenville 1, 151	154,	**01-Dec-2016**	**----**	----	----	**02-Dec-2016**	29-Dec-2016	✓

Quality Control Parameter Frequency Compliance

The following report summarises the frequency of laboratory QC samples analysed within the analytical lot(s) in which the submitted sample(s) was(were) processed. Actual rate should be greater than or equal to the expected rate. A listing of breaches is provided in the Summary of Outliers.

Matrix: **WATER**

Evaluation: × = Quality Control frequency not within specification ; ✓ = Quality Control frequency within specification.

Quality Control Sample Type		Count		Rate (%)			Quality Control Specification
Analytical Methods	*Method*	*QC*	*Regular*	***Actual***	***Expected***	*Evaluation*	
Laboratory Duplicates (DUP)							
Alkalinity by PC Titrator	ED037-P	2	15	**13.33**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Chloride by Discrete Analyser	ED045G	4	36	**11.11**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Organic Carbon	EP002	2	15	**13.33**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Fluoride by PC Titrator	EK040P	2	19	**10.53**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Major Anions - Dissolved	ED040F	1	5	**20.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Major Cations - Dissolved	ED093F	1	5	**20.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Nitrite and Nitrate as N (NOx) by Discrete Analyser	EK059G	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Standard Anions -by IC (Extended Method)	ED009-X	2	11	**18.18**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Dissolved Solids (High Level)	EA015H	2	14	**14.29**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Kjeldahl Nitrogen as N By Discrete Analyser	EK061G	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Organic Carbon	EP005	2	15	**13.33**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Phosphorus as P By Discrete Analyser	EK067G	2	19	**10.53**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Laboratory Control Samples (LCS)							
Alkalinity by PC Titrator	ED037-P	1	15	**6.67**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Chloride by Discrete Analyser	ED045G	4	36	**11.11**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Organic Carbon	EP002	2	15	**13.33**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Fluoride by PC Titrator	EK040P	1	19	**5.26**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Nitrite and Nitrate as N (NOx) by Discrete Analyser	EK059G	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Standard Anions -by IC (Extended Method)	ED009-X	1	11	**9.09**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Dissolved Solids (High Level)	EA015H	2	14	**14.29**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Kjeldahl Nitrogen as N By Discrete Analyser	EK061G	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Organic Carbon	EP005	2	15	**13.33**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Phosphorus as P By Discrete Analyser	EK067G	1	19	**5.26**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Method Blanks (MB)							
Chloride by Discrete Analyser	ED045G	2	36	**5.56**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Organic Carbon	EP002	1	15	**6.67**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Fluoride by PC Titrator	EK040P	1	19	**5.26**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Major Anions - Dissolved	ED040F	1	5	**20.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Major Cations - Dissolved	ED093F	1	5	**20.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Nitrite and Nitrate as N (NOx) by Discrete Analyser	EK059G	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Standard Anions -by IC (Extended Method)	ED009-X	1	11	**9.09**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Dissolved Solids (High Level)	EA015H	1	14	**7.14**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Kjeldahl Nitrogen as N By Discrete Analyser	EK061G	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Organic Carbon	EP005	1	15	**6.67**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Phosphorus as P By Discrete Analyser	EK067G	1	19	**5.26**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Matrix Spikes (MS)							

Matrix: **WATER**

Evaluation: × = Quality Control frequency not within specification ; ✓ = Quality Control frequency within specification.

Quality Control Sample Type		Count		Rate (%)			Quality Control Specification
Analytical Methods	*Method*	*QC*	*Regular*	***Actual***	***Expected***	*Evaluation*	
Matrix Spikes (MS) - Continued							
Chloride by Discrete Analyser	ED045G	2	36	**5.56**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Organic Carbon	EP002	1	15	**6.67**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Fluoride by PC Titrator	EK040P	1	19	**5.26**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Nitrite and Nitrate as N (NOx) by Discrete Analyser	EK059G	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Standard Anions -by IC (Extended Method)	ED009-X	1	11	**9.09**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Kjeldahl Nitrogen as N By Discrete Analyser	EK061G	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Organic Carbon	EP005	1	15	**6.67**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Total Phosphorus as P By Discrete Analyser	EK067G	1	19	**5.26**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard

Brief Method Summaries

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the US EPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request. The following report provides brief descriptions of the analytical procedures employed for results reported in the Certificate of Analysis. Sources from which ALS methods have been developed are provided within the Method Descriptions.

Analytical Methods	*Method*	*Matrix*	*Method Descriptions*
Total Dissolved Solids (High Level)	EA015H	WATER	In house: Referenced to APHA 2540C. A gravimetric procedure that determines the amount of `filterable` residue in an aqueous sample. A well-mixed sample is filtered through a glass fibre filter (1.2um). The filtrate is evaporated to dryness and dried to constant weight at 180+/-5C. This method is compliant with NEPM (2013) Schedule B(3)
Standard Anions -by IC (Extended Method)	ED009-X	WATER	In house: Referenced to APHA 4110. This method is compliant with NEPM (2013) Schedule B(3)
Alkalinity by PC Titrator	ED037-P	WATER	In house: Referenced to APHA 2320 B This procedure determines alkalinity by automated measurement (e.g. PC Titrate) using pH 4.5 for indicating the total alkalinity end-point. This method is compliant with NEPM (2013) Schedule B(3)
Major Anions - Dissolved	ED040F	WATER	In house: Referenced to APHA 3120. The 0.45µm filtered samples are determined by ICP/AES for Sulfur and/or Silcon content and reported as Sulfate and/or Silica after conversion by gravimetric factor.
Chloride by Discrete Analyser	ED045G	WATER	In house: Referenced to APHA 4500 Cl - G.The thiocyanate ion is liberated from mercuric thiocyanate through sequestration of mercury by the chloride ion to form non-ionised mercuric chloride.in the presence of ferric ions the librated thiocynate forms highly-coloured ferric thiocynate which is measured at 480 nm APHA 21st edition seal method 2 017-1-L april 2003
Major Cations - Dissolved	ED093F	WATER	In house: Referenced to APHA 3120 and 3125; USEPA SW 846 - 6010 and 6020; Cations are determined by either ICP-AES or ICP-MS techniques. This method is compliant with NEPM (2013) Schedule B(3) Sodium Adsorption Ratio is calculated from Ca, Mg and Na which determined by ALS in house method QWI-EN/ED093F. This method is compliant with NEPM (2013) Schedule B(3) Hardness parameters are calculated based on APHA 2340 B. This method is compliant with NEPM (2013) Schedule B(3)
Fluoride by PC Titrator	EK040P	WATER	In house: Referenced to APHA 4500-F C: CDTA is added to the sample to provide a uniform ionic strength background, adjust pH, and break up complexes. Fluoride concentration is determined by either manual or automatic ISE measurement. This method is compliant with NEPM (2013) Schedule B(3)
Nitrite and Nitrate as N (NOx) by Discrete Analyser	EK059G	WATER	In house: Referenced to APHA 4500-NO3- F. Combined oxidised Nitrogen (NO2+NO3) is determined by Chemical Reduction and direct colourimetry by Discrete Analyser. This method is compliant with NEPM (2013) Schedule B(3)
Total Kjeldahl Nitrogen as N By Discrete Analyser	EK061G	WATER	In house: Referenced to APHA 4500-Norg D (In house). An aliquot of sample is digested using a high temperature Kjeldahl digestion to convert nitrogenous compounds to ammonia. Ammonia is determined colorimetrically by discrete analyser. This method is compliant with NEPM (2013) Schedule B(3)
Total Nitrogen as N (TKN + Nox) By Discrete Analyser	EK062G	WATER	In house: Referenced to APHA 4500-Norg / 4500-NO3-. This method is compliant with NEPM (2013) Schedule B(3)

Analytical Methods	Method	Matrix	Method Descriptions
Total Phosphorus as P By Discrete Analyser	EK067G	WATER	In house: Referenced to APHA 4500-P H, Jirka et al (1976), Zhang et al (2006). This procedure involves sulphuric acid digestion of a sample aliquot to break phosphorus down to orthophosphate. The orthophosphate reacts with ammonium molybdate and antimony potassium tartrate to form a complex which is then reduced and its concentration measured at 880nm using discrete analyser. This method is compliant with NEPM (2013) Schedule B(3)
Ionic Balance by PCT DA and Turbi SO4 DA	EN055 - PG	WATER	In house: Referenced to APHA 1030F. This method is compliant with NEPM (2013) Schedule B(3)
Dissolved Organic Carbon	EP002	WATER	In house: Referenced to APHA 5310 B. This method is compliant with NEPM (2013) Schedule B(3) . Samples are combusted at high termperature in the presence of an oxidative catalyst. The evolved carbon dioxide is quantified using an IR detector.
Total Organic Carbon	EP005	WATER	In house: Referenced to APHA 5310 B, The automated TOC analyzer determines Total and Inorganic Carbon by IR cell. TOC is calculated as the difference. This method is compliant with NEPM (2013) Schedule B(3)
Stable Isotopes - Carbon C12/13 ratio in water matrices	* STABISO-WAT	WATER	Isotopes in water matrices subcontracted to an external supplier (Environmental Isotopes). NATA accreditation does not cover performance of this service.

Preparation Methods	Method	Matrix	Method Descriptions
TKN/TP Digestion	EK061/EK067	WATER	In house: Referenced to APHA 4500 Norg - D; APHA 4500 P - H. This method is compliant with NEPM (2013) Schedule B(3)

CHAIN OF CUSTODY

ALS Laboratory: **please tick →**

☐ADELAIDE 3/1 Burma Road Pooraka SA 5095
Ph: 08 8162 5130 E: adelaide@alsglobal.com

☐BRISBANE 2 Byth Street Stafford QLD 4053
Ph: 07 3243 7222 E: samples.brisbane@alsglobal.com

☐GLADSTONE 46 Callemondah Drive Gladstone QLD 4680
Ph: 07 4978 7944 E: gladstone@alsglobal.com

☐MACKAY 78 Harbour Road Mackay QLD 4740
Ph: 07 4944 0177 E: mackay@alsglobal.com

☐MELBOURNE 2-4 Westall Road Springvale VIC 3171
Ph: 03 8549 9600 E: samples.melbourne@alsglobal.com

☐MUDGEE 1/29 Sydney Road Mudgee NSW 2850
Ph: 02 6372 6735 E: mudgee.mail@alsglobal.com

☐NEWCASTLE 5/585 Maitland Road Mayfield West NSW 2304
Ph: 02 4014 2500 E: samples.newcastle@alsglobal.com

☐NOWRA 4/13 Geary Place North Nowra NSW 2541
Ph: 02 4423 2063 E: nowra@alsglobal.com

☐PERTH 10 Hod Way Malaga WA 6090
Ph: 08 9209 7655 E: samples.perth@alsglobal.com

☐SYDNEY 277-
Ph: 02 8784 855

☐TOWNSVILLE
Ph: 07 4796 060

☐WOLLONGON
Ph: 02 4225 312

Environmental Division
Brisbane
Work Order Reference
EB1628486

Telephone : - 61-7-3243 7222

CLIENT: Earth Search

OFFICE:

PROJECT: GDE Assess **PROJECT NO.:**

ORDER NUMBER: **PURCHASE ORDER NO.:**

PROJECT MANAGER: Ned Hamer **CONTACT PH:** 0429049154

SAMPLER: Ned Hamer **SAMPLER MOBILE:** 0429 049 154

COC Emailed to ALS? (YES **)** **EDD FORMAT (or default):**

Email Reports to (will default to PM if no other addresses are listed): ned@earthsearch.com.au

Email Invoice to (will default to PM if no other addresses are listed): as above

TURNAROUND REQUIREMENTS :
(Standard TAT may be longer for some tests e.g.. Ultra Trace Organics)
☐ Standard TAT **(List due date):**☑
☑ Non Standard or urgent TAT **(List due date):** See below for Radon

ALS QUOTE NO.: BNBQ/101/15

COUNTRY OF ORIGIN:

COC SEQUENCE NUMBER (Circle)
COC: [✓ 1] 2 3 4 5 6 7
OF: [✓ 1] 2 3 4 5 6 7

FOR LABORATORY
Custody Seal Intact?
Free ice / frozen ice bric receipt?
Random Sample Tempe
Other comment:

RELINQUISHED BY:	**RECEIVED BY:**	**RELINQUISHED BY:**	
	CHRIS		
DATE/TIME: 1/12/16 20:50	DATE/TIME: 1/12/16 2050	DATE/TIME:	DATE/TIME:

COMMENTS/SPECIAL HANDLING/STORAGE OR DISPOSAL:

ANALYSIS REQUIRED including SUITES (NB. Suite Codes must be listed to attract suite price)
Where **Metals** are required, specify **Total** (unfiltered bottle required) or **Dissolved** (field filtered bottle required).

ALS USE ONLY **LAB ID**	**SAMPLE DETAILS** MATRIX: Solid(S) Water(W) **SAMPLE ID**	**DATE / TIME**	**MATRIX**	**CONTAINER INFORMATION** **TYPE & PRESERVATIVE** *(refer to codes below)*	**TOTAL BOTTLES**	TDS	Alkalinity Total, Bicarb, Carb, Hydroxy	Sulphate - SO4 by ICPAES	Chloride Major Cats	Bromide, Iodide Fluoride	Total Nitrogen as N Total Phosphorus as P	TOC DOC field filtered	Carbon 13C 14C Strontium (87/86Sr) Stable isotopes 18O 2D	**Additional Information** Comments on likely contaminant levels, dilutions, or samples requiring specific QC analysis etc. (*) Radon (222 Rn) to ANSTO
1	Bowenville 1	1/12/16 16:30	W		6	X	X	X	X	X	X	X	X	X Vial labelled "BO"
2	154	1/12/16 11:00	W		6	X	X	X	X	X	X	X	X	X Vial labelled "154"
3	151	1/12/16 10:30	W		6	X	X	X	X	X	X	X	X	(*)
4	Dup	1/12/16 10:30	W		1	X			X	X				Urgent
														3 day H.T.
														Air freight
														over-night to
														ANSTO
														in Lucas
														Heights
					TOTAL									

Attn: Robert Chisari
B21
ANSTO
New Illawarra Rd
Lucas Heights
NSW 2234

Water Container Codes: P = Unpreserved Plastic; N = Nitric Preserved Plastic; ORC = Nitric Preserved ORC; SH = Sodium Hydroxide/Cd Preserved; S = Sodium Hydroxide Preserved Plastic; AG = Amber Glass Unpreserved; AP - Airfreight Unpreserved Plastic
V = VOA Vial HCl Preserved; VB = VOA Vial Sodium Bisulphate Preserved; VS = VOA Vial Sulfuric Preserved; AV = Airfreight Unpreserved Vial SG = Sulfuric Preserved Amber Glass; H = HCl preserved Plastic; HS = HCl preserved Speciation bottle; SP = Sulfuric Preserved Plastic; F = Formaldehyde Preserved Glass;
Z = Zinc Acetate Preserved Bottle; E = EDTA Preserved Bottles; ST = Sterile Bottle; ASS = Plastic Bag for Acid Sulphate Soils; B = Unpreserved Bag; LI = Lugols Iodine Preserved Bottles; STT = Sterile Sodium Thiosulfate Preserved Bottles.

SAMPLE RECEIPT NOTIFICATION (SRN)

Work Order : **EB1628281**

Client	: **EARTH SEARCH**	Laboratory	: Environmental Division Brisbane
Contact	: MR NED HAMER	Contact	: Customer Services EB
Address	: 15 HAMPSON STREET KELVIN GROVE QUEENSLAND 4059	Address	: 2 Byth Street Stafford QLD Australia 4053
E-mail	: ned@earthsearch.com.au	E-mail	: ALSEnviro.Brisbane@alsglobal.com
Telephone	: ----	Telephone	: +61-7-3243 7222
Facsimile	: ----	Facsimile	: +61-7-3243 7218
Project	: GDE Assess	Page	: 1 of 3
Order number	: ----	Quote number	: EB2016EARSEA0001 (BNBQ/101/16)
C-O-C number	: ----	QC Level	: NEPM 2013 B3 & ALS QC Standard
Site	: ----		
Sampler	: NED HAMER		

Dates

Date Samples Received	: 30-Nov-2016 10:00 AM	Issue Date	: 30-Nov-2016
Client Requested Due Date	: 07-Dec-2016	Scheduled Reporting Date	: **07-Dec-2016**

Delivery Details

Mode of Delivery	: Carrier	Security Seal	: Intact.
No. of coolers/boxes	: 1	Temperature	: 4.2°C - Ice present
Receipt Detail	: MEDIUM ESKY	No. of samples received / analysed	: 2 / 2

General Comments

- This report contains the following information:
    - Sample Container(s)/Preservation Non-Compliances
    - Summary of Sample(s) and Requested Analysis
    - Proactive Holding Time Report
    - Requested Deliverables
- Discounted Package Prices apply only when specific ALS Group Codes ('W', 'S', 'NT' suites) are referenced on COCs.
- Please direct any turn around / technical queries to the laboratory contact designated above.
- Sample Disposal - Aqueous (14 days), Solid (60 days) from date of completion of work order.
- Analysis will be conducted by ALS Environmental, Brisbane, NATA accreditation no. 825, Site No. 818 (Micro site no. 18958).
- **Carbon 13C and 14C, Dtrontium 87/86 and Stable Isotopes 18O and 2O will be subcontracted to Environmental Isotopes Pty Ltd. The estimated due date for this data is 7/01/17.**
- **Radon 222 analysis will be subcontracted to ANSTO Isotopes, samples sent as soon as possible, as pre Ned Hamer. The estimated due date for this analysis is 7/01/17.**
- **Breaches in recommended extraction / analysis holding times (if any) are displayed overleaf in the Proactive Holding Time Report table.**

Sample Container(s)/Preservation Non-Compliances

All comparisons are made against pretreatment/preservation AS, APHA, USEPA standards.

Method *Client sample ID*	Sample Container Received	Preferred Sample Container for Analysis
Dissolved Organic Carbon : EP002		
Broadwater 1	- Clear Plastic Bottle - Natural	- Amber DOC Filtered- Sulfuric Preserved
GDE 1	- Clear Plastic Bottle - Natural	- Amber DOC Filtered- Sulfuric Preserved

Summary of Sample(s) and Requested Analysis

Some items described below may be part of a laboratory process necessary for the execution of client requested tasks. Packages may contain additional analyses, such as the determination of moisture content and preparation tasks, that are included in the package.

If no sampling time is provided, the sampling time will default to 15:00 on the date of sampling. If no sampling date is provided, the sampling date will be assumed by the laboratory for processing purposes and will be shown bracketed without a time component.

Matrix: **WATER**

Laboratory sample ID	*Client sampling date / time*	*Client sample ID*	WATER - ED037-P Alkalinity as CaCO3 (PCT)	WATER - ED040F Dissolved Major Anions	WATER - ED045G Chloride by Discrete Analyser	WATER - EK040-P Fluoride(PC)	WATER - EP002 Dissolved Organic Carbon (DOC)	WATER - MSC-WAT (Subcontracted) Miscellaneous Subcontracting	WATER - NT-01 Major Cations (Ca, Mg, Na, K)
EB1628281-001	29-Nov-2016 10:00	Broadwater 1	✓	✓	✓	✓	✓	✓	✓
EB1628281-002	29-Nov-2016 13:30	GDE 1	✓	✓	✓	✓	✓	✓	✓

Matrix: **WATER**

Laboratory sample ID	*Client sampling date / time*	*Client sample ID*	WATER - EA015H Total Dissolved Solids - High Level	WATER - ED009-X Standard Anions (Extended method	WATER - EK062G Total Nitrogen as N (TKN + NOx reported) By	WATER - EK067G Total Phosphorus as P By Discrete Analyser	WATER - EP005 Total Organic Carbon (TOC)	WATER - RAD-WAT (Subcontracted) Radon in water matrices
EB1628281-001	29-Nov-2016 10:00	Broadwater 1	✓	✓	✓	✓	✓	✓
EB1628281-002	29-Nov-2016 13:30	GDE 1	✓	✓	✓	✓	✓	✓

Proactive Holding Time Report

Sample(s) have been received within the recommended holding times for the requested analysis.

Requested Deliverables

NED HAMER

- *AU Certificate of Analysis - NATA (COA)	Email	ned@earthsearch.com.au
- *AU Interpretive QC Report - DEFAULT (Anon QCI Rep) (QCI)	Email	ned@earthsearch.com.au
- *AU QC Report - DEFAULT (Anon QC Rep) - NATA (QC)	Email	ned@earthsearch.com.au
- A4 - AU Sample Receipt Notification - Environmental HT (SRN)	Email	ned@earthsearch.com.au
- A4 - AU Tax Invoice (INV)	Email	ned@earthsearch.com.au
- Attachment - Report (SUBCO)	Email	ned@earthsearch.com.au
- Chain of Custody (CoC) (COC)	Email	ned@earthsearch.com.au
- EDI Format - XTab (XTAB)	Email	ned@earthsearch.com.au

SAMPLE RECEIPT NOTIFICATION (SRN)

Work Order : **EB1628373**

Client	: **EARTH SEARCH**	Laboratory	: Environmental Division Brisbane
Contact	: MR NED HAMER	Contact	: Customer Services EB
Address	: 15 HAMPSON STREET KELVIN GROVE QUEENSLAND 4059	Address	: 2 Byth Street Stafford QLD Australia 4053
E-mail	: ned@earthsearch.com.au	E-mail	: ALSEnviro.Brisbane@alsglobal.com
Telephone	: ----	Telephone	: +61-7-3243 7222
Facsimile	: ----	Facsimile	: +61-7-3243 7218
Project	: GDE Assess	Page	: 1 of 2
Order number	: ----	Quote number	: EB2016EARSEA0001 (BNBQ/101/16)
C-O-C number	: ----	QC Level	: NEPM 2013 B3 & ALS QC Standard
Site	: ----		
Sampler	: NED HAMER		

Dates

Date Samples Received	: 01-Dec-2016 10:00 AM	Issue Date	: 01-Dec-2016
Client Requested Due Date	: 08-Dec-2016	Scheduled Reporting Date	: **08-Dec-2016**

Delivery Details

Mode of Delivery	: Carrier	Security Seal	: Intact.
No. of coolers/boxes	: 1	Temperature	: °C - Ice present
Receipt Detail	: MEDIUM ESKY	No. of samples received / analysed	: 2 / 2

General Comments

- This report contains the following information:
  - Sample Container(s)/Preservation Non-Compliances
  - Summary of Sample(s) and Requested Analysis
  - Proactive Holding Time Report
  - Requested Deliverables
- Discounted Package Prices apply only when specific ALS Group Codes ('W', 'S', 'NT' suites) are referenced on COCs.
- Please direct any turn around / technical queries to the laboratory contact designated above.
- Sample Disposal - Aqueous (14 days), Solid (60 days) from date of completion of work order.
- Analysis will be conducted by ALS Environmental, Brisbane, NATA accreditation no. 825, Site No. 818 (Micro site no. 18958).
- **Carbon 13C and 14C, Dtrontium 87/86 and Stable Isotopes 18O and 2O will be subcontracted to Environmental Isotopes Pty Ltd. The estimated due date for this data is 8/01/17.**
- **Radon 222 analysis will be subcontracted to ANSTO Isotopes, samples sent as soon as possible, as pre Ned Hamer. The estimated due date for this analysis is 8/01/17.**
- **Breaches in recommended extraction / analysis holding times (if any) are displayed overleaf in the Proactive Holding Time Report table.**

Sample Container(s)/Preservation Non-Compliances

All comparisons are made against pretreatment/preservation AS, APHA, USEPA standards.

- **No sample container / preservation non-compliance exists.**

Summary of Sample(s) and Requested Analysis

Some items described below may be part of a laboratory process necessary for the execution of client requested tasks. Packages may contain additional analyses, such as the determination of moisture content and preparation tasks, that are included in the package.

If no sampling time is provided, the sampling time will default to 15:00 on the date of sampling. If no sampling date is provided, the sampling date will be assumed by the laboratory for processing purposes and will be shown bracketed without a time component.

Matrix: **WATER**

Laboratory sample ID	*Client sampling date / time*	*Client sample ID*	WATER - ED037-P Alkalinity as CaCO3 (PCT)	WATER - ED040F Dissolved Major Anions	WATER - ED045G Chloride by Discrete Analyser	WATER - EK040-P Fluoride(PC)	WATER - EP002 Dissolved Organic Carbon (DOC)	WATER - MSC-WAT (Subcontracted) Miscellaneous Subcontracting	WATER - NT-01 Major Cations (Ca, Mg, Na, K)
EB1628373-001	30-Nov-2016 13:00	Spring 1	✓	✓	✓	✓	✓	✓	✓
EB1628373-002	30-Nov-2016 14:30	Swamp 1	✓	✓	✓	✓	✓	✓	✓

Matrix: **WATER**

Laboratory sample ID	*Client sampling date / time*	*Client sample ID*	WATER - EA015H Total Dissolved Solids - High Level	WATER - ED009-X Standard Anions (Extended method	WATER - EK062G Total Nitrogen as N (TKN + NOx reported) By	WATER - EK067G Total Phosphorus as P By Discrete Analyser	WATER - EP005 Total Organic Carbon (TOC)	WATER - RAD-WAT (Subcontracted) Radon in water matrices
EB1628373-001	30-Nov-2016 13:00	Spring 1	✓	✓	✓	✓	✓	✓
EB1628373-002	30-Nov-2016 14:30	Swamp 1	✓	✓	✓	✓	✓	✓

Proactive Holding Time Report

Sample(s) have been received within the recommended holding times for the requested analysis.

Requested Deliverables

NED HAMER

- *AU Certificate of Analysis - NATA (COA)	Email	ned@earthsearch.com.au
- *AU Interpretive QC Report - DEFAULT (Anon QCI Rep) (QCI)	Email	ned@earthsearch.com.au
- *AU QC Report - DEFAULT (Anon QC Rep) - NATA (QC)	Email	ned@earthsearch.com.au
- A4 - AU Sample Receipt Notification - Environmental HT (SRN)	Email	ned@earthsearch.com.au
- A4 - AU Tax Invoice (INV)	Email	ned@earthsearch.com.au
- Attachment - Report (SUBCO)	Email	ned@earthsearch.com.au
- Chain of Custody (CoC) (COC)	Email	ned@earthsearch.com.au
- EDI Format - XTab (XTAB)	Email	ned@earthsearch.com.au

SAMPLE RECEIPT NOTIFICATION (SRN)

Work Order : **EB1628486**

Client	: **EARTH SEARCH**	Laboratory	: Environmental Division Brisbane
Contact	: MR NED HAMER	Contact	: Customer Services EB
Address	: 15 HAMPSON STREET KELVIN GROVE QUEENSLAND 4059	Address	: 2 Byth Street Stafford QLD Australia 4053
E-mail	: ned@earthsearch.com.au	E-mail	: ALSEnviro.Brisbane@alsglobal.com
Telephone	: ----	Telephone	: +61-7-3243 7222
Facsimile	: ----	Facsimile	: +61-7-3243 7218
Project	: GDE Assess	Page	: 1 of 2
Order number	: ----	Quote number	: EB2016EARSEA0001 (BNBQ/101/16)
C-O-C number	: ----	QC Level	: NEPM 2013 B3 & ALS QC Standard
Site	: ----		
Sampler	: NED HAMER		

Dates

Date Samples Received	: 01-Dec-2016 8:50 PM	Issue Date	: 01-Dec-2016
Client Requested Due Date	: 08-Dec-2016	Scheduled Reporting Date	: **08-Dec-2016**

Delivery Details

Mode of Delivery	: Client Drop Off	Security Seal	: Not Available
No. of coolers/boxes	: 1	Temperature	: 32.3°C - Ice Bricks present
Receipt Detail	: MEDIUM ESKY	No. of samples received / analysed	: 4 / 4

General Comments

- This report contains the following information:
  - Sample Container(s)/Preservation Non-Compliances
  - Summary of Sample(s) and Requested Analysis
  - Proactive Holding Time Report
  - Requested Deliverables
- Discounted Package Prices apply only when specific ALS Group Codes ('W', 'S', 'NT' suites) are referenced on COCs.
- Please direct any turn around / technical queries to the laboratory contact designated above.
- Sample Disposal - Aqueous (14 days), Solid (60 days) from date of completion of work order.
- Analysis will be conducted by ALS Environmental, Brisbane, NATA accreditation no. 825, Site No. 818 (Micro site no. 18958).
- **Carbon 13C and 14C, Dtrontium 87/86 and Stable Isotopes 18O and 2O will be subcontracted to Environmental Isotopes Pty Ltd. The estimated due date for this data is 8/01/17.**
- **Radon 222 analysis will be subcontracted to ANSTO Isotopes, samples sent as soon as possible, as pre Ned Hamer. The estimated due date for this analysis is 8/01/17.**
- **Breaches in recommended extraction / analysis holding times (if any) are displayed overleaf in the Proactive Holding Time Report table.**

Sample Container(s)/Preservation Non-Compliances

All comparisons are made against pretreatment/preservation AS, APHA, USEPA standards.

- **No sample container / preservation non-compliance exists.**

Summary of Sample(s) and Requested Analysis

Some items described below may be part of a laboratory process necessary for the execution of client requested tasks. Packages may contain additional analyses, such as the determination of moisture content and preparation tasks, that are included in the package.

If no sampling time is provided, the sampling time will default to 15:00 on the date of sampling. If no sampling date is provided, the sampling date will be assumed by the laboratory for processing purposes and will be shown bracketed without a time component.

Matrix: **WATER**

Laboratory sample ID	*Client sampling date / time*	*Client sample ID*	WATER - ED037-P Alkalinity as CaCO3 (PCT)	WATER - ED040F Dissolved Major Anions	WATER - ED045G Chloride by Discrete Analyser	WATER - EK040-P Fluoride(PC)	WATER - EP002 Dissolved Organic Carbon (DOC)	WATER - MSC-WAT (Subcontracted) Miscellaneous Subcontracting	WATER - NT-01 Major Cations (Ca, Mg, Na, K)
EB1628486-001	[01-Dec-2016]	Bowenville 1	✓	✓	✓	✓	✓	✓	✓
EB1628486-002	[01-Dec-2016]	154	✓	✓	✓	✓	✓	✓	✓
EB1628486-003	[01-Dec-2016]	151	✓	✓	✓	✓	✓	✓	✓
EB1628486-004	[01-Dec-2016]	DUP			✓	✓			✓

Matrix: **WATER**

Laboratory sample ID	*Client sampling date / time*	*Client sample ID*	WATER - EA015H Total Dissolved Solids - High Level	WATER - ED009-X Standard Anions (Extended method	WATER - EK062G Total Nitrogen as N (TKN + NOx reported) By	WATER - EK067G Total Phosphorus as P By Discrete Analyser	WATER - EP005 Total Organic Carbon (TOC)	WATER - RAD-WAT (Subcontracted) Radon in water matrices
EB1628486-001	[01-Dec-2016]	Bowenville 1	✓	✓	✓	✓	✓	✓
EB1628486-002	[01-Dec-2016]	154	✓	✓	✓	✓	✓	✓
EB1628486-003	[01-Dec-2016]	151	✓	✓	✓	✓	✓	
EB1628486-004	[01-Dec-2016]	DUP	✓	✓				

Proactive Holding Time Report

Sample(s) have been received within the recommended holding times for the requested analysis.

Requested Deliverables

NED HAMER

- *AU Certificate of Analysis - NATA (COA)	Email	ned@earthsearch.com.au
- *AU Interpretive QC Report - DEFAULT (Anon QCI Rep) (QCI)	Email	ned@earthsearch.com.au
- *AU QC Report - DEFAULT (Anon QC Rep) - NATA (QC)	Email	ned@earthsearch.com.au
- A4 - AU Sample Receipt Notification - Environmental HT (SRN)	Email	ned@earthsearch.com.au
- A4 - AU Tax Invoice (INV)	Email	ned@earthsearch.com.au
- Chain of Custody (CoC) (COC)	Email	ned@earthsearch.com.au
- EDI Format - XTab (XTAB)	Email	ned@earthsearch.com.au

lab #	sample name	87/86Sr	2se	2sd
CTB1 Sr	EB 1628373_001_AH	.708862	.000005	.00007
CTB2 Sr	EB 1628373_002_AH	.706974	.000004	.00005
CTB3 Sr	EB 1628281_001_AH	.707062	.000004	.00004
CTB4 Sr	EB 1628281_002_AH	.705176	.000002	.00003
CTB5 Sr	EB 1628486_001_AH	.705002	.000003	.00003
CTB6 Sr	EB 1628486_002_AH	.707966	.000003	.00004
CTB7 Sr	EB 1628486_003_AH	.708142	.000003	.00003
IAPSO (seawater)		.709174	.000003	.00003
SRM987 (500ng) 87/86Sr = .710245 ± .000006 (2sd) 12 measurements.				
(Phoenix TIMS reference measurements 2/12/2016 to 21/12/2016).				

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RENTALS

Equipment Certification Report – TPS 90FLMV Water Quality Meter

This Water Quality Meter has been performance checked and calibrated as follows:

Sensor	Concentration	Span 1	Span 2	Traceability Lot #	Pass?
pH	pH 4.01 / pH 7.00	4.01 pH	7.02 pH	288786/289006	☑
Conductivity	12.88 mS/cm	0.0 mS/cm	12.92 mS/cm	NK1898	☑
TDS		ppk	ppk		☐
Dissolved Oxygen	Sodium Sulphite / Air	0.0 ppm in Sodium Sulphite	8.64 ppm Saturation in Air	3728	☑
Check only					
Redox (ORP) *	Electrode operability test	240mV +/- 10%	232 mV	NL1050 NL1051	☑

* This meter uses an Ag/AgCl ORP electrode. To convert readings to SHE (Standard Hydrogen Electrode), add 199mV to the mV reading.

☑ Battery Status 7.9V (min 7.2V)
☑ Electrical Safety Tag attached (AS/NZS 3760)

☑ Temperature 22.2 °C
☑ Electrodes Cleaned and checked

Tag No: TFN026

Valid to: 21/2/17

Date: 29/11/16

Signed: RBLt

Please check that the following items are received and that all items are cleaned and decontaminated before return. A minimum $30 cleaning / service / repair charge may be applied to any unclean or damaged items. Items not returned will be billed for at the full replacement cost.

Sent	Returned	Item
☑	☐	90FLMV Unit. Ops check/Battery status: 7.9V
☑	☐	pH sensor with wetting cap, 5m
☑	☐	Conductivity/TDS/Temperature K=10 sensor, 5m
☑	☐	Dissolved oxygen YSI5739 sensor with wetting cap, 5m
☑	☐	Redox (ORP) sensor with wetting cap, 5m
☑	☐	Power supply 240V to 12V DC 200mA
☑	☐	Instruction Manual
☑	☐	Quick Guide
☑	☐	Bottle with storage solution for pH and ORP sensors
☑	☐	Carry Case
☑	☐	Check to confirm electrical safety (tag must be valid)

Date: 29/11/16

Signed: RBLt

TFS Reference	CB002814	Return Date: / /	
Customer Reference		Return Time:	
Equipment ID	90FLMVBH	Condition on return:	
Equipment Serial No.	T5993		

"We do more than give you great equipment… We give you great solutions!"

Phone: (Free Call) 1300 735 295		Fax: (Free Call) 1800 675 123		Email: RentalsAU@Thermofisher.com
Melbourne Branch 5 Caribbean Drive, Scoresby 3179	Sydney Branch Level 1, 4 Talavera Road, North Ryde 2113	Adelaide Branch 27 Beulah Road, Norwood, South Australia 5067	Brisbane Branch Unit 2/5 Ross St Newstead 4006	Perth Branch 121 Beringarra Ave Malaga WA 6090

Issue 7 Aug 15 G0563

Attachment 3: Hydrographs

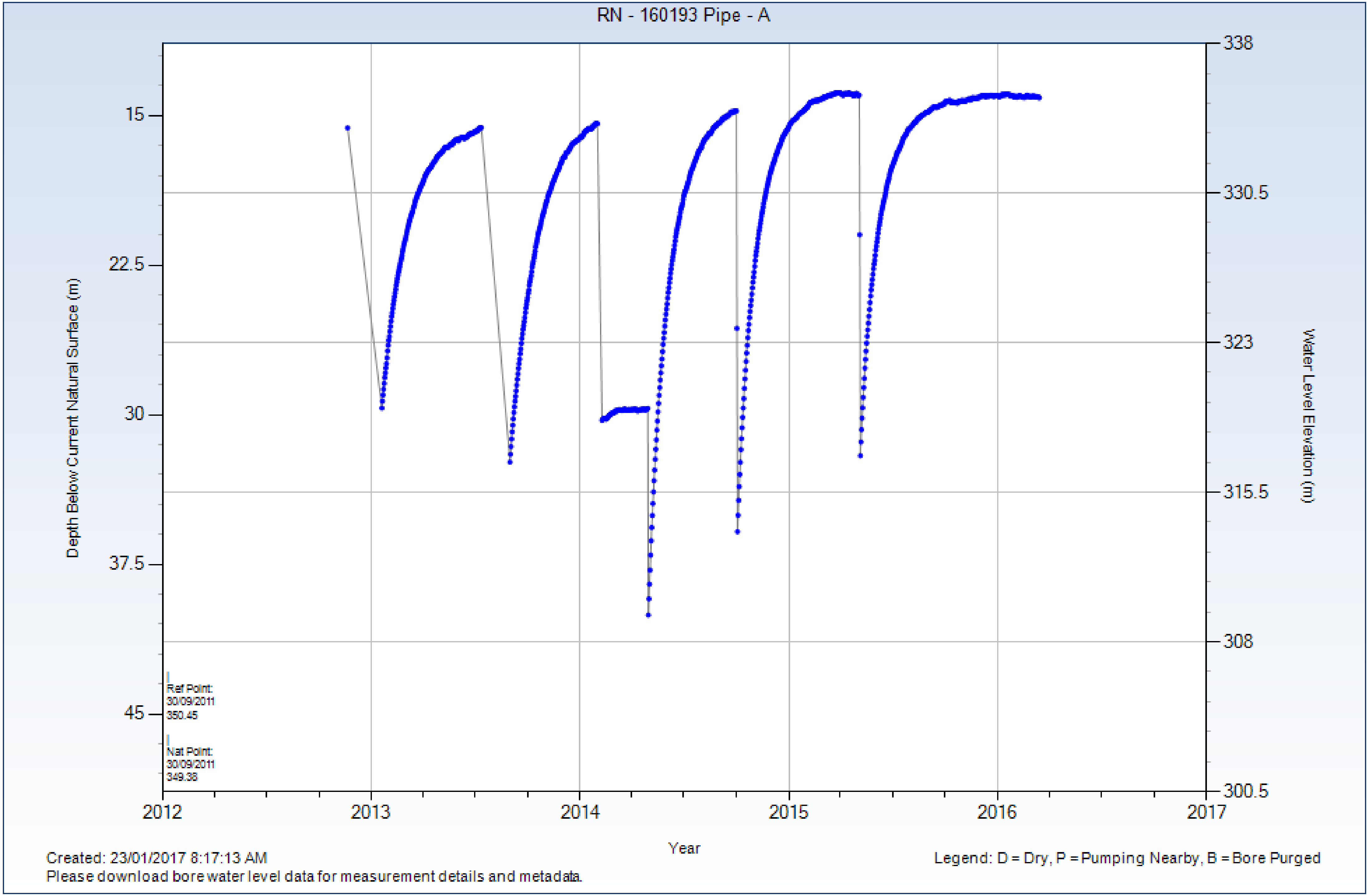
Hydrograph reference table

Bore ID	Monitored aquifer	Depth to SWL[1] (m)		Comment
		DRNM GW DB	Hydrograph	
RN160193A	Springbok Sandstone		14.3	Up to 20m fluctuation in recorded water levels. Springbok Sandstone reported in bore report as being present from 367-379m below ground surface, overlain by Orallo Formation, Gubberamunda Sandstone and a thick sequence of Westbourne Formation indicating this bore does not represent the watertable aquifer in this area.
RN160194A	Springbok Sandstone	2.57	3.7	Hydrograph indicates seasonal variability typically around 2-4m. Water level data indicates a confined, artesian system when affected by pumping therefore the Springbok Sandstone in this area does not represent the watertable aquifer. This is supported by the bore report stratigraphy which indicates overlying Orallo Formation, Gubberamunda Sandstone and Westbourne Formation to a depth of 322m below ground level.
RN160348 (Kedron-570)	Springbok Sandstone	-	29.8	Stable groundwater levels over monitoring period from 2012-2016.
Kedron 572	Springbok Sandstone		12.4	Seasonal fluctuation in the order of 2 m over monitoring record commencing 2015.
RN160349 (Daandine 124)	Springbok Sandstone	21.2	21.6	Relatively stable groundwater levels over longer-term. Fluctuation in the order of 0.1-0.2m. Step change in level in recent record likely to be data error rather than representative of actual levels.
RN160518A	Gubberamunda Sandstone	35.07	32.6	Significant seasonal fluctuation (>1m) and longer term declining trend from start of monitoring record to mid-2014, followed by a steady increase in levels.
RN160519A	Springbok Sandstone	8.26	8	Bore screening confined Springbok Sandstone at a depth of 240-261m with overlying Gubberamunda Sandstone and Westbourne Formation (125m thick sequence of Westbourne). Muted seasonal fluctuation apparent in hydrograph.
RN160521 (Poppy GW2)	Springbok Sandstone	51.54	51.4	Typical groundwater level fluctuations of around 0.1m. Slight increase in levels over longer-term trend. Borehole screened at base on Springbok from 172-177m below ground surface. Springbok Sandstone reported in bore report from 74.4-178.3m therefore not considered to represent watertable aquifer at this location.
RN160526A	Springbok Sandstone	6.48	1.7	Significant seasonal variability (>10 m) in confined Springbok Sandstone aquifer. Borehole screened from 160-173m below ground surface with Westbourne Formation present from 30-67.6m below ground surface, overlain by Gubberamunda Sandstone.
RN160541	Gubberamunda Sandstone	-	55.2	Relatively stable longer-term groundwater level record with fluctuation in the order of 0.1-0.2m.

Bore ID	Monitored aquifer	Depth to SWL[1] (m)		Comment
		DRNM GW DB	Hydrograph	
RN160547A	Springbok Sandstone	42.09	41.4	Slight increasing longer-term trend in levels from 2014-2016 with step change in mid-2016. Unclear whether this is a result of external influences (i.e. pumping) or a logger error. Slight declining trend observed from the start of 2016. Screened/open hole from 54-65m below ground surface therefore across Gubberamunda, Westbourne and Springbok.
RN160554A	Gubberamunda Sandstone	80.3	79.6	Muted seasonal response. Slight decreasing trend overall however monitoring record is limited (~2 years) to properly assess longer-term trends.
RN160628A	Gubberamunda Sandstone	45.63	45.1	Clear declining trend in water levels from start of monitoring record in mid-2011. Water levels have steadily fallen by around 2m, with limited seasonal fluctuation. Bore report indicates thick sequence of Orallo Formation (0-222m below ground) with this borehole screening (open hole) deeper Gubberamunda Sandstone (359.15-389.45m).
RN160638F	Springbok Sandstone	35.83	43.2	Confined system. Significant fluctuation over a number of years.
RN160639A	Gubberamunda Sandstone	-	42.5	Hydrograph influenced by step changes in data – not likely to be real. Slight overall increase in groundwater levels in overall trend when data interference removed.
RN160670A	Springbok Sandstone	37.79	37.3	Slight overall decline in groundwater levels.
RN160677E	Walloon Coal Measures	-	-14.0	Bore screens a deep, confined system and artesian conditions are indicated. Decline of around 30 m in borehole pressure since commencement of monitoring in 2014.
RN160685 (Ruby Jo GW2)	Springbok Sandstone	-	55.3	Minor fluctuations in water level record since 2014 (~0.1m) with step-change at the start of 2015 considered to be a data error.
RN160687D	Springbok Sandstone	42.62	27.1	Shows some seasonal fluctuation (~0.4m) and short-term variability in the order of 0.1-0.2m.
RN160693A	Springbok Sandstone	24.94	24	Relatively stable longer-term record. Short-term variability in the order of 0.1-0.2m.
RN160696A	Gubberamunda Sandstone		93.7	Longer-term variability of around 1.0m and short-term fluctuations of around 0.1-0.2m.
RN160699 (Hopeland 17)	Springbok Sandstone	-	14.9	Relatively stable long-term record. Some shorter term variability of 0.5-1.0m. Confined system with 170m of Westbourne Formation overlying Springbok Sandstone.
RN160704A	Gubberamunda Sandstone		62.9	Seasonal fluctuation in the order of 0.5m and shorter-term variability of around 0.1m. Appears the datum reference was re-set at the start of 2015.
RN160705A	Gubberamunda Sandstone		52.1	Water level fluctuation in the order of 1.0-2.0m.

Bore ID	Monitored aquifer	Depth to SWL[1] (m)		Comment
		DRNM GW DB	Hydrograph	
RN160728A	Springbok Sandstone	72.14	71.3	Relatively stable longer-term record with slight decreasing trend. Shorter-term variability in the order of 0.1-0.2m.
RN160811A	Gubberamunda Sandstone	23.91	23.9	Relatively stable longer-term record. Shorter-term variability in the order of 0.1m. Appears the datum reference was re-set part way through the monitoring reocrd.
RN160812A	Springbok Sandstone	-	44.5	Relatively stable longer-term record. Shorter-term variability in the order of 0.1m. Response to pumping events apparent.
RN160941 (Glenburnie-18)	Springbok Sandstone	-	43.9	Confined Springbok system due to overlying Westbourne Formation. Slightly decreasing water level trend.
RN123130A	Orallo Formation		34.1	Watertable aquifer. Fluctuation of around 2m over <6 months.
RN42230088A	Condamine Alluvium	19.22	18	Significant decline in groundwater levels over monitoring period. Levels have dropped from around 10m below ground in 1967 to around 18.5m in current monitoring data. Slight water level recovery noted in more recent data.
RN42230159	Condamine Alluvium		20.7	Watertable aquifer. Seasonal fluctuation in the order of 2 m.
RN42230210A	Condamine Alluvium	11.12	10.8	Significant fluctuation in water level and overall long-term decline of around 3m from 1967 to 2010. Recovery to resembling 1967 records in monitoring data since 2014.
RN41620043A	Springbok Sandstone	-	13.9	Water level fluctuations in the order of 1 to 1.5m. Likely seasonal response to pumping/extraction.
RN42231411A	Condamine Alluvium	-	17.8	Fluctuation in water level and overall long-term decline of around 1.5m from 1990 to 2010. Current monitoring data indicates recovery above 1990 levels, indicating drawdown impact to aquifer prior to the commencement of monitoring at this location.
RN42230153A	Condamine Alluvium	-	20.8	Watertable aquifer. 3 to 4 m seasonal fluctuation in groundwater levels. Overall declining trend since commencement of monitoring in 2013.
RN42231370	Condamine Alluvium	-	38.5	Watertable aquifer. 1.5 to 4 m seasonal fluctuation in groundwater levels.
Daandine 161	Condamine Alluvium	-	15.0	Watertable aquifer. Highly variable groundwater elevation. Seasonal fluctuation in the order of 4 to 5 m and overall declining trend of 1 to 2 m since 2013.
Macalister 7	Condamine Alluvium	-	30.1	Watertable aquifer. 1.2 m fluctuation in groundwater level observed over relatively short and recent monitoring period (commenced in August 2017).

1: Depth to water table data sourced from either the DNRM groundwater database, UWIR monitoring bore hydrographs (available on Queensland Globe – CSG add in) or Arrow monitoring hydrographs. In some cases where data was reported as groundwater elevation only, the depth to groundwater has been approximated using an estimate of natural surface elevation.



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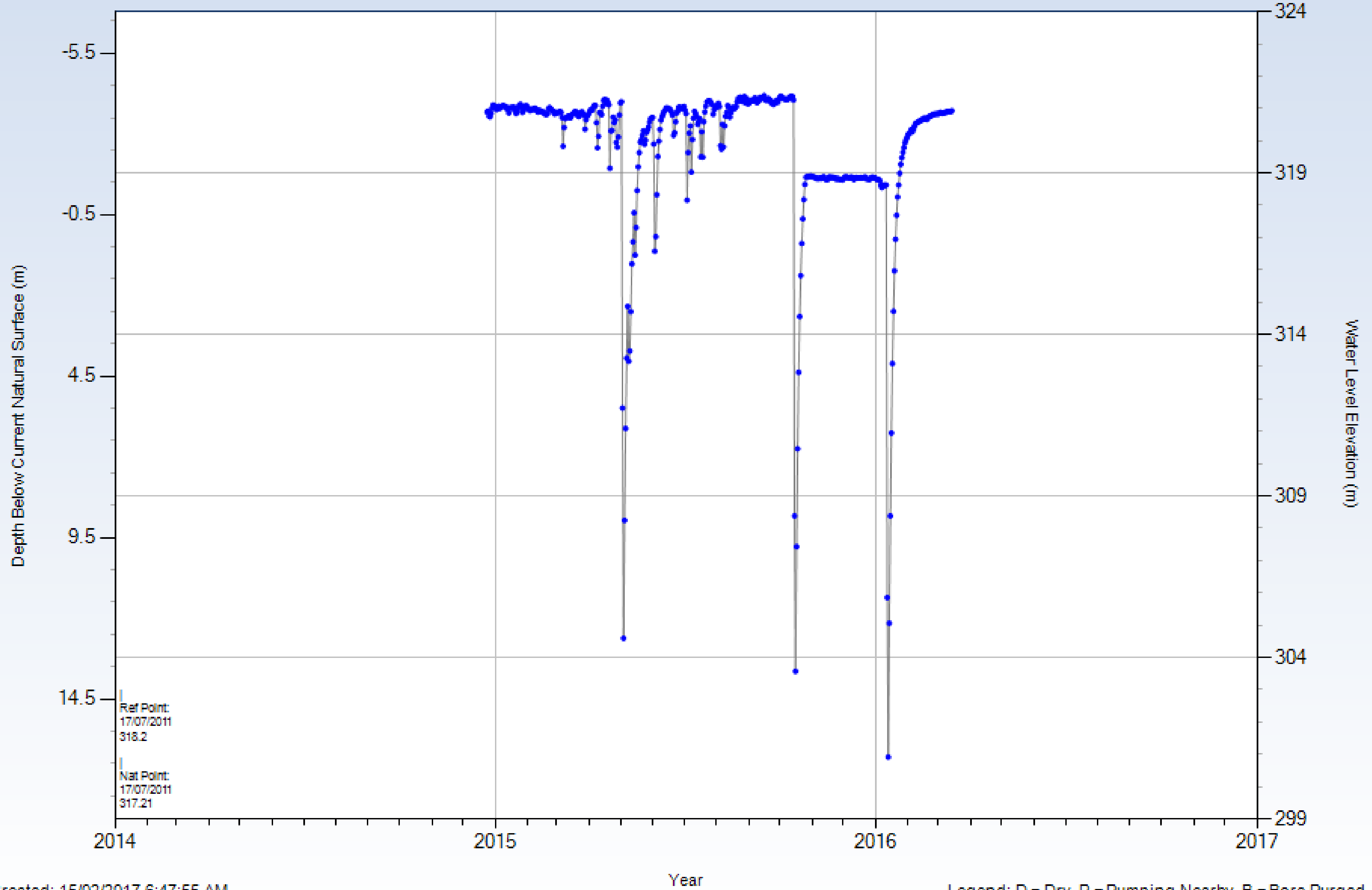
Please download bore water level data for measurement details and metadata.

Legend: D = Dry, P = Pumping Nearby, B = Bore Purged

RN - 160194 Pipe - A



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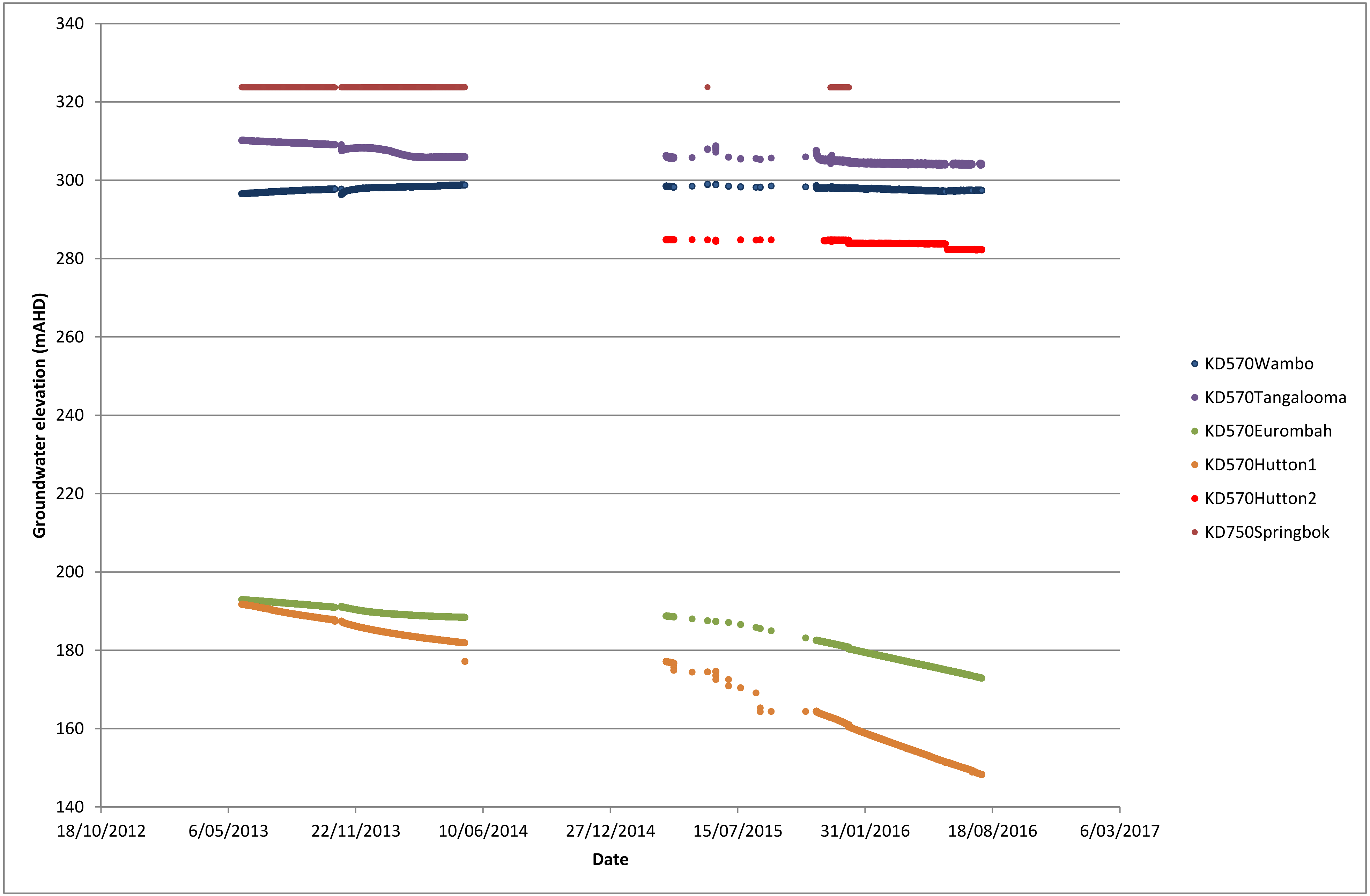
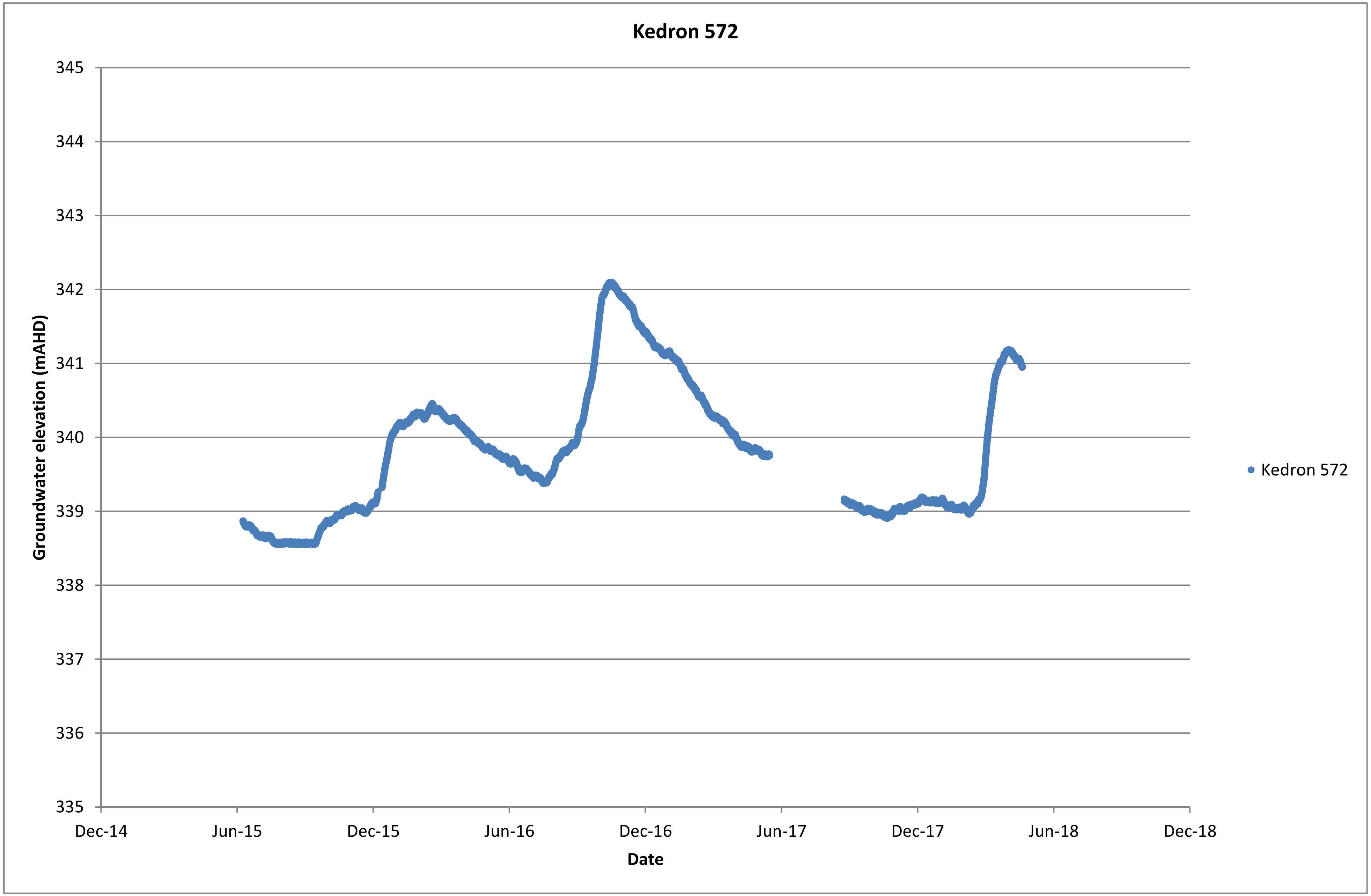
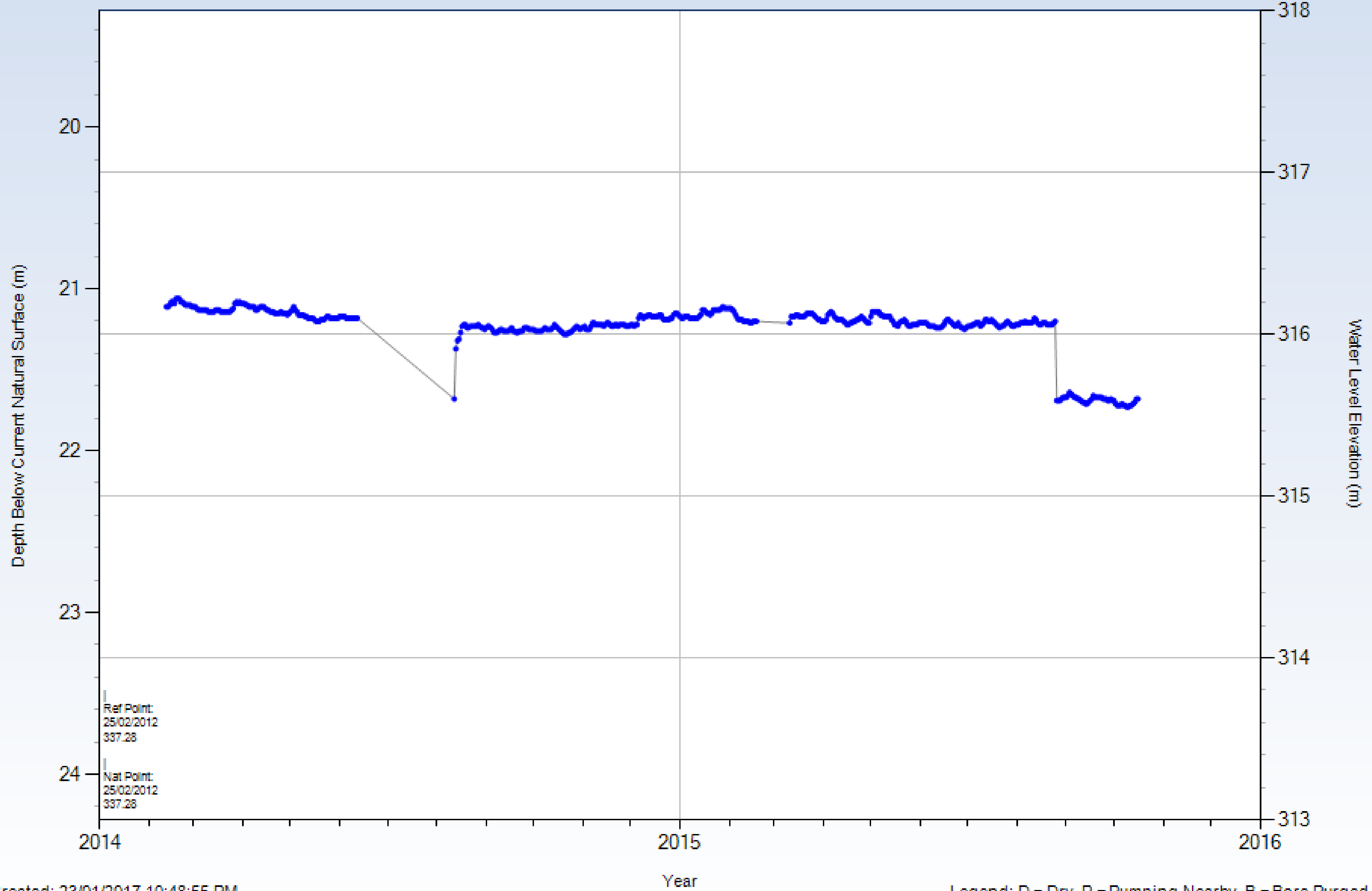
Legend: D = Dry, P = Pumping Nearby, B = Bore Purged

KEDRON 570 (RN160348)




Kedron 572
345
344
343
342
341
340
339
338
337
336
335
Groundwater elevation (mAHD)
Dec-14
Jun-15
Dec-15
Jun-16
Dec-16
Jun-17
Dec-17
Jun-18
Dec-18
Date
● Kedron 572

RN - 160349 Pipe - A



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Legend: D = Dry, P = Pumping Nearby, B = Bore Purged

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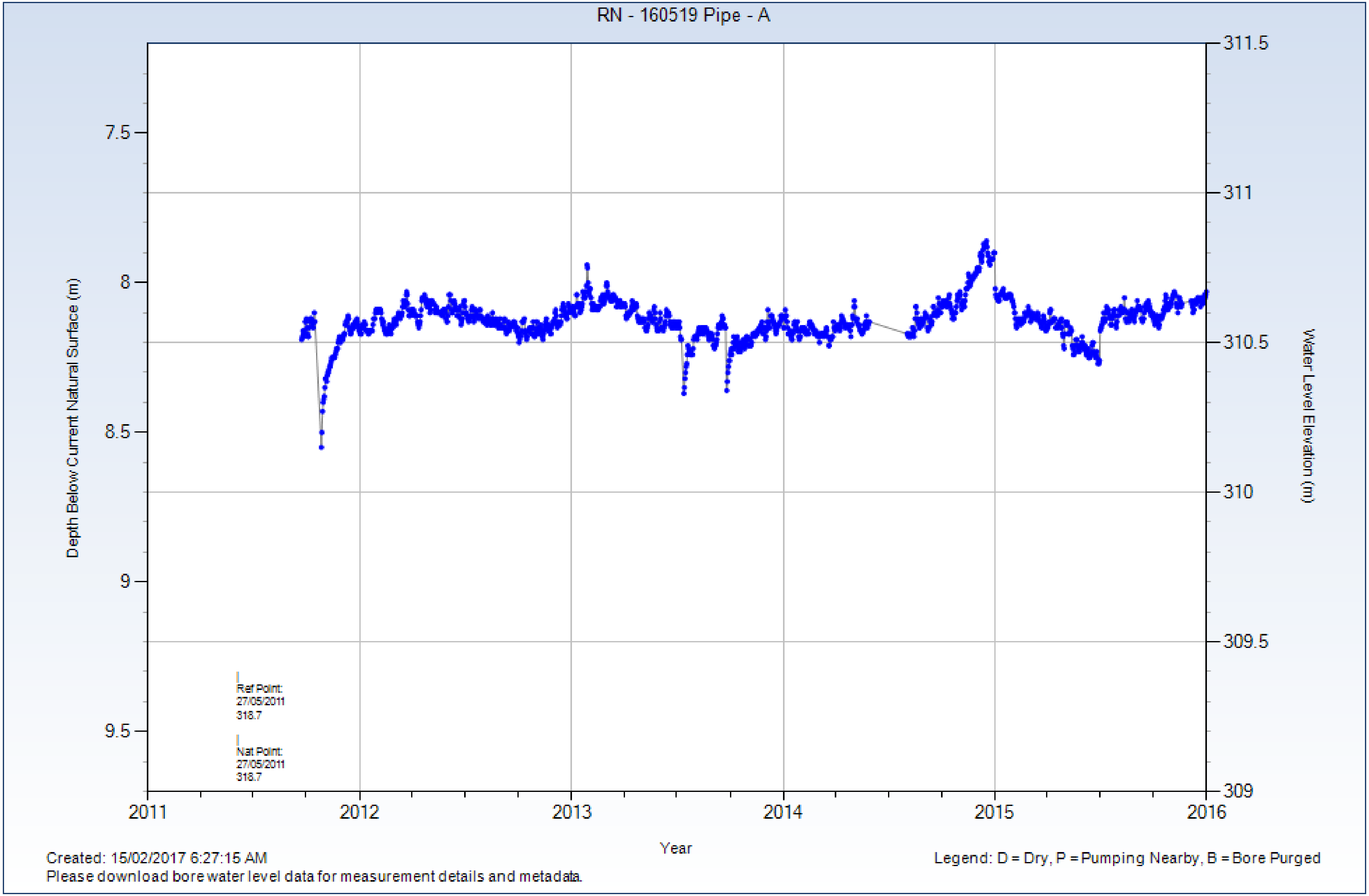

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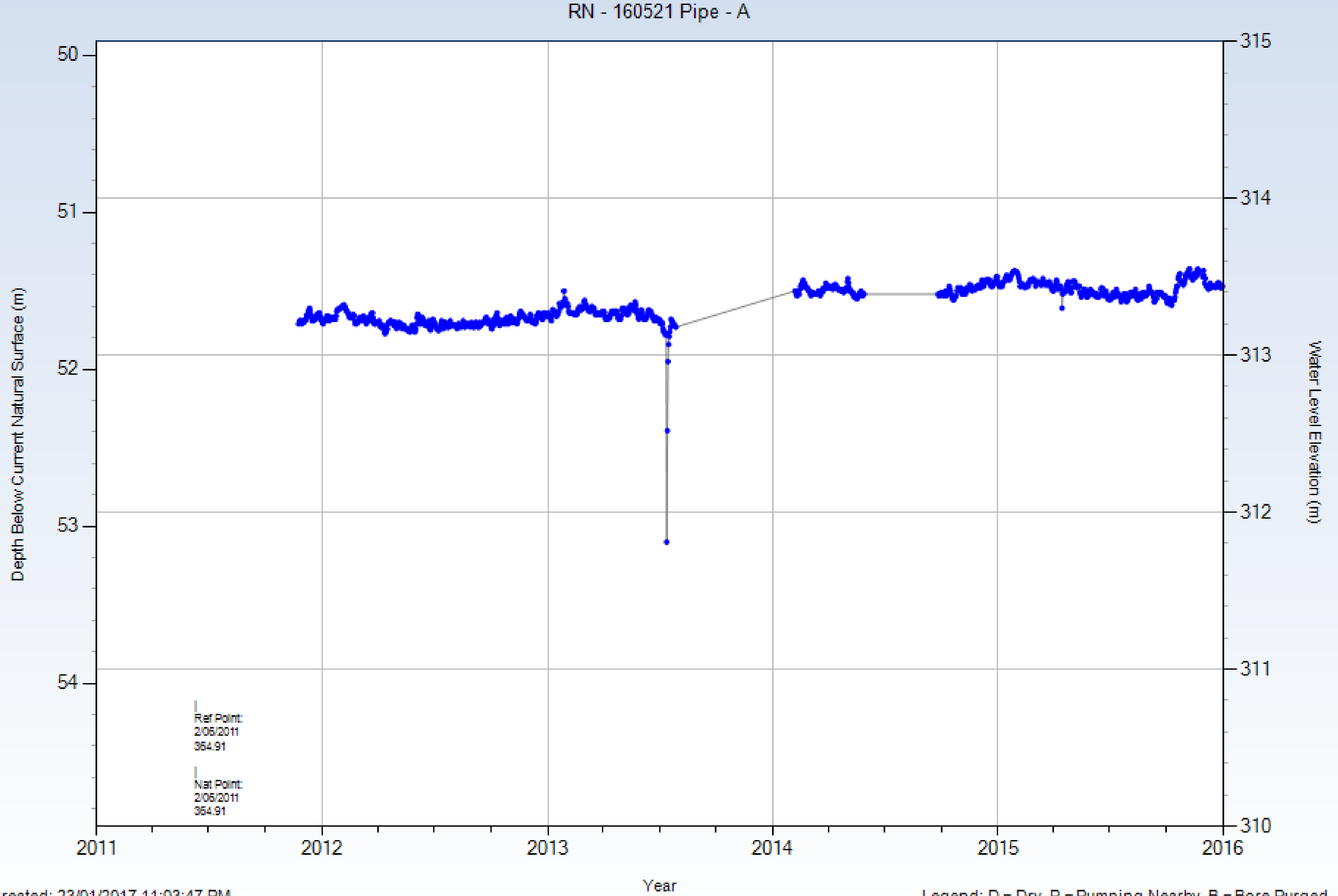
Legend: D = Dry, P = Pumping Nearby, B = Bore Purged



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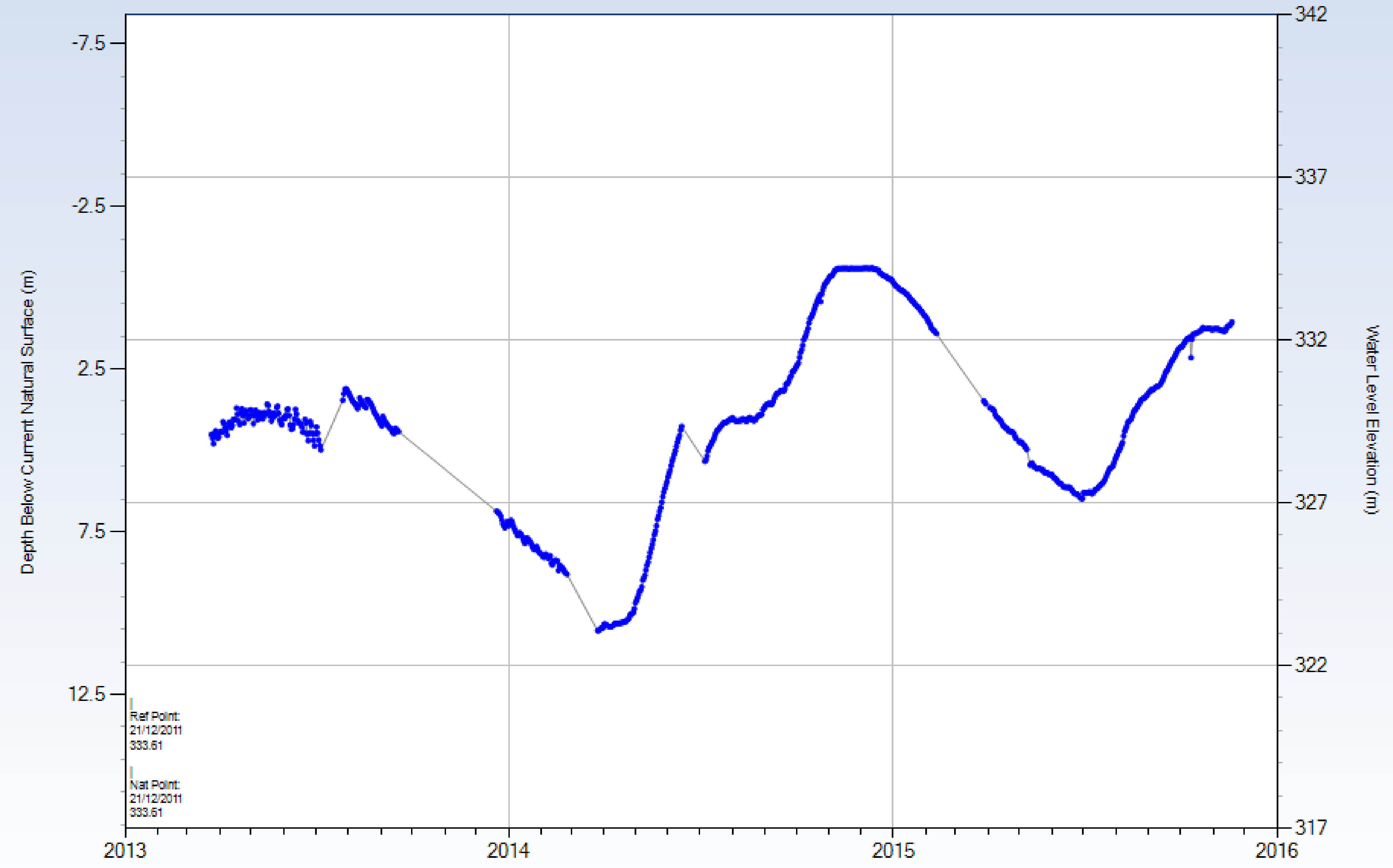
RN - 160526 Pipe - A



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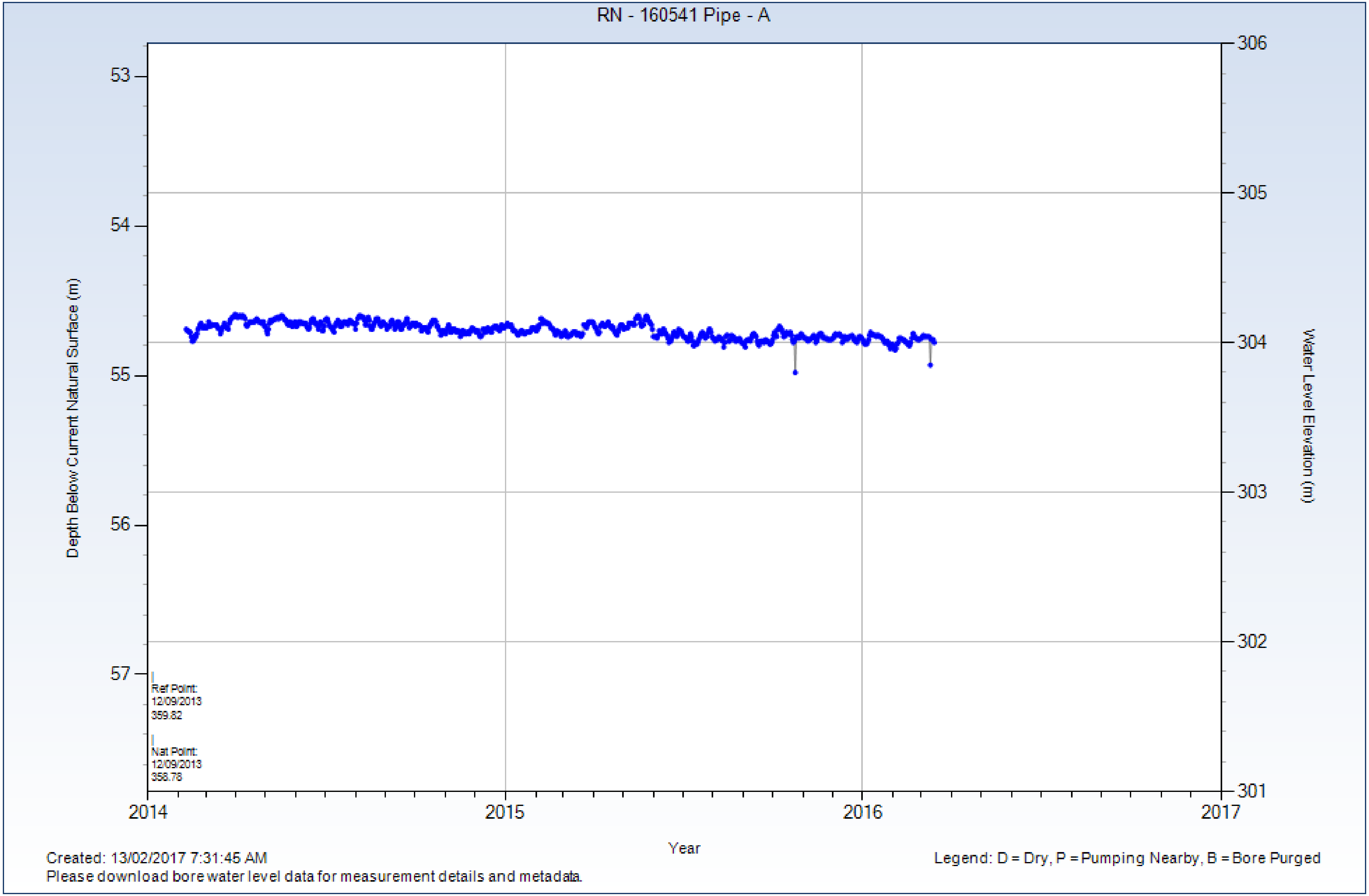
Legend: D = Dry, P = Pumping Nearby, B = Bore Purged



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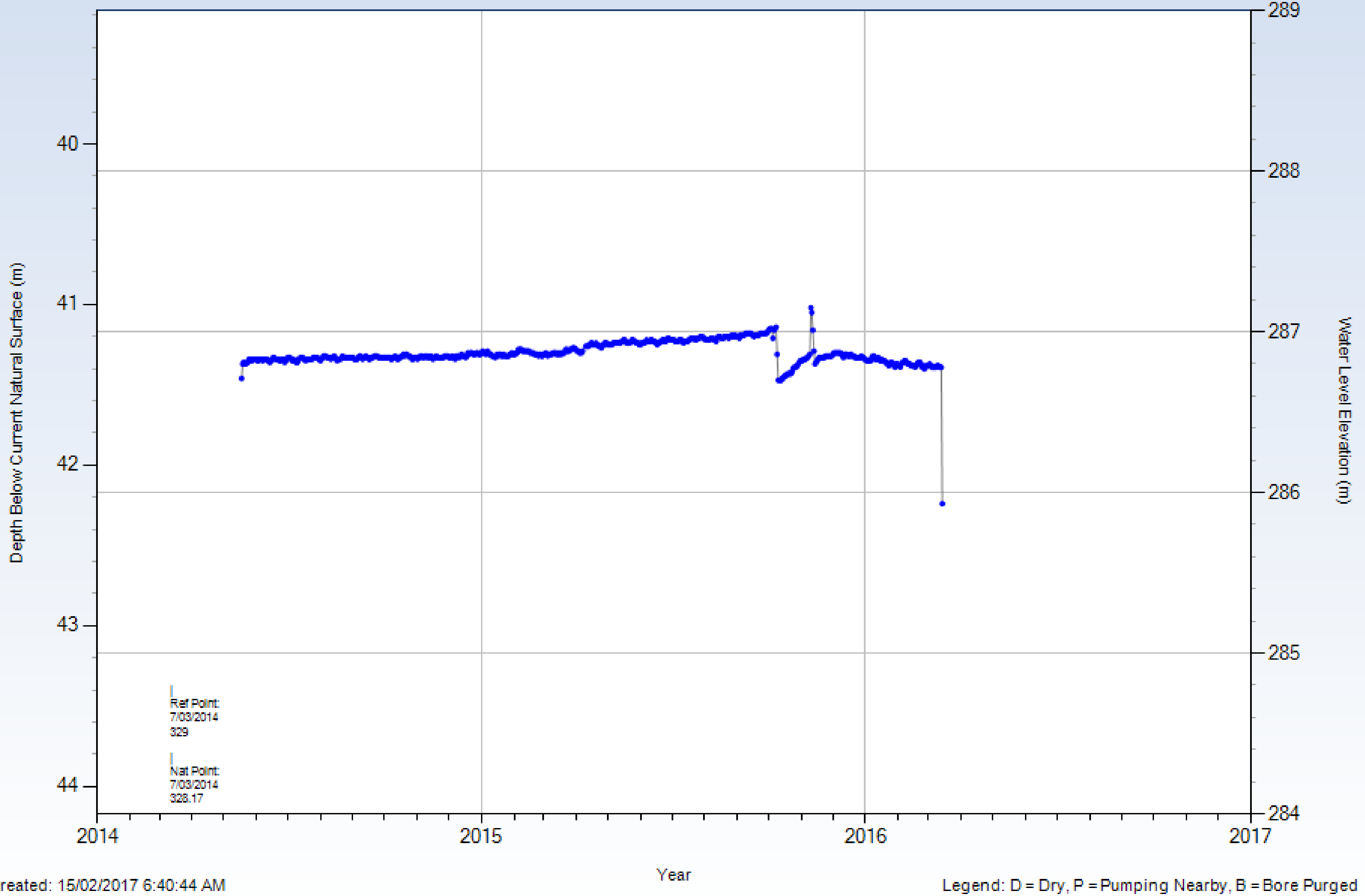
RN - 160547 Pipe - A



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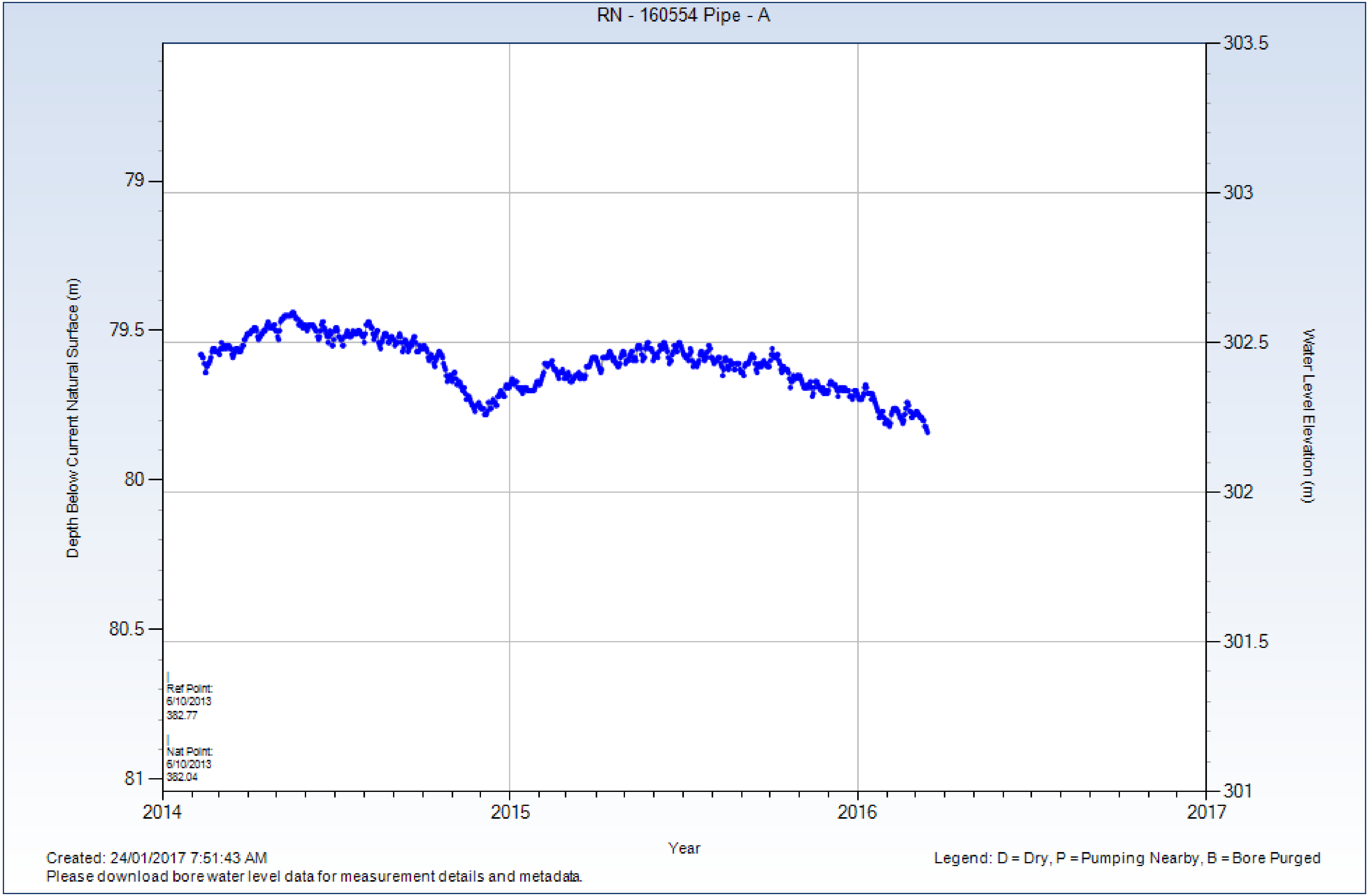
Legend: D = Dry, P = Pumping Nearby, B = Bore Purged



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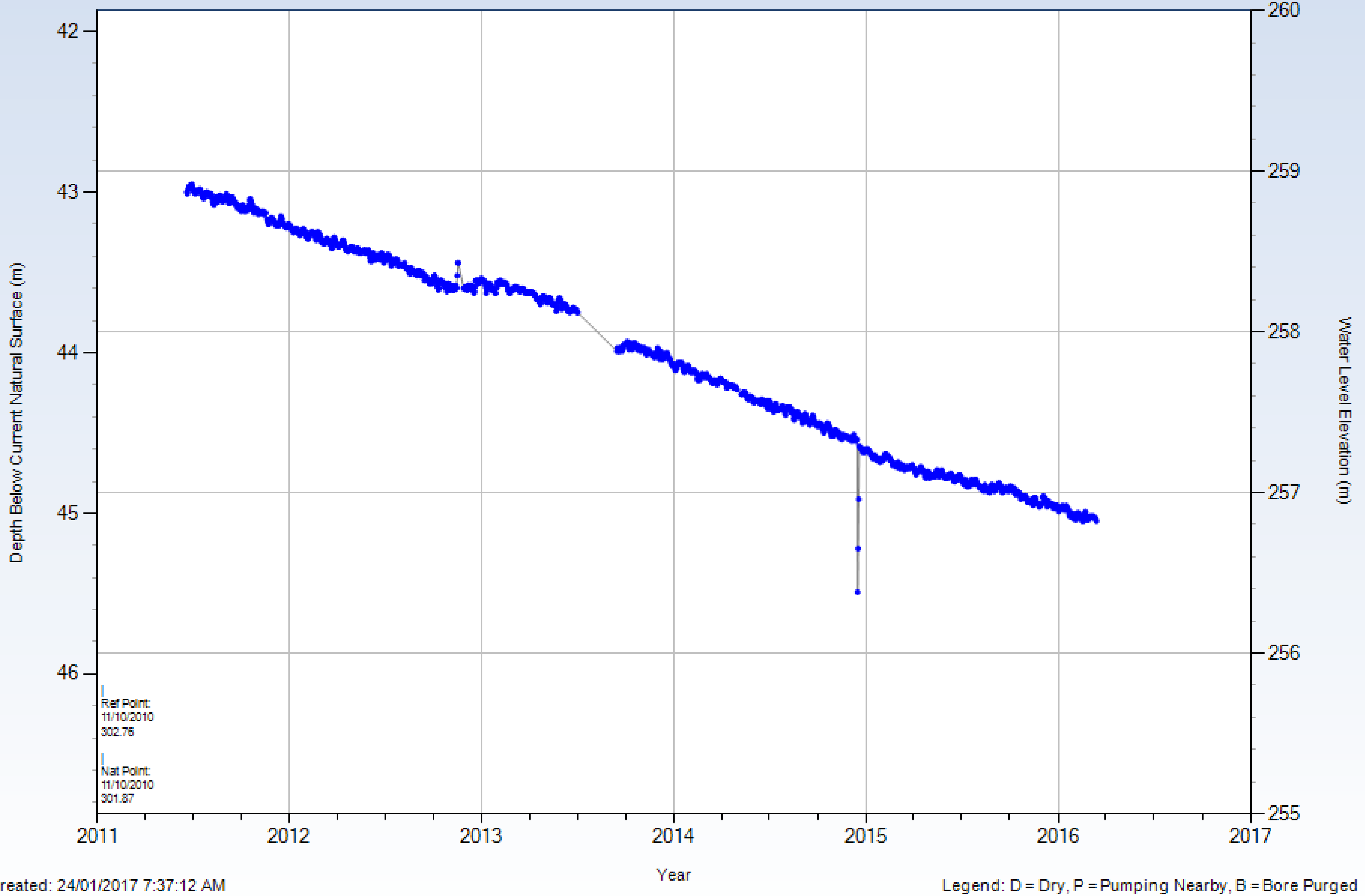

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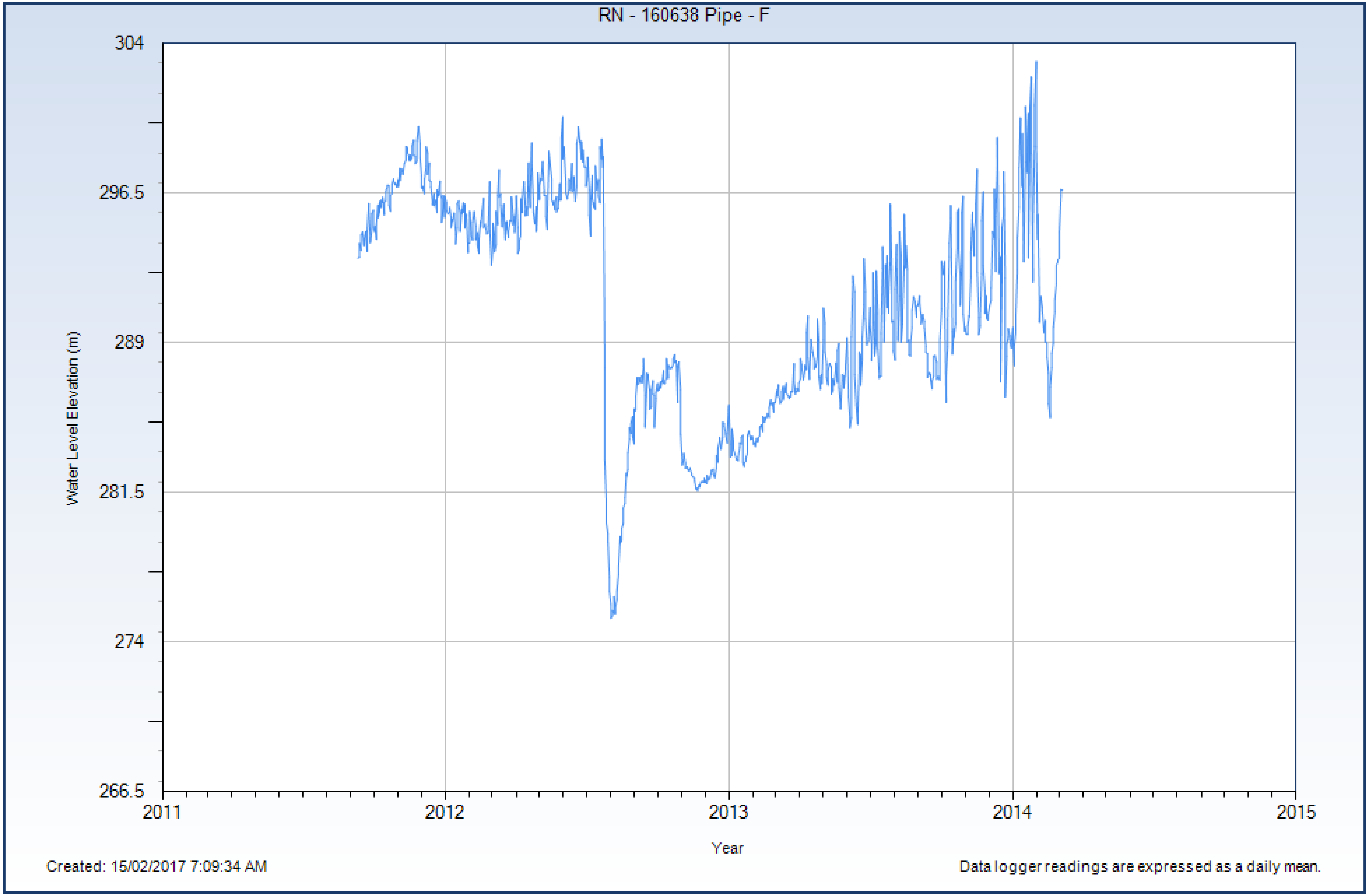
Legend: D = Dry, P = Pumping Nearby, B = Bore Purged



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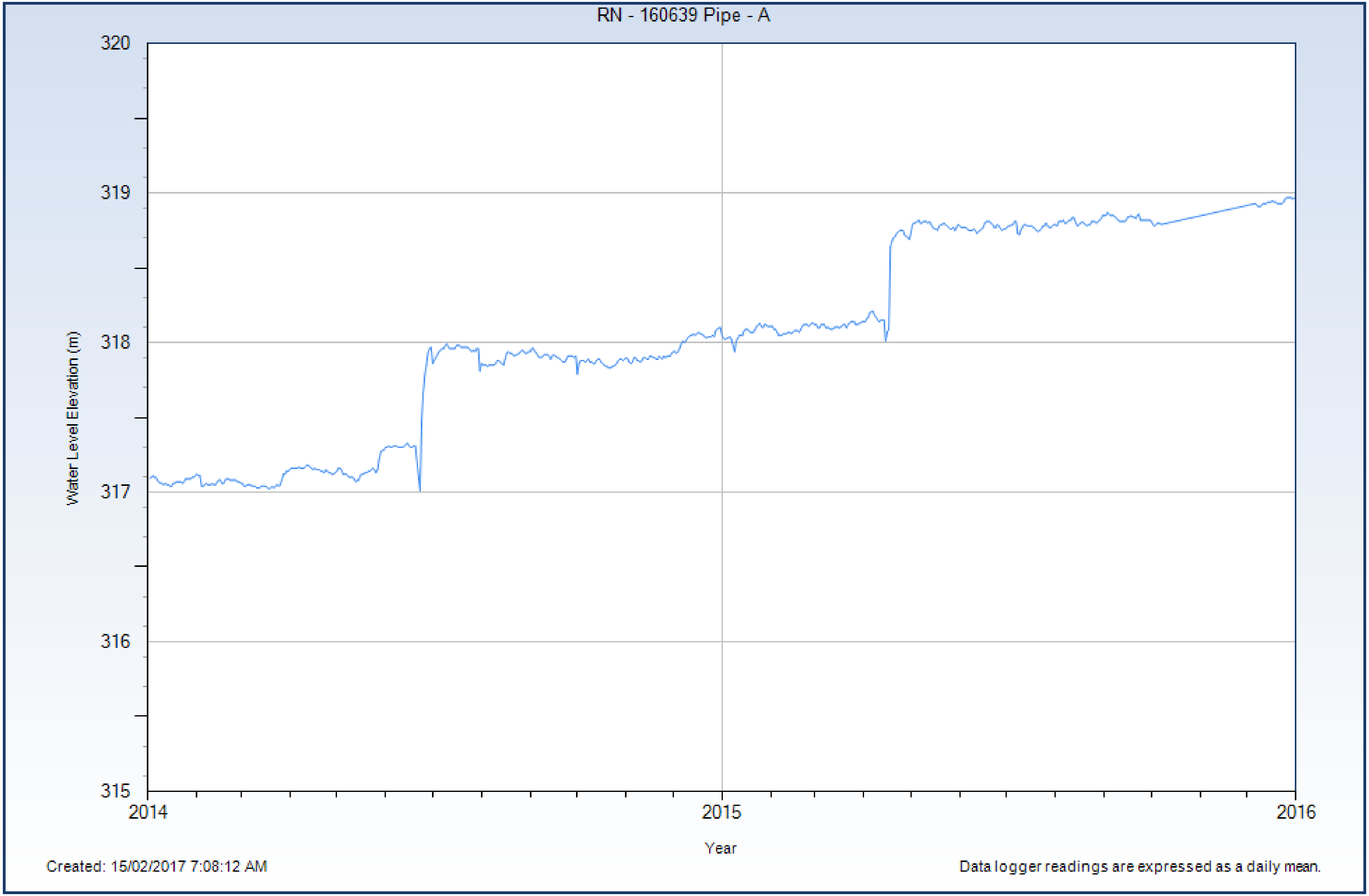
Data logger readings are expressed as a daily mean.


RN - 160639 Pipe - A
320
319
318
317
316
315
Water Level Elevation (m)
2014
2015
2016
Year
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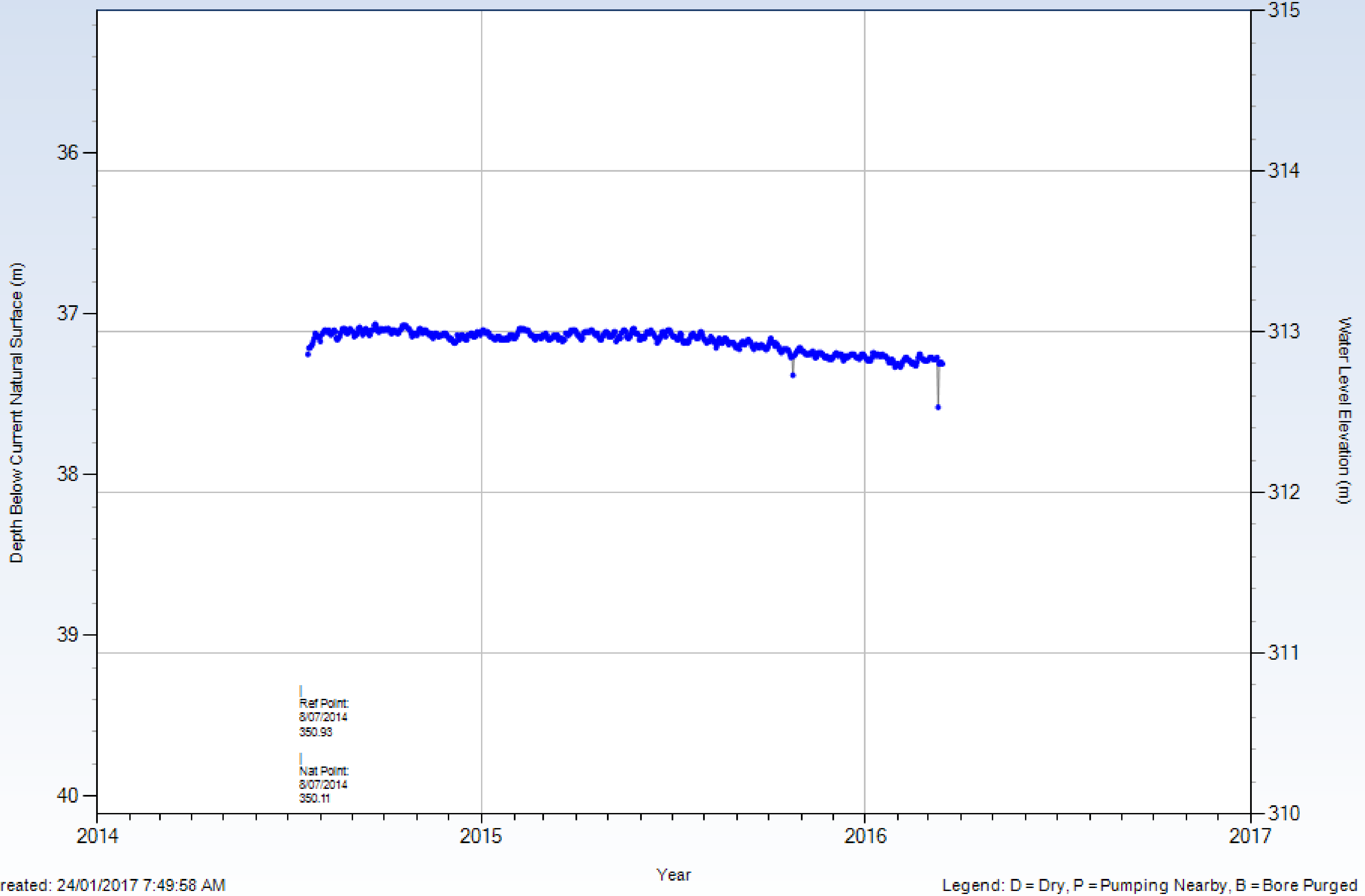
Data logger readings are expressed as a daily mean.

RN - 160670 Pipe - A



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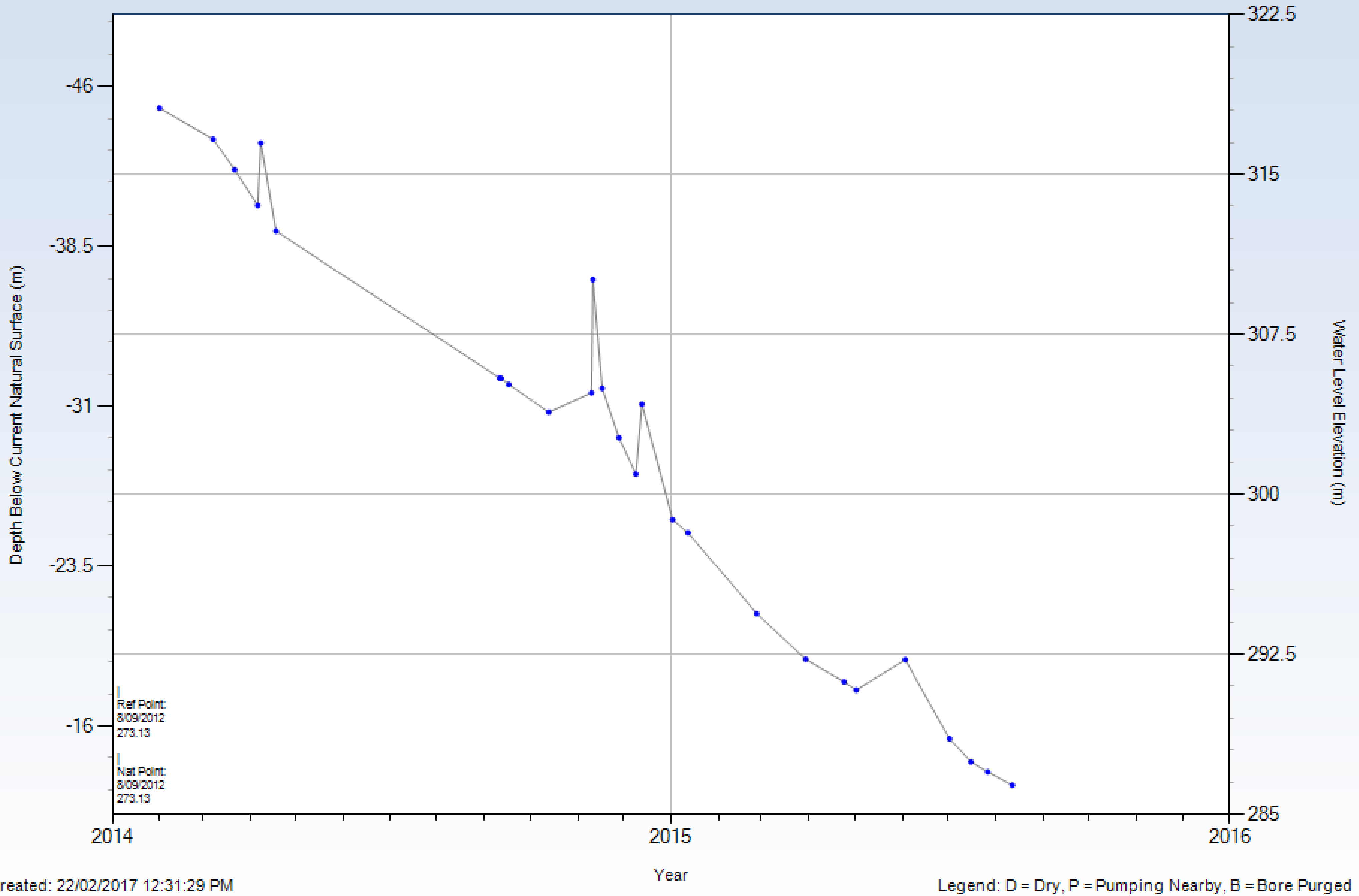
Legend: D = Dry, P = Pumping Nearby, B = Bore Purged

RN - 160677 Pipe - E



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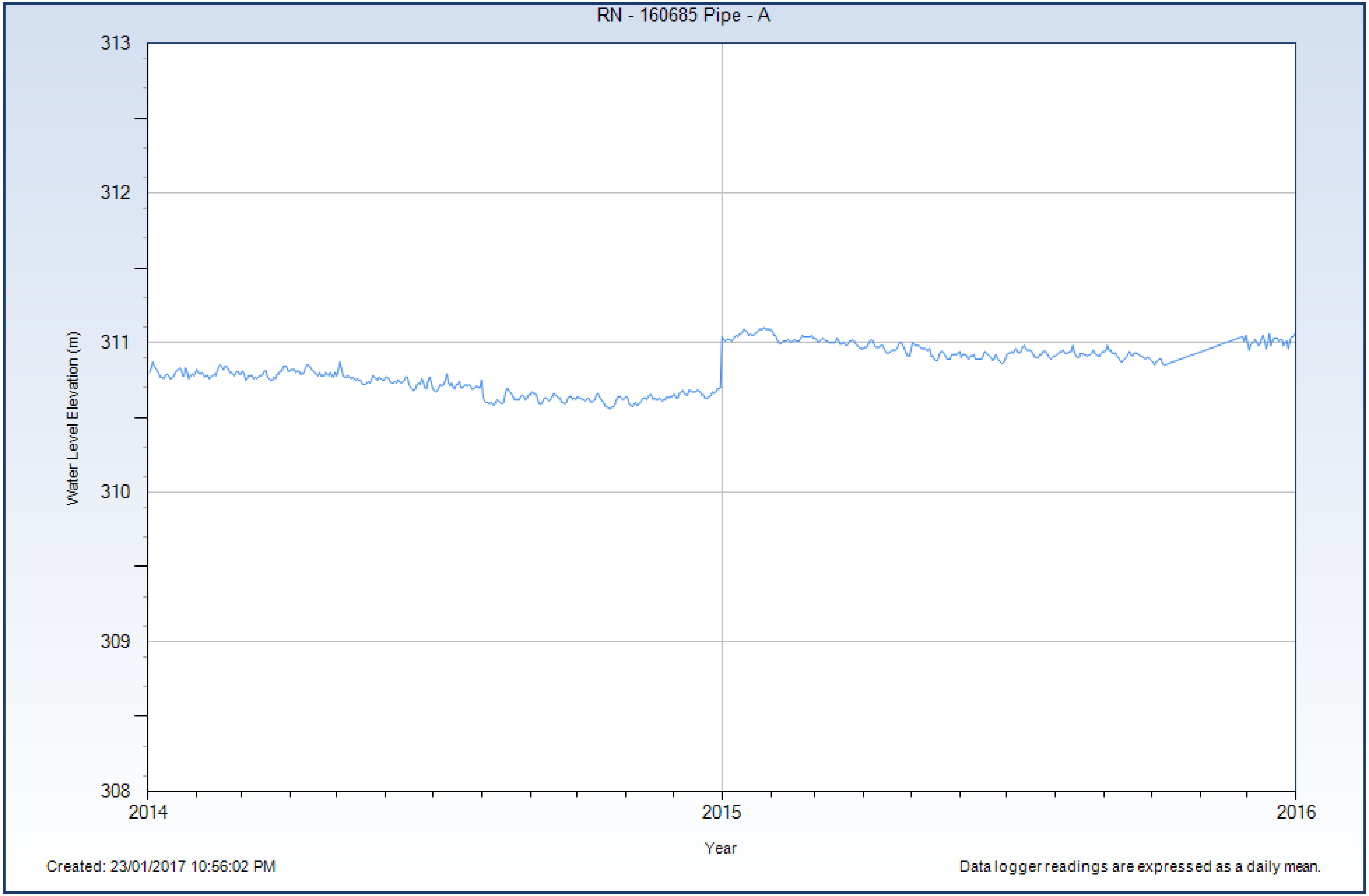
Legend: D = Dry, P = Pumping Nearby, B = Bore Purged


RN - 160685 Pipe - A
Water Level Elevation (m)
313
312
311
310
309
308
2014
2015
2016
Year
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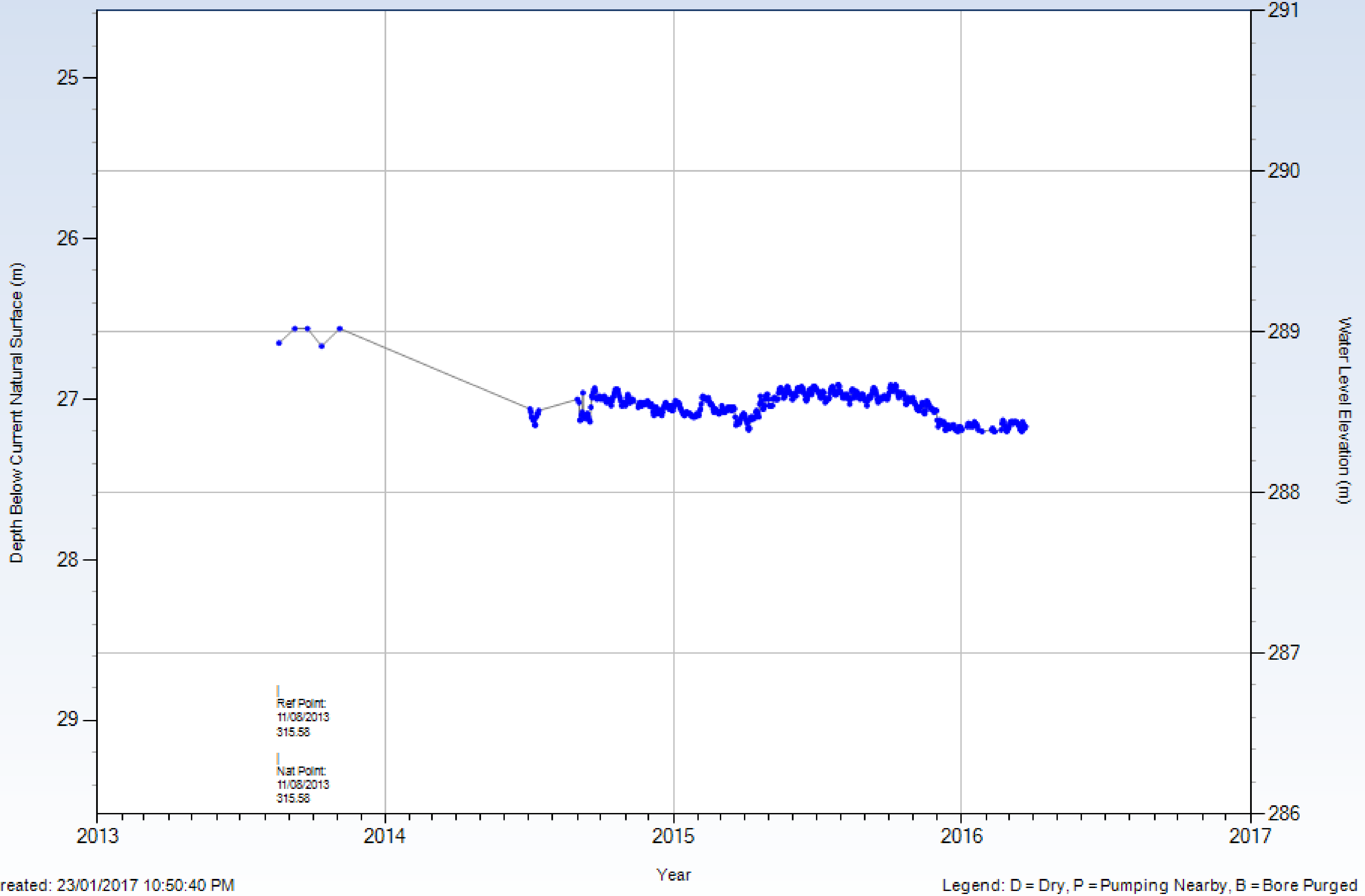
Data logger readings are expressed as a daily mean.

RN - 160687 Pipe - D



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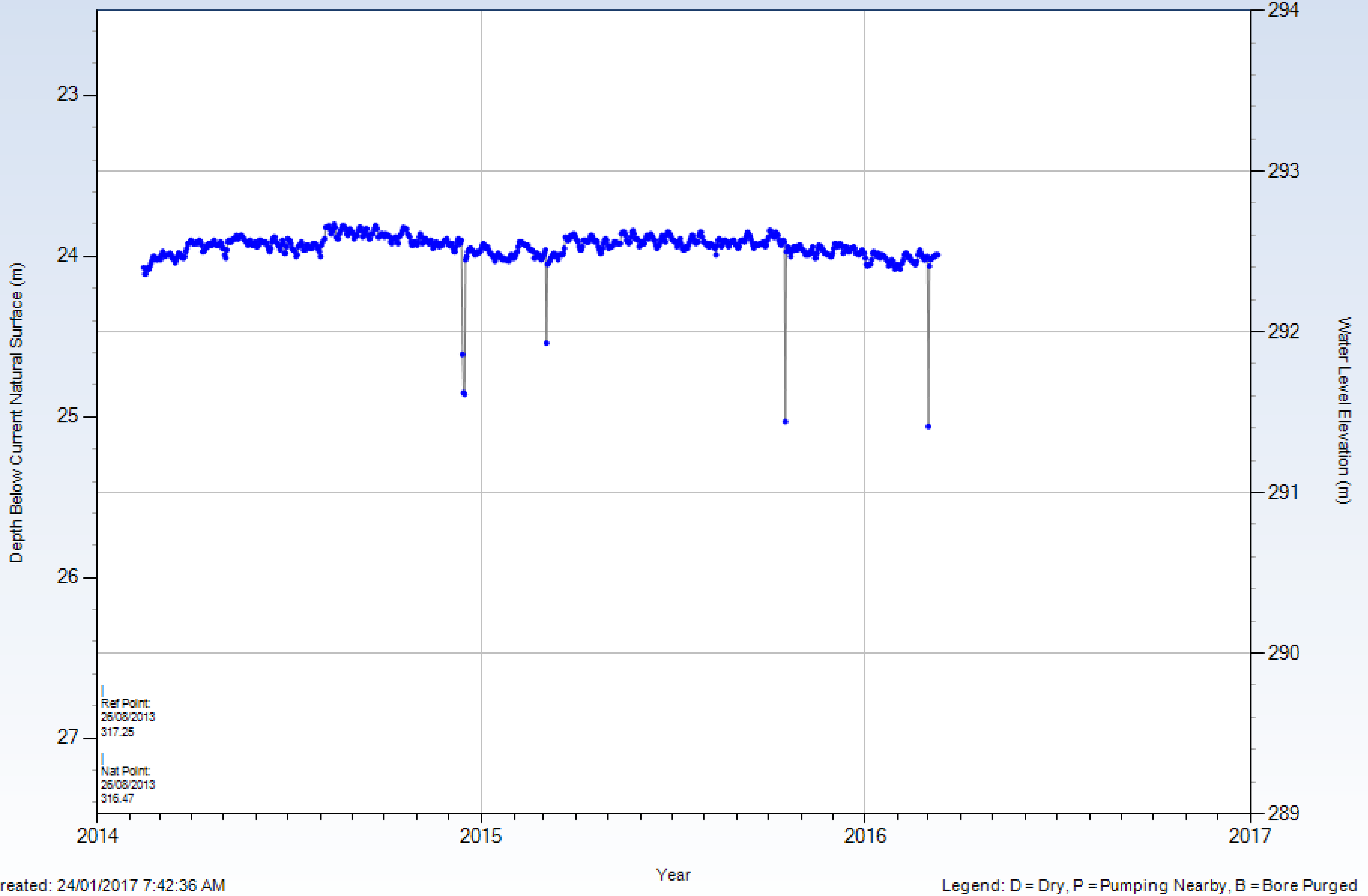
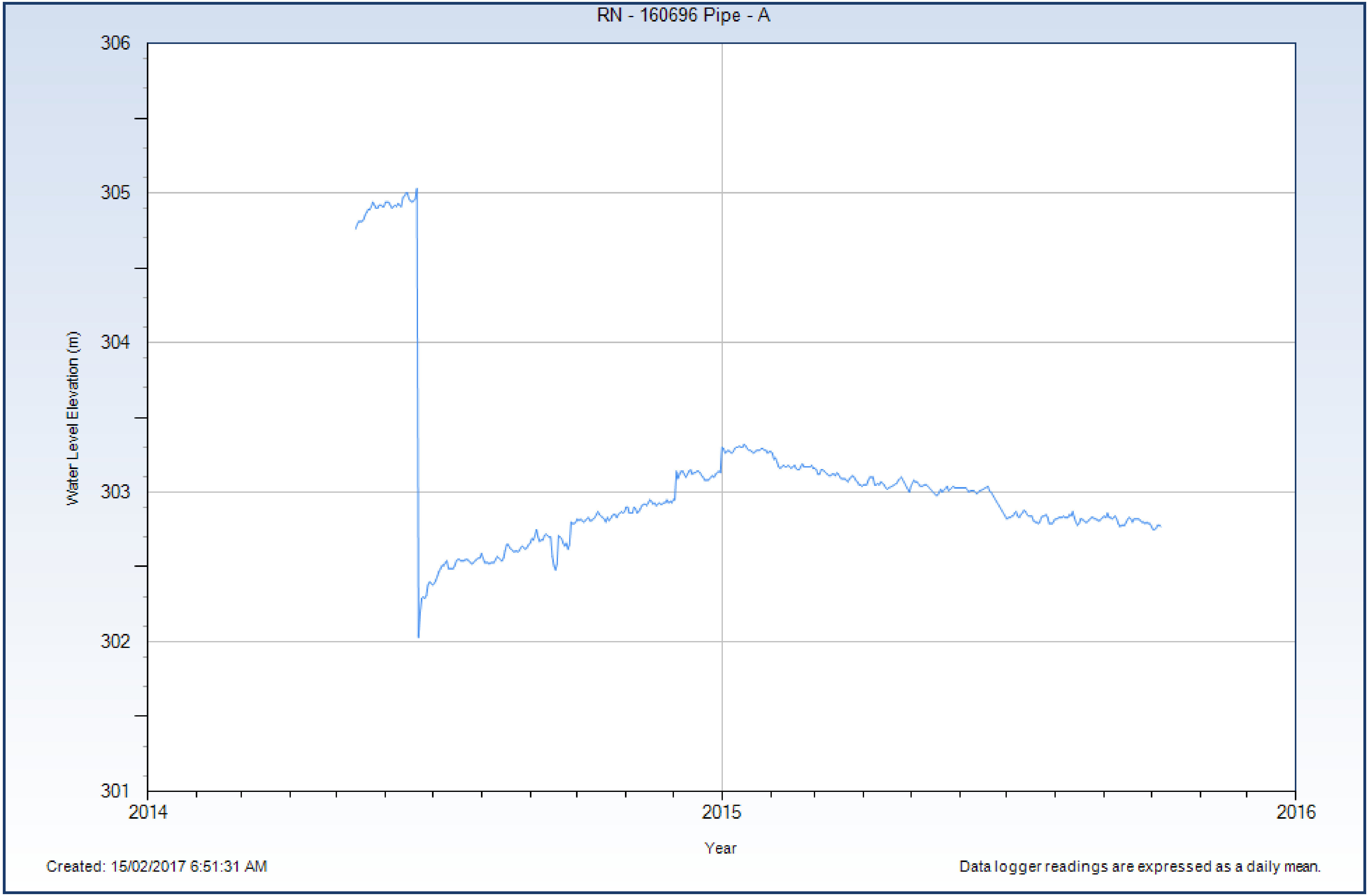
Legend: D = Dry, P = Pumping Nearby, B = Bore Purged

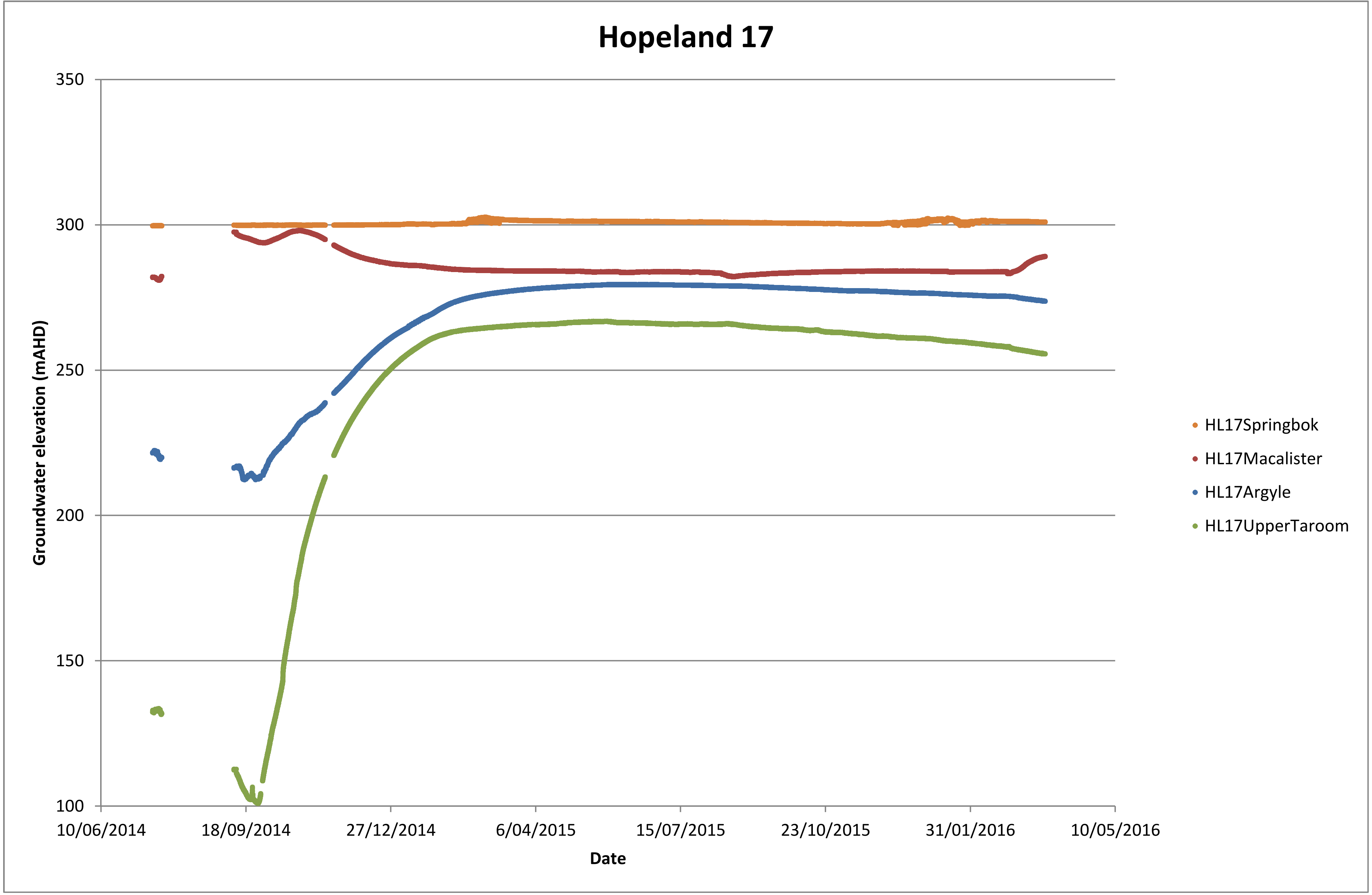
RN - 160693 Pipe - A

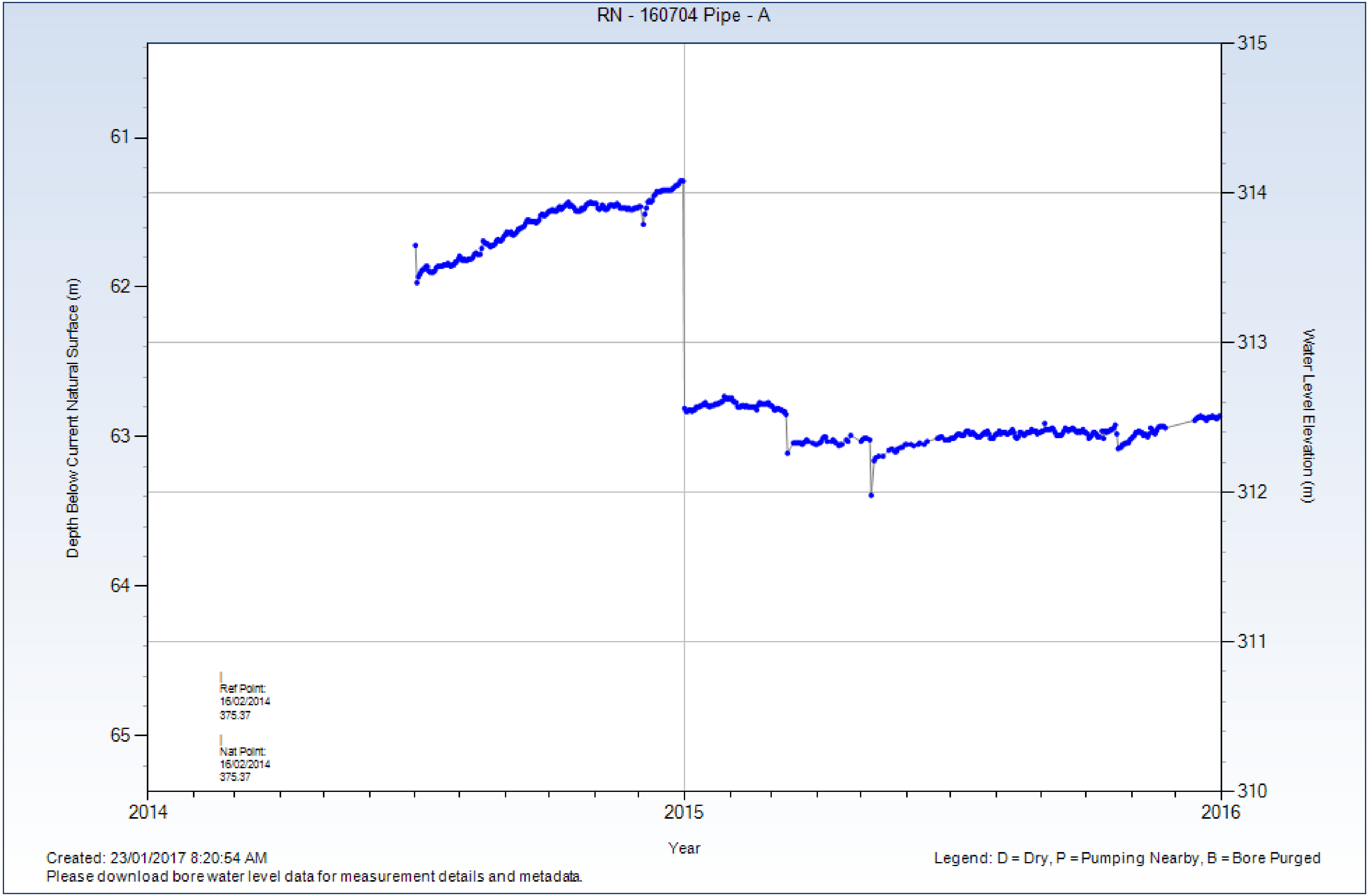


Created: 24/01/2017 7:42:36 AM
Please download bore water level data for measurement details and metadata.

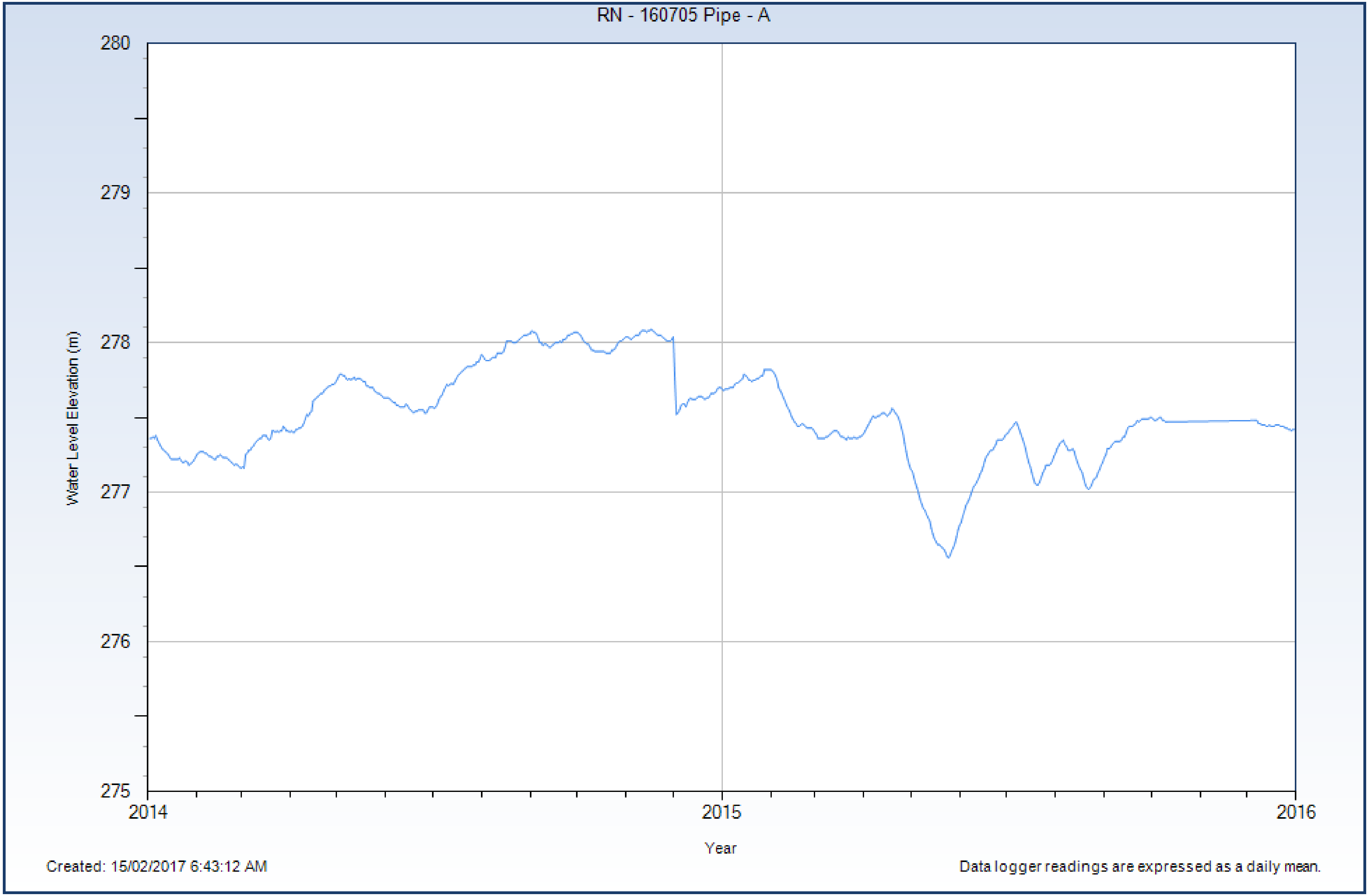
Legend: D = Dry, P = Pumping Nearby, B = Bore Purged


RN - 160696 Pipe - A
Water Level Elevation (m)
306
305
304
303
302
301
2014
2015
2016
Year
Created: 15/02/2017 6:51:31 AM
Data logger readings are expressed as a daily mean.


Hopeland 17
350
300
250
200
150
100
Groundwater elevation (mAHD)
10/06/2014
18/09/2014
27/12/2014
6/04/2015
15/07/2015
23/10/2015
31/01/2016
10/05/2016
Date
HL17Springbok
HL17Macalister
HL17Argyle
HL17UpperTaroom

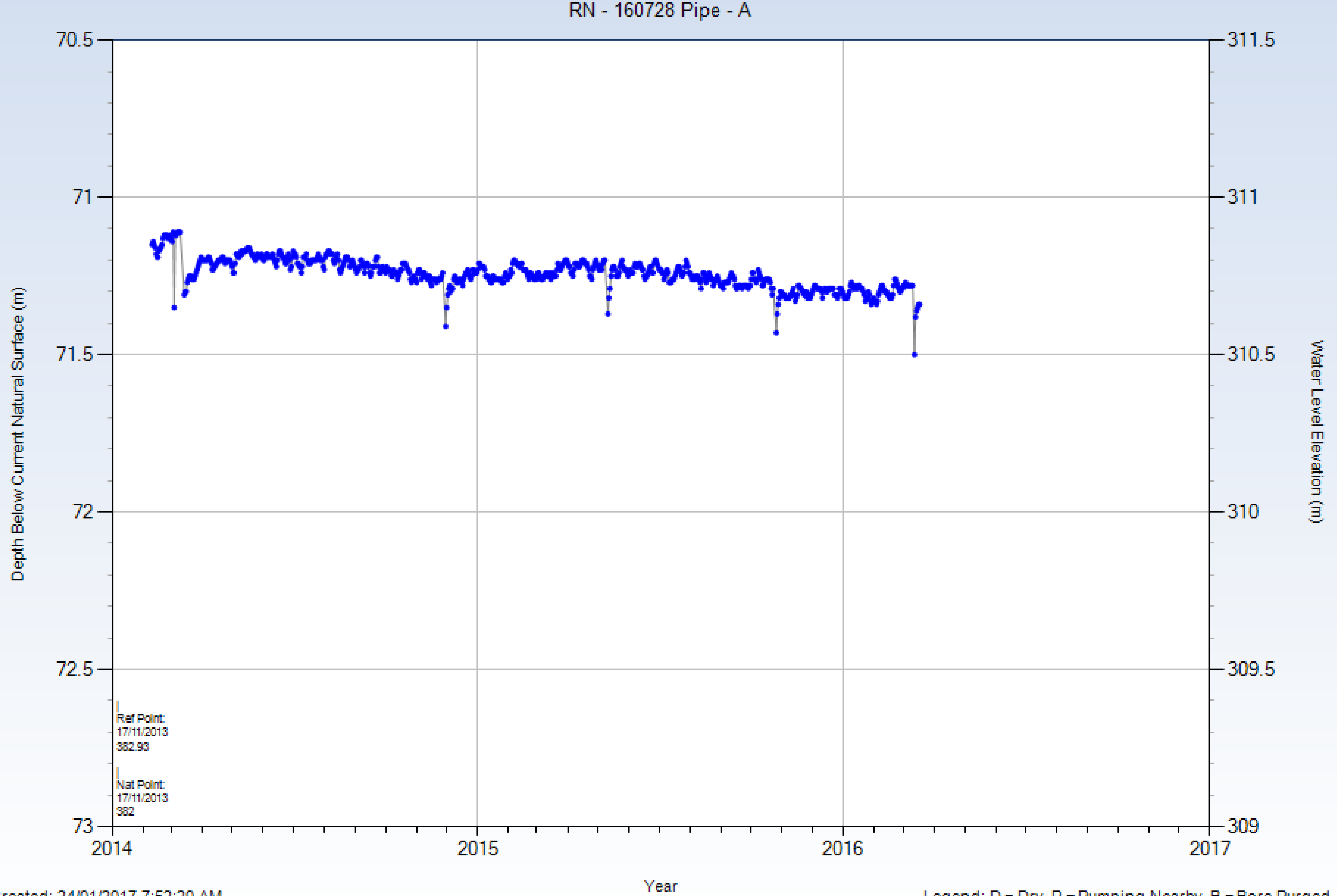


Created: 23/01/2017 8:20:54 AM
Please download bore water level data for measurement details and metadata.



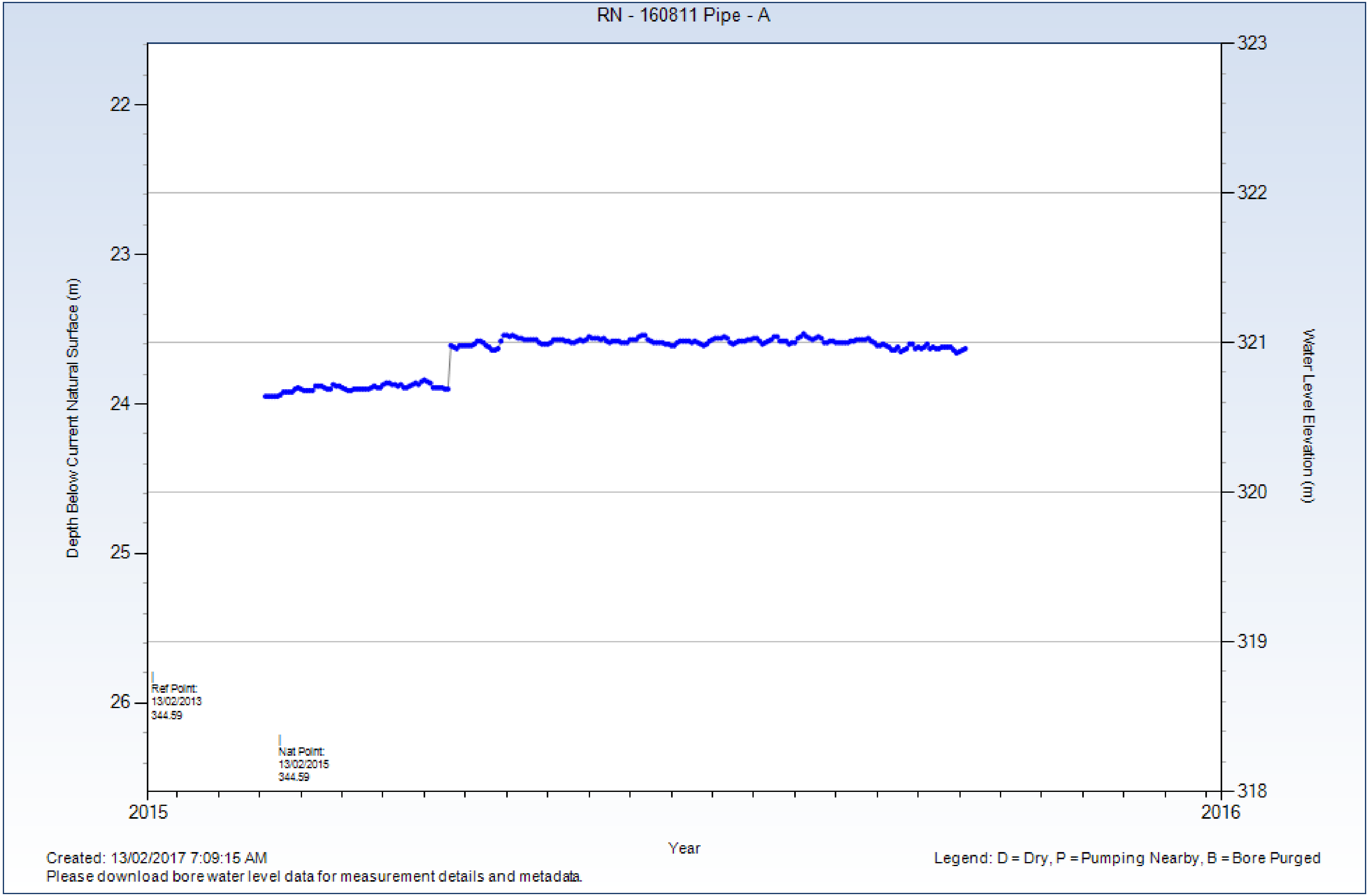
Created: 15/02/2017 6:43:12 AM

Data logger readings are expressed as a daily mean.

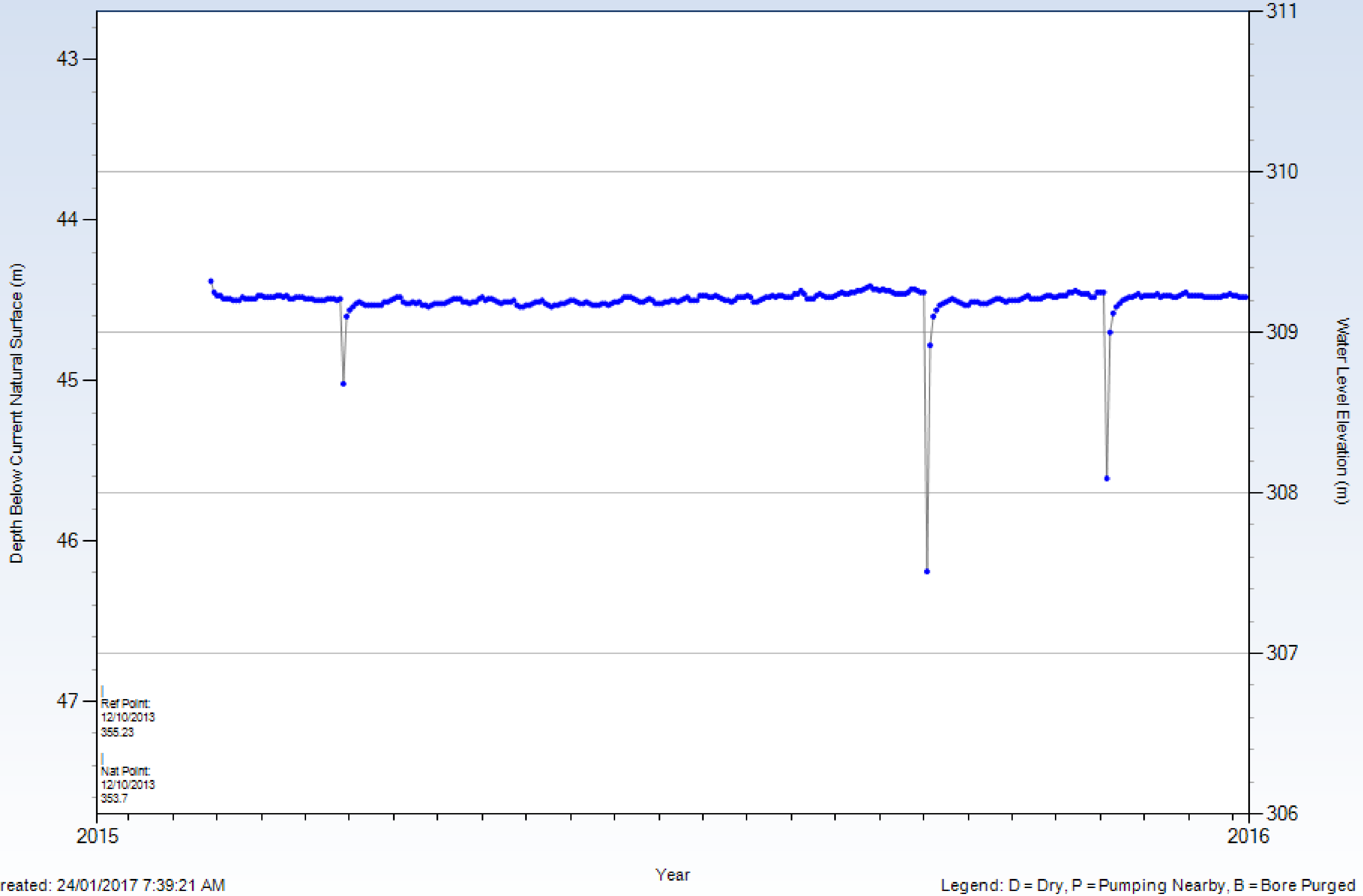


Created: 24/01/2017 7:52:20 AM
Please download bore water level data for measurement details and metadata.

Legend: D = Dry, P = Pumping Nearby, B = Bore Purged

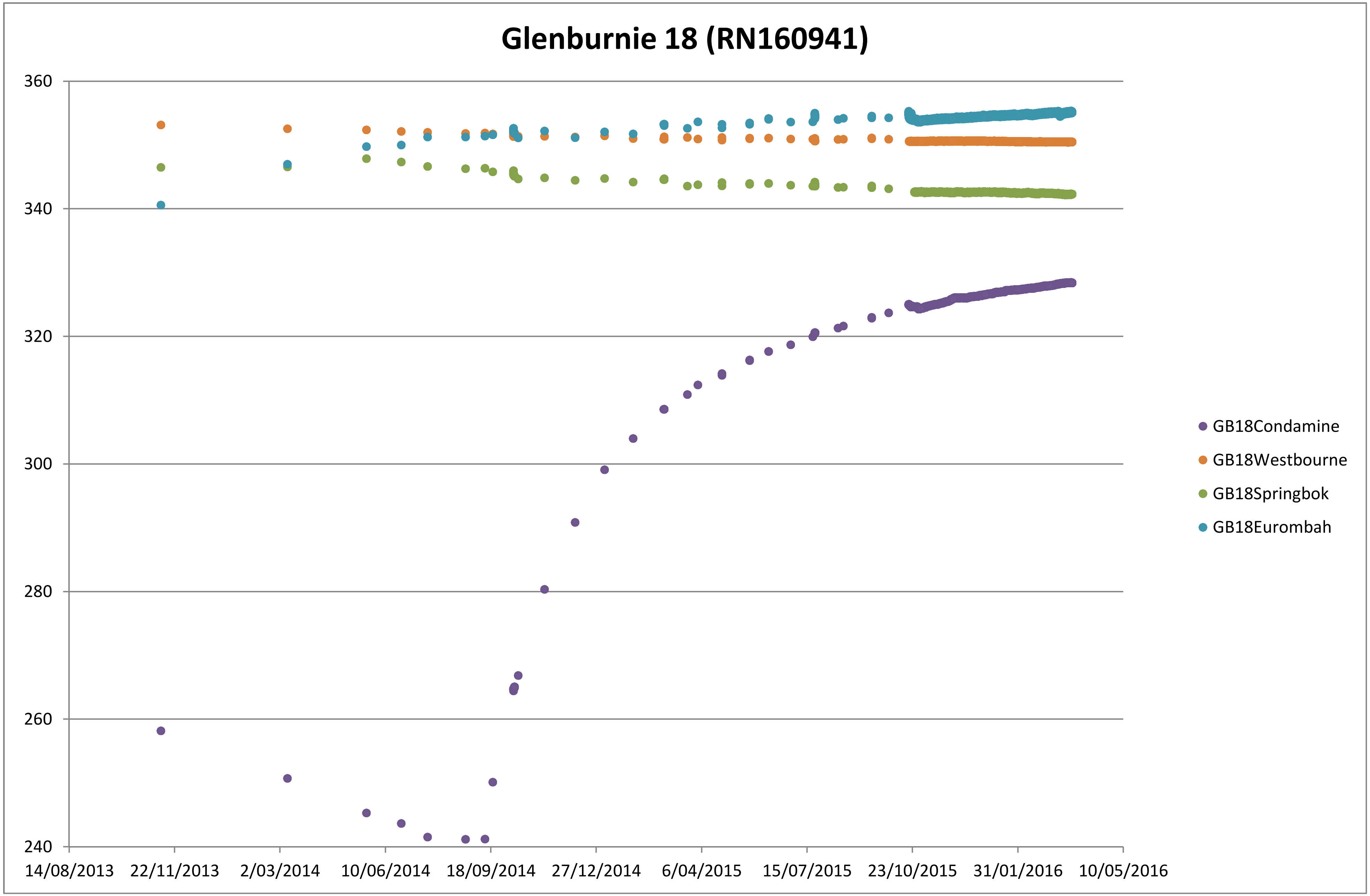

RN - 160811 Pipe - A
Depth Below Current Natural Surface (m)
22
23
24
25
26
Water Level Elevation (m)
323
322
321
320
319
318
2015
2016
Year
Ref Point:
13/02/2013
344.59
Nat Point:
13/02/2015
344.59
Created: 13/02/2017 7:09:15 AM
Please download bore water level data for measurement details and metadata.
Legend: D = Dry, P = Pumping Nearby, B = Bore Purged

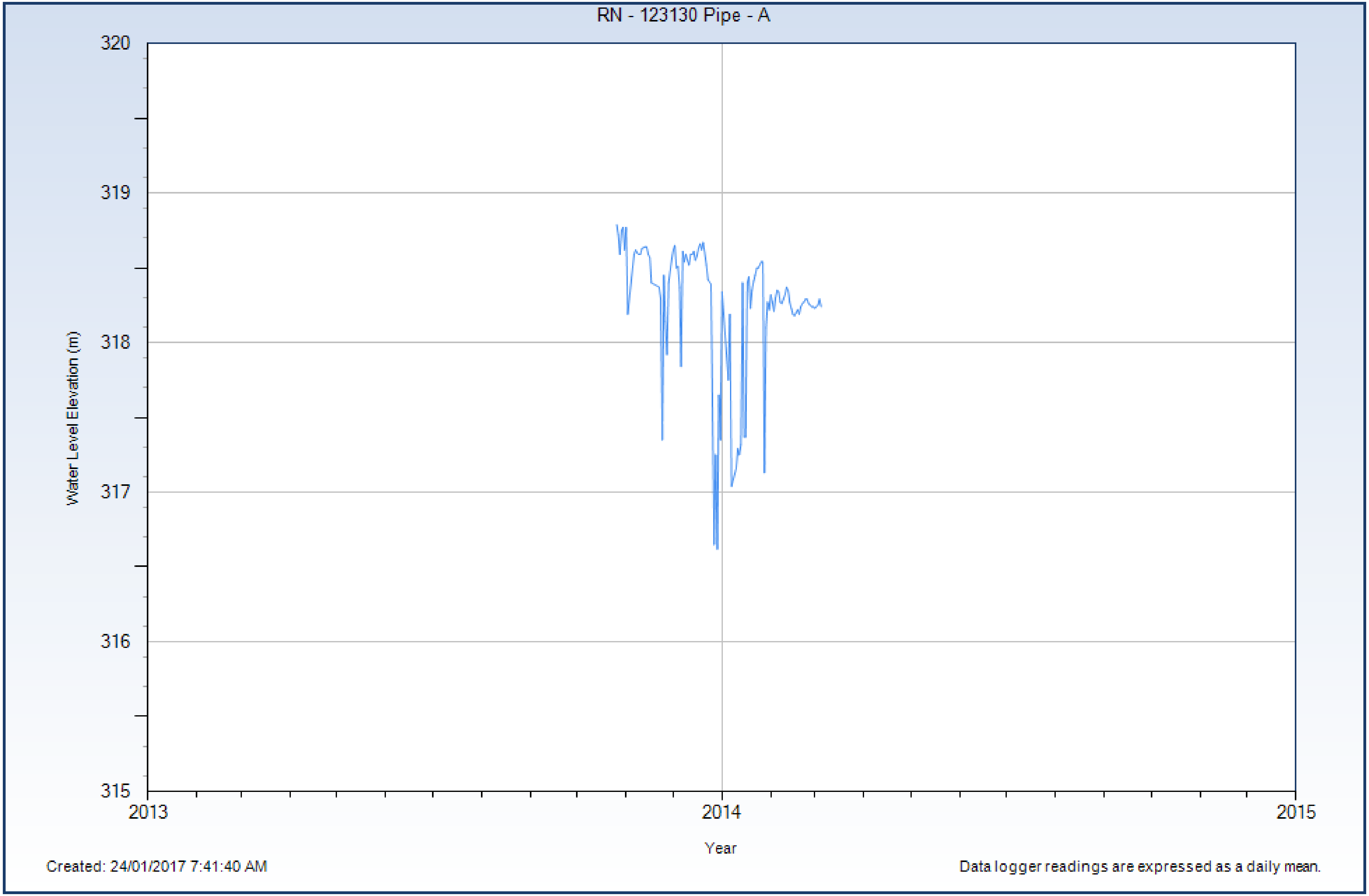
RN - 160812 Pipe - A



Created: 24/01/2017 7:39:21 AM
Please download bore water level data for measurement details and metadata.

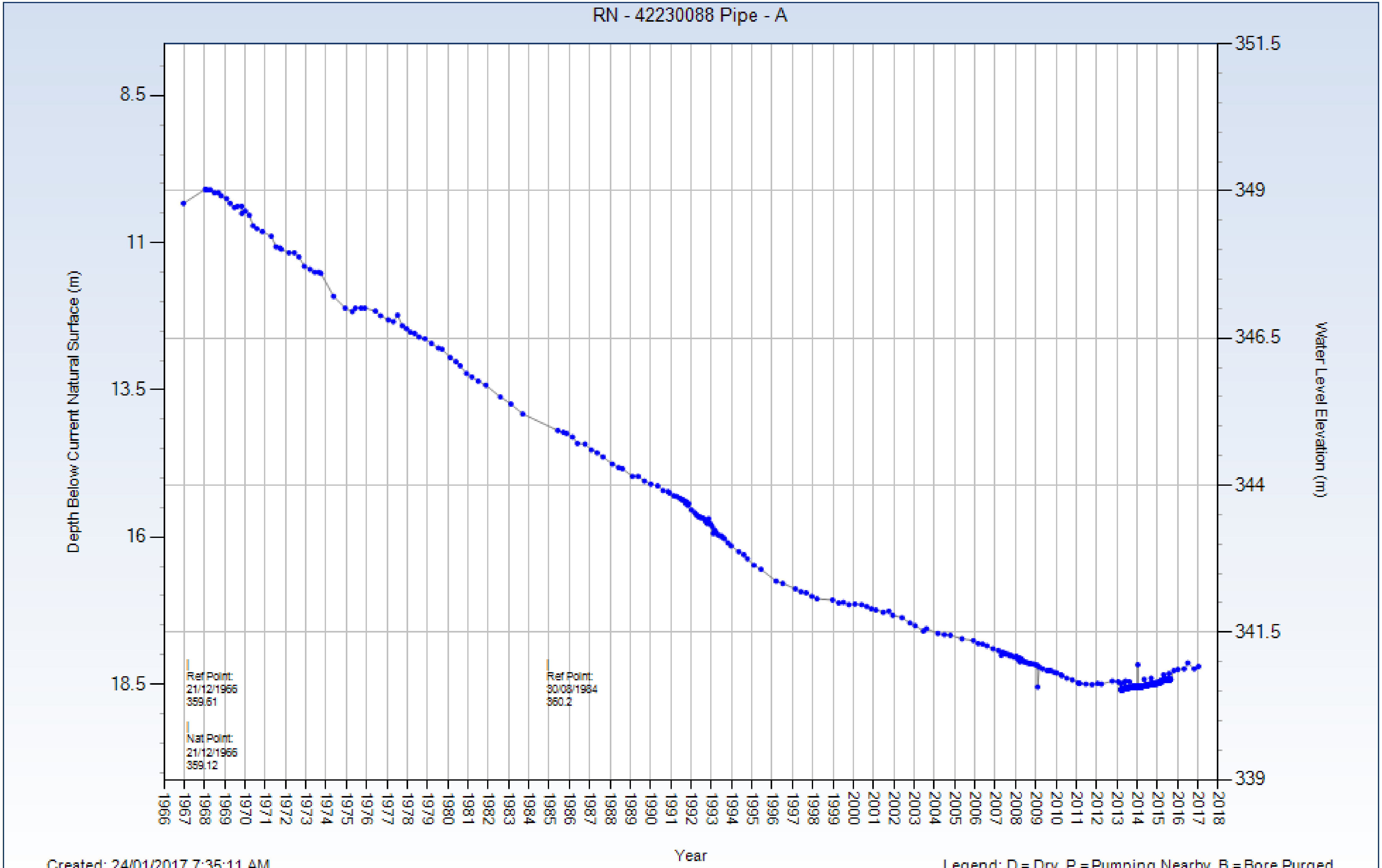
Legend: D = Dry, P = Pumping Nearby, B = Bore Purged


Glenburnie 18 (RN160941)
360
340
320
300
280
260
240
14/08/2013
22/11/2013
2/03/2014
10/06/2014
18/09/2014
27/12/2014
6/04/2015
15/07/2015
23/10/2015
31/01/2016
10/05/2016
GB18Condamine
GB18Westbourne
GB18Springbok
GB18Eurombah


RN - 123130 Pipe - A

Created: 24/01/2017 7:41:40 AM

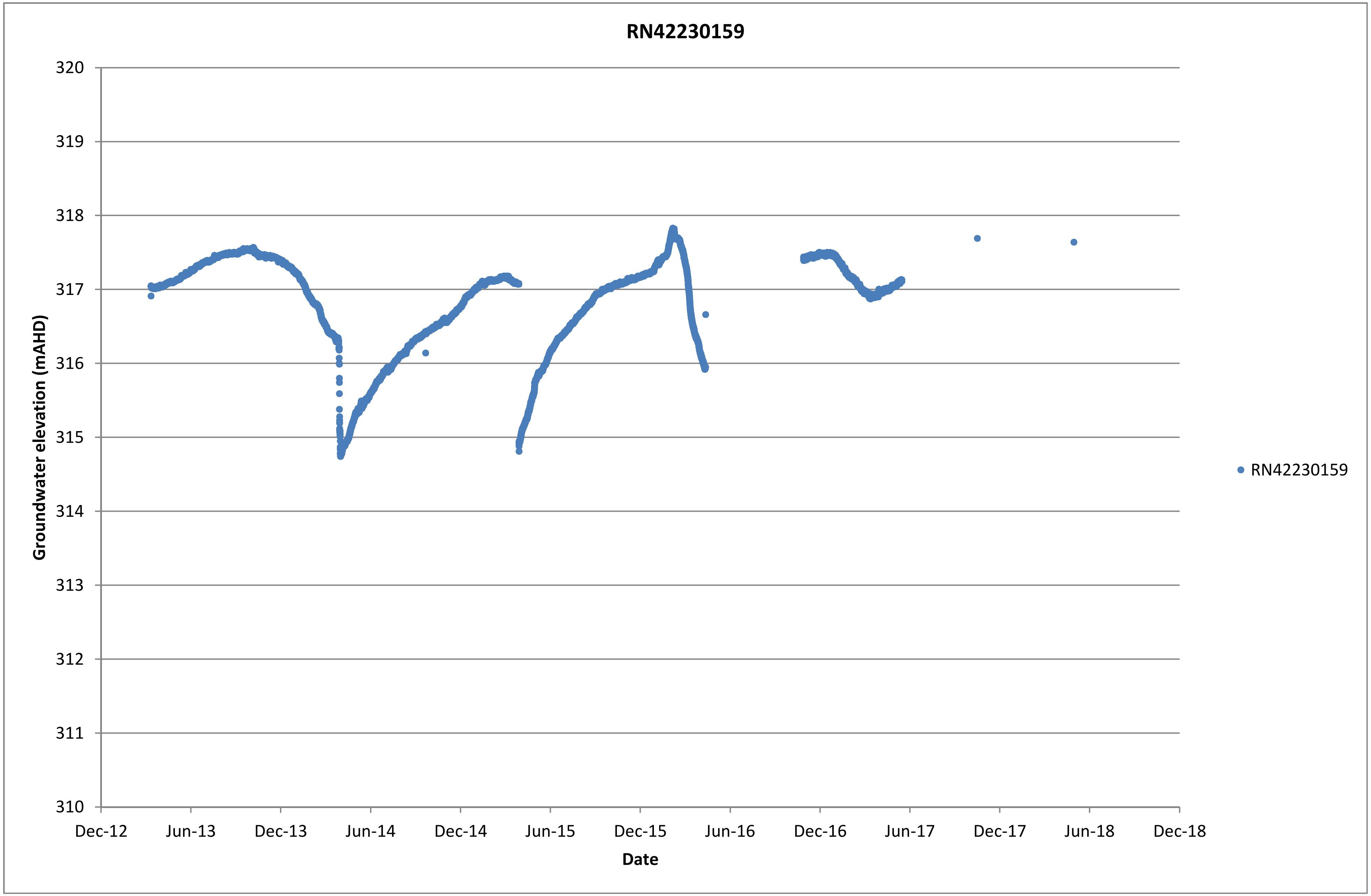
Data logger readings are expressed as a daily mean.



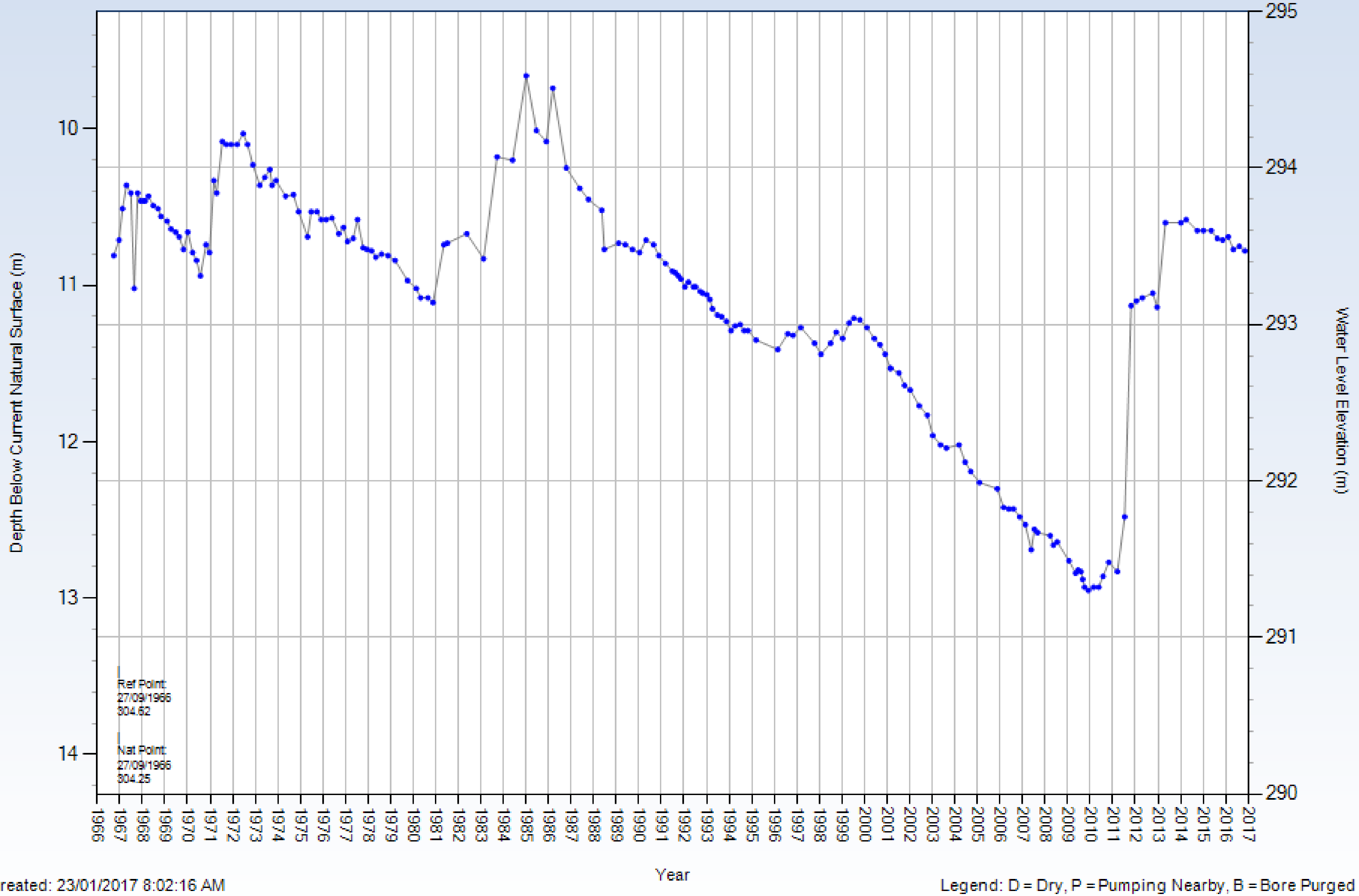
Created: 24/01/2017 7:35:11 AM

Please download bore water level data for measurement details and metadata.

Legend: D = Dry, P = Pumping Nearby, B = Bore Purged

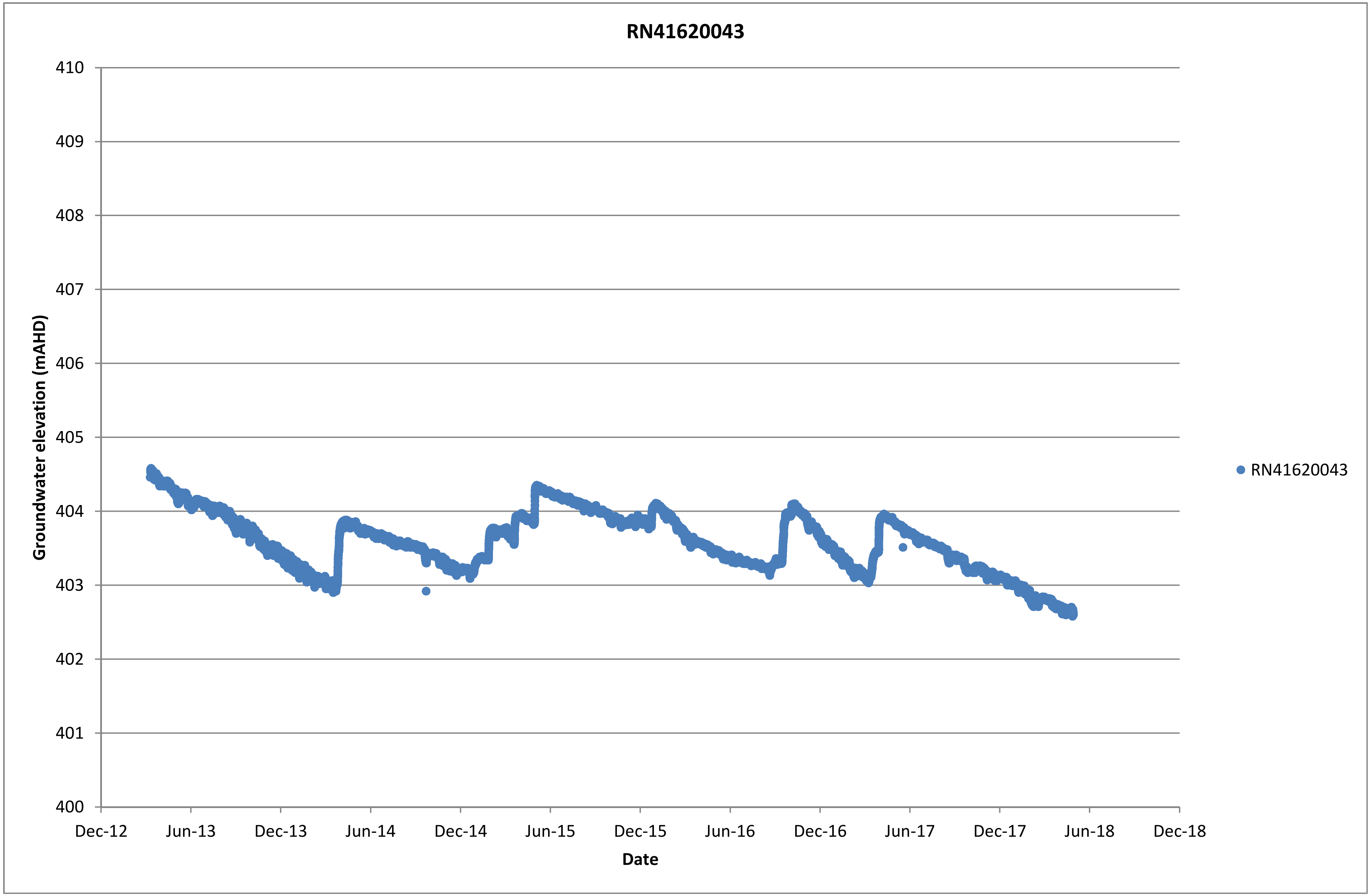

RN42230159
320
319
318
317
316
315
314
313
312
311
310
Groundwater elevation (mAHD)
Dec-12
Jun-13
Dec-13
Jun-14
Dec-14
Jun-15
Dec-15
Jun-16
Dec-16
Jun-17
Dec-17
Jun-18
Dec-18
Date
● RN42230159

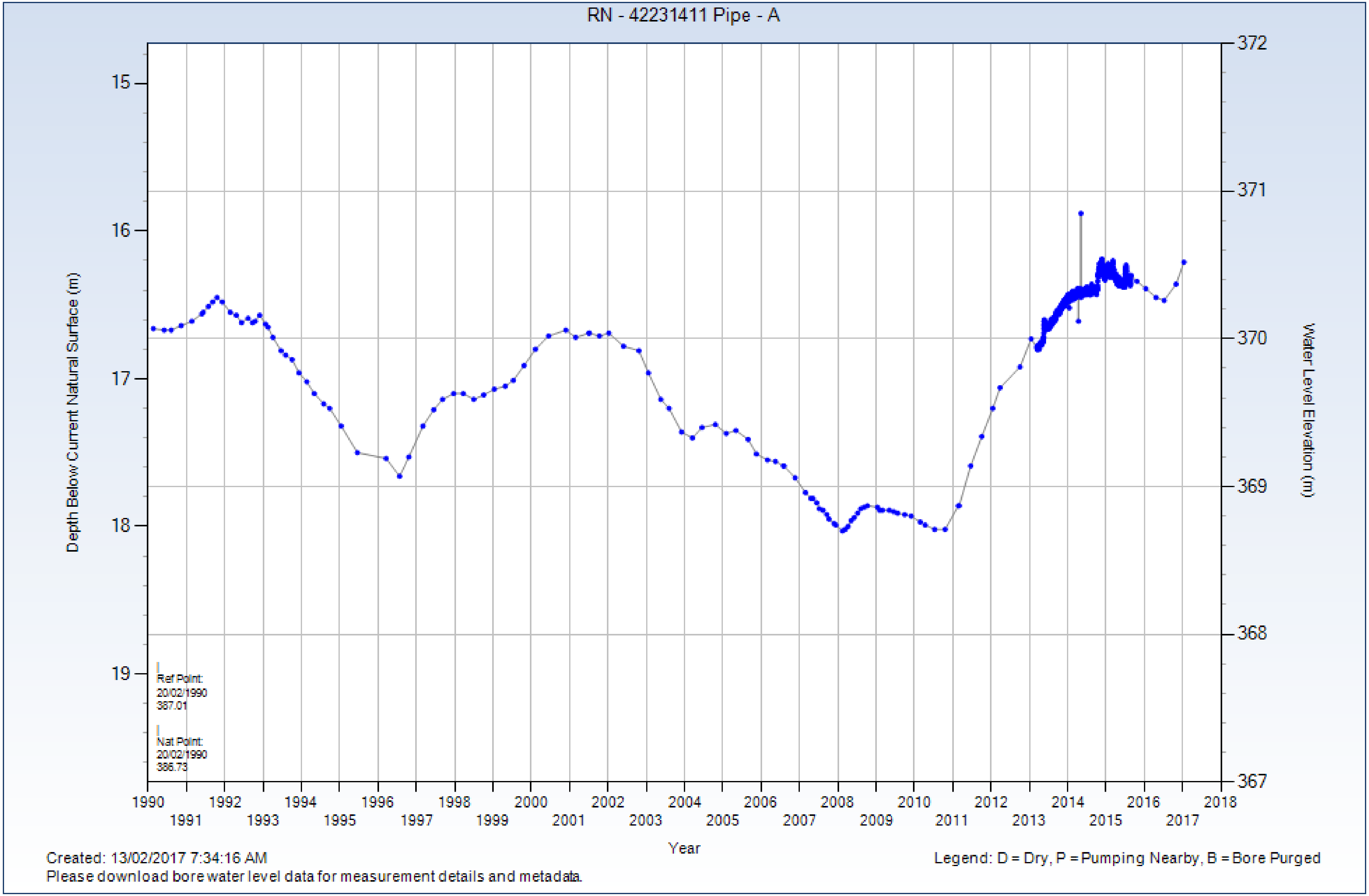
RN - 42230210 Pipe - A

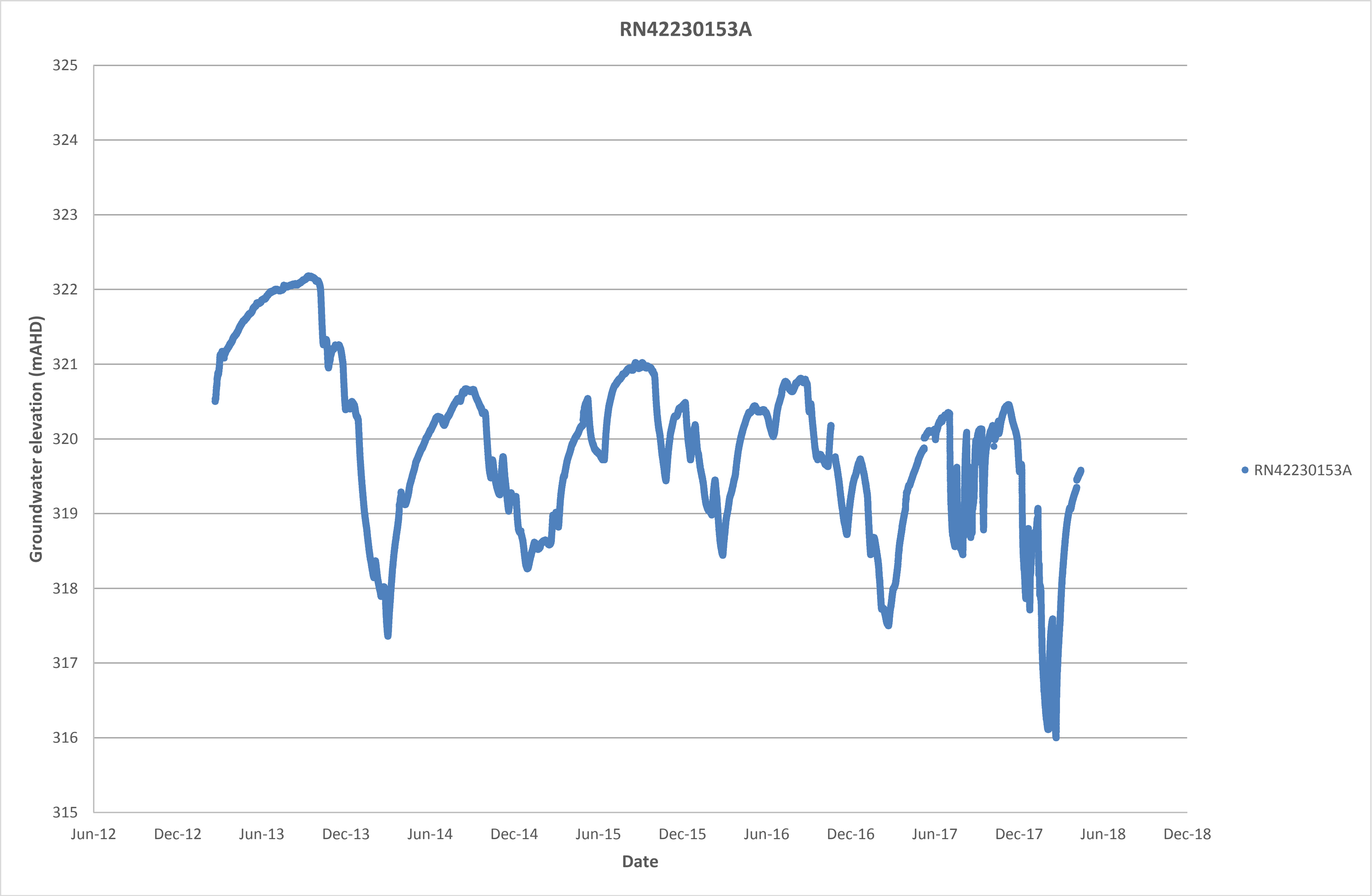


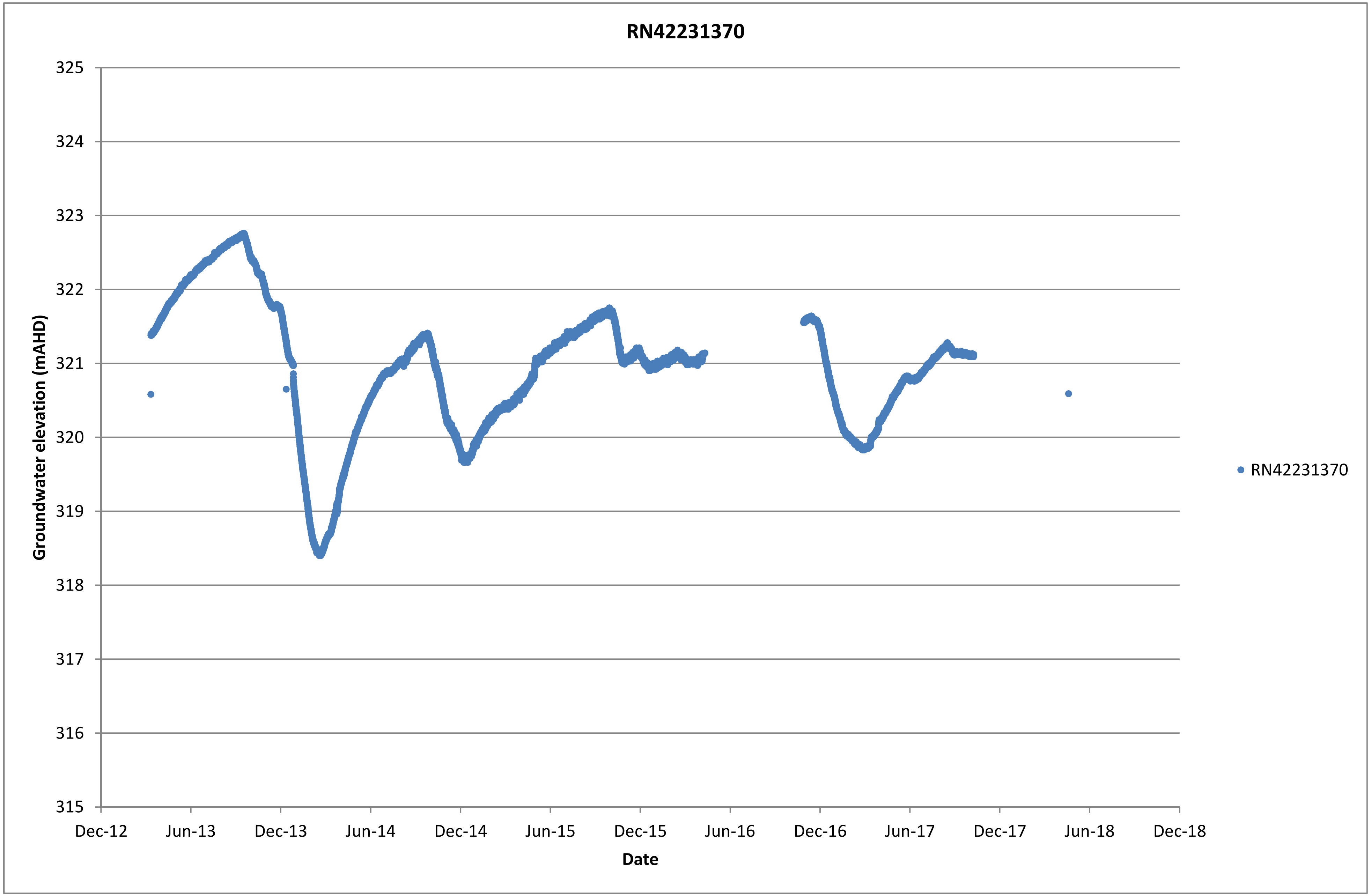
Created: 23/01/2017 8:02:16 AM
Please download bore water level data for measurement details and metadata.

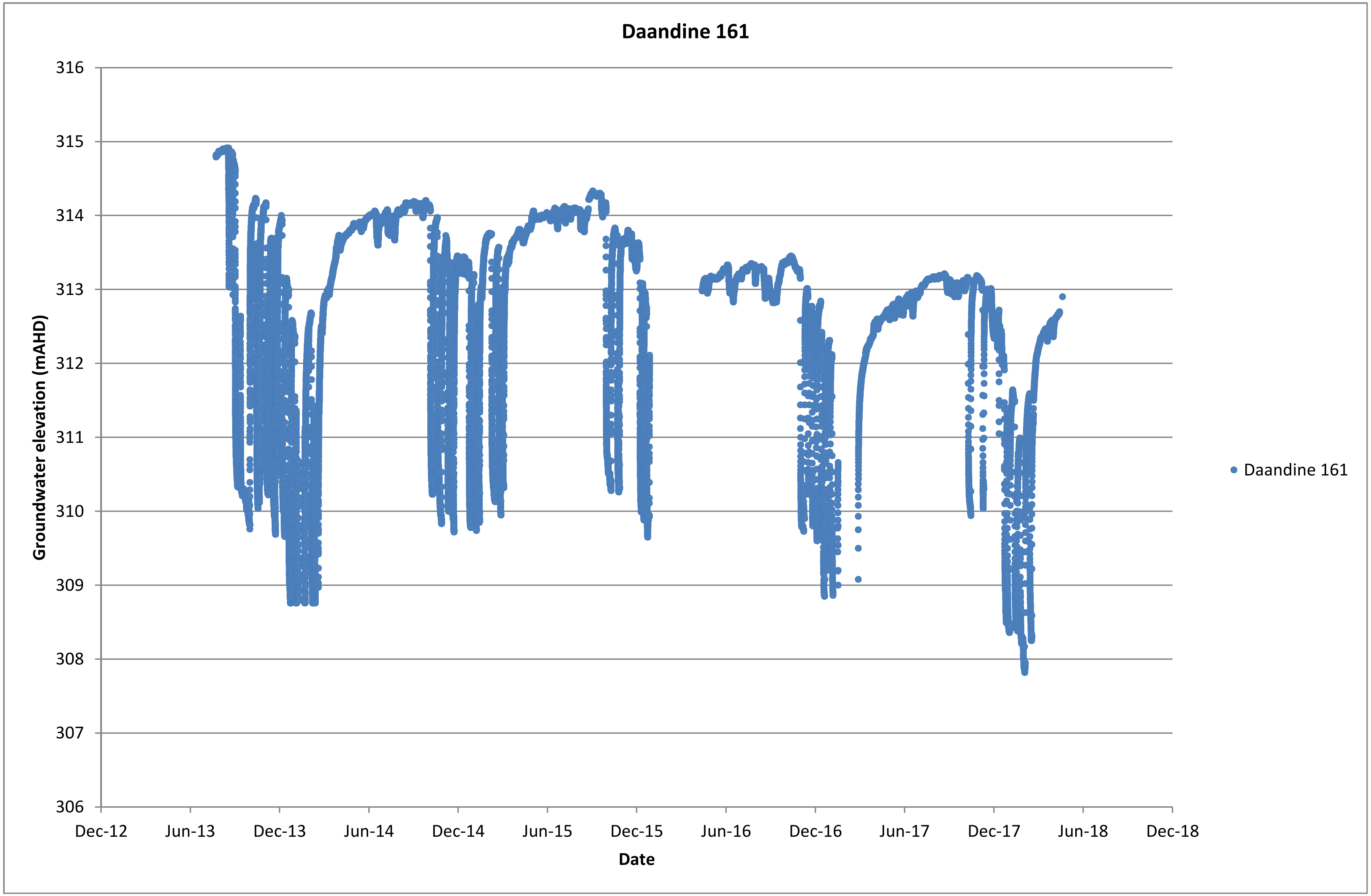
Legend: D = Dry, P = Pumping Nearby, B = Bore Purged

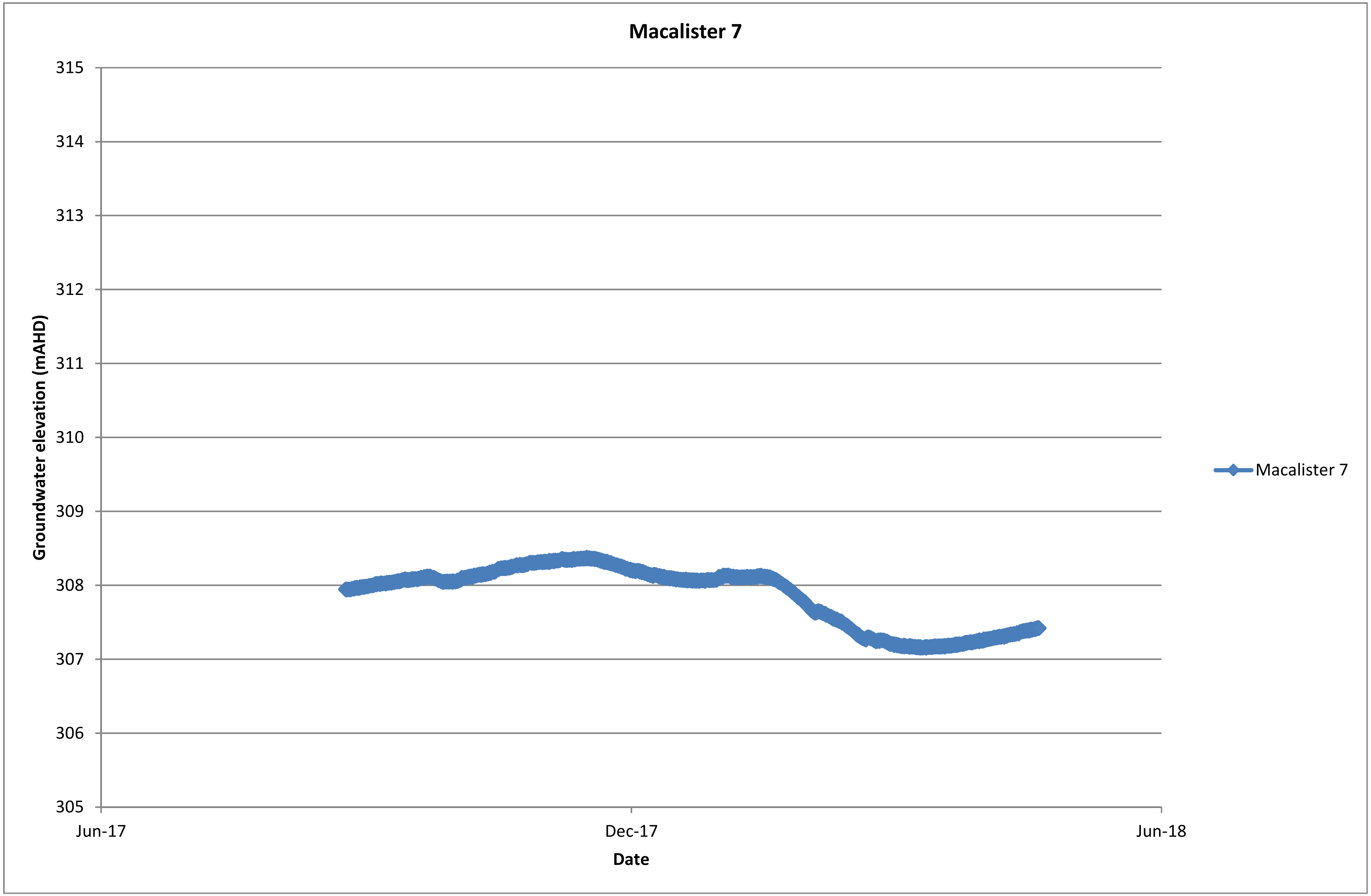

RN41620043
Groundwater elevation (mAHD)
410
409
408
407
406
405
404
403
402
401
400
Dec-12
Jun-13
Dec-13
Jun-14
Dec-14
Jun-15
Dec-15
Jun-16
Dec-16
Jun-17
Dec-17
Jun-18
Dec-18
Date
● RN41620043


RN - 42231411 Pipe - A
Depth Below Current Natural Surface (m)
15
16
17
18
19
Water Level Elevation (m)
372
371
370
369
368
367
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year
Ref Point:
20/02/1990
387.01
Nat Point:
20/02/1990
386.73
Created: 13/02/2017 7:34:16 AM
Please download bore water level data for measurement details and metadata.
Legend: D = Dry, P = Pumping Nearby, B = Bore Purged


RN42230153A
325
324
323
322
321
320
319
318
317
316
315
Groundwater elevation (mAHD)
Jun-12
Dec-12
Jun-13
Dec-13
Jun-14
Dec-14
Jun-15
Dec-15
Jun-16
Dec-16
Jun-17
Dec-17
Jun-18
Dec-18
Date
● RN42230153A

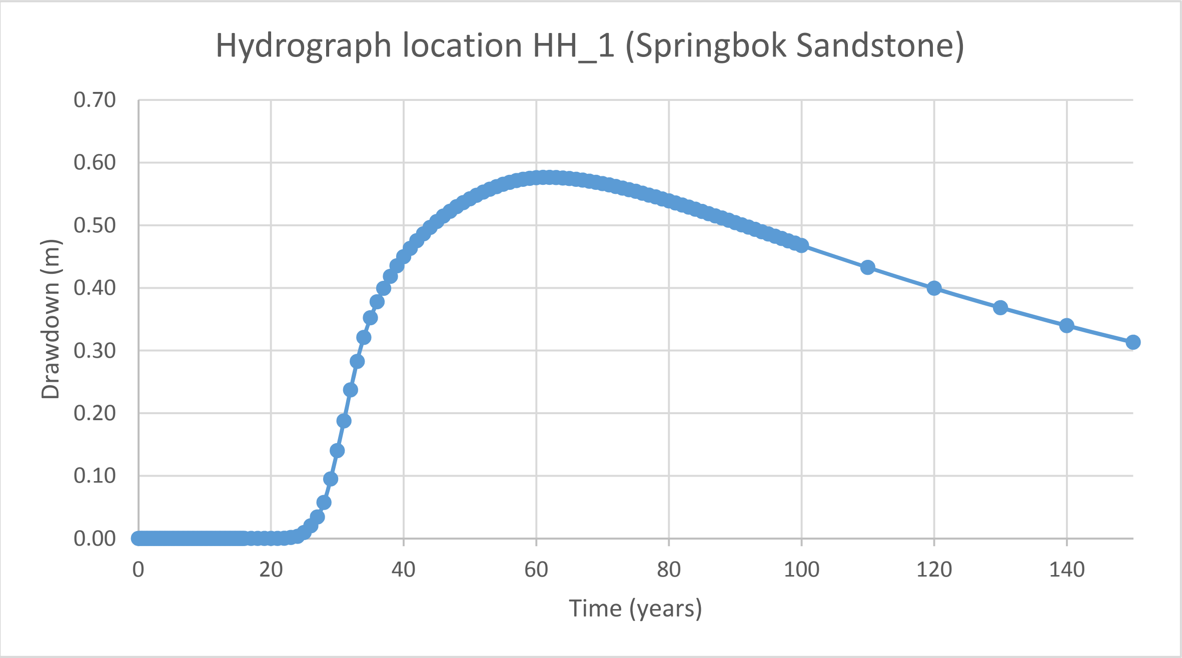

RN42231370
325
324
323
322
321
320
319
318
317
316
315
Groundwater elevation (mAHD)
Dec-12
Jun-13
Dec-13
Jun-14
Dec-14
Jun-15
Dec-15
Jun-16
Dec-16
Jun-17
Dec-17
Jun-18
Dec-18
Date
● RN42231370

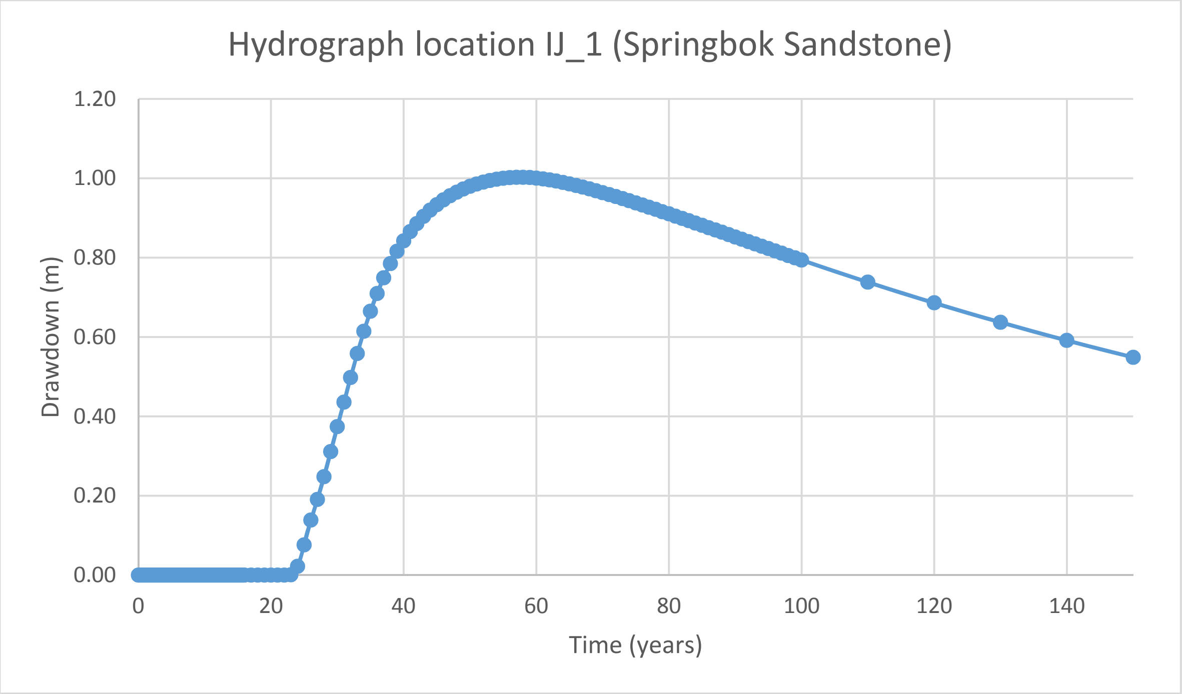

Daandine 161
316
315
314
313
312
311
310
309
308
307
306
Groundwater elevation (mAHD)
Dec-12
Jun-13
Dec-13
Jun-14
Dec-14
Jun-15
Dec-15
Jun-16
Dec-16
Jun-17
Dec-17
Jun-18
Dec-18
Date
● Daandine 161

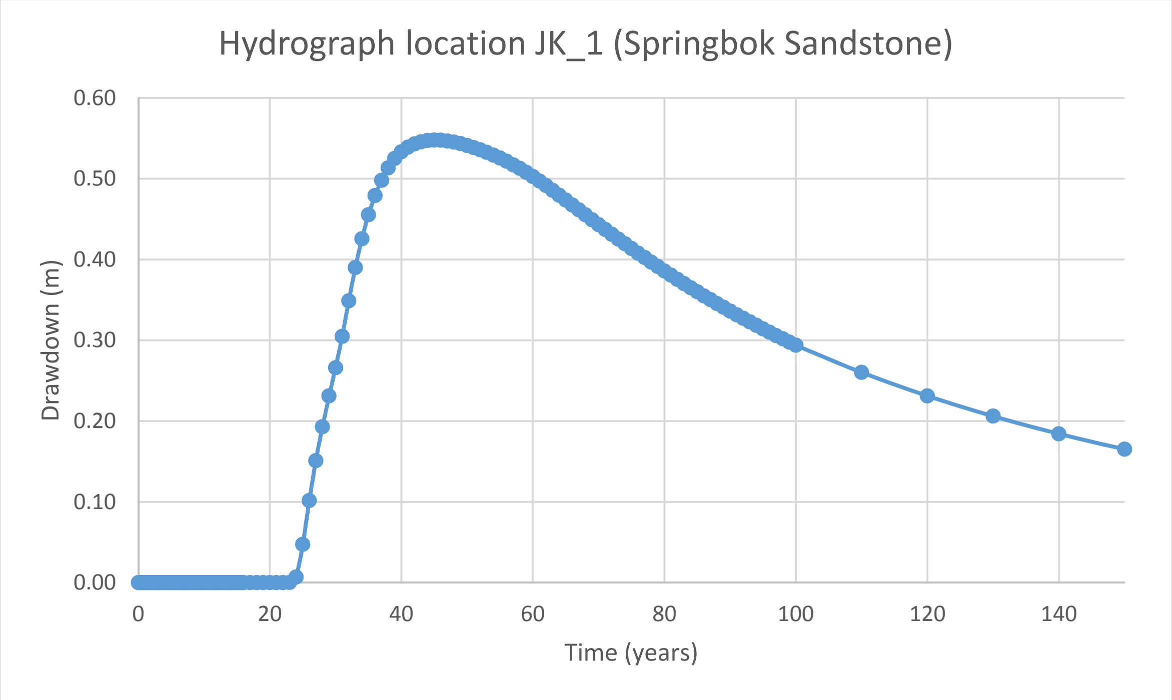

Macalister 7
315
314
313
312
311
310
309
308
307
306
305
Groundwater elevation (mAHD)
Jun-17
Dec-17
Jun-18
Date
Macalister 7

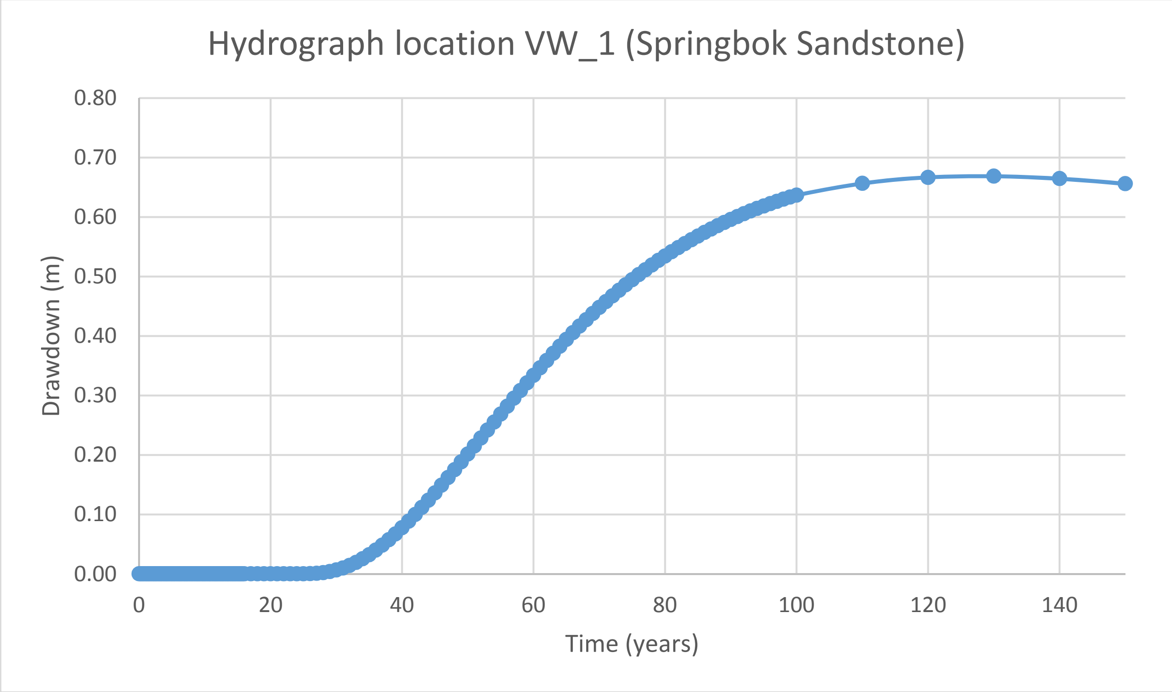
Attachment 4: GHD 2013 model hydrographs

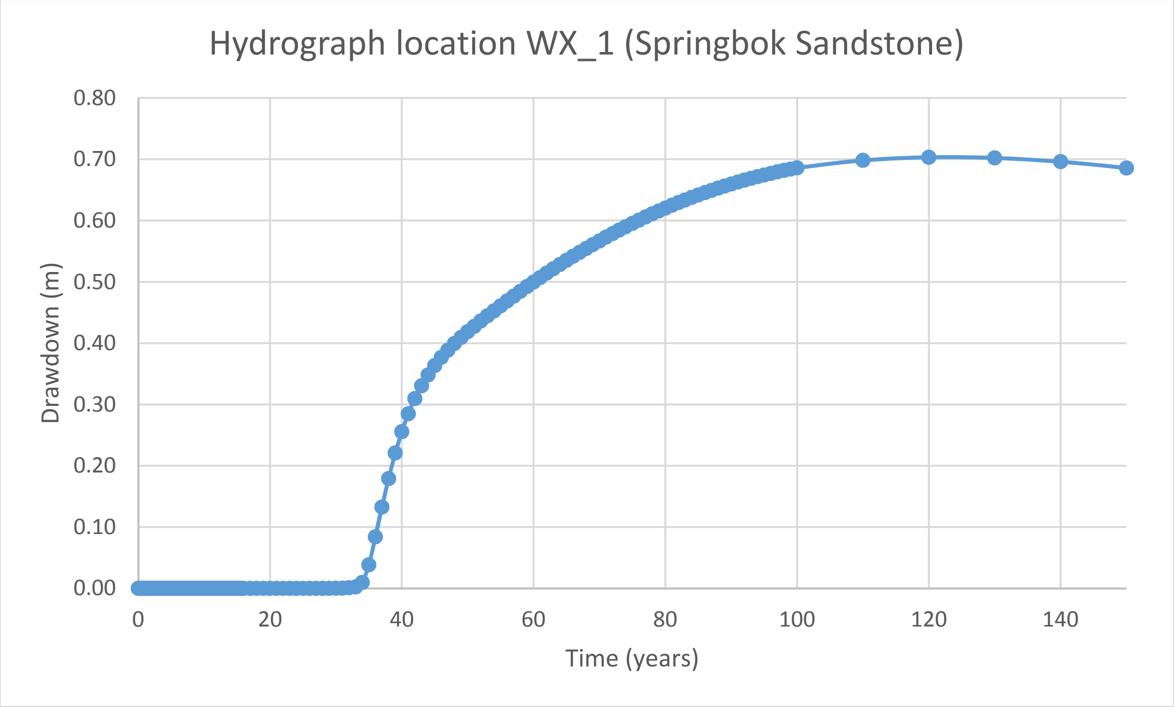
Hydrographs – locations beyond the 1.0 m drawdown contour (refer Section 2.1.3)

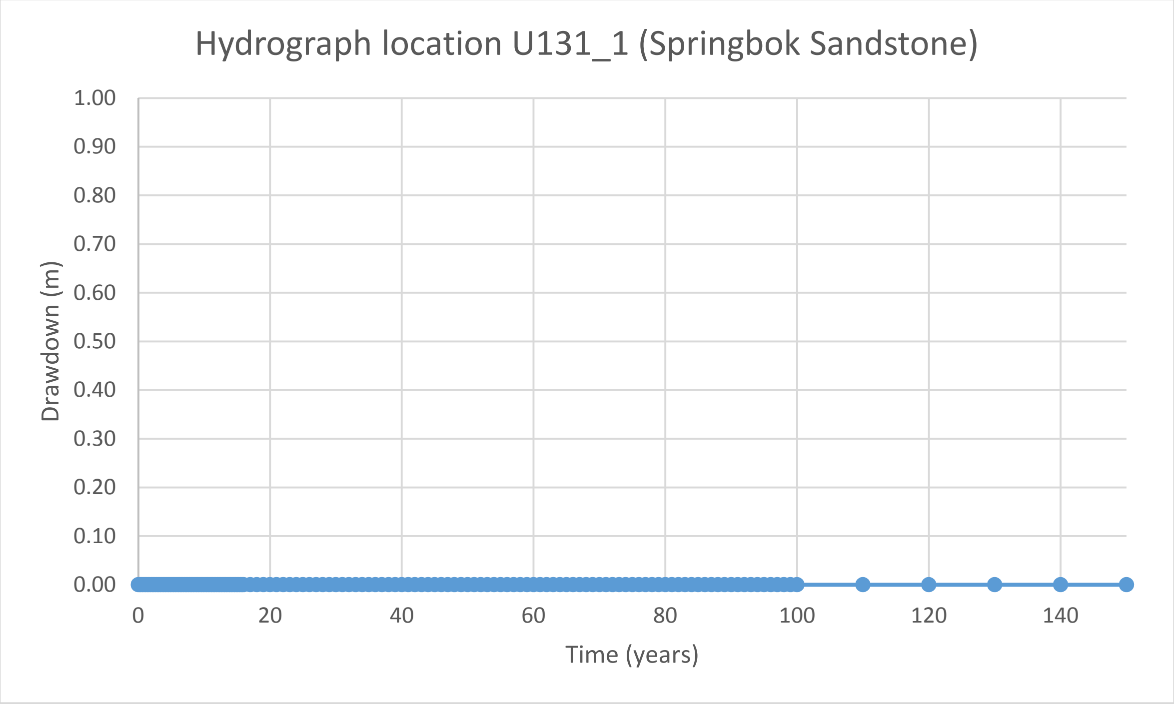


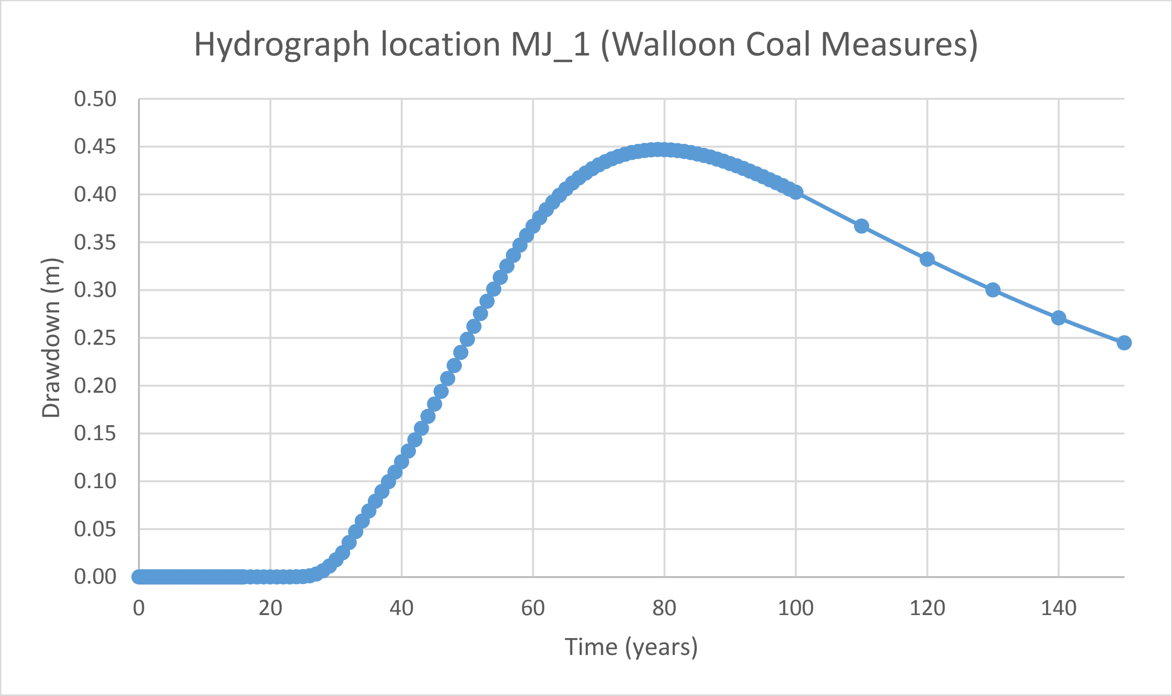


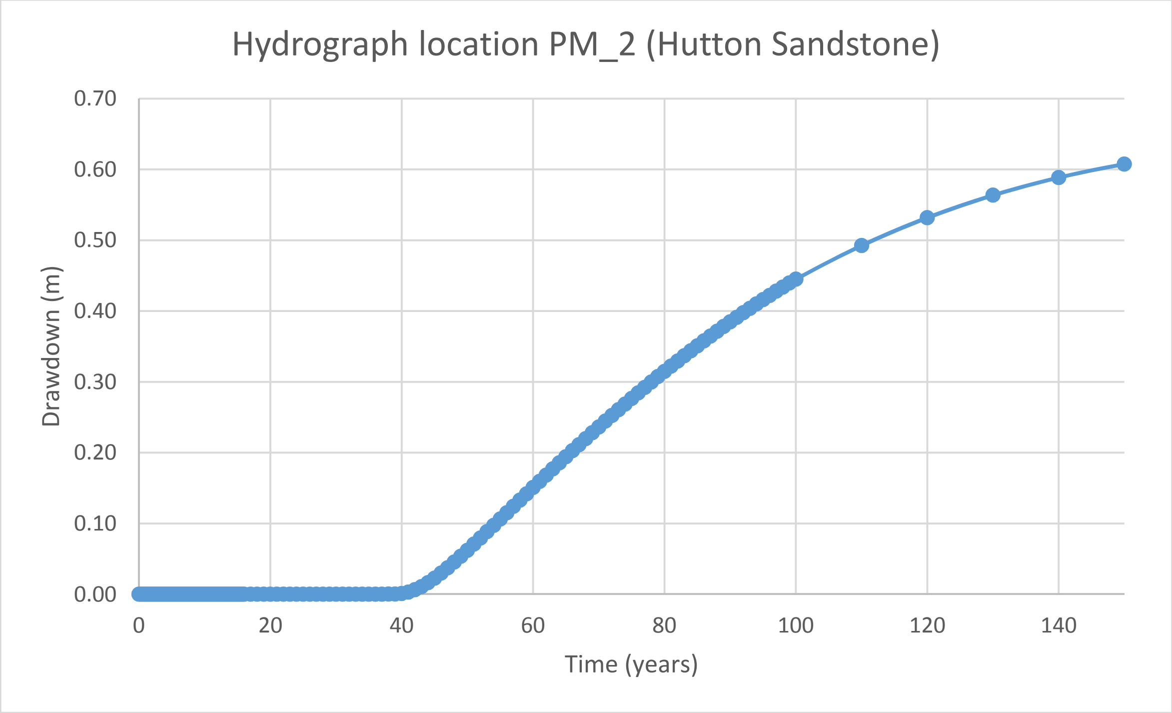

Hydrograph location JK_1 (Springbok Sandstone)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Drawdown (m)
0
20
40
60
80
100
120
140
Time (years)

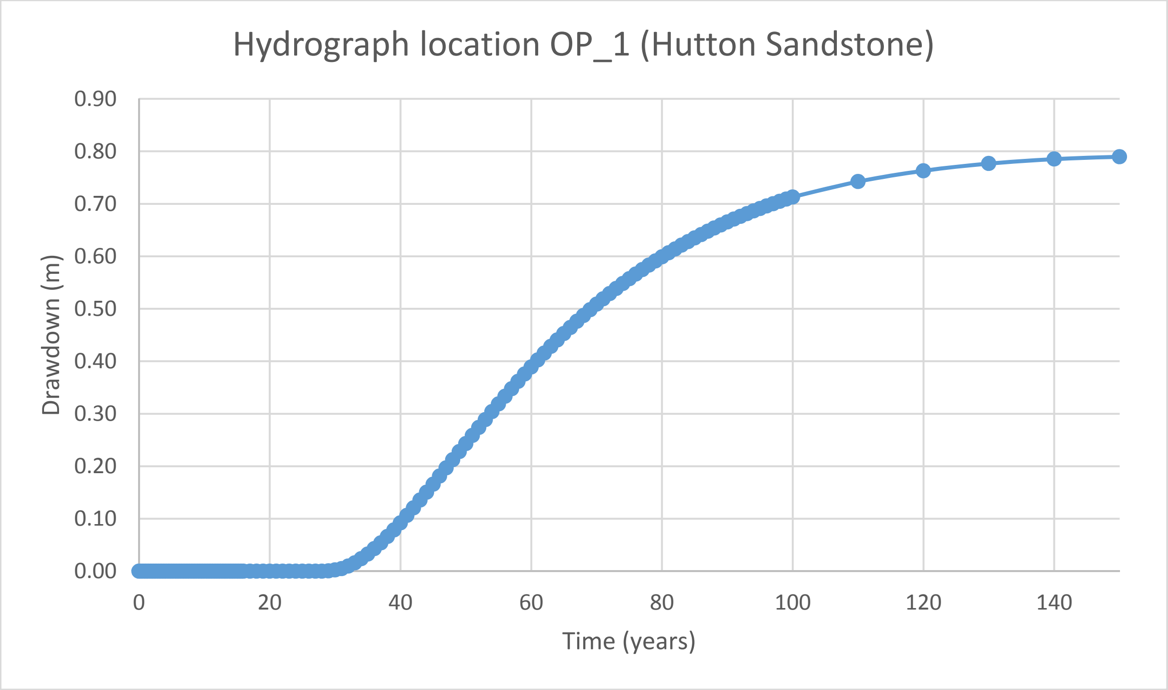

Hydrograph location VW_1 (Springbok Sandstone)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Drawdown (m)
0
20
40
60
80
100
120
140
Time (years)

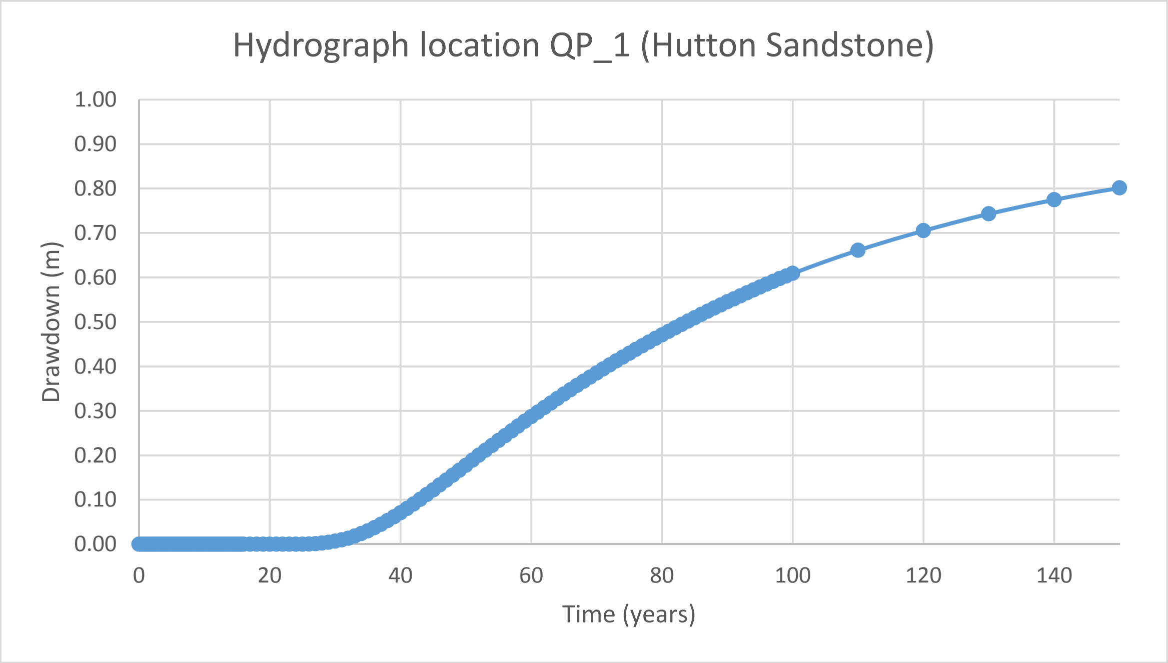

Hydrograph location WX_1 (Springbok Sandstone)
Drawdown (m)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
20
40
60
80
100
120
140
Time (years)

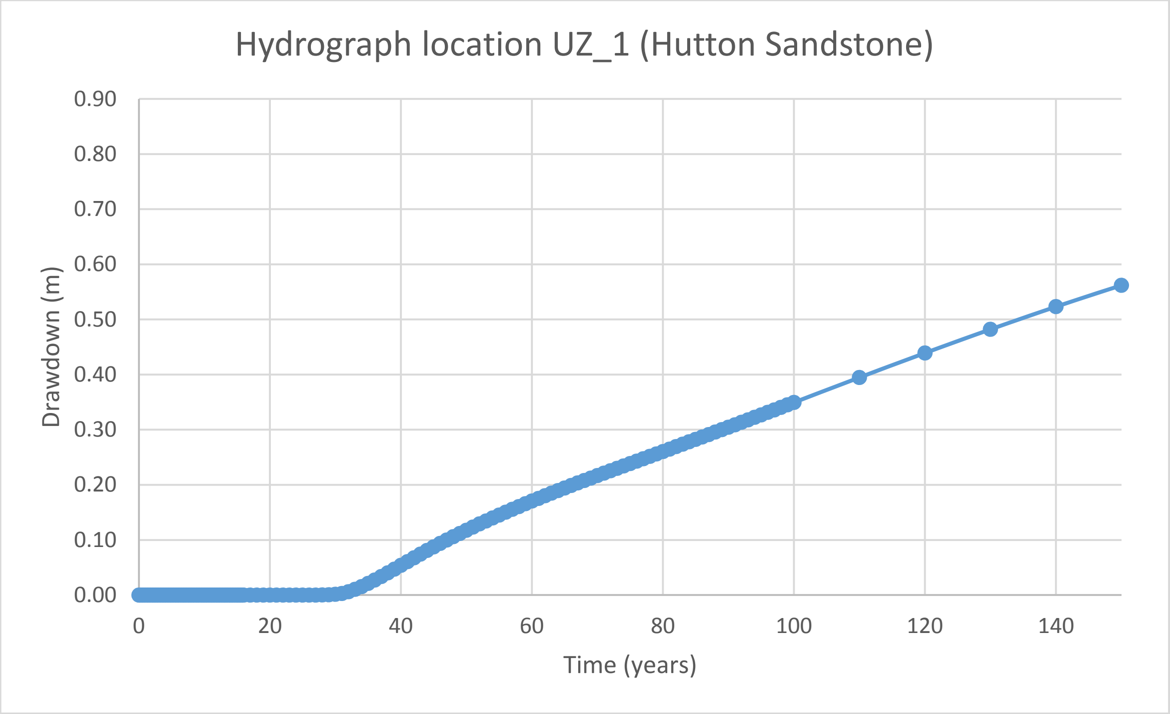

Hydrograph location U131_1 (Springbok Sandstone)
Drawdown (m)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
20
40
60
80
100
120
140
Time (years)

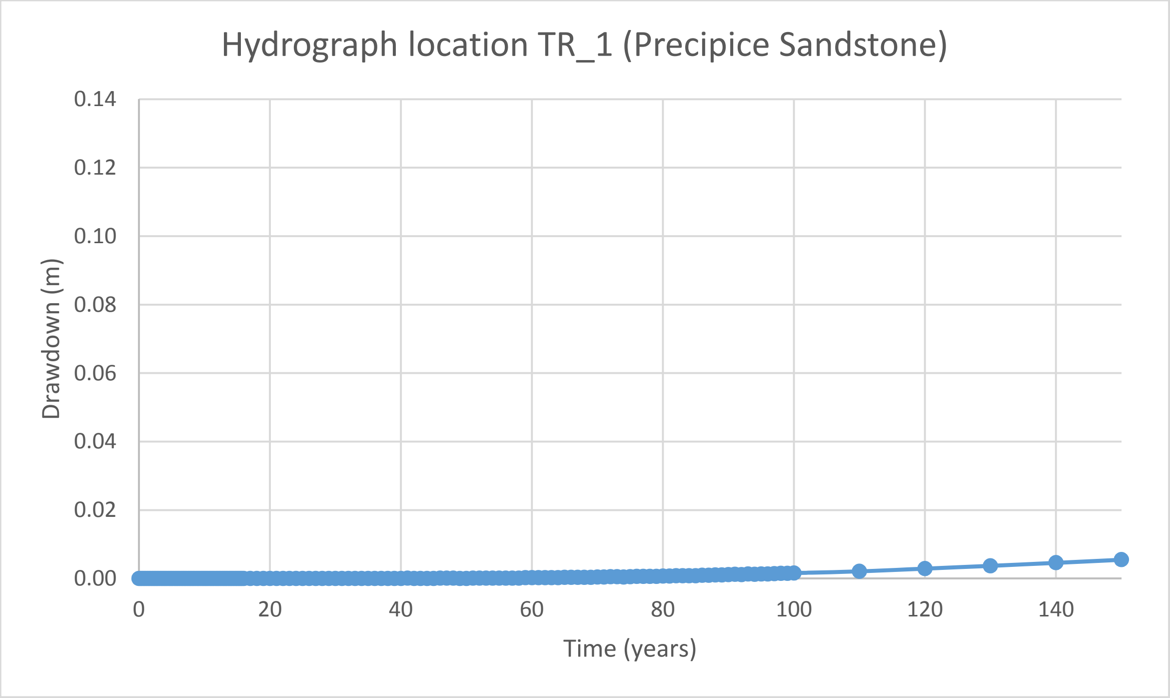

Hydrograph location MJ_1 (Walloon Coal Measures)
Drawdown (m)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
20
40
60
80
100
120
140
Time (years)


Hydrograph location PM_2 (Hutton Sandstone)
Drawdown (m)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
20
40
60
80
100
120
140
Time (years)

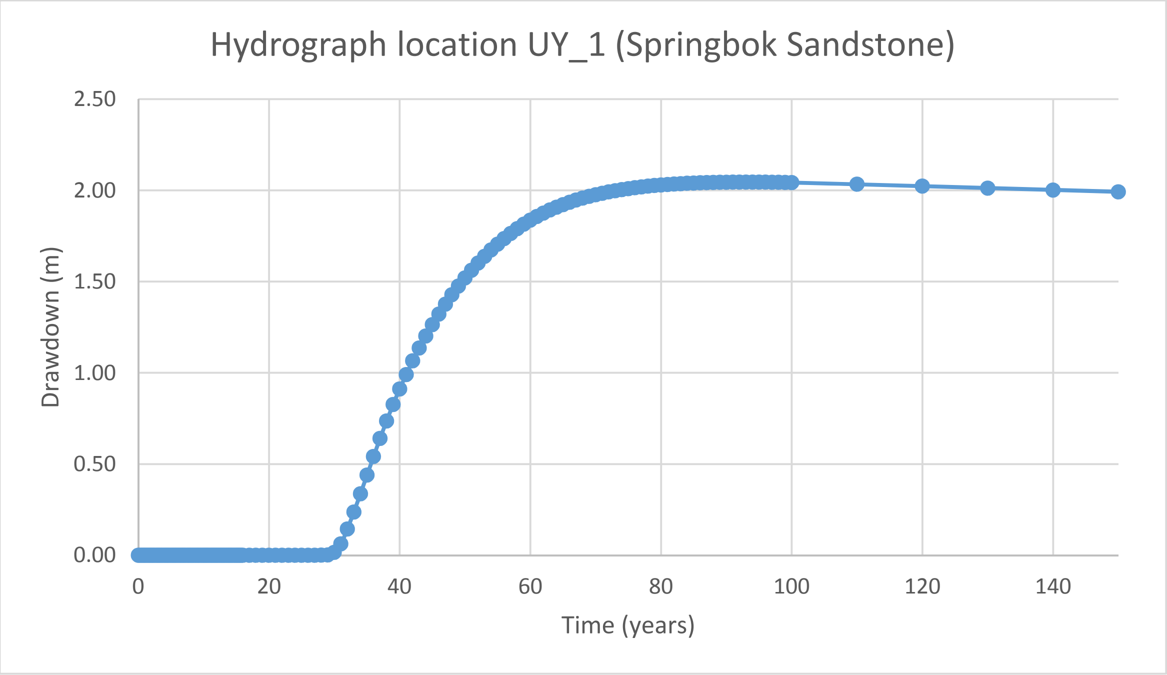

Hydrograph location OP_1 (Hutton Sandstone)
Drawdown (m)
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
20
40
60
80
100
120
140
Time (years)

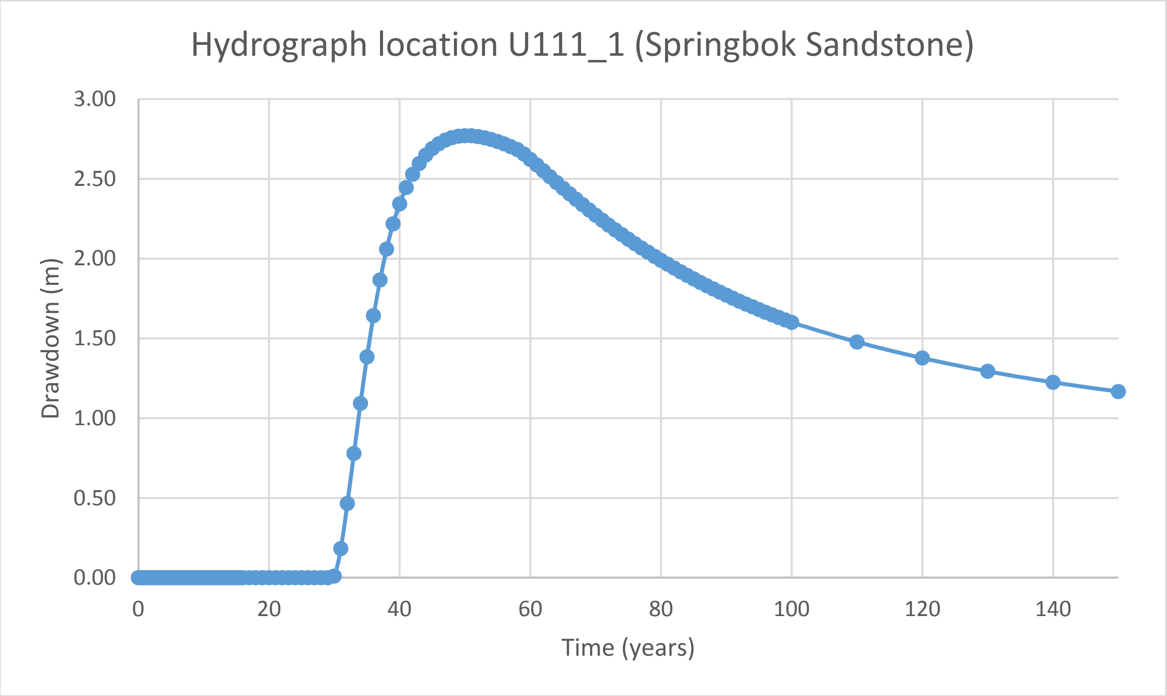

Hydrograph location QP_1 (Hutton Sandstone)
Drawdown (m)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
20
40
60
80
100
120
140
Time (years)

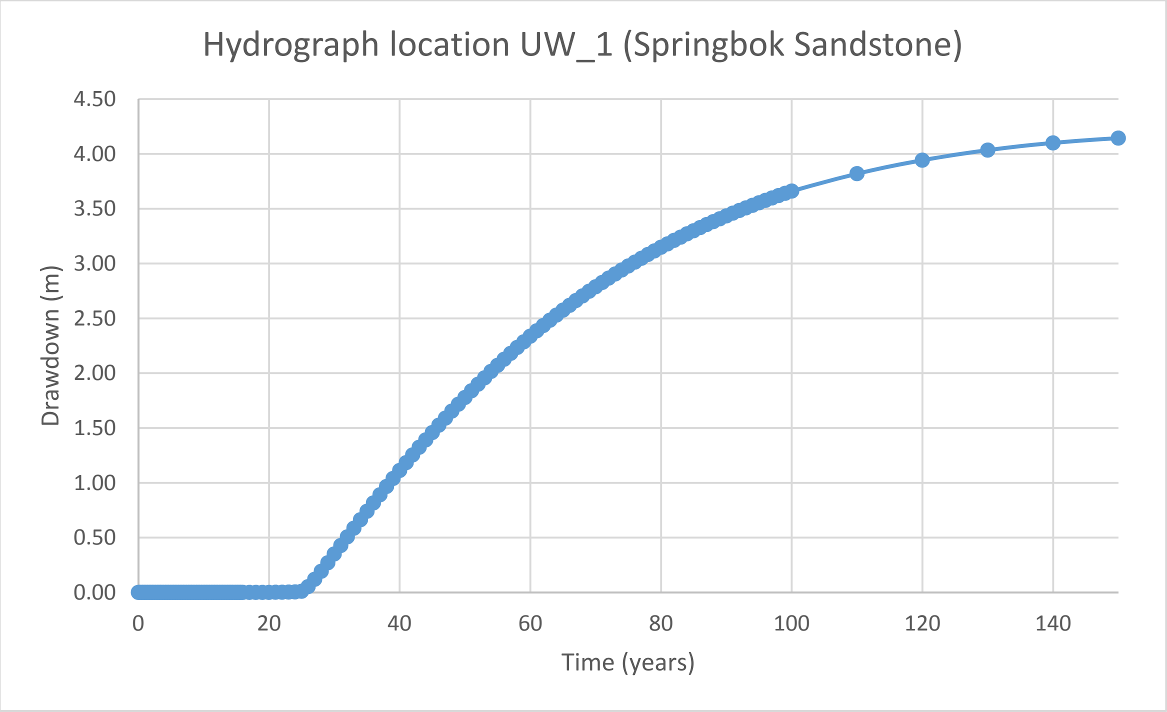

Hydrograph location UZ_1 (Hutton Sandstone)
Drawdown (m)
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
20
40
60
80
100
120
140
Time (years)


Hydrograph location TR_1 (Precipice Sandstone)
Drawdown (m)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
20
40
60
80
100
120
140
Time (years)

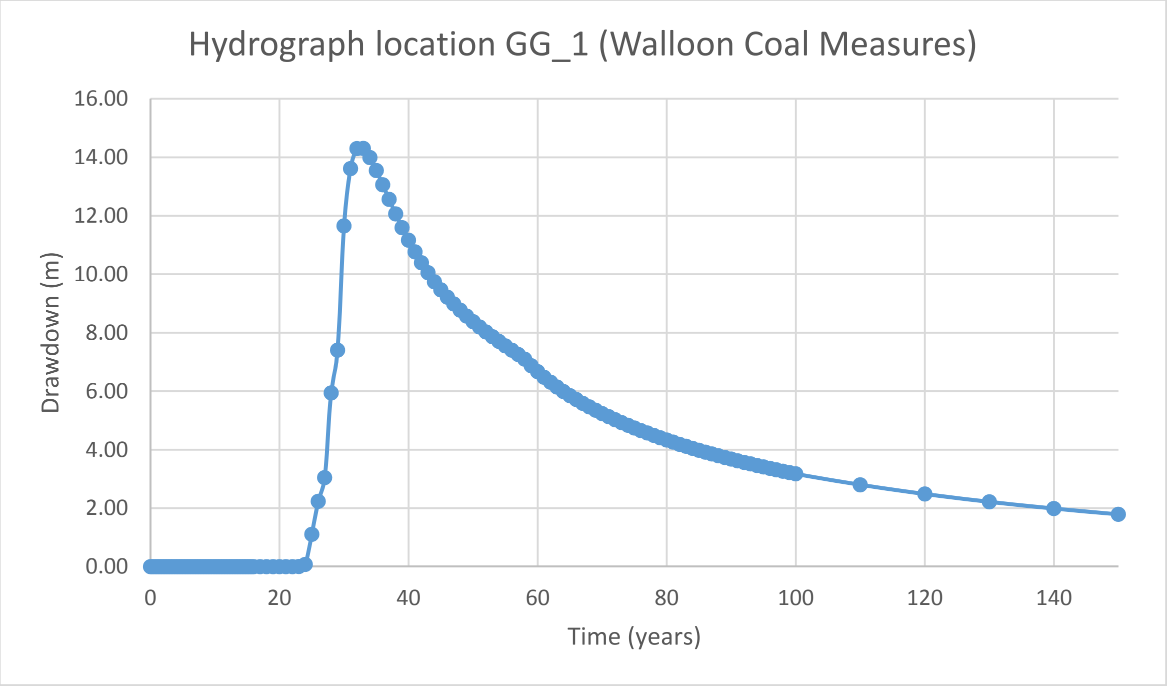
Risk area 3b hydrographs (refer Section 5.2.3)

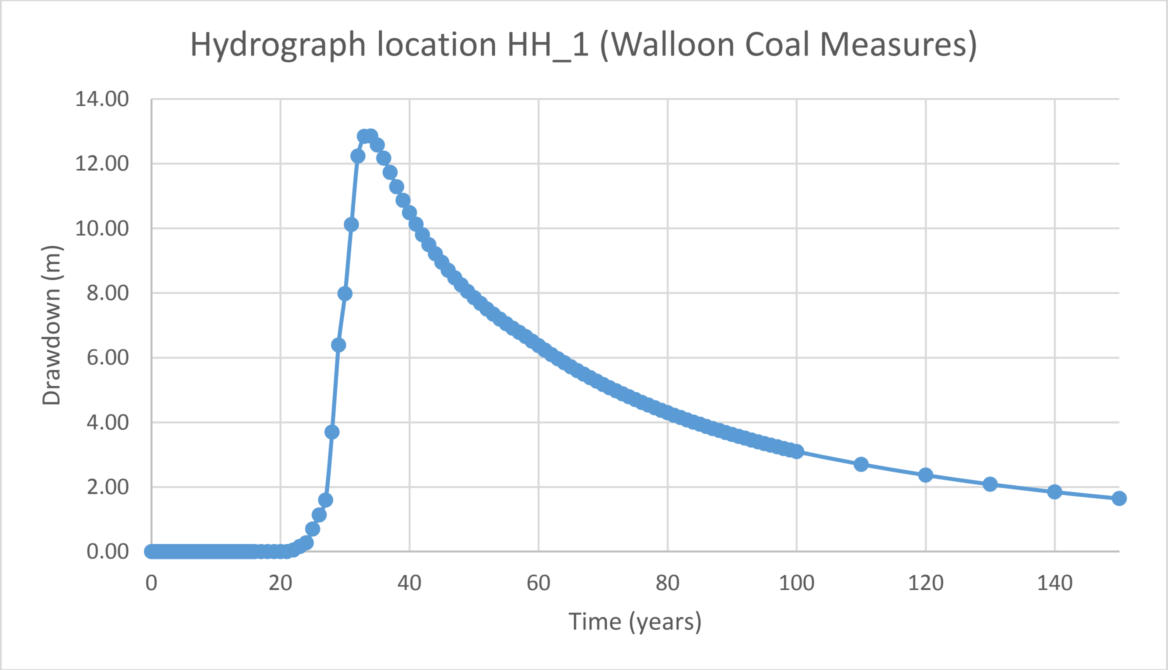






Risk area 4 hydrographs (refer Section 5.2.4)




Hydrograph location HH_1 (Walloon Coal Measures)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Drawdown (m)
0
20
40
60
80
100
120
140
Time (years)